UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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MEMORANDUM TO CHIEF DESIGNING ENGINEER

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# HYDRAULIC MODEL STUDIES FOR THE DESIGN OF THE MARSHALL FORD DAM

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Denver, Colorado
February 1, 1937

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DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
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MEMORANDUM TO ASSISTANT CHIEF DESIGNING ENGINEER
(J. E. Warnock and J. W. Ball)

Subject: Hydraulic model studies for the design of the Marshall Ford Dam.

1. Introduction.- When a project involves the construction of two separate structures, as in the case of the initial and ultimate development of the Marshall Ford Dam, many features of the first structure must be designed for the more severe conditions encountered in the second. Two such features on the Marshall Ford Dam, outstanding from the hydraulic standpoint, are the training walls and the stilling pool. It was mainly for the purpose of determining the best design of these two features that a sectional model of the ultimate development was constructed at the Fort Collins laboratory.

The first plans of the ultimate development provided a 730-foot (gross length) uncontrolled overfall spillway; a siphon spillway, consisting of 28 individual siphons; and a set of 24 sluice conduits, for handling floods. These three methods of flood regulation combined in one structure made the stilling pool problem complicated and except for the siphons, pointed to the construction of a model which would include as much of the prototype as possible. The less-than-atmospheric pressure, present in siphon action, made a larger model more desirable so a sectional model on a scale ratio of 1:40.8 was built, figure 1. It included four siphons, four sluices, 105 feet of prototype crest and required a flow about equal to the maximum capacity of the laboratory pump.

2. The Model.- A metal lined tank 11 feet long, 2 feet 6-7/8 inches wide and 8 feet deep was connected by a flange to one of the 24-inch conduits of the laboratory supply system. The upstream face of the model dam was installed at one end of the tank. The model under-structure was a framework of welded angle iron surmounted by 16-gage galvanized iron bents shaped

nearly to the crest outline. A covering of 20-gage sheet metal gave the final shape of the model dam. An apron of sheet iron was fastened to the floor and soldered to the model understructure. The flume, which contained the sand bed and apron, extended 105 feet beyond the end of the apron. Glass panels were installed along one side to aid in visual studies as well as to facilitate photographing the stilling pool in action. The wooden tailwater regulator, which was a gate hinged at the bottom, extended the full width of the flume. Regulation was obtained by a windlass and ratchet mounted across the top of the flume. The metal siphons were attached to the model face by flanges. The parabolic curved sluice conduits were shaped from commercial brass tubing, the inside diameter (2½ inches) determined the model scale ratio. The tubes were soldered at the downstream end and were held in place by flanges at the upper end. Each tube was provided with a bell-shaped entrance, figure 2.

## TEST ON PRELIMINARY DESIGN STILLING POOL

3. Initial Tests.- Preliminary observations on the model with the original design of apron shown on figure 2, consisting mainly of visual tests, were made during the second week of December 1936. Very rough flow, attributed to the siphon jets, resulted. However, the siphons were eliminated from the design before organized testing of the model began, so test 1, and all subsequent tests were conducted accordingly.

The crest and sluices were calibrated individually and collectively to ascertain the prototype quantity represented on the model. Coefficient and discharge curves were prepared from these calibration data, figures 3 and 4. A study of these curves shows a reduced discharge through the sluices with flows over the crest. This reduction was attributed to the back pressures exerted on the exits of the sluice conduits by the spillway jet. Three possible operating conditions were studied; the sluices discharging alone, the sluices and crest discharging together and the crest discharging alone.

4. Sluices Discharging Alone.- Very satisfactory conditions prevailed in the pool, with normal tailwater, when various quantities were passed through the sluices only, plate 1. The remote possibility of always operating all sluices at the same time with a low reservoir elevation led to further tests, in which an attempt was made to determine a satisfactory procedure for setting the sluiceways in operation when the reservoir surface was near the crest elevation. Sluice 1, nearest the powerhouse, was operated with a minimum tailwater to simulate conditions when opened with no flow in the river below the dam. At 5,000 second-feet the jet swept down the apron over the sill and excessively scoured the river-bed immediately downstream from the sill, plate 2. A dentated

sill was placed on the apron. Slight improvement was noted and a complete set of tests with various discharges and normal tailwater were made. A discharge of 2,000 second-feet gave conditions which, although not serious were not altogether desirable. The return flow on the apron, from the right crowded the jet against the wall of the model where rough conditions, with considerable splash resulted. Although the jet continued downstream over the sill, very little erosion was noted in the stream bed, plate 3. Sand was deposited on the apron to the right of this sluice. Discharges of 3,000 and 4,000 second-feet gave considerably worse conditions with excessive erosion immediately below the sill and more sand deposited on the apron, plate 4. Conditions were practically the same for sluices 1 and 2 discharging, plate 5. Three sluices operating improved conditions. However, the improvement may not be representative because of the narrowness of the model; also, some of the change was probably due to the deeper tailwater. A visual test with the two center sluices on the model operating gave fairly good results and it was believed that a systematic operation of the sluices, starting at the center of the spillway, might eliminate any danger to the toe of the apron. It was also believed, that much better conditions would result with the apron depressed in the region immediately below the 4:1 slope in the section containing sluices 5 and 6. The short sectional model prevented a satisfactory investigation either of the sluice operating program, or of the depressed section, and it was decided to build a model representing at least half of the spillway. Commercial size brass tubing and the laboratory pump capacity made a 1:68 scale the most desirable. The designs are practically completed and the model will be constructed immediately.

5. Crest and Sluices Operating Together. - The second possible operating condition, crest and sluices operating simultaneously, was studied. Although the jump did not sweep off the apron at the higher discharges, the conditions in the pool were very rough, plate 6. The tailwater was deepened until a very good jump formed. This procedure was followed in order to determine approximately the amount the apron should be lowered to obtain good conditions. The original $7\frac{1}{2}$-foot trapezoidal sill with a 2:1 sloping upstream face indicated that the apron should be lowered about $3\frac{1}{2}$ feet, figure 5. When the same procedure was followed, with a $7\frac{1}{2}$-foot 1:1 sloping trapezoidal sill installed at the end of the apron, the pool became rougher and slightly additional depth was necessary to produce a satisfactory jump in the pool. A dentated sill installed on the apron considerably improved conditions with a satisfactory jump forming on the apron at normal tailwater, plate 7.

Comparative water surface profiles and erosion profiles along the center-line of the model flume were taken, figure 6. The dentated sill proved to be better than either the 2:1 or the 1:1 trapezoidal sill. More water was held on the apron and less erosion occurred downstream.

