UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

- - -

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: HYDRAULIC MODEL EXPERIMENTS OF

THE IMPERIAL DAM AND DESILTING WORKS

BOOK I

STUDIES OF SPILLWAY, SLUICEWAY, AND STILLING POOLS

- - -

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PREFACE

The hydraulic model experiments for the design of the Imperial Dam as described in this report were made in the hydraulic laboratories of the U. S. Bureau of Reclamation at Denver, and Montrose, Colorado, under the direction of E. W. Lane, Research Engineer, and the report was prepared under the direction of Jacob E. Warnock, Research Engineer.

The studies in the Denver laboratory were under the supervision of J. B. Drisko, Assistant Engineer, who was assisted by T. G. Owen, F. L. Panuzio, H. M. Martin, J. M. Buswell, and L. R. Brooks, Junior Engineers. The portion of the studies performed at the Montrose laboratory was under the supervision of C. W. Thomas, Assistant Engineer. This report was prepared by J. N. Bradley, Assistant Engineer, assisted by R. K. Vierck, A. H. Neal, H. W. Brewer, E. C. Parks, and J. D. McCrum, Junior Engineers.

These studies were made under the general supervision of J. L. Savage, Chief Designing Engineer. All engineering work of the Bureau of Reclamation was under the direction of R. F. Walter, Chief Engineer, and all activities of the Bureau were under the direction of Dr. Elwood Mead, Commissioner.

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I. INTRODUCTION

1. THE SPILLWAY

The Imperial Dam, a part of the Boulder Canyon project, will be located on the Colorado River about 4.5 miles upstream from the existing Laguna Dam and approximately 20 miles, by river, above Yuma, Arizona, (fig. 1). The purpose of the dam is to raise the level of the river above the site so that water can be diverted at all stages of flow into the All-American canal on the California side of the river, and, as an ultimate development, into the Gila Valley canal on the Arizona side. As rock lies at a considerable depth below the river bed at the site, it was impractical to design the dam on a rigid foundation. Instead, the dam, which will consist mainly of hollow concrete construction, will rest directly on the sand river bed. Its over-all length will be approximately 3,400 feet, of which 1197.5 feet will constitute a free overflow weir, and 241.5 feet, between the overflow weir and the All-American canal headworks on the California side, will serve as a sluiceway controlled by radial gates, (fig. 2).

The overflow weir will have a total height of 31 feet from foundation to crest and will consist of a hollow concrete dam (Ambursen type) partly filled with sand and gravel ballast for added weight. A reinforced concrete paving, 170 feet in length, will be constructed upstream from the dam to increase the length of underseepage, and a heavy concrete apron will be provided downstream from the overflow section on which the hydraulic jump will form.

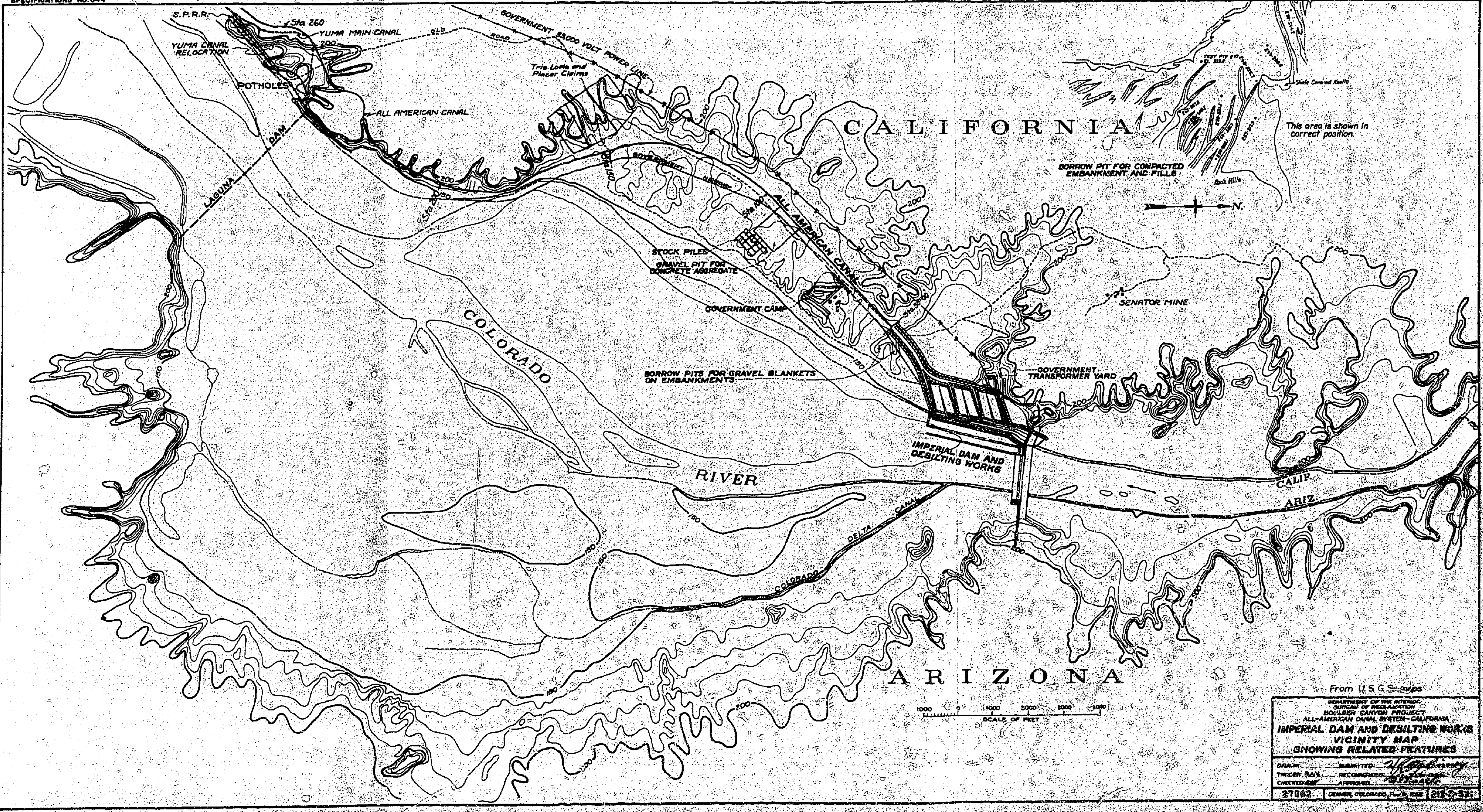
Three rows of sheet piling will be driven under the upstream paving and one row will be provided at the end of the downstream apron. The elevation of the downstream apron will be one foot lower than the crest of Laguna Dam. The final overflow weir was designed for a maximum discharge of 134,500 second-feet which will require a head of approximately 10 feet on the crest.

Careful consideration was given to the stilling pool below the spillway to make certain that it would confine the jump for all expected conditions of discharge and tailwater. The upper end of the pool floor in the final design (fig. 22) is on a 4:1 slope which makes it possible to hold the front of the jump on this portion of the apron for a wide range of tailwater depths. Without this slope, an exceptionally long stilling pool would be required.

With the river bed excavated to elevation 150.0 as in the final design (fig. 22), the water leaving the stilling pool, for a discharge of 150,000 second-feet and a tailwater depth of 18 feet, would have a velocity of about 7 feet per second. This

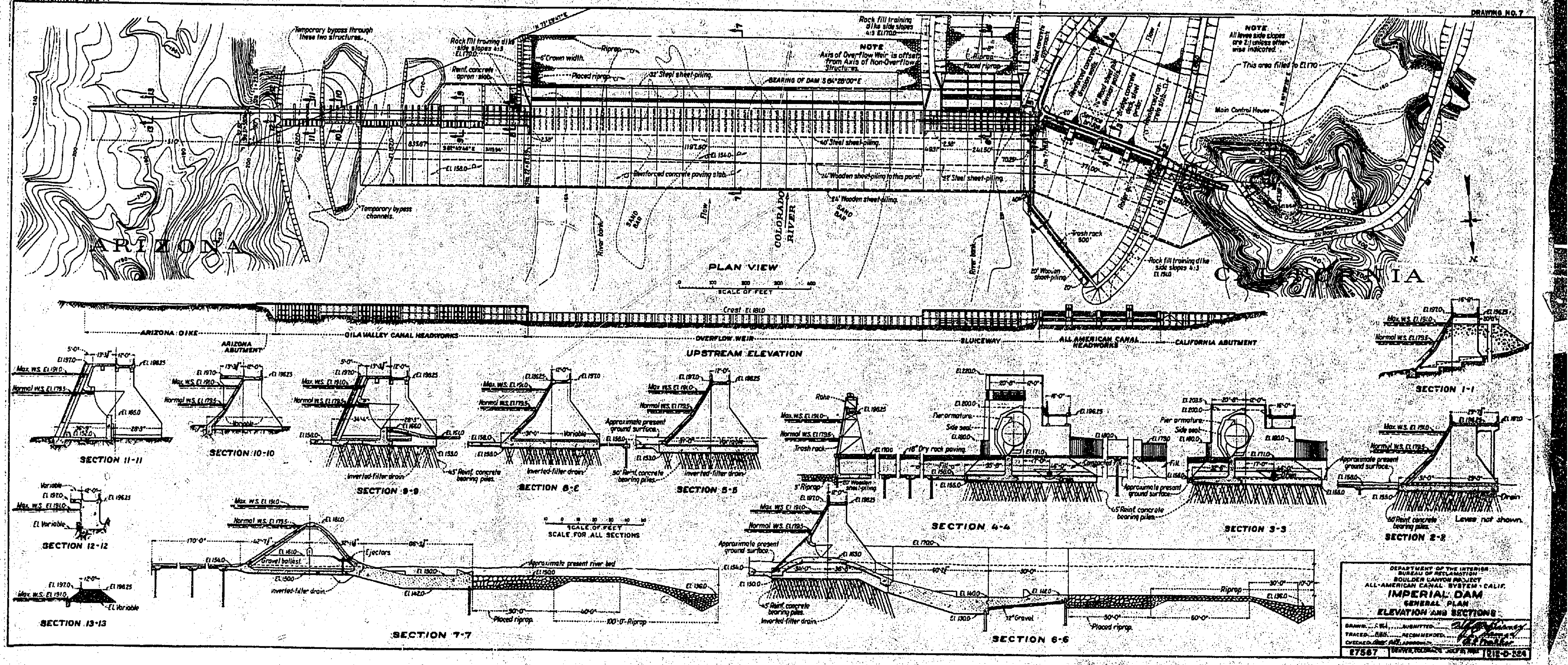
SPECIFICATIONS NO. 644

FIG. 1
DRAWING NO. 2



SPECIFICATIONS NO. 644

FIG. 2



velocity is quite high for the type of material encountered at the dam site. Should retrogression of the river downstream from the dam cause the tailwater to drop below elevation 168 for the maximum flow condition, this velocity would become greater than 7 feet per second. Observations made at Laguna Dam, a few miles down the river where the bed material is similar, disclosed that a velocity of 6 feet per second caused excessive erosion. It is practically impossible to materially reduce the velocity downstream from the dam, so, in any case, it will be necessary to heavily riprap the river bed for some distance below the stilling pool.

The model showed the original spillway stilling pool to be inadequate and negative pressures were recorded on the overflow face of the dam. As a result, the overflow section was redesigned and a satisfactory stilling pool was obtained only after a very extensive series of tests. Numerous types of stepped aprons and sills were tried in various positions on the pool floor to obtain a hydraulic jump that would be effective for a wide range of tailwater conditions. In spite of the fact that some combinations of stepped apron and sill gave very good results, it was necessary to drop the pool floor two feet to obtain the desired tailwater range.

2. THE SLUICEWAY

A sluiceway (section 6-6, fig. 2) is to be constructed adjacent to the All-American canal intake to withdraw a major portion of the bed load of silt carried by the Colorado River before the water is allowed to enter the intake works. The bottom of the sluiceway gate openings will be at elevation 163.0 and the floor of the approach to the intake gates will be at a higher elevation such that the major portion of the bed load will be flushed through the sluiceway gates and transported downstream by the sluiceway channel.

As finally designed, the sluiceway will consist of twelve radial gates each 16 feet in length with a lift of 7 feet. The crest will be at elevation 163.0 and each gate will have an approximate capacity of 2,500 second-feet. The sluiceway will be similar to the dam in that 180 feet of concrete apron will be provided at elevation 154.0 upstream from the dam under which three rows of sheet piling will be driven to check underseepage. A heavy concrete apron will be provided below the dam on which the hydraulic jump will form and two rows of sheet piling will be provided under this apron.

The problem in the design of the sluiceway was, in one respect, similar to that of the dam in that it was pertinent that the sluiceway stilling pool operate satisfactorily for a wide range of tailwater conditions to guard against any unforeseen change of river conditions. As originally designed, the stilling pool operated satisfactorily for only a limited tailwater range. Consequently, an extensive series of tests were made which resulted in the development of two other types of stilling pool: (1) a double-jump pool, and (2) a single-jump pool with a long sloping apron.

It is difficult to state which was the most satisfactory, but the single-jump pool with long sloping apron was favored as it is the less expensive of the two to construct and it conforms more closely to the standard stilling pool design. In both cases, however, energy dissipation was very effective and the permissible tailwater range was satisfactory.

Due to the uncertainty of conditions surrounding the spillway and sluiceway, it was considered that model studies offered the only safe solution to the problems involved.

II. THE IMPERIAL DAM SPILLWAY

1. THE LABORATORY

The major portion of the Imperial Dam model studies described in this report was made in the laboratory located in the old Customhouse in Denver, Colorado. The discharge for the model was measured over a 90-degree, V-notch weir and then pumped into the drag flume head tank (fig. 3). From here it flowed down the flume, over the model of the dam, through the settling basin, and back to the weir tank. The head on the measuring weir was observed from two point gages, one connected to either side of the weir tank. The head on the crest of the model was measured with point gages located in the flume. The tailwater elevation was observed from three piezometers located 6, 10, and 14 feet downstream from the axis of the dam. Profiles of water surfaces and sand surfaces were obtained with a movable point gage mounted on a carriage which could be slid longitudinally along the flume on two level bars, one mounted on each side of the flume. A steel tape stretched along one of the bars indicated the horizontal position of the gage with respect to the axis of the dam. Practically all measurements were made on the center line of the flume as friction along the sides was quite noticeable.

2. THE ORIGINAL MODEL

A model representing 60 feet of the Imperial Dam spillway section was constructed on a scale of 1:30 in the laboratory drag flume as shown on figure 4. The model consisted of two pieces, the spillway portion and the downstream horizontal apron (fig. 4). The crest portion was made by bending a piece of 20-gage sheet metal, two feet in width, over four heavy metal ribs and soldering it in place. Fifteen 1/8-inch piezometers were installed in staggered positions on the overflow section for measuring pressures. The floor of the drag flume was set on a slope of 0.008 as shown on figure 4, to provide sufficient depth for erosion tests below the dam. The model was installed in the drag flume before a window so that the erosion and hydraulic action below the stilling pool could be visually observed. The paving of the river bed upstream from the dam was represented by sand.

The downstream apron was heavy sheet metal soldered to angle irons, pinned to the dam at the upstream end and bolted to the floor of the flume at the downstream end. A wooden sill was bolted to the end of the downstream apron. A sand bed was constructed below the sill to study erosion in this region. Four piezometers were installed along the center line of the apron to measure pressures on the floor of the stilling pool. Rubber tubes

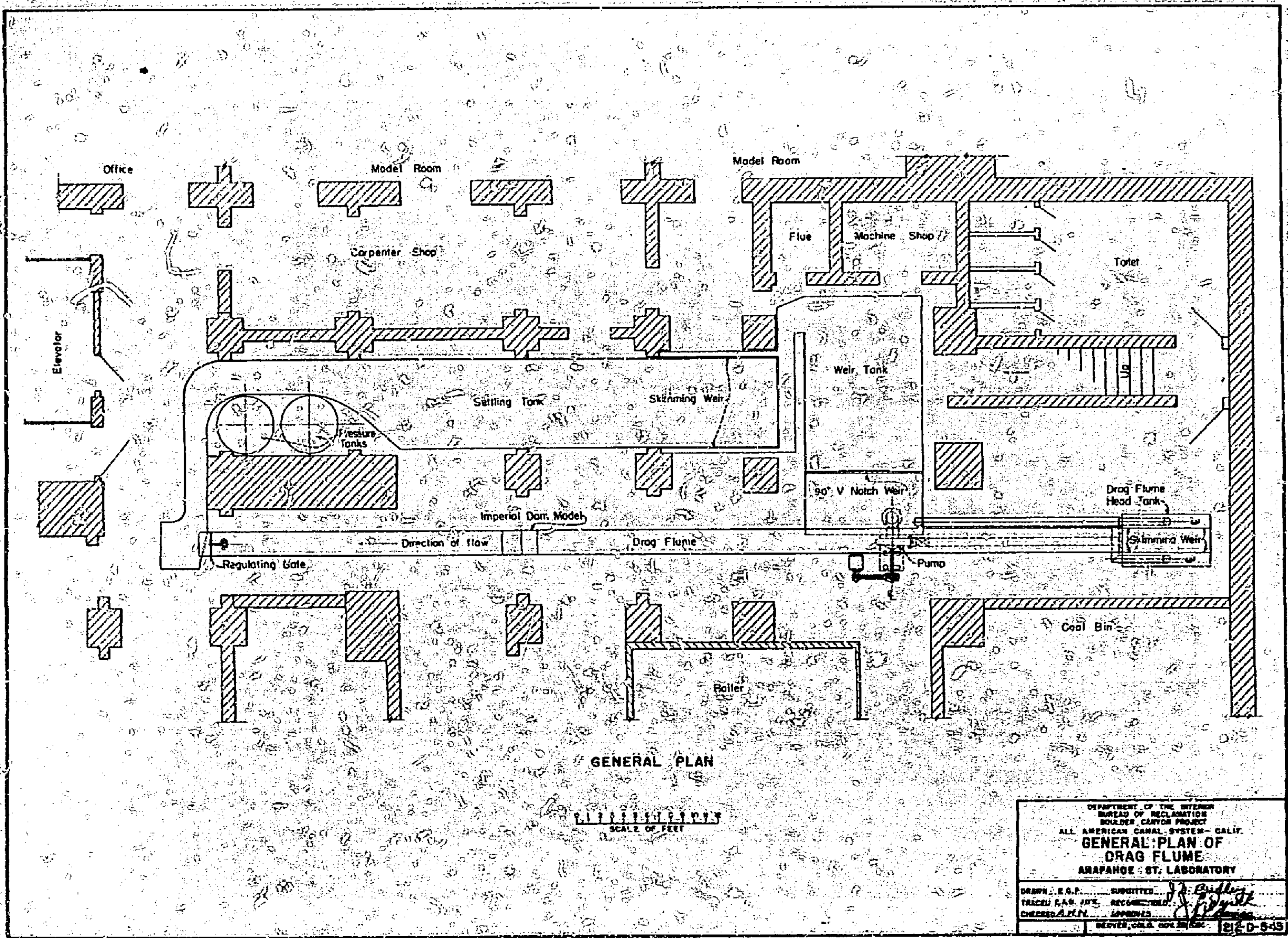
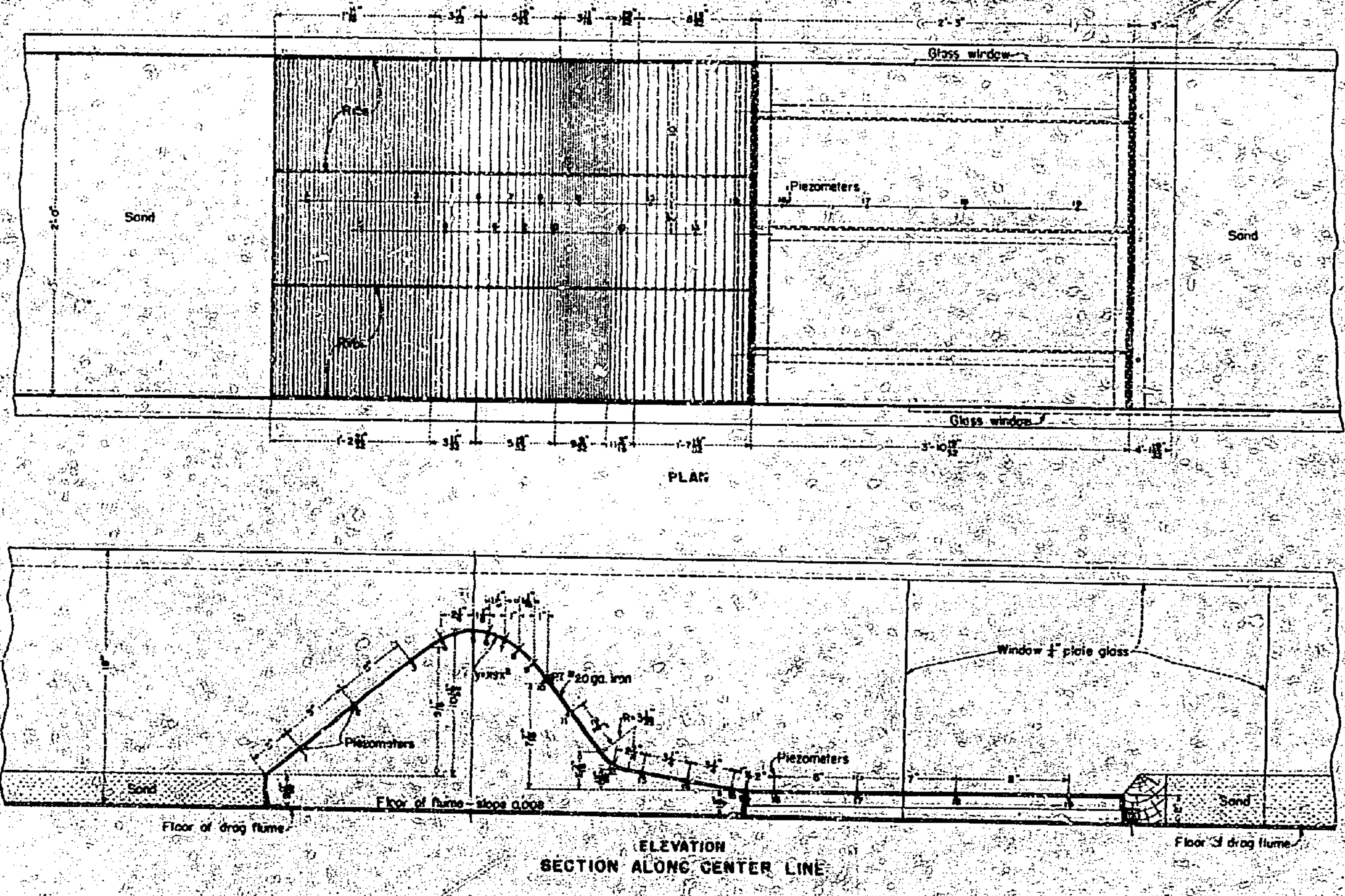

Office
Model Room
Model Room
Carpenter Shop
Flue
Machine Shop
Toilet
Elevator
Weir Tank
Settling Tank
Skimming Weir
Pressure Tanks
90° V Notch Weir
Drag Flume Head Tank
Skimming Weir
Imperial Dam Model
Direction of flow
Drag Flume
Regulating Gate
Pump
Coal Bin
Boiler
GENERAL PLAN
SCALE OF FEET
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
ALL AMERICAN CANAL SYSTEM - CALIF.
GENERAL PLAN OF
DRAG FLUME
ARAPAHOE ST. LABORATORY
DRAWN E.C.P.
TRACED E.A.S.
CHECKED A.M.N.
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLO.
212-D-545
FIGURE 3

FIGURE 4



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HYDRAULIC MODEL STUDIES

IMPERIAL DAM TYPE D-I
GENERAL PLAN OF MODEL
MODEL SCALE 1:30

DRAWN S.H.B. E.C.P. SUBMITTED
TRACED J.H.R. J.R.K. RECOMMENDED
CHECKED J.H.R. APPROVED
DENVER, COLO. AUGUST 14, 1934 | 21-D-544

connecting the piezometers to a reading board were passed through a hole in the floor beneath the dam.

