UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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HYDRAULIC LABORATORY REPORT NO. 125

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HYDRAULIC MODEL STUDIES RELATING TO THE DESIGN OF THE KESWICK DAM, SPILLWAY AND FISHWAY CENTRAL VALLEY PROJECT, CALIFORNIA

By

J. W. BALL, ASSOCIATE ENGINEER
and
J. A. LINDSEY, ASSISTANT ENGINEER

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Denver, Colorado
April 28, 1943

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

- - -

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: HYDRAULIC MODEL STUDIES
RELATING TO THE DESIGN OF THE KESWICK DAM
SPILLWAY AND FISHWAY
CENTRAL VALLEY PROJECT --CALIFORNIA

- - -

By

J. W. Ball, Associate Engineer
and
J. A. Lindsey, Assistant Engineer

- - -

Under direction of
J. E. Warnock, Engineer
and
R. F. Blanks, Senior Engineer

Denver, Colorado
April 28, 1943

PREFACE

Designs of the Keswick Dam spillway and fishway were evolved from hydraulic model studies conducted in the hydraulic laboratory of the Bureau of Reclamation, Denver, Colorado, from May 1940 to April 1942.

The preliminary designs of the Keswick Dam were prepared under the direction of Senior Engineer W. E. Blomgren. Structural features of the final design were prepared under the direction of Senior Engineer H. W. Tabor. Migratory-fish-control structures were designed under the direction of Senior Engineer D. C. McConaughy, with Aquatic Biologist H. B. Holmes, in charge, Hydraulic Section, U. S. Bureau of Fish and Wildlife Control, serving consultant. The laboratory investigation was conducted and this report prepared under the direction of Engineer J. E. Warnock, in charge of the hydraulic laboratory. Credit is due Engineer J. N. Bradley and Associate Engineer H. G. Dewey, Jr., who contributed to the development of the designs.

All laboratories of the Bureau of Reclamation in Denver, Colorado, are in the Materials, Testing, and Control Division, under the supervision of Senior Engineer R. F. Blanks. All design work is under the supervision of Chief Designing Engineer J. L. Savage, and all work of the Bureau of Reclamation is directed by Chief Engineer S. O. Harper. The activities of the Bureau of Reclamation are directed by Commissioner John C. Page.

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Denver, Colorado, April 28, 1943.

MEMORANDUM TO CHIEF DESIGNING ENGINEER:
(J.W.Ball and J.A.Lindsey through J.E.Warnock)

Subject: Hydraulic model studies relating to the design of the Keswick Dam spillway and fishway - Central Valley Project.

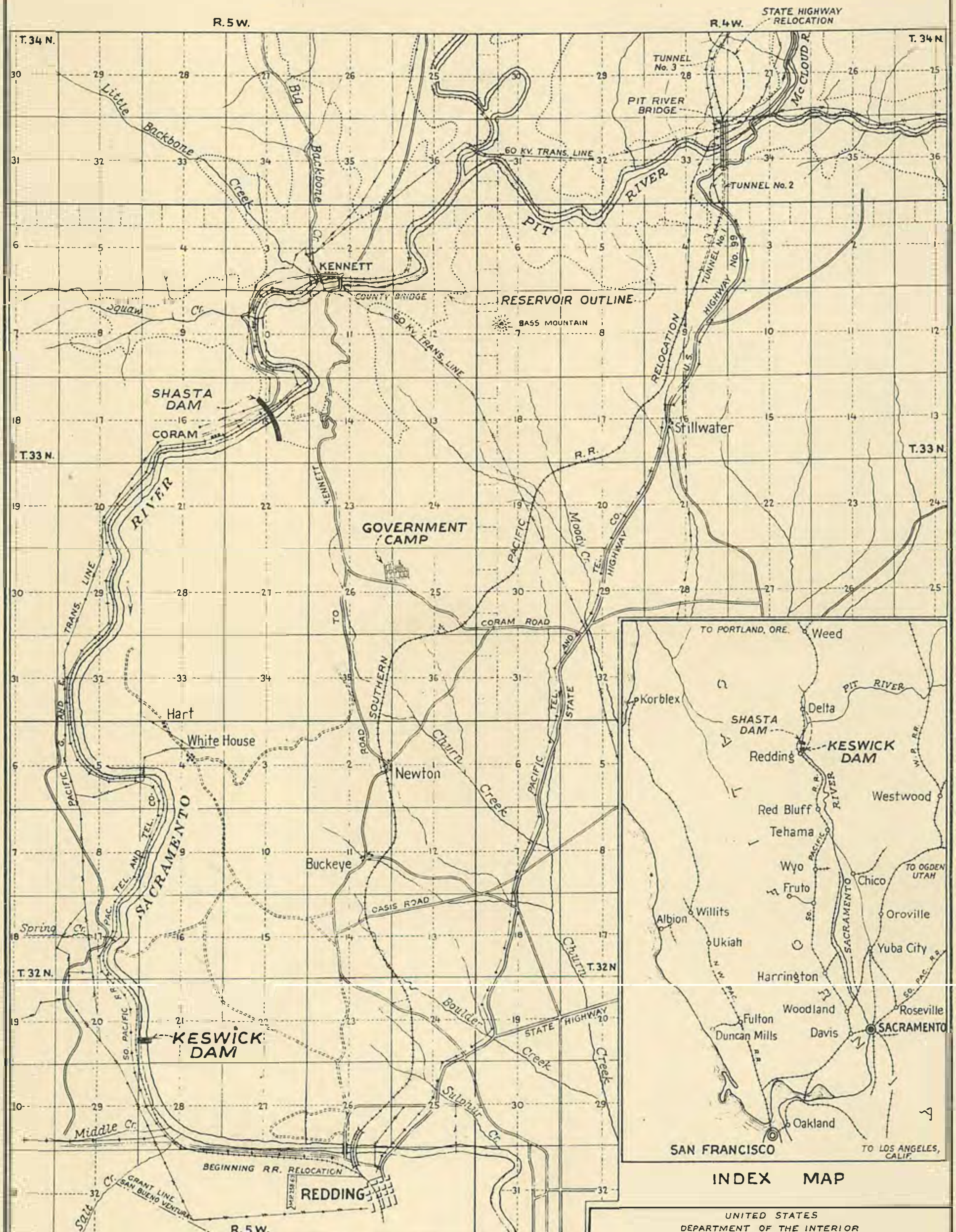
INTRODUCTION

1. The prototype. The Keswick Dam is under construction on the Sacramento River approximately 4 miles above Redding, California, and 9 miles below the Shasta Dam (figure 1). The dam is to be built in two stages--the initial and the ultimate. The height of Shasta Dam will be so great that it is infeasible to construct a fishway around it; therefore, the purpose of the initial development of Keswick Dam will be to provide a barrier for trapping the migratory fish before they reach the Shasta tailrace. The original design of the initial development consisted of a low barrier to elevation 510.00 with an overflow spillway, fish trap, and stoplog section. The spillway would have been adequate for all normal flows, but it would have been necessary to remove the stoplogs at flood stages to handle discharge of 180,000 second-feet.

The final design of the initial development consisted of a spillway crest carried to elevation 503.00, with the exception of 20-foot wide sections at the piers, forming four channels 40 feet wide through this section of the structure (figure 2). The piers will be constructed to elevation 550.00 and the adjacent 5-foot sections of the spillway to their ultimate height, elevation 537.00. During this stage of construction no provision for regulating the reservoir water surface will be made and the four channels between the piers will serve as a spillway.

With no obstruction in these channels the fish migrating upstream could, under certain conditions, pass through the spillway and continue on to Shasta Dam where no trapping facilities are provided. To prevent this by-passing and the necessity of constructing temporary traps at Shasta Dam, a barrier will be erected at Keswick Dam. This obstacle will consist of weirs, of sufficient height to keep the fish from leaping over them, placed in the four channels of the spillway section.

The weirs will be hinged wooden gates which, in the vertical position, will span the upstream ends of the channels between the piers. The ends of the gates resting against the vertical portion of the completed crest sections form a barrier approximately 10 feet high. The gates will be latched in the down (or horizontal) position in the forebay until the flow conditions are such that the fish could swim through the spillway section to the river upstream. The gates will then be unlatched, permitting the hydraulic forces to raise them and form the barrier.



VICINITY MAP

0 — 2
SCALE OF MILES

UNITED STATES
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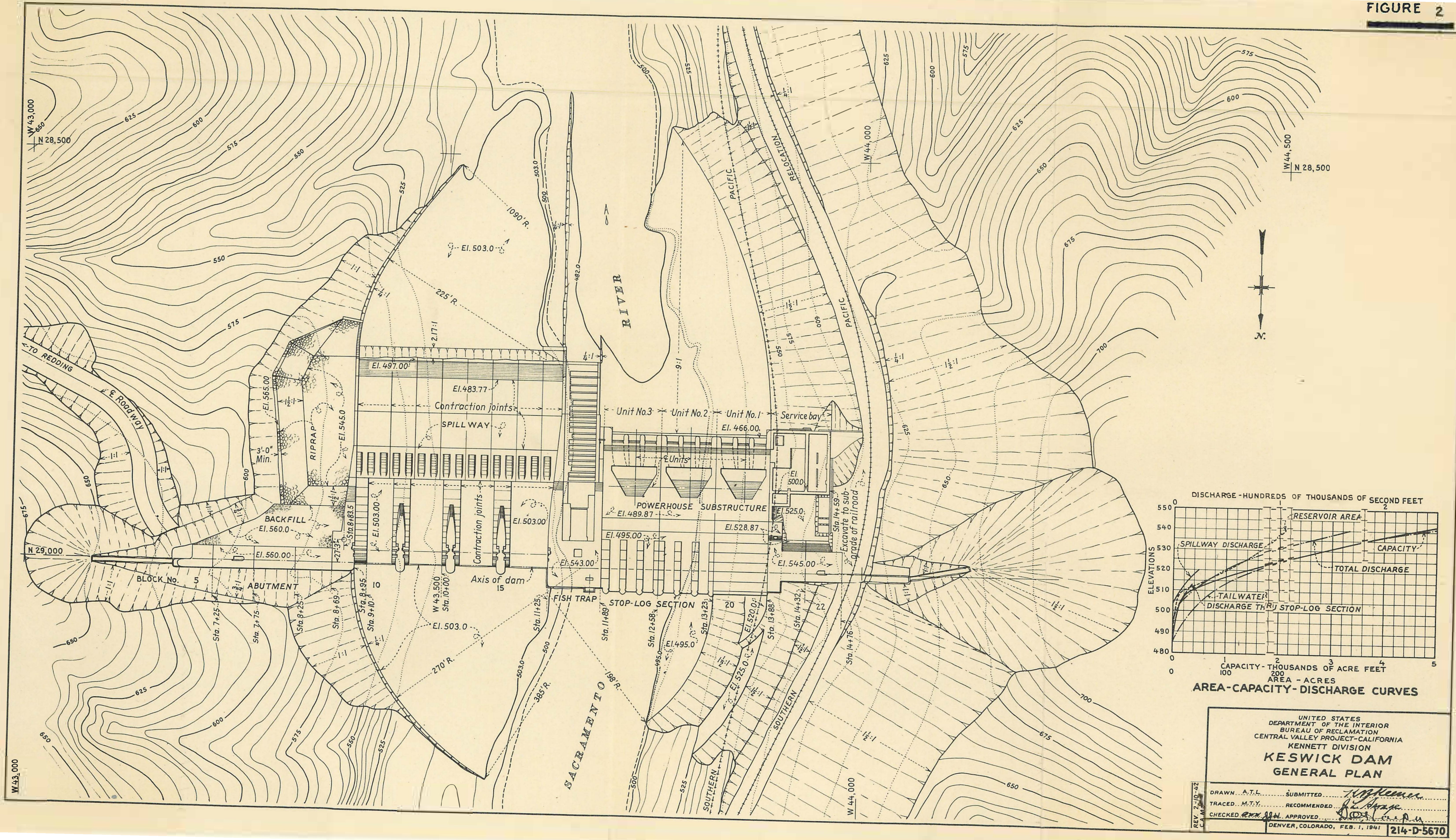
CENTRAL VALLEY PROJECT - CALIFORNIA
KENNETT DIVISION

KESWICK DAM
LOCATION MAP

DRAWN C.V.H.-S.R.E.	SUBMITTED [signature]		
TRACED V.M.S.	RECOMMENDED [signature]		
CHECKED [initials]	APPROVED [signature]		
	DENVER, COLORADO, FEB. 1, 1941	214-D-5664	

FIGURE 2



TO REDDING
Roadway 3
BACKFILL
El. 560.0
El. 560.00
BLOCK No. 5
ABUTMENT
RIPRAP
El. 565.00
El. 545.0
3'-0" Min.
El. 497.00
El. 483.77
Contraction joints
SPILLWAY
El. 503.00
El. 503.0
Axis of dam
1090' R.
225' R.
270' R.
385' R.
198' R.
SACRAMENTO
RIVER
FISH TRAP
STOP-LOG SECTION
Unit No.3
Unit No.2
Unit No.1
Service bay
El. 466.00
℄ Units
POWERHOUSE SUBSTRUCTURE
El. 489.87
El. 495.00
El. 528.87
El. 525.0
El. 543.00
El. 545.00
El. 520.0
El. 525.0
El. 495.0
El. 500.0
Sta. 14+59 Excavate to sub-grade of railroad
PACIFIC
RELOCATION
SOUTHERN
N.
W 43,000
N 28,500
N 29,000
W 44,000
W 44,500
W 43,500
DISCHARGE - HUNDREDS OF THOUSANDS OF SECOND FEET
RESERVOIR AREA
SPILLWAY DISCHARGE
CAPACITY
TOTAL DISCHARGE
TAILWATER
DISCHARGE THRU STOP-LOG SECTION
ELEVATIONS
CAPACITY - THOUSANDS OF ACRE FEET
AREA - ACRES
AREA-CAPACITY-DISCHARGE CURVES
UNITED STATES
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BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT-CALIFORNIA
KENNETT DIVISION
KESWICK DAM
GENERAL PLAN
REV. 2-10-42 C.A.M.
DRAWN A.T.L.
TRACED M.T.Y.
CHECKED R.W.H. J.J.H.
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO, FEB. 1, 1941
214-D-5670

The ultimate stage development will be a straight gravity type concrete dam, approximately 590 feet long and 120 feet high, having a spillway, fishway, and power plant as appurtenant structures (figures 3 and 4). Three purposes will be served by the ultimate development. It will provide (1) hydroelectric power, (2) a barrier with facilities for trapping migratory fish, and (3) regulation of the fluctuating discharges from Shasta Dam. The spillway crest will be at elevation 537.00 and four 50- by 50-foot regulating gates will maintain the reservoir at elevation 587.00. The maximum discharge capacity will be 250,000 second-feet. The spillway will discharge onto a rock bench excavated from the left bank of the river. Water flowing over the bench and into the old river channel will attract the fish to the left side of the stream and thus enable them to locate the entrance to the fishway.

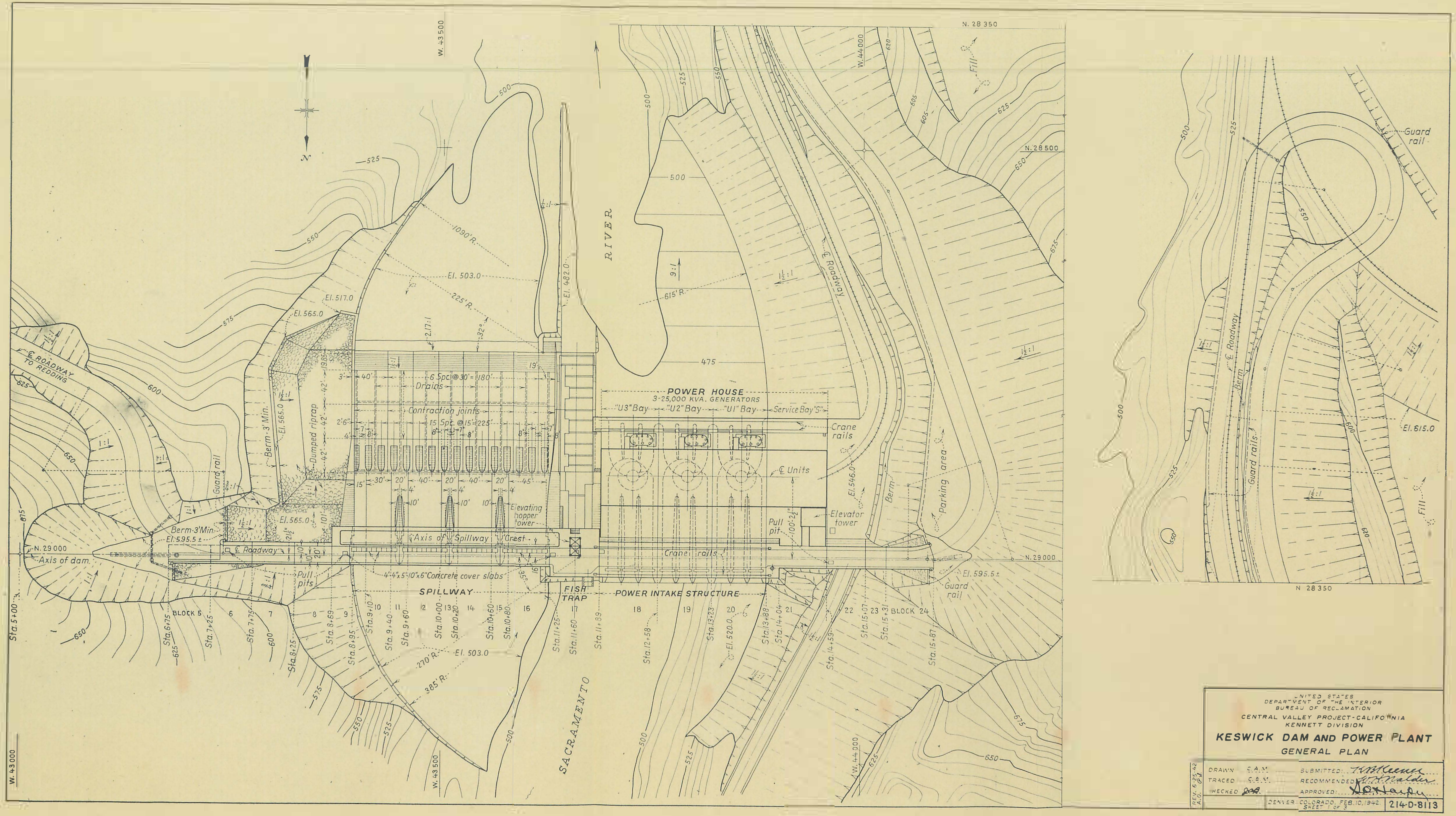
The function of the fishway is to attract the fish migrating upstream to spawn into a trap from which they are expeditiously removed and transported by tank trucks to the holding or spawning ponds at the hatchery. The fishway structure will consist of a fish ladder or series of pools separated by 20- by 3-foot rectangular-notched weirs, holding chambers, and an elevator (figure 5). The pools of the ladder are 13 feet 1 inch long by 38 feet wide by 6 feet deep, with every third pool having an auxiliary water supply from conduits discharging through slotted openings in the floor. This water supply is necessary to add an auxiliary flow at the approximate elevation of the tailwater to provide the proper velocities for attracting the fish to the downstream end of the ladder. The fish moving up the fishway will jump from pool to pool, pass through a trap and enter the holding chamber, pass through another trap and enter the brail chamber, where a sloping brail will be raised to force the fish into a large container. When this container is full, it will be raised to the top of the dam by an elevator and the fish will be discharged into specially built trucks which will haul them to a hatchery.

The power plant will occupy the right side of the structure and will discharge directly into the old river channel.

2. Scope of tests. Five hydraulic models were constructed during the course of the investigation. A 1 to 80 model was used to study the hydraulic features of the initial and ultimate stage developments of the dam. A 1 to 48 model represented a section of the ultimate stage spillway and was used to study the flow conditions and scour for various spillway designs. A 1 to 20 model was used to determine the operating characteristics and the turbulence in the various pools of the fishway. A 1 to 10 model was constructed for a detailed study of turbulent flow conditions in the auxiliary outlet pools of the fishway ladder. A model of temporary gate was built to ascertain the probable impact velocities on closure of the temporary weirs erected in the spillway section.