6. Discharges over Crest Only.- The third possible operating condition, discharge over the crest only, was investigated. The sluices were closed and discharges from 40,000 to 360,000 second-feet, the latter about maximum reservoir elevation, were allowed to pass over the crest. The pool action (with 2:1 trapezoidal sill) was very desirable for flows up to and including 80,000 second feet, plates 8 and 9. For higher discharges the roughness of the pool increased and the jump formed downstream over the sill. The sheet of water entering the pool swept along the bottom and turned upward at the sill. Two rollers were formed, one back on the apron, and another in the stream immediately below the sill. The 1:1 sloping trapezoidal sill gave practically the same results while the dentated sill showed considerable improvement. Because the crest is never likely to operate without the sluices and since the jump does not sweep entirely off the apron, the conditions encountered in these studies are not considered critical. The pressure distribution on the crest was obtained, figure 7. All discharges below 360,000 second-feet produced positive or zero pressures. Slight negative pressure was noted at the downstream end of the parabolic curve for this discharge. Because of the remote possibility of the occurrence of a flood of this magnitude and because of the pressures for the other flows, this condition is not considered critical.

7. Training wall Tests.- The maximum water surface along the wall and the pressures in the pool (on both sides of the wall) will be obtained on the 1:68 model which is now under construction. Practically the same time will be required to construct this model as to alter the 1:40.8 model for obtaining the same data.

8. Conclusions.-

Sills.- The 7½-foot dentated sill was superior to the trapezoidal sills.

Sluices only Operating.- Very good conditions will result when all sluices are opened under a low head and the reservoir and tailwater elevations increase simultaneously.

Opening sluice 1 or sluices 1 and 2, under high head, will give undesirable action in the stilling pool and cause excessive scour at the end of the apron and training wall.

Also, the opening of two adjacent sluices near the center of the spillway (under high head) would be undesirable because of the fin that forms between them when they spread on the apron. The fin shoots over the sill and might cause erosion of the stream bed. The operation of alternate or every third sluice might improve conditions. However, it is felt that a satisfactory solution of the sluice problem can only be obtained by studies on a model with more flexibility than the narrow one used for the tests discussed in this memorandum. The 1:68 model previously mentioned will serve to solve this problem satisfactorily.

Sluice and Crest Operating Simultaneously.- Floods up to 500,000 second-feet can be efficiently handled when the sluices and crest operate together. The conditions in the stilling pool will be rough but the jump will always form on the apron.

Crest Discharging Alone.- A very effective hydraulic jump will form on the apron for all discharges up to approximately 100,000 second-feet. The pool will be rough for higher flows with the jump forming well out on the end of the apron and over the sill. Improvement will result if the sluices are set in operation before the discharge over the crest reaches 100,000 second-feet.

Very slight negative pressures will occur on the crest for 360,000 second-feet. Practically zero pressures will exist for smaller discharges and the condition is not considered serious.