The piezometer reading board (plate VI-D) had a manifold across the top connected by rubber hose to each manometer tube. Before the start of a test, the pressure in the manifold was reduced by operating a suction pump connected at one end causing any air entrapped in the rubber connecting tubes to flow toward the manifold and escape from the water. The valve on the manifold was then opened, returning the pressure to atmospheric, and the testing started. The metal can on the right end of the manifold tube was used to increase the air volume of the apparatus. This piezometer arrangement was very satisfactory and consistent readings were obtained throughout the tests. An apparatus such as this is very useful where portions of the piezometer tubing are inaccessible and connections numerous.

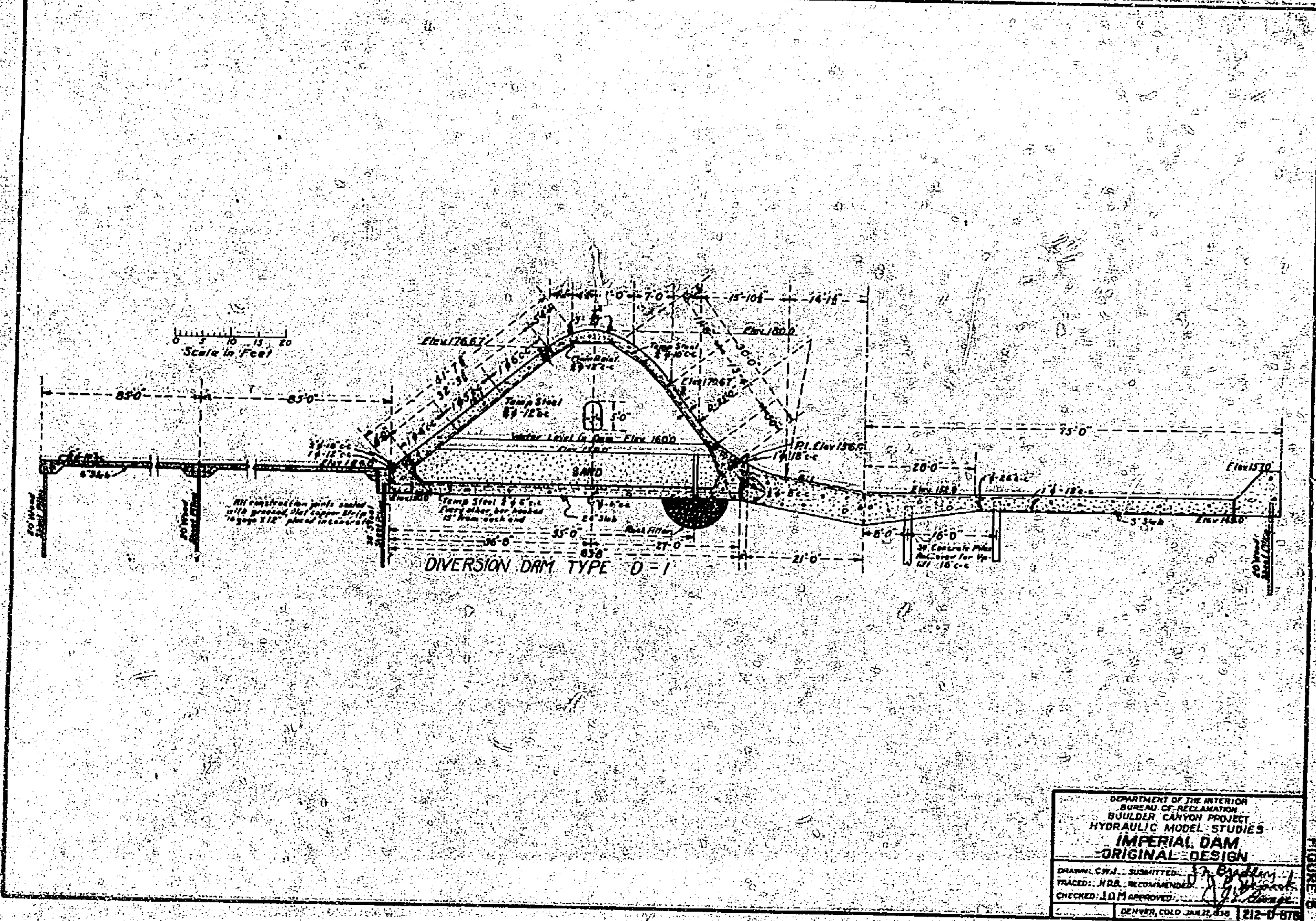
3. TESTS ON STILLING POOL (ORIGINAL SPILLWAY DESIGN)

A. Crest-length, 1,072 Feet, Pool Floor at Elevation 152.0

a. Original Stilling Pool Design

As originally designed, the ogee spillway section was 1,072 feet long, capable of discharging 150,000 second-feet with a maximum head of about 11.5 feet on the crest. In this case, the maximum discharge per foot of crest would be 140 second-feet. Figure 5 shows a section of the overflow weir and stilling pool as originally designed and test 1-1, figure 6, shows a profile of the water surface for the maximum discharge and tailwater elevation. It was intended that the front of the jump would form on the 6:1 sloping apron for all expected variations of discharge and tailwater with the horizontal pool floor 75 feet in length at elevation 152.0 and the large beveled sill on the end of this floor (sill A-1, fig. 7).

The action in the pool was satisfactory for all discharges with a tailwater elevation in the vicinity of 168, but when the tailwater was dropped to 166 for the maximum discharge, the jump left the pool. Erosion of the sand bed below the sill during a 30-minute run appears excessive (test 1-1, fig. 6). Inasmuch as the size of the sand in the model was not in proportion to the scale ratio, the results must be judged only in a qualitative or indicative manner. By using the same size sand throughout all the tests even though it was too large, it served as a basis of comparison in determining which of the pool layouts produced the least scour of the sand bed. Plates I-A and B show the the dam as originally designed, except that the sill on the end of the pool floor is not the original. Photographs C and D show the stilling pool in action during one of the preliminary


Scale in Feet
DIVERSION DAM TYPE D-1
SAND
Water Level in Dam - Elev 160.0
Temp Steel
Elev 176.67
Elev 180.0
Elev 157.0
Elev 138.0
Rock Filter
20'-0"
75'-0"
21'-0"
85'-0"
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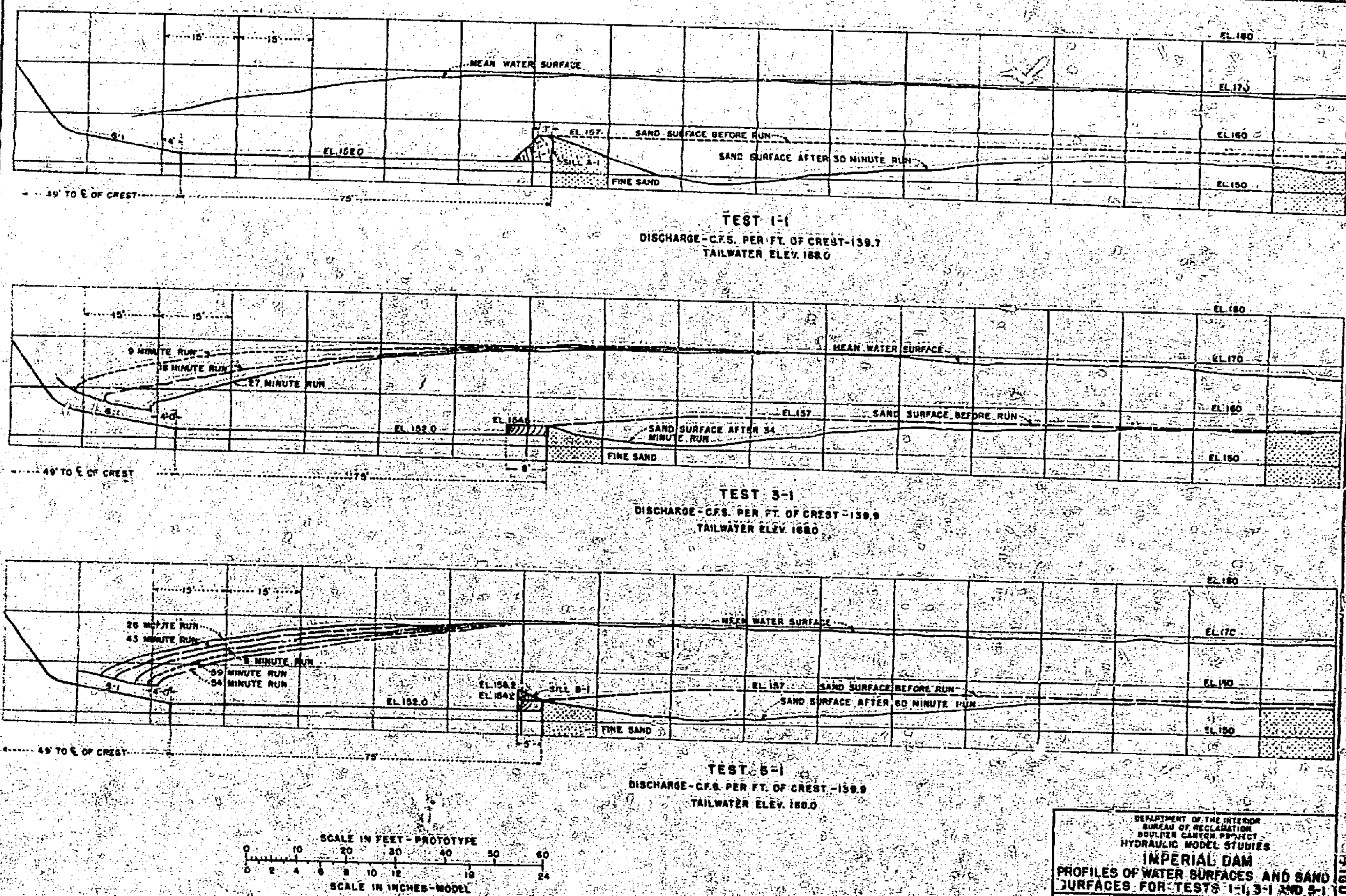
HYDRAULIC MODEL STUDIES
IMPERIAL DAM
ORIGINAL DESIGN
DENVER, COLO.
212-D-878

FIGURE 5



TEST 1-1
DISCHARGE - C.F.S. PER FT. OF CREST - 139.7
TAILWATER ELEV. 168.0

TEST 3-1
DISCHARGE - C.F.S. PER FT. OF CREST - 139.9
TAILWATER ELEV. 168.0

TEST 5-1
DISCHARGE - C.F.S. PER FT. OF CREST - 139.9
TAILWATER ELEV. 168.0

POOL FLOOR AT ELEVATION 152.0
LENGTH OF CREST 1072 FEET

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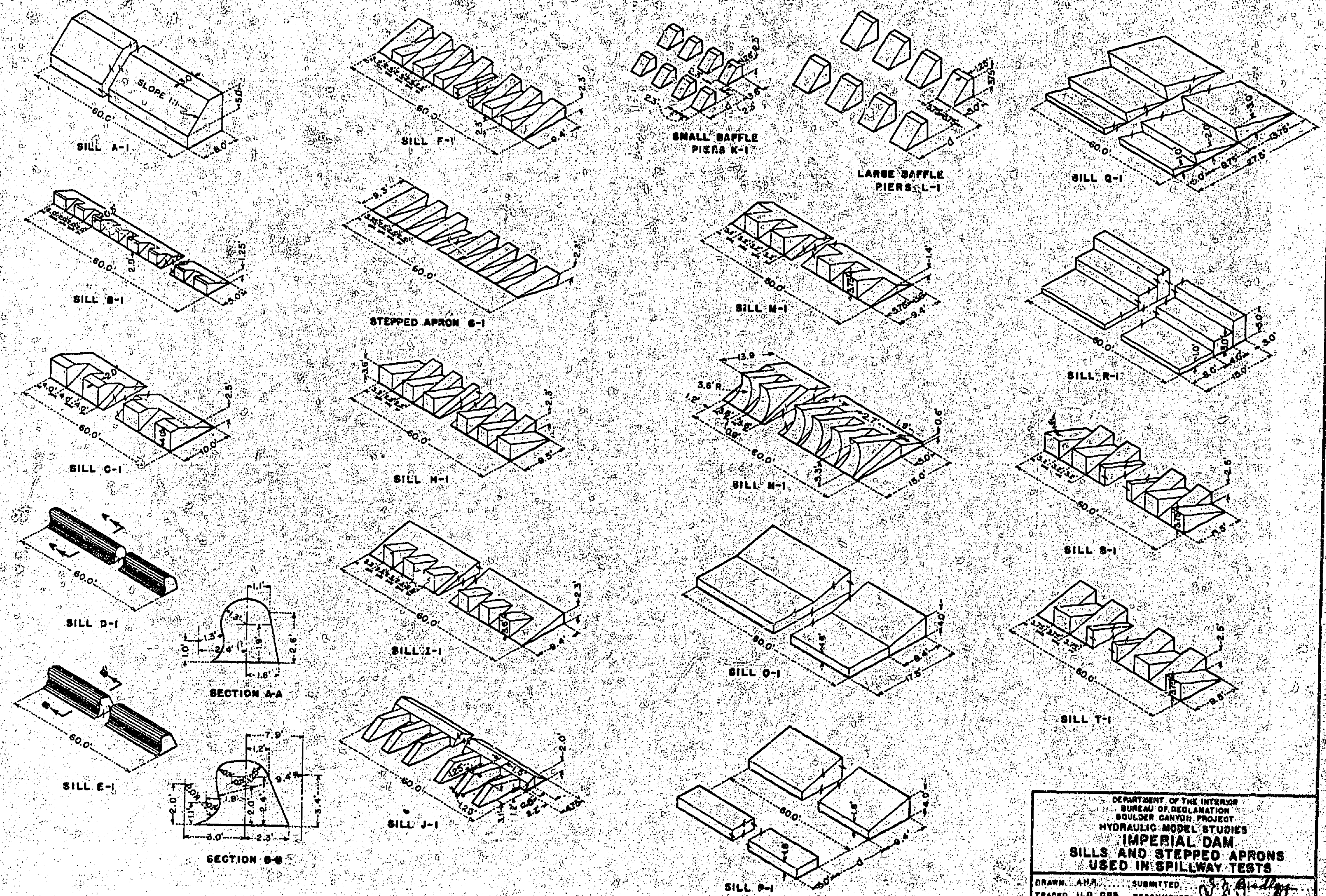
HYDRAULIC MODEL STUDIES

IMPERIAL DAM
PROFILES OF WATER SURFACES AND SAND SURFACES FOR TESTS 1-1, 3-1 AND 5-1

DRAWN H.W.B. SUBMITTED
TRACED A.B.F. O.R.S. RECOMMENDED
CHECKED J.R.B. APPROVED
DENVER, COLO., NOV. 13, 1934
212-D-545

FIGURE 8

FIGURE 7



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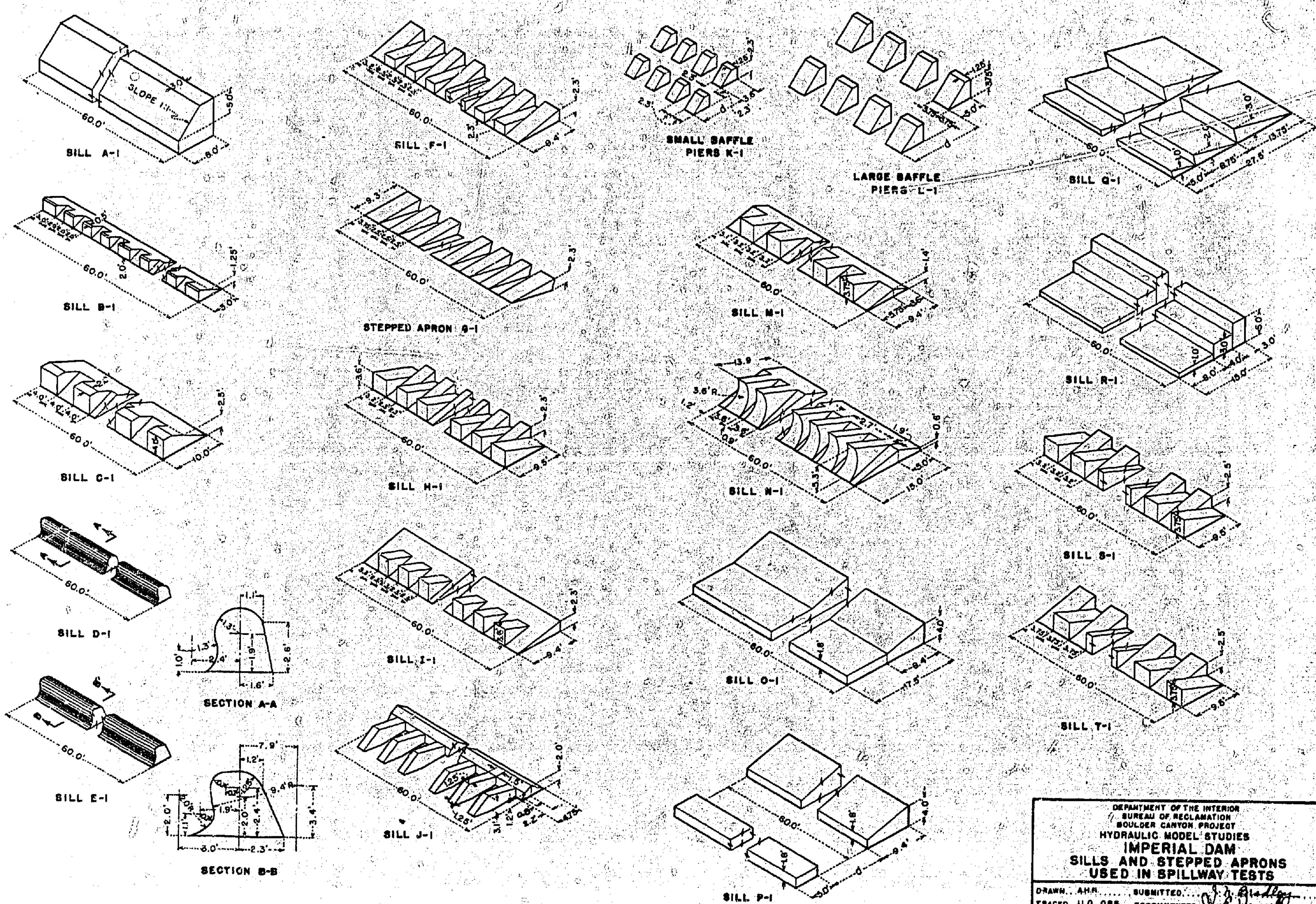
HYDRAULIC MODEL STUDIES
IMPERIAL DAM
SILLS AND STEPPED APRONS USED IN SPILLWAY TESTS

DRAWN. A.H.R. SUBMITTED.
TRACED. I.L.O. C.R.S. RECOMMENDED.
CHECKED. J.H.S. APPROVED.

