HYD 177

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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HYDRAULIC MODEL STUDIES OF THE SPILLWAY AND OUTLETS FOR THE FRESNO DAM

MILK RIVER PROJECT

Hydraulic Laboratory Report No. 177

ENGINEERING AND GEOLOGICAL
CONTROL AND RESEARCH DIVISION

BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO

JULY 6, 1945

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FOREWORD

The hydraulic model studies concerning the spillway and outlet works of the Fresno Dam on the Milk River in Montana, were made in 1937 and 1938 by the Bureau of Reclamation in the Hydraulic Laboratory of the Colorado Agricultural and Mechanical College at Fort Collins, Colorado. The investigation was under the general direction of J. E. Warnock, and the testing was supervised by J. W. Ball. Preparation of the model designs and the testing was accomplished through the combined efforts of R. R. Buirgy, H. W. Brewer, M. R. Spindler, and L. V. Wilson.

Due to more urgent work at the time of the investigation, the report was not completed until 1945.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
July 6, 1945

Laboratory Report No. 177
Hydraulic Laboratory
Compiled by: J. W. Ball
and R. C. Bessel
Reviewed by: J. W. Ball

Subject: Hydraulic Model Studies of the Spillway and Outlets for the Fresno Dam--Milk River Project--Montana.

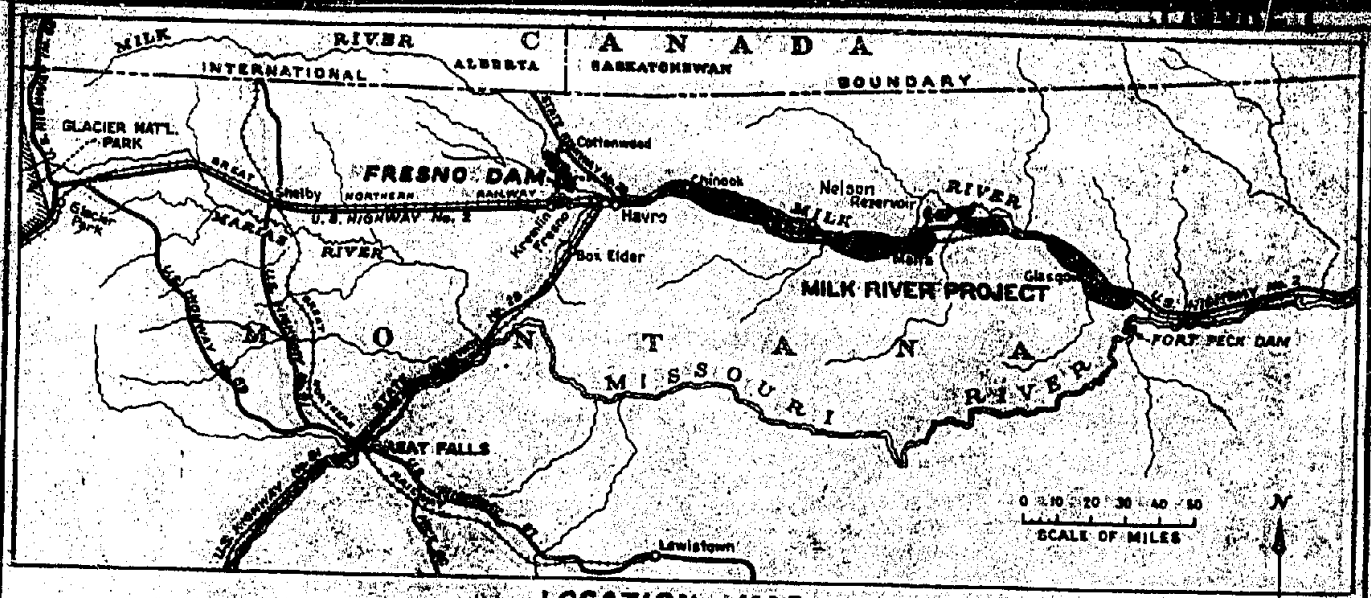
INTRODUCTION

The Problem. The problem concerning the Fresno Dam on the Milk River in Montana, was to study the proposed designs of the spillway and outlet works by hydraulic model tests, and to make whatever changes were indicated to assure safe and economical operation of these structures.

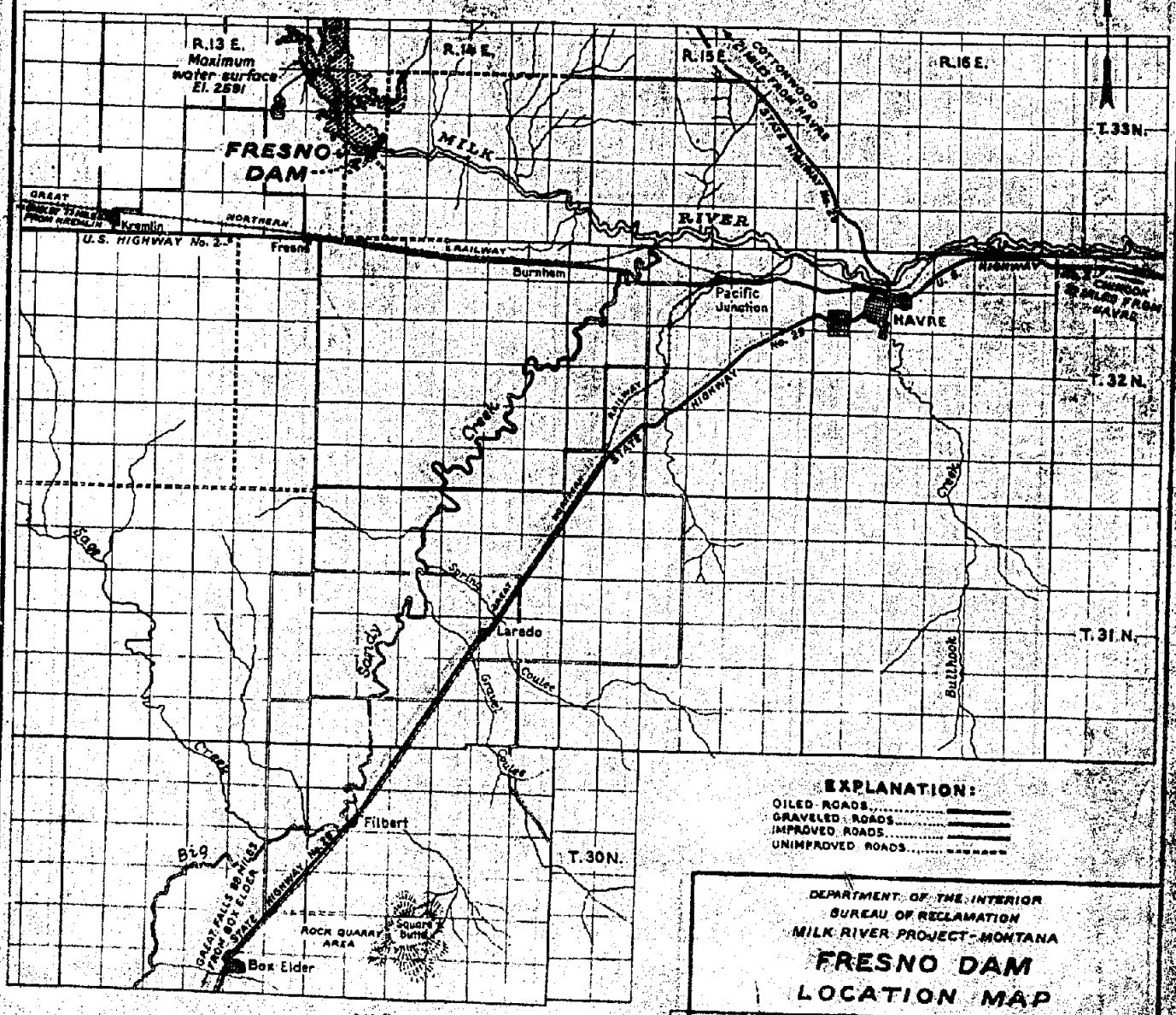
The Project. The Fresno Dam, located on the Milk River about one hundred miles northeast of Great Falls, Montana, near the Canadian Border (Figure 1), is an earthfill dam, 2,100 feet long, with a height of approximately eighty feet. The principal hydraulic features involved in its construction are an outlet works and a concrete-lined, open-channel spillway.

The outlet works consists of a trashrack structure, a section of 12-foot, horseshoe-shaped, concrete-lined conduit extending from a trash-rack structure in the reservoir to a gate chamber in the dam, and a section of tunnel having a semicircular crown and an arched floor from the gate chamber to a control house located in the left training-wall of the spillway stilling pool (Figure 2). The outlet flow plunges from the control house into the spillway stilling pool, where the energy is dissipated and the water moves on downstream with little or no destructive action.

The concrete-lined uncontrolled spillway with an approach channel, crest, chute, and stilling pool in the left abutment of the dam will serve to convey floodwaters safely past the dam (Figure 2). The spillway has a design capacity of 51,000 second-feet with a total drop of 63 feet.



LOCATION MAP



VICINITY MAP

EXPLANATION:

OILED ROADS
GRAVELED ROADS
IMPROVED ROADS
UNIMPROVED ROADS

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MILK RIVER PROJECT - MONTANA

FRESNO DAM
LOCATION MAP

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TRACED: C.B.M. RECOMMENDED: [illegible]
CHECKED: [illegible] APPROVED: [illegible]

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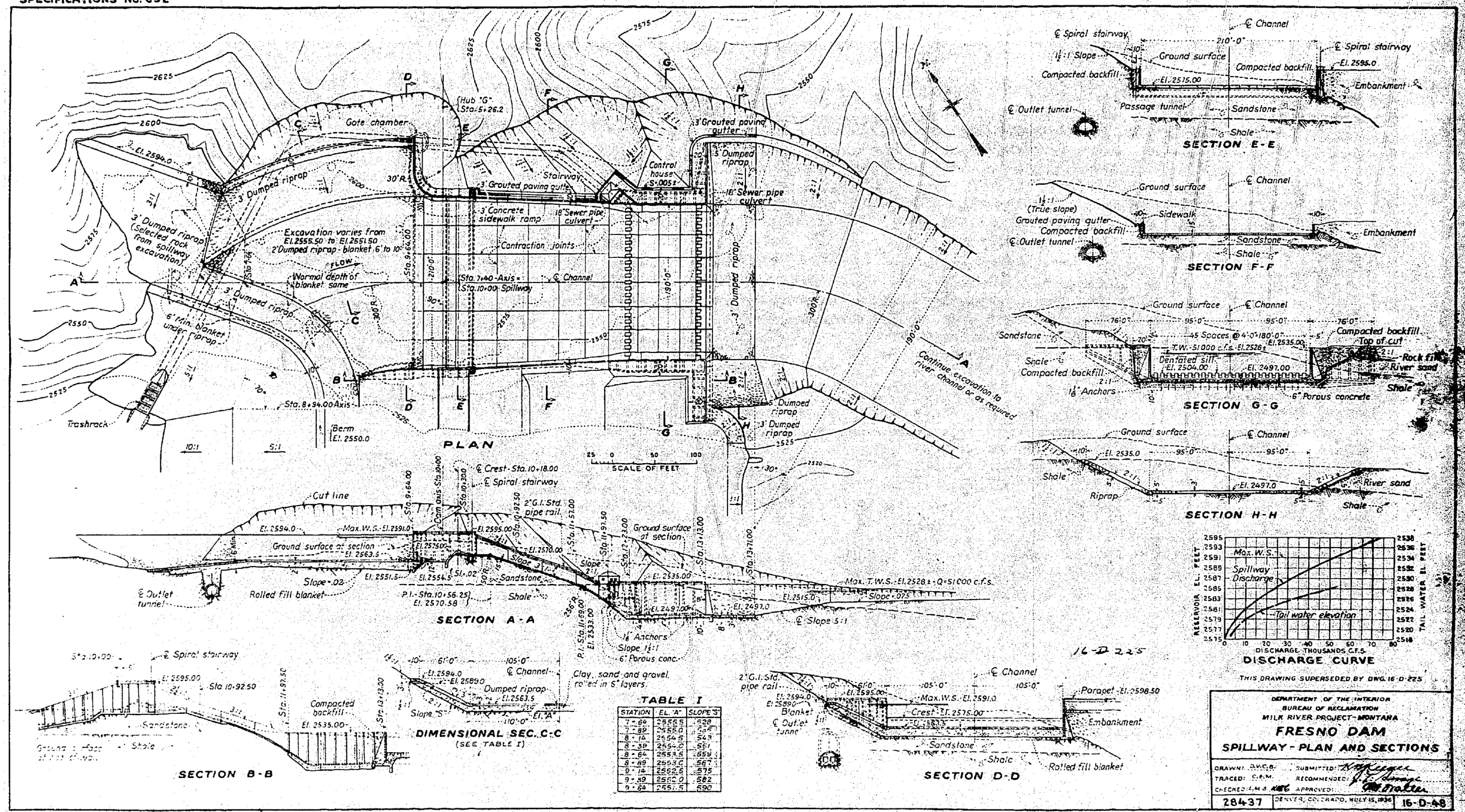

TABLE I

STATION	EL. "A"	SLOPE "S"
7+64	2556.5	.528
7+89	2555.0	.536
8+14	2554.5	.543
8+39	2554.0	.551
8+64	2553.5	.559
8+89	2553.0	.567
9+14	2552.5	.575
9+49	2550.0	.582
9+64	2551.5	.590

The shallow approach channel is riprapped and transitions are provided at each end of the spillway to produce smooth flow over the uncontrolled crest. The chute width converges from 210 feet at the crest to 190 feet at the stilling pool entrance. The pool, for dissipating the energy in the spillway flow, is rectangular in cross-section with a constant width of 190 feet.

In order to ascertain the feasibility of the proposed design of these hydraulic features, a 1:60 model was built and tested in the Colorado A&M College Hydraulic Laboratory at Fort Collins, Colorado.

PURPOSE OF MODEL STUDY

Scope of tests. The purpose of the hydraulic investigation concerning the spillway and outlet works of Fresno Dam was to check the adequacy of the designs proposed for these structures and to determine what revisions, if any, were required to make them operate satisfactorily.

The investigation included extensive tests to determine the shape of the right entrance wall to the spillway giving optimum flow conditions with a minimum of erosion on the face of the dam and on the floor of the approach channel. This testing was necessitated since the intersection of the wall with the face of the dam induced complex flow conditions which were difficult to eliminate. Only minor testing, with no revisions necessary, was required on the left wall, a condition attributed to the nearness of the canyon wall to that end of the spillway.

The capacity of the spillway was found to be inadequate in the initial operations, and it was necessary to conduct tests to increase the discharge. These tests involved pressure, water surface and quantity measurements for two different elevations of the spillway-chute floor immediately downstream from the crest. The study was expanded to obtain information concerning the effect of floor elevation, both upstream and downstream from the crest, on the capacity of the spillway, the data to be used for design purposes. Charts of these data are presented, but more extensive studies have been made since, and the results of these are presented in Laboratory Reports HYD 118 and 182.

Extensive testing was required in determining the length and depth of the spillway stilling pool, and the type of sill for the stilling pool floor, to obtain a design which would reduce the energy in the high-velocity flow to nondestructive form and prevent scour in the downstream riverbed which might endanger the structure.

Extensive studies were made concerning the shape of the wing-walls at the end of the stilling pool to prevent erosion at the end of the apron and of the riprapped banks downstream.

A study of flow conditions below the outlet structure, both in the concrete channel immediately downstream and in the spillway stilling pool, was made. The shape and alinement of the channel were changed to obtain optimum flow conditions when the spillway and outlets were operating singly or simultaneously.

Summary of Results. The excessive erosion of the floor of the approach channel to the spillway, adjacent to the right wing-wall and upstream cutoff wall, indicated by the model studies of the proposed original design, was reduced to a minimum by replacing the vertical wall with one having a warped surface blending into the 3:1 slope of the upstream face of the dam. The approach conditions to the left wing-wall were of such nature that it was unnecessary to change the original curved vertical shape.

The desired maximum spillway discharge of 51,000 second-feet for a reservoir elevation of 2591 was obtained by lowering the floor of the spillway chute immediately downstream from the crest. By lowering this section approximately two feet, the capacity change indicated by the model was from 47,000 to 51,400 second-feet.

The floor of the stilling pool was raised and shortened when the model indicated the original design to be more than adequate. A very effective stilling pool for the spillway flow was indicated, providing the pool floor was raised two and one-half feet (prototype), shortened approximately seventeen feet, and steps and sills were placed on the apron.

Numerous tests were required, varying the shape and alinement of the wing-walls at the end of the pool, to obtain a design that would prevent excessive erosion of the floor and slopes of the channel between the

stilling pool of the spillway and the river. Through these tests a special shape of warped transition was developed, and the undesirable conditions were reduced to a minimum. A similar, but less extensive, design was used for the right wall, since the conditions were indicated to be less severe than at the left side.

The angle between the axis of the outlets and the centerline of the spillway was reduced to improve the flow conditions in the spillway and in the channel immediately downstream from the pool. The outlet channel below the control house was diverged and the center wall shortened to spread and reduce the thickness of the jet as it plunged into the pool. Flow conditions from the outlets were improved materially by this change.

The design evolved from the model studies is shown on Figure 3.

THE MODEL

Description of the Model. The 1:60 model of the spillway and outlet works of the Fresno Dam, except for the concrete crest and wing-walls, was of metal-lined wooden construction (Figure 4).

Separate tanks were used to represent the reservoir and downstream river channel because this type of construction enabled the major portion of the model to be built outside the boxes where the wooden parts would not be subjected to moisture.

A shallow approach to the spillway entrance made it imperative that this part of the model be reproduced accurately. A comparatively large head box was therefore required to contain the upstream topography, which was shaped of fine sand with layers of small rock representing the riprapped surface. A rock baffle in the head tank quieted the water satisfactorily before it reached the approach channel.

The original entrance wing-walls, which were vertical and curved, were shaped from sheet metal and soldered to the end bents of the model crest and the tank lining.

The original crest of the model was precast by framing several bents of the crest profile together and filling between with a wet

FIGURE 3

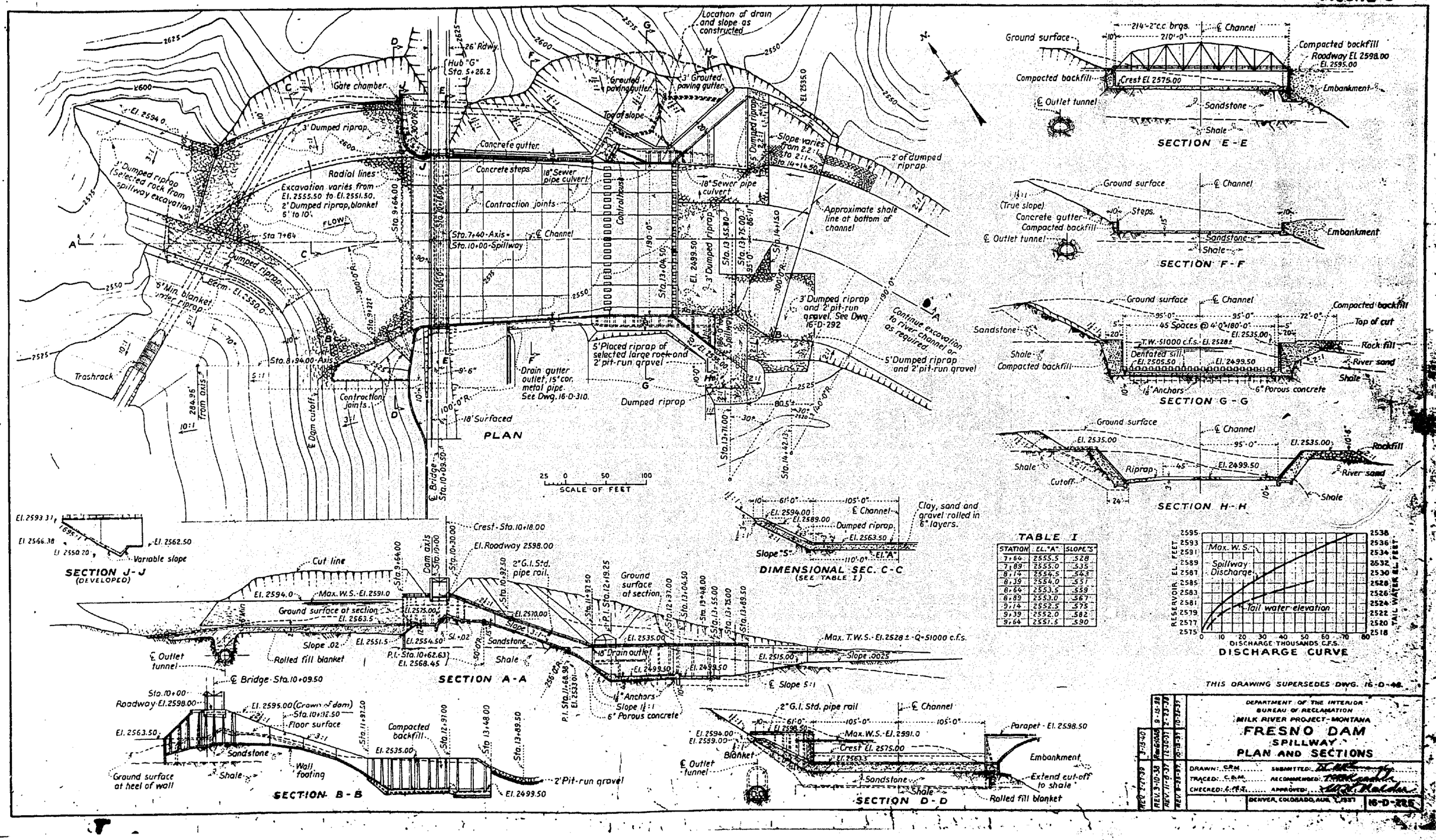

TABLE I

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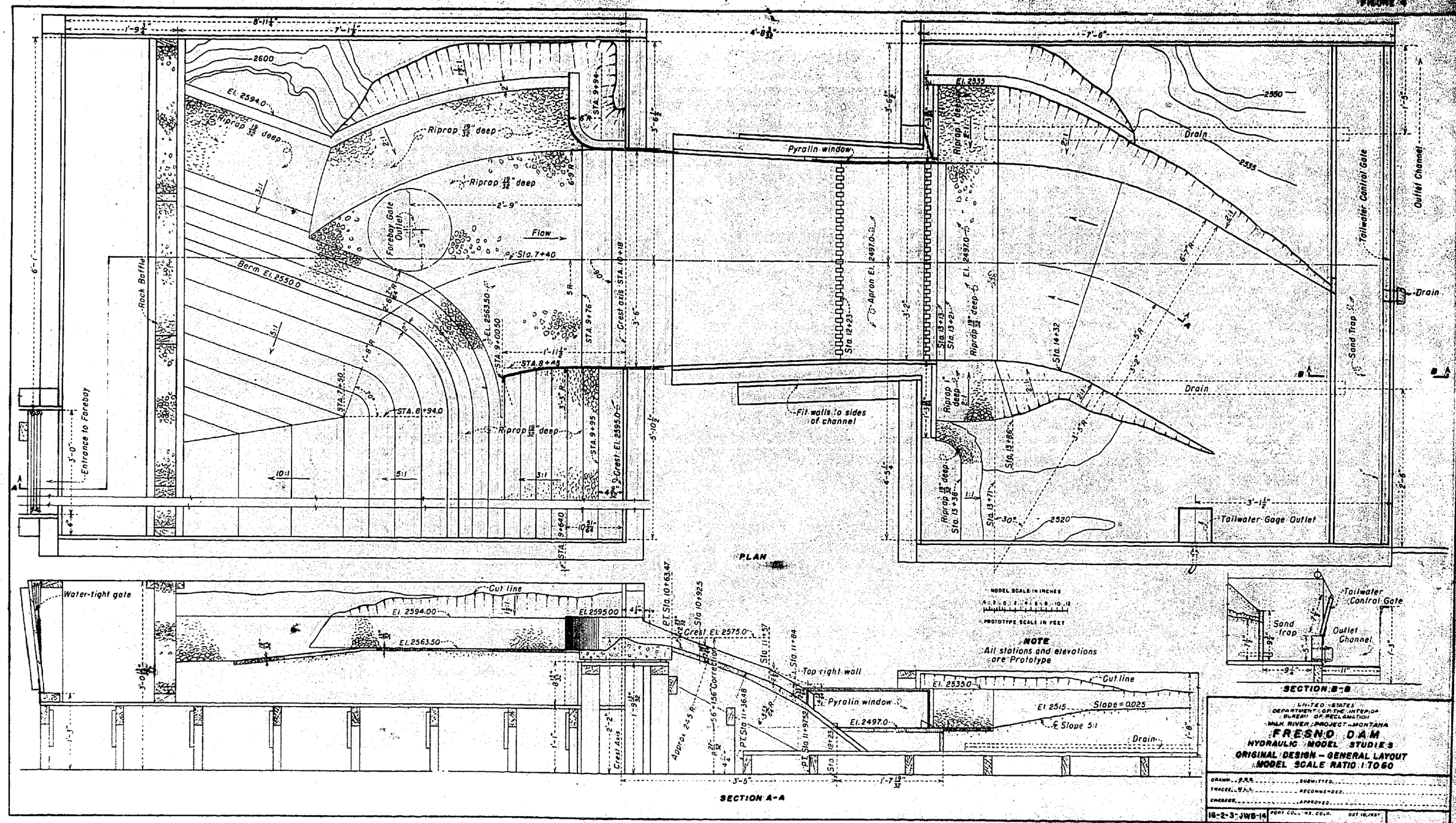
FIGURE 4
PLAN
SECTION A-A
SECTION B-B
Water-tight gate
Cut line
El. 2594.00
El. 2595.00
El. 2563.50
Crest El. 2575.0
Top right wall
Pyralin window
El. 2497.0
El. 2535.0
El. 2515
Slope = 0.025
Slope 5:1
Drain
Crest Axis
Approx. 245 R
Sta. 11+57
Sta. 11+84
Sta. 11+36.48
Sta. 12+23
Sta. 13+86
Sta. 13+71
Sta. 13+36
Sta. 13+21
Sta. 13+13
Sta. 14+32
Sta. 7+40
Sta. 8+45
Sta. 8+94.0
Sta. 9+00.50
Sta. 9+76
Sta. 9+95
Sta. 9+64.0
Sta. 10+18
Sta. 10+92.5
Sta. 10+63.47
Crest axis
Crest El. 2595.0
Crest El. 2563.50
Berm El. 2550.0
Rock Baffle
Entrance to Forebay
Forebay Gate Outlet
Flow
Riprap 19/32" deep
Riprap 1" deep
Pyralin window
Apron El. 2497.0
Fit walls to sides of channel
Tailwater Gage Outlet
Tailwater Control Gate
Outlet Channel
Sand Trap
Drain
El. 2594.0
El. 2535
2600
2550
2535
2520
MODEL SCALE IN INCHES
PROTOTYPE SCALE IN FEET
NOTE
All stations and elevations are Prototype
UNITED STATES
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MILK RIVER PROJECT - MONTANA
FRESNO DAM
HYDRAULIC MODEL STUDIES
ORIGINAL DESIGN - GENERAL LAYOUT
MODEL SCALE RATIO 1 TO 60
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
16-2-3-JWB-14
FORT COLLINS, COLO.
OCT 10, 1937