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J. E. Warnock

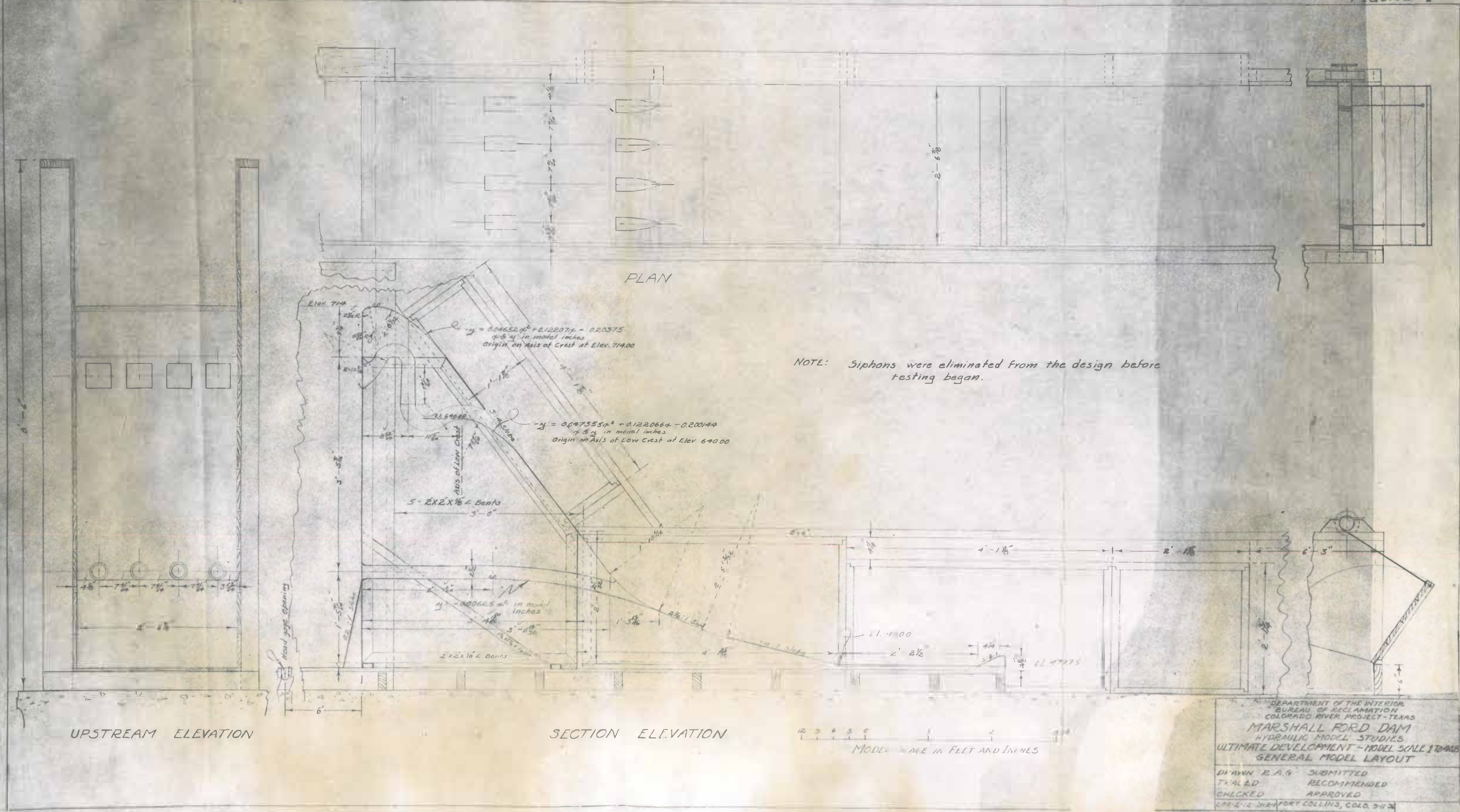
J. W. Ball

## List of Figures



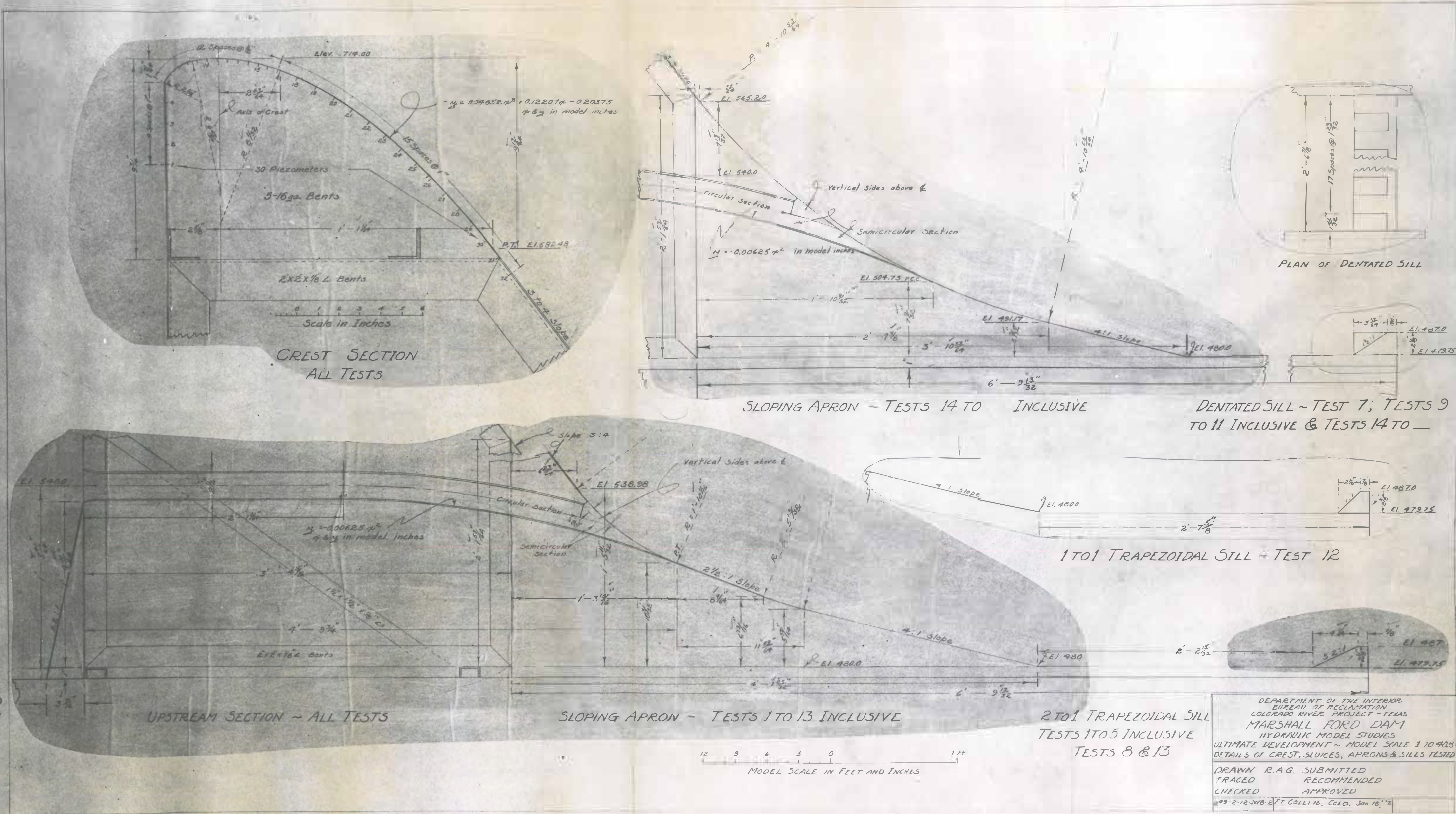
## List of Plates

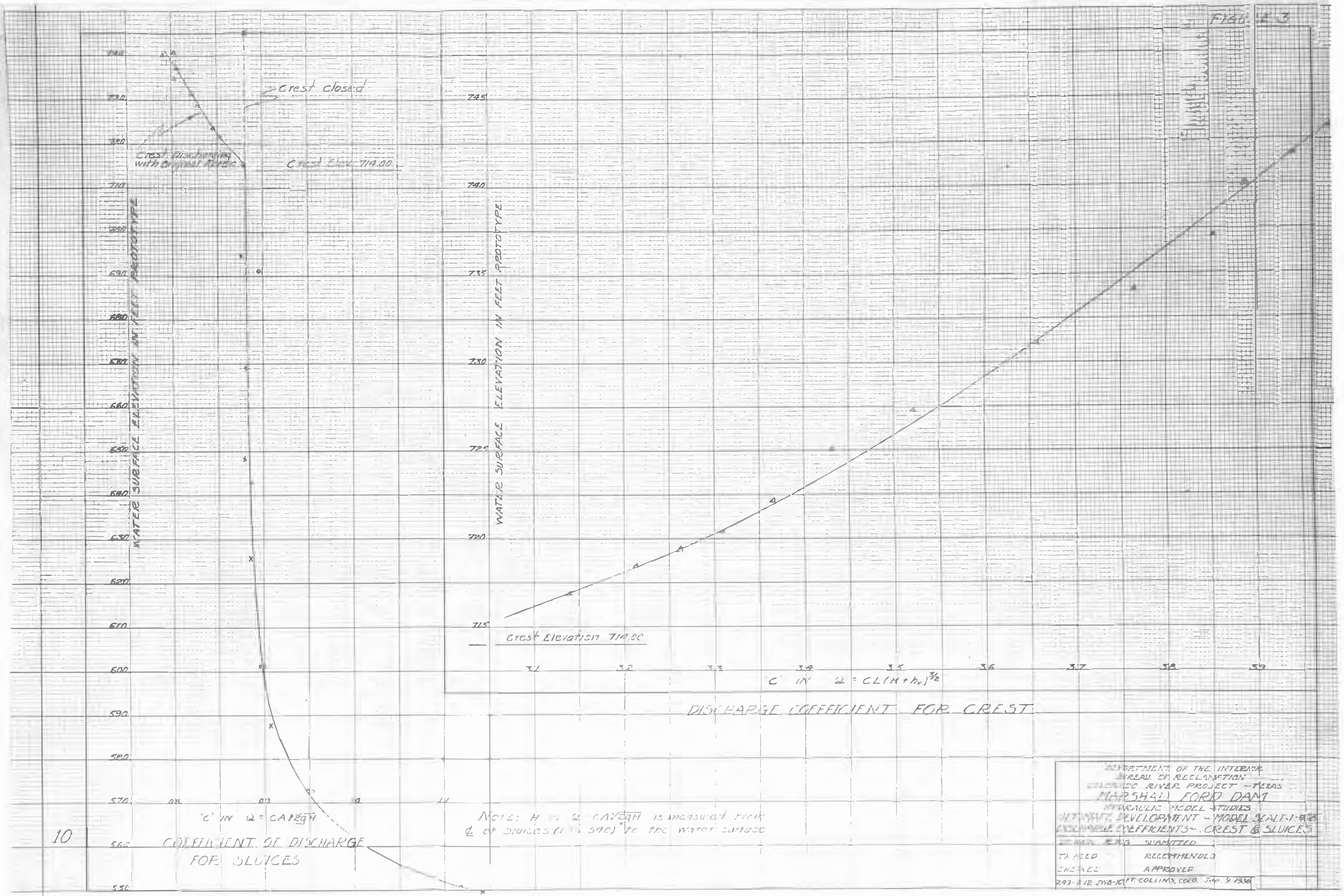
FIGURE 1


PLAN
UPSTREAM ELEVATION
SECTION ELEVATION
NOTE: Siphons were eliminated from the design before testing began.
Origin on Axis of Crest at Elev. 714.00
Origin on Axis of Low Crest at Elev. 640.00
5 - 2x2x1/8 ∠ Bents
Head gage Opening
MODEL SCALE IN FEET AND INCHES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER PROJECT - TEXAS
MARSHALL FORD DAM
HYDRAULIC MODEL STUDIES
ULTIMATE DEVELOPMENT - MODEL SCALE
GENERAL MODEL LAYOUT
DRAWN R.A.G.
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
FORT COLLINS, COLO.

1

FIGURE 2


CREST SECTION
ALL TESTS
Elev. 714.00
Axis of Crest
30 Piezometers
5-16ga. Bents
2x2x⅛ ∟ Bents
15 Spaces @ 1"
P.T. El. 692.48
3 to 4 Slope
Scale in Inches
SLOPING APRON - TESTS 14 TO INCLUSIVE
El. 565.20
El. 540.0
Circular Section
Vertical sides above ℄
Semicircular Section
y = -0.00625 x² in model inches
El. 504.73 P.C.C.
El. 491.17
4:1 Slope
El. 480.0
PLAN OF DENTATED SILL
17 Spaces @ 23/32
El. 487.0
El. 479.75
DENTATED SILL ~ TEST 7; TESTS 9 TO 11 INCLUSIVE & TESTS 14 TO __
El. 540.0
Slope 3:4
El. 538.98
Vertical sides above ℄