DENVER, COLO., DEC. 4, 1934 | 212-D-547

FIGURE 7



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BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM
SILLS AND STEPPED APRONS USED IN SPILLWAY TESTS

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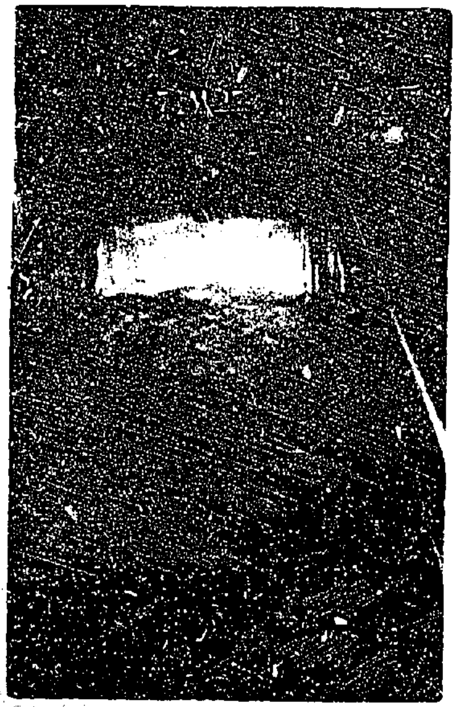
212-D-547

A. ORIGINAL SPILLWAY.

B. ORIGINAL SPILLWAY,
SHOWING SAND BED.



C. MAXIMUM DISCHARGE 86.6 SECOND-FEET
PER FOOT OF CREST.
TAILWATER ELEVATION 167.3.

D. MAXIMUM DISCHARGE 86.6 SECOND-FEET
PER FOOT OF CREST.
TAILWATER ELEVATION 166.0.

CREST LENGTH 1732 FEET. POOL FLOOR AT ELEVATION 152.0.

tests with a maximum discharge using a crest-length of 1,072 feet. Photograph C was taken with the maximum tailwater and photograph D with a lower tailwater depth.

A predicted tailwater rating curve for the river below the dam is shown on figure 8. Upon the completion of the dam and desilting works, the regime of the river below the dam may change considerably due to the dumping of silt into the river, hence, a stilling pool capable of operating satisfactorily for a wide range of tailwater conditions is desired.

As the dam is very long with only a sand and gravel foundation, it is very important that a stilling pool be constructed that will produce a minimum amount of erosion below the sill and not allow the hydraulic jump to leave the pool for any condition likely to be encountered. Undercutting of the paving on such a long dam would probably result in serious damage; therefore, every precaution is necessary in arriving at a safe and dependable design.

b. Scour Tests

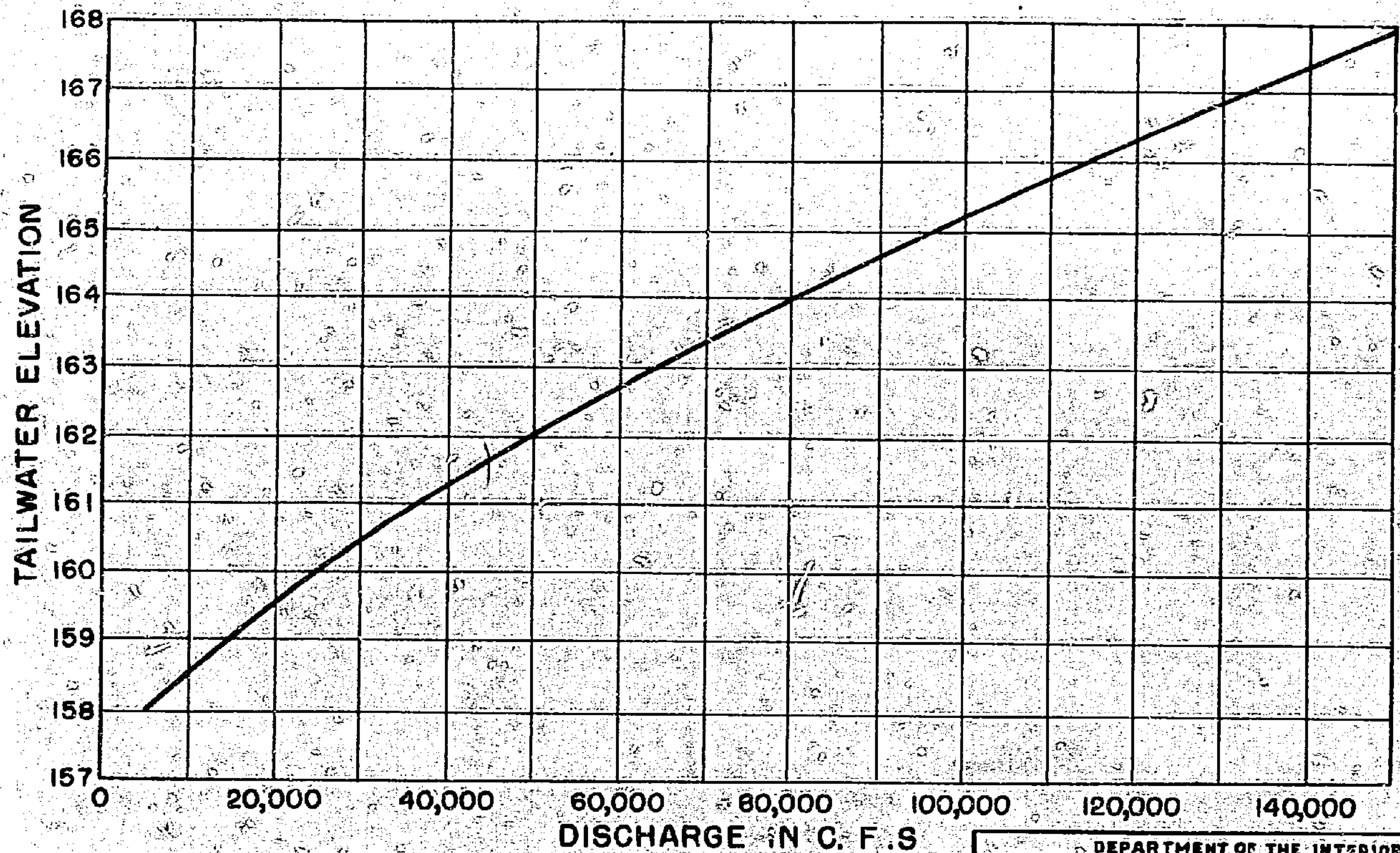
Four other tests in addition to test 1-1 were made at the maximum discharge of 140 second-feet per foot of crest using a 1,072-foot crest-length and a tailwater elevation of 168. These tests constituted a comparison of the effectiveness of the hydraulic jump and the degree of scour in the sand bed for various sills placed on the end of a stilling pool floor 75 feet long.[1]

Test 3-1 (fig. 6) shows a profile of the water surface in the pool taken at 9, 18, and 27 minutes after the start of the test and the sand surface downstream from the sill before and after a 34-minute run. In this case, a rectangular sill 2.5 feet high was installed on the end of the 75-foot pool floor. The water surface in the pool dropped as the test proceeded although the tailwater elevation in the river remained constant. This can be explained by the fact that, as the sand was eroded, the cross section of the river was increased, thus resulting in a reduction of friction and a more efficient channel.

Test 5-1 (fig. 6) was made under the same conditions as test 3-1, except a Rehbock sill was installed on a rectangular sill 2.2 feet high. The water surfaces in the pool were observed at 9,

[1]The length of the pool floor as referred to throughout this report will be defined as that length of horizontal paving from the point at which the sloped apron intersects it to the downstream end of the sill.

FIGURE 8



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT

HYDRAULIC MODEL STUDIES
IMPERIAL DAM
PREDICTED TAILWATER CURVE
FOR BELOW IMPERIAL DAM

DRAWN J.N.B. SUBMITTED Bradley
TRACED O.R.S. RECOMMENDED
CHECKED J.C.M. APPROVED

DENVER, COLO., FEB. 24, 1936 — 212-D-843

26, 43, 54, and 59 minutes after the start of the test, and the surface of the sand bed was measured before and after the test. Again it is evident that the water surface in the pool dropped as the scour proceeded. In this case, however, the front of the jump did not recede uniformly with the time of the test. This can be explained by the fact that as the bed scoured below the sill, the displaced sand formed a dike farther downstream which temporarily reduced the effective area of the river and caused the water surface in the pool to fluctuate. As the test proceeded, this dike gradually eroded and the water surface in the pool dropped accordingly. From this experience it is evident that the effect of the elevation of the river bed on the water surface in the pool is quite important.

It was desired that the water should not rise on the face of the spillway higher than elevation 158 for the maximum discharge as it would interfere with the operation of the ejectors located in the bucket. It was also desired that the jump remain in the pool for a tailwater elevation of approximately 160.0 for the maximum flow.

The layouts previously described failed completely to satisfy these requirements as the jump would not form in the pool for a tailwater below elevation 165.0 for the maximum discharge. The next step in the solution of the problem was to reduce the discharge per foot of crest by lengthening the spillway section to 1,300 feet.

Some 250 stilling pool layouts were tried on the original model using numerous combinations of sills and stepped aprons on pool floors of various lengths, some of which were at elevation 152.0 and the remainder at 150.0. The most representative of the group are discussed or illustrated in the following pages. All comparative tests were made at the maximum discharge of 150,000 second-feet, but the discharge per foot of crest varied, depending upon the total crest-length used.

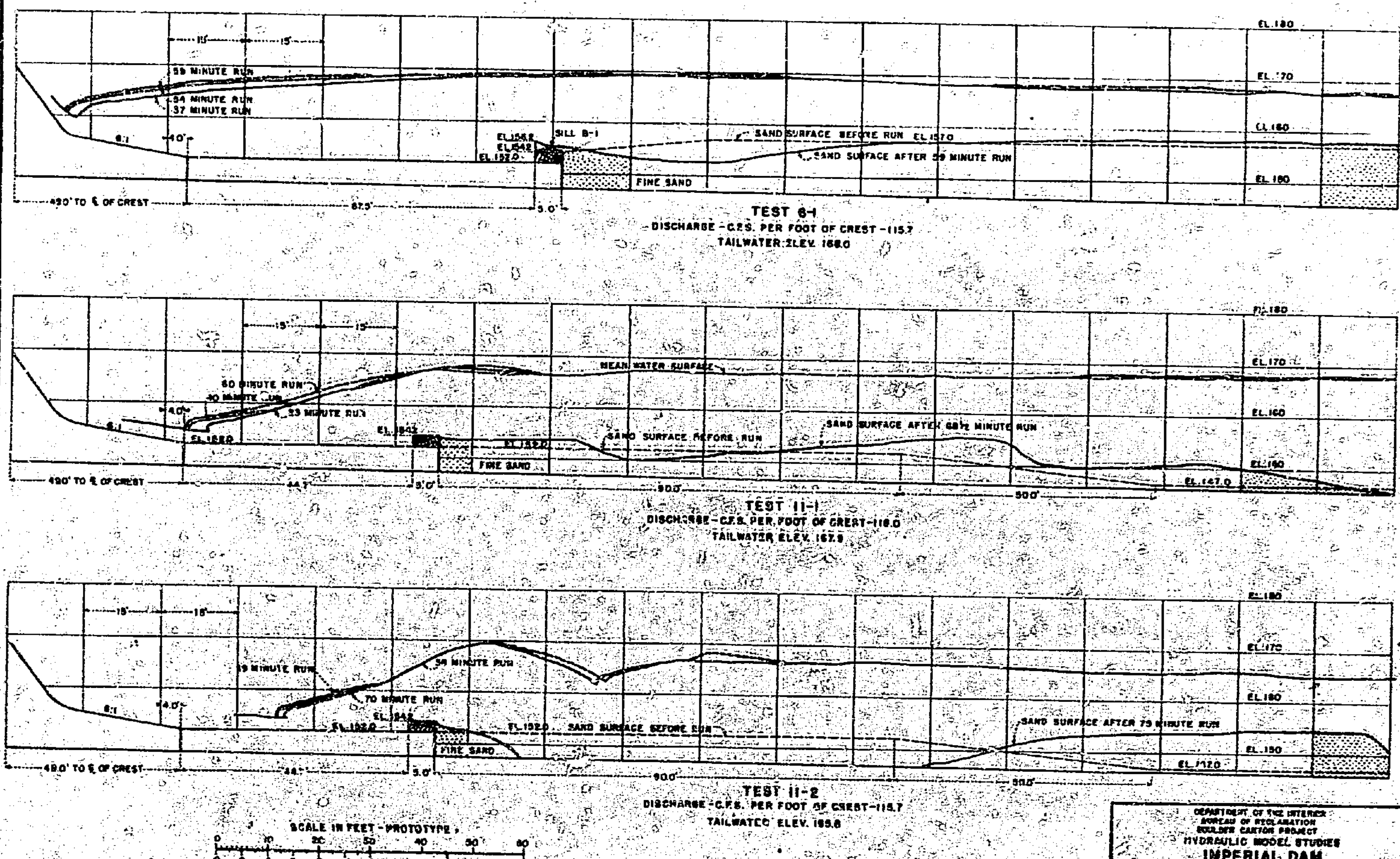
Three different lengths were used on the original model, 1,072, 1,300 and 1,732 feet, with corresponding maximum discharges of 140, 115.4, and 86.6 second-feet per foot of crest. The longer the spillway, the less difficult the solution, as the energy to dissipate per foot of spillway will be less.

B. Crest-length 1,300 Feet, Pool Floor at Elevation 152.0

a. Scour Tests

In test 6-1 (fig. 9), the layout was very similar to that in test 5-1, except that the discharge per foot of crest was reduced to 115.4 second-feet. The reduction in discharge lessened the

FIGURE 9



TEST 6-1
DISCHARGE - C.F.S. PER FOOT OF CREST - 115.7
TAILWATER ELEV. 168.0

TEST 11-1
DISCHARGE - C.F.S. PER FOOT OF CREST - 118.0
TAILWATER ELEV. 167.9

TEST 11-2
DISCHARGE - C.F.S. PER FOOT OF CREST - 115.7
TAILWATER ELEV. 165.8

POOL FLOOR AT ELEVATION 152.0
LENGTH OF CREST 1300 FEET

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BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM
PROFILES OF WATER SURFACES AND SAND SURFACES FOR TESTS 6-1, 11-1 AND 11-2

DRAWN H.W.B. ... SUBMITTED ...
TRACED ... RECOMMENDED ...
CHECKED J.R.B. ... APPROVED ...
DENVER, COLO. ... 212-D-848

scour as would be expected. The water surface profiles taken 37, 54, and 59 minutes after the start of the test and the sand surfaces measured before and after the test are plotted for test 6-1. In this case, the front of the jump advanced up the dam as the test proceeded, as a dike was built above the original sand surface and the effective area of the channel reduced.

Test 7-2 (fig. 10) was made with sill B-1 (fig. 7) moved upstream, reducing the pool length to 35 feet. The remainder of the original floor served as 42 feet of paving below the sill. For the maximum discharge and a tailwater elevation of 168, conditions in the pool and river were fairly good. When the tailwater was lowered, however, they were anything but satisfactory.

Tests 11-1 and 11-2 (fig. 9) were made at the same discharge but different tailwater depths, using a rectangular sill 2.2 feet high installed on the end of a pool floor 49.7 feet long. The water surface advanced up the dam as test 11-1 proceeded, which was again due to a large dike formed in the sand bed. In test 11-2, the tailwater was dropped to elevation 165.8 for the maximum discharge of 115.7 second-feet. At the beginning of the test, the jump swept out of the pool. As erosion proceeded, the jump moved back in the pool taking the form of a double jump with the front of the first roller near the center of the stilling pool and the front of the second roller some distance downstream from the sill, as indicated in test 11-2. Erosion was very severe, but most of this occurred when the jump left the pool.

Tests 14-1 and 14-2 (fig. 10) continue to illustrate the disadvantages of these layouts at the lower tailwater depths. In this case, the height of the sill was increased to elevation 155.0 and the sand bed was leveled to the same elevation. Results, although slightly better, were very similar to those in the preceding two tests. Test 14-1 was made at the maximum discharge and tailwater depth. When the tailwater was lowered 2 feet in test 14-2, a secondary jump was formed and erosion was excessive.

C. Crest-length 1,732 Feet; Pool Floor at Elevation 152.0

a. Comparative Tests

Twenty-seven comparative tests were made at the maximum discharge of 86.6 second-feet per foot of crest for a 1,732-foot crest-length with the pool floor at elevation 152.0. The runs differed only in respect to minor changes, such as the type of sill, length of pool, and shape and type of the sand bed. The layouts for twelve of the most representative runs chosen from the group are shown on figure 11. The sills used are shown in detail on figure 7.

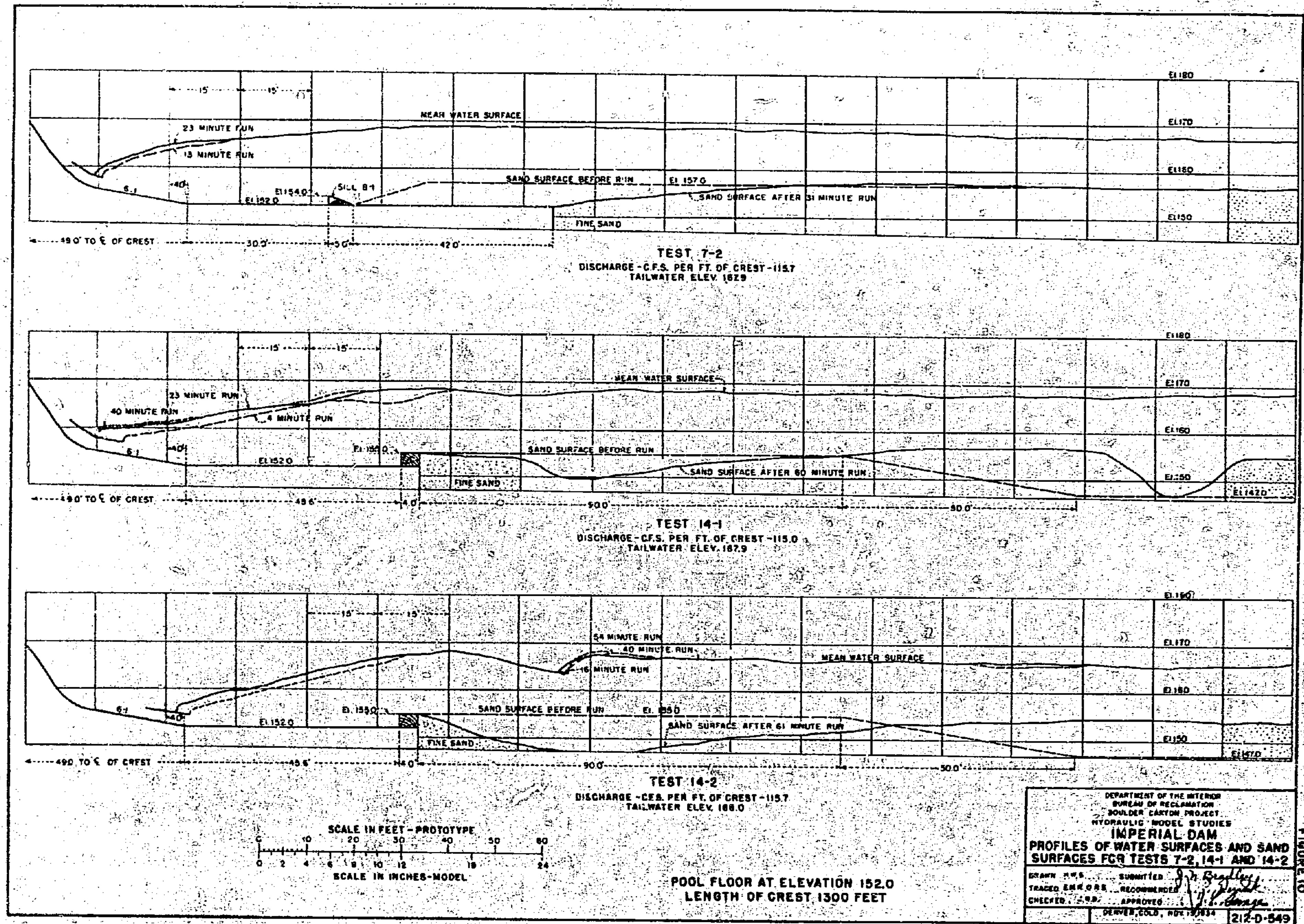
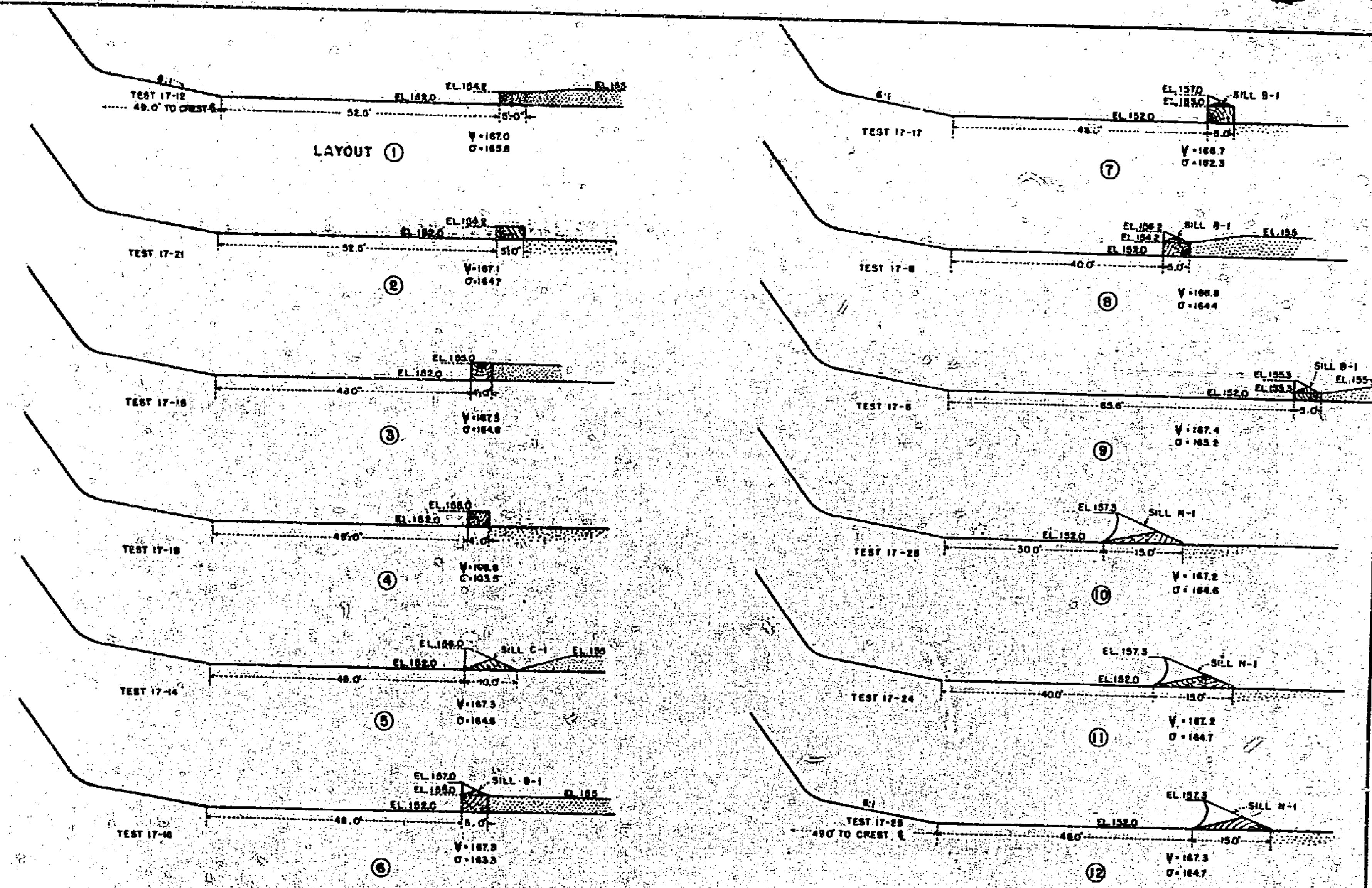