mixture of two parts cement to one part of moulding plaster. Careful screeding and rapid handling produced a smooth finish. The mixture used for this purpose was chosen because of its negligible volume change during the hardening period. Crest piezometers were fastened to the bents before the pouring was done. A second crest shape was made similar to the first but was cast in place.

The floor of the spillway channel immediately downstream from the crest was shaped of bents faced with 1-inch sheathing covered with 26-gage galvanized sheet iron. Training walls of wood screwed to this floor formed the main spillway channel.

The junction of the crest and head tank was made watertight by soldering. The spillway channel was joined to the tailwater tank in like manner.

The stilling pool at the end of the spillway channel consisted of a false floor, training walls, sills, and wing-walls. All except the latter were constructed of oil-treated redwood.

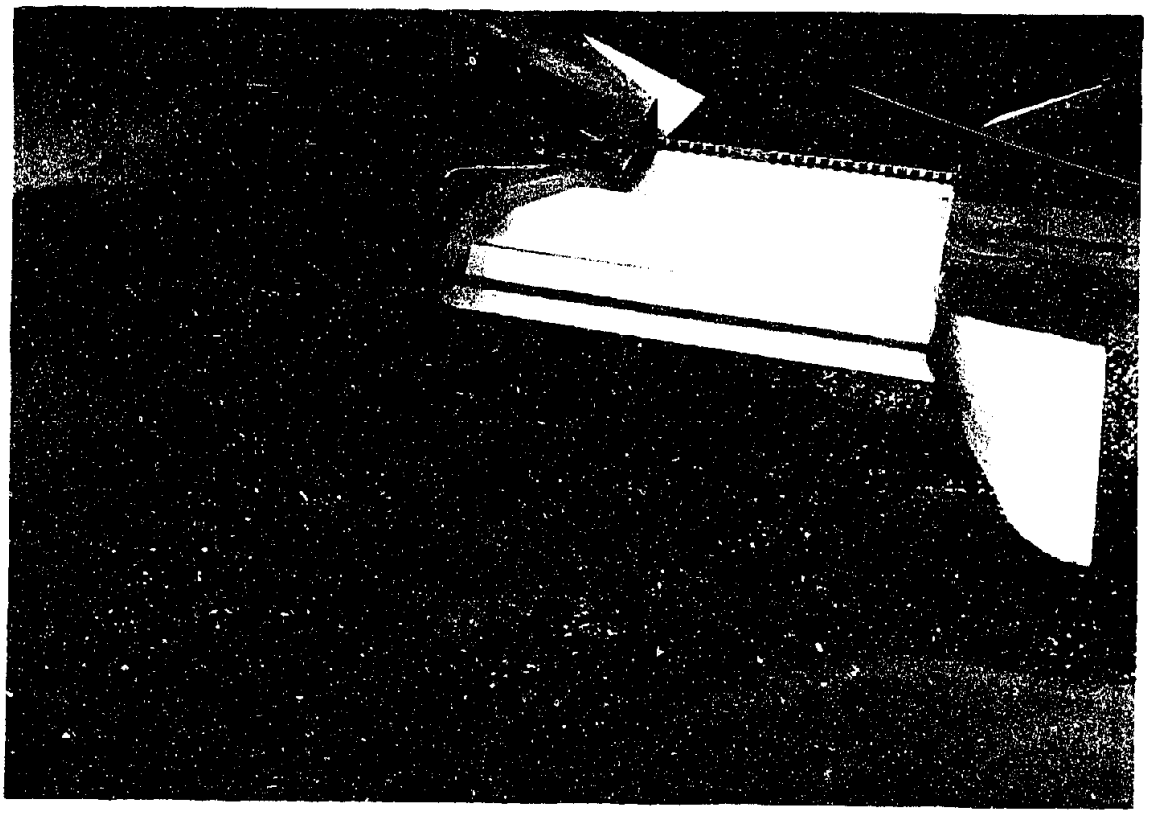
The wing-walls, warping from vertical at the upstream end to a flatter slope at the downstream end, were formed by screeding a mixture of cement and moulding plaster between templates. The downstream river bed was built up in the same manner as that upstream. Rapid reproduction of the downstream contours was made possible by fastening brass rods of the proper length to the tank floor.

Metal channels edged with galvanized screen and raised slightly off the floor provided rapid draining to facilitate photographing between runs.

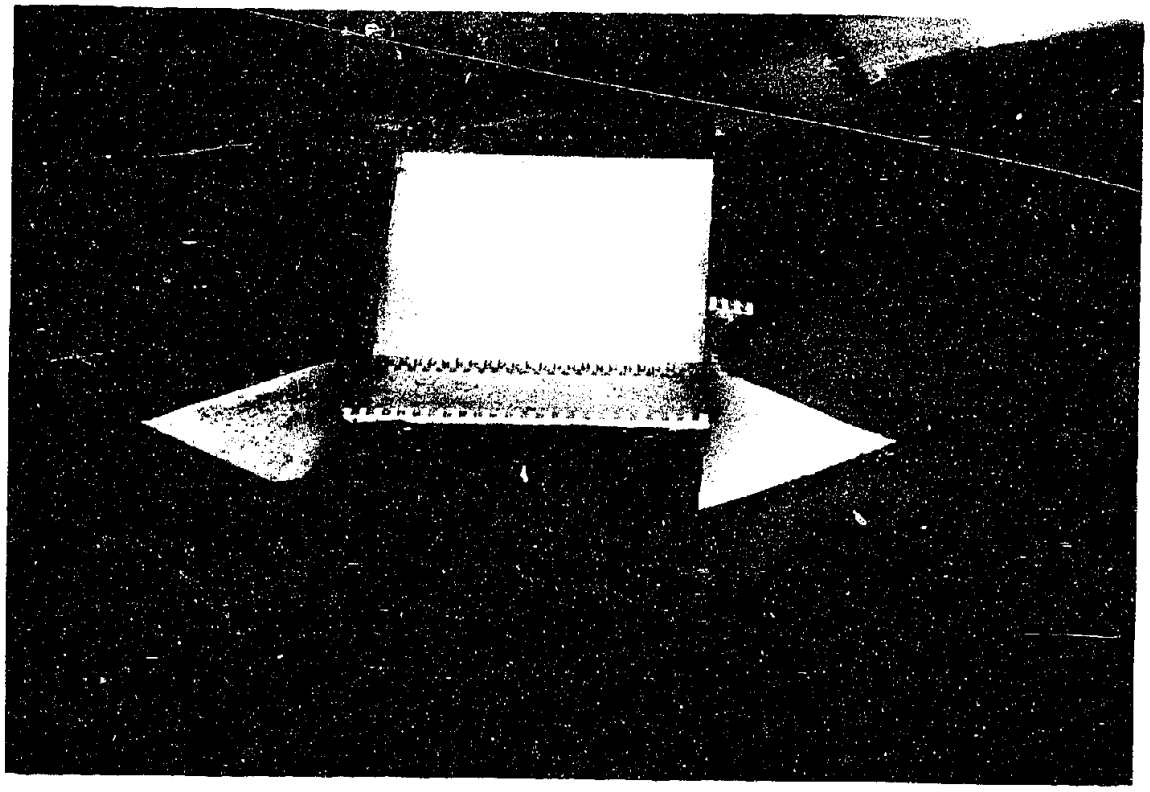
The outlet works at the upstream end of the stilling pool consisted of metal transitions and a diverging redwood exit-channel. The outlet supply was conveyed from a small portable 90-degree V-notch weir to the transitions through copper tubing.

The model, with all recommended features included, is shown on Figures 5 and 6.

The tailwater regulator was of the variable-height weir type consisting of a canvas-covered gate, hinged at the floor and controlled by wire rope and a pipe supported over the model. A car steering wheel



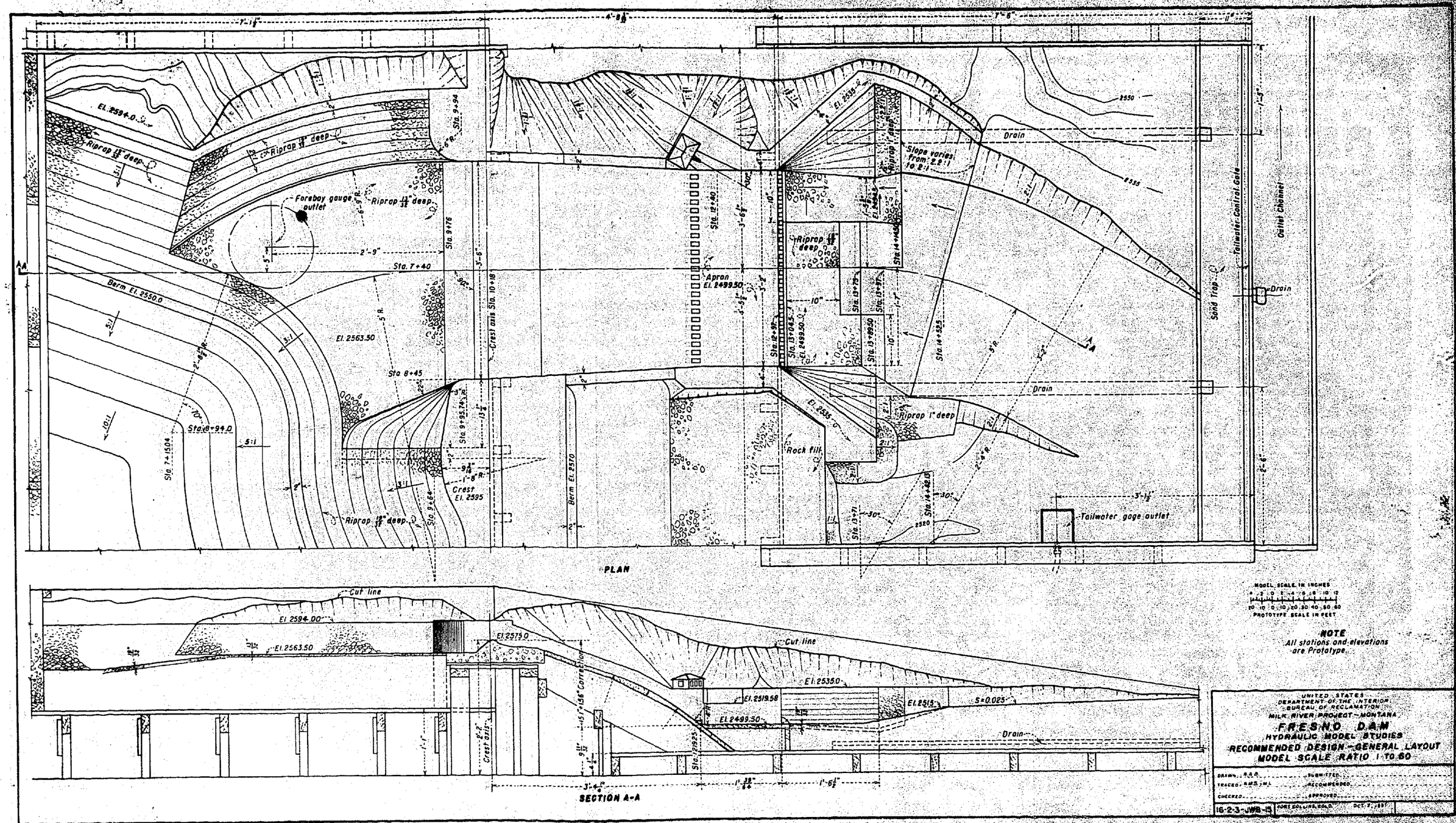
A - Looking downstream



B - Looking upstream

1:60 MODEL OF FRESNO DAM SPILLWAY WITH
RECOMMENDED DESIGN FEATURES INCLUDED

FIGURE 6



PLAN
SECTION A-A
Forebay gauge outlet
Riprap 13/32" deep
Riprap 1" deep
Berm El. 2550.0
Berm El. 2570
Crest axis Sta. 10+18
Crest El. 2595
Apron El. 2499.50
Rock fill
Slope varies from 2.2:1 to 2:1
Drain
Sand Trap
Tailwater Control Gate
Outlet Channel
Tailwater gage outlet
Cut line
El. 2594.00
El. 2563.50
El. 2575.0
El. 2535.0
El. 2519.58
El. 2515
El. 2499.50
S=0.025
Crest axis
MODEL SCALE IN INCHES
PROTOTYPE SCALE IN FEET
NOTE
All stations and elevations are Prototype.
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MILK RIVER PROJECT—MONTANA
FRESNO DAM
HYDRAULIC MODEL STUDIES
RECOMMENDED DESIGN—GENERAL LAYOUT
MODEL SCALE RATIO 1 TO 60
DRAWN
TRACED
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SUBMITTED
RECOMMENDED
APPROVED
16-2-3-JWB-15
FORT COLLINS, COLO.
OCT. 2, 1957

served as a means of revolving the pipe, thereby winding or unwinding the wire rope which in turn raised or lowered the top edge of the gate.

The flow of water for the model was supplied from a 30,000-cubic-foot reservoir above the laboratory and was discharged by hand-operated gates into a diverging flume to the weir channel, which was 19 feet long, 10 feet wide, and 7 feet 3 inches deep. The quantity of water flowing was measured by one of three calibrated weirs, the type depending upon the character of the tests being conducted in the laboratory. A V-notch weir was used for small quantities during calibration, while the 2-foot cipolletti was used when large quantities were necessary. A 4-foot cipolletti weir was used when special unrelated calibration tests were in progress.

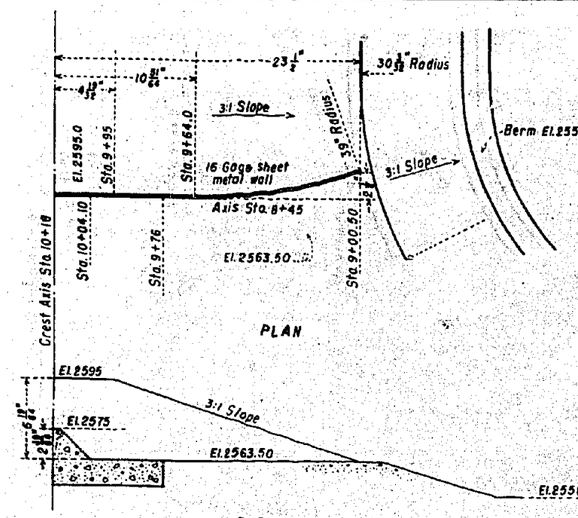
The head on the weir was regulated by operating a waste gate located 13 feet upstream from the weir plate. The head was measured by a hook gage and a Cornell-type float gage located in a stilling well connected to the weir channel by a pipe.

From the weir, the water passed into an open channel, thence through a 24-inch conduit system under the laboratory floor, to a riser fastened to the model head tank. The flow then passed over the model spillway to the stilling pool, where it was released to channels of the laboratory supply system for recirculation. The reservoir and tailwater elevations were measured by a piezometer and float gage, respectively.

THE INVESTIGATION

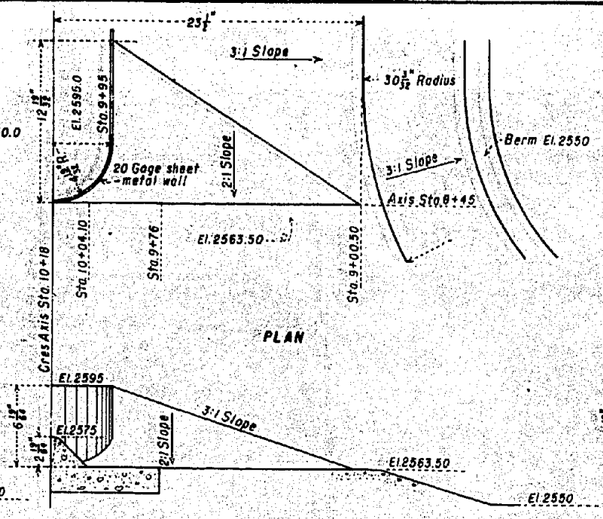
Original Approach Wing-wall Design. The original design of the right wing-wall to the spillway approach-channel (design 1, Figure 7) was a vertical, 195-foot radius, curved wall with its top coincident with the surface of the upstream face of the dam (Figure 8A). During the preliminary tests on this wall the upstream riprap was omitted and a fine-grained sand used to magnify the erosion. This design produced undesirable flow conditions with scour near the wall and along the footing upstream from the crest. The drawdown from the reservoir to the spillway caused a lateral flow from the right along the face of the dam, which interferred with the longitudinal flow in the approach-channel, producing a large swirling jet adjacent to the training wall, causing this scour (Figures 8B and C). The disturbance extended down

FIGURE 7

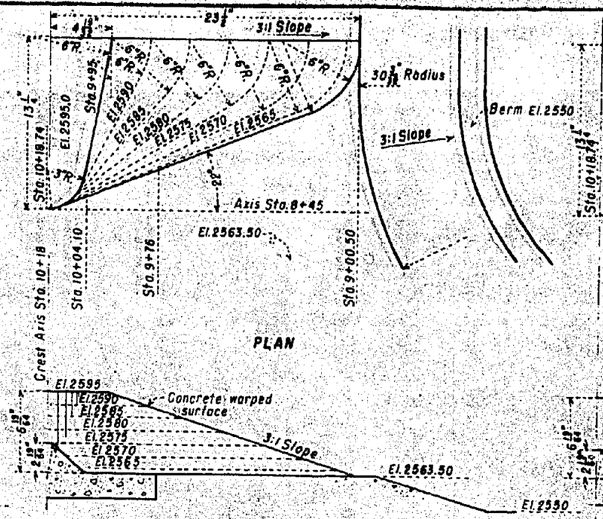


DESIGN NO. 1-ORIGINAL-TESTS 1 AND 2

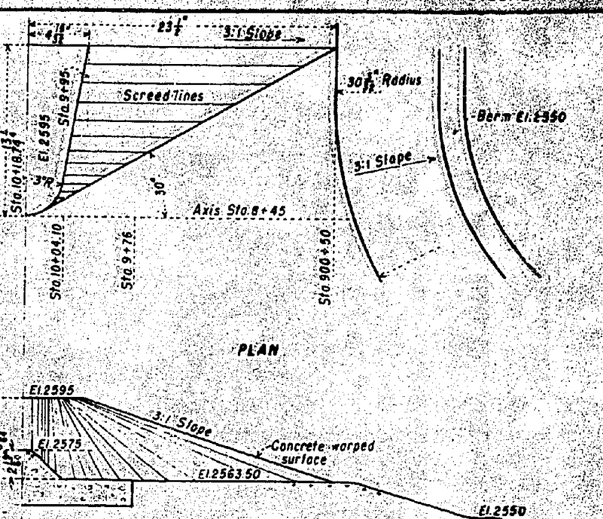
RIPRAP INSTALLED FOR TEST 2



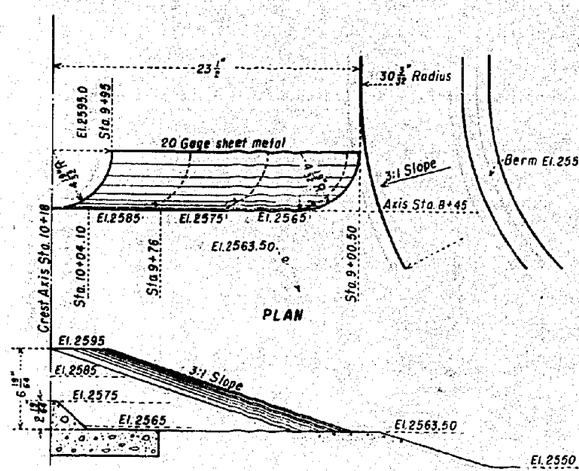
DESIGN NO. 3-TEST 4



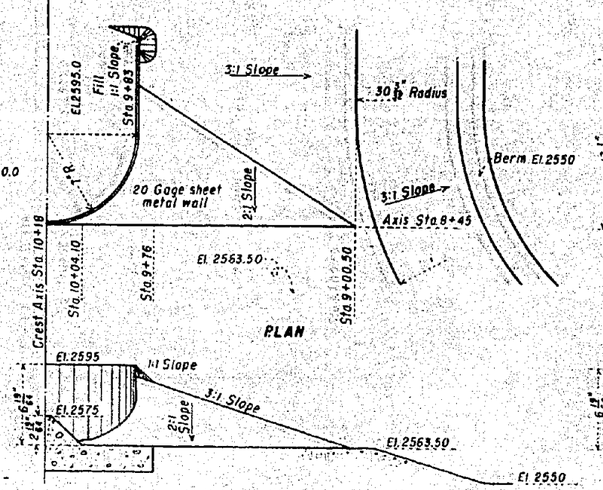
DESIGN NO. 5-TEST 6-9 INCL. AND 11 AND 12



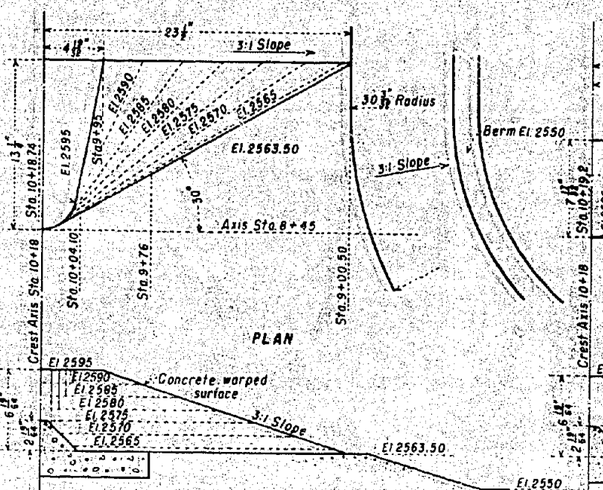
DESIGN NO. 7-TESTS 13 AND 14



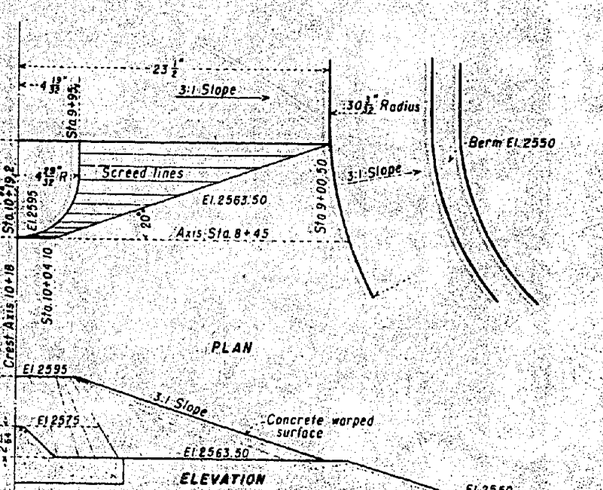
DESIGN NO. 2-TEST 3



DESIGN NO. 4-TEST 5



DESIGN NO. 6-TEST 10



DESIGN NO. 8-TESTS 15-24 INCL.