Circular Section
Semicircular Section
y = -0.00625 x²
x & y in model inches
2½:1 Slope
4:1 Slope
El. 480.0
El. 480
UPSTREAM SECTION ~ ALL TESTS
SLOPING APRON - TESTS 1 TO 13 INCLUSIVE
1 TO 1 TRAPEZOIDAL SILL - TEST 12
El. 480.0
El. 487.0
El. 479.75
2 TO 1 TRAPEZOIDAL SILL
TESTS 1 TO 5 INCLUSIVE
TESTS 8 & 13
El. 487
El. 479.75
MODEL SCALE IN FEET AND INCHES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER PROJECT - TEXAS
MARSHALL FORD DAM
HYDRAULIC MODEL STUDIES
ULTIMATE DEVELOPMENT ~ MODEL SCALE 1 TO 40.31
DETAILS OF CREST, SLUICES, APRONS & SILLS TESTED
DRAWN R.A.G. SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED
FT. COLLINS, COLO.


Crest closed
Crest Elev. 714.00
WATER SURFACE ELEVATION IN FEET PROTOTYPE
'C' IN Q = CA√2gH
COEFFICIENT OF DISCHARGE FOR SLUICES
Note: H in Q = CA√2gH is measured from ℄ of sluices (El. 590) to the water surface
WATER SURFACE ELEVATION IN FEET PROTOTYPE
Crest Elevation 714.00
'C' IN Q = CL(H+hv)^3/2
DISCHARGE COEFFICIENT FOR CREST
DEPARTMENT OF THE INTERIOR
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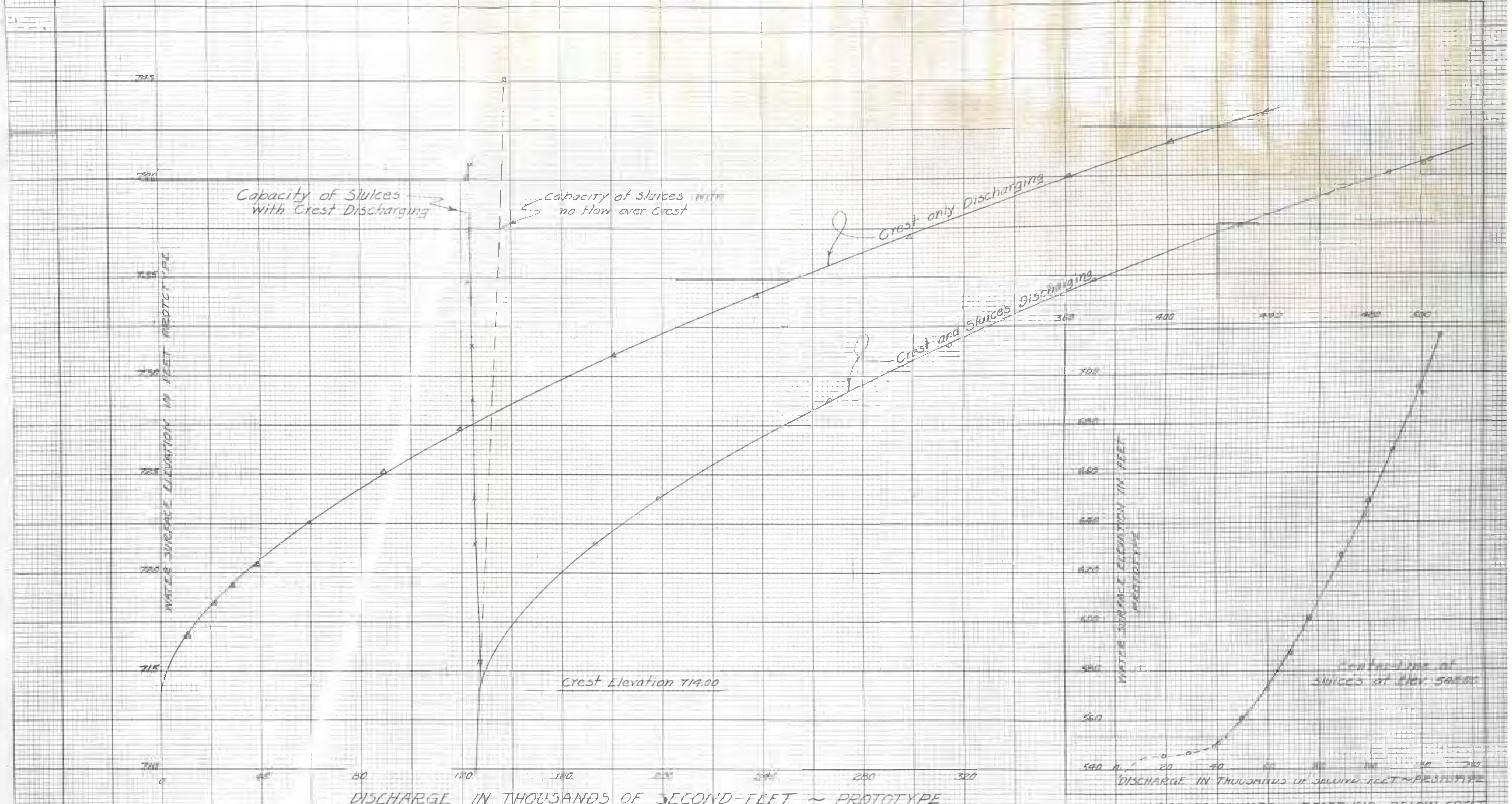
RIVER PROJECT - TEXAS
MARSHALL FORD DAM
HYDRAULIC MODEL STUDIES
DEVELOPMENT - MODEL SCALE 1:
COEFFICIENTS - CREST & SLUICES
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
FT. COLLINS, COLO. 9 1938