MEAN WATER SURFACE
23 MINUTE RUN
13 MINUTE RUN
SAND SURFACE BEFORE RUN
EL 157.0
SAND SURFACE AFTER 31 MINUTE RUN
EL 154.0
SILL 8.1
EL 152.0
FINE SAND
490' TO ℄ OF CREST
30.0'
3.0'
42.0'
EL 180
EL 170
EL 160
EL 150
TEST 7-2
DISCHARGE - C.F.S. PER FT. OF CREST - 115.7
TAILWATER ELEV. 162.9
MEAN WATER SURFACE
40 MINUTE RUN
23 MINUTE RUN
4 MINUTE RUN
EL 155.0
EL 152.0
SAND SURFACE BEFORE RUN
SAND SURFACE AFTER 60 MINUTE RUN
FINE SAND
EL 142.0
49.6'
4.0'
90.0'
50.0'
TEST 14-1
DISCHARGE - C.F.S. PER FT. OF CREST - 115.0
TAILWATER ELEV. 167.9
54 MINUTE RUN
40 MINUTE RUN
16 MINUTE RUN
MEAN WATER SURFACE
EL 155.0
EL 152.0
SAND SURFACE BEFORE RUN
SAND SURFACE AFTER 61 MINUTE RUN
FINE SAND
EL 147.0
TEST 14-2
DISCHARGE - C.F.S. PER FT. OF CREST - 115.7
TAILWATER ELEV. 168.0
SCALE IN FEET - PROTOTYPE
SCALE IN INCHES - MODEL
POOL FLOOR AT ELEVATION 152.0
LENGTH OF CREST 1300 FEET
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM
PROFILES OF WATER SURFACES AND SAND SURFACES FOR TESTS 7-2, 14-1 AND 14-2
DENVER, COLO.
212-D-549

FIGURE 10



For Sill Details See Figure 7

V = Tailwater elevation recorded when front of jump moved up on dam to elevation 158.0

σ = Tailwater elevation recorded just as jump left the pool.

POOL FLOOR AT ELEVATION 152.0
LENGTH OF CREST 1732 FEET

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BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

IMPERIAL DAM
COMPARATIVE STILLING POOL TESTS

DRAWN A.H.R. ... SUBMITTED ...
TRACED A.V.F., D.R.R. ... RECOMMENDED ...
CHECKED ... A.R.B ... APPROVED ...

FIGURE 11

An accurate account of the shapes of the sand beds was not kept for this set of runs. During these runs particular interest was paid to two points:

(1) The tailwater elevation recorded when the front of the jump advanced up the dam to elevation 158.0, and

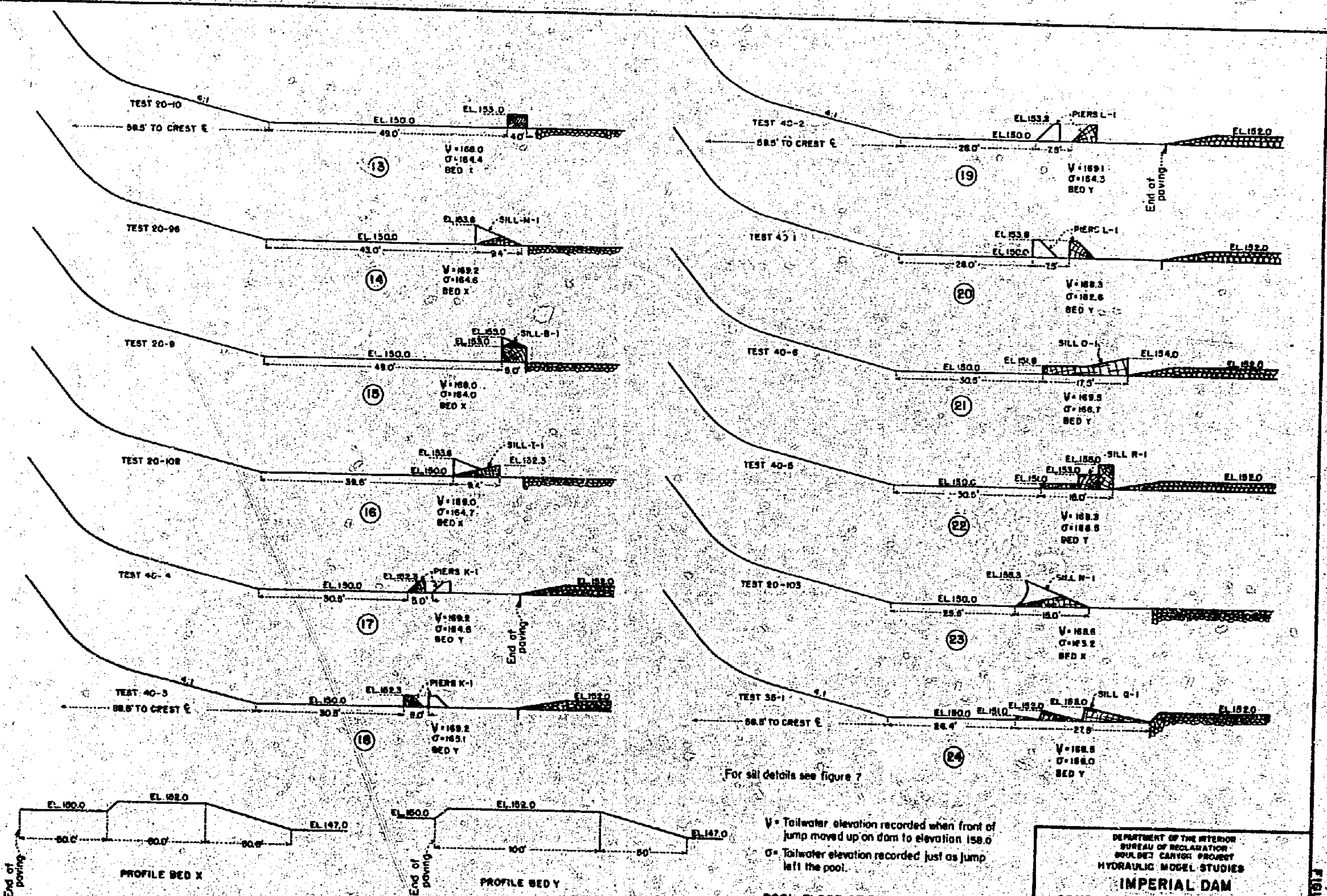
(2) The tailwater elevation at which the jump swept out of the pool.

By referring to figure 15, these two characteristics for any of the pool layouts on figure 11 can be obtained. The lower curve indicates the tailwater elevation at which the jump left the pool and is designated by "σ". The intermediate curve shows the recorded tailwater elevation when the front of the jump moved up the dam to elevation 158.0, and is designated by "ψ". The upper curve, which is "$\psi - \sigma$" shows the permissible range of tailwater for each of the twelve layouts. The best pool, when rated on the two points just mentioned, is the one that requires the highest tailwater to back the front of the jump up on the dam to elevation 158.0, and at the same time the one that will keep the jump confined to the pool for the lowest tailwater elevation. The best layout on figure 11 is 7 which shows a tailwater range of 4.4 feet (fig. 15). This range is inadequate for Imperial Dam.

D. Crest-length 1,300 Feet, Pool Floor at Elevation 150.0

a. Comparative Tests

As the permissible tailwater range was small in the series of tests previously described, the pool floor was dropped 2 feet to elevation 150.0 to increase the tailwater depth in the pool. The 6:1 sloping apron was replaced by one with a slope of 4:1 to confine the front of the jump to a shorter horizontal distance for the various discharges and tailwater depths. Dropping the pool floor increased the tailwater range approximately 2 feet. Comparative runs were made with this revision involving some 170 pool layouts. The most representative of the group are shown on figures 12, 13, and 14. The layouts differed in types of sills, length of pool floor, types of stepped aprons, combinations of stepped aprons and sills, and shape and type of the sand beds below the sills. These comparative runs were judged mainly from the two points previously mentioned. The pool characteristics for the 36 representative layouts are shown on figure 15. There was a wide variation in the tailwater range for these layouts which depend not only on the length of apron and type of sill but also on the shape and elevation of the sand bed downstream from the sill. Contrary to expectations, the most complicated types of sills and stepped aprons gave the best results. In



For sill details see figure 7

V = Tailwater elevation recorded when front of jump moved up on dam to elevation 158.0

σ = Tailwater elevation recorded just as jump left the pool.

POOL FLOOR AT ELEVATION 150.0
LENGTH OF CREST 1300 FEET
LAYOUTS WITH SILLS

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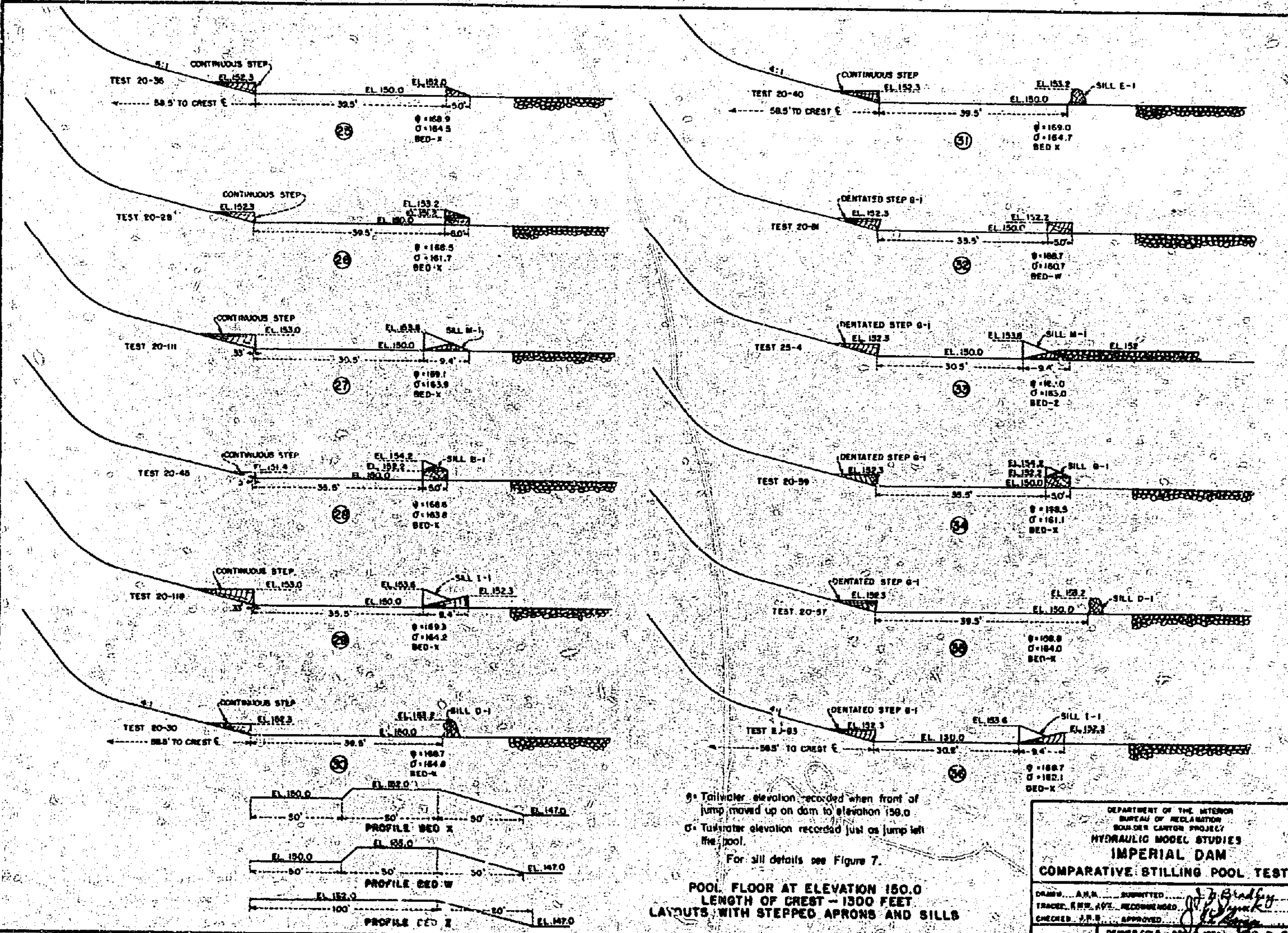
HYDRAULIC MODEL STUDIES

IMPERIAL DAM
COMPARATIVE STILLING POOL TESTS

DRAWN A.H.R. SUBMITTED J.N. Bradley
TRACED W.H.B., E.E.B. RECOMMENDED J. E. Warnock
CHECKED A.H.R. APPROVED J. L. Savage
DENVER, COLO. NOV. 2, 1934. 212-D-551

FIGURE 12



φ= Tailwater elevation recorded when front of jump moved up on dam to elevation 158.0

σ= Tailwater elevation recorded just as jump left the pool.

For sill details see Figure 7.

POOL FLOOR AT ELEVATION 150.0
LENGTH OF CREST – 1300 FEET
LAYOUTS WITH STEPPED APRONS AND SILLS

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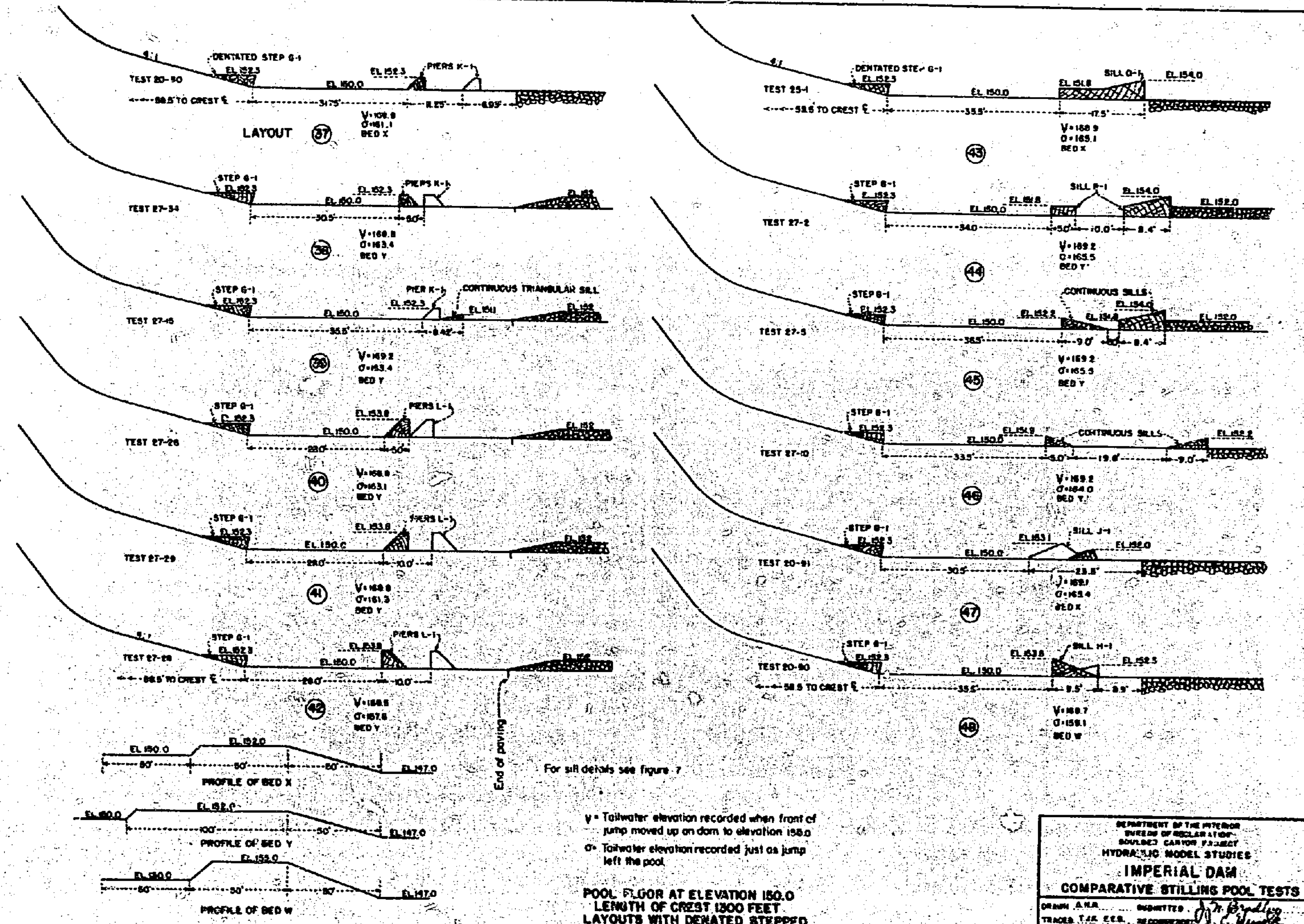
HYDRAULIC MODEL STUDIES
IMPERIAL DAM
COMPARATIVE STILLING POOL TESTS

DRAWN A.N.R. SUBMITTED
TRACED E.W.R. RECOMMENDED
CHECKED J.R.B. APPROVED

DENVER, COLO. 1934 162-D-662

FIGURE 14



For sill details see figure 7

V = Tailwater elevation recorded when front of jump moved up on dam to elevation 158.0

σ = Tailwater elevation recorded just as jump left the pool

POOL FLOOR AT ELEVATION 150.0
LENGTH OF CREST 1300 FEET
LAYOUTS WITH DENTATED STEPPED APRON AND SILLS

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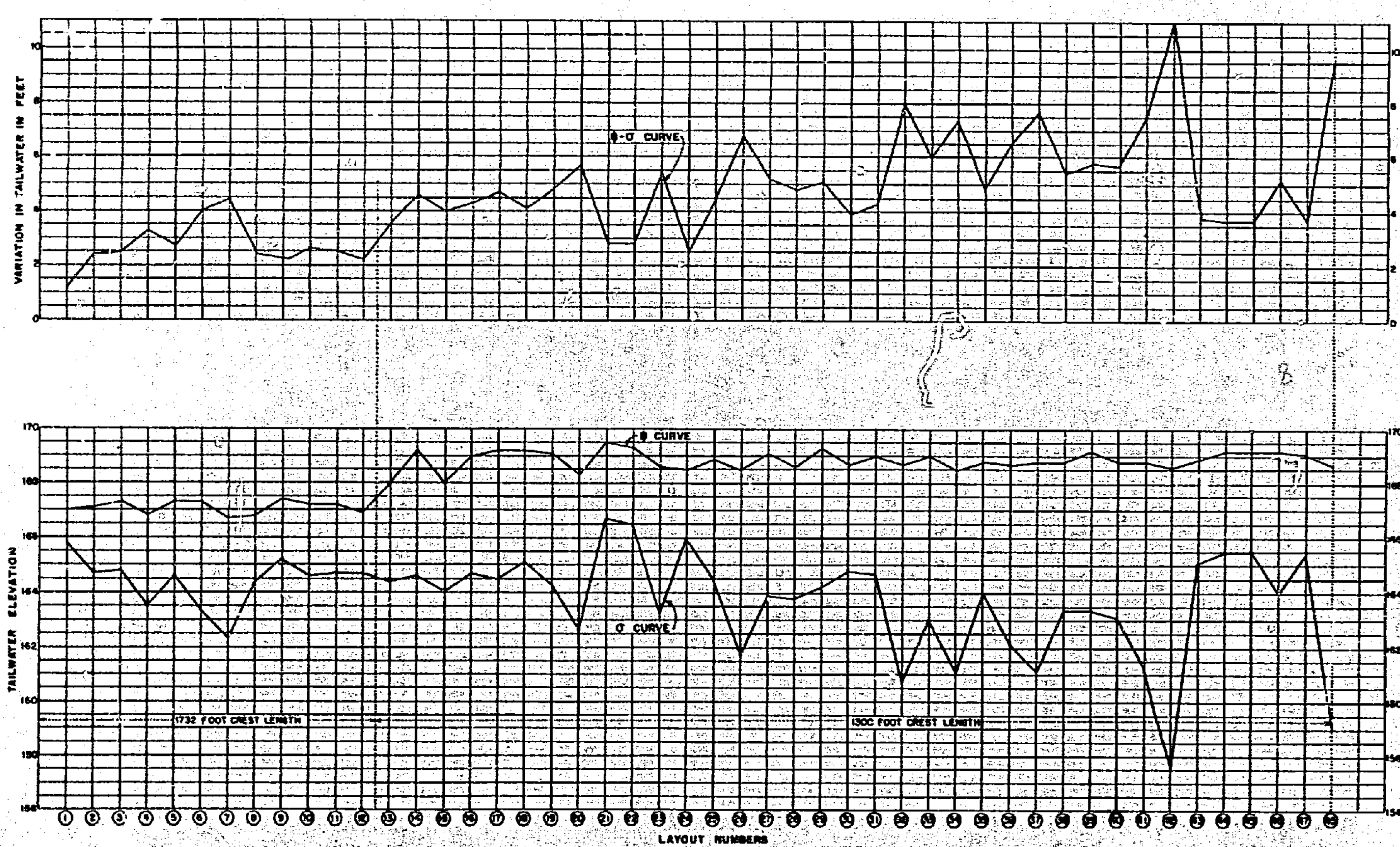
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM
COMPARATIVE STILLING POOL TESTS

DRAWN A.N.R. SUBMITTED
TRACED T.A.R. E.E.S. RECOMMENDED
CHECKED J.R.D. APPROVED
DENVER, COLO., DEC. 3, 1934
212-D-553



FOR STILLING POOL LAYOUTS
SEE FIGURES 11, 12, 13, AND 14.