0 1 2 3 4 5 6 7 8 9 10 11 12
SCALE-MODEL INCHES

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MILK RIVER PROJECT-MONTANA

FRESNO DAM

HYDRAULIC MODEL STUDIES

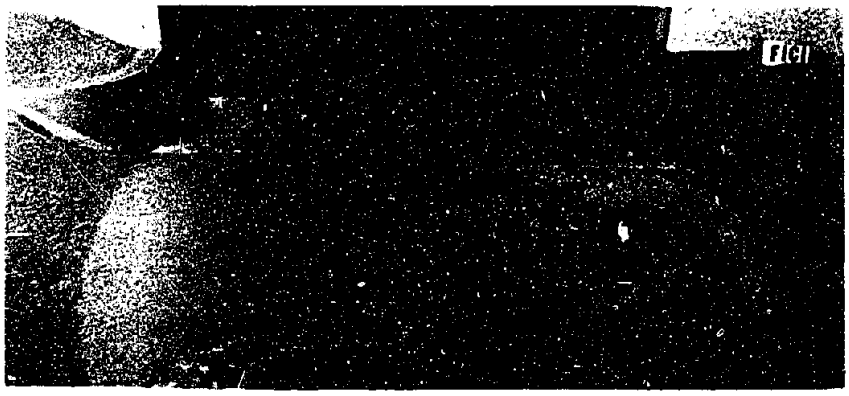
DETAILS OF WING WALLS AT RIGHT END OF CREST
MODEL SCALE RATIO 1:TO 60

DRAWN L.V.W. SUBMITTED
TRACED K.A.P. RECOMMENDED
CHECKED APPROVED

16-2-3-JWB-3 FORT COLLINS, COLORADO JULY 1, 1937

A - Spillway approach and wing walls

B - Flow conditions in approach and around wing walls. Discharge 51,000 second-feet



C - Scour caused by discharge of 51,000 second-feet

FLOW CONDITIONS AND EROSION IN APPROACH CHANNEL
OF 1:60 MODEL OF FRESNO DAM SPILLWAY

ORIGINAL DESIGN WING WALLS WITHOUT RIPRAP

the chute to the apron, but it did not seem to affect the stilling pool action. Although the erosion adjacent to the wall could be reduced materially by adding riprap to the upstream topography, it was deemed advisable to obtain a wall design which would correct the undesirable flow conditions, as well as minimize the scour with the riprap omitted.

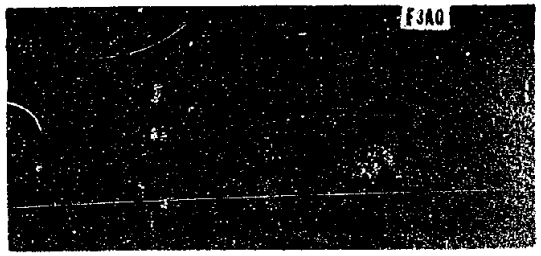
For comparison, the maximum flow of 51,000 second-feet (prototype), or 1.83 second-feet (model) was used throughout this phase of the investigation. A design shaped of an inclined elliptical cylinder, used successfully on a previous model, was tried.

Inclined Elliptical Wall. An elliptical cylinder inclined on a 3:1 slope, having a 23-foot radius quarter circle as a horizontal cross-section (design 2, Figure 7), gave practically the same results as the original design (Figure 9A). Its failure to improve conditions was attributed to the drawdown and transverse flow upstream from the crest. There had been only a slight drop in the water surface where the shape had proven satisfactory for another structure. A design similar to that of the left wing-wall, where no adverse conditions were noted, was then tested.

Vertical Wing-walls. A vertical wall with a 23-foot radius curve (design 3, Figure 7) showed a decided improvement in surface conditions, but gave only slight improvement in the erosion of the approach channel immediately upstream from the right end of the crest (Figure 9B). The failure of this wall to perform as well as the left wall was ascribed to the difference in the direction of flow toward it. The effect of moving the wall upstream and increasing the radius of the curve was investigated.

A vertical wall with a 35-foot radius curve (design 4, Figure 7) gave practically the same flow conditions as the wall with the shorter radius curve. There was a slight increase of erosion so an entirely new shape was selected for the next test.

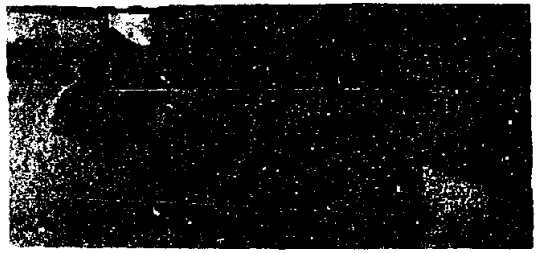
Warped Wing-walls. A warped wall consisting of a combination of a vertical cylinder, an inclined elliptical cylinder, and a warp was installed (design 5, Figure 7). The surface disturbance on the warp



Before run

Discharge 51,000 second feet

Design 2

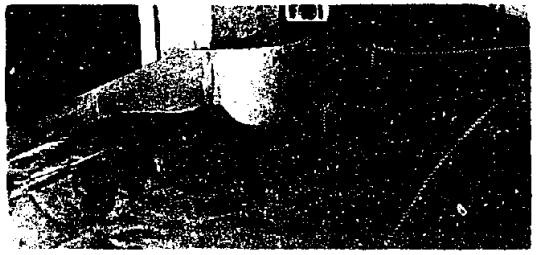


Erosion

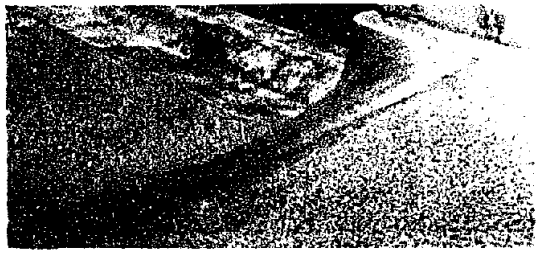
Before run

Discharge 51,000 second-feet

Design 3



Erosion



Before run

Discharge 51,000 second-feet
Entrance transition with warped surface and 15-foot radius

Design 6

Erosion

FLOW CONDITIONS AND EROSION IN APPROACH CHANNEL OF 1:60 MODEL OF FRESNO DAM SPILLWAY - VARIOUS DESIGN OF RIGHT WING WALL - NO RIPRAP ON UPSTREAM TOPOGRAPHY

FIGURE 9

was slightly more than for [illegible] design 2 or 3, but the erosion was reduced to a negligible amount (Figure 9C). Potassium permanganate dye, introduced into the water near the outer edge of the warp, disclosed streaming flow from the transition to the crest. This design was considered satisfactory and recommended as a tentative solution pending results from succeeding tests on similar designs. In order to simplify the wall, the inclined elliptical cylinder was eliminated in the next test.

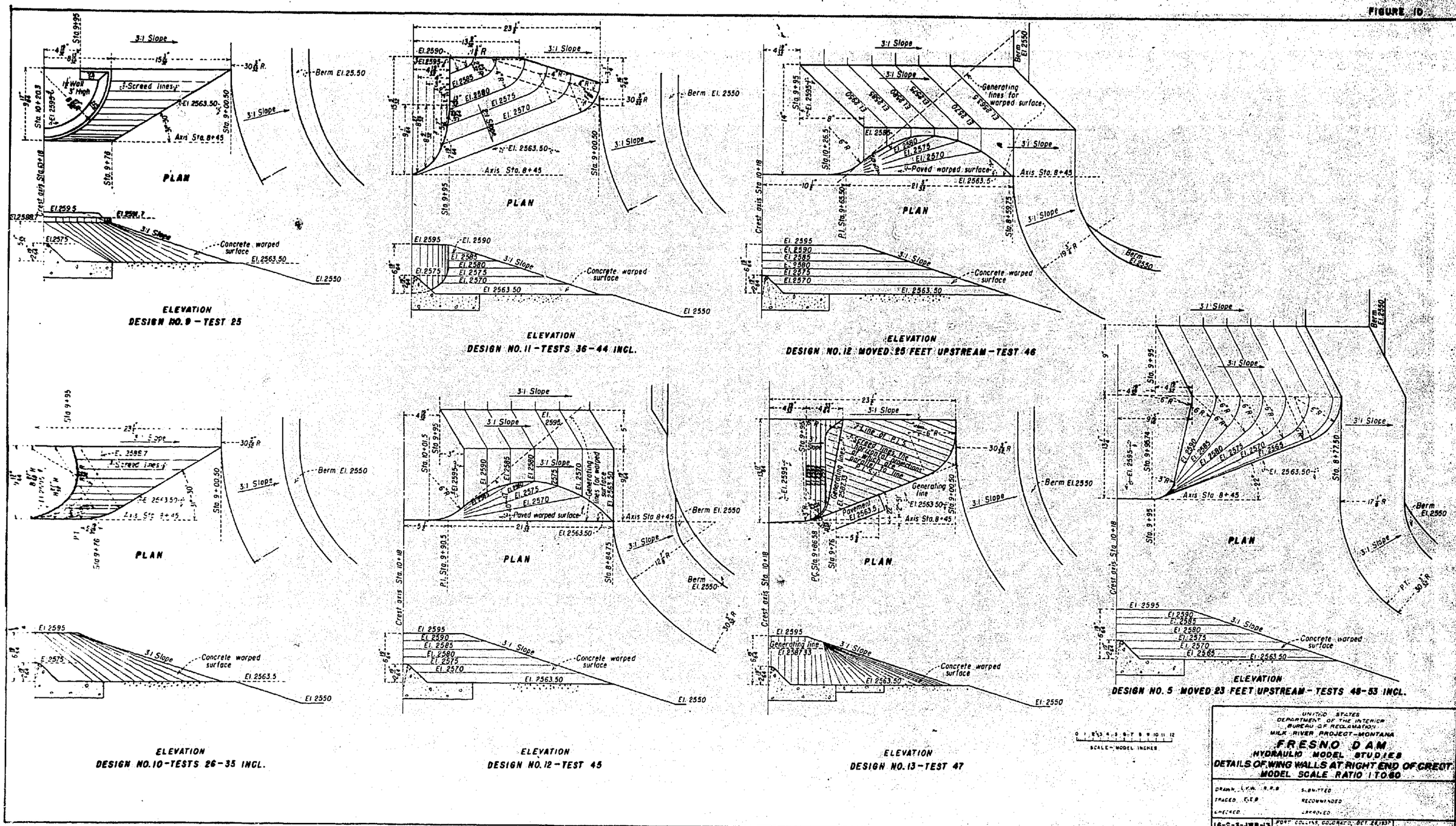
A wall, consisting of a vertical cylinder immediately upstream from the crest, with a warped surface connecting it to a 3:1 slope on the upstream face of the dam (design 6, Figure 7), was investigated. The surface appearance at the wall was practically the same as for design 5. A little more erosion occurred upstream from the crest and adjacent to the wall. This increase in erosion was probably due to a change in currents caused by the less streamlined shape of the transition.

The shape of design 6 was altered to reduce the area in which the eddy formed adjacent to the wall. This was accomplished by placing the screed lines for the warped surface normal to the crest axis (design 7, Figure 7). The change did not affect the surface disturbance. The erosion along the base of the warp and upstream from the crest was increased. Even so, other variations of this shape were tried.

Alterations to design 7 were made by moving the top edge of the wall upstream and reducing the angle of the base of the warp with the center line of the spillway channel (design 8, Figure 7). This design gave more surface disturbance and erosion than either design 6 or 7. This condition was apparently caused by the abrupt change in direction of flow caused by the transition wall. It was believed that a more gradual transition between the face of the dam and the spillway channel would improve the flow conditions.

A 44.25-foot radius curve was placed at the top of the wall (elevation 2588.7), and the warp surface changed slightly (design 9, Figure 10). The water flowed over the upstream corner of this wall so a parapet three feet high was placed around the edge of the warp. Flow conditions did not change materially from those for design 8, but the erosion was somewhat less (Figure 11A). Further improvement was desired so minor changes were made for subsequent tests.

FIGURE 10



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MILK RIVER PROJECT – MONTANA

FRESNO DAM

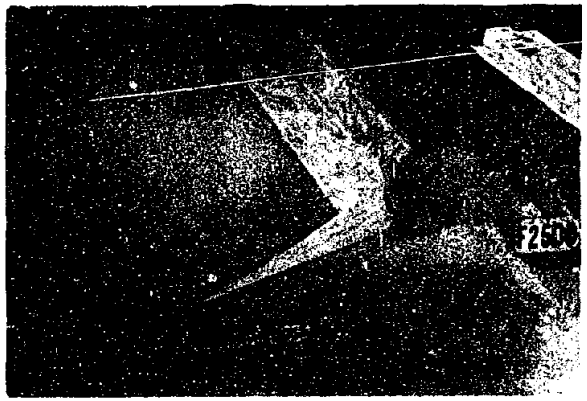
HYDRAULIC MODEL STUDIES

DETAILS OF WING WALLS AT RIGHT END OF CREST

MODEL SCALE RATIO 1 TO 60

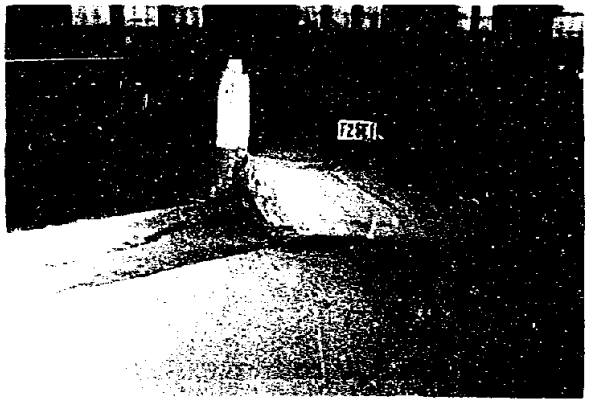
DRAWN L.V.W. R.R.B. SUBMITTED
TRACED E.E.B. RECOMMENDED
CHECKED APPROVED

16-2-3-JWB-13 FORT COLLINS, COLORADO, OCT. 26, 1937



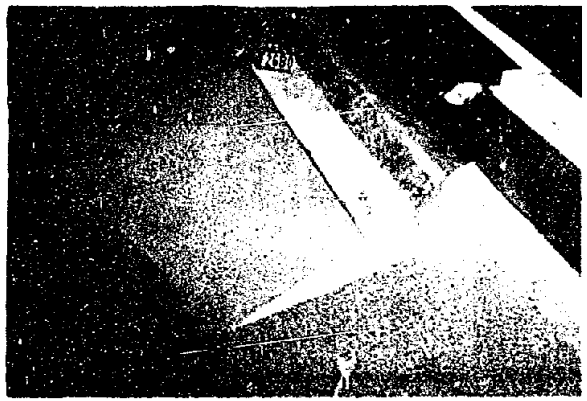
Before run

Discharge 51,000 second-feet

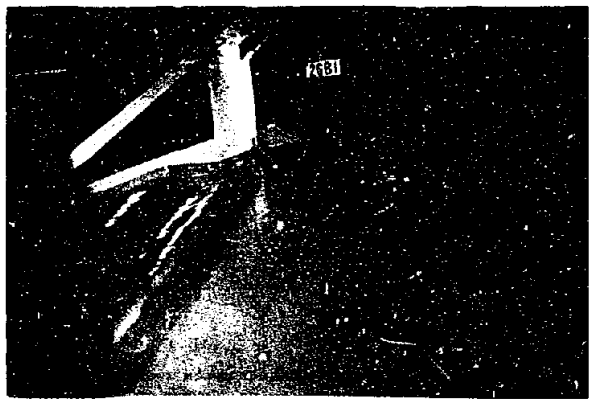


Erosion

Design 9



Before run



Discharge 51,000 second-feet

Erosion

Design 10

FLOW CONDITIONS AND EROSION IN APPROACH CHANNEL OF 1:60 MODEL OF FRESNO DAM SPILLWAY - VARIOUS DESIGN OF WARPED WINGWALL, NO RIPRAP ON UPSTREAM TOPOGRAPHY

FIGURE 11

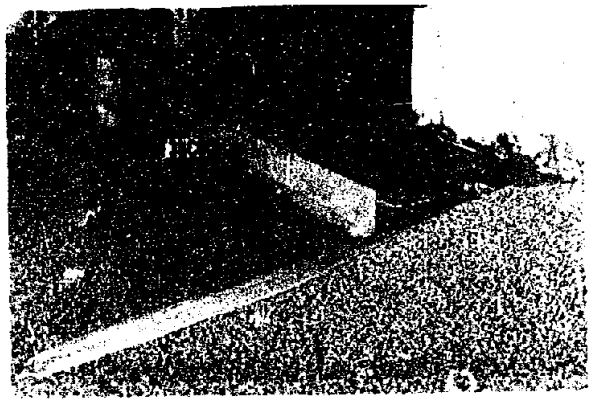
The vertical parapet was removed from design 9, the spillway side of the warp curved and its top raised to elevation 2595.0 (design 10, Figure 10). Flow conditions improved, but the erosion remained about the same as for design 8 (Figure 11B). The results were comparable with those for design 6, the surface conditions being slightly better and the erosion slightly worse. The difference was small, however, and any choice between the two would depend on ease of construction rather than hydraulic action.

The difficulty in constructing the warped transitions tested thus far was forseen, thus a simpler design was sought. A shape similar to design 3, except for the paved slopes, was constructed (design 11, Figure 10). There was a slight surface disturbance and a tendency for the approaching current to roll against the vertical wall before it entered the spillway channel. Erosion was negligible (Figure 12A), but the vertical part of the wall required a substantial footing, and the depth of excavation required to provide this footing made the design too expensive. Moreover, it was considered inadvisable to excavate such a large quantity from the dam proper.

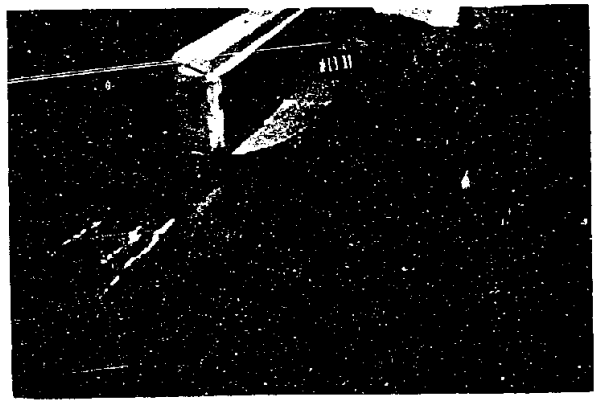
Another warp was constructed in an attempt to eliminate the objectionable features of the previous designs. The surface shape was generated by passing a straightedge along two screed lines while keeping it normal to the spillway centerline (design 12, Figure 10). The hydraulic conditions with this wall were similar, but slightly less severe than for the original design (Figure 12B), and was therefore unsatisfactory.

The warped section of the wing-wall in design 12 was moved 25 feet upstream and a 25-foot section of vertical wall placed between it and the spillway (design 13, Figure 10). This, in effect, moved the drawdown region (between the reservoir to the spillway channel) farther upstream, but resulted in no improvement in flow or erosion conditions. Its ineffectiveness was attributed to the combination of shallow approach and transverse flow.

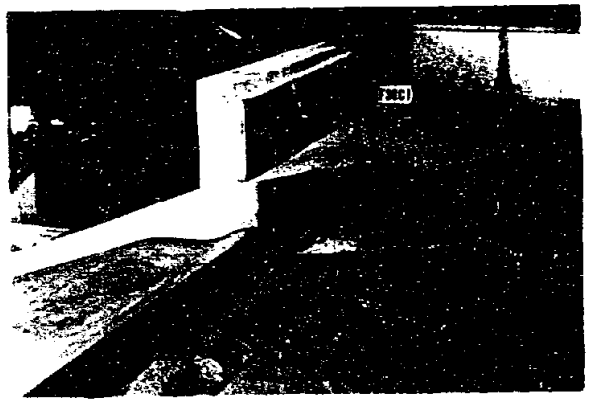
At this point it was thought that further investigation was unnecessary. Several of the wing-wall designs up to this point were satisfactory with design 5 outstanding. This design was recommended for the right wing wall of the Fresno Dam Spillway.