Studies on the 1 to 80 model of the ultimate development were made to obtain pressures on the spillway, determine the discharge characteristics, and study flow conditions encountered in the river channel by the migratory fish. The pressure tests were made to ascertain the presence or absence

FIGURE 3



UNITED STATES
DEPARTMENT OF THE INTERIOR
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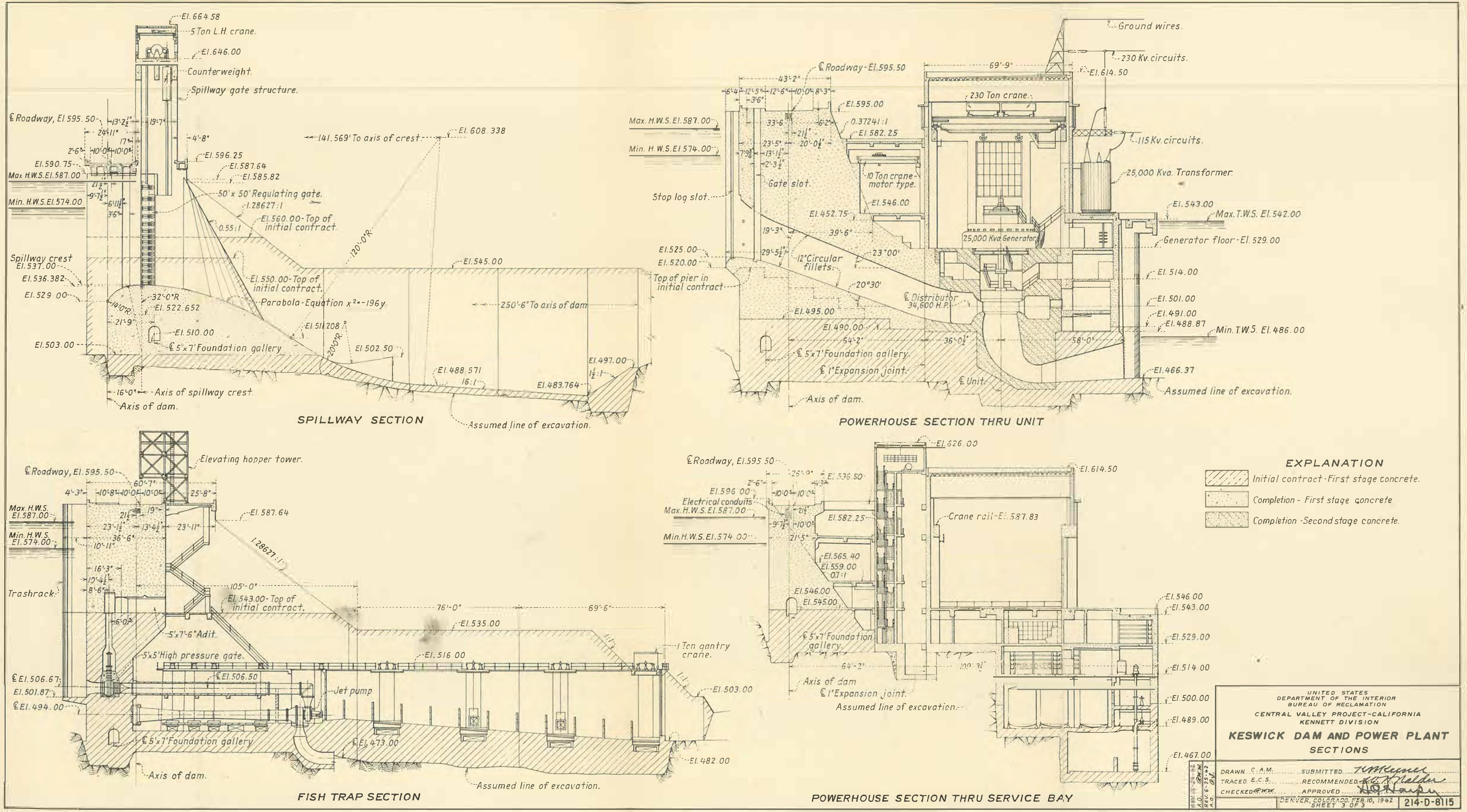
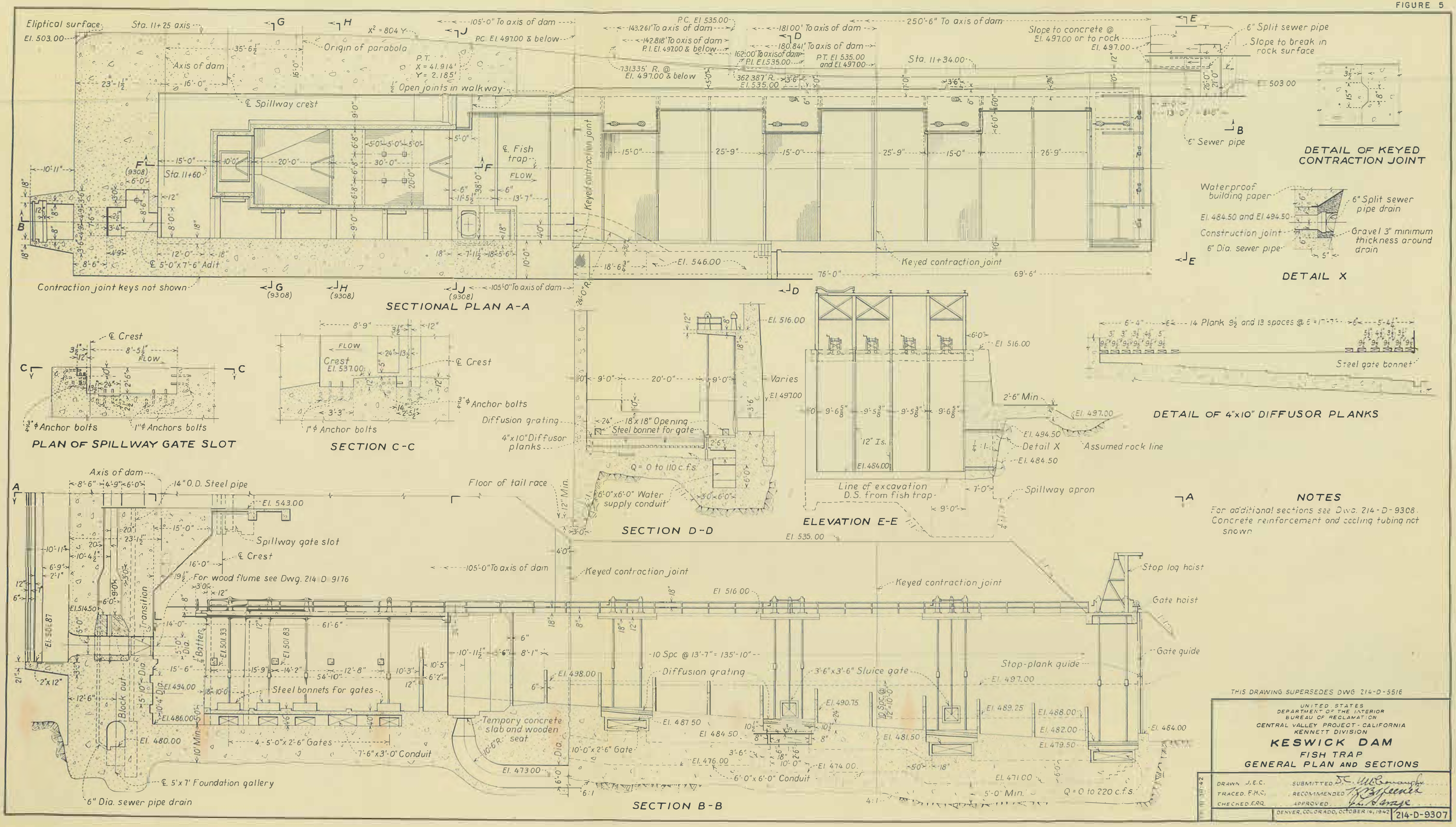
CENTRAL VALLEY PROJECT-CALIFORNIA
KENNETT DIVISION
KESWICK DAM AND POWER PLANT
GENERAL PLAN
DRAWN S.A.M.
TRACED C.E.V.
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO, FEB. 10, 1942
SHEET 1 OF 3
214-D-8113
SACRAMENTO
RIVER
POWER HOUSE
3-25,000 KVA. GENERATORS
"U3" Bay
"U2" Bay
"U1" Bay
Service Bay "S"
Crane rails
℄ Units
Elevator tower
Pull pit
SPILLWAY
FISH TRAP
POWER INTAKE STRUCTURE
Axis of Spillway Crest
Axis of dam
℄ Roadway
℄ ROADWAY TO REDDING
Dumped riprap
Berm-3' Min.
Guard rail
Drains
Contraction joints
6 Spc. @ 30' = 180'
15 Spc. @ 15' = 225'
Elevating hopper tower
4'x4'x5'10"x6" Concrete cover slabs
Pull pits
Parking area
Berm
El. 503.0
El. 517.0
El. 565.0
El. 595.5 ±
El. 482.0
El. 546.0
El. 520.0
El. 615.0
1090' R.
225' R.
615' R.
270' R.
385' R.
BLOCK 5
BLOCK 24
Sta. 5+00
Sta. 6+75
Sta. 7+25
Sta. 7+75
Sta. 8+25
Sta. 8+69
Sta. 8+95
Sta. 9+10
Sta. 9+40
Sta. 9+60
Sta. 10+00
Sta. 10+20
Sta. 10+60
Sta. 10+80
Sta. 11+25
Sta. 11+60
Sta. 11+89
Sta. 12+58
Sta. 13+23
Sta. 13+88
Sta. 14+04
Sta. 14+59
Sta. 15+07
Sta. 15+31
Sta. 15+87
N. 29 000
N. 28 350
N. 28 500
W. 43 500
W. 43 000
W. 44 000
Fill
Guard rails
℄ Roadway

FIGURE 4



SPILLWAY SECTION
El. 664.58
5 Ton L.H. crane.
El. 646.00
Counterweight.
Spillway gate structure.
℄ Roadway, El. 595.50
Max H.W.S. El. 587.00
Min. H.W.S. El. 574.00
El. 590.75
El. 596.25
El. 587.64
El. 585.82
141.569' To axis of crest.
El. 608.338
50' x 50' Regulating gate.
1.28627:1
El. 560.00 - Top of initial contract
0.55:1
120'-0" R.
Spillway crest El. 537.00
El. 536.382
El. 529.00
El. 550.00 - Top of initial contract.
Parabola - Equation x² = -196y
32'-0" R
El. 522.652
El. 510.00
El. 503.00
℄ 5'x7' Foundation gallery
El. 511.208
20'-0" R
El. 502.50
El. 545.00
250'-6" To axis of dam
El. 488.571
16:1
El. 483.764
El. 497.00
16'-0" - Axis of spillway crest.
Axis of dam.
Assumed line of excavation.
POWERHOUSE SECTION THRU UNIT
℄ Roadway - El. 595.50
69'-9"
Ground wires.
230 Kv. circuits.
El. 614.50
230 Ton crane.
El. 595.00
0.37241:1
El. 582.25
Max. H.W.S. El. 587.00
Min. H.W.S. El. 574.00
115 Kv. circuits.
10 Ton crane motor type.
25,000 Kva. Transformer.
Gate slot.
Stop log slot.
El. 546.00
El. 452.75
El. 543.00
Max. T.W.S. El. 542.00
39'-6"
25,000 Kva Generator
Generator floor - El. 529.00
El. 525.00
El. 520.00
12" Circular fillets.
23°00'
Top of pier in initial contract
20°30'
℄ Distributor 34,600 H.P.
El. 514.00
El. 501.00
El. 491.00
El. 488.87
Min. T.W.S. El. 486.00
El. 495.00
El. 490.00
54'-2"
36'-0½"
58'-0"
℄ 5'x7' Foundation gallery.
℄ 1" Expansion joint.
℄ Unit.
El. 466.37
Axis of dam.
Assumed line of excavation.
FISH TRAP SECTION
Elevating hopper tower.
℄ Roadway, El. 595.50
60'-7"
Max. H.W.S. El. 587.00
Min. H.W.S. El. 574.00
El. 587.64
1.28627:1
Trashrack.
105'-0"
El. 543.00 - Top of initial contract.
76'-0"
69'-6"
El. 535.00
5'x7'-6" Adit.
5'x5' High pressure gate.
El. 516.00
1 Ton gantry crane.
℄ El. 506.67
El. 501.87
℄ El. 494.00
℄ El. 506.50
Jet pump
El. 503.00
℄ 5'x7' Foundation gallery
El. 473.00
El. 482.00
Axis of dam.
Assumed line of excavation.
POWERHOUSE SECTION THRU SERVICE BAY
El. 626.00
℄ Roadway, El. 595.50
El. 614.50
El. 596.00
Electrical conduits
Max. H.W.S. El. 587.00
Min. H.W.S. El. 574.00
El. 582.25
Crane rail - El. 587.83
El. 565.40
El. 559.00
0.7:1
El. 546.00
El. 545.00
℄ 5'x7' Foundation gallery.
64'-2"
Axis of dam
℄ 1" Expansion joint.
Assumed line of excavation.
El. 546.00
El. 543.00
El. 529.00
El. 514.00
El. 500.00
El. 489.00
El. 467.00
EXPLANATION
Initial contract - First stage concrete.
Completion - First stage concrete
Completion - Second stage concrete.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
KENNETT DIVISION
KESWICK DAM AND POWER PLANT
SECTIONS
DRAWN C.A.M.
TRACED E.C.S.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO, FEB. 10, 1942
SHEET 3 OF 3
214-D-8115

FIGURE 5


SECTIONAL PLAN A-A
Contraction joint keys not shown
PLAN OF SPILLWAY GATE SLOT
SECTION C-C
SECTION D-D
ELEVATION E-E
SECTION B-B
DETAIL OF KEYED CONTRACTION JOINT
DETAIL X
DETAIL OF 4"x10" DIFFUSOR PLANKS
NOTES
For additional sections see Dwg. 214-D-9308.
Concrete reinforcement and cooling tubing not shown
THIS DRAWING SUPERSEDES DWG 214-D-5516
UNITED STATES
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CENTRAL VALLEY PROJECT-CALIFORNIA
KENNETT DIVISION
KESWICK DAM
FISH TRAP
GENERAL PLAN AND SECTIONS
DRAWN J.E.C.
TRACED F.H.C.
CHECKED E.R.Q.
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO, OCTOBER 14, 1942
214-D-9307

of negative pressures on the spillway face. The discharge studies were made to ascertain the effectiveness of the hydraulic jump and the distribution of the flow after the water left the spillway apron. Studies of the flow conditions in the river channel gave assurance that the migratory fish would be induced to enter the fishway. Also, tests on this model indicated the need of a larger one of the spillway to enable a more detailed study of the hydraulic jump and the scour of the river bed downstream.

A 1 to 48 scale model of a section of the spillway was constructed in a flume with a glass panel side for observing and photographing flow conditions. Tests were made on various types of sills, dentates, and apron profiles to obtain a combination which would give the most satisfactory jump conditions and the minimum scour downstream. The economics of the design were also considered, as it was necessary for the apron to be short and comparatively high to avoid excessive rock excavation.

Tests were made on the 1 to 20 scale fishway model to determine the operating characteristics of the fish ladder, the head loss in the auxiliary water supply conduit system, the flow characteristics at high and low tailwater stages, and the effectiveness of the water-supply baffling devices in the elimination of turbulence. The purpose of these tests was to discover any undesirable features and evolve satisfactory improvements.

Investigations made on the 1 to 10 scale model of a portion of the auxiliary water supply conduit and fish ladder were primarily directed toward the elimination of turbulence in the pools of the ladder to which auxiliary water was supplied. This was important since observations on other fishway structures have shown that the fish will avoid or become confused where there are boils or strong upward currents and may attempt to swim against them. Many combinations of baffles in the dissipator were tried before a satisfactory one was evolved.

A model of the temporary gate weir to be erected in the spillway portion of the structure was constructed to an indefinite scale to determine the probable velocity of the top of the gate when the closure is made. It was necessary to know the magnitude of this velocity to design the gates strong enough to withstand the forces imparted by the impact of the ends of the gates on the crest sections. It would have been necessary to construct an elaborate model to evaluate the numerous variables, but as it was only desired to check the assumption that the terminal velocity of the top of the gate was equal to the velocity of flow through the channel before the gate was unlatched, a rather simple model was constructed to ascertain the relative velocities of the gate and flow through the channel.

3. Summary of the investigation. The original design of the initial stage development of the project was tested on the 1 to 80 scale model and found to have inadequate flood capacity. Undesirable flow characteristics existed in the spillway, at the entrance to the fishway, and downstream from the powerhouse stop-log section under certain operating conditions. These were eliminated by revisions which made the structure more closely resemble the ultimate development.

When the ultimate stage development was tested on the 1 to 80 scale model, the spillway was found inadequate as the hydraulic jump was formed over the downstream end of the apron. The recommended design, obtained from studies on the 1 to 48 model, proved satisfactory when tested on this model.

Detailed studies of the spillway were conducted on a 1 to 48 scale sectional model to ascertain the most effective and efficient spillway apron profile. Various types of sills, dentates, and steps were tested before a satisfactory energy dissipator was evolved which consisted of a row of 8-foot thick streamlined steps spaced 7 feet apart with their top surfaces sloped upward at 10 to 1 from the horizontal. These tests also demonstrated that, should retrogression of the river bed lower the tailwater elevation sufficient to cause the jump to utilize only the downstream portion of the apron, the condition could be corrected by adding a row of dentates on the $1\frac{1}{2}$:1 slope at the end of the apron.

Flow characteristics in the river, pertaining to the operation of the fishway, were studied on the 1 to 80 scale model of both the initial and ultimate stage developments. Unsatisfactory flow conditions on the original design of the initial stage were eliminated on the revised design when the flow was evenly distributed over the rock bench downstream. The flow conditions in both the original and final designs of the ultimate stage were satisfactory for proper operation of the fishway, except that the latter required a sloping extension to the right spillway training wall and a block of concrete carried to elevation 503.00 in the same region to prevent excessive flow over the bench at the entrance to the fish ladder.

A model was constructed to the scale ratio of 1 to 20 to study the operating characteristics of the fishway. The tests indicated the necessity of completely redesigning the baffling devices to eliminate undesirable turbulence, uneven flow distribution, and strong upward currents in the pools and chambers. Turbulent conditions in the brail and holding chambers were eliminated by forcing the water to follow a circuitous path around the walls of those chambers before being admitted to them. The fish ladder, which consisted of a succession of pools separated by rectangular weirs, had satisfactory flow characteristics from pool to pool. The model was too small for detailed studies pertaining to turbulence so another model was constructed to a scale of 1 to 10 to study the flow in one of the ladder pools to which auxiliary water was supplied from beneath by the auxiliary conduit system. Numerous designs were tested on this model before one was evolved which successfully eliminated all of the undesirable flow characteristics. The recommended design outlet consisted of a wide, shallow cross conduit, tapering upward, with small step-like baffles placed transversely on the floors to force the water upwards and out through the slotted openings into the pool.

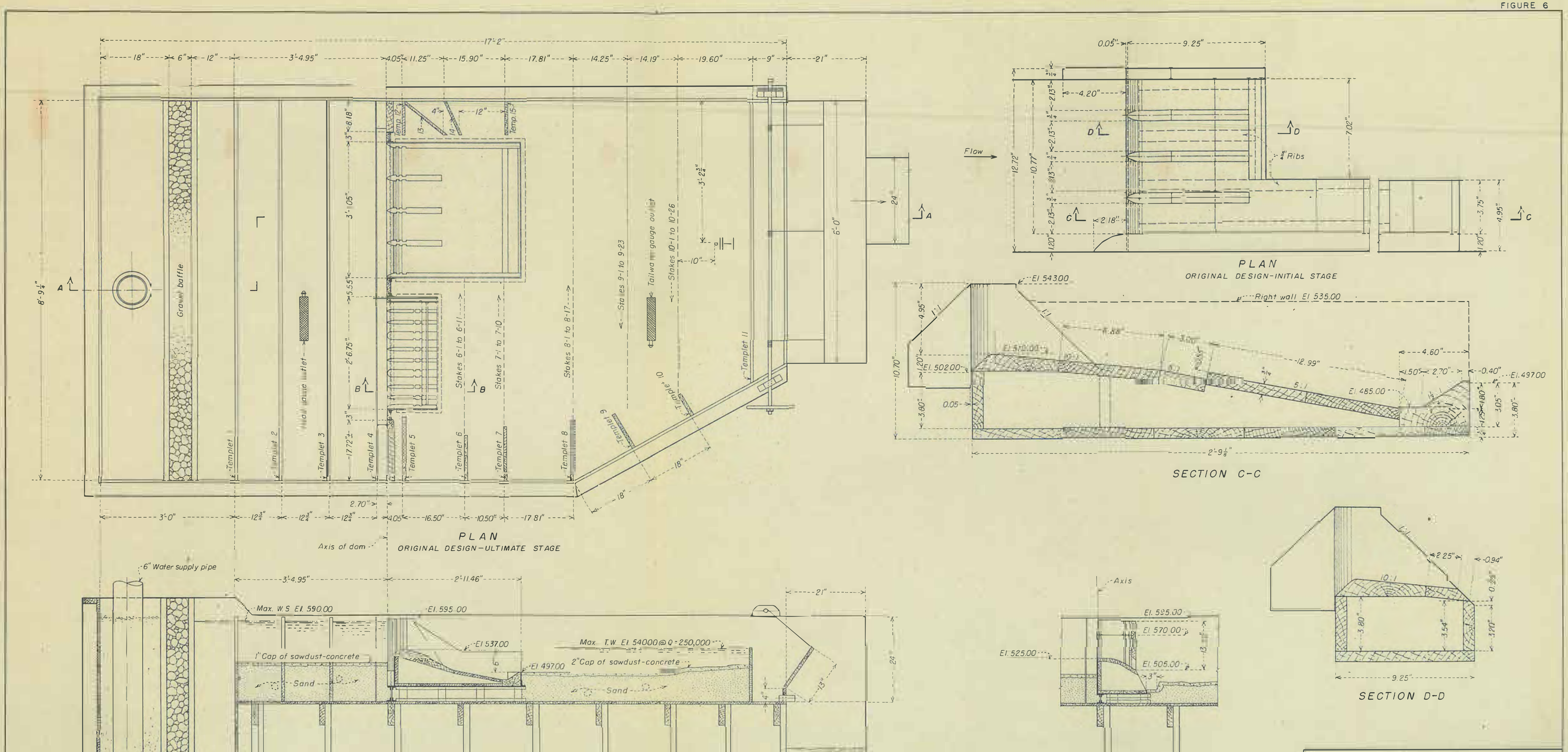
Tests on the temporary gate weir model demonstrated that the top of the gate moved at a velocity greater than the velocity of the stream of water and that it reached a maximum between 10 and 20 degrees from the vertical. The velocity was decreased somewhat as the gate neared closure, due to the cushioning effect of the water between the pier sections and the ends of the gate. Further tests demonstrated that when the tailwater elevation is raised, the cushioning effect is correspondingly greater with a consequent reduction in the impact of the gate on the piers. The tests indicated that the factor of safety used in the design would prove sufficient to prevent destruction of the gates at closure.