φ = Tailwater elevation recorded when front of jump moved up on dam face to elevation 158.0

σ = Tailwater elevation recorded just as jump left the pool.

φ-σ = Permissible tailwater range for each layout.

All comparative runs were made at the maximum designed discharge of 150,000 c.f.s.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM
CURVES SHOWING TAILWATER RANGES FOR COMPARATIVE RUNS

DRAWN J.R.B. SUBMITTED
TRACED R.H. LETT RECOMMENDED
CHECKED J.R.B. APPROVED
DENVER, COLO.

FIGURE 18

the usual case, the simpler ones are the most satisfactory. Layouts 42 and 48, shown on figure 14, were outstanding in their range of tailwater and effectiveness (fig. 15). It will be noted that the beds are different in the two. In both cases, the construction of the sills and stepped aprons would be complicated. More will be said about these two layouts subsequently.

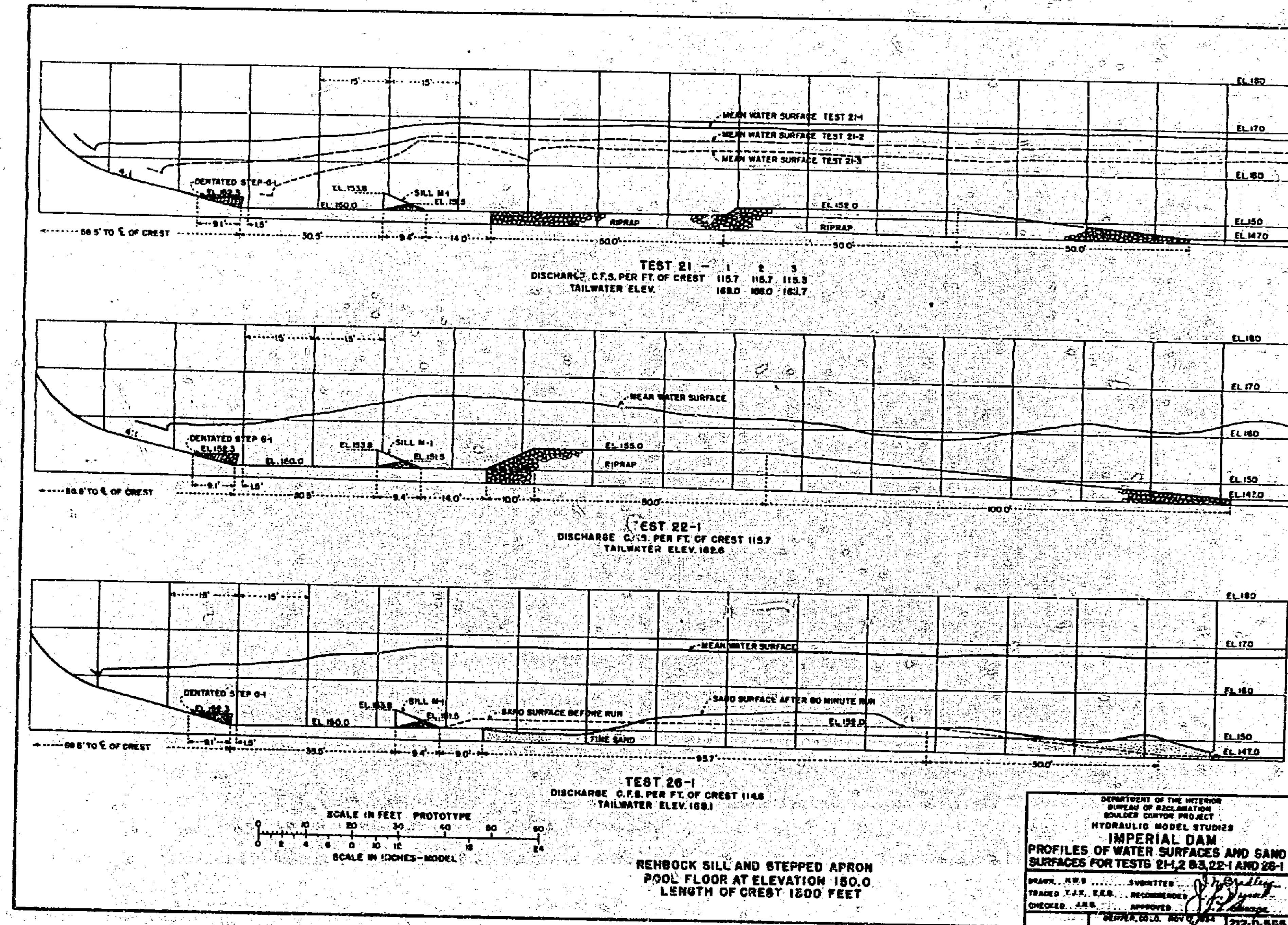
b. Individual Tests

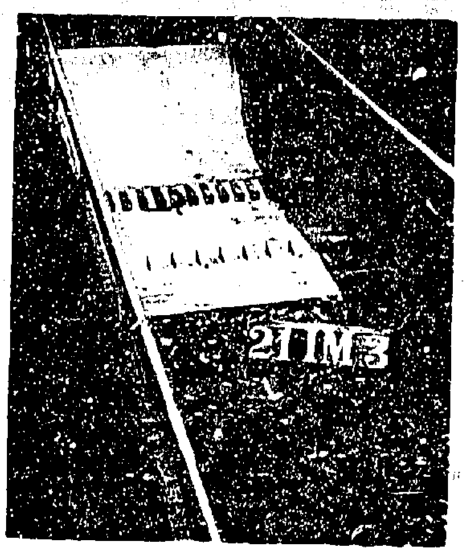
Profiles of the water surfaces in the pool and the sand surfaces below the sill are included in this report for a few of the most promising layouts, shown on figures 12, 13, and 14. In tests 21 and 22 (fig. 16), the layouts are identical, except for the shape of the sand bed below the sill, and are comparable to layout 33 (fig. 13). A dentated step (C-1, fig. 7) was installed on the end of the sloped apron and a dentated sill (M-1, fig. 7) was placed on the end of a pool floor 40 feet long. The paving was extended 14 feet downstream from the sill and the beds were paved with riprap to prevent them from changing shape during the runs. Test 21 shows the water surface plotted for the maximum discharge, using three different tailwater elevations; namely, 169.0, 166.0, and 163.7. Conditions were quite satisfactory for the first two, but a secondary jump formed when the tailwater was lowered to 163.7. A reference to layout 33 (fig. 15) shows a tailwater range of 6.0 feet. Plate II-A shows the layout for test 21. Plates II-B and -C show the pool in operation for a discharge of approximately 115 second-feet per foot of crest using two tailwater elevations; namely, 166.0 and 163.7. The secondary jump can be seen on photograph C. Plate II-D is a side view of the jump for the same discharge and a tailwater elevation of 169.0. In test 22-1, the tailwater elevation was dropped to 162.6, and the high bed directly downstream from the sill prevented the formation of a secondary jump. On the other hand, the bed velocities were much higher in test 22-1 than in test 21-3, which is a very undesirable feature. The high velocities and shallow depth are responsible for the surface waves created above the bed in test 22-1.

The layout in test 26-1 (fig. 16) was similar to that in tests 21 and 22, except that the pool was lengthened to 45 feet, and the riprap was replaced by sand leveled to elevation 152.0. The test was made at the maximum discharge of 114.6 second-feet per foot of crest and a tailwater elevation of 168.1 A profile was made of the river bed at the end of a 60-minute run.

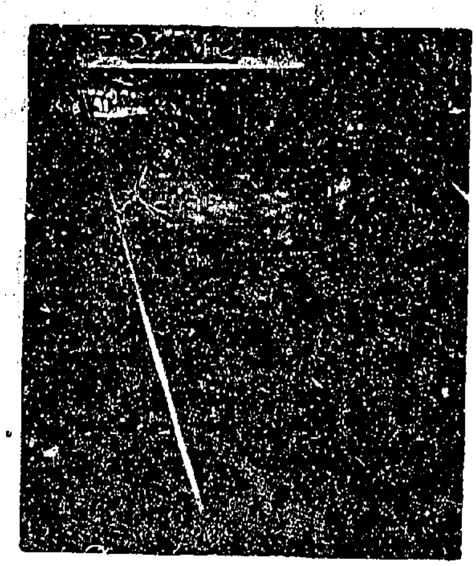
Tests 36-1, 37-1, and 38-1 (fig. 17) show profiles of the water and sand surfaces obtained on pier layouts for the maximum discharge and tailwater depth. In test 38-1, small staggered piers (K-1, fig. 7) with vertical faces upstream were placed on the end of

FIGURE 16

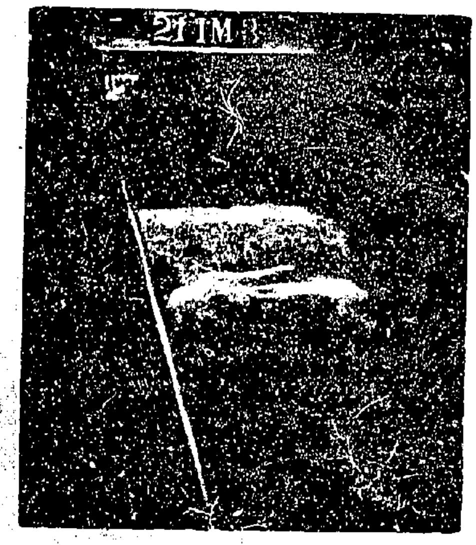

MEAN WATER SURFACE TEST 21-1
MEAN WATER SURFACE TEST 21-2
MEAN WATER SURFACE TEST 21-3
DENTATED STEP G-1
SILL M-1
RIPRAP
EL. 180
EL. 170
EL. 160
EL. 150
EL. 147.0
EL. 150.0
EL. 152.0
EL. 155.0
EL. 153.8
EL. 151.5
58.5' TO ℄ OF CREST
TEST 21 — 1 2 3
DISCHARGE C.F.S. PER FT. OF CREST 115.7 115.7 115.5
TAILWATER ELEV. 168.0 166.0 163.7
MEAN WATER SURFACE
TEST 22-1
DISCHARGE C.F.S. PER FT. OF CREST 115.7
TAILWATER ELEV. 162.6
SAND SURFACE BEFORE RUN
SAND SURFACE AFTER 80 MINUTE RUN
FINE SAND
TEST 26-1
DISCHARGE C.F.S. PER FT. OF CREST 114.6
TAILWATER ELEV. 168.1
SCALE IN FEET PROTOTYPE
SCALE IN INCHES-MODEL
REHBOCK SILL AND STEPPED APRON
POOL FLOOR AT ELEVATION 150.0
LENGTH OF CREST 1500 FEET
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM
PROFILES OF WATER SURFACES AND SAND SURFACES FOR TESTS 21-1,2 & 3, 22-1 AND 26-1
DRAWN... SUBMITTED
TRACED... RECOMMENDED
CHECKED... APPROVED
DENVER, COLO.
212-D-555



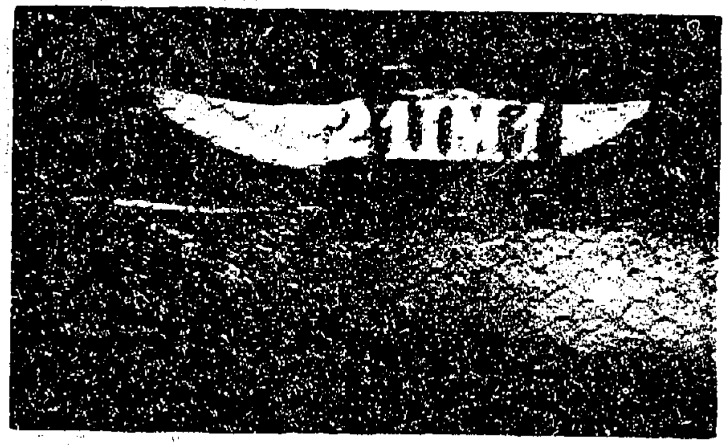
A. SET-UP WITH DENTATED STEPPED APRON AND REHBOCK SILL.



B. MAXIMUM DISCHARGE 115.7 SEC.-FT. PER FOOT OF CREST. TAILWATER ELEVATION 166.0.

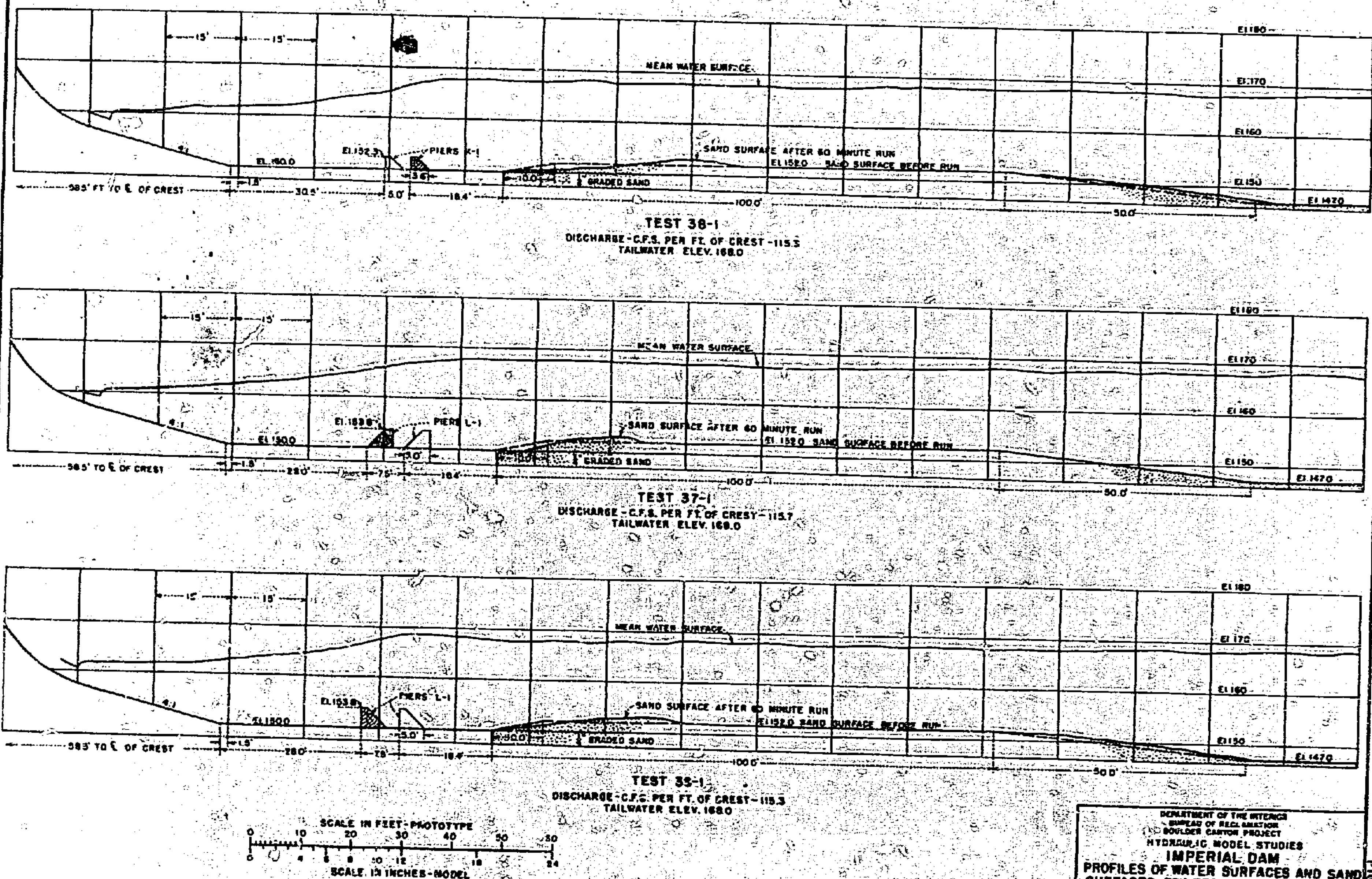


C. MAXIMUM DISCHARGE 115.3 SEC.-FT. PER FOOT OF CREST. TAILWATER ELEVATION 163.7.



D. SIDE VIEW OF JUMP WITH DISCHARGE OF 115.7 SECOND-FEET PER FOOT OF CREST. TAILWATER ELEVATION 169.0.

DENTATED STEP AND REHBOCK SILL.
CREST LENGTH 1300 FEET. POOL FLOOR AT ELEVATION 150.0.



BAFFLE PIERS
POOL FLOOR AT ELEVATION 150.0
LENGTH OF CREST 1300 FEET

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

IMPERIAL DAM

PROFILES OF WATER SURFACES AND SAND SURFACES FOR TESTS 38-1, 37-1 AND 35-1

DRAWN H.W.B. ... SUBMITTED ...
TRACED H.W. ORS. ... RECOMMENDED ...
CHECKED J.R.B. ... APPROVED ...
DENVER, COLO. NOV. 30, 1934

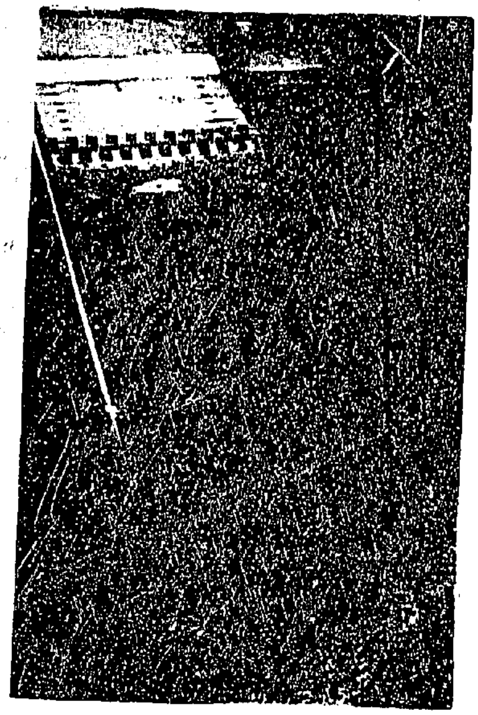
212-D-556

FIGURE 17

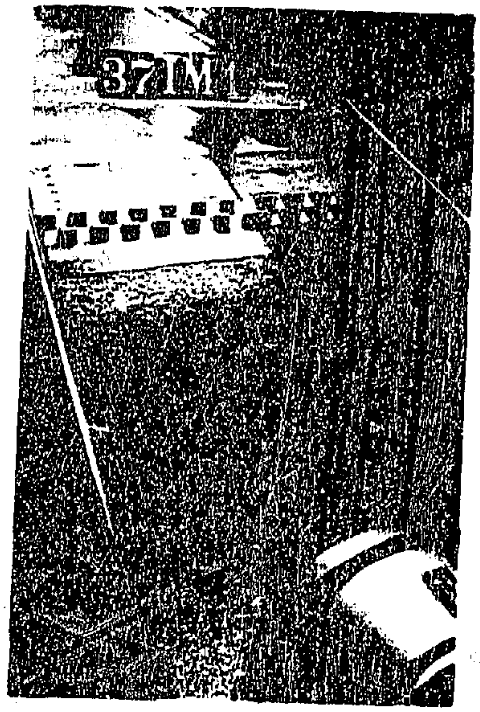
a pool floor 39 feet long. The stepped apron was removed previous to these tests. Plate III-A is a view of the layout taken after a 60-minute run, and plate III-D shows the spillway in operation at a discharge of 115.4 second-feet per foot of crest, with a tailwater elevation of 166.0. In test 37-1, the large, staggered piers (L-1, fig. 7) were placed with their vertical faces downstream on a pool floor 40.5 feet long. Plate III-B shows this layout photographed after a 60-minute run, and plate IV-B is a side view of the jump as it was leaving the pool for a tailwater elevation 164.3. In test 36-1, the same large piers were located in identical positions on the pool floor, except that their vertical faces were turned upstream (plate III-C). Plate IV-A shows a side view of the jump as it was leaving the pool in this layout for a tailwater elevation of 162.6. In none of the three tests was erosion of the sand bed appreciable; however, the sand in this case was graded uniformly to approximately 1/4 inch while in previous studies, fine sand was used. Tests 36-1, 37-1, and 38-1 (fig. 17) are identical with layouts 18, 19, and 20, respectively, on figure 12. Referring to the curves on figure 15, it can be seen that the tailwater ranges for these are not large. Layout 20, which is the best of the three, shows a range of only 5.7 feet.

Tests 29-1, 30-1, and 31-1 (fig. 18) are practically duplicates of tests 36-1, 37-1, and 38-1, except that a dentated step was installed on the sloping apron. Erosion was excessive for test 31-1, in which the small piers were turned with their vertical faces downstream, and less pronounced in test 30-1, in which the large piers were placed with their vertical faces downstream.