Before run

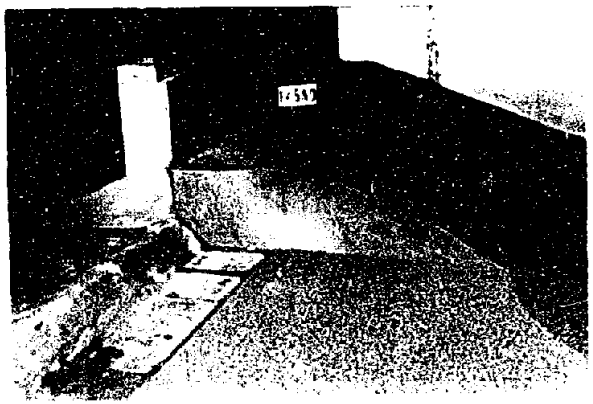


A - Discharge 51,000 second-feet

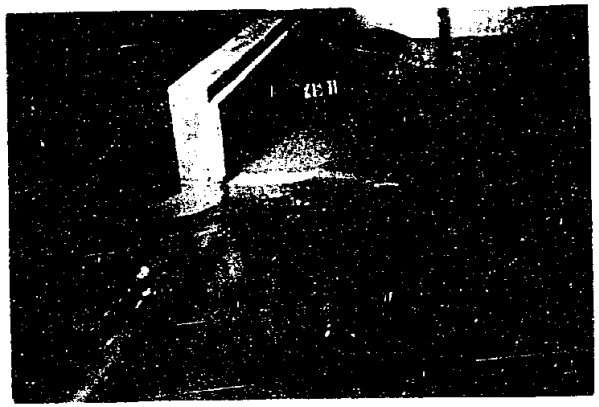


Erosion

Design 11



Before run



B - Discharge 51,000 second-feet

Erosion

Test 12

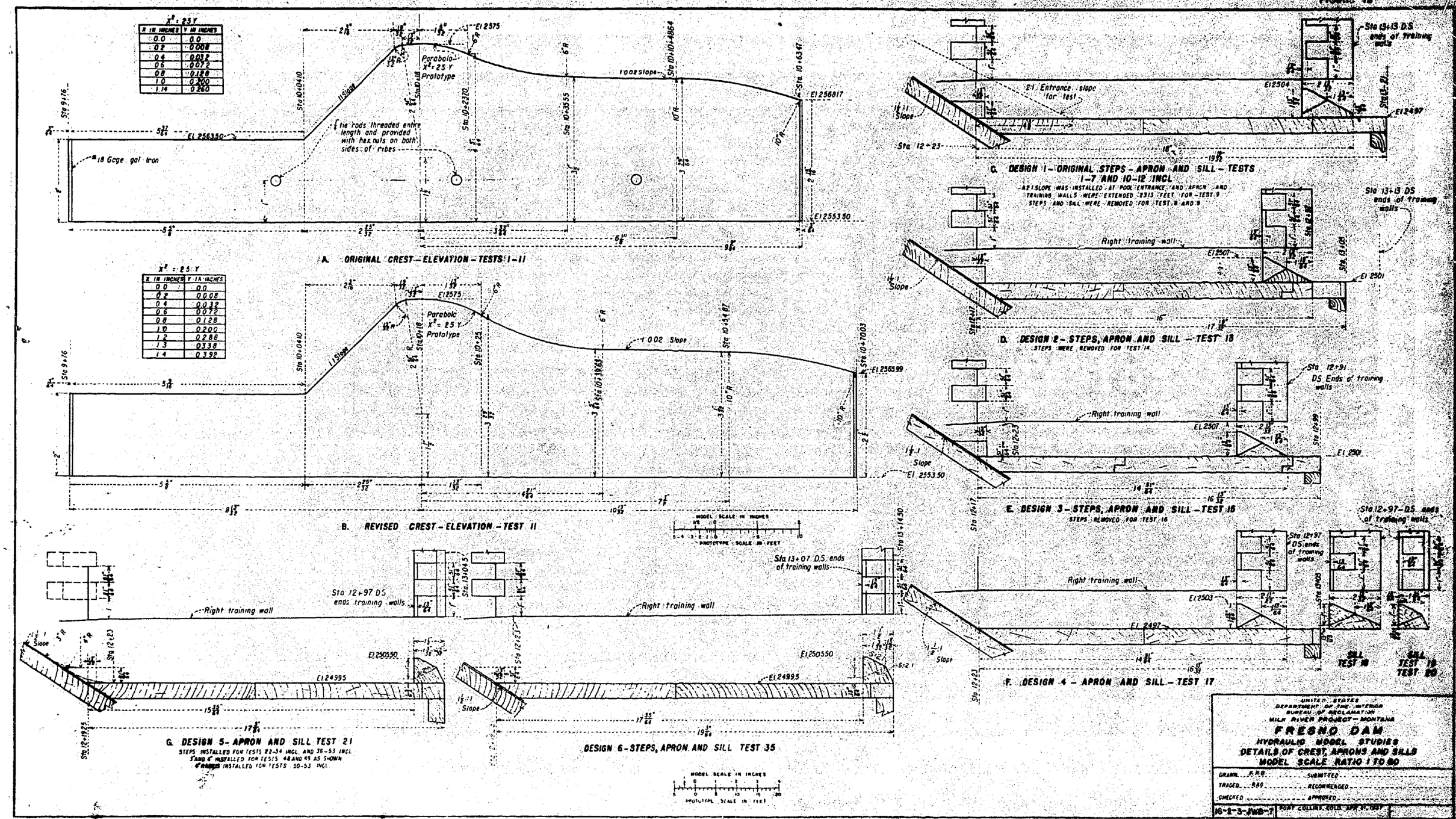
FLOW CONDITIONS AND EROSION IN APPROACH CHANNEL OF 1:60 MODEL OF THE FRESNO DAM SPILLWAY - DESIGNS 11 AND 12 OF WARPED RIGHT WING WALL.

FIGURE 12

Original Crest Design. The original crest (Figure 13A), with the original right wing-wall, was calibrated to ascertain the spillway capacity with the reservoir at elevation 2591.0. The discharge was found to be 47,000 second-feet or 4,000 second-feet less than the desired capacity of 51,000 second-feet. The reason for the low discharge was investigated when computations indicated an additional 18 feet of crest length would be necessary to obtain the 4,000 second-feet. It was believed that the swirling jet, which formed at the right end of the spillway with this design wing-wall, contributed to the difference. The design of the wall was revised, but the increase in flow was slight, making the capacity 47,500 second-feet. The estimated additional length of crest required to increase this quantity to 51,000 second-feet was 15 feet. When the change in the wing-wall design failed to increase the spillway discharge substantially, the possibility of submerged flow over the crest was investigated. Pressures and water surface profiles were taken along the center line of the crest (Figure 14). The water surface profiles directly downstream from the crest revealed that the flow did not completely attain the shape of a free jet, and that the pressures, which were above atmospheric, were excessive at the apex of the crest for large spillway discharges. These characteristics indicated that the difference in elevation of the crest and the chute floor immediately downstream was insufficient to prevent interference with the flow over the crest. With this in mind, a lower floor design was incorporated in the model and comparable data obtained.

Final Crest Design. The floor of the chute was lowered approximately two feet (Figure 13B). This increased the capacity of the crest to 51,400 second-feet with the reservoir at elevation 2591.0. The flow over the crest followed a path nearer that of a free jet and the pressures on the crest were decreased noticeably (Figure 15).

These changes in the flow conditions increased the discharge coefficient from 3.5 to 3.8. Further lowering of the floor of the chute would probably give additional capacity, but the maximum flow with the reservoir elevation of 2591.0 was slightly in excess of the



$X^2 = 25Y$
X IN INCHES | Y IN INCHES
0.0 | 0.0
0.2 | 0.008
0.4 | 0.032
0.6 | 0.072
0.8 | 0.128
1.0 | 0.200
1.14 | 0.260
A. ORIGINAL CREST – ELEVATION – TESTS 1–11
$X^2 = 25Y$
X IN INCHES | Y IN INCHES
0.0 | 0.0
0.2 | 0.008
0.4 | 0.032
0.6 | 0.072
0.8 | 0.128
1.0 | 0.200
1.2 | 0.288
1.3 | 0.338
1.4 | 0.392
B. REVISED CREST – ELEVATION – TEST 11
Parabola $X^2 = 25Y$ Prototype
1.002 Slope
1:1 Slope
#18 Gage gal iron
tie rods threaded entire length and provided with hex nuts on both sides of ribes
MODEL SCALE IN INCHES
PROTOTYPE SCALE IN FEET
C. DESIGN 1 – ORIGINAL STEPS – APRON AND SILL – TESTS 1–7 AND 10–12 INCL
A 2:1 SLOPE WAS INSTALLED AT POOL ENTRANCE AND APRON AND TRAINING WALLS WERE EXTENDED 2313 FEET FOR TEST 9
STEPS AND SILL WERE REMOVED FOR TEST 8 AND 9
2:1 Entrance slope for test
Sta 13+13 D.S. ends of training walls
D. DESIGN 2 – STEPS, APRON AND SILL – TEST 13
STEPS WERE REMOVED FOR TEST 14
Right training wall
Sta 12+91 DS Ends of training walls
E. DESIGN 3 – STEPS, APRON AND SILL – TEST 15
STEPS REMOVED FOR TEST 16
Sta 12+97 DS ends of training walls
F. DESIGN 4 – APRON AND SILL – TEST 17
SILL TEST 18
SILL TEST 19 TEST 20
Sta 12+97 DS ends training walls
Sta 13+07 D.S. ends of training walls
Right training wall
G. DESIGN 5 – APRON AND SILL TEST 21
STEPS INSTALLED FOR TESTS 22–34 INCL AND 36–53 INCL
3" AND 4" INSTALLED FOR TESTS 48 AND 49 AS SHOWN
4" RADIUS INSTALLED FOR TESTS 50–53 INCL
DESIGN 6 – STEPS, APRON AND SILL TEST 35
UNITED STATES
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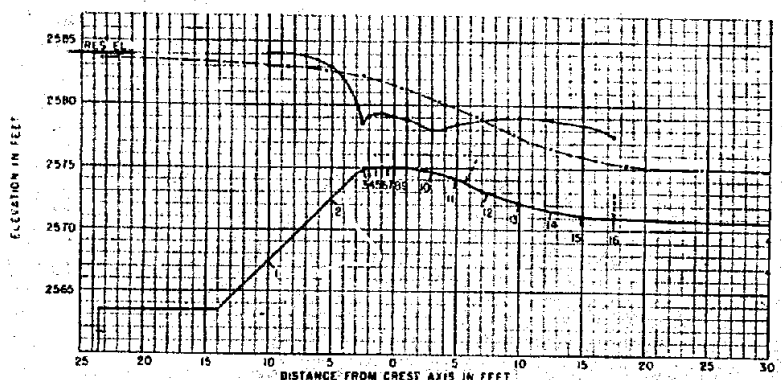
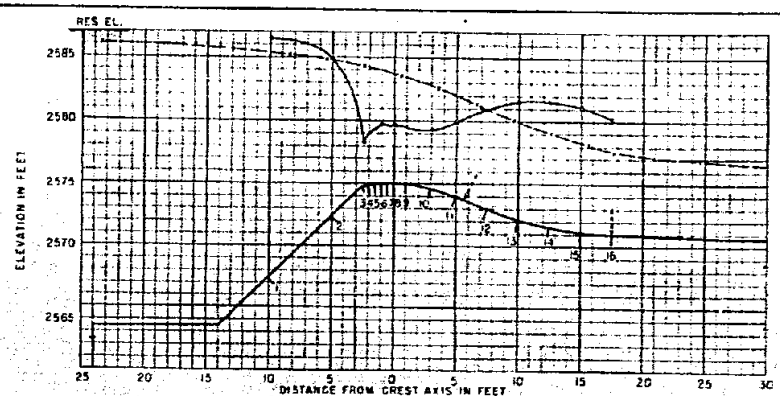
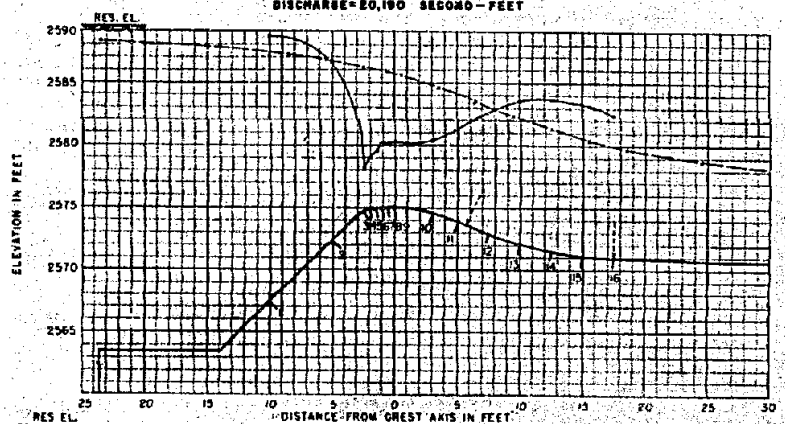
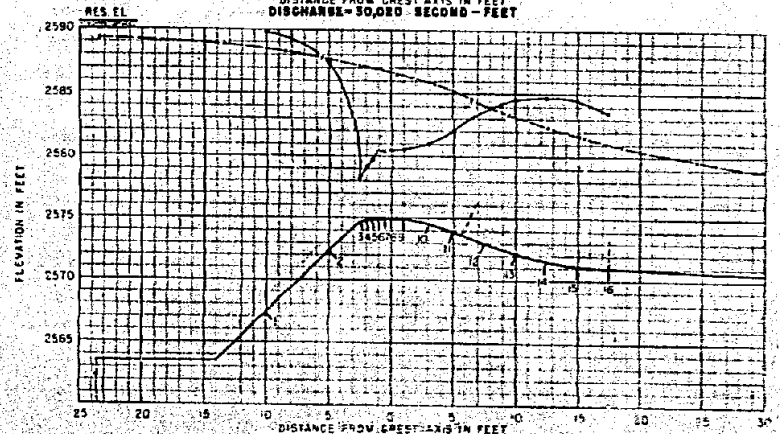
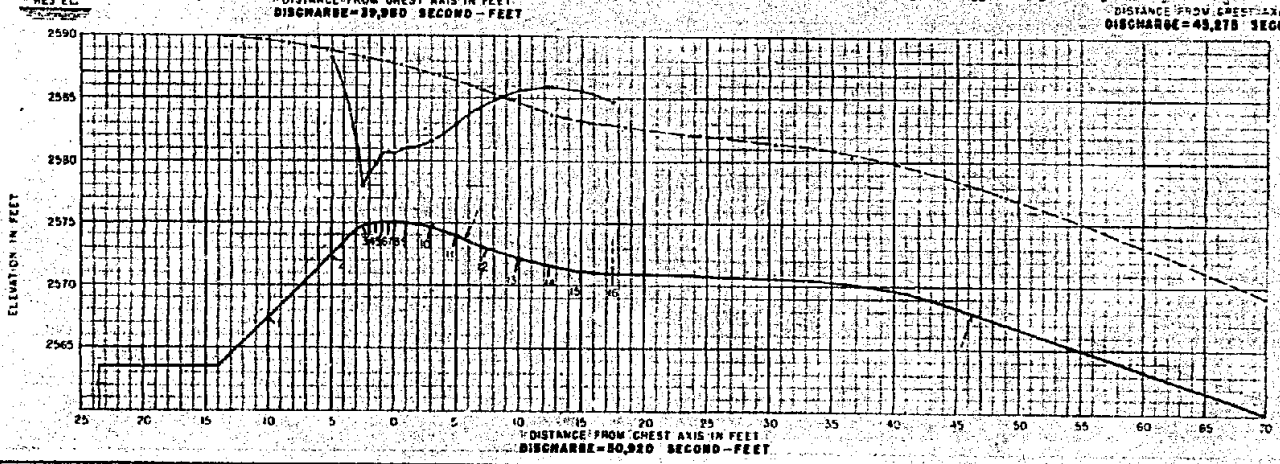
MILK RIVER PROJECT – MONTANA
FRESNO DAM
HYDRAULIC MODEL STUDIES
DETAILS OF CREST, APRONS AND SILLS
MODEL SCALE RATIO 1 TO 60
DRAWN F.R.B.
TRACED R.A.G.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
16-2-3-JWB-7
FORT COLLINS, COLO. APR. 21, 1937











LEGEND

PRESSURE

WATER SURFACE

ORIGINAL DESIGN

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MILK RIVER PROJECT - MONTANA

FRESNO DAM

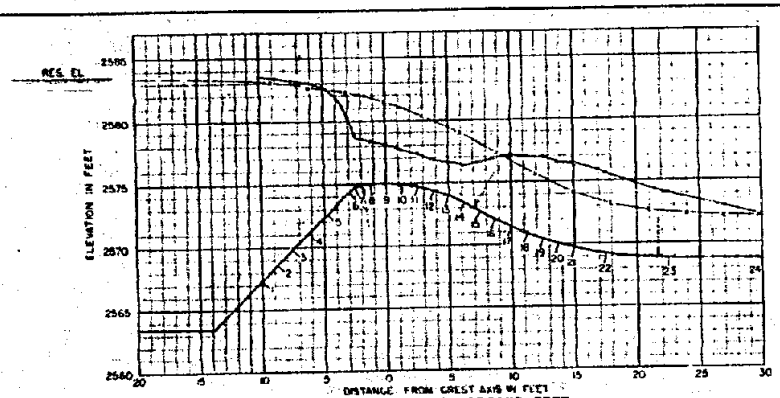
HYDRAULIC MODEL STUDIES

PRESSURE AND WATER SURFACE OVER CREST
MODEL-SCALE RATIO 1 TO 60

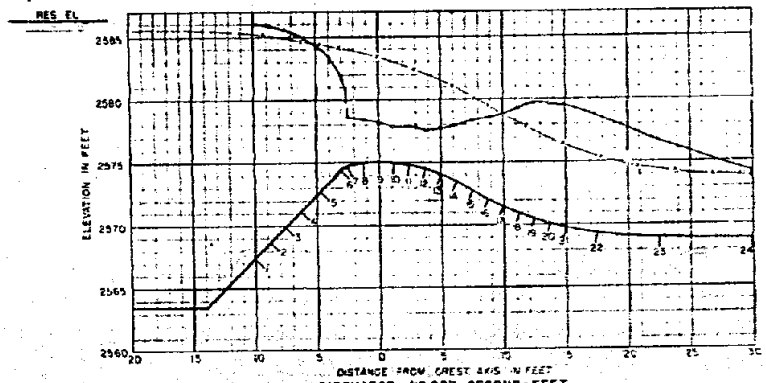
DRAWN ..... SUBMITTED .....
TRACED ..... RECOMMENDED .....
CHECKED ..... APPROVED .....

16-2-3 JWB-1

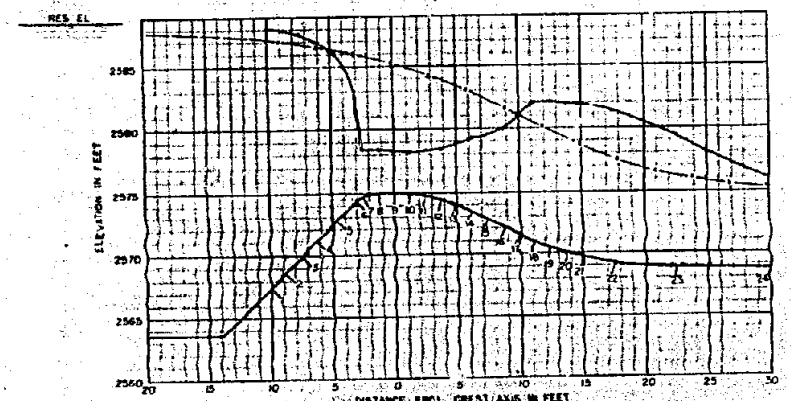
FIGURE 16



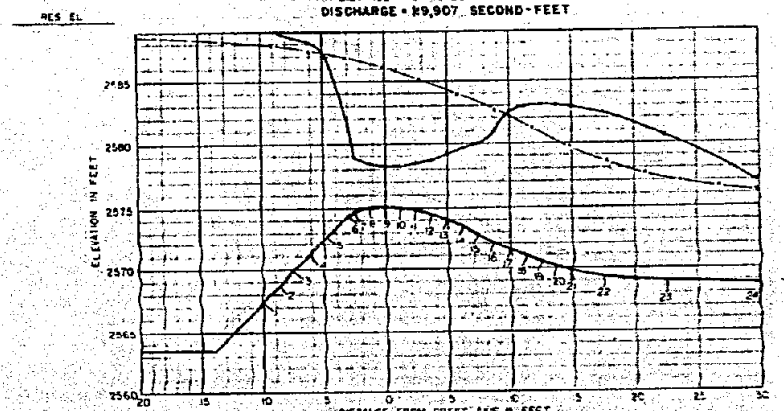
DISCHARGE = 20,122 SECOND-FEET



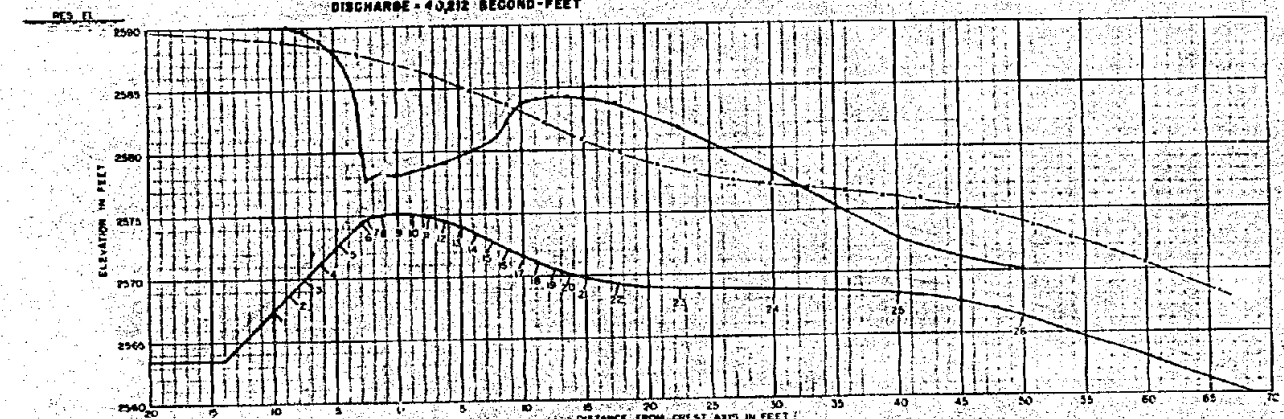
DISCHARGE = 29,907 SECOND-FEET



DISCHARGE = 40,212 SECOND-FEET



DISCHARGE = 45,188 SECOND-FEET



DISCHARGE = 50,919 SECOND-FEET

LEGEND

PRESSURE

WATER SURFACE

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MILK RIVER PROJECT - MONTANA

FRESNO DAM

HYDRAULIC MODEL STUDIES

PRESSURE AND WATER SURFACE - REVISED CREST

MODEL SCALE RATIO 1 TO 60

DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED

18-2-3-JWB-6

FIGURE 15

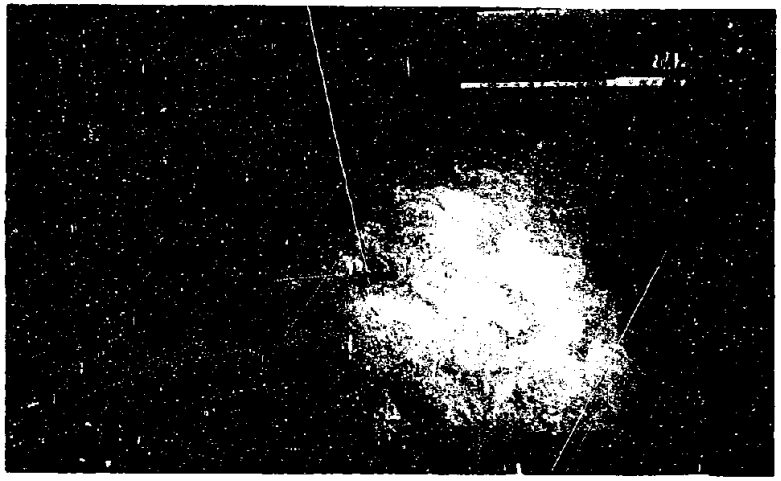
designed discharge, making the added expense unjustified.

Stilling Pool Design 1 (Original Design). In the preliminary tests, the slope of the pool entrance was changed from 1-1/2:1 to 2:1 in order to determine the effect of the different entrance slopes on the formation of the jump. No noticeable difference occurred (Figure 16), so all subsequent tests were made with the 1-1/2:1 sloped entrance. With the steps and sill removed for these tests, an efficient appearing jump formed on the apron for 51,000 second-feet. This resulted even though the jump-height curve, which was computed without considering friction losses, was three feet above the tailwater elevation for this discharge (Figure 17). Apparently the decrease in velocity caused by friction compensated for the lack of tailwater depth, and the erosion immediately downstream from the end of the apron affected a deepening of the pool which supported the formation of the jump. Since the pool length was less than three times the tailwater depth necessary to form a jump at a discharge of 51,000 second-feet, it was believed that some type of sill should be placed on the apron. After the steps and a sill were installed (design 1, Figure 13C), unequal distribution of flow was noted in the spillway chute, with deeper water on the left side than on the right. This condition, which was very noticeable at the maximum discharge, was attributed to the direction of the flow approaching the crest and was not considered serious.