FIGURE 4




DISCHARGE OF SLUICES ~ RESERVOIR BELOW CREST

NOTE: Curves are for 700 foot Crest length; and 24 - 8'-6" Dia. Sluices.

Curves were calculated from the coefficient curves. Observed points are shown.

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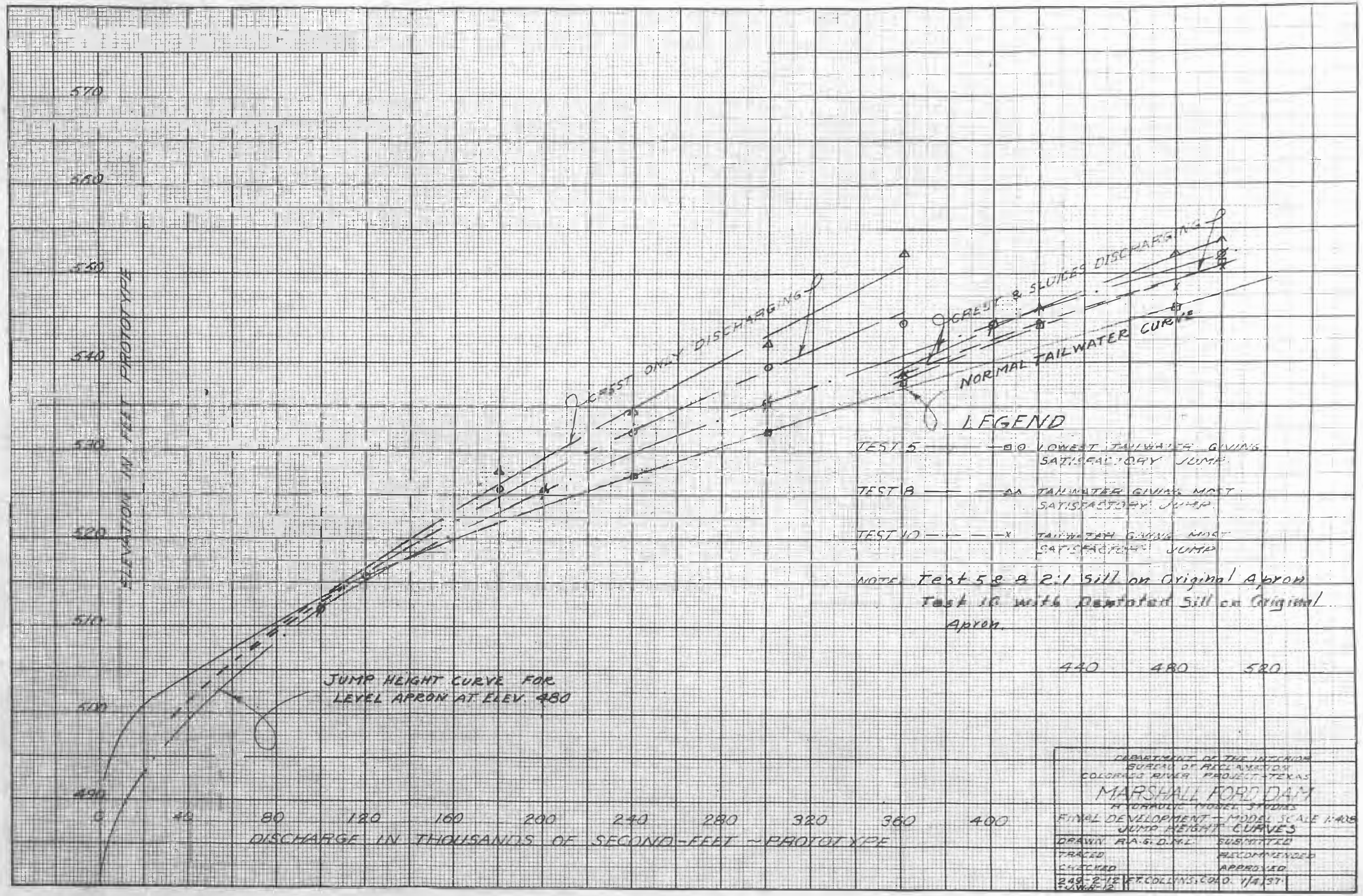
COLORADO RIVER PROJECT ~ TEXAS
MARSHALL FORD DAM
HYDRAULIC MODEL STUDIES
ULTIMATE DEVELOPMENT ~ MODEL SCALE 1:40.8
DISCHARGE CURVES ~ ORIGINAL APRON

DRAWN R.A.G. SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED
249-D-12-JWB-N FT. COLLINS, COLO. Jan. 9 '37

FIGURE 5



570
560
550
540
530
520
510
500
490
0
40
80
120
160
200
240
280
320
360
400
440
480
520
ELEVATION IN FEET PROTOTYPE
DISCHARGE IN THOUSANDS OF SECOND-FEET ~ PROTOTYPE
CREST ONLY DISCHARGING
CREST & SLUICES DISCHARGING
NORMAL TAILWATER CURVE
JUMP HEIGHT CURVE FOR
LEVEL APRON AT ELEV. 480
LEGEND
TEST 5 LOWEST TAILWATER GIVING SATISFACTORY JUMP
TEST 8 TAILWATER GIVING MOST SATISFACTORY JUMP
TEST 10 TAILWATER GIVING MOST SATISFACTORY JUMP
NOTE: Test 5 & 8 2:1 Sill on Original Apron
Test 10 with Dentated Sill on Original Apron.
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BUREAU OF RECLAMATION
COLORADO RIVER PROJECT-TEXAS
MARSHALL FORD DAM
HYDRAULIC MODEL STUDIES
FINAL DEVELOPMENT - MODEL SCALE 1:40.8
JUMP HEIGHT CURVES
DRAWN R.A.S. D.M.L.
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
249-2-12
FT. COLLINS, COLO. 1/4/37.