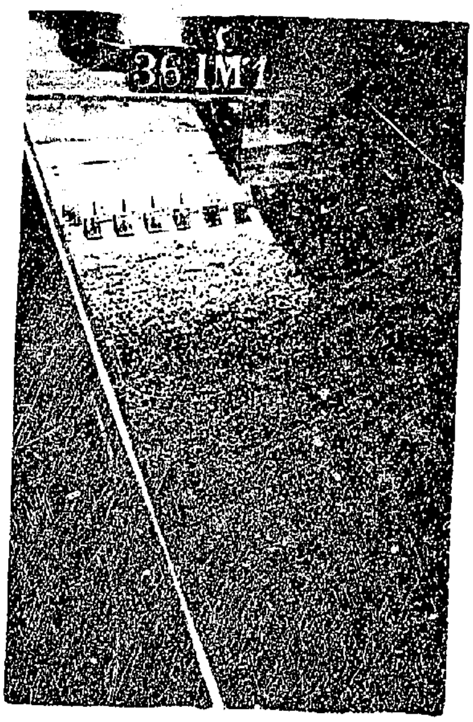
Plate V-A is a view of the layout for test 31-1 taken after a 61-minute run, and B shows the layout for test 30-1 after a 67-minute run. Test 29-1 (fig. 18) conclusively shows that the best results while using piers were obtained with the large ones installed with their vertical faces upstream. This is especially true from the standpoint of erosion. Erosion of the sand bed during this test was negligible as can be seen on figure 18 and plate V-C. None of the three tests were duplicated in the comparative runs. There are two layouts, however, that resemble tests 31-1 and 29-1. Layout 38 on figure 14 is the same as the layout in test 31-1, except that the piers are reversed. Layout 42 (fig. 14) is the same as that in test 29-1, except that the pier spacings are slightly different. Layout 38 (fig. 15) shows a tailwater range of 5.4 feet with a minimum tailwater at elevation 163.4, while layout 42 shows a range of 11.0 feet with a minimum tailwater elevation of 157.6 which is regarded as very satisfactory characteristics. Unusual results were obtained by the use of variations of the compound Rehbock sill (sills F-1, H-1, S-1, and T-1 on figure 7). In test 44-5 (fig. 19) sill S-1 was installed on the end of a pool floor



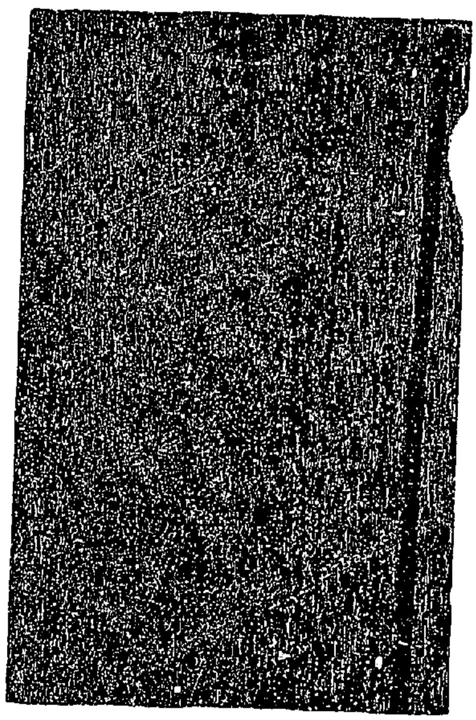
A. SET-UP WITH SMALL PIERS.
VERTICAL FACES UPSTREAM.



B. SET-UP WITH LARGE PIERS.
VERTICAL FACES DOWNSTREAM.

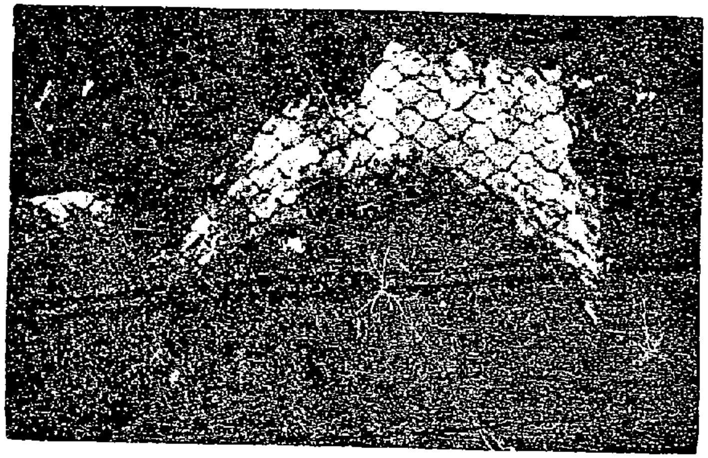


C. SET-UP WITH LARGE PIERS.
VERTICAL FACES UPSTREAM.

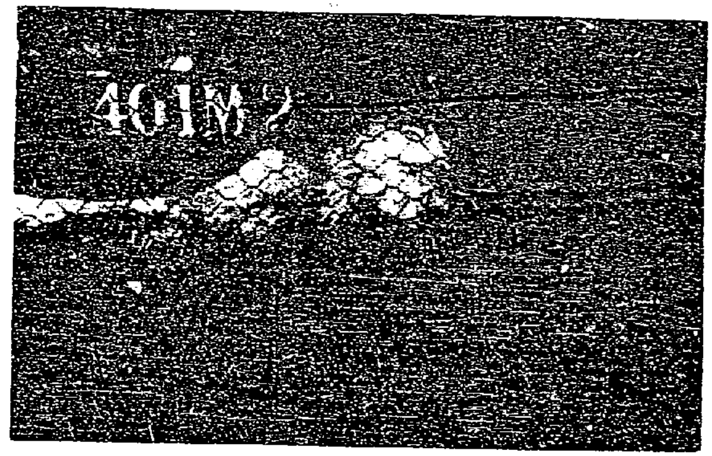


D. SMALL PIERS VERTICAL FACES UPSTREAM.
DISCHARGE 115.4 SECOND-FEET PER FOOT
OF CREST. TAILWATER ELEVATION 165.0.

PIERS ONLY.
CREST LENGTH 1300 FEET. POOL FLOOR AT ELEVATION 150.0.

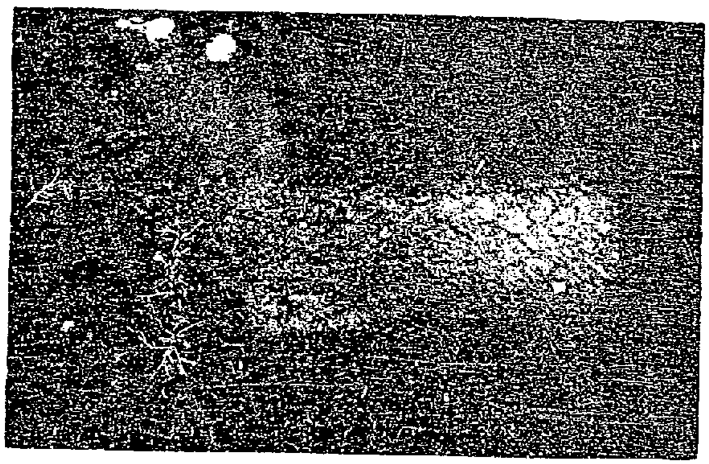


A. LARGE PIERS - VERTICAL FACES UPSTREAM. DISCHARGE 115.4 SECOND-FEET PER FOOT OF CREST. TAILWATER ELEVATION 162.6.



B. LARGE PIERS - VERTICAL FACES DOWNSTREAM. DISCHARGE 115.4 SECOND-FEET PER FOOT OF CREST. TAILWATER ELEVATION 164.3.

BAFFLE PIERS ONLY



C. DISCHARGE 115.4 SECOND-FEET PER FOOT OF CREST. TAILWATER ELEVATION 166.0.

D. DISCHARGE 115.4 SECOND-FEET PER FOOT OF CREST. TAILWATER ELEVATION 162.4.

DENTATED STEP AND COMPOUND REHBOCK SILL.
CREST LENGTH 1300 FEET. POOL FLOOR AT ELEVATION 150.0.

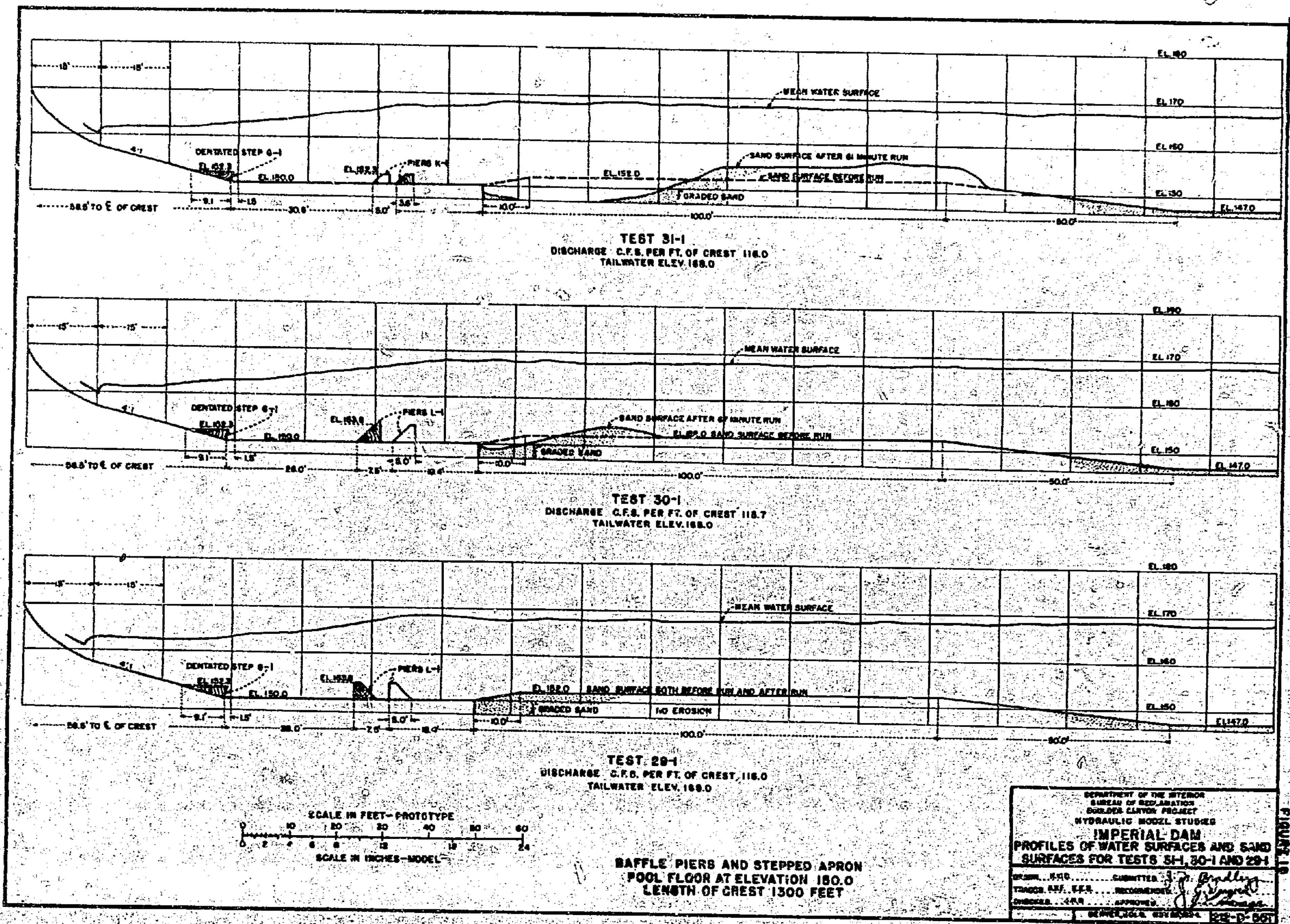
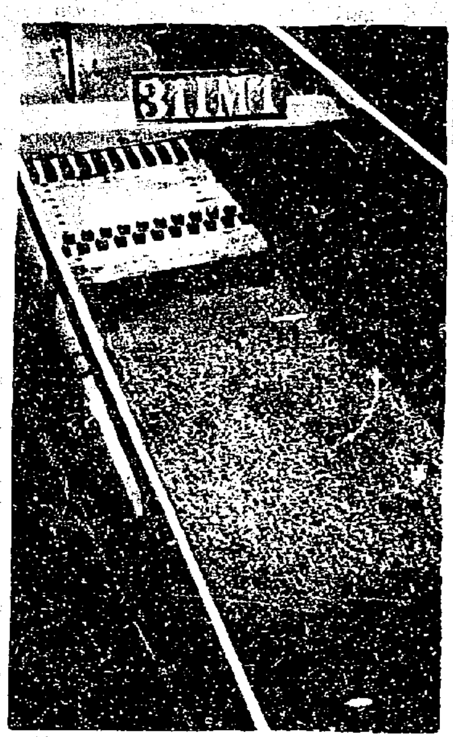
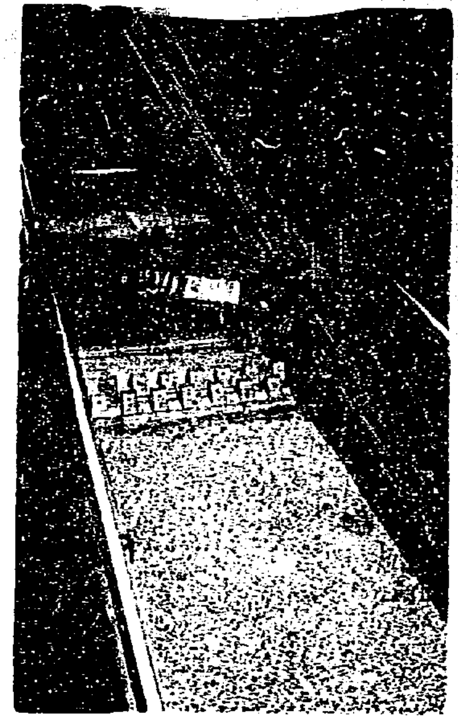

MEAN WATER SURFACE
SAND SURFACE AFTER 61 MINUTE RUN
SAND SURFACE BEFORE RUN
GRADED SAND
DENTATED STEP G-1
PIERS K-1
EL. 150.0
EL. 152.0
EL. 147.0
58.5' TO ℄ OF CREST
100.0'
50.0'
TEST 31-1
DISCHARGE C.F.S. PER FT. OF CREST 116.0
TAILWATER ELEV. 168.0
PIERS L-1
SAND SURFACE AFTER 67 MINUTE RUN
TEST 30-1
DISCHARGE C.F.S. PER FT. OF CREST 115.7
TAILWATER ELEV. 168.0
SAND SURFACE BOTH BEFORE RUN AND AFTER RUN
NO EROSION
TEST 29-1
DISCHARGE C.F.S. PER FT. OF CREST 116.0
TAILWATER ELEV. 168.0
SCALE IN FEET—PROTOTYPE
SCALE IN INCHES—MODEL
BAFFLE PIERS AND STEPPED APRON
POOL FLOOR AT ELEVATION 150.0
LENGTH OF CREST 1300 FEET
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM
PROFILES OF WATER SURFACES AND SAND SURFACES FOR TESTS 31-1, 30-1 AND 29-1
DENVER, COLO.

FIGURE 18



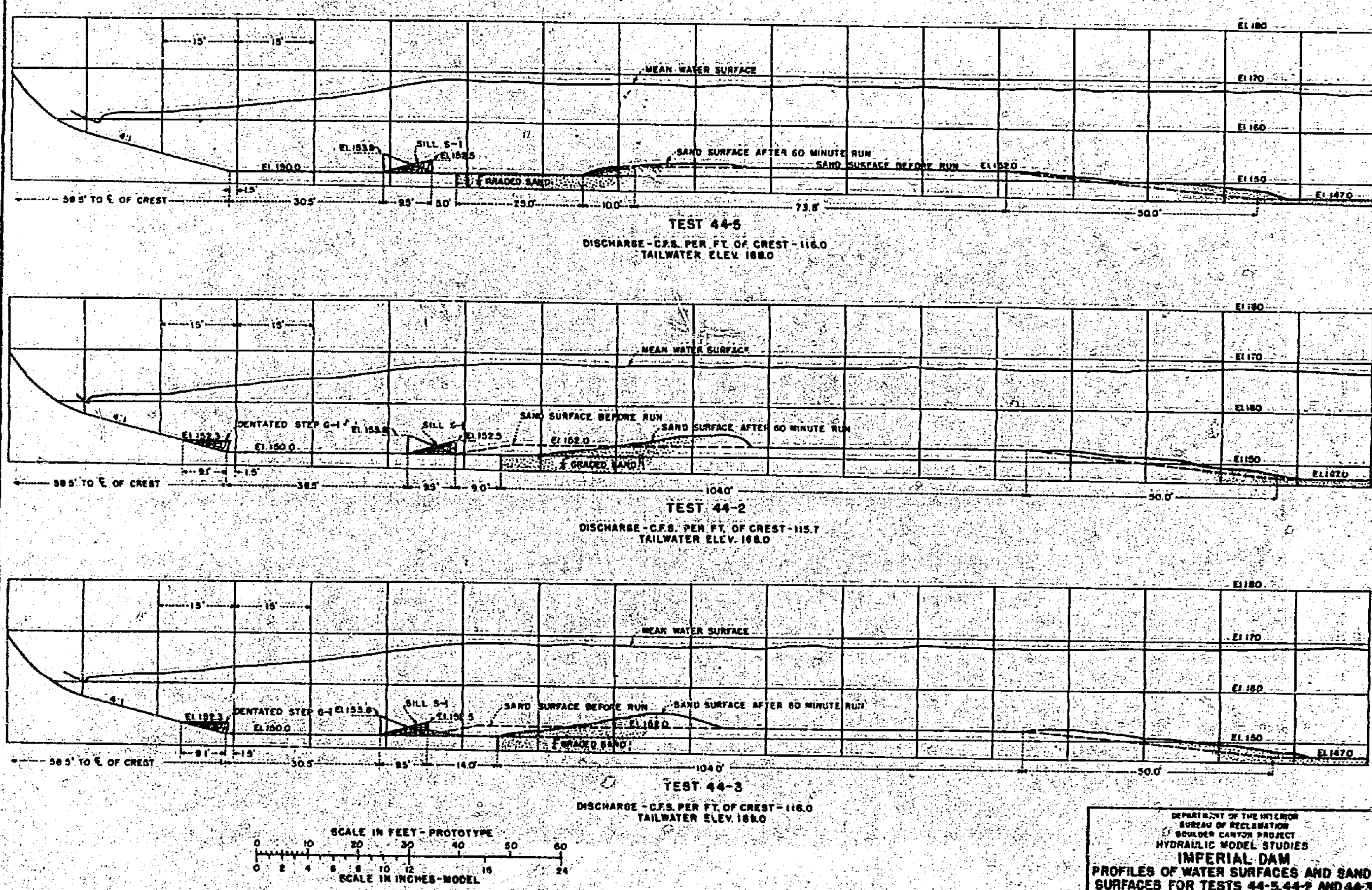
A. SMALL PIERS - VERTICAL FACES DOWNSTREAM. SAND BED AFTER 61-MINUTE RUN.

B. LARGE PIERS - VERTICAL FACES DOWNSTREAM. SAND BED AFTER 67-MINUTE RUN.



C. LARGE PIERS - VERTICAL FACES UPSTREAM. SAND BED AFTER 62.5-MINUTE RUN.

DENTATED STEP AND PIERS.
CREST LENGTH 1300 FEET. POOL FLOOR AT ELEVATION 150.0.



COMPOUND REHBOCK SILL
POOL FLOOR AT ELEVATION 150.0
LENGTH OF CREST 1200 FEET

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

IMPERIAL DAM

PROFILES OF WATER SURFACES AND SAND SURFACES FOR TESTS 44-5, 44-2 AND 44-3

DRAWN H.E.B. SUBMITTED
TRACED H.E.B. DRB. RECOMMENDED
CHECKED J.E.B. APPROVED
DENVER, COLO.
272-D-559

FIGURE 19

40 feet long. The stepped apron was omitted in this case. Erosion of the sand bed was practically negligible. Plate VI-A shows the layout and sand bed photographed after a 60-minute run. There was no comparative run made for this layout and as a result, the tailwater range is unknown.

Tests 44-2 and 44-3 (fig. 19) were made with sill S-1 on pool floors 46 and 40 feet long, respectively. The dentated step G-1 was again installed on the end of the sloping apron. Plate VI-B and -C show the layouts and the sand beds after runs of 60 minutes duration. Erosion in each case is noticeable. Layout 48 (fig. 14) is similar to the layout for test 44-2, except that the beds differ, and sill H-1 was used instead of sill S-1. Referring to figure 15, layout 48 has a tailwater range of 9.5 feet with a minimum tailwater elevation of 159.1 for the maximum discharge. This is the second best layout tried. It should be noted, however, that the highest portion of the bed for layout 48 was at elevation 155 (fig. 14), while for test 44-2 (fig. 19) the bed was at elevation 152. The higher bed should produce the wider tailwater range. Plate IV-C and -D shows side views of the hydraulic jump for the layout in test 44-2 (fig. 19) for the maximum flow and tailwater elevations of 166.0 and 162.4, respectively. Dropping the river bed from elevation 155 to 152 decreased the tailwater range by approximately three feet.

c. Conclusions

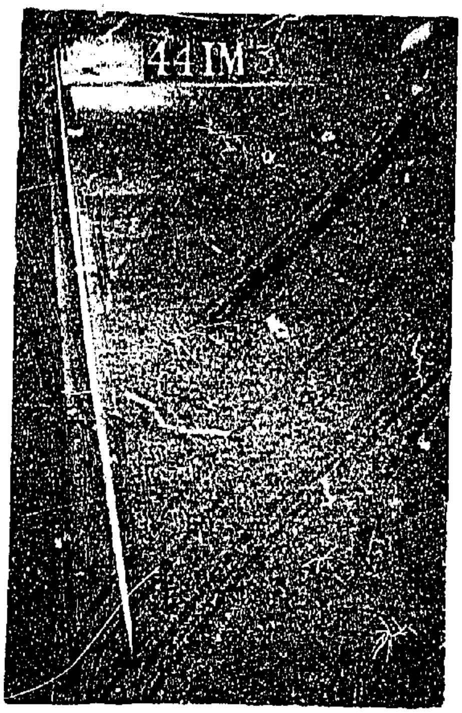
Of the numerous stilling pools tested, layouts 42 and 48 (fig. 14) had outstanding characteristics, especially with respect to the minimum allowable tailwater and the tailwater range (fig. 15).