A prominent roll appeared at the water surface over the sill and the jump seemed somewhat drowned at all discharges (Figures 18, 19C, and E), (normal tailwater). Even so, a return flow immediately downstream from the left wing wall of the pool washed away the 2:1 riprapped slope (Figure 18F). The drowned condition was ascribed to the high sill and stepped apron.

A study of the relation between the tailwater rating curve and the theoretical jump-height curve (apron elevation 2497) shows deeper tailwater than necessary to form a good jump for discharges below 40,000 second-feet, and a depth too shallow for greater discharges (Figure 17). However, a jump-height curve obtained by varying the

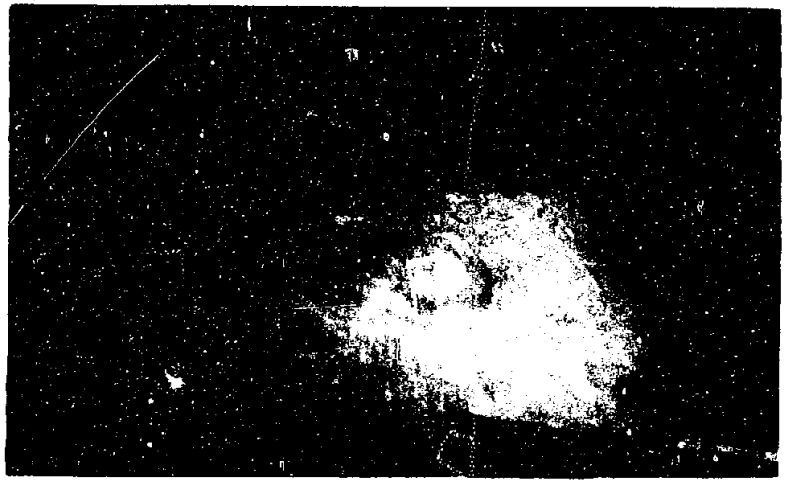
Normal tailwater



Tailwater 6 feet below normal

A - Pool entrance with 1½:1 slope

Normal tailwater



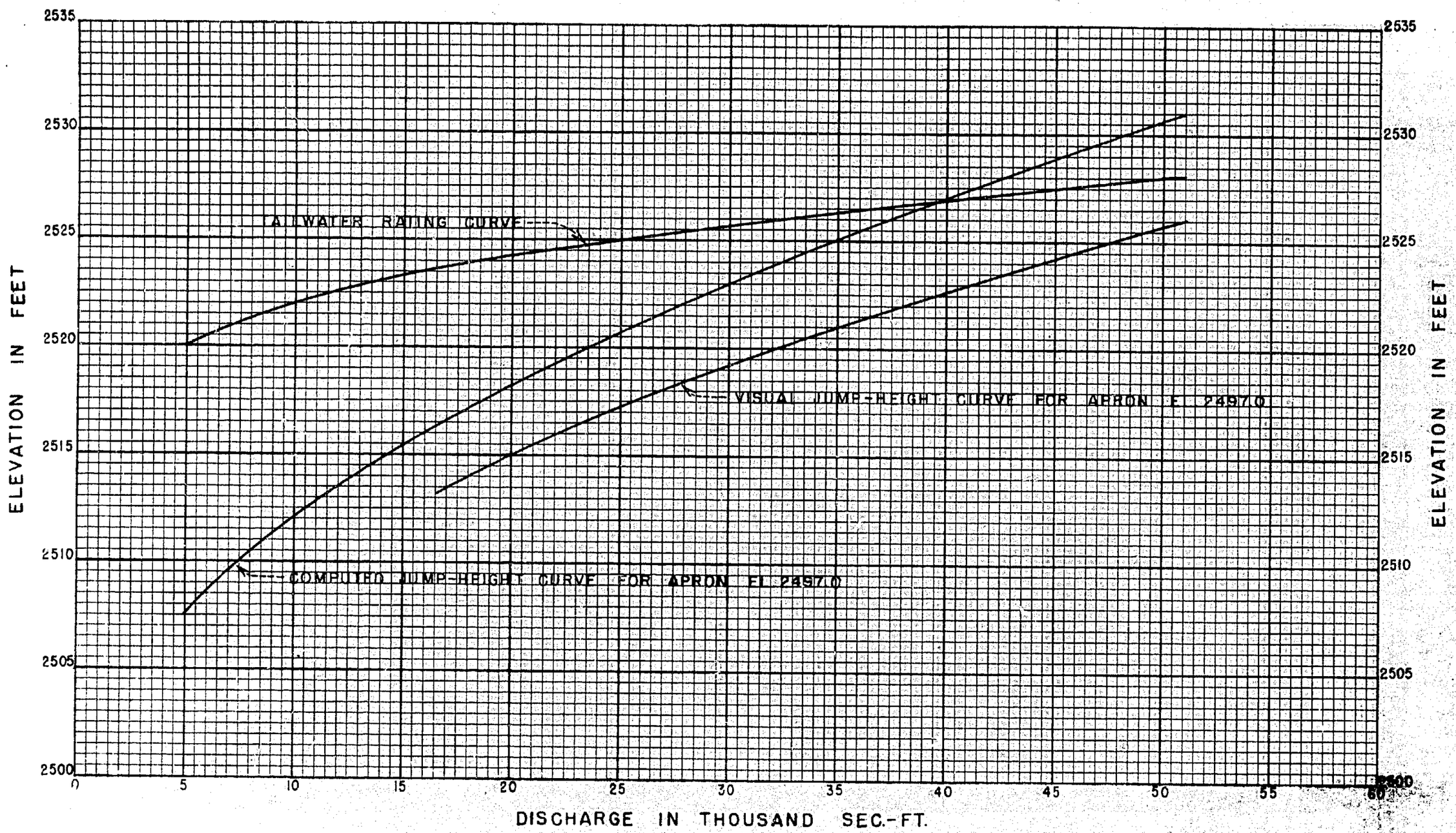
Tailwater 6 feet below normal

B - Pool entrance with 2:1 slope

FLOW CONDITIONS IN STILLING POOL OF 1:60 MODEL OF FRESNO DAM SPILLWAY
EFFECT OF ENTRANCE SLOPE ON POOL ACTION. NO SILL OR STEPS ON APRON.

FIGURE 16

FIGURE 17



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MILK RIVER PROJECT-MONTANA

FRESNO DAM

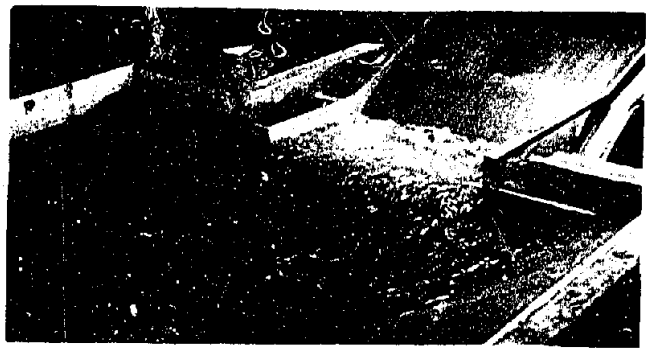
HYDRAULIC MODEL STUDIES

JUMP-HEIGHT AND T.W. EL. CURVES

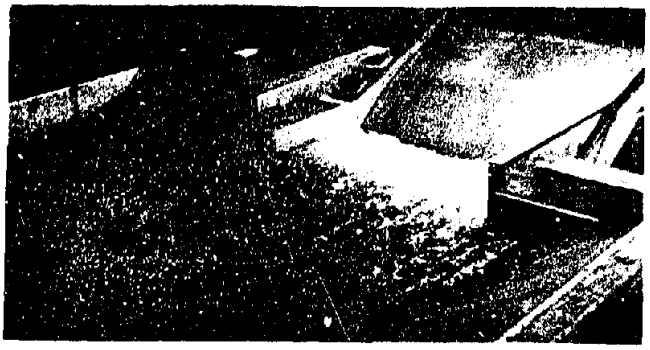
MODEL SCALE RATIO 1:60

DRAWN. R.R.B. ..... SUBMITTED .....
TRACED. A.H.W. ..... RECOMMENDED .....
CHECKED ..... APPROVED .....

16-2-3 JWB-4 | DENVER, COLORADO 3-19-67

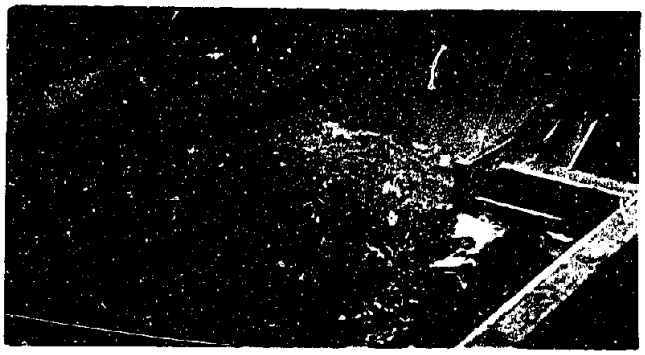


A - Normal tailwater

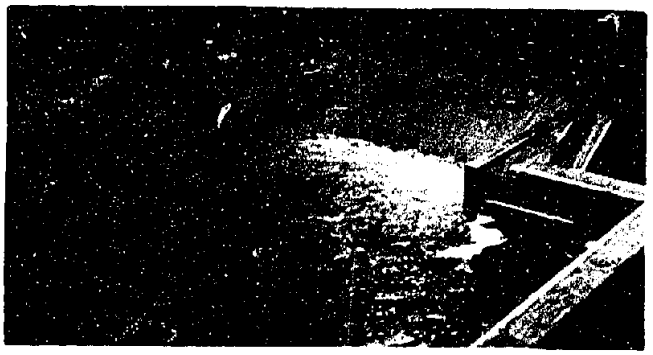


B - Tailwater 6.5 feet below normal

Discharge 70,000 second-feet



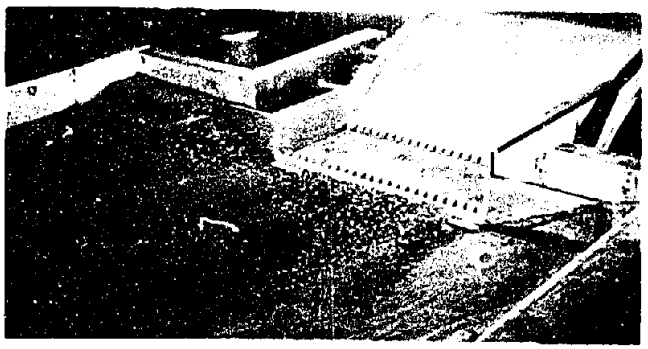
C - Normal tailwater



D - Tailwater 5.5 feet below normal

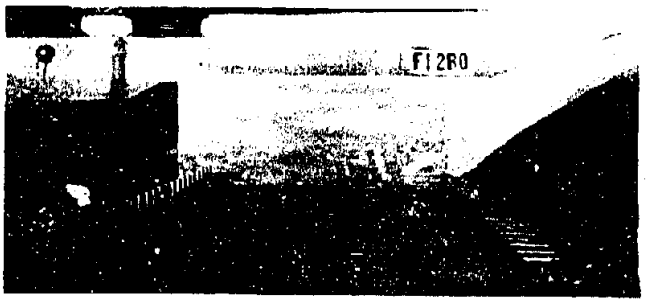
Discharge 51,000 second-feet

Before test



After test

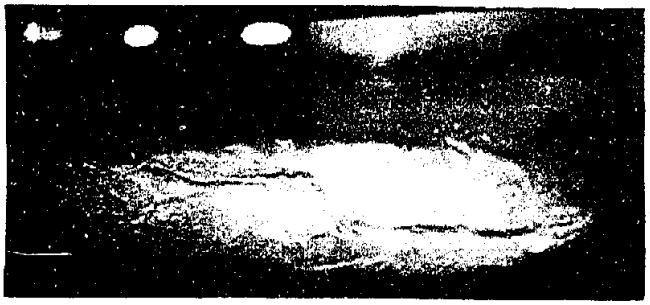
FLOW CONDITIONS AND EROSION IN STILLING POOL OF 1:60 MODEL OF FRESNO DAM SPILLWAY. ORIGINAL DESIGN - 98-FOOT APRON WITH STEPS AT ENTRANCE, 7-FOOT SILL PLACED WITH UPSTREAM EDGE 20 FEET FROM END OF APRON



A - Side view of pool

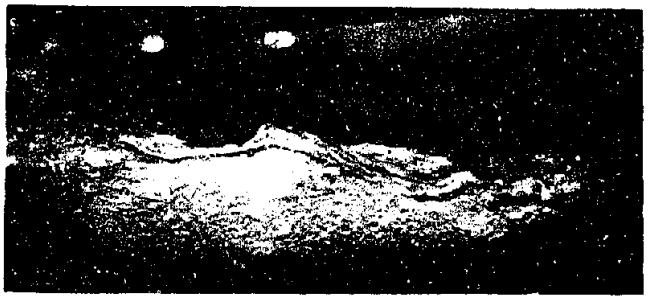
B - Discharge 10,000 second-feet

C - Normal tailwater



D - Tailwater 6.5 feet below normal

Discharge 30,000 second-feet



E - Normal tailwater

F Tailwater 2.7 feet below normal

Discharge 51,000 second-feet

FLOW CONDITIONS IN STILLING POOL OF 1:60 MODEL OF FRESNO DAM SPILLWAY ORIGINAL DESIGN - 98-FOOT APRON WITH STEPS AT ENTRANCE, 7-FOOT STILL PLACED WITH UPSTREAM EDGE 20 FEET FROM END OF APRON.

tailwater to form the most efficient appearing jump indicated that the apron could be raised about 2.2 feet without producing less desirable conditions for the maximum discharge. The difference between the theoretical jump-height curve and that obtained in this manner was attributed to the effect of the steps, sill, and friction. Should retrogression of the riverbed lower the tailwater, with the apron raised 2.2 feet, the steps would assist in keeping the jump on the apron, and thus serve as a factor of safety against sweeping out. The drowned condition at lower flows could be alleviated, partially at least, by the use of a sloping apron, but the action and the erosion for these discharges were not objectionable, and its use might have proven unsatisfactory for the maximum discharge. Since the conditions at lower flows were satisfactory, all subsequent observations for the pool design were made at the maximum discharge. Three possible methods to improve flow conditions for the design discharge were suggested. They were: (1) Raising the pool floor, retaining the apron length and using the same or a smaller sill; (2) Maintaining the floor elevation and shortening the pool; or (3) Raising the floor and shortening the pool. The third method seemed more economical than either of the other two, so the model was altered accordingly for the next test.

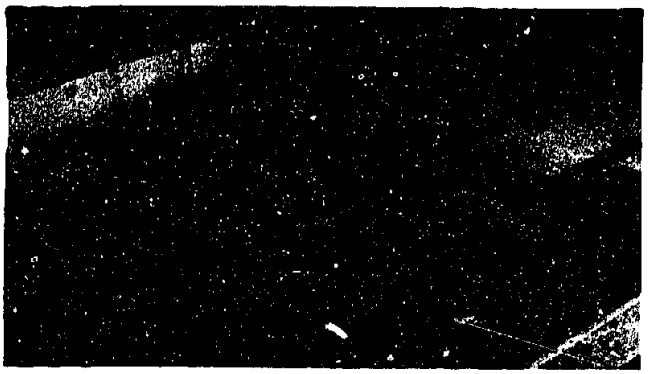
Stilling Pool Design 2. When the floor was raised four feet, shortened 10 feet, and the 7-foot sill replaced by one 6 feet high (design 2, Figure 13D), the pool became rough at 51,000 second-feet (Figure 20A). More erosion occurred at the apron cutoff wall than on the original design, but the 2:1 slope downstream from the left wing-wall was only slightly disturbed (Figure 20B). A shorter apron was indicated for the next test.

Stilling Pool Design 3. The apron was shortened an additional 6 feet, and the wing-walls moved upstream (design 3, Figure 13E). This resulted in a very rough water surface in the pool with the jump forming farther downstream. The erosion at the end of the apron was not increased materially over that for design 2, and there was little

A - Discharge 51,000 second-feet

B - Erosion caused by 51,000 second-feet

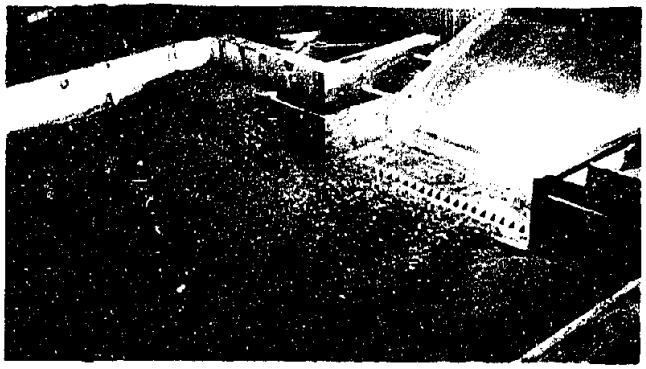
Design 2 - Steps on apron



C - Discharge 51,000 second-feet

D - Erosion caused by 51,000 second-feet

Design 3 - No steps on apron



E - Discharge 51,000 second-feet

F - Erosion caused by 51,000 second-feet

Design 4 - No steps on apron

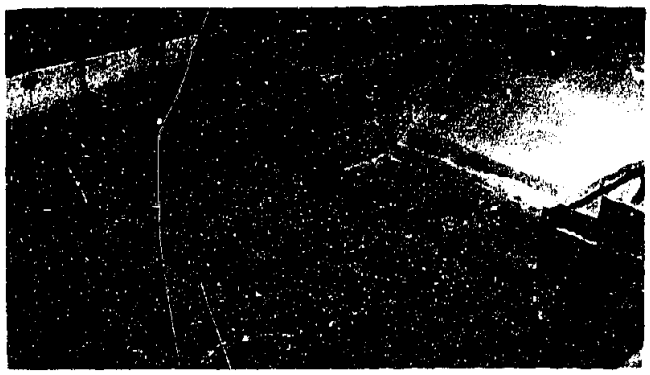
FLOW CONDITIONS AND EROSION IN STILLING POOL OF 1:60 MODEL
OF FRESNO DAM SPILLWAY - POOL DESIGNS 2, 3, AND 4.

difference in the condition of the 2:1 excavated slope downstream from the wing-walls. It was necessary to raise the tailwater 1.7 feet to obtain the most desirable jump. The jump was nearly swept off the apron when the steps were removed from the upstream end of the pool to determine their effectiveness. More impact was noted on the sill and the height of the roll over the sill was increased (Figure 20C). This design was considered inadequate because it was necessary to raise the tailwater 4.4 feet to form a satisfactory jump. As it seemed desirable to obtain a satisfactory design which did not include the steps on the apron, the pool floor was lowered for the next test.

Stilling Pool Design 4. With the pool floor lowered to elevation 2497.0 and the apron length of 82 feet kept constant (design 4, Figure 13F), there was a noticeable decrease in erosion (Figure 20F). In all the tests discussed in the previous paragraphs, the deepest erosion along the cutoff wall at the end of the apron occurred immediately downstream from each end of the sill. The same conditions, noted previously in tests on a model of the Bull Lake Spillway, had been improved somewhat by the use of a sill having dentals, instead of spaces, adjacent to the training walls. The dentals on the Fresno sill were therefore arranged in a similar manner (design 4, test 18, Figure 13F). Only a slight improvement was noted. However, this improvement seemed desirable, so a sill of this type was used for all subsequent tests. The persistent roughness of the pool seemed to indicate that the apron was too short, but as it was not economical to lengthen the walls or the floor, the sill was truncated and moved downstream so that the upstream edge was at the same station as the ends of the training walls (design 4, test 19, Figure 13F). Although the appearance of the jump changed but slightly by this lengthening (Figure 21A), the erosion was considerably decreased, and this sill was recommended for use on the Fresno Spillway.

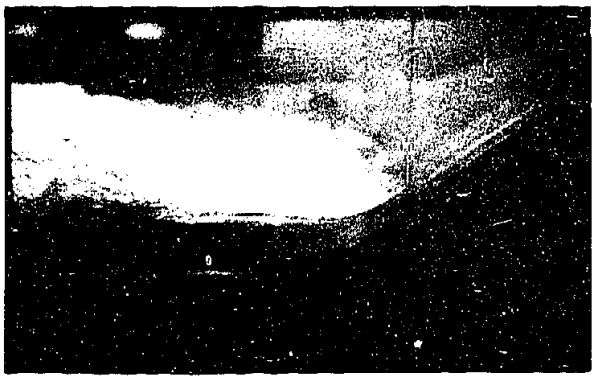
The maximum depth of scour was slightly below elevation 2497 (the pool floor) at the downstream corners of the apron, and material was deposited against the sill between these areas (Figure 21B). The excavated slope downstream from the left wing-wall of the stilling pool was destroyed.

A - Discharge 51,000 second-feet

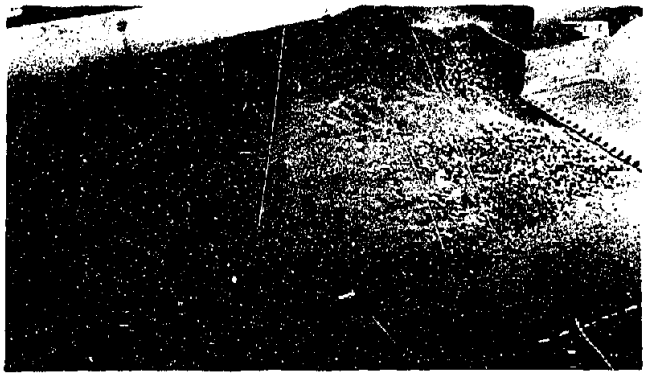


B - Erosion caused by 51,000 second-feet

Design 4 - Truncated sill - no steps on apron



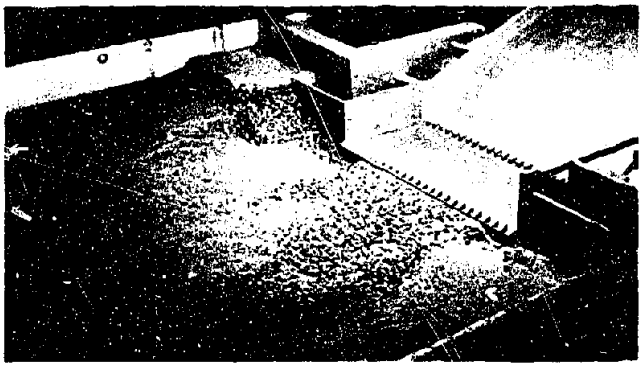
C - Discharge 51,000 second-feet



D - Erosion caused by 51,000 second-feet.

Design 5 - Truncated sill - no steps on apron

E - Discharge 51,000 second-feet



F - Erosion caused by 51,000 second-feet.