SPILLWAY STUDIES

4. Description of 1 to 80 model. The model of the initial stage development, including the topography 273 feet upstream and 647 feet downstream from the axis of the dam, was built to a scale of 1 to 80 (figures 6 and 7). Water was supplied and regulated by the laboratory piping system; a gravel baffle was used to distribute the flow evenly; and the tailwater elevation was regulated by a tailgate. The spillway, piers, stop logs, and fishway were made of redwood and enclosed in two metal frames bolted to the bottom of the model box. The powerhouse or stop-log section was enclosed in one frame and the spillway section in the other to facilitate removal of one section without interfering with the other when design changes were made. The revised design of the initial stage and the original design of the ultimate stage were constructed in the same manner. The final design of the ultimate stage spillway was constructed by cutting a series of ribs to the spillway shape and covering them with sheet metal. The piers, gates, retaining walls, steps, and fishway were made of redwood. The original design powerhouse was used for all tests on the ultimate development.

5. Tests on the initial-stage development. Hydraulic model tests of the initial stage demonstrated the need for revision of the proposed design since the stop-log section at elevation 505.00 was 5 feet lower than the spillway crest at elevation 510.00, and consequently at low discharges the greater portion of the flow passed over this section instead of the spillway (figure 7A). The spillway was inadequate for the anticipated floods. These objectionable conditions were eliminated by increasing the length of the spillway crest from 71 feet 8 inches to 150 feet and raising the stop-log section to elevation 520.00 (figure 7B). This design proved satisfactory as the spillway had ample discharge capacity and an effective stilling pool. The discharge capacity through the structure was 132,000 second-feet with the stop logs at elevation 520.00 and 172,000 second-feet when they were removed to elevation 500.00.

6. Studies on the 1 to 80 model of original design of ultimate development. Tests on the original design of the ultimate development indicated that the spillway apron should be revised to more effectively dissipate the energy in the spillway flow before it reaches the rock bench. The hydraulic jump occurred too near the end of the apron with the result that a slight reduction of the tailwater elevation would sweep it off onto the bench (figure 8B). As the 1 to 80 model was too small to effectively study the action of the spillway, the 1 to 48 scale sectional model of one-half the spillway was constructed.



UNITED STATES
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BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT-CALIFORNIA
KENNETT DIVISION

KESWICK DAM

HYDRAULIC MODEL STUDIES - 1 TO 80 SCALE
DETAILS OF 1 TO 80 SCALE MODEL

DRAWN H.G.D., Jr. SUBMITTED
TRACED G.R.C.—N.H. RECOMMENDED
CHECKED.. APPROVED

DENVER, COLORADO — FEB. 4, 1943

21

A. Original design - Spillway discharge, 25,000 second-feet; fishway discharge, 300 second-feet; and tailwater elevation 504.20.

B. Modified design - Spillway discharge, 15,000 second-feet; fishway discharge, 300 second-feet; and tailwater elevation 498.75.

FLOW CONDITIONS IN INITIAL DEVELOPMENT

KESWICK DAM - 1:80 MODEL

FIGURE 8

A. Spillway discharge, 3,000 second-feet; fishway discharge, 300 second-feet; no powerhouse discharge; and tailwater elevation 488.00.

B. Spillway discharge, 50,000 second-feet; no fishway or powerhouse discharge; and tailwater elevation 513.75.

FLOW CONDITIONS IN ORIGINAL DESIGN OF ULTIMATE DEVELOPMENT
KESWICK DAM - 1:80 MODEL

7. Description of 1 to 48 model. The 1 to 48 model represented a portion of the center bays of the spillway and was placed in a rectangular flume with a glass panel to provide observation and photography of the spillway action and downstream scour. The model spillway was constructed of wooden ribs covered with galvanized iron (figure 9). A sand bed eight inches deep was placed in the flume to determine the relative scour downstream from the apron for each spillway shape. The tailwater elevation was adjusted to conform with the prototype by means of a tailwater gate at the downstream end of the flume. The steps, which were placed on the spillway to assist in the energy dissipation, were wood with the exception of one of metal to permit installation of piezometer connections for pressure measurements.

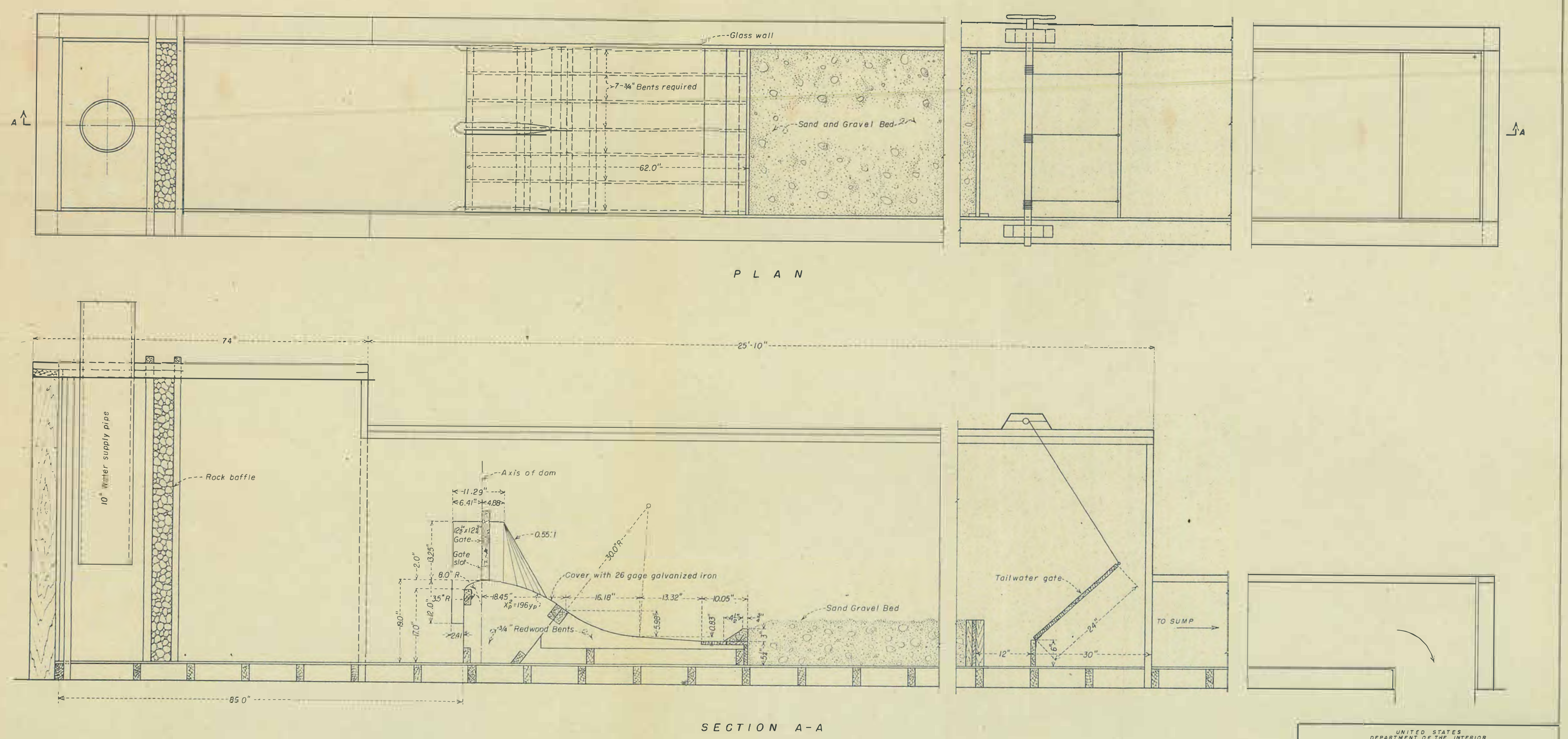
8. Development of recommended spillway design. A series of tests was made on the 1 to 48 model to obtain the most economical spillway design which would provide adequate protection for the toe of the structure and the rock bench downstream and effectively dissipate the energy released on the spillway apron.

In order to determine the relative safety of a proposed design, sweep-out tests at the higher discharges were made by lowering the tailwater elevation until the hydraulic jump left the spillway apron. The tailwater elevation was also adjusted to that elevation at which the most satisfactory jump was formed. When the normal tailwater elevation, sweep-out elevation, and satisfactory jump elevation is plotted against the discharge, the efficiency of the design is apparent. The most efficient design would be one in which the normal tailwater and satisfactory jump curves coincide and the sweep-out curve is considerably lower (figure 10). A satisfactory design was considered to be one where the jump would not leave the apron after a reasonable amount of retrogression of the river channel.

The original spillway design was tested in the 1 to 48 model to demonstrate its inadequacy and to establish a basis for subsequent improvements (design 1, figures 11 and 12 A and B). The location of the jump at normal tailwater and the scour after the run were recorded by photographs and were compared with subsequent tests on the various proposed designs to establish the relative improvement accruing from the revisions. These tests definitely indicated that the original design of the spillway could be revised to improve the operating characteristics.

The first revision to the design consisted of steps placed on the apron at the pool entrance arranged to break up the jet and move the jump further upstream (design 2, figure 11). The steps effected a noticeable improvement, but the hydraulic jump was still too far downstream and considerable energy was present when the flow reached the rock bench.

The spillway was then redesigned, using sloping apron computations based on the design at Wheeler Dam in the Tennessee River. The radius of the curve connecting the parabolic section of the crest with the sloping



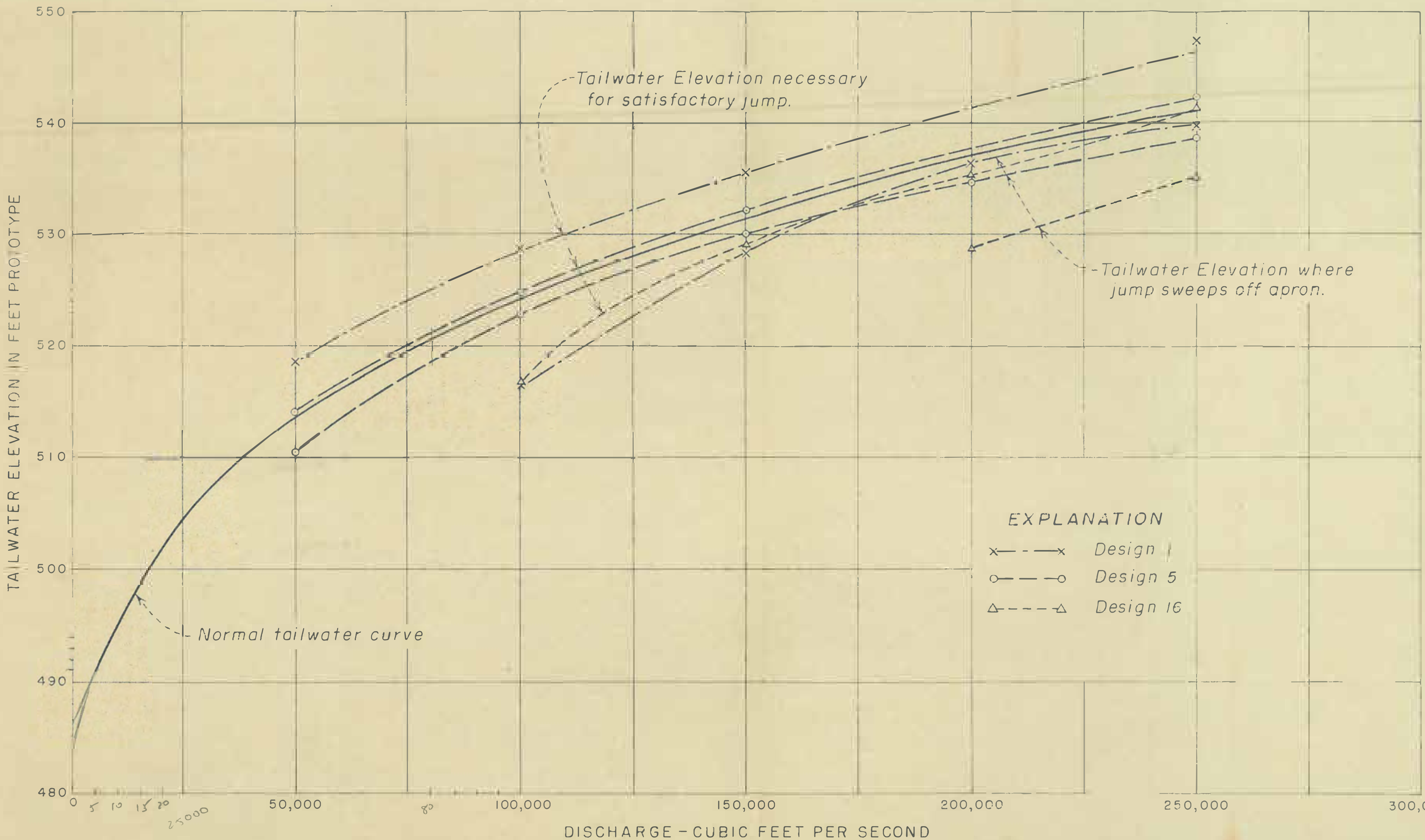
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT-CALIFORNIA
KENNETT DIVISION

KESWICK DAM

HYDRAULIC MODEL STUDIES - 1 TO 48 SCALE

DETAILS OF SECTIONAL MODEL

DRAWN J.A.L.	SUBMITTED
TRACED G.R.C.-P.V.L.	RECOMMENDED
CHECKED	APPROVED
	DENVER, COLORADO - FEB. 4, 1943



CENTRAL VALLEY PROJECT - CALIFORNIA
KESWICK DAM
HYDRAULIC MODEL STUDIES - SCALE 1:48
STILLING POOL CHARACTERISTICS
VARIOUS APRON DESIGNS

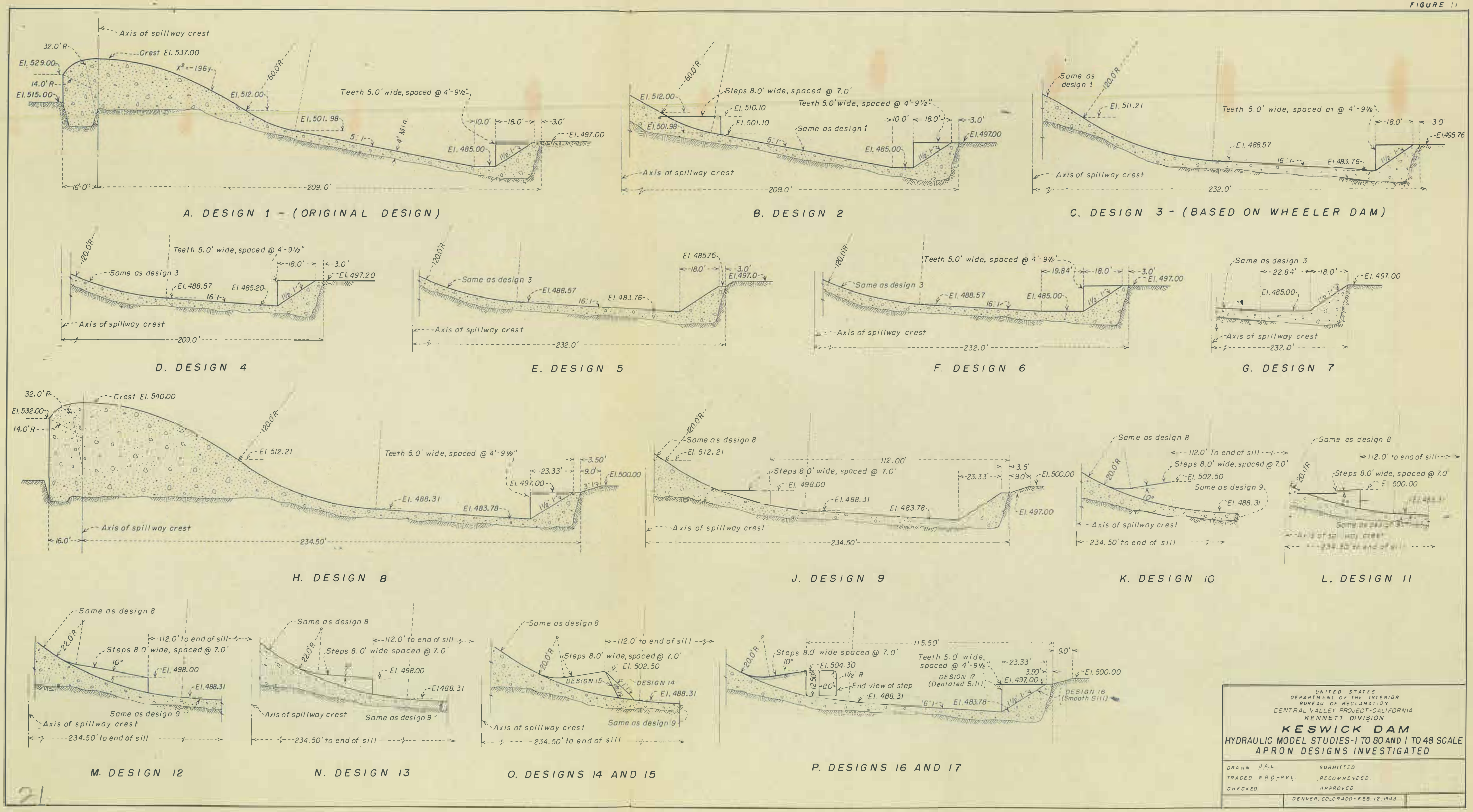
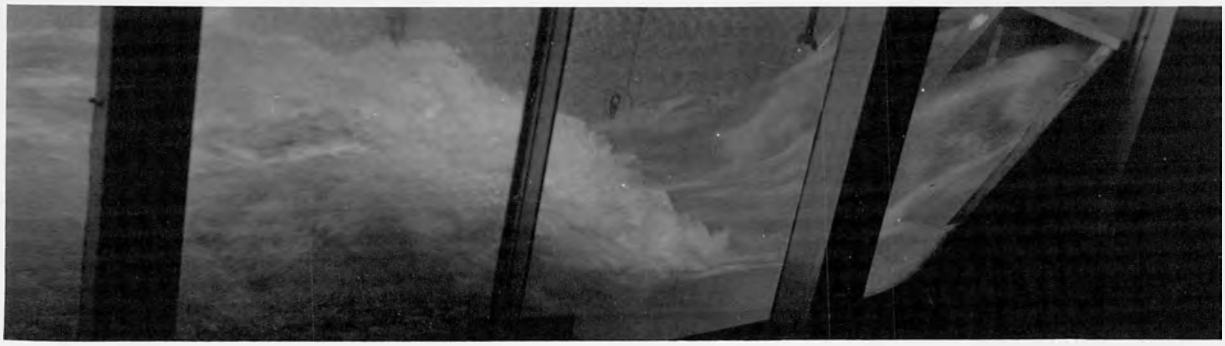
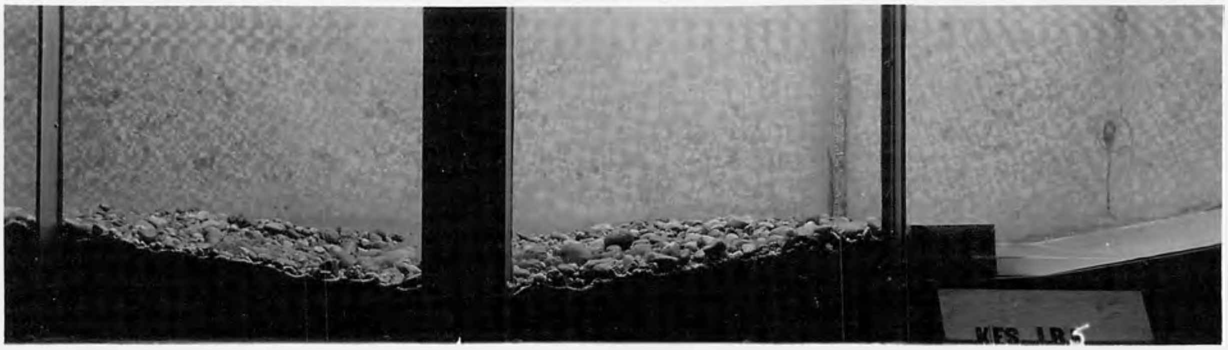