The material on stilling pools included in this report is a condensation of the more favorable results obtained in a long series of tests.

4. PRESSURES ON DOWNSTREAM FACE OF ORIGINAL DESIGN

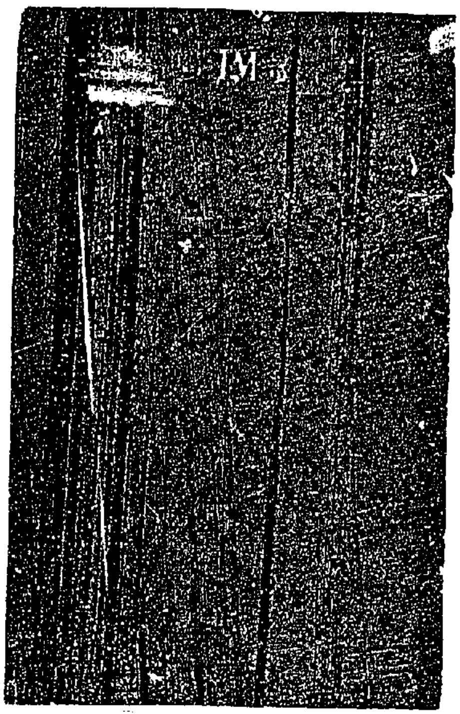
A. Approach Floor at Elevation 154.0

The pressures on the face of the dam were investigated by the installation of fifteen piezometers on the dam face as shown on figure 4. The piezometer pressures and water surface measurements are plotted on figure 20 for discharges ranging from 38.45 to 166.37 second-feet per foot of crest for a crest-length of 1,300 feet. The maximum designed discharge for that crest-length is 115.68 second-feet per foot.

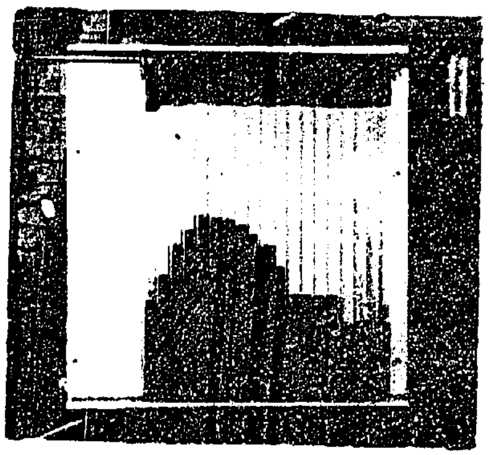


A. COMPOUND REHBOCK SILL. SAND BED AFTER 60-MINUTE RUN.

B. DENTATED STEP AND COMPOUND REHBOCK SILL ON 45-FOOT APRON. SAND BED AFTER 60.5 MIN. RUN.

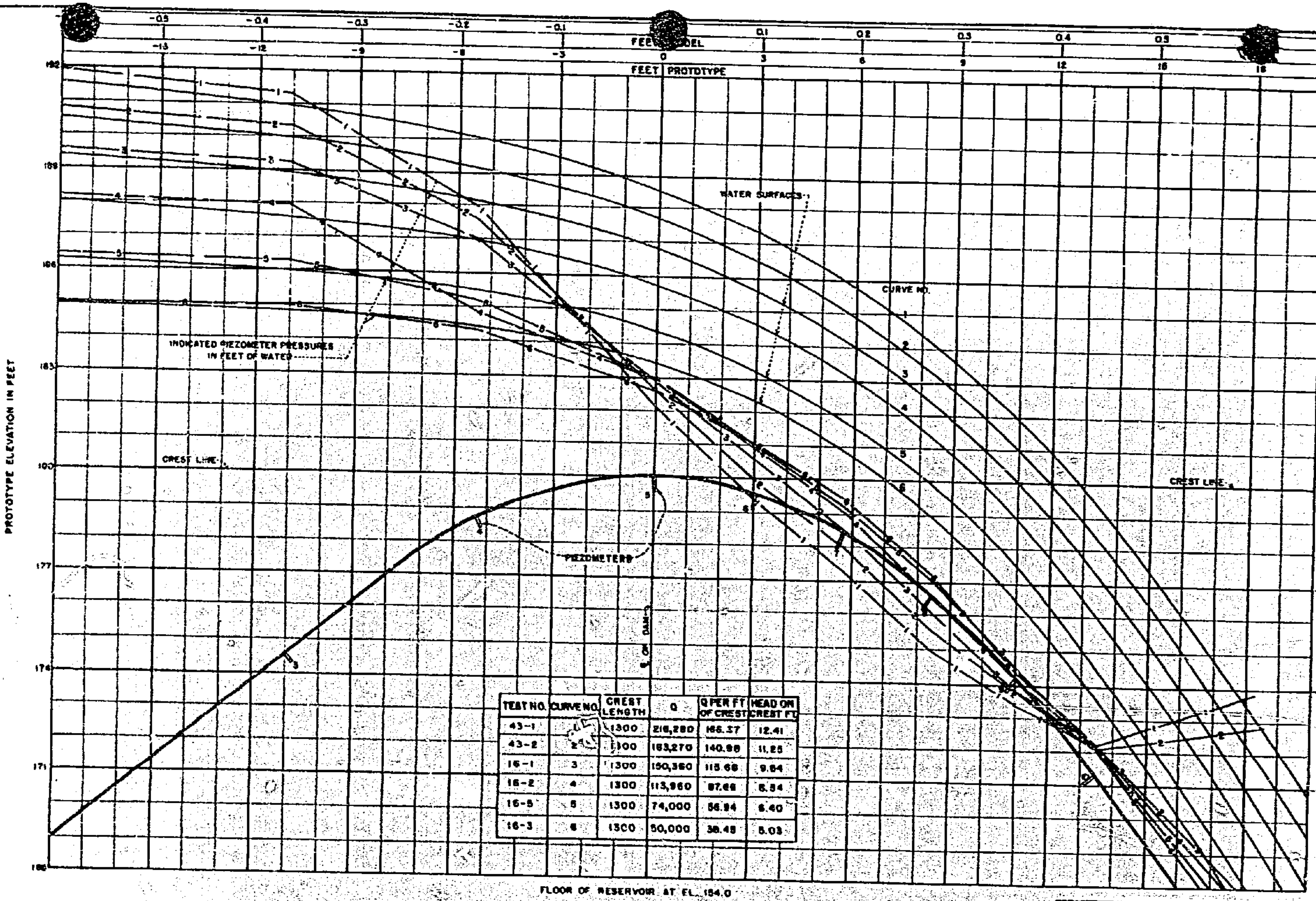


C. DENTATED STEP AND COMPOUND REHBOCK SILL ON 40-FOOT APRON. SAND BED AFTER 60-MINUTE RUN.



D. VIEW OF PIEZOMETER BOARD.

CREST LENGTH 1300 FEET. POOL FLOOR AT ELEVATION 169.0.



TEST NO.	CURVE NO.	CREST LENGTH	Q	Q PER FT OF CREST	HEAD ON CREST FT
43-1	1	1300	216,280	166.37	12.41
43-2	2	1300	183,270	140.98	11.25
16-1	3	1300	150,360	115.66	9.64
16-2	4	1300	113,960	87.66	8.54
16-5	5	1300	74,000	56.94	6.40
16-3	6	1300	50,000	38.48	5.03

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

IMPERIAL DAM (ORIGINAL)
COMPARISON OF WATER SURFACES AND INDICATED PRESSURES ON DAM

DRAWN F.P.A.K. ... SUBMITTED ...
TRACED A.V.F. E.E.B. ... RECOMMENDED ...
CHECKED T.E.G. ... APPROVED ...
DENVER, COLO. NOV. 4, 1934. 2/2-D-559

FIGURE 20

The pressure line drops below the dam face for the maximum designed discharge. A slight negative pressure was recorded for a discharge of 87.66 second-feet per foot of crest. For discharges less than 87.66 second-feet per foot of crest, the pressures on the dam face are positive.

As there is an uncertainty as to the applicability of the laws of hydraulic similitude where a negative pressure is involved and as a negative pressure is conducive to cavitation, it has been the practice to avoid negative pressures insofar as possible. Since there was a negative pressure present in the model with the maximum designed discharge, the section was revised to eliminate this condition. The effect of that revision will be discussed subsequently. Slight negative pressures may not be cause for alarm as they will probably depress the lower nappe enough to keep it in constant contact with the dam face but where it is possible to alter the design to eliminate them, it is believed to be advisable to do so. Large negative pressures, on the other hand, should be avoided as experience has shown these to be responsible for considerable damage to faces of spillways, especially when the concrete is not of the best quality.

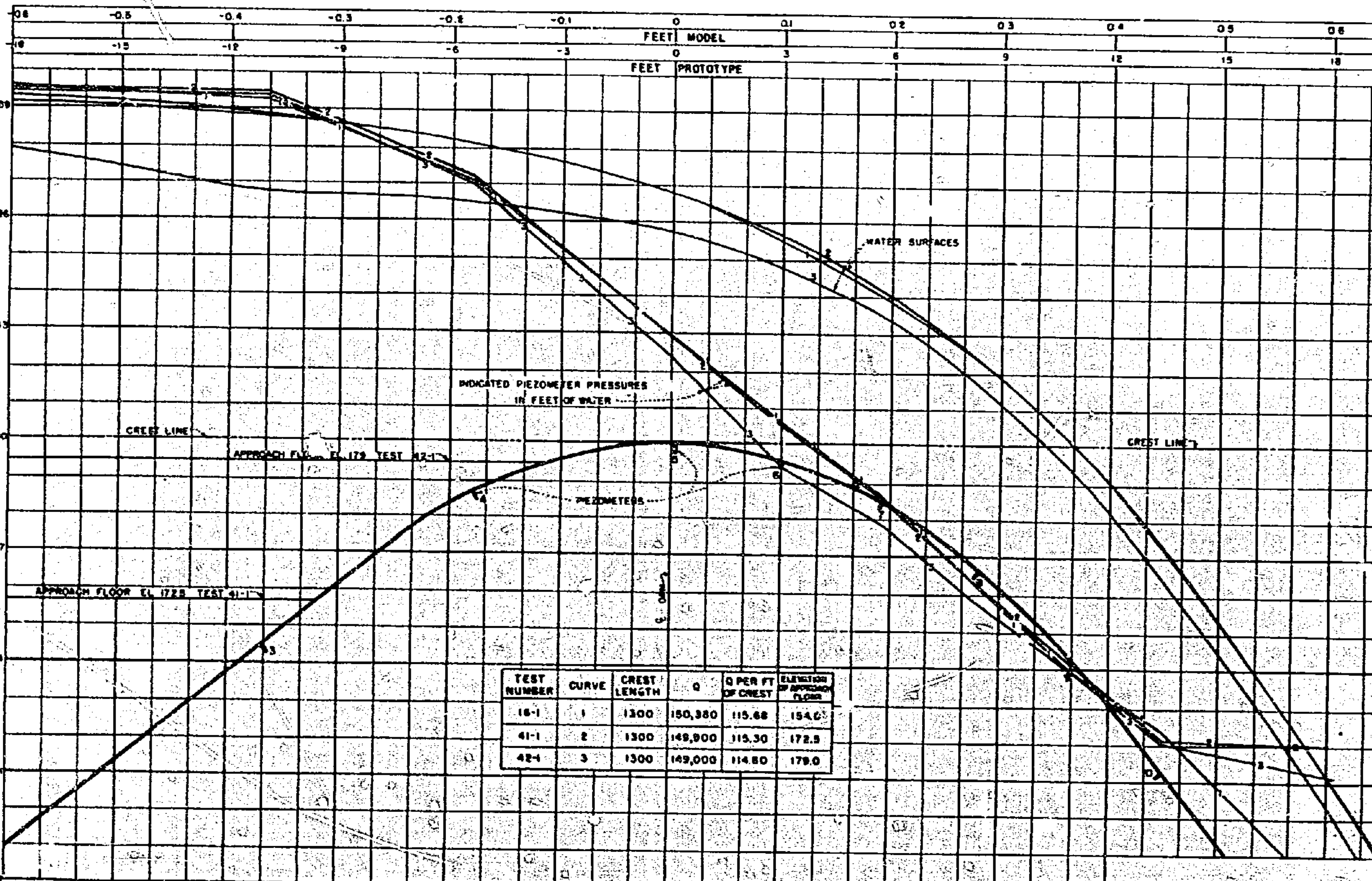
B. Effect Produced by Silting of Reservoir

Assuming that the reservoir above Imperial Dam will gradually fill with silt similar to the condition at Laguna Dam, comparative tests were made with the reservoir floor at three different elevations; namely, 154, 172.5, and 179 for the maximum discharge of 115 second-feet per foot of crest. The three tests are plotted on figure 21. As the reservoir capacity is reduced, the approach velocity to the crest is increased; thus the tendency is for the lower nappe to spring free of the dam and create larger negative pressures on the spill face as shown in test 42-1 (fig. 21).

5. THE HEAD DISCHARGE RELATION AND COEFFICIENT OF DISCHARGE (ORIGINAL DESIGN)

The relation of head to discharge obtained on the original model is plotted on figure 22. The curve shows that a head of 10.0 feet will be required to pass the maximum discharge of 150,000 second-feet over a crest 1,300 feet in length. These tests were made with the floor of the reservoir at elevation 154.0.

Using the equation $Q = C\,L\,H^{3/2}$, the coefficients of discharge were computed from the above results. These are also plotted against the head on the crest in figure 22. For the maximum discharge



TEST NUMBER	CURVE	CREST LENGTH	Q	Q PER FT OF CREST	ELEVATION OF APPROACH FLOOR
16-1	1	1300	150,380	115.68	154.0
41-1	2	1300	149,900	115.30	172.5
42-1	3	1300	149,000	114.60	179.0

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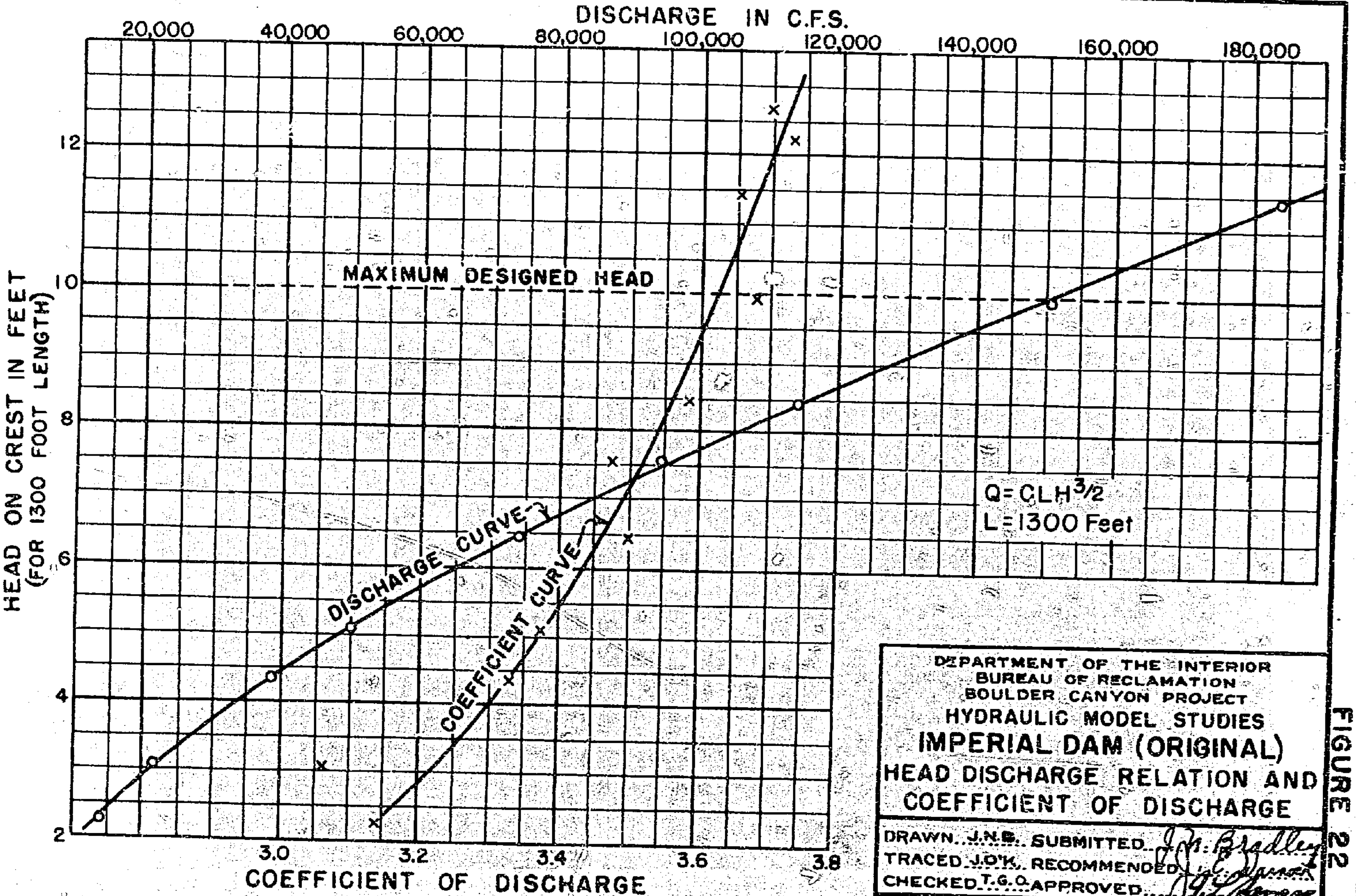
HYDRAULIC MODEL STUDIES

IMPERIAL DAM (ORIGINAL)
COMPARISON OF WATER SURFACES AND INDICATED PRESSURES ON DAM WITH RAISED APPROACH

DRAWN A.M.M. SUBMITTED
TRACED EMM ORD. RECOMMENDED
CHECKED E.A.D. APPROVED
DENVER, COLO., NOV. 1934

212-D-560

FIGURE 21



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

IMPERIAL DAM (ORIGINAL)

HEAD DISCHARGE RELATION AND COEFFICIENT OF DISCHARGE

DRAWN J.N.B. SUBMITTED J.N. Bradley
TRACED J.O'K. RECOMMENDED
CHECKED T.G.O. APPROVED
DENVER, COLO. 4-16-35 212-D-561

FIGURE 22

of 150,000 second-feet the coefficient of discharge is approximately 3.62.

6. THE REVISED SPILLWAY DESIGN

The shape of the spillway cross section was revised to that shown on figure 23 to eliminate the negative pressures on the downstream face of the dam and provide a more efficient spillway section. The height of the crest was increased one foot to elevation 181.0, the length of the crest was changed to 1,335 feet, the slope of the upstream face of the dam was decreased to 1-1/2:1, and the shape of the downstream face was revised to fit the lower nappe of water flowing over it for the maximum discharge. The upstream and downstream aprons remained at their previous elevations of 154.0 and 150.0, respectively.

7. THE REVISED MODEL

A model of the revised dam was constructed similar to the original one and placed in the same position in the laboratory flume. Twenty-four piezometers having 1/8-inch holes were installed in staggered positions along the face of the dam, as shown on figure 24, and six additional piezometers were built into the horizontal pool floor. The head and tailwater gages remained in the same positions as in the previous tests.