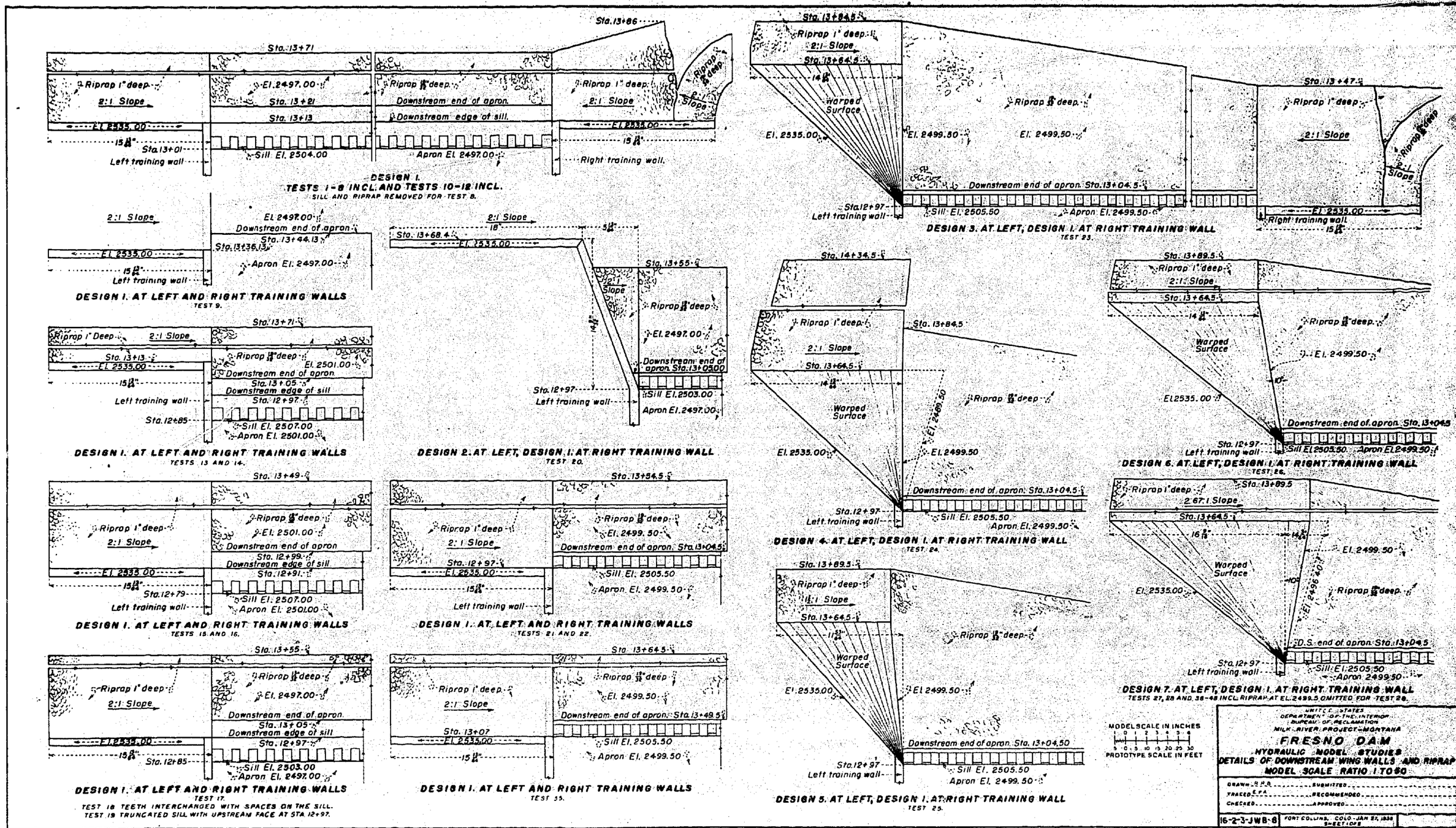
Design 5 - Truncated sill - steps on apron

FLOW CONDITIONS AND EROSION IN STILLING POOL OF 1:60
MODEL OF FRESNO DAM SPILLWAY - POOL DESIGNS 4 AND 5.

An effort was made to prevent the scour of the slope by changing the wing-wall design. A vertical wall was extended downstream at an angle of 20 degrees with the training wall, thence into the bank parallel to the end of the apron. The erosion was eliminated immediately below the left end of the sill, but a deep hole was dug at the downstream end of the wing-wall and it was not considered satisfactory. These investigations were temporarily deferred when the pool floor was raised to correspond with designs obtained from models tested previously.

Stilling Pool Design 5. The pool floor was raised 2-1/2 feet to elevation 2499.5, and the ends of the training walls kept at the same station as design 4 (design 5, Figure 13). This change effected a 3.75-foot increase in pool length at its entrance, which partially compensated for the decreased tailwater depth caused by raising the apron. The jump was not satisfactory and more erosion occurred (Figure 21D). The addition of the steps in the pool entrance gave a satisfactory jump with normal tailwater (Figure 21E), but even so, the erosion was only slightly decreased (Figure 21F). This design was considered satisfactory, providing some method was used to minimize the scour below the pool corners. As the wing-wall used with design 4 gave a minimum of erosion at the apron cutoff wall, pool design 5 was considered ample providing an effective wing-wall was included.

Original Design of Downstream Wing-walls to Stilling Pool. With the original design wing-walls (design 1, Figure 22), the erosion at the downstream corners of the stilling pool nearly reached the bottom of the 8-foot apron cutoff wall in several tests. The two areas of scour were always below the apron elevation, even though the area was riprapped with gravel representing from 12- to 30-inch material on the prototype. For this reason it was deemed advisable to determine the cause of the scour and to evolve a means for minimizing it. The worst conditions occurred at maximum discharge, so all tests were made with a flow of 51,000 second-feet. The duration of each run of the model tests at this discharge was fixed at three-quarters of an hour, since comparatively stable conditions were established in this length of time.

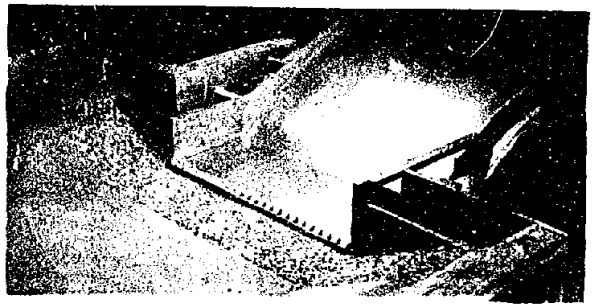


DESIGN 1.
TESTS 1-8 INCL. AND TESTS 10-12 INCL.
SILL AND RIPRAP REMOVED FOR TEST 8.
DESIGN 1. AT LEFT AND RIGHT TRAINING WALLS
TEST 9.
DESIGN 1. AT LEFT AND RIGHT TRAINING WALLS
TESTS 13 AND 14.
DESIGN 1. AT LEFT AND RIGHT TRAINING WALLS
TESTS 15 AND 16.
DESIGN 1. AT LEFT AND RIGHT TRAINING WALLS
TEST 17.
TEST 18 TEETH INTERCHANGED WITH SPACES ON THE SILL.
TEST 19 TRUNCATED SILL WITH UPSTREAM FACE AT STA. 12+97.
DESIGN 2. AT LEFT, DESIGN 1. AT RIGHT TRAINING WALL
TEST 20.
DESIGN 1. AT LEFT AND RIGHT TRAINING WALLS
TESTS 21 AND 22.
DESIGN 1. AT LEFT AND RIGHT TRAINING WALLS
TEST 35.
DESIGN 3. AT LEFT, DESIGN 1. AT RIGHT TRAINING WALL
TEST 23.
DESIGN 4. AT LEFT, DESIGN 1. AT RIGHT TRAINING WALL
TEST 24.
DESIGN 5. AT LEFT, DESIGN 1. AT RIGHT TRAINING WALL
TEST 25.
DESIGN 6. AT LEFT, DESIGN 1. AT RIGHT TRAINING WALL
TEST 26.
DESIGN 7. AT LEFT, DESIGN 1. AT RIGHT TRAINING WALL
TESTS 27, 28 AND 38-48 INCL. RIPRAP AT EL. 2499.5 OMITTED FOR TEST 28.
MODEL SCALE IN INCHES
PROTOTYPE SCALE IN FEET
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MILK RIVER PROJECT-MONTANA
FRESNO DAM
HYDRAULIC MODEL STUDIES
DETAILS OF DOWNSTREAM WING WALLS AND RIPRAP
MODEL SCALE RATIO 1 TO 50
DRAWN R.R.B. SUBMITTED
TRACED E.P.A. RECOMMENDED
CHECKED APPROVED
16-2-3-JWB-8
FORT COLLINS, COLO. JAN 27, 1938
SHEET 1 OF 2

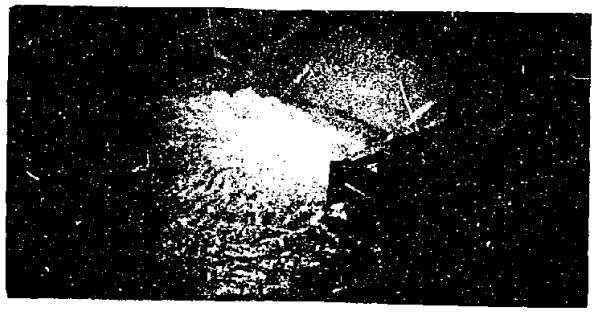
After investigating the flow conditions by injecting dye in the water downstream from the pool, the erosion was ascribed to currents which moved transversely from the pool corners along the apron immediately downstream from the sill. Apparently these currents were set up by the water moving into the low pressure area immediately downstream from the sill. These currents assisted the slowly moving back roll on the stream bed to deposit material against the downstream edge of the central portion of the sill (Figure 23A). More severe conditions existed at the left corner of the pool than at the right because of the slightly unbalanced flow conditions in the spillway chute. For this reason, and because of the necessity to expedite the work, tests were conducted on the left side only. Besides the undesirable erosion at the cutoff wall, there was a large eddy which destroyed the 2:1 riprapped excavated slope just downstream from the wing-wall. A design used successfully on a model of a similar structure led to a change in the wing-wall shape.

Downstream Wing-wall, Design 2. A vertical wall was extended 71.5 feet downstream at an angle of 20 degrees with the training wall, thence parallel to the end of the apron into the bank (design 2, Figure 22). This eliminated the erosion at the cutoff wall (Figure 23B), but an eddy, forming immediately downstream from the wing-wall, destroyed the 2:1 excavated slope and eroded a deep hole at the corner of the wall. A warped wall similar to that used on the Pilot Knob Wasteway was considered.

Downstream Wing-wall, Design 3. A warped wall was extended from vertical at the end of the main training wall to a 2:1 slope at a point 60 feet downstream from the end of the apron. The bottom streamward edge was level at elevation 2499.5, and extended downstream perpendicular to the end of the apron (design 3, Figure 22). The riprap along the streamward and downstream edges was moved by currents until both were exposed to a depth varying from 4 to 6 feet (Figure 23C). The eddy near the bank at the downstream edge of the wall was very small, so it was concluded that the riprapped surface was too steep. Most of the riprap moved from this area had rolled to the foot of the slope. The wall was altered in an attempt to prevent the erosion at its edges.

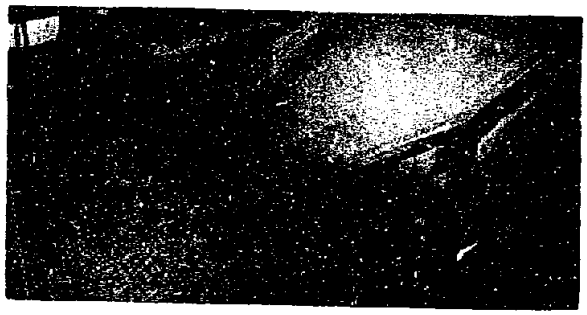


Before test

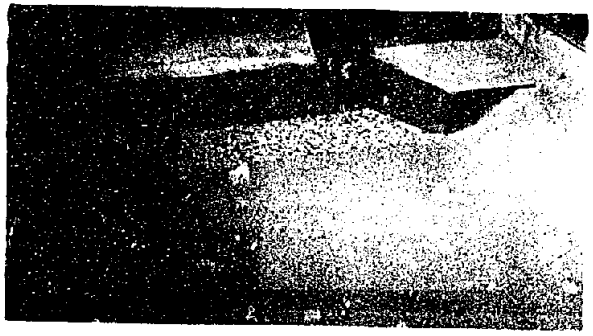


Discharge 51,000 second-feet

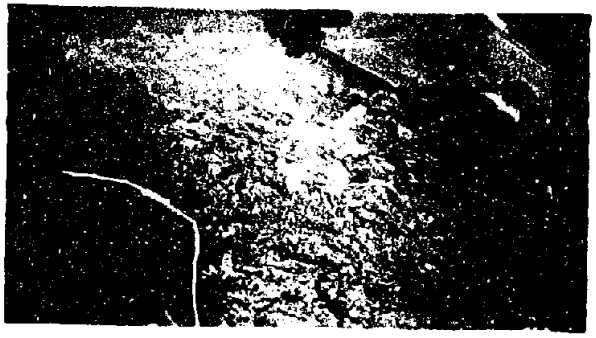
Original wing wall - Design 1



After test

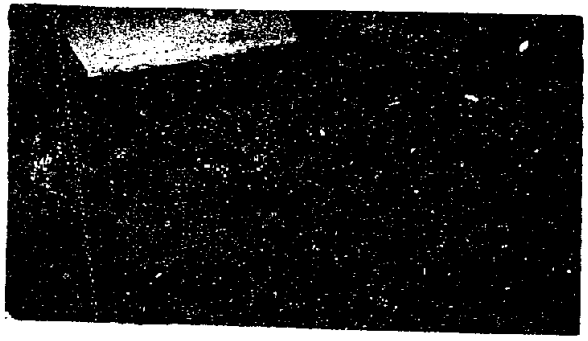


Before test

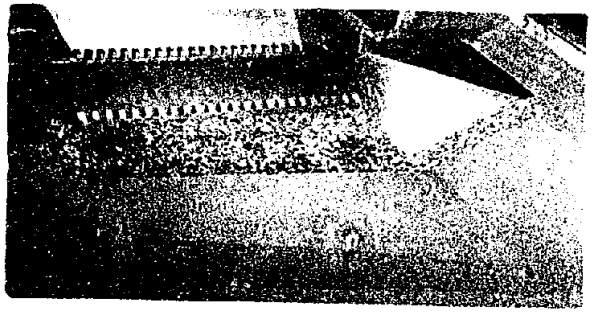


Discharge 51,000 second-feet

Vertical wing wall - Design 2



After test



Before test

Discharge 51,000 second-feet

Warped Wing Wall - Design 3

After test

FIGURE 23

FLOW CONDITIONS AND EROSION DOWNSTREAM FROM APRON OF 1:60 MODEL OF FRESNO DAM SPILLWAY WING WALL - DESIGNS 1, 2, AND 3.

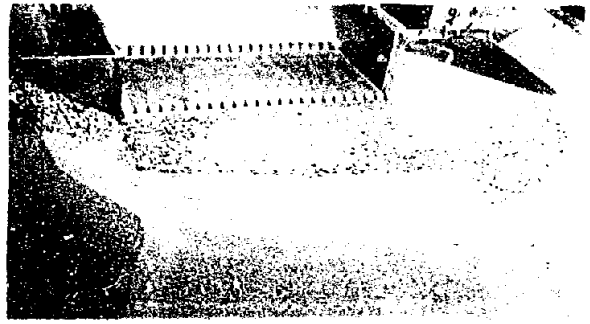
Downstream Wing-wall, Design 4. The edge of the warp in design 3 was extended downward to elevation 2489.5, and a wider band of riprap placed on the 2:1 slope (design 4, Figure 22). The depth of scour along the right edge of the warp was about the same as for design 3, but the condition immediately downstream from the left end of the sill was considerably improved (Figure 24A). Sand and riprap were deposited, instead of washed from this area. The downstream edge was exposed for a depth of about 3 feet, even with the wider band of riprap. The design was altered near the base for the next test.

Downstream Wing-wall, Design 5. The wall was extended from vertical at the downstream end of the training wall to a 1-1/2:1 slope at a point 60 feet downstream from the apron (design 5, Figure 22). The right edge flared outward at an angle of 5 degrees with the training wall. The flow conditions appeared the same as for design 5, but the erosion along the edges of the wall was considerably increased (Figure 24B).

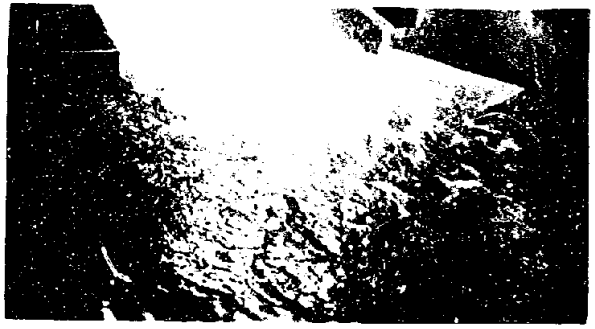
Downstream Wing-wall, Design 6. The edge at the base of the warp was flared 10 degrees outward from the training wall and the downstream edge placed on a 2:1 slope (design 6, Figure 22). The flow conditions were similar to those for the designs previously tested and were considered satisfactory (Figure 24C). However, the erosion was practically the same as for design 3 and the warp was again altered.

Downstream Wing-wall, Design 7. The wall was extended from the vertical at the end training wall to a 2.67:1 slope at its downstream end (design 7, Figure 22). The base of the warp at elevation 2499.5 flared at an angle of 10 degrees from the end of the training wall toward the centerline of the pool and extended down to elevation 2496.4. Flow conditions were comparable with those for previous designs and the maximum erosion along the base of the wall was about 3 feet below the apron (Figure 25A and B). Only a slight portion of the downstream edge of the wing-wall was exposed to a depth of about 2.5 feet. This wall was considered satisfactory, but the warp was changed because most of the riprap was washed from the downstream right corner, and and without riprap in this area in a previous similar test the erosion increased considerably.

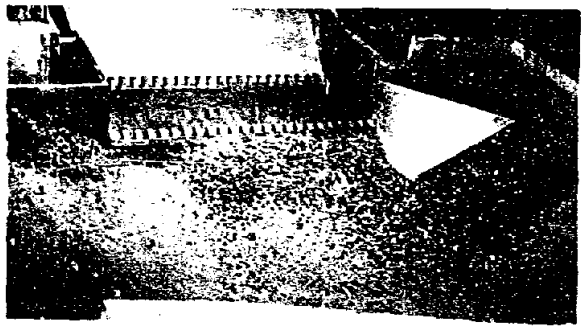
Downstream Wing-wall, Design 8. The warp was extended from vertical at the downstream end of the training wall to a 2.34:1 slope at a distance of 60 feet downstream from the end of the apron (design 8, Figure 26). The streamward edge with its downstream end at elevation 2494.5 converged at an angle of 10 degrees from the end of the training wall toward the center line of the pool. The erosion along the right edge was about 9 feet below the apron elevation and some of the downstream edge was exposed to a depth of about 2.5 feet (Figure 25D). Without riprap the erosion along the base of the wall was practically the same.



Before test

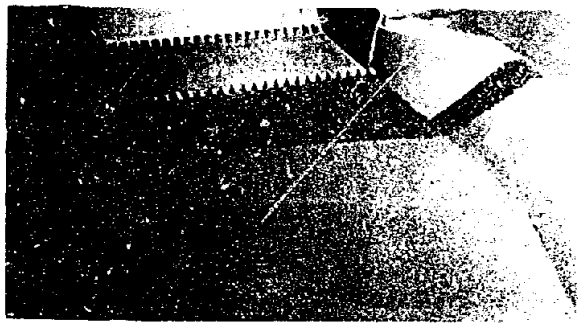


Discharge 51,000 second-feet

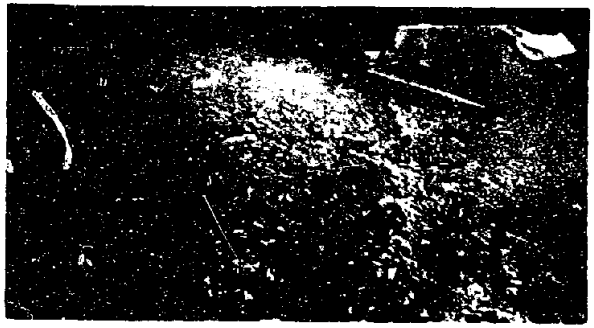


After test

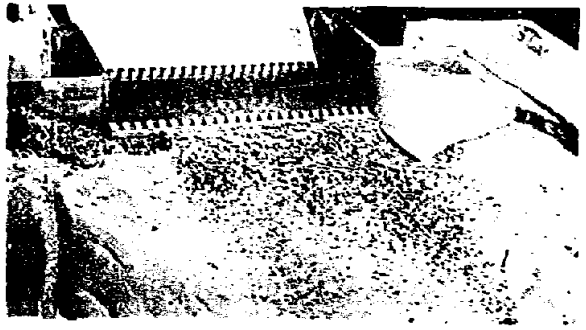
Warped wing wall - Design 4



Before test



Discharge 51,000 second-feet

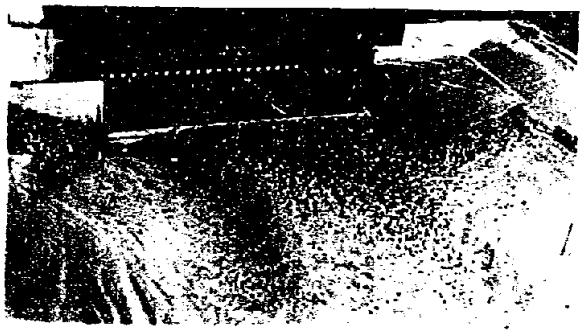


After test

Warped wing wall - Design 5

Before test

Discharge 51,000 second-feet

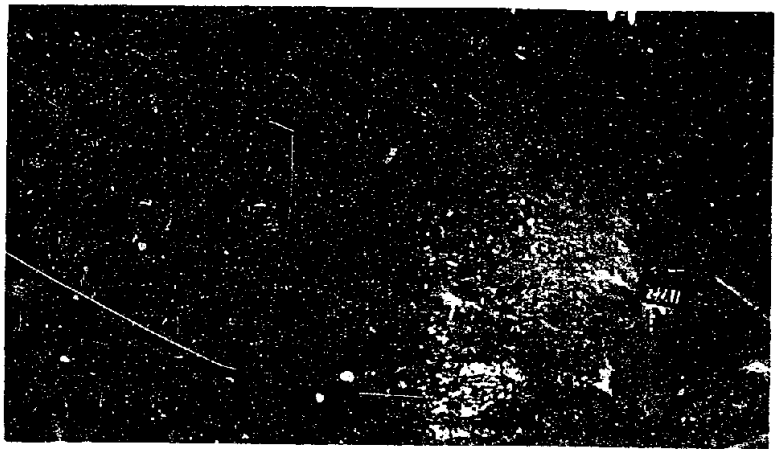


After test

Warped wing wall - Design 6

FIGURE 24

FLOW CONDITIONS AND EROSION DOWNSTREAM FROM APRON OF 1:60 MODEL OF FRESNO DAM SPILLWAY WING WALL - DESIGNS 4, 5, AND 6.



A - Design 7 - Discharge 51,000 second-feet.

B - Erosion after discharge of 51,000 second-feet.

Downstream wing wall - Design 7

C - Before test

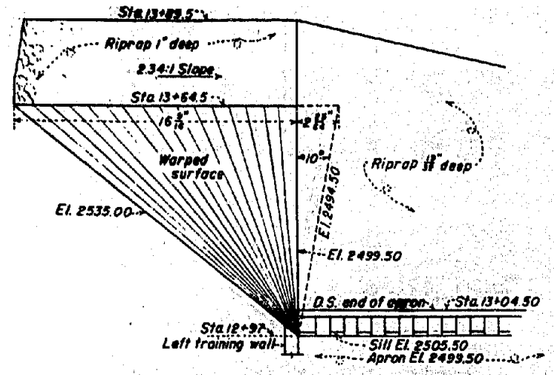
D - Erosion after discharge of 51,000 second-feet.

Downstream wing wall - Design 8

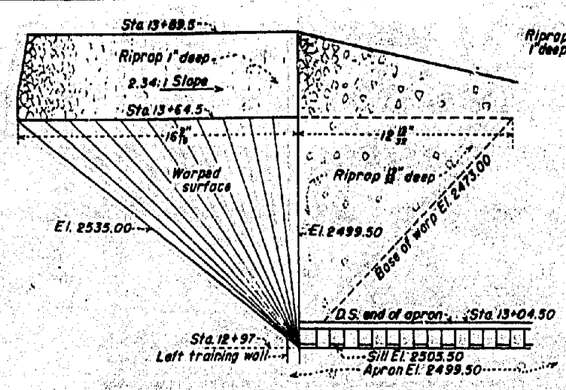
FLOW CONDITIONS AND EROSION DOWNSTREAM FROM APRON OF 1:60 MODEL OF FRESNO DAM SPILLWAY - WING WALL - DESIGNS 7 AND 8.