Axis of spillway crest
32.0' R
Crest El. 537.00
El. 529.00
$X^2 = -196y$
14.0' R
El. 515.00
El. 512.00
60.0' R
Teeth 5.0' wide, spaced @ 4'-9½"
El. 501.98
5:1
4' Min.
10.0'
18.0'
3.0'
El. 497.00
El. 485.00
1½:1
16'-0"
209.0'
A. DESIGN 1 - (ORIGINAL DESIGN)
Steps 8.0' wide, spaced @ 7.0'
El. 510.10
El. 501.10
Same as design 1
B. DESIGN 2
Same as design 1
120.0' R
El. 511.21
Teeth 5.0' wide, spaced at @ 4'-9½"
El. 488.57
16:1
El. 483.76
El. 495.76
232.0'
C. DESIGN 3 - (BASED ON WHEELER DAM)
Same as design 3
El. 485.20
El. 497.20
D. DESIGN 4
El. 485.76
E. DESIGN 5
19.84'
F. DESIGN 6
22.84'
G. DESIGN 7
Crest El. 540.00
El. 532.00
El. 512.21
Teeth 5.0' wide, spaced @ 4'-9½"
23.33'
3.50'
9.0'
El. 500.00
El. 497.00
El. 488.31
El. 483.78
234.50'
H. DESIGN 8
Same as design 8
112.00'
Steps 8.0' wide, spaced @ 7.0'
El. 498.00
J. DESIGN 9
112.0' To end of sill
20.0' R
El. 502.50
Same as design 9
10°
234.50' to end of sill
K. DESIGN 10
L. DESIGN 11
22.0' R
M. DESIGN 12
N. DESIGN 13
DESIGN 15
DESIGN 14
O. DESIGNS 14 AND 15
115.50'
El. 504.30
12.50'
8.0'
1½' R
End view of step
DESIGN 17 (Dentated Sill)
DESIGN 16 (Smooth Sill)
P. DESIGNS 16 AND 17
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT-CALIFORNIA
KENNETT DIVISION
KESWICK DAM
HYDRAULIC MODEL STUDIES-1 TO 80 AND 1 TO 48 SCALE
APRON DESIGNS INVESTIGATED
DRAWN J.A.L.
TRACED G.R.C.-P.V.L.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO - FEB. 12, 1943

FIGURE 12



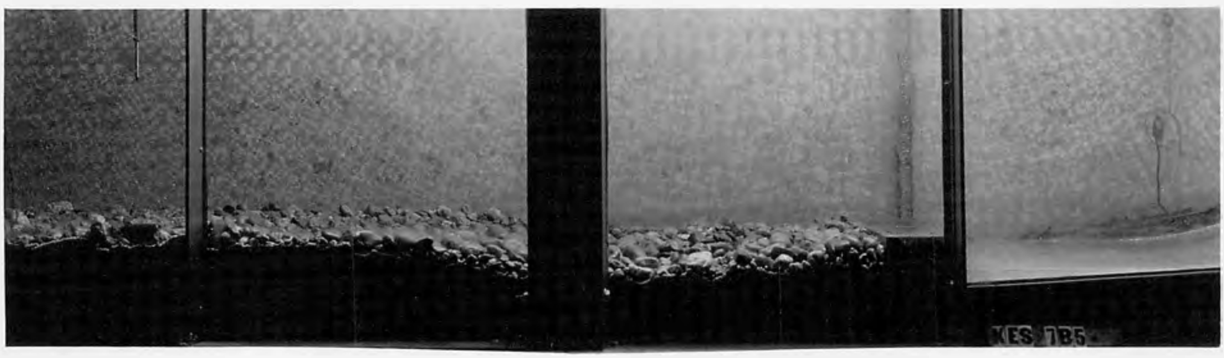
A. Discharge - 250,000 second-feet.



B. Erosion of sand-gravel bed.

DESIGN 1 (ORIGINAL) - 5:1 SLOPING APRON WITH DENTATED SILL

C. Discharge - 250,000 second-feet.



D. Erosion of sand-gravel bed.

DESIGN 3 - 16:1 SLOPING APRON WITH DENTATED SILL

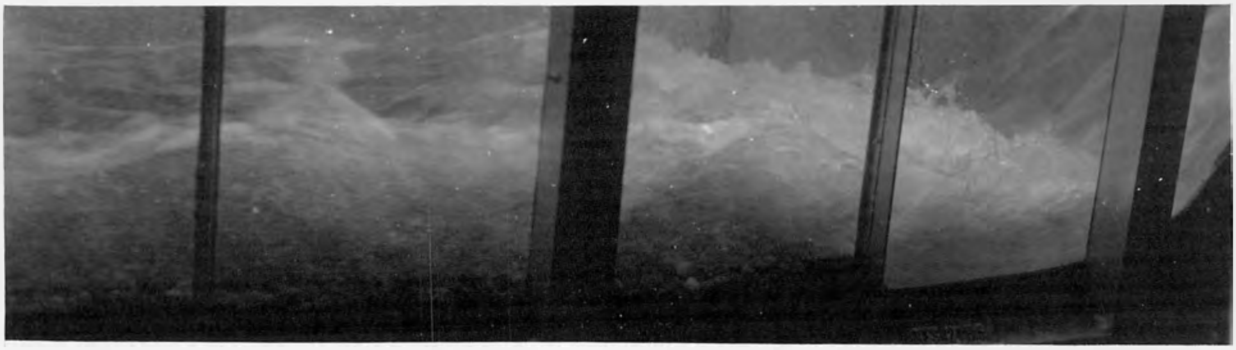
COMPARISON OF FLOW AND EROSION

KESWICK DAM - 1:48 MODEL OF ULTIMATE DEVELOPMENT

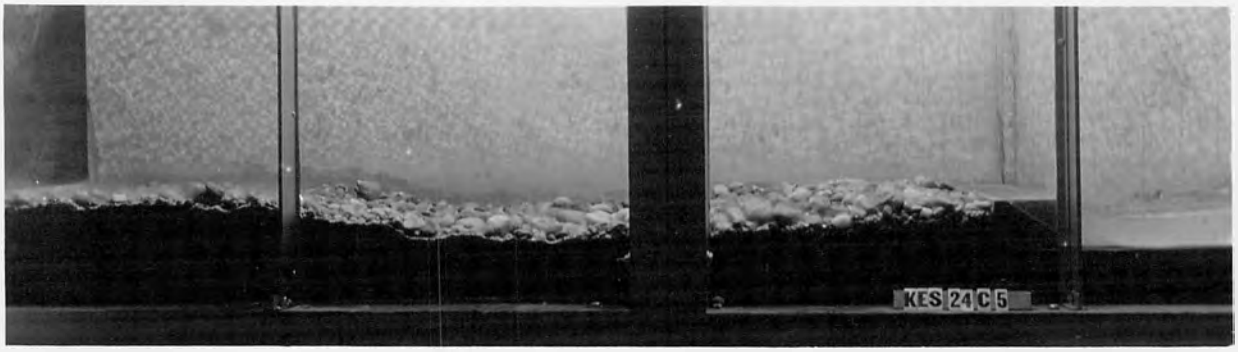
apron was increased from 60 feet to 120 feet (prototype). The apron slope was changed from 5 to 1 to 16 to 1, and the apron lengthened 23 feet (design 3, figure 11). A dentated sill 12 feet high was added, similar to the one used in tests on the original design. This arrangement proved satisfactory as the stilling pool had sufficient length to properly transform the kinetic energy of the jet to turbulent energy and dissipate the latter on the spillway apron (figure 12 C and D). The dentated sill was moved upstream to make the apron the same length as in the original design (design 4, figure 11), but the test demonstrated that the apron should be at least as long as in design 3. When this sill was replaced with one having a trapezoidal cross-section the dissipation of energy was incomplete, indicating the dentated sill to be the better design, (design 5, figure 11). By raising the sill to elevation 497.00, the flow conditions were improved and scour practically eliminated (design 6, figure 11). Flow conditions were not adverse when the dentated sill was replaced with a smooth sill, but the scour was excessive (design 7, figure 11). The crest was raised to elevation 540.00, and the rock bench downstream to elevation 500.00 (design 8, figure 11). Flow conditions were satisfactory and there was very little scour (figure 13 A and B).

Impact of the jet on the dentates might lead to excessive maintenance costs on this type of sill; consequently, investigations were made of the effectiveness of apron steps placed near the pool entrance. The purpose of these steps was to introduce turbulent eddies, thereby increasing the energy dissipation and decreasing the length of apron required. Steps were tested with top surfaces horizontal, inclined 10 degrees upward, inclined 5 degrees upward, inclined 10 degrees downward, inclined 5 degrees downward, inclined 10 degrees upward with a 1 to 1 slope on the downstream face, inclined 10 degrees upward with a 1/2 to 1 slope on the downstream face, and inclined 10 degrees upward, with a vertical downstream face, and with the top edges streamlined (designs 9 to 16, inclusive, figure 11). This series of tests demonstrated that the step with the 10-degree upward slope produced the most desirable results because of the more rapid dissipation of energy (figures 13 to 17, inclusive). The steps which were inclined downward were ineffective, since the scour after maximum discharge was almost as great as without steps. Those with sloping downstream faces, because of the streamlining effect, prevented the formation of eddies immediately downstream, consequently dissipating less energy and increasing the scour downstream from the apron. Pressure tests revealed subatmospheric pressures on the edges of the steps. By rounding and consequently streamlining these edges, the pressures were made atmospheric or greater (figure 18). A paint test was made to delineate the streamlines on the steps (figure 19). The test was made by coating the steps with a thick white lead paint, bringing the discharge up to the maximum as quickly as possible, and after a few moments of flow, cutting off the flow as rapidly as possible.

Up to this point in the tests, a movable bed of gravel had been used downstream from the spillway. Inasmuch as the bench downstream from the spillway apron is to be solid rock in the prototype, an investigation of the difference in effect between a movable bed and a rock bench in the



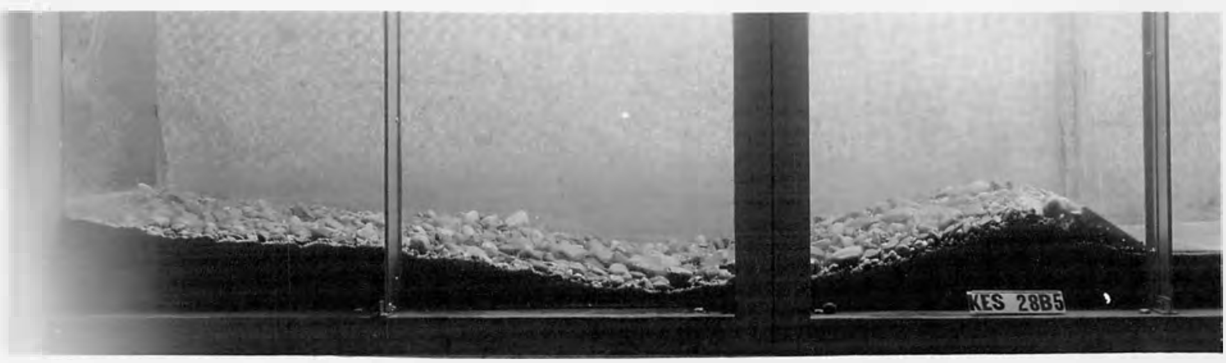
A. Discharge - 250,000 second-feet.



B. Erosion of sand-gravel bed.

DESIGN 8 - DENTATED SILL AT END OF APRON

C. Discharge - 250,000 second-feet.



D. Erosion of sand-gravel bed.

DESIGN 9 - TRAPEZOIDAL SILL AND STEPS WITH TOP SURFACES HORIZONTAL

COMPARISON OF FLOW AND EROSION

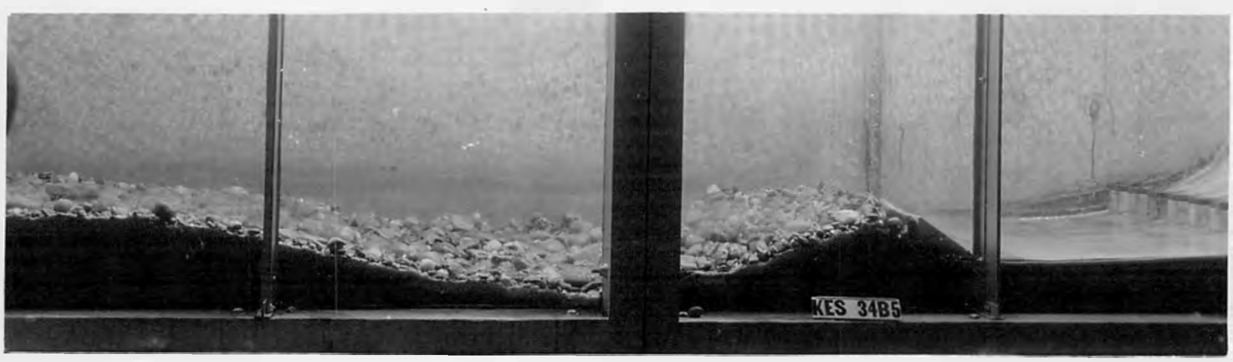
KESWICK DAM - 1:48 MODEL OF ULTIMATE DEVELOPMENT

A. Discharge - 250,000 second-feet.

B. Erosion of sand-gravel bed.

DESIGN 10 - TRAPEZOIDAL SILL AND STEPS WITH 10-DEGREE UPWARD SLOPE ON TOP SURFACES

C. Discharge - 250,000 second-feet.



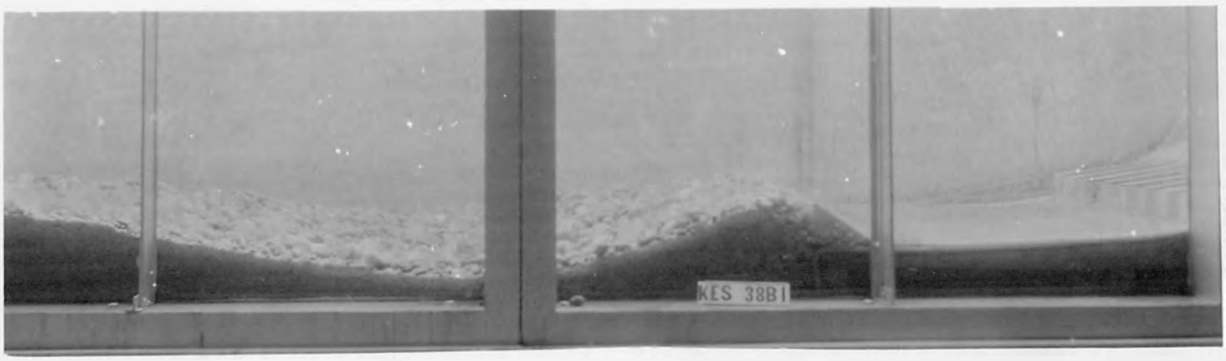
D. Erosion of sand-gravel bed.

DESIGN 11 - TRAPEZOIDAL SILL AND STEPS WITH 5-DEGREE UPWARD SLOPE ON TOP SURFACES

COMPARISON OF FLOW AND EROSION

KESWICK DAM - 1:48 MODEL OF ULTIMATE DEVELOPMENT

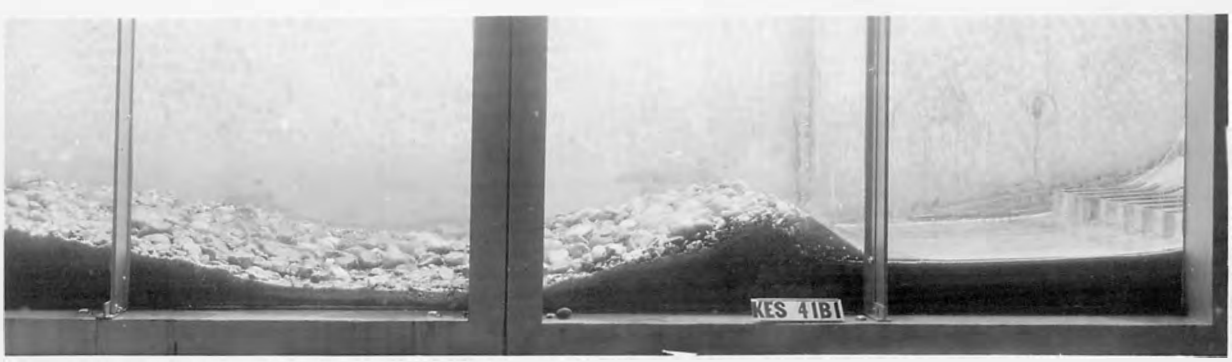
A. Discharge - 250,000 second-feet.



B. Erosion of sand-gravel bed.

DESIGN 12 - TRAPEZOIDAL SILL AND STEPS WITH 10-DEGREE DOWNWARD SLOPE ON TOP SURFACES

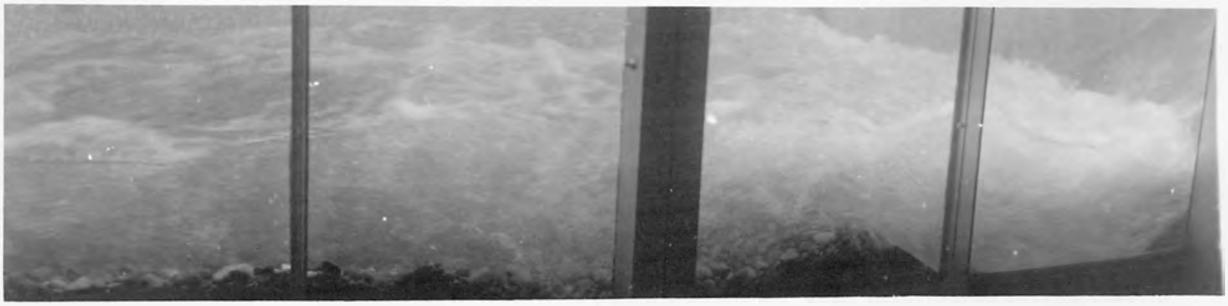
C. Discharge - 250,000 second-feet.



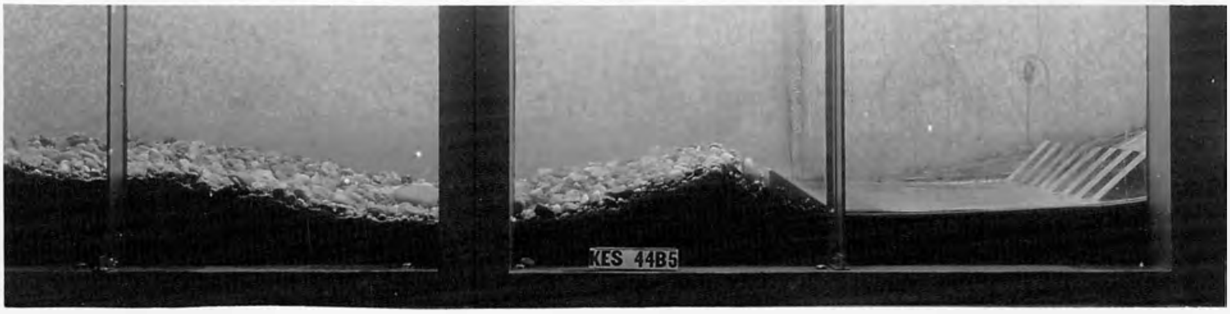
D. Erosion of sand-gravel bed.