FIGURE 6

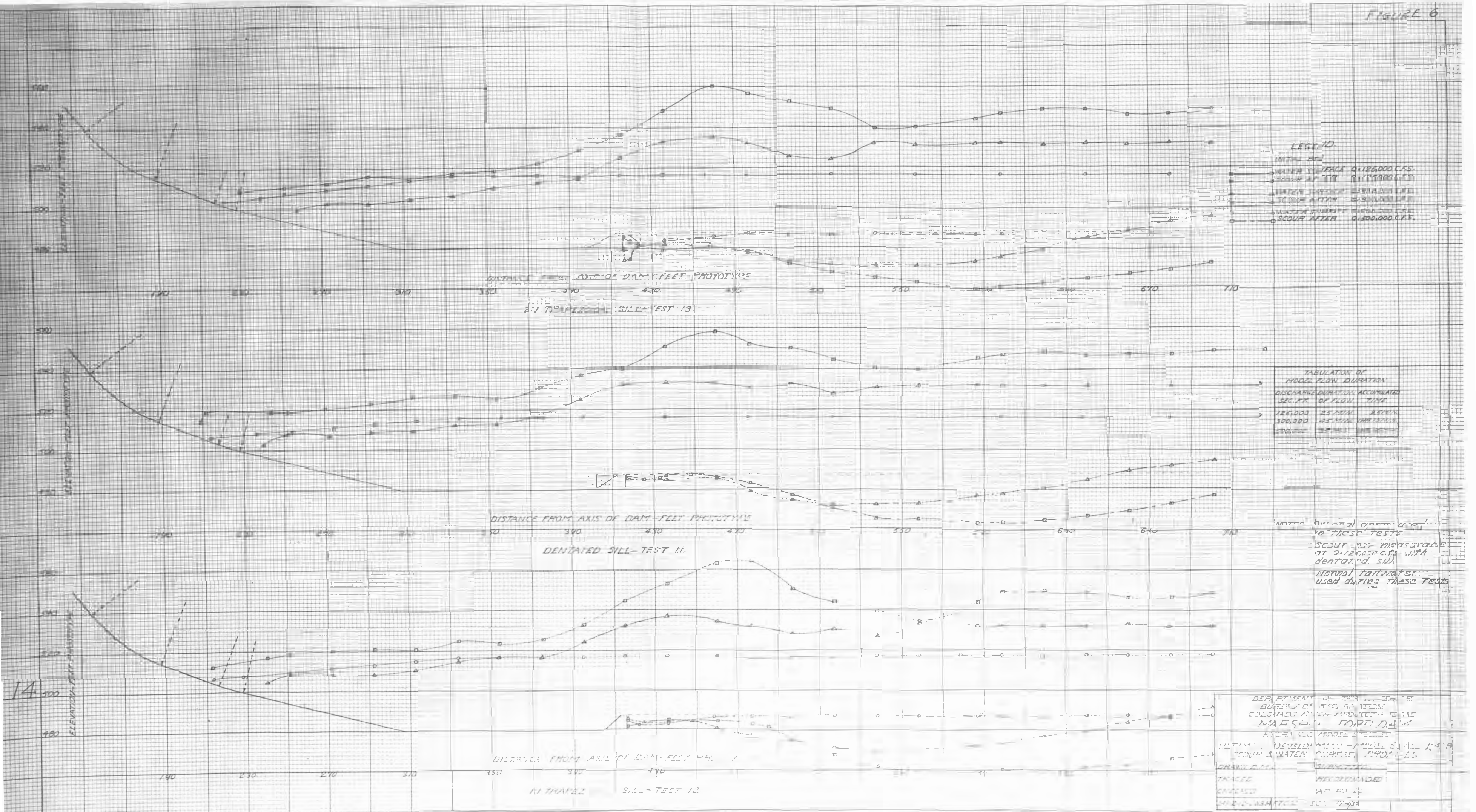
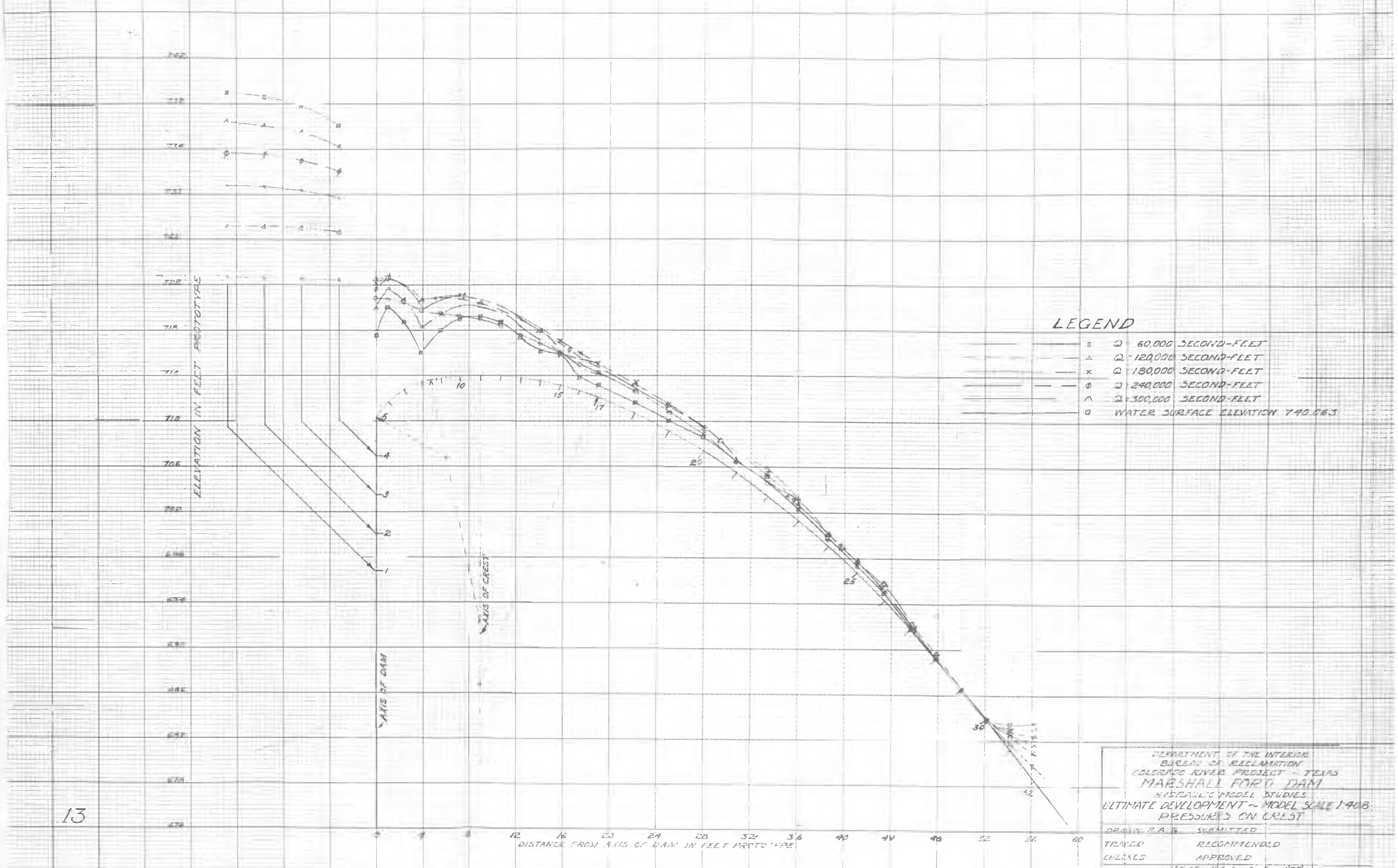