FIGURE 25

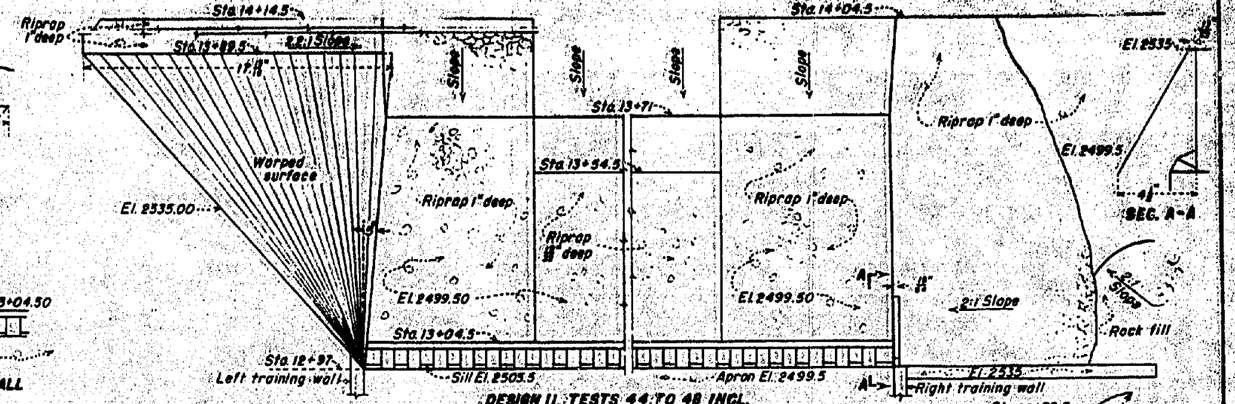
FIGURE 25



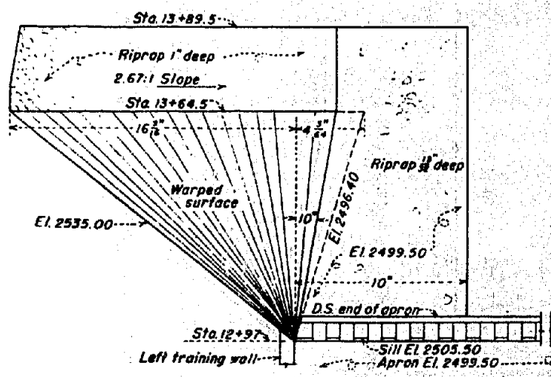
DESIGN 8, AT LEFT, DESIGN 1, AT RIGHT TRAINING WALL
TEST 29 AND 30. RIPRAP AT EL. 2499.5 OMITTED FOR TEST 29

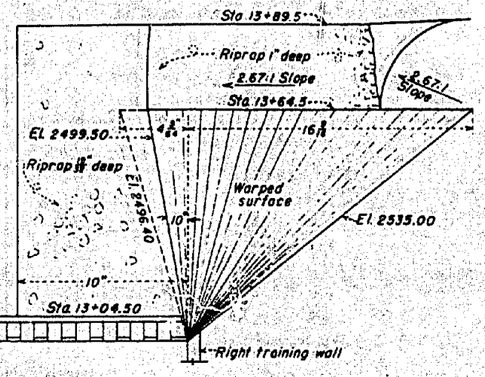


DESIGN 9 AT LEFT, DESIGN 1 AT RIGHT TRAINING WALL
TEST 31

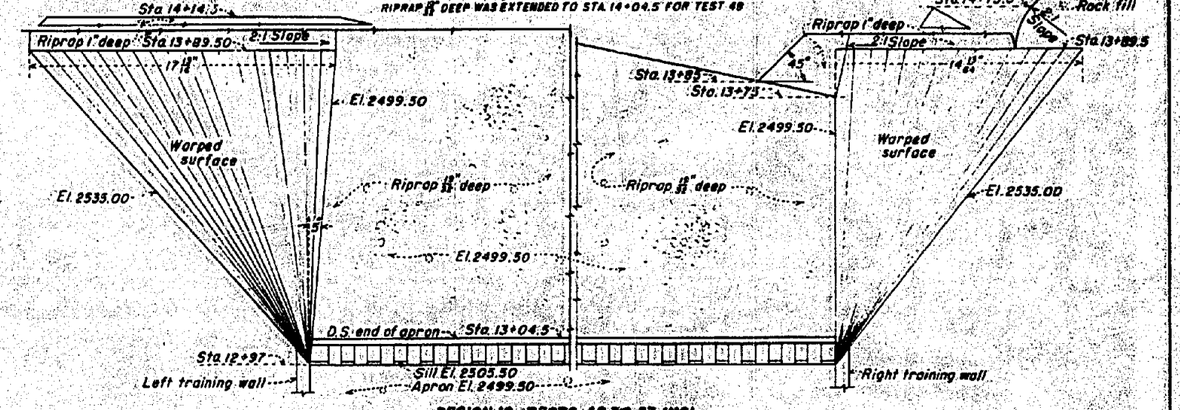


DESIGN 11, TESTS 44 TO 48 INCL.
RIPRAP 13/32" DEEP WAS EXTENDED TO STA. 14+04.5 FOR TEST 48

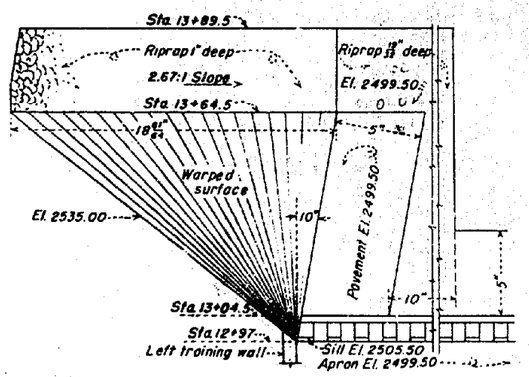




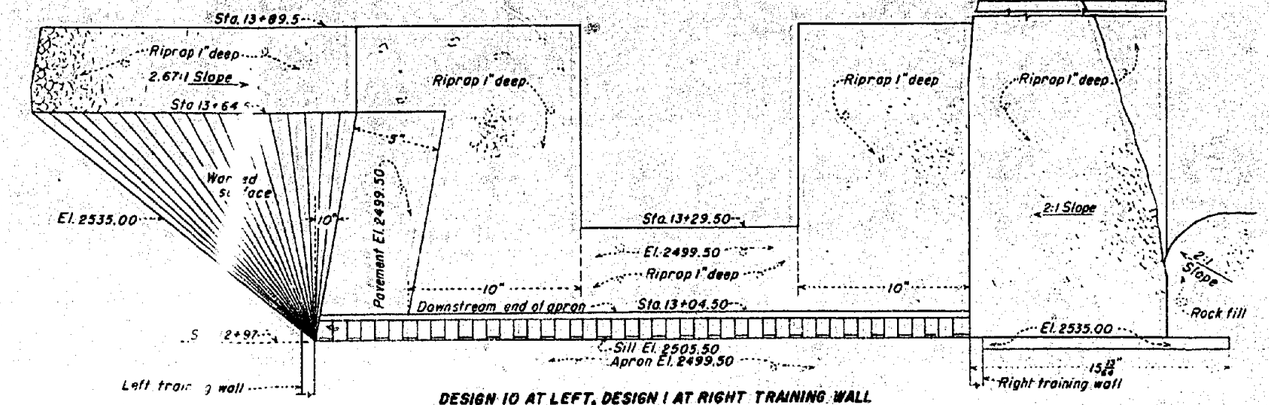
DESIGN 7, AT LEFT AND RIGHT TRAINING WALLS
TEST 32



DESIGN 12, TESTS 49 TO 53 INCL.
TESTS 51 TO 53 INCL. RIPRAP INSTALLED AS SHOWN ON DRAWING 16-2-3 JWB 15



DESIGN 10 AT LEFT, DESIGN 7, AT RIGHT TRAINING WALL
TESTS 33 AND 34



DESIGN 10 AT LEFT, DESIGN 1 AT RIGHT TRAINING WALL
TESTS 36 AND 37

MODEL SCALE IN INCHES
PROTOTYPE SCALE IN FEET

UNITED STATES
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MILK RIVER PROJECT—MONTANA

FRESNO DAM
HYDRAULIC MODEL STUDIES
DETAILS OF DOWNSTREAM WING WALLS AND RIPRAP
MODEL SCALE RATIO 1 TO 60

DRAWN R.P.S. SUBMITTED
TRACED B.A.P. RECOMMENDED
CHECKED APPROVED

16-23-JWB-16 FORT COLLINS, COLORADO FEB 2, 1938
SHEET 2 OF 2

Downstream Wing-wall, Design 9. The base of the warp was extended, as in previous tests (design 9, Figure 26). The conditions at the downstream edge were very desirable, but the maximum depth along the base was about 7 feet below the apron elevation.

Downstream Wing-wall, Designs 10, 11 and 12. Since deep erosion occurred along the streamward edge of the left warp in the previous tests this area was paved (design 10, Figure 26). The pavement eliminated all scour except that along the downstream edge of the warp and the downstream edge of the pavement. This indicated that the warp and pavement were both too short, especially with the flow concentrated on the left side of the pool.

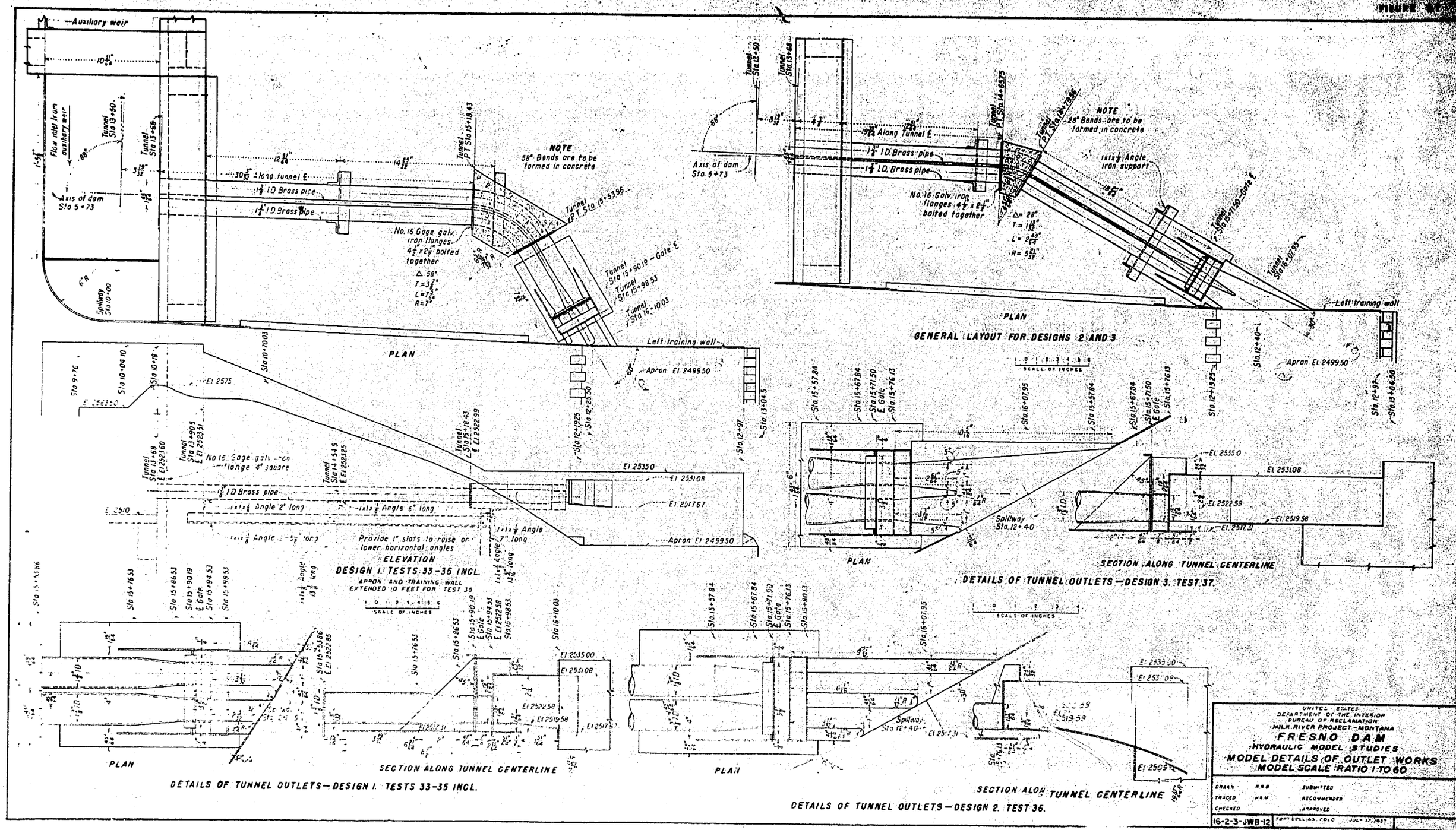
Other tests were made in which the warp was lengthened (designs 11 and 12, Figures 26). These did not prove satisfactory.

The Recommended Design of Downstream Wing-walls. The results thus far had not produced a solution for the downstream wing-walls. It was decided that design 7 was the most desirable so this design was installed again on both downstream corners of the model and more extensive tests performed. The maximum discharge was maintained on the model for 45 minutes. The conditions during and at the end of this run were very desirable. Practically no material was moved downstream from the apron with a discharge of 45,000 second-feet or less. The change was attributed to the improvement of flow conditions resulting from the installation of the warp at the end of the right training wall. Design 7 was therefore recommended.

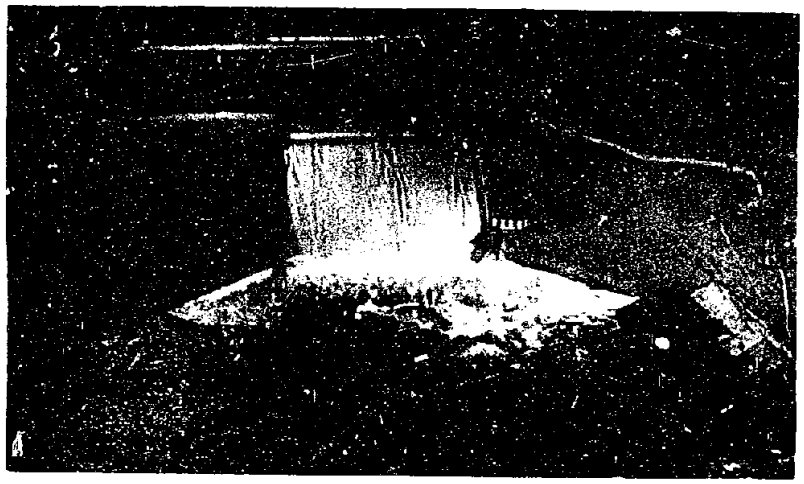
Original Design Outlet Works. The original design outlets were installed in the left training wall (design 1, Figure 27), and the spillway and outlets operated at full capacity. Erosion of the riprapped surface at the right edge of the pavement on the left warp occurred to a maximum depth of 5.4 feet below the pavement.

Return flow was apparent downstream from both wing-walls, however, it was much more pronounced downstream from the left wall causing excessive erosion, damaging the 2:1 riprapped slope (Figure 28B).

Outlet Works, Design 2. The angle of the centerline of the outlets with that of the spillway was changed from 60 to 30 degrees to ascertain if some of the erosion and back flow could be eliminated (Figure 27).

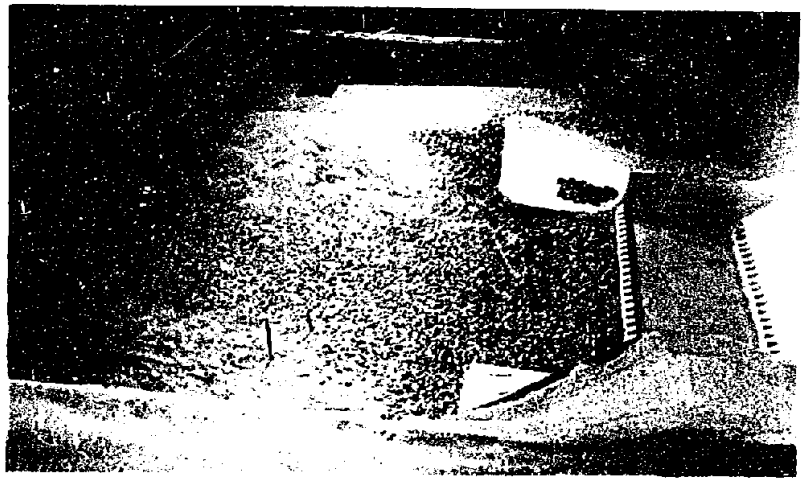


Auxiliary weir
Flow inlet from auxiliary weir
Axis of dam Sta 5+73
Spillway Sta 10+00
NOTE
58° Bends are to be formed in concrete
No. 16 Gage galv. iron flanges 4½" x 2½" bolted together
Tunnel Sta 15+90.19 - Gate ℄
Tunnel Sta 15+98.53
Tunnel Sta 16+10.03
Left training wall
Apron El. 2499.50
PLAN
Along Tunnel ℄
1⅛" I.D. Brass pipe
No. 16 Galv. iron flanges 4½" x 2½" bolted together
NOTE
28° Bends are to be formed in concrete
1x1x⅛ Angle iron support
Tunnel Sta 15+71.50 - Gate ℄
Tunnel Sta 16+07.95
Apron El. 2499.50
GENERAL LAYOUT FOR DESIGNS 2 AND 3
SCALE OF INCHES
No. 16 Gage galv. iron flange 4" square
1⅛" I.D. Brass pipe
1x1x⅛ Angle 2" long
1x1x⅛ Angle 6" long
1x1x⅛ Angle 7" long
Provide 1" slots to raise or lower horizontal angles
ELEVATION
DESIGN 1. TESTS 33-35 INCL.
APRON AND TRAINING WALL EXTENDED 10 FEET FOR TEST 35
SECTION ALONG TUNNEL CENTERLINE
DETAILS OF TUNNEL OUTLETS—DESIGN 1. TESTS 33-35 INCL.
Spillway Sta 12+40
SECTION ALONG TUNNEL CENTERLINE
DETAILS OF TUNNEL OUTLETS—DESIGN 3. TEST 37.
SECTION ALONG TUNNEL CENTERLINE
DETAILS OF TUNNEL OUTLETS—DESIGN 2. TEST 36.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MILK RIVER PROJECT - MONTANA
FRESNO DAM
HYDRAULIC MODEL STUDIES
MODEL DETAILS OF OUTLET WORKS
MODEL SCALE RATIO 1 TO 60
DRAWN R.R.B.
TRACED H.A.M.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
16-2-3-JWB-12
FORT COLLINS, COLO.
JULY 17, 1937

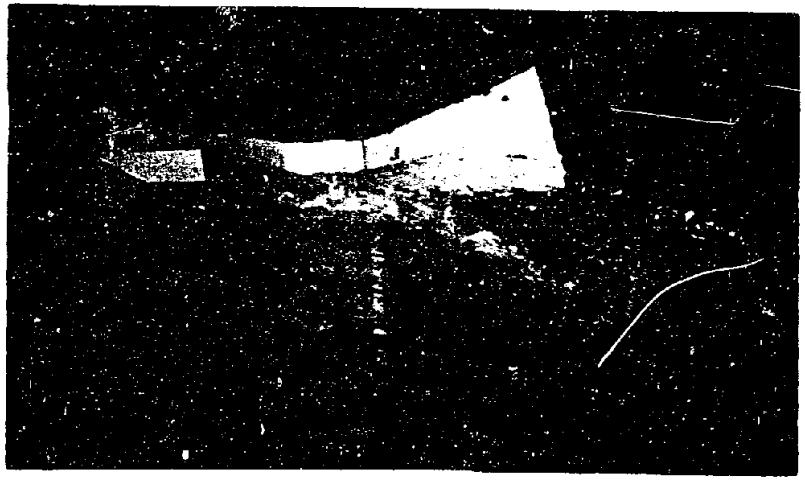


A - Maximum discharge over spillway and through tunnels

B - Erosion caused by maximum discharge over spillway and through tunnels.



C - Erosion caused by maximum discharge over spillway and through tunnels



D - Both tunnels discharging full capacity

FLOW CONDITIONS AND EROSION DOWNSTREAM FROM APRON OF 1:60 MODEL OF FRESNO DAM SPILLWAY - ALL RECOMMENDED FEATURES INCLUDED.

FIGURE 28

The erosion was decreased and the backflow improved considerably. It was felt that minor changes in the floor and pier of the outlet channel would give additional improvement, and changes to these parts of the structure were investigated.

Outlet Works, Design 3. The center pier was shortened and the floor of the outlet tunnel altered for the next design (design 3, Figure 27). The shortening of the center pier caused the water from the two outlet pipes to unite into one jet before reaching the opening in the training wall. This flat sheet of water passed over the sill at a distance of 25 feet from the training wall and caused some erosion at the end of the apron (Figure 29.). This erosion was not serious and the arrangement for the outlet tunnels was considered satisfactory.

General Crest Study Concerning the Effect of the Elevation of the Approach and Downstream Floor on the Discharge Coefficient of a Crest. In view of the effect of the chute floor elevation on the discharge of the Fresno Spillway, the design section desired a series of tests to obtain data for use in the designing of crests having shallow approaches and downstream channels. These data were for the purpose of determining the elevation of the channel floor, both upstream and downstream of the crest, that would give the effect of a change in floor elevation on the coefficient of discharge.

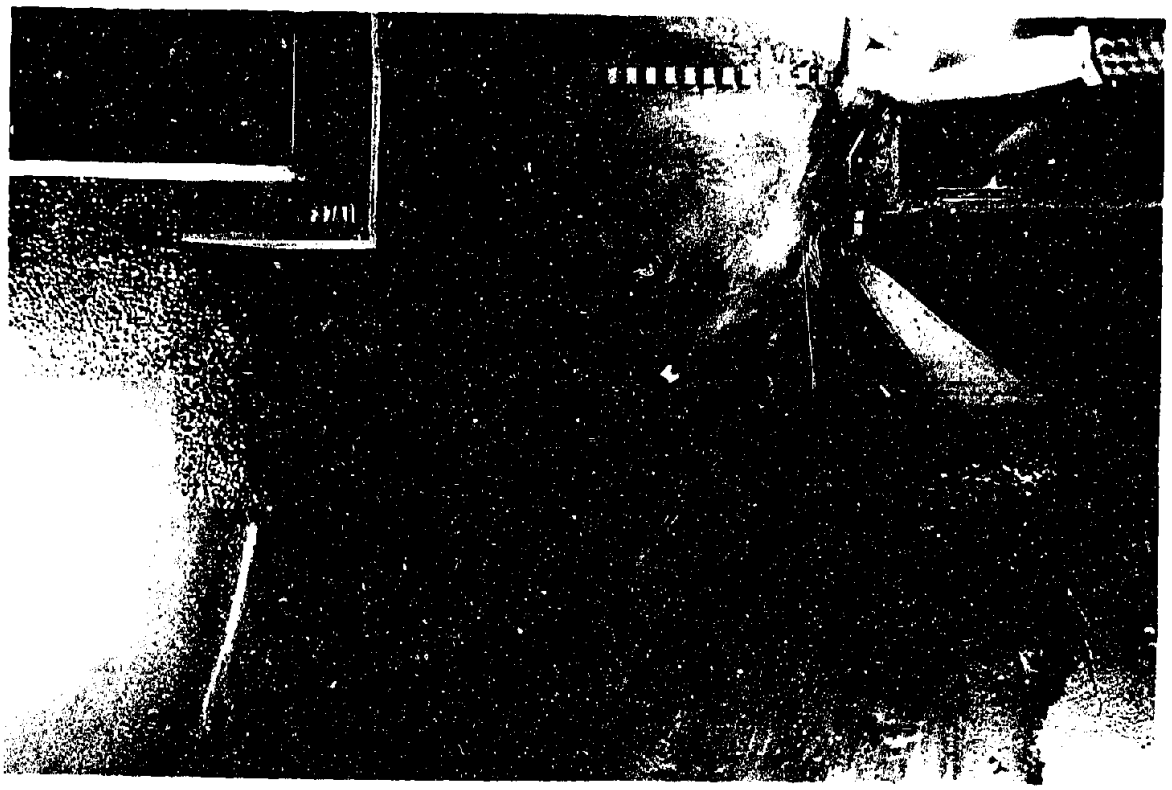
This study was performed using a crest similar to the 1 to 60 model of the Fresno Dam Spillway crest. The data taken during the study was compiled and graphs of the results prepared (Figures 30 and 31).