DESIGN 13 - TRAPEZOIDAL SILL AND STEPS WITH 5-DEGREE DOWNWARD SLOPE ON TOP SURFACES

COMPARISON OF FLOW AND EROSION
KESWICK DAM - 1:48 MODEL OF ULTIMATE DEVELOPMENT

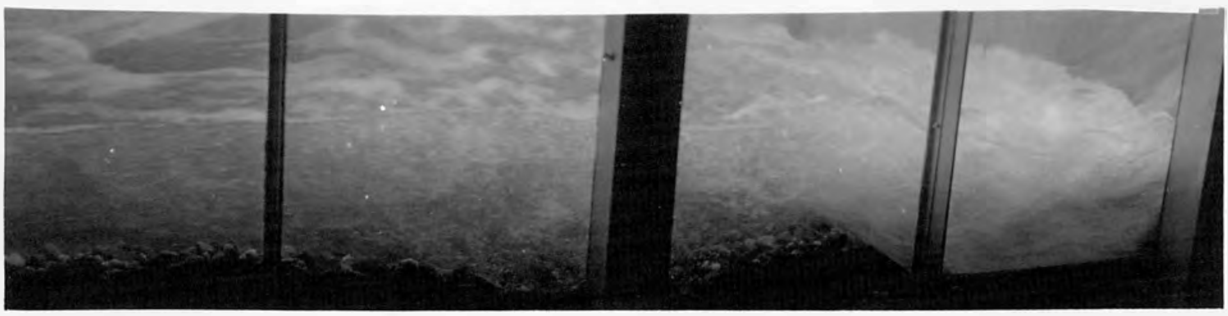


A. Discharge - 250,000 second-feet.

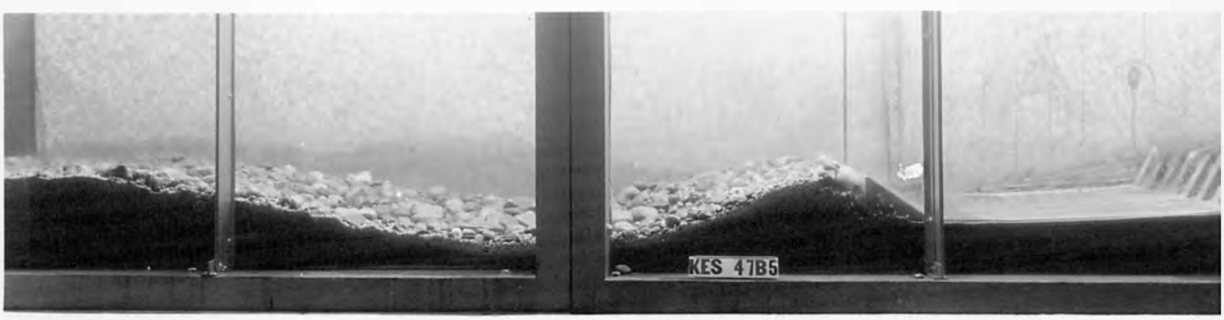


B. Erosion of sand-gravel bed.

DESIGN 14 - TRAPEZOIDAL SILL AND STEPS WITH 1:1 SLOPE ON DOWNSTREAM SIDE



C. Discharge - 250,000 second-feet.

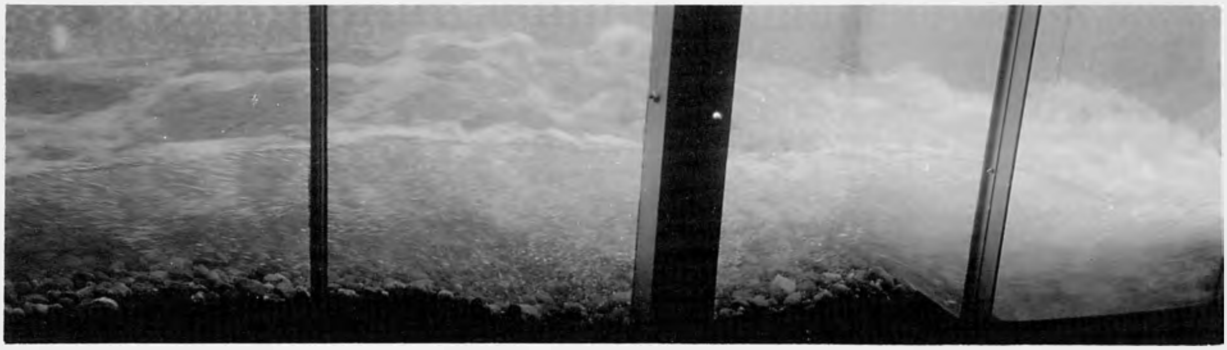


D. Erosion of sand-gravel bed.

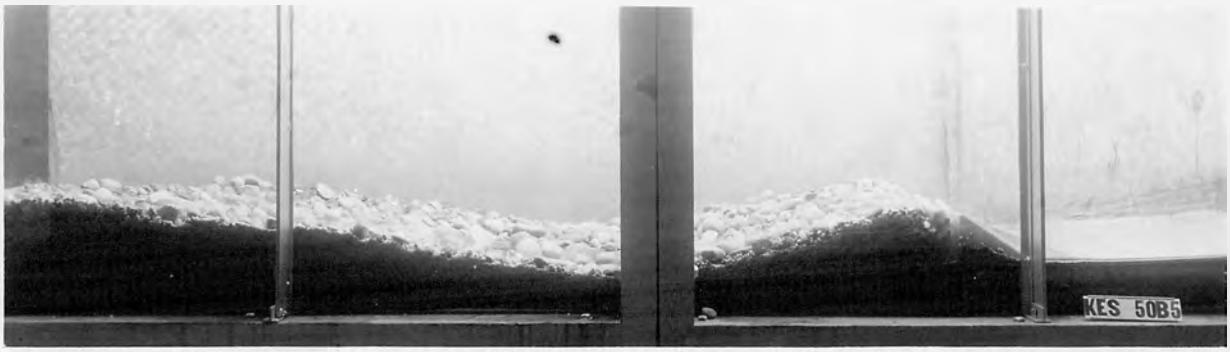
DESIGN 15 - TRAPEZOIDAL SILL AND STEPS WITH $\frac{1}{2}$:1 SLOPE ON DOWNSTREAM SIDE

COMPARISON OF FLOW AND EROSION
KESWICK DAM - 1:48 MODEL OF ULTIMATE DEVELOPMENT

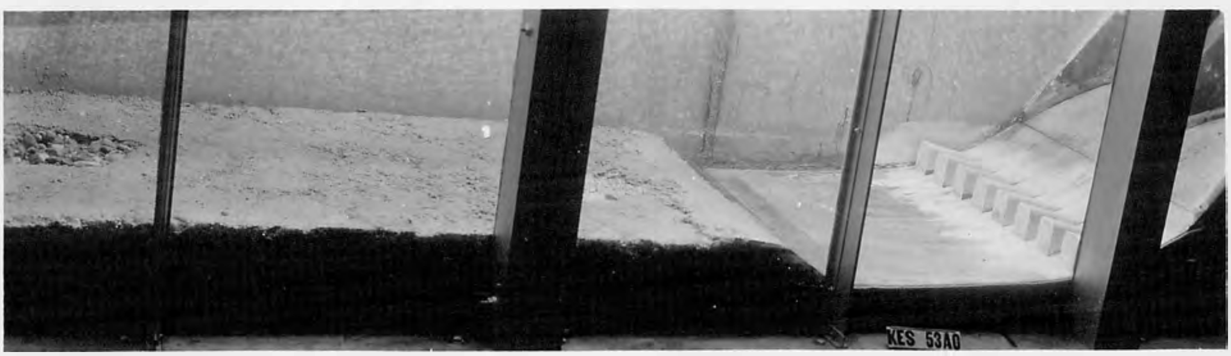
FIGURE 17



A. Discharge - 250,000 second-feet.



B. Erosion of sand-gravel bed.

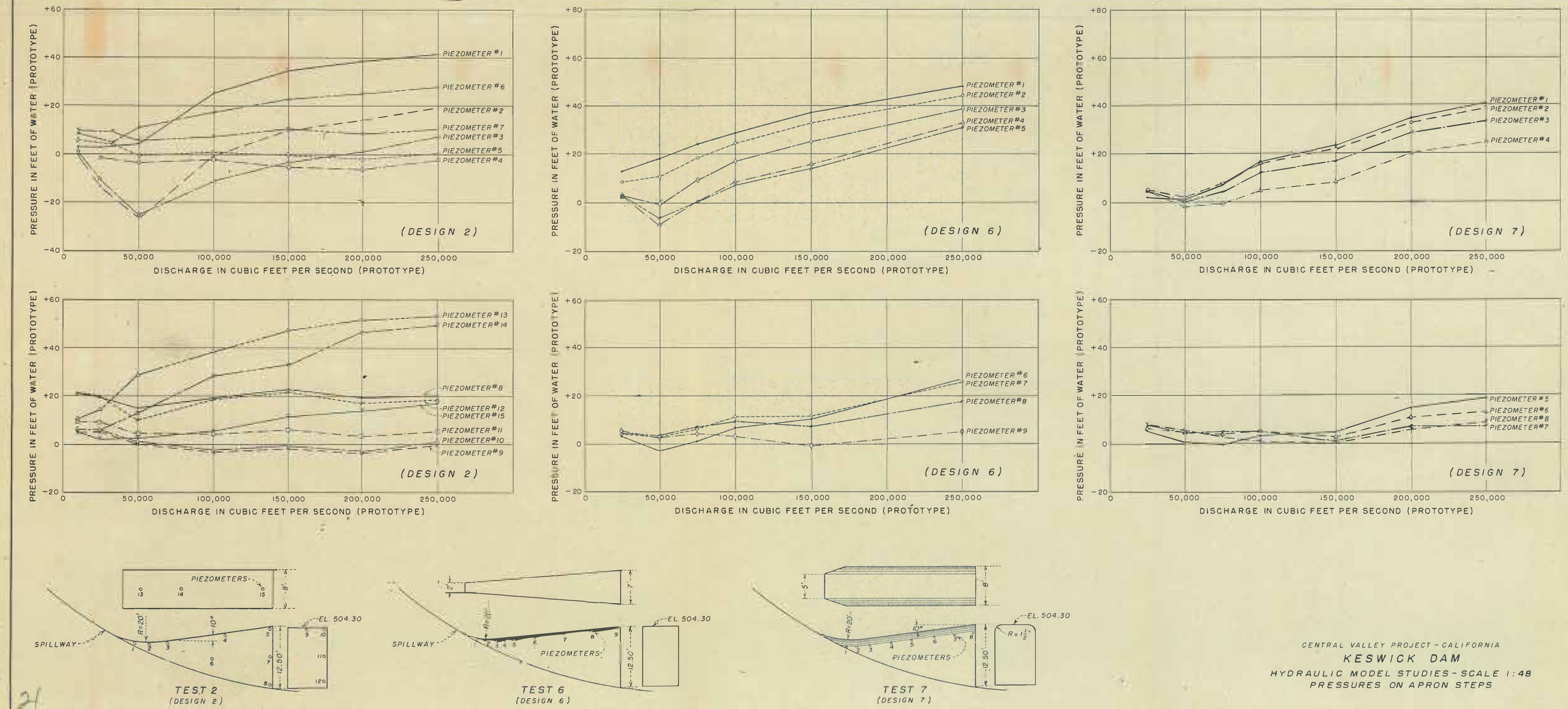


C. Sand-gravel bed stabilized with concrete.

D. Discharge - 250,000 second-feet.

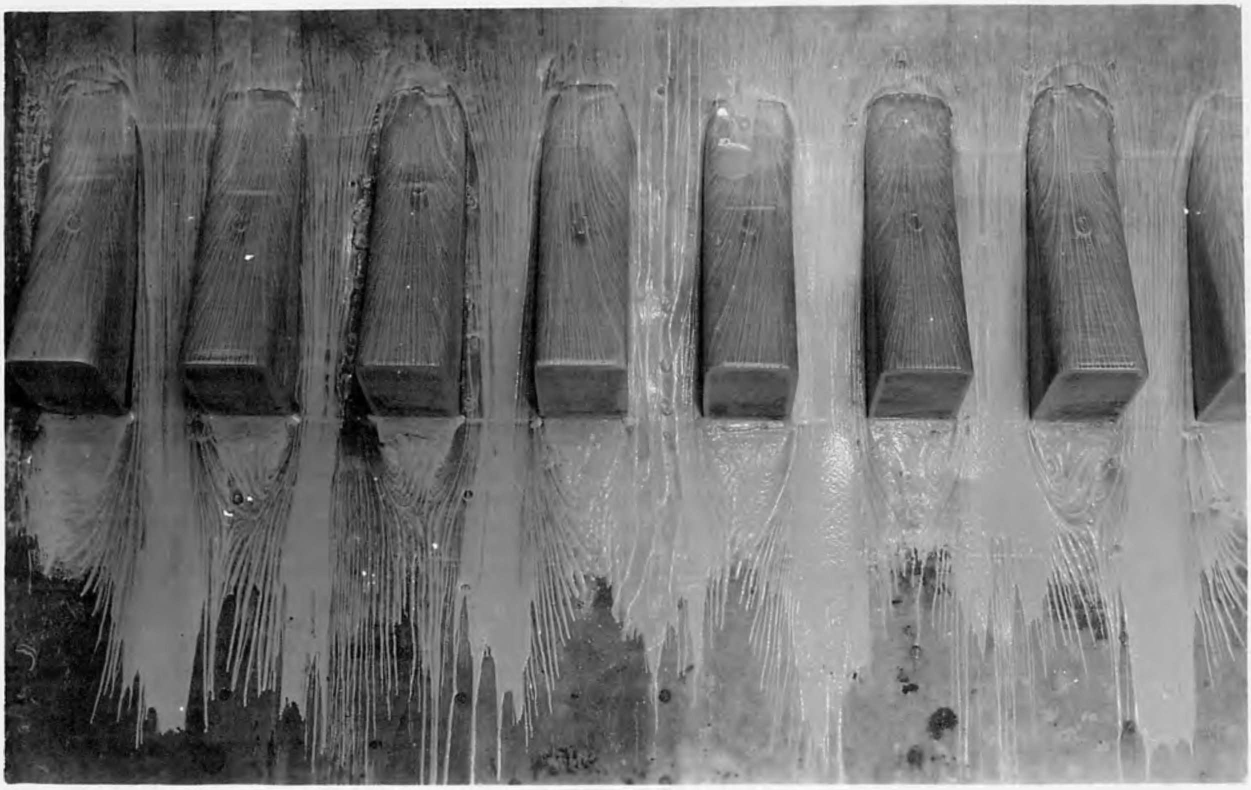
DESIGN 16 - TRAPEZOIDAL SILL AND STREAMLINED STEPS ON APRON

EFFECT OF STABLE RIVER BED ON STILLING POOL ACTION
KESWICK DAM - 1:48 MODEL OF ULTIMATE DEVELOPMENT



CENTRAL VALLEY PROJECT - CALIFORNIA
KESWICK DAM
HYDRAULIC MODEL STUDIES - SCALE 1:48
PRESSURES ON APRON STEPS

21



A. Plan view.

B. Oblique view.

FLOW LINES ON APRON STEPS AFTER DISCHARGE OF 50,000 SECOND-FEET

KESWICK DAM - 1:48 MODEL OF ULTIMATE DEVELOPMENT

model was made. A layer of concrete was placed to elevation 500.00 to replace the movable bed. When the model was tested, the hydraulic jump was considerably worse than with the movable beds. It was necessary to raise the tailwater elevation from one to two feet (prototype) above the normal level before the jump became satisfactory. A reduction in the tailwater elevation of $3\frac{1}{2}$ feet below the normal level was necessary to sweep it from the apron at the maximum discharge of 250,000 second-feet. This test showed that the sand-gravel bench had considerable effect upon the jump characteristics. Its efficiency was improved by the increased friction and by the roller which was formed in the bucket-like pocket scoured downstream from the sill during high discharges.

When the smooth trapezoidal sill was replaced with a dentated sill, the jump characteristics were greatly improved. The satisfactory jump curve coincided with the normal tailwater curve and the jump could not be swept from the apron except with the tailwater elevation 10 feet below normal for the maximum discharge of 250,000 second-feet. It was found that if the bench were excavated to elevation 503.00 instead of to elevation 500.00 as originally planned, the tailwater would rise sufficiently to give adequate dissipation of the turbulent energy, thus eliminating the necessity for the dentated sill. In addition, it was noted on subsequent tests on the 1 to 80 model that the tailwater elevation was appreciably higher on the bench downstream from the spillway than in the old river channel, indicating that the tests on the 1 to 48 sectional model were conservative. The dentated sill could be added in the future if the bench should erode and the jump tended to sweep from the spillway apron (design 17, figure 11).

9. Tests of the recommended design on the 1 to 80 model. After determining an acceptable spillway profile on the 1 to 48 sectional model, it was incorporated in the 1 to 80 model to study its action in conjunction with the other hydraulic features of the dam. The spillway operated satisfactorily under all conditions of flow expected on the prototype (figures 20 and 21). The hydraulic jump could not be swept from the apron at maximum discharge by lowering the tailwater elevation in the river channel. The rock bench was sufficiently high to prevent the tailwater falling below the sweep-out elevation. Pressure tests were made on the spillway section along the center of the second bay to the left of the powerhouse. The pressures were satisfactory, that is, greater than atmospheric, for all discharges (figure 22). The crest was calibrated by measuring the head over it for various discharges (figure 23). The prototype, however, should give slightly higher discharges for the same heads as the friction factor was not to scale, being relatively greater for the model.

The downstream end of the piers were streamlined to eliminate fins forming downstream on the original design (figure 24). Other tests made will be described subsequently under fishway studies.

A. Spillway discharge, 25,000 second-feet; fishway discharge, 300 second-feet; no powerhouse discharge; and tailwater elevation 504.20.

B. Spillway discharge, 50,000 second-feet; fishway discharge, 300 second-feet; no powerhouse discharge; and tailwater elevation 513.60.

FLOW CONDITIONS IN RECOMMENDED DESIGN OF SPILLWAY
KESWICK DAM - 1:80 MODEL OF ULTIMATE DEVELOPMENT

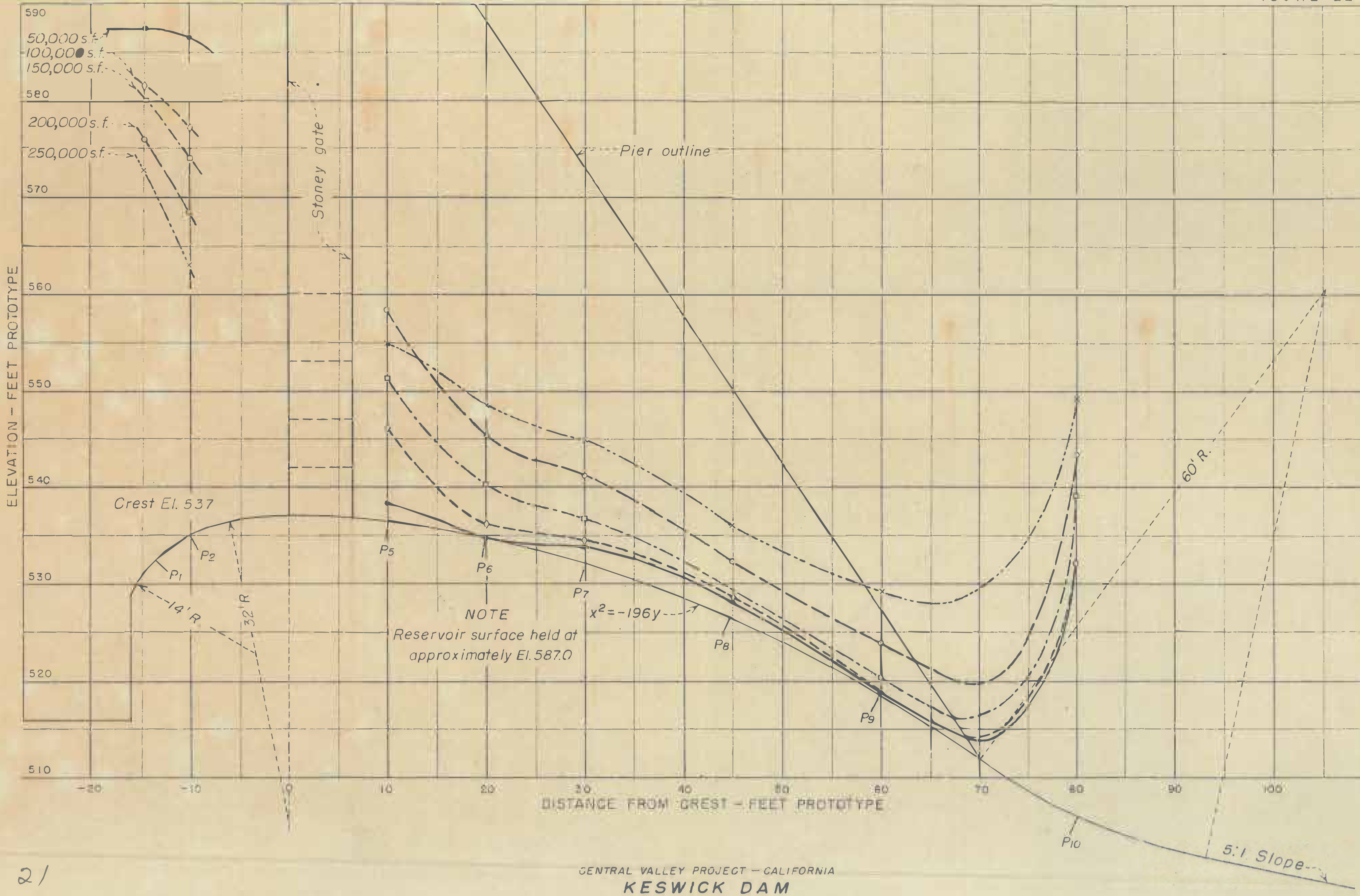
A. Spillway discharge, 100,000 second-feet; no fishway or powerhouse discharge; and tailwater elevation 524.20.