DISTANCE FROM AXIS OF DAM - FEET PROTOTYPE
2:1 TRAPEZOIDAL SILL - TEST 13
DISTANCE FROM AXIS OF DAM - FEET PROTOTYPE
DENTATED SILL - TEST 11.
ELEVATION - FEET PROTOTYPE
LEGEND.
SCOUR AFTER Q=300,000 C.F.S.
TABULATION OF
MODEL FLOW DURATION
DISCHARGE SEC. FT.
DURATION OF FLOW
ACCUMULATED TIME
Normal tailwater
used during these Tests
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED

FIGURE 7


LEGEND
Q = 60,000 SECOND-FEET
Q = 120,000 SECOND-FEET
Q = 180,000 SECOND-FEET
Q = 240,000 SECOND-FEET
Q = 300,000 SECOND-FEET
WATER SURFACE ELEVATION 740.063
ELEVATION IN FEET PROTOTYPE
DISTANCE FROM AXIS OF DAM IN FEET PROTOTYPE
AXIS OF DAM
AXIS OF CREST
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER PROJECT - TEXAS
MARSHALL FORD DAM
HYDRAULIC MODEL STUDIES
ULTIMATE DEVELOPMENT ~ MODEL SCALE 1:40.8
PRESSURES ON CREST
DRAWN R.A.B. SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED
247-R-12-JWB-13 FT. COLLINS, COLO. Jan. 11, '37


Discharge 20,000 Second-feet

Discharge 40,000 Second-feet

Discharge 60,000 Second-feet

Discharge 80,000 Second-feet

Discharge 100,000 Second-feet

Discharge 120,000 Second-feet

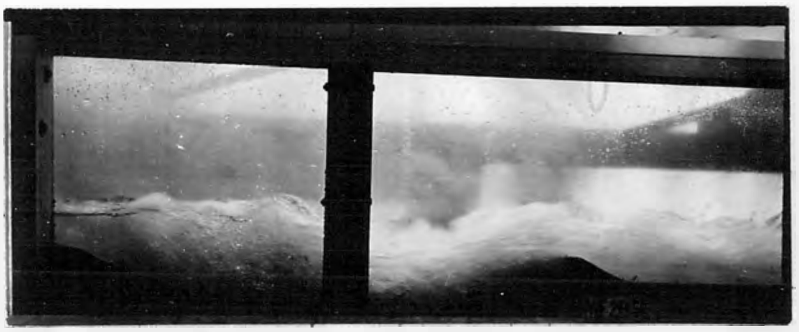
Before Test


After Discharge of 120,000 Second-feet

FLOW CONDITIONS - ALL SLUICES DISCHARGING - NORMAL TAILWATER.

PLATE 1.

Discharge 5,000 Second-feet



Discharge 5,000 Second-feet

After Discharge of 5,000 Second-feet

ACTION OF SLUICE 1. DISCHARGING — MINIMUM TAILWATER

$7\frac{1}{4}$-FOOT 2:1 TRAPEZOIDAL SILL

Discharge 2,000 Second-feet

Discharge 3,000 Second-feet

Discharge 4,000 Second-feet


After Discharge 5,000 Second-feet

Discharge 5,000 Second-feet

SLUICE 1 ONLY OPERATING - NORMAL TAILWATER - $7\frac{1}{4}$-FOOT DENTATED SILL

PLATE 3.

PLATE 4.