One graph (Figure 30) gives the coefficient of discharge for various heads and floor elevations upstream, and the variation of the coefficient with channel floor elevation for constant heads of 12 and 16 feet.

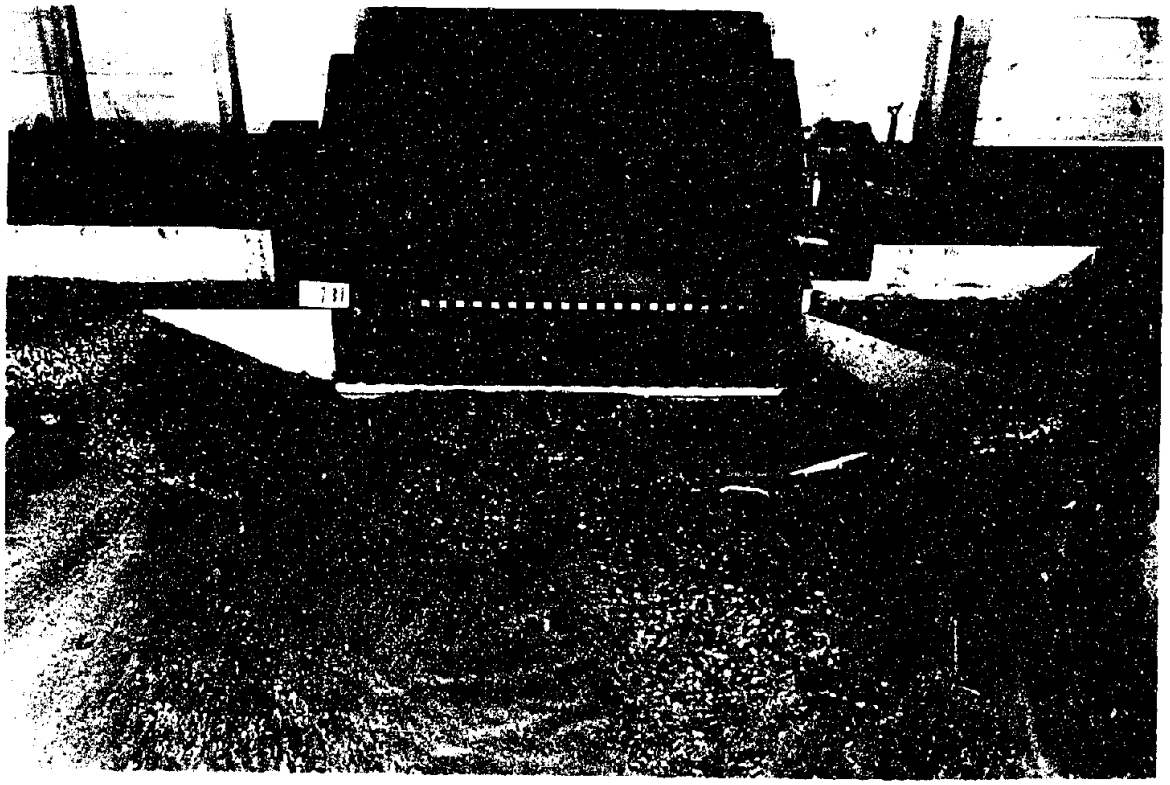
The second graph (Figure 31) shows the discharge coefficient for various heads and downstream floor elevations and the variation of the coefficient with floor elevation for a constant head of 16 feet. This study was continued on a broader scope and the results are contained in Hydraulic Laboratory Report HYD 118, by J. N. Bradley, dated December 31, 1942.

CONCLUSIONS AND RECOMMENDATIONS

Left Wing-wall. The originally designed left wing-wall to the spillway entrance, vertical and curved toward the bank on a 30-foot

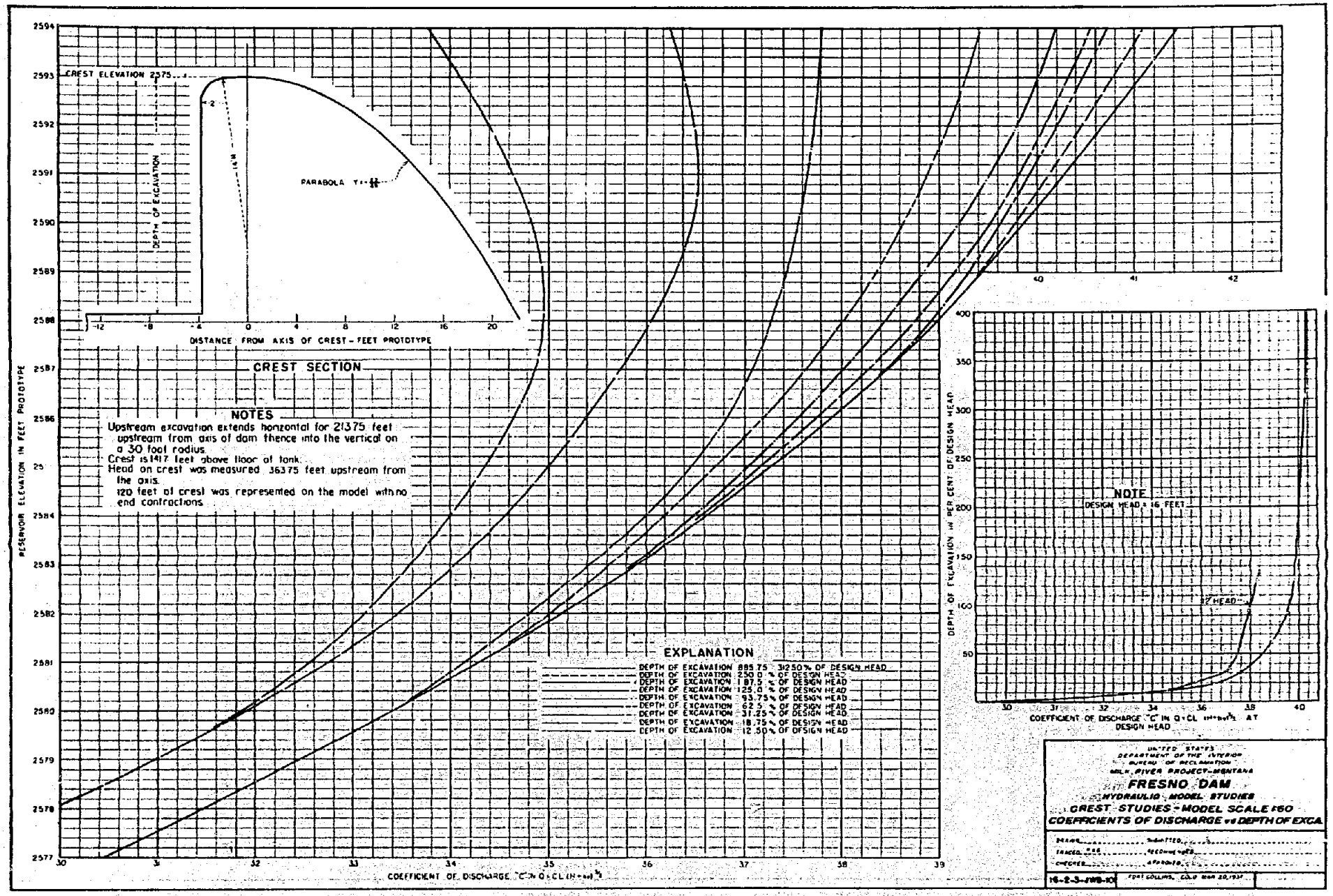


A - Tunnel outlets discharging 2500 second-feet, flow lines shown by confetti.



B - Erosion caused by discharge of 2500 second-feet.

FLOW LINES AND EROSION IN STILLING POOL OF 1:60 MODEL OF FRESNO DAM SPILLWAY - RECOMMENDED DESIGN OUTLET WORKS.


CREST ELEVATION 2575
DEPTH OF EXCAVATION
PARABOLA
DISTANCE FROM AXIS OF CREST - FEET PROTOTYPE
CREST SECTION
NOTES
Upstream excavation extends horizontal for 21375 feet upstream from axis of dam thence into the vertical on a 30 foot radius.
Crest is 1417 feet above floor of tank.
Head on crest was measured 36375 feet upstream from the axis.
120 feet of crest was represented on the model with no end contractions.
RESERVOIR ELEVATION IN FEET PROTOTYPE
COEFFICIENT OF DISCHARGE "C" IN Q=CL
EXPLANATION
DEPTH OF EXCAVATION 885.75 - 312.50% OF DESIGN HEAD
DEPTH OF EXCAVATION 250.0 % OF DESIGN HEAD
DEPTH OF EXCAVATION 187.5 % OF DESIGN HEAD
DEPTH OF EXCAVATION 125.0 % OF DESIGN HEAD
DEPTH OF EXCAVATION 93.75% OF DESIGN HEAD
DEPTH OF EXCAVATION 62.5 % OF DESIGN HEAD
DEPTH OF EXCAVATION 31.25% OF DESIGN HEAD
DEPTH OF EXCAVATION 18.75% OF DESIGN HEAD
DEPTH OF EXCAVATION 12.50% OF DESIGN HEAD
NOTE
DESIGN HEAD = 16 FEET
DEPTH OF EXCAVATION IN PER CENT OF DESIGN HEAD
COEFFICIENT OF DISCHARGE "C" IN Q=CL AT DESIGN HEAD
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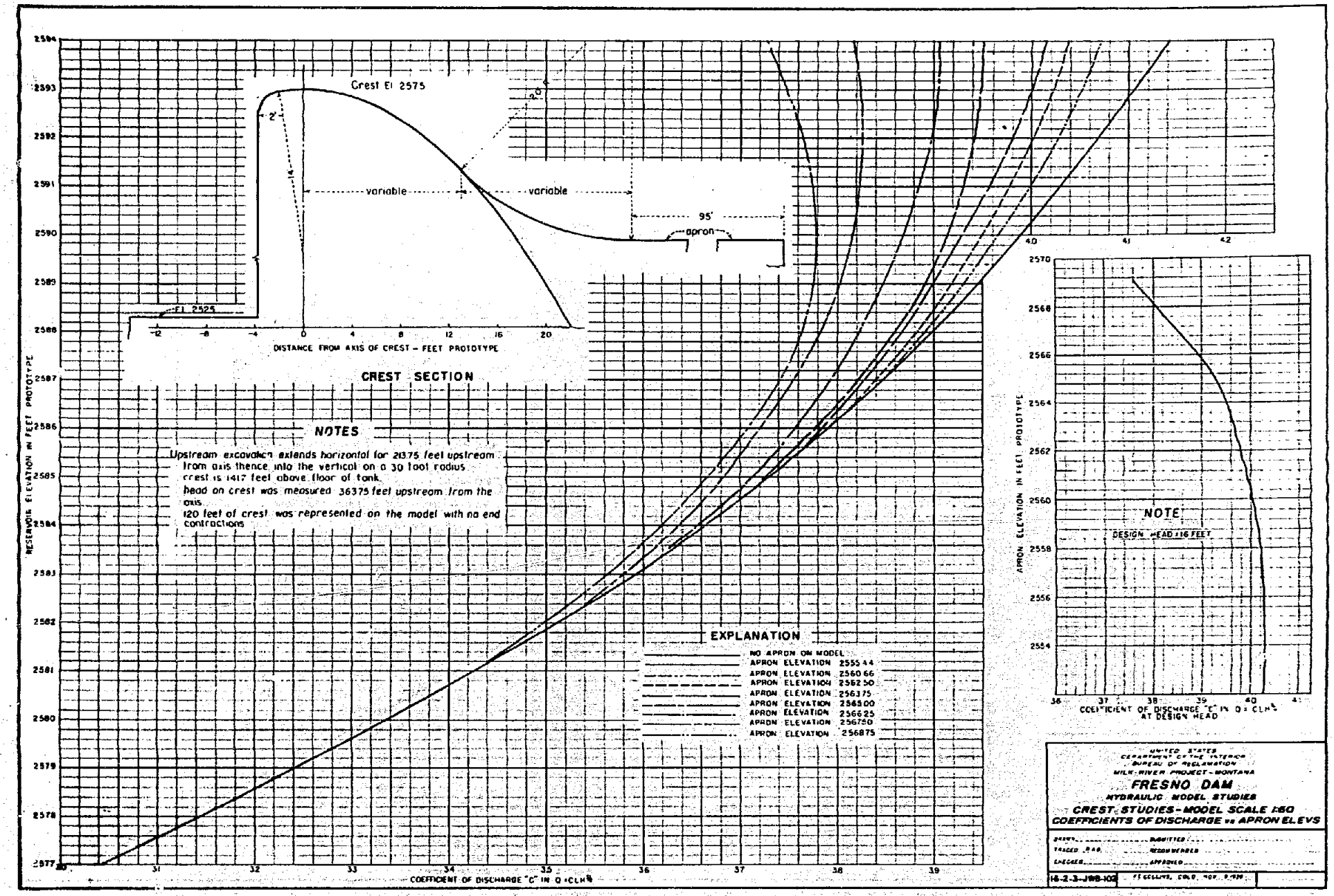
FRESNO DAM
HYDRAULIC MODEL STUDIES
CREST STUDIES - MODEL SCALE 1:60
COEFFICIENTS OF DISCHARGE vs DEPTH OF EXCA.
16-2-3-JWB-10
FORT COLLINS, COLO MAR 20, 1937

FIGURE 30



Crest El 2575
2'
14'
20'
variable
variable
95'
apron
El 2525
-12
-8
-4
0
4
8
12
16
20
DISTANCE FROM AXIS OF CREST – FEET PROTOTYPE
CREST SECTION
NOTES
Upstream excavation extends horizontal for 213.75 feet upstream from axis thence into the vertical on a 30 foot radius
crest is 141.7 feet above floor of tank.
head on crest was measured 363.75 feet upstream from the axis.
120 feet of crest was represented on the model with no end contractions
RESERVOIR ELEVATION IN FEET PROTOTYPE
2594
2593
2592
2591
2590
2589
2588
2587
2586
2585
2584
2583
2582
2581
2580
2579
2578
2577
30
31
32
33
34
35
36
37
38
39
40
41
42
COEFFICIENT OF DISCHARGE "C" IN Q = CLH%
EXPLANATION
NO APRON ON MODEL
APRON ELEVATION 2555.44
APRON ELEVATION 2560.66
APRON ELEVATION 2562.50
APRON ELEVATION 2563.75
APRON ELEVATION 2565.00
APRON ELEVATION 2566.25
APRON ELEVATION 2567.50
APRON ELEVATION 2568.75
APRON ELEVATION IN FEET PROTOTYPE
2570
2568
2566
2564
2562
2560
2558
2556
2554
NOTE
DESIGN HEAD = 16 FEET
36
37
38
39
40
41
COEFFICIENT OF DISCHARGE "C" IN Q = CLH%
AT DESIGN HEAD
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MILK RIVER PROJECT – MONTANA
FRESNO DAM
HYDRAULIC MODEL STUDIES
CREST STUDIES – MODEL SCALE 1:60
COEFFICIENTS OF DISCHARGE vs APRON ELEVS
DRAWN
SUBMITTED
TRACED R.A.B.
RECOMMENDED
CHECKED
APPROVED
16-2-3-JWB-102
FT. COLLINS, COLO. NOV. 9, 1939

radius, will give very satisfactory flow conditions for all spillway discharges. There will be no undesirable scouring of the approach channel to endanger the upstream cutoff wall, especially with the upstream topography riprapped as shown in the specification drawing (Figure 2.). It was therefore recommended that the original shape of this wall be retained.

Right Wing-wall. The adverse flow conditions, which caused deep erosion adjacent to the wall and upstream from the crest, made the original design of the right wall unsatisfactory. Of the different shapes tested in the laboratory design 5, Figure 7 was the most desirable. As erosion of the approach channel was negligible (Figure 9C), and very little disturbance occurred on the water surface near the wall, design 5 was recommended for the right end of the Fresno Spillway. This design was used on the prototype structure (Figure 3).

Crest. Lowering the floor of the original chute just downstream from the crest two feet gave the discharge desired. It is believed that additional lowering of the floor would increase the discharge, but due to added costs in excavation, this was considered unnecessary. The coefficient of discharge curve is shown in Figure 32.

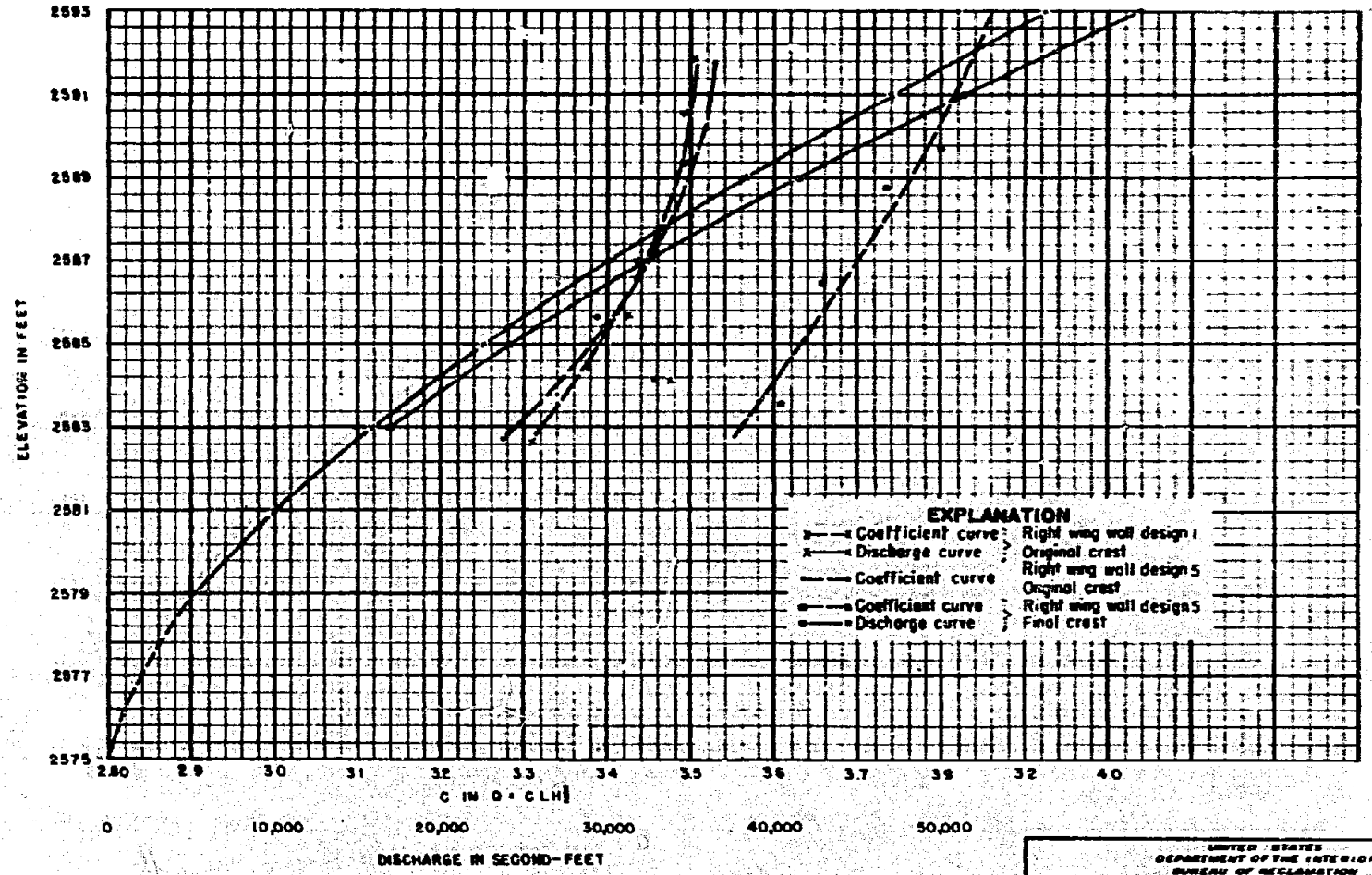
Stilling Pool. The original pool, with the Rehbock sill and stepped apron, was deeper than necessary for all flows.

Pool design 2 was too shallow as well as too short for discharges near the maximum, but was very satisfactory for discharges of 40,000 second-feet and less. The erosion near the downstream corners was undesirable because it moved material away from the apron cutoff wall.

Further shortening of the pool (6 feet), as in design 3, did not improve conditions.

The short pool with floor elevation 2,497, design 4, was satisfactory, except for the erosion along the apron cutoff wall. The change in sill design, truncating it and placing its upstream face at the same station as the ends of the training walls improved the pool appearance as well as decreased the erosion.

Pool design 5, with the apron at elevation 2,499.5 and lengthened 3.75 feet from design 4, was satisfactory when the steps were installed at the upstream end of the pool, and when a wing-wall was placed



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MILK RIVER PROJECT—MONTANA

FRESNO DAM

HYDRAULIC MODEL STUDIES
DISCHARGE COEFFICIENTS & DISCHARGE CURVES
MODEL SCALE 1:60

DRAWN RRB SUBMITTED
TRACED DVA RECOMMENDED
CHECKED APPROVED

16-2-3-JUN-6 FORT COLLINS, COLO MARCH 30, 1937

FIGURE 32

downstream from the left training wall. It was therefore recommended that this pool design, including the sill, or one of similar construction (Figure 7, test 22, design 5), be adopted for the Fresno Spillway, and that additional studies be made to determine a more desirable design for the downstream wing-walls. Design 5 was used in the prototype structure.

The apron length referred to in this report is the distance from the intersection of the pool floor with the entrance slope, to the end of the apron. The pool length is defined as the distance from the upstream face of the sill to the intersection of the floor with the entrance slope.

Downstream Wing-walls. The original design wing-walls allowed excessive scour to occur along the apron cutoff wall, near the corners of the pool at the maximum discharge. Also, the large return flow, or eddy, which formed immediately downstream from these walls, would destroy the excavated slopes and possibly damage the walls. A vertical wall similar to design 2, Figure 22, would probably be quite expensive because of the large foundation required, and would possibly be damaged by undermining at the downstream corner. Design 7 was the most satisfactory of the warped walls. It should give ample protection to the excavated slope and the apron cutoff. It does not seem necessary to place as much riprap downstream from the apron as in the vicinity of the wing-walls. The depth of the riprap should be 5 feet in the critical areas. It was suggested that the riprap be placed as shown for design 7, Figure 25, and this design was used.

It is believed that the erosion of the excavated slopes on the model is more severe relatively than that which will occur on the prototype. The shale material on the prototype and its compactness should prevent excessive erosion.

Outlet Works. The original design outlet works was found to be unsatisfactory. The jets from the outlets struck the flow from the spillway, ejecting some of the water from the left corner of the pool, causing an eddy to form. This condition was very serious for it would cause the right wing wall to be undermined. Changing the angle with the center line of the spillway from 60 to 30 degrees and using a

level floor in the outlet channel minimized this condition, and design 3, Figure 27, was recommended and used for the prototype structure.

- - -