B. Spillway discharge, 250,000 second-feet; no fishway or powerhouse discharge; and tailwater elevation 541.00.

FLOW CONDITIONS IN RECOMMENDED DESIGN OF SPILLWAY

KESWICK DAM 1:30 MODEL OF ULTIMATE DEVELOPMENT

FIGURE 22



21

CENTRAL VALLEY PROJECT — CALIFORNIA

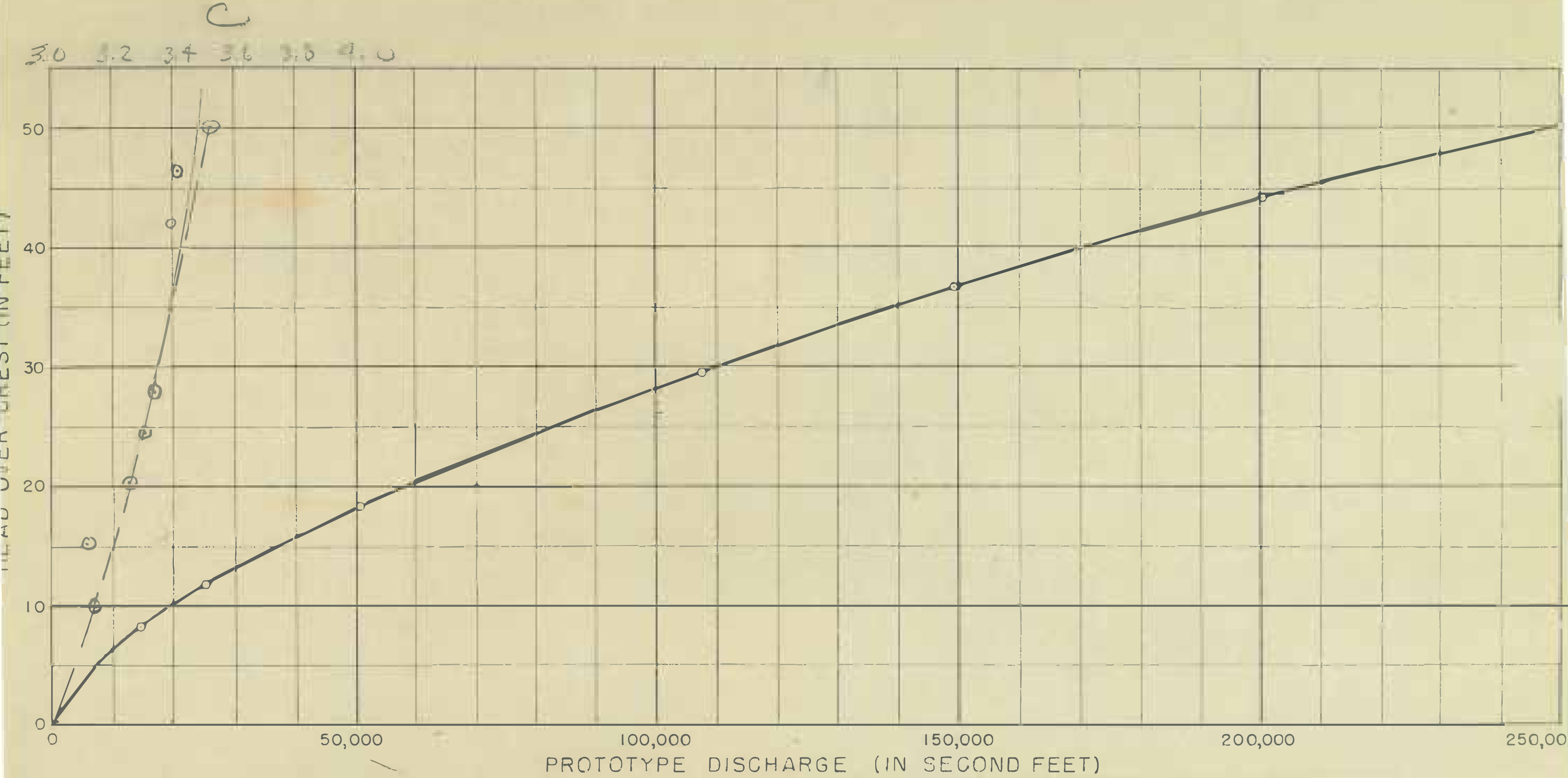
KESWICK DAM

HYDRAULIC MODEL STUDIES - 1 TO 80 SCALE

PIEZOMETRIC PRESSURES ON SPILLWAY CREST

J.W.B. — 9-18-40

30



$$C = \frac{Q}{LH_0^{3/2}}$$

$L = 200$

CENTRAL VALLEY PROJECT - CALIFORNIA

KESWICK DAM

HYDRAULIC MODEL STUDIES - 1 TO 80 SCALE

FREE DISCHARGE CURVE

ULTIMATE STAGE

FINAL DESIGN

J.A.L. — 3-21-41

FIGURE 23

A. Fin downstream from original design of spillway piers.

B. Elimination of fin by streamlining of piers.

FLOW CONDITIONS IN STILLING POOL SHOWING EFFECT OF STREAMLINING SPILLWAY PIERS

KESWICK DAM 1:80 MODEL OF ULTIMATE DEVELOPMENT

10. Fishway studies on the 1 to 80 model. The flow conditions to be encountered in the stream adjacent to the fishway in the original design of the initial stage, were studied in the 1 to 80 model and found to be unsatisfactory. The concentration of flow from the spillway section produced eddies and undesirable currents at the fishway entrance (figure 7A). These conditions were eliminated by altering the design to resemble more closely the ultimate stage. In this design the flow of water over the bench produced conditions that should enable the fish to locate the fishway entrance without difficulty (figure 7B).

Though the original design of the ultimate stage was reasonably satisfactory from the standpoint of fishway operation (figure 8A), hydraulic conditions dictated the changes in spillway design previously described. When the revised spillway design was included in the 1 to 80 scale model, flow conditions were satisfactory for the fishway (figure 25).

Operation of the powerhouse did not appear to have an adverse effect upon the flow conditions at the entrance to the fishway ladder. A sloping extension to the right spillway training wall and a block of concrete carried to elevation 503.00, where the bench was too low, was installed to prevent excessive flow over the bench into the river channel downstream from the fishway (figure 4). Since the 1 to 80 model was too small for a detailed study of the fishway operation, a 1 to 20 scale model was constructed.

Provision has been made for a flow of approximately 320 second-feet of water through the fish ladder, of which 100 second-feet will be introduced into the holding pool at the head of the ladder to maintain a depth of 12 inches over the weirs. The remaining 220 second-feet will be introduced farther down the ladder near the tailwater surface to provide sufficient velocity with little turbulence to attract the migrating fish into the ladder. It was for the latter purpose that provision was made for the additional water supply in every third pool of the ladder. The actual distribution of the 220 second-feet will depend upon field experience after the structure has been placed in operation, but for purposes of these tests, it was assumed that it will be introduced through one pool of the ladder--an extreme condition.

11. Description of the 1 to 20 model. The 1 to 20 scale fishway model was constructed, employing sheet metal for the head box, conduits, and gates. The remainder of the model was wood (figures 26 and 27). Slide gates were used to control the flow through the fishway, except in the head box, where rubber corks were used.

12. Method of operation of 1 to 20 model. A point gage was installed above the holding pool and the weir at the holding pool was calibrated by comparison with the flow through a V-notch weir. When one or more of the auxiliary water supplies to the ladder was used, the total discharge

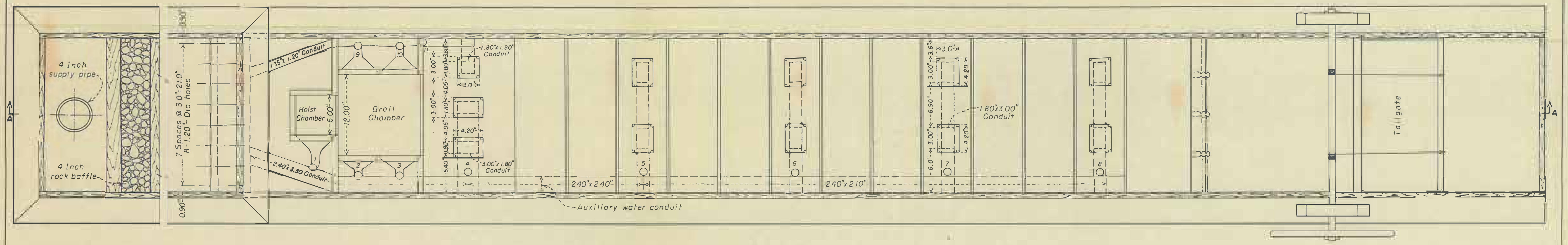
FIGURE 25

A. Spillway discharge, 3,000 second-feet; fishway discharge, 300 second-feet; no powerhouse discharge; and tailwater elevation 488.00.

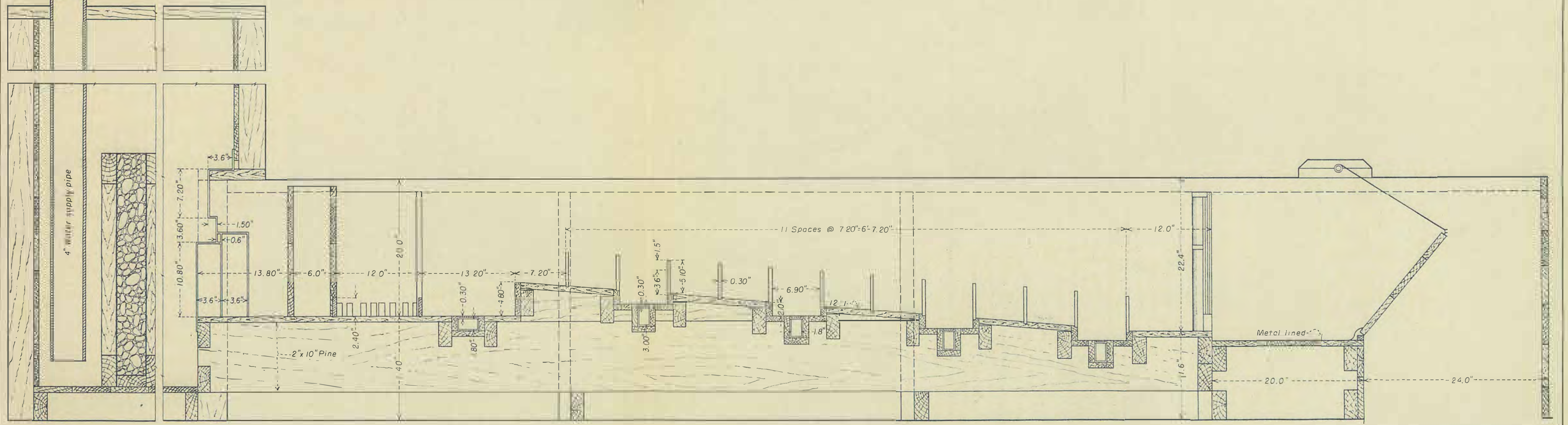
B. Spillway discharge, 15,000 second-feet; fishway discharge, 300 second-feet; no powerhouse discharge; and tailwater elevation 498.75.

FLOW CONDITIONS IN RIVER CHANNEL WITH RECOMMENDED DESIGN OF SPILLWAY

KESWICK DAM - 1:80 MODEL OF ULTIMATE DEVELOPMENT



PLAN



SECTION A-A

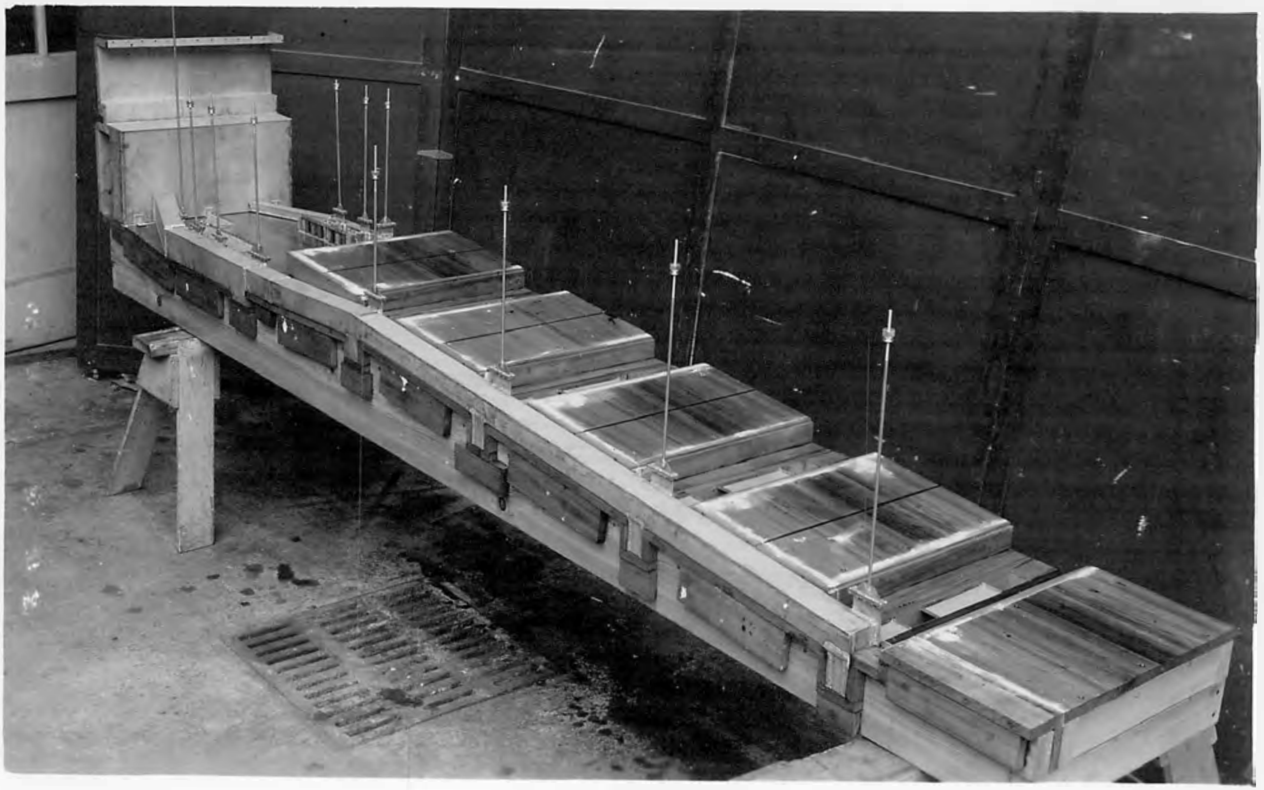
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT-CALIFORNIA
KENNETT DIVISION

KESWICK DAM

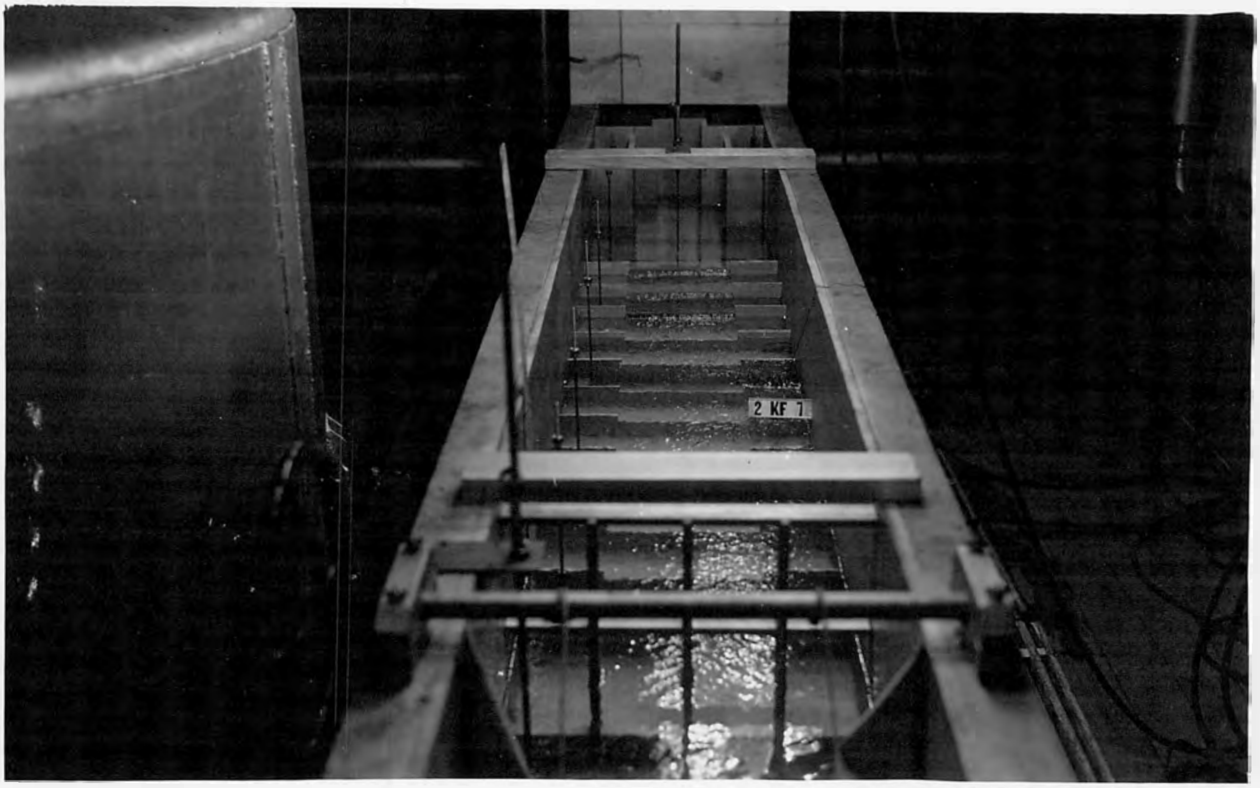
HYDRAULIC MODEL STUDIES - 1 TO 20 SCALE
PLAN AND SECTION OF FISHWAY MODEL

DRAWN	SUBMITTED
TRACED GRC-FLD	RECOMMENDED.
CHECKED.	APPROVED

DENVER, COLORADO — OCT 17, 1940



A. .**Partial** assembly of model showing metal conduits, auxiliary outlets and control gates.



B. Completed model - Discharge, 300 second-feet; and tailwater elevation 497.00.

ORIGINAL DESIGN OF FISHWAY STRUCTURE

KESWICK DAM - 1:20 MODEL OF FISHWAY

Denver, Colorado, June 5, 1943.

MEMORANDUM TO CHIEF DESIGNING ENGINEER
(E. S. Gray through J. E. Warnock)

Subject: Hydraulic model tests of flange gaskets for 72-inch ring-follower gates in outlet works - Anderson Ranch Dam, Boise project.

1. Introduction. Gaskets for large flanges and the shape of the groove for them have already been developed and applied satisfactorily in the field. The gaskets used have been round solid rubber of good grade tread stock.

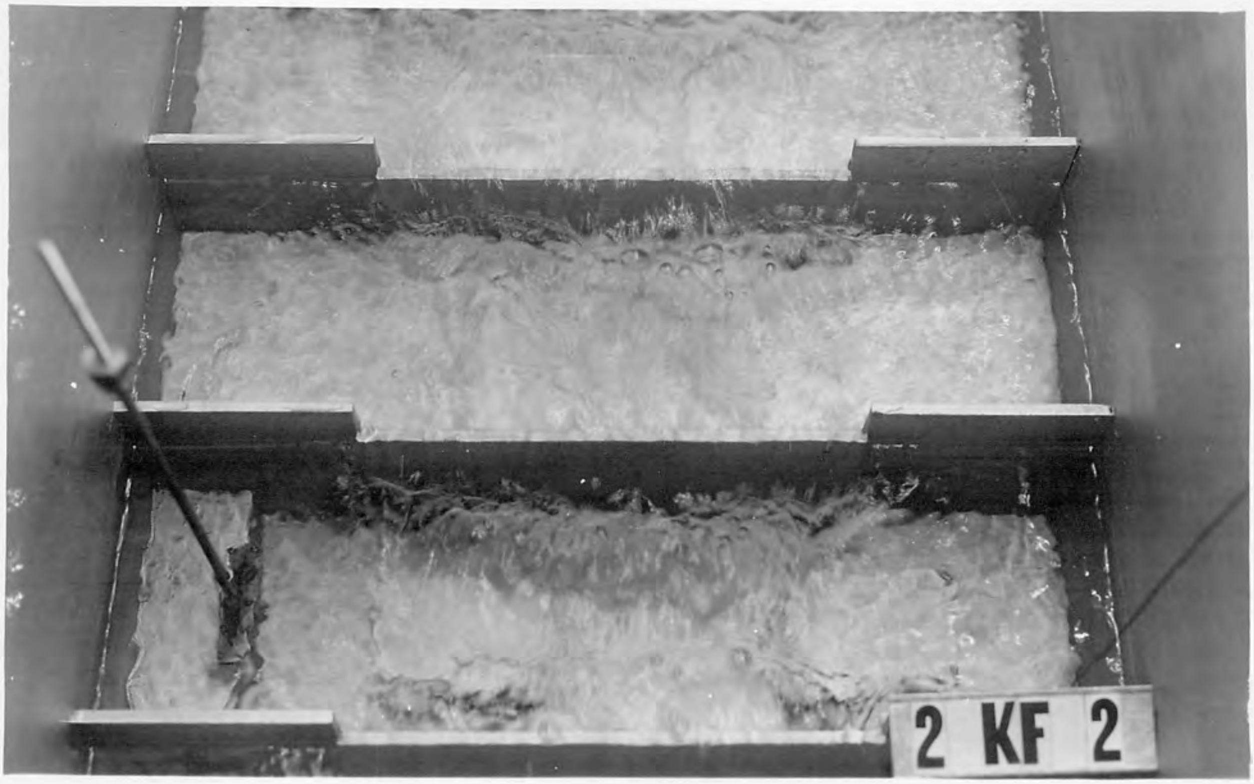
The war has brought on a shortage of the critical material, rubber, so that other materials have been proposed as gaskets. The tests were instituted with this in mind.

2. Scope of the tests. It was desired to test several materials and shapes, in suitable grooves at 400 pounds per square inch water pressure. The grooves were subject to change and several designs were proposed.

3. The testing apparatus and procedure. The testing apparatus is shown in figure 1. The detail of the model in which the gaskets were installed for the tests is shown in figure 2.

The apparatus consisted of the model, a hand pump, an air reservoir, Bourdon gages, and suitable water supply piping with inlet and relief valves. The model was made of two flat plates representing two flanges. In one plate was cut the groove for holding the gaskets and the other plate was flat over the groove; the designed compression was produced when the plates were bolted together until the spacer stop was reached.