Discharge 3,000 Second-feet

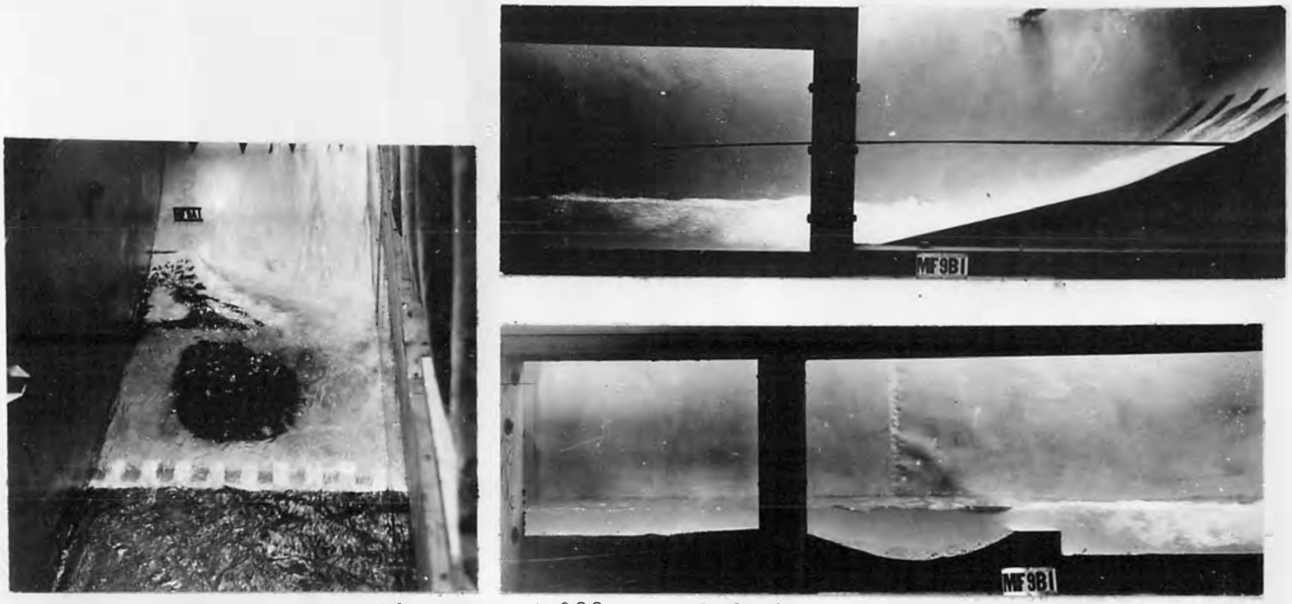

Discharge 4,000 Second-feet


Discharge 5,000 Second-feet

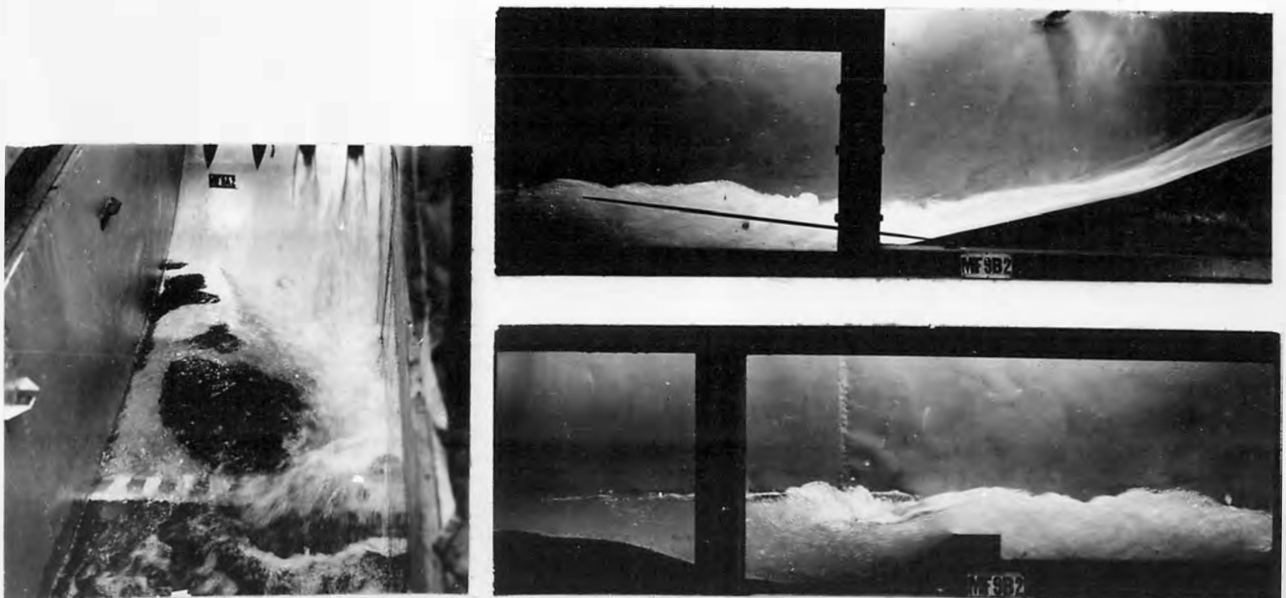
After Discharge of 5,000 Second-feet

ACTION WITH SLUICE NO.1 OPERATING - NORMAL TAIL WATER

$7\frac{1}{4}$-FOOT DENTATED SILL




Discharge 4,000 second-feet




Discharge 6,000 second-feet

ACTION OF SLUICES 1 AND 2 OPERATING - NORMAL TAILWATER - $7\frac{1}{4}$-FOOT DENTATED SILL

Discharge 240,000 Second-feet

Discharge 300,000 Second-feet

Normal Tailwater

Normal Tailwater

Tailwater 0.8 Feet above Normal

Discharge 360,000 Second-feet

Normal Tailwater

Tailwater 2.4 Feet above Normal

Discharge 420,000 Second-feet

Normal Tailwater

Tailwater 4.0 Feet above Normal

Discharge 500,000 Second-feet

STILLING POOL ACTION - SLUICES AND CREST DISCHARGING - $7\frac{1}{4}$-FOOT 2:1 TRAPEZOIDAL SILL

PLATE 6.

Discharge 240,000 Second-feet

Discharge 300,000 Second-feet

Normal Tailwater

Normal Tailwater

Tailwater 1.7 Feet above Normal

Discharge 360,000 Second-feet

Normal Tailwater

Tailwater 3.1 Feet above Normal

Discharge 420,000 Second-feet

Normal Tailwater

Tailwater 2.9 Feet above Normal

Discharge 500,000 Second-feet

STILLING POOL ACTION - SLUICES AND CREST DISCHARGING - DENTATED SILL.

PLATE 7.

Discharge 60,000 Second-feet

Discharge 120,000 Second-feet


Discharge 60,000 Second-feet


Discharge 120,000 Second-feet

STILLING POOL ACTION - CREST ONLY DISCHARGING - NORMAL TAILWATER

$7\frac{1}{4}$-FOOT 2:1 TRAPEZOIDAL SILL.

Normal Tailwater

Tailwater 3.7 Feet above Normal

Discharge 180,000 Second-feet

Normal Tailwater

Tailwater 3.9 Feet above Normal

Discharge 240,000 Second-feet

Normal Tailwater


Tailwater 7.4 Feet above Normal

Discharge 300,000 Second-feet

Normal Tailwater

Tailwater 7.4 Feet above Normal

Discharge 360,000 Second-feet

STILLING POOL ACTION - CREST ONLY DISCHARGING - 7½-FOOT 2:1 TRAPEZOIDAL SILL


Sluices only Discharging - 125,000 Second-feet - Normal Tailwater.

Flow Conditions - Reservoir Elevation 740.


Scour below Sill

Crest only Discharging

Discharge 300,000 Second-feet - Normal Tailwater


Scour below Sill

Crest and Sluices Discharging

Discharge 500,000 Second-feet - Normal Tailwater


Scour below Sill

Crest and Sluices Discharging.

ACTION OF STILLING POOL - 200-FOOT RADIUS BUCKET - 4:1 SLOPING APRON - DENTATED SILL

PLATE 10


Discharge 240,000 Second-feet


Discharge 300,000 Second-feet

Normal Tailwater.


Normal Tailwater


Tailwater 6.9 Feet above Normal

Discharge 360,000 Second-feet.


Normal Tailwater


Tailwater 2 Feet above Normal

Discharge 420,000 Second-feet.

Normal Tailwater

Tailwater 2.2 Feet above Normal

Discharge 500,000 Second-feet

STILLING POOL ACTION CREST AND SLUICES DISCHARGING

200-FOOT RADIUS BUCKET - 4:1 SLOPING APRON - DENTATED SILL.

PLATE 11