The procedure in testing was to form a circular gasket of the material, place it in the groove, clamp the plates together firmly, then apply water pressure in the annular space between the plates and inside of the gasket. The pressure was brought up slowly until a maximum of 550 pounds per square inch was reached. The sustained pressure tests were usually started at about 450 pounds and then allowed to remain for minutes, hours, or days. If for days, the pressure dropped to about 250 pounds overnight then in the morning it was pumped up to 420 pounds and held to an average pressure of about 400 pounds throughout the day. The gaskets were examined after being subjected to the hydraulic tests.



A. Action with flow of 120 second-feet through pools of ladder.

B. Action with flow of 120 second-feet through pools of ladder and 180 second-feet from auxiliary outlet in floor of pool in foreground.

FLOW CONDITIONS IN ORIGINAL DESIGN OF FISHWAY LADDER

KESWICK DAM - 1:20 MODEL OF FISHWAY

was first established by closing all the gates except those in the brail and holding chambers and measuring the discharge over the holding pool weir. The gage was then adjusted to the reading corresponding to the discharge through the brail and holding chambers, and the proper discharge through the auxiliary water supply was then obtained by opening the conduit gate until the gage point touched the surface of the water in the holding pool. The tailwater elevation was varied by raising and lowering the tail gate. Currents in the pools were traced by adding a few drops of potassium-permanganate solution to the water.

13. Operating characteristics of the ladder. Flow characteristics from pool to pool down the ladder were considered satisfactory for the proper operation of the fishway (figure 28). The tests demonstrated that a ladder slope of 1 to 12 gave flow conditions which would induce the fish to climb the ladder. The velocities were also sufficiently low to obviate the danger of possible injury to the fish if forced against the side of the fishway by the currents. This factor was one of the most important design considerations to be checked by the model study, for all cuts, bruises, and similar injuries to salmon will not heal in fresh water. The plan of admitting additional water from below into every third pool by means of the auxiliary water supply system to maintain the proper velocity in the fishway entrance seemed quite satisfactory with the exception of minor modifications to be described subsequently. When the tailwater elevation rises, the upstream auxiliary conduits will be opened to introduce the auxiliary flow at the approximate tailwater surface. This may be done by closing the downstream outlets, or partially closing them when the upstream outlets are opened.

14. Head losses in the conduit system. The head box on the original design was quite effective in reducing the head on the auxiliary water supply conduit system. A slide gate on the intake conduit proved equally effective on the final design. Tests made on the original design of the fishway gave head losses between the head box and the downstream end of the conduit system averaging about seven feet (prototype). It should be borne in mind, however, that the head loss in the prototype structure might be somewhat different because of viscous effects and difference in gate construction.

All water supply outlets in the fishway were ample to carry the maximum discharge, both in the original and final designs.

15. Turbulence studies on the original design. Hydraulic studies on the 1 to 20 scale fishway model showed conclusively that the baffling devices in the original design failed to distribute evenly the flow into the various chambers and pools, and also failed to prevent the formation of turbulent currents. These turbulent currents are very undesirable in a fishway as past experience has shown that the fish will avoid them.

16. Brail and hoist chambers. In the original design the water was admitted through the walls of the brail and hoist chambers by devices consisting of an expanding section of conduit shaped like a flat frustrum of a pyramid with vertical baffles to break up the velocity and distribute

the flow (figure 26). The tests showed that the arrangement of the baffles should be changed to equalize the flow from the openings since the two center ports carried most of the flow, while that through the outer two was negligible. This unequal flow produced undesirable turbulence and strong upward currents in these pools at the higher discharges.

17. Holding pool. The conduit openings on the floor of the holding pool were covered by horizontal rectangular baffles one foot longer and one foot wider than the openings and set 18 inches (prototype) above the floor (figure 26). This type of baffle did not prove effective as most of the flow came out at the downstream end of the cross conduit, producing undesirable turbulence and unequal distribution of flow.

18. Auxiliary conduit outlets. Every third pool in the ladder was provided with a supplementary water supply from the auxiliary cross conduits, which opened into the floor of the pool in two places. Baffles similar to those in the holding pool were provided to eliminate turbulence. The tests indicated that these openings should be redesigned for when the gate of the cross conduit was partially closed, the high velocity jet flowing past the first opening drew water from the pool into the conduit, and most of the flow was discharged through the far side of the second opening, producing a very pronounced turbulent boil on the left side of the pool (figure 28B). When the gate was open 100 percent, the flow conditions were somewhat better, but the flow from the second opening was still disproportionately large.

19. Revised design of holding pools and hoist chamber. The conduit system and baffling devices were completely redesigned after the studies on the original design indicated that undesirable flow conditions were present at the conduit outlets. The upper portion of the 1 to 20 model was rebuilt to study the revised holding-pool design. The revised design eliminated the head box used previously and the water was admitted directly from the forebay by a conduit controlled by a slide gate. In the ultimate prototype structure a large portion of the fishway water supply will be drawn from the tailwater through a jet pump operated by a high-pressure discharge from the reservoir. In this design the supply water to the conduit side of the model fishway, holding brail, and hoist chambers, was compelled to pass from the conduit side across the upstream end of the fishway to the opposite side, thence downstream to a cross conduit under the chamber floor and back to the conduit side, where it entered the chambers through four supply portals. As a result there was a noticeable inequality of flow from the supply portals. This condition was remedied by removing the bulkhead at the upstream end of the conduit side, thereby appreciably shortening the flow path to the supply portals and improving the approach to them.

The 1 to 20 scale model proved inadequate to study turbulence at the auxiliary cross-conduit outlets; consequently, a larger model of this feature was constructed to a scale ratio of 1 to 10.

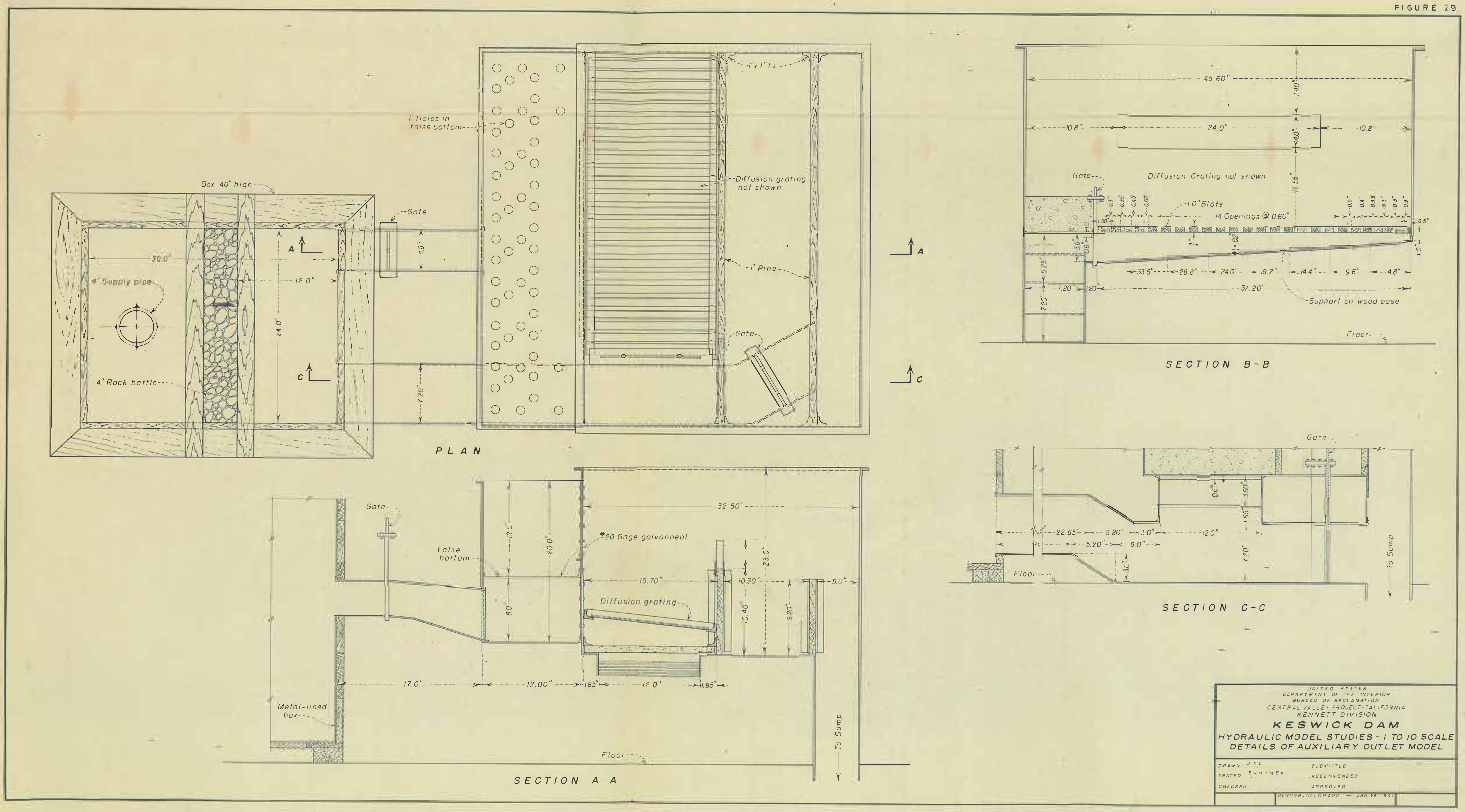
20. Description of 1 to 10 model. The 1 to 10 model consisted of one ladder pool and its auxiliary water supply system (figure 29). The model was arranged so that the ladder flow could be supplied over the upstream weir. It was constructed mainly of sheet metal, with the exception of the baffles and tailwater gate which were redwood.

21. Tests leading to recommended design of outlets. A revised design of the auxiliary cross-conduit outlets which was incorporated in the 1 to 10 model (design 2, figure 30) differed quite radically from the original design. The cross conduit was the same width as the pool at the gate, then tapered upward and inward to the opposite side of the pool. The intended purpose was to force the water in equal amounts through slotted openings in the floor. Tests made on the 1 to 10 model with the maximum discharge of 220 second-feet, and the minimum discharge of 110 second-feet (prototype) showed that the flow was not uniformly distributed and surface boils were present (figure 31A). Some improvement was noted when the spacing of the cross-beams was altered to change the openings from approximately equal areas to openings where the areas were reduced progressively until the area of the final opening was about one-fifteenth the area of the fourth opening (design 3, figure 30). This reduction in area was necessary as the water had a tendency to flow directly to the end of the conduit and out of the openings. A curved plate placed in the main conduit improved the flow distribution, eliminating the boil near the gate. The change in the spacing and size of the openings removed the boil at the left side of the pool. Some turbulence persisted (figure 31B) thus this design was not wholly satisfactory. The main supply conduit was revised both in size and in location (design 4, figure 30). On the model, the main conduit was carried beyond the gate, to represent the conditions present when water was flowing to another auxiliary outlet downstream. An overflow tank was also added to assimilate conditions present when water was flowing into the pool from the upstream weir. Numerous minor revisions were made but no appreciable improvement in the flow conditions was noted, indicating the necessity of a major revision.

22. Recommended design of outlets. The model was revised by reducing the size of the gate from $11\frac{1}{2}$ by 4 feet to 10 by $2\frac{1}{2}$ feet; the inward taper of the cross conduit was eliminated, that is, a constant width was used across the width of the pool; the upward taper was retained; and 2-inch steps were placed every four feet (prototype) on the bottom of the cross conduit (design 5, figure 30). These steps markedly improved the flow conditions in the chamber by decreasing the tendency of the water to be concentrated at the end of the conduit. The operating characteristics were improved to such an extent that there was no pronounced boiling or turbulence, even at the maximum discharge of 220 second-feet (figure 32B). A metal grill was built to approximate the additional baffling effect of the grating which prevents the fish from entering the conduits. This further improved the flow conditions (figure 33).

23. Description of temporary gate weir.

To prevent the fish by-passing Keswick Dam and continuing to Shasta Dam where no trapping facilities were provided, it was necessary to erect

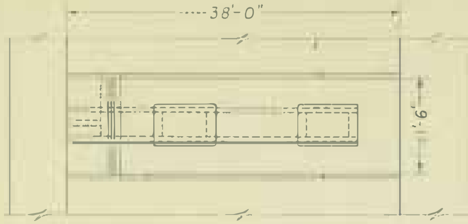


UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT-CALIFORNIA
KENNETT DIVISION

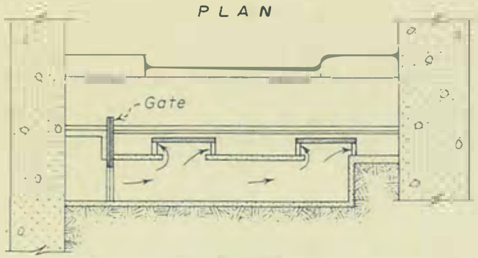
KESWICK DAM

HYDRAULIC MODEL STUDIES - 1 TO 10 SCALE
DETAILS OF AUXILIARY OUTLET MODEL

DRAWN. J.A.L. SUBMITTED
TRACED. E.J.H.-M.E.K. RECOMMENDED
CHECKED APPROVED
DENVER, COLORADO — JAN. 28, 1941

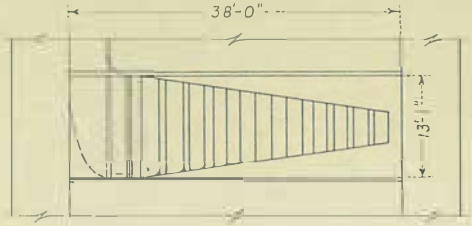


PLAN



SECTION

DESIGN 1
(Original Design)



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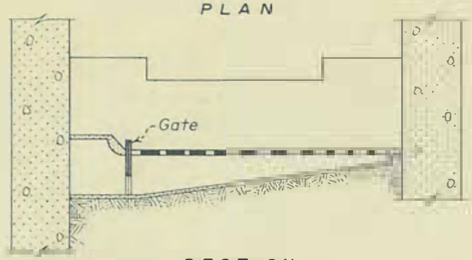
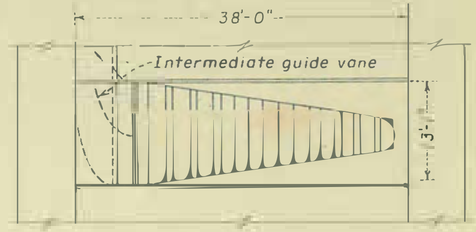


SECTION

DESIGN 2



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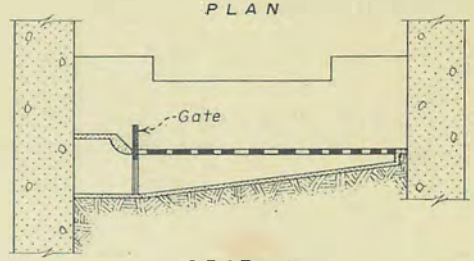

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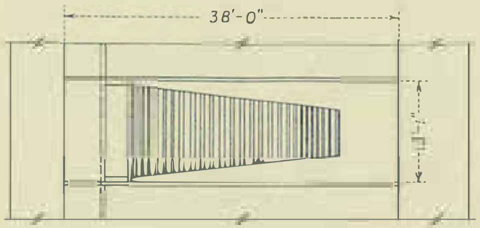
DESIGN 3



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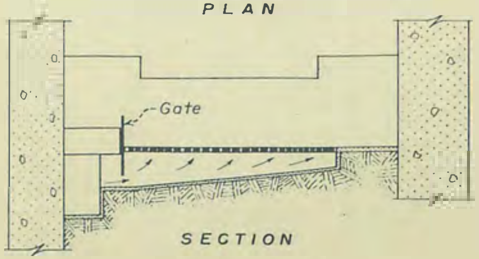
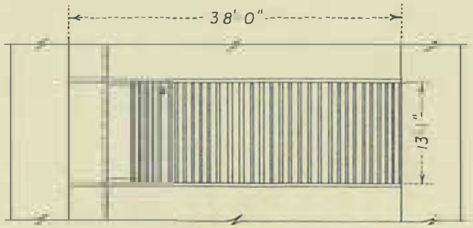


SECTION

DESIGN 4



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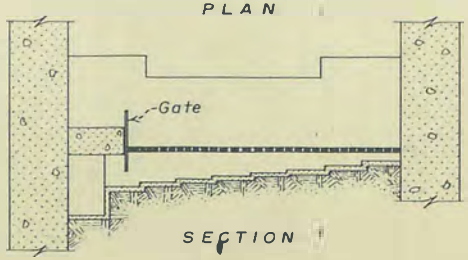

SECTION

DESIGN 5
(Recommended Design)

NOTES
Dimensions are prototype.
Views are schematic only.

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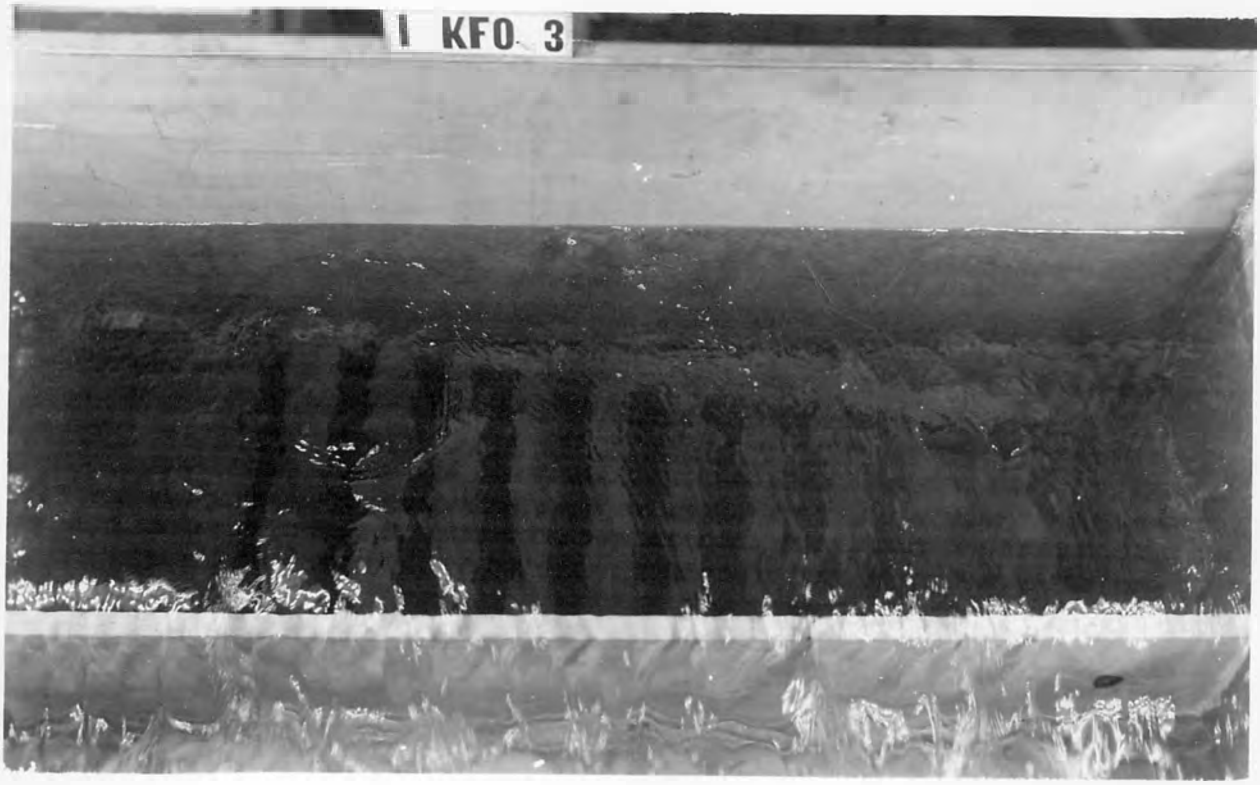
KESWICK DAM

HYDRAULIC MODEL STUDIES - 1 TO 16 SCALE
AUXILIARY FISHWAY SUPPLY OUTLET - TESTED DESIGNS

DRAWN... K.J. ...... SUBMITTED.
TRACED... E.J.H.-F.L.D. .... RECOMMENDED..
CHECKED... .... APPROVED.
DENVER, COLORADO. - MARCH 3, 1943.

FIGURE 30

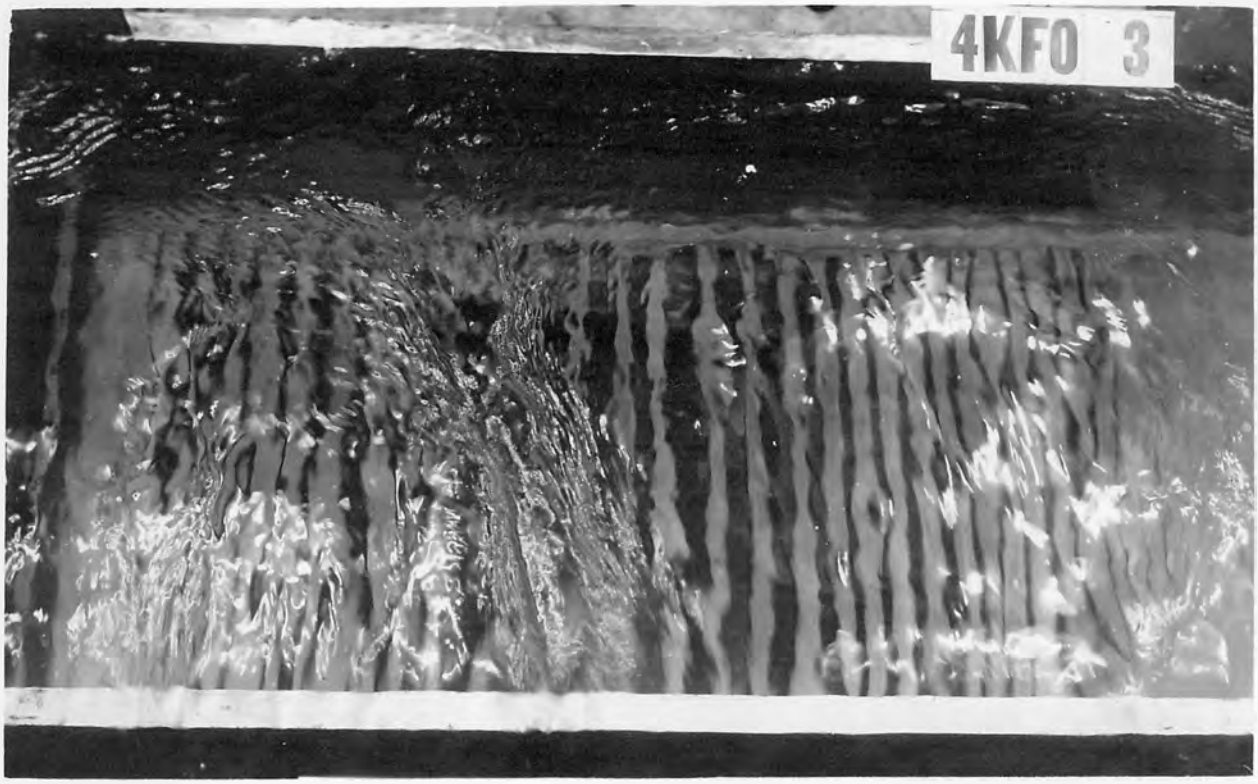


A. Design 2, figure 30.

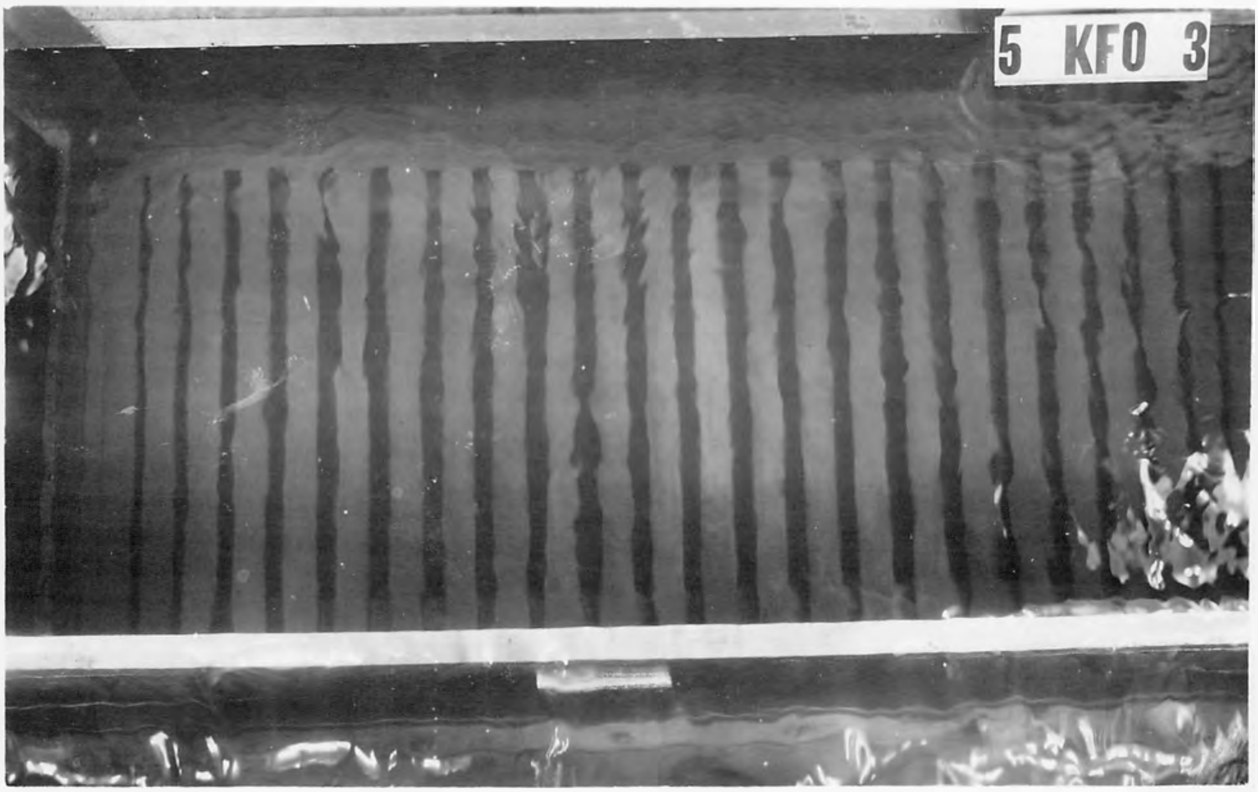
B. Design 3, figure 30.

FLOW CONDITIONS WITH DISCHARGE OF 220 SECOND-FEET THROUGH AUXILIARY SUPPLY OUTLET

KESWICK DAM - 1:10 MODEL OF FISHWAY AUXILIARY SUPPLY



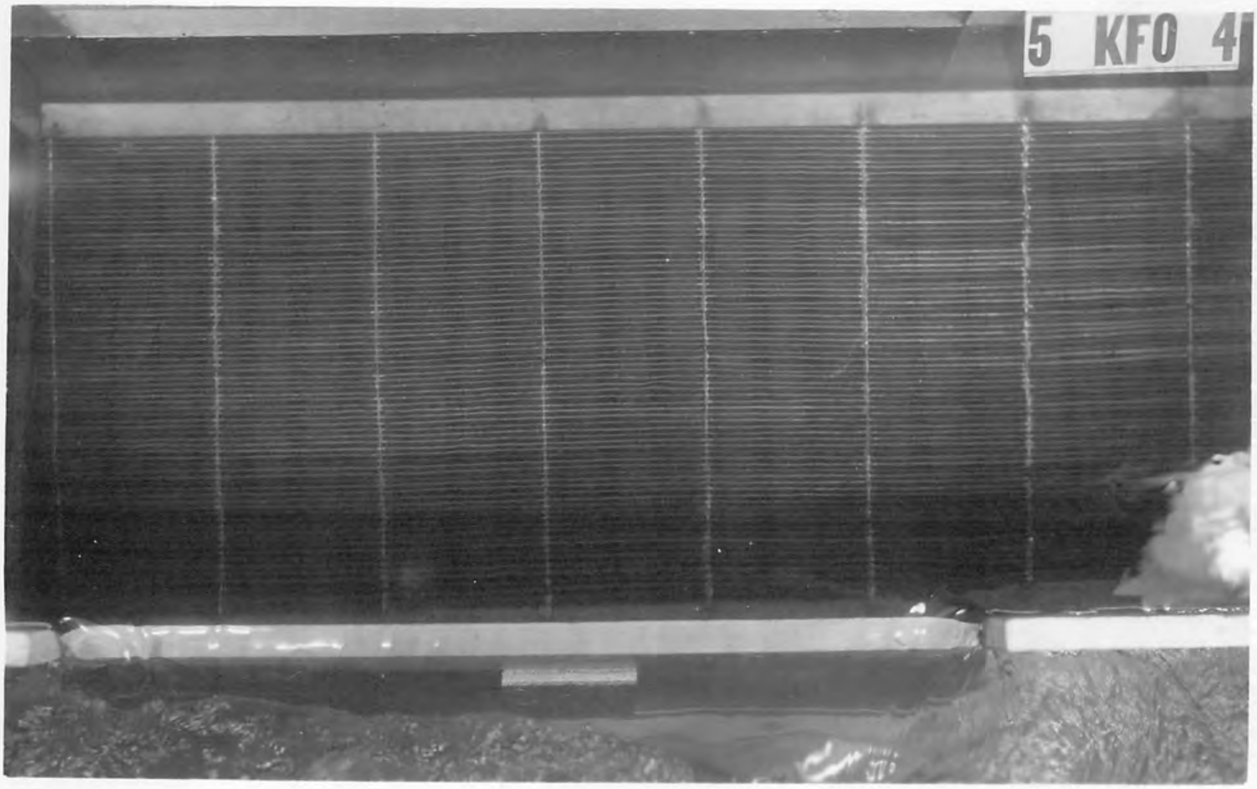
A. Design 4, figure 30.



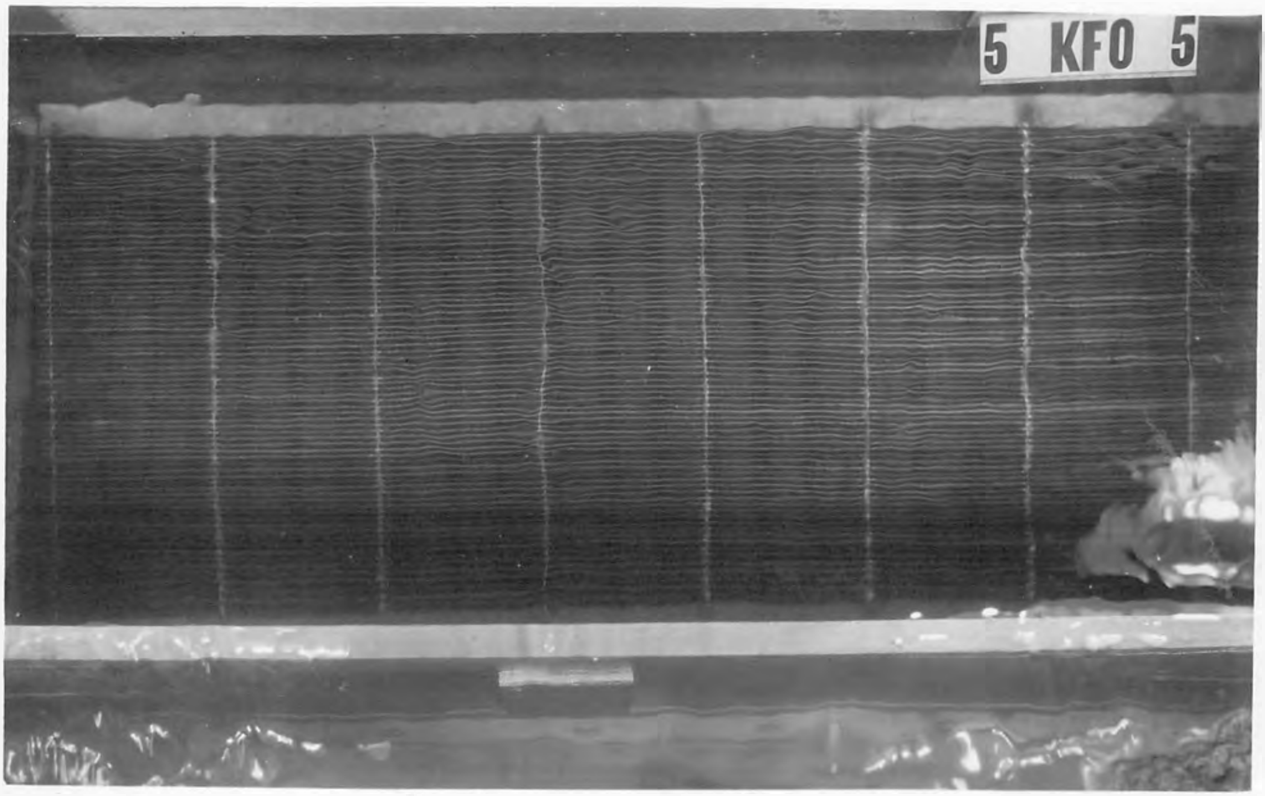
B. Design 5 (recommended design), figure 30.

FLOW CONDITIONS WITH DISCHARGE OF 220 SECOND-FEET
THROUGH AUXILIARY SUPPLY OUTLET

KESWICK DAM - 1:10 MODEL OF FISHWAY AUXILIARY SUPPLY



A. Flow through auxiliary supply only - 110 second-feet.



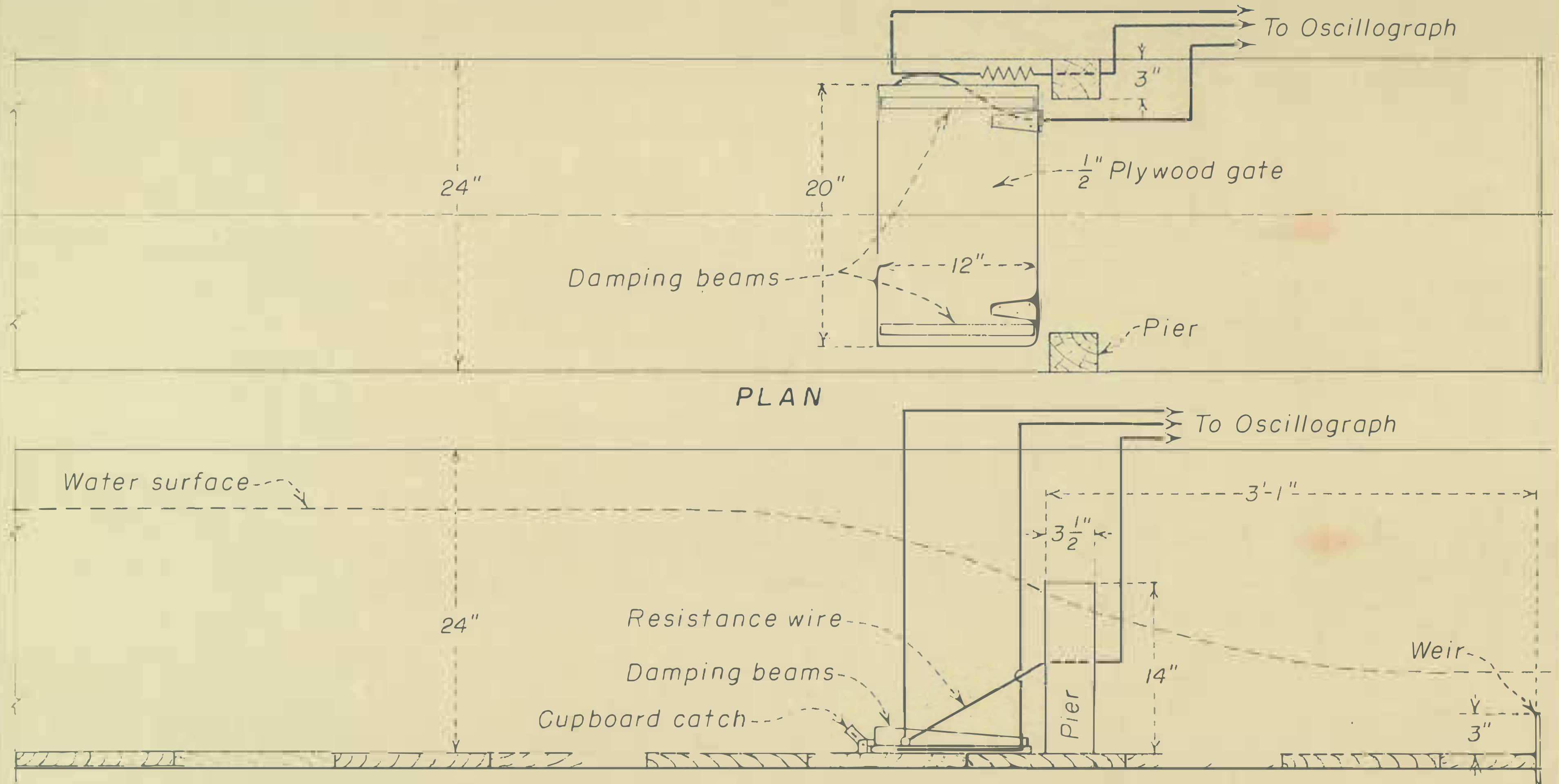
B. Flow through auxiliary supply only - 220 second-feet.

FLOW CONDITIONS WITH RECOMMENDED DESIGN OF AUXILIARY SUPPLY AND GRATING IN PLACE a barrier in the spillway section of the initial development. The design consisted of hinged wood gates spanning the upstream ends of the channels between the piers. It was planned to keep the gates latched in a horizontal position except during times when the flow conditions were favorable for the fish to navigate the channels during their migration upstream. The gates would then be unlatched, allowing the buoyancy and dynamic forces to raise them into place, forming weirs ten feet high across the channels. This method of placing the gates in the vertical position made it essential that they withstand the impact imparted by contact with the piers at closure. Since the magnitude of the impact depended on the velocity with which the gate came in contact with the pier sections, it was considered advisable to investigate the probable velocities at time of contact. For these studies a gate weir was constructed disregarding scale. It consisted of a 20- by 12-inch wooden gate placed in a flume 2 feet wide with a resistance wire and contacts at one end to determine the angular velocity by oscillograph records (figure 34). The oscillograph was calibrated for positions of the gate at 0, 10, 20, and 30 degrees from the vertical; this calibration, together with the 60-cycle timing curve on the oscillograph record, enabled determination of the time elapsed in the movement of the gate from one position to another. The angular velocity of the gate in degrees per second was obtained and the velocity of the top edge of the gate computed. The effect of the velocity of the water through the channel was obtained by varying the tailwater elevation.

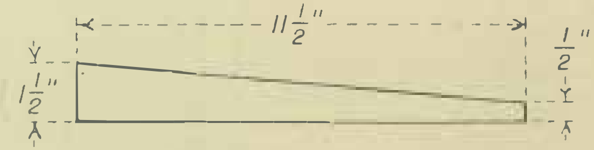
24. Results of temporary gate-weir studies. Preliminary visual studies indicated that the impact forces were of great magnitude. When the gate was unlatched it would rise slowly due to buoyancy until dynamic forces of the water began to affect it, whereupon its velocity increased rapidly and the gate reached the vertical position with such rapidity as to produce impact accompanied by excessive vibration of the entire model.

When the oscillograph apparatus was installed to measure the velocities of the upper edge of the gate it was found to be moving faster than the water flowing through the section previous to its release. The gate attained its maximum velocity at a point between 10 and 20 degrees from the vertical, and the velocity decreased as the gate approached the vertical position, apparently due to the cushioning effect of the water being forced from between the vertical face of the pier sections and the ends of the gate.

After the above tests had been completed, two beams, trapezoidal in side elevation, were placed on the downstream side of the gate just inside the channel walls. It was believed that a dash-pot action would take place between the end portions of the gate and the vertical faces of the pier sections when the gate approached the vertical position, thereby cushioning the impact force. Although the studies were visual only, the design gave encouraging results as a definite decrease in the impact was noted. However, as the gate design had already been established and was considered adequate to withstand the probable forces to which it would be subjected, further testing was not deemed necessary.



SECTION ON CENTER



DETAIL OF DAMPING BEAM

CENTRAL VALLEY PROJECT - CALIFORNIA

KESWICK DAM

HYDRAULIC MODEL STUDIES

DETAILS OF GATE WEIR MODEL

ANALYSIS OF RESULTS

25. Conclusions. The spillway studies developed a design which would adequately protect the toe of the structure. The steps developed for the spillway will assist in the effective dissipation of energy on the spillway apron almost as well as a dentated sill with much less danger of being destroyed by cavitation or abrasion. Discharge characteristics of the recommended design of the ultimate stage were satisfactory for all anticipated flows.

The rock bench at the downstream end of the spillway section established flow conditions which would tend to attract the fish to the right side of the channel and thus enable them to locate the entrance to the fishway ladder. The recommended fishway design should be reasonably free of turbulence and consequently should be more efficient than the design originally proposed. The auxiliary supply system will enable the addition of a supplemental flow at the same elevation as the tailwater.

The temporary gate weir on the prototype will probably have a velocity at its top edge greater than the initial velocity of the water passing through the channel, but due to the relatively greater mass of the prototype gate the velocity differential is expected to be less than that given by the model tests. The factor of safety used in the gate design seemed ample to assure against the destruction of the gate by impact on closure.

26. Recommendations. On the basis of the hydraulic model studies conducted on various features of the Keswick Dam spillway and fishway it is recommended that:

(a) The stop-log section of the initial stage be carried to elevation 520.00 to prevent overtopping the structure during large floods.

(b) The spillway section of the initial stage be constructed to include as many features as feasible of the ultimate stage.

(c) The spillway apron profile be constructed as determined from the model tests (design 16, figure 11).

(d) The rock bench downstream from the spillway be excavated to elevation 503.00 instead of elevation 497.00 as originally planned.

(e) Streamlined steps with top surface slopes of 10 degrees upward from the horizontal be placed on the spillway apron.

(f) A sloping extension to the right spillway training wall be constructed to prevent a concentrated flow spilling off the bench at the fishway entrance.

(g) The water distributing system in the fishway be arranged similar to that which proved satisfactory in the model tests (figure 5).

(h) The auxiliary water supply outlets consist of an upward sloping cross conduit, practically as wide as the pool, with steps to force the water out through slotted openings in the floor (design 5, figure 30).

(i) The auxiliary gate weir remain as originally designed.

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J. W. Ball.

J. A. Lindsey.