8. PRESSURES ON DOWNSTREAM FACE OF REVISED SPILLWAY

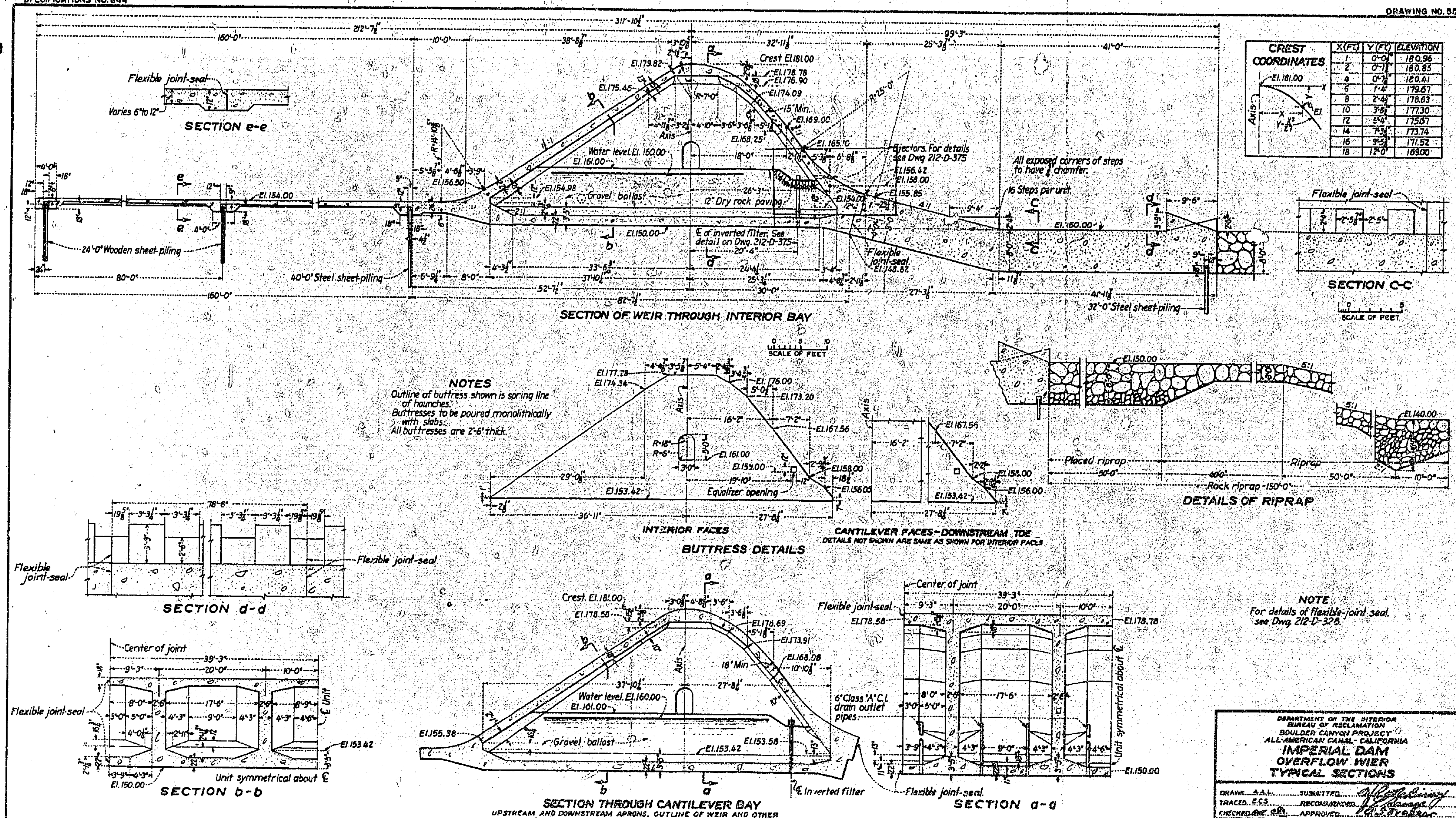
A. Approach Floor at Elevation 154.0

Piezometric pressures and water surface profiles obtained from the revised model are plotted on figure 25. The curve designated as 1 on figure 25 represents the observed pressures on the face of the dam for the maximum designed discharge of 150,000 second-feet. For this discharge, piezometer 10 showed a slight negative pressure, which is negligible.

For the partial discharges, the pressures are decidedly positive over the entire face of the dam. The revised spillway shape shows a very definite improvement over the original one in this respect.

B. Effect Produced by Silting of Reservoir

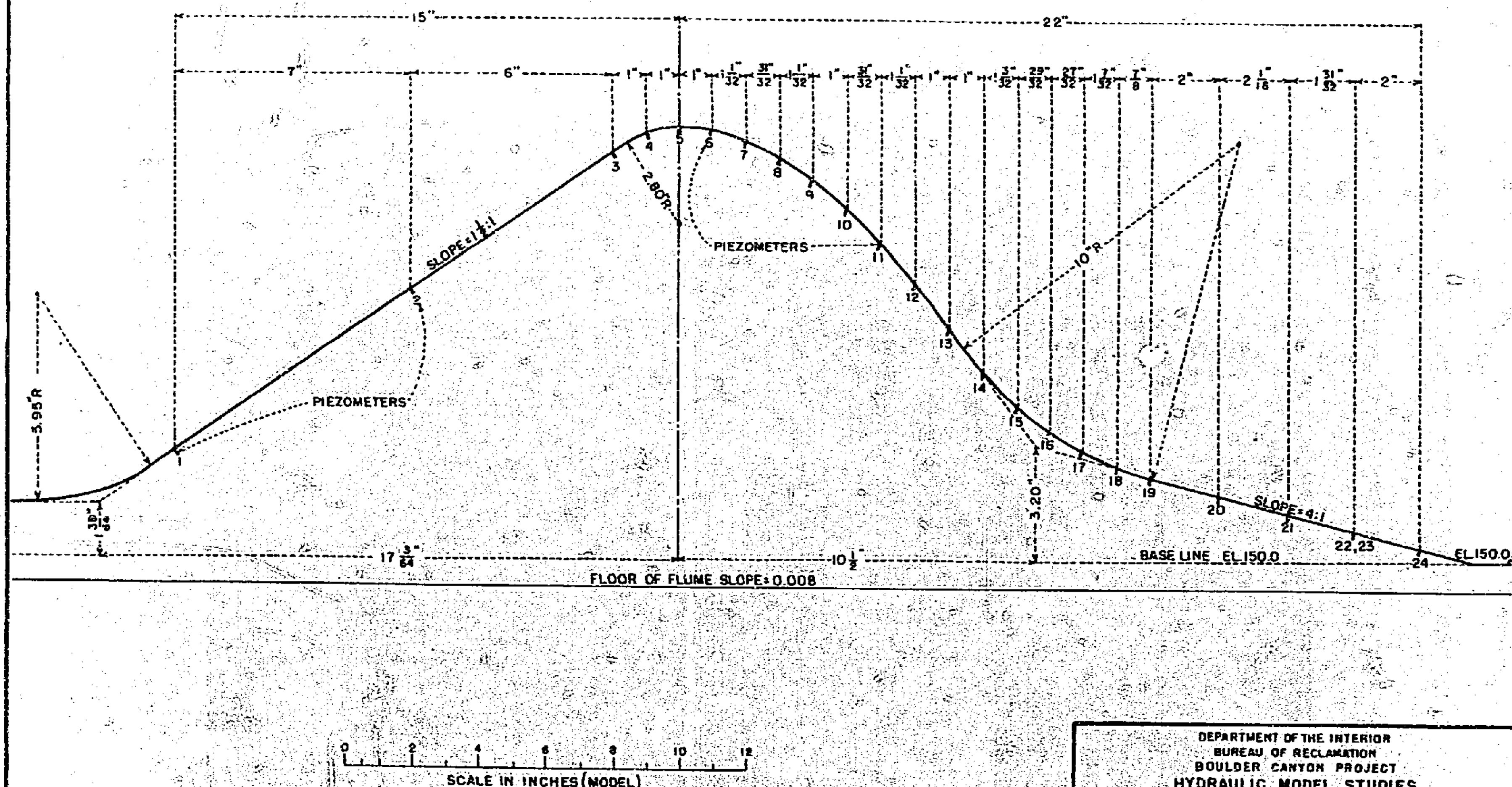
Upon plotting the pressures on the revised dam face for the above runs with different approach depths it was found that



CREST COORDINATES ($Y = \frac{X^2}{27}$, El. 181.00)

X (Ft.)	Y (Ft.)	ELEVATION
1	0'-0[illegible]"	180.96
2	0'-1[illegible]"	180.85
4	0'-7[illegible]"	180.41
6	1'-4"	179.67
8	2'-4[illegible]"	178.63
10	3'-8[illegible]"	177.30
12	5'-4"	175.67
14	7'-3[illegible]"	173.74
16	9'-5[illegible]"	171.52
18	12'-0"	169.00

FIGURE 24



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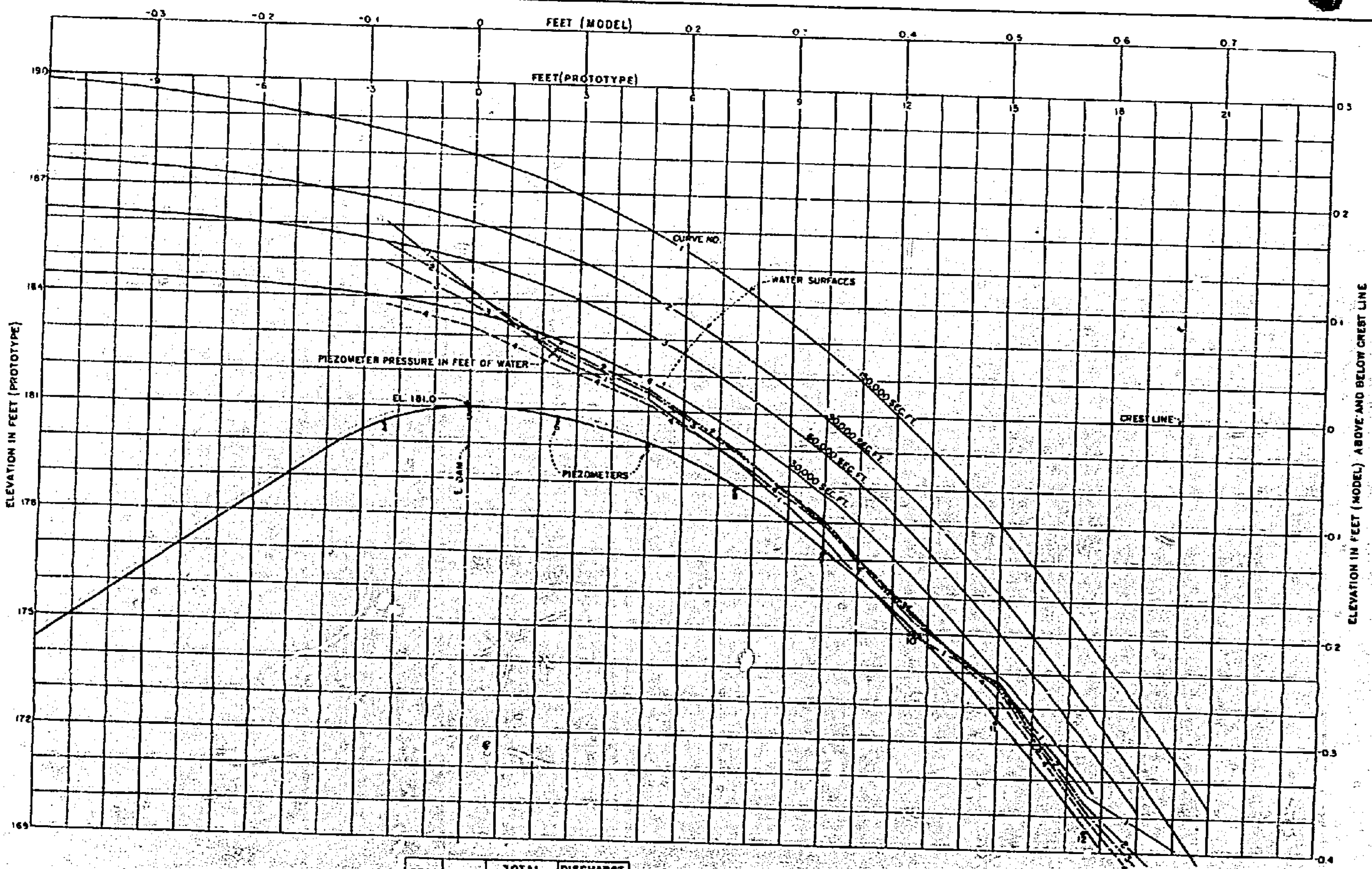
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

IMPERIAL DAM MODEL (REVISED)

LOCATION OF PIEZOMETERS IN DAM FACE

DRAWN. A.H.R. . . . SUBMITTED. J. H. Bradley
TRACED. E.F.J. H.S. RECOMMENDED. [signature]
CHECKED. J.R.B. . . APPROVED. [signature]

212-D-562



TEST NO.	CURVE NO.	TOTAL DISCHARGE IN C.F.S.	DISCHARGE PER FOOT OF CREST IN C.F.S.
17-R3	1	150,000	112.36
17-R4	2	90,000	67.42
11-R5	3	60,000	44.94
17-R5	4	30,000	22.47

LENGTH OF CREST = 1335 FEET
FLOOR OF RESERVOIR AT EL. 154.0

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HYDRAULIC MODEL STUDIES
IMPERIAL DAM (REVISED)
WATER SURFACE PROFILES AS INDICATED PRESSURES ON DAM

DRAWN J.R.B. SUBMITTED
TRACED S.P.C.B. H3 RECOMMENDED
CHECKED T.R.G. APPROVED

212-D-585

FIGURE 26

the negative pressure recorded at piezometer 10 (curve 1, fig. 25) did not change as the approach depth was decreased. Also, the remainder of the piezometers continued to read positive. In other words, raising the floor of the reservoir did not increase the negative pressure on the downstream face of the dam, as might be expected.

9. THE HEAD DISCHARGE RELATION AND THE COEFFICIENT OF DISCHARGE (REVISED DESIGN)

A. Approach Floor at Elevation 154.0

The head discharge relation for the revised design of the Imperial Dam spillway is shown on figure 26. Using a crest-length of 1,335 feet, the model showed that a head of 9.7 feet would be required on the crest for the maximum discharge of 150,000 second-feet which is an improvement over the original design. In the revised design, the discharge per foot of crest was slightly less and the dam was of a more efficient shape.

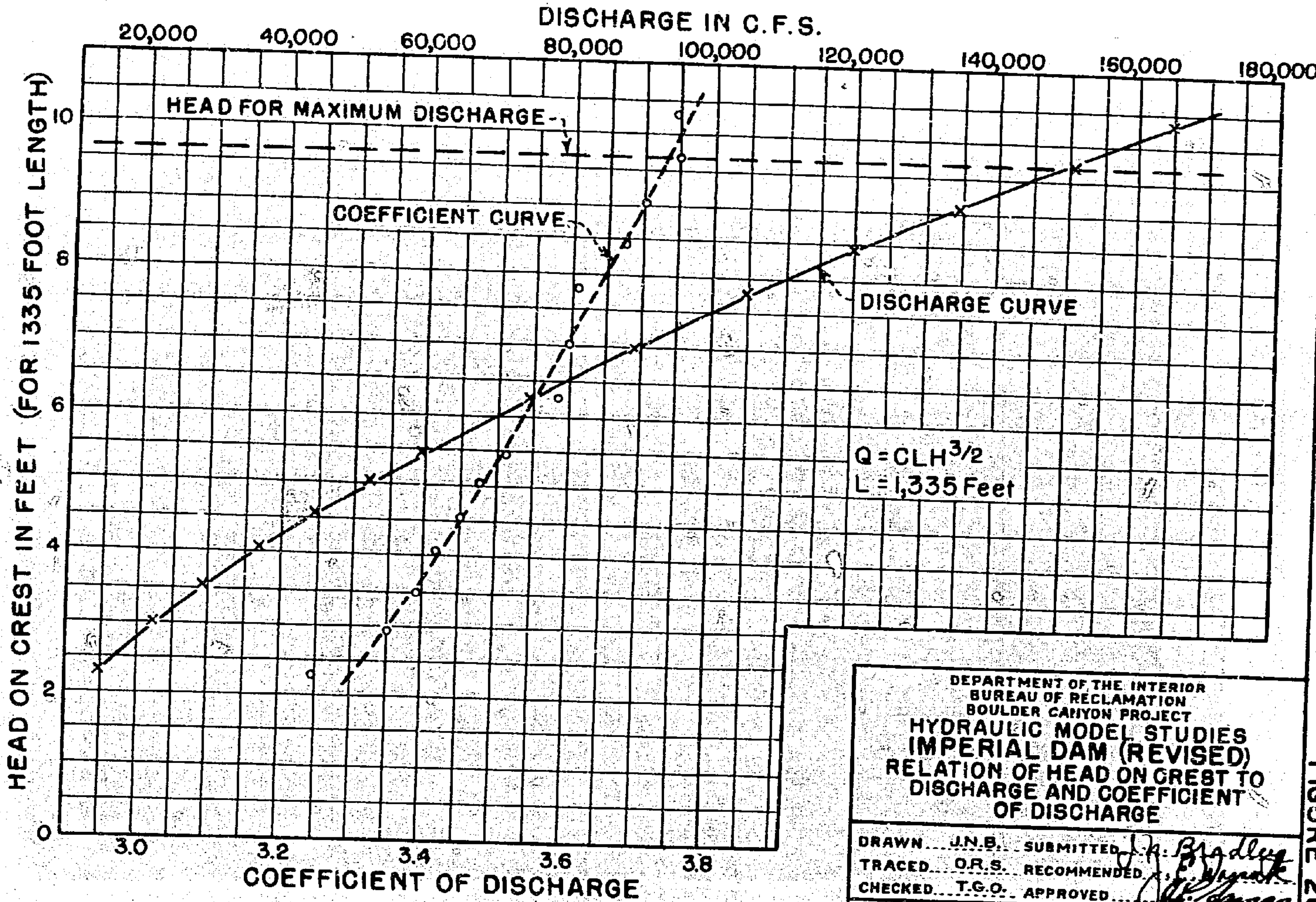
The coefficients of discharge were computed from the equation $Q = C L H^{3/2}$, and are shown on figure 26. The coefficient of discharge is 3.730 for a discharge of 150,000 second-feet and a head of 9.70 feet on the crest, which is a noticeable improvement over that obtained on the original spillway shape. For the same head on the crest the coefficient of discharge obtained on the original design (fig. 22) was 3.612.

B. Effect Produced by Silting of Reservoir

The effect on the head discharge relationship caused by the reservoir becoming filled with silt, which inevitably will occur, was studied by making a few runs on the model at the maximum discharge with different depths of approach. The results of this study are plotted on figure 27. With the reservoir filled to elevation 175, the curves show that a head of 9.81 feet will be required on the crest for maximum discharge and the coefficient of discharge will drop to 3.622.

10. STUDY OF RIVER BED DOWNSTREAM FROM STILLING POOL

As a definite study on the effect that the shape of the river bed below the stilling pool has on the hydraulic characteristics of the pool, twenty-one different bed layouts were tried and the characteristics recorded for each. The pool layout remained the same throughout these tests and is shown as layout 1 on figure 28. Dentated step G-1 was used in combination with sill H-1 (fig. 7) on a pool floor 41 feet long. The twenty-one bed layouts are shown on figure 28, and the stilling pool characteristics for each are



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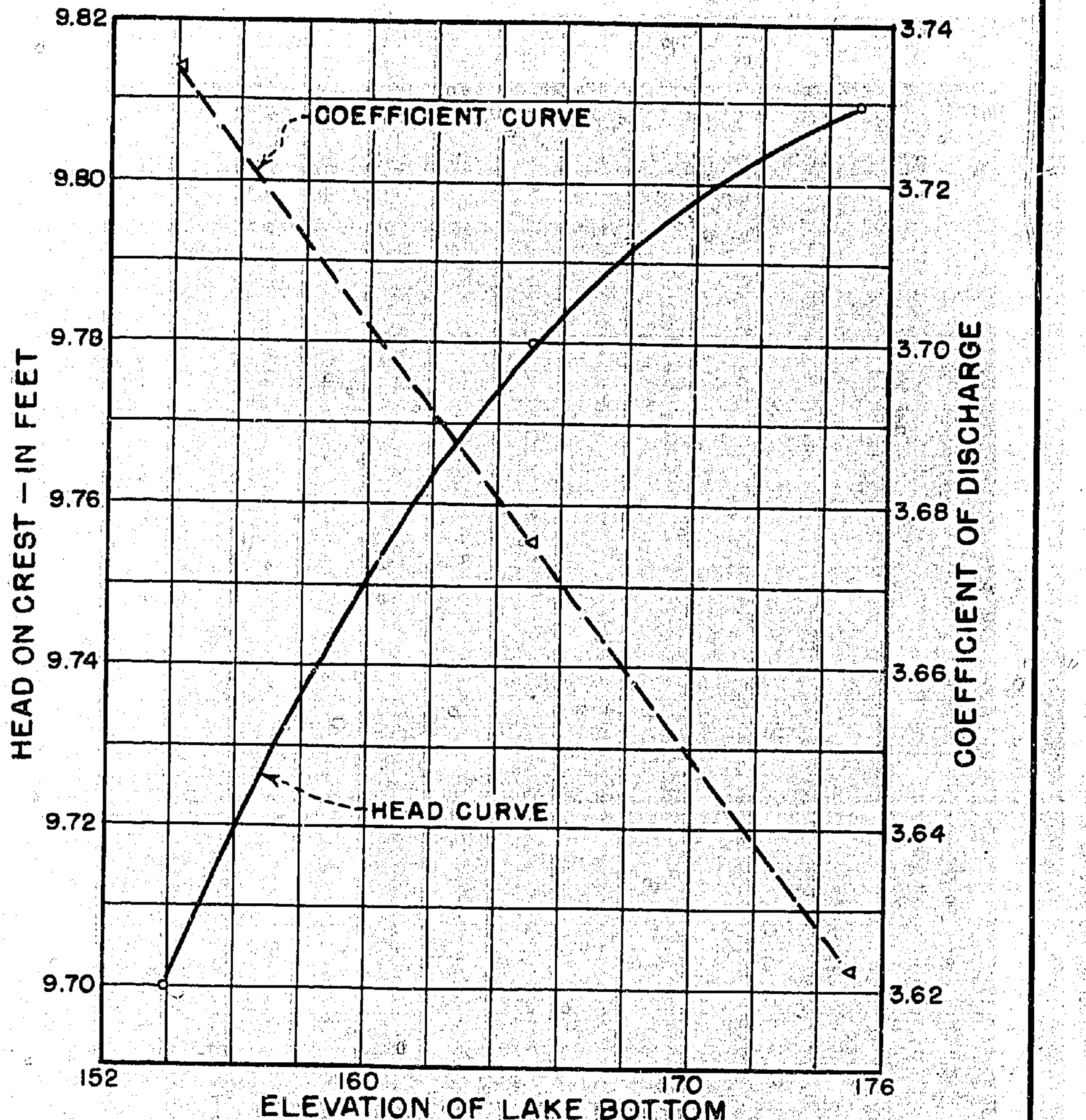
HYDRAULIC MODEL STUDIES
IMPERIAL DAM (REVISED)
RELATION OF HEAD ON CREST TO DISCHARGE AND COEFFICIENT OF DISCHARGE

DRAWN J.N.B.	SUBMITTED J. N. Bradley
TRACED O.R.S.	RECOMMENDED [signature]
CHECKED T.G.O.	APPROVED [signature]
	DENVER, COLO., 1-27-36 212-D-564

FIGURE 26

FIGURE 27



$Q = CLH^{3/2}$
L = 1,335 Feet
Q = 150,000 c.f.s.

NOTE
Discharge was held constant at 150,000 c.f.s. during these runs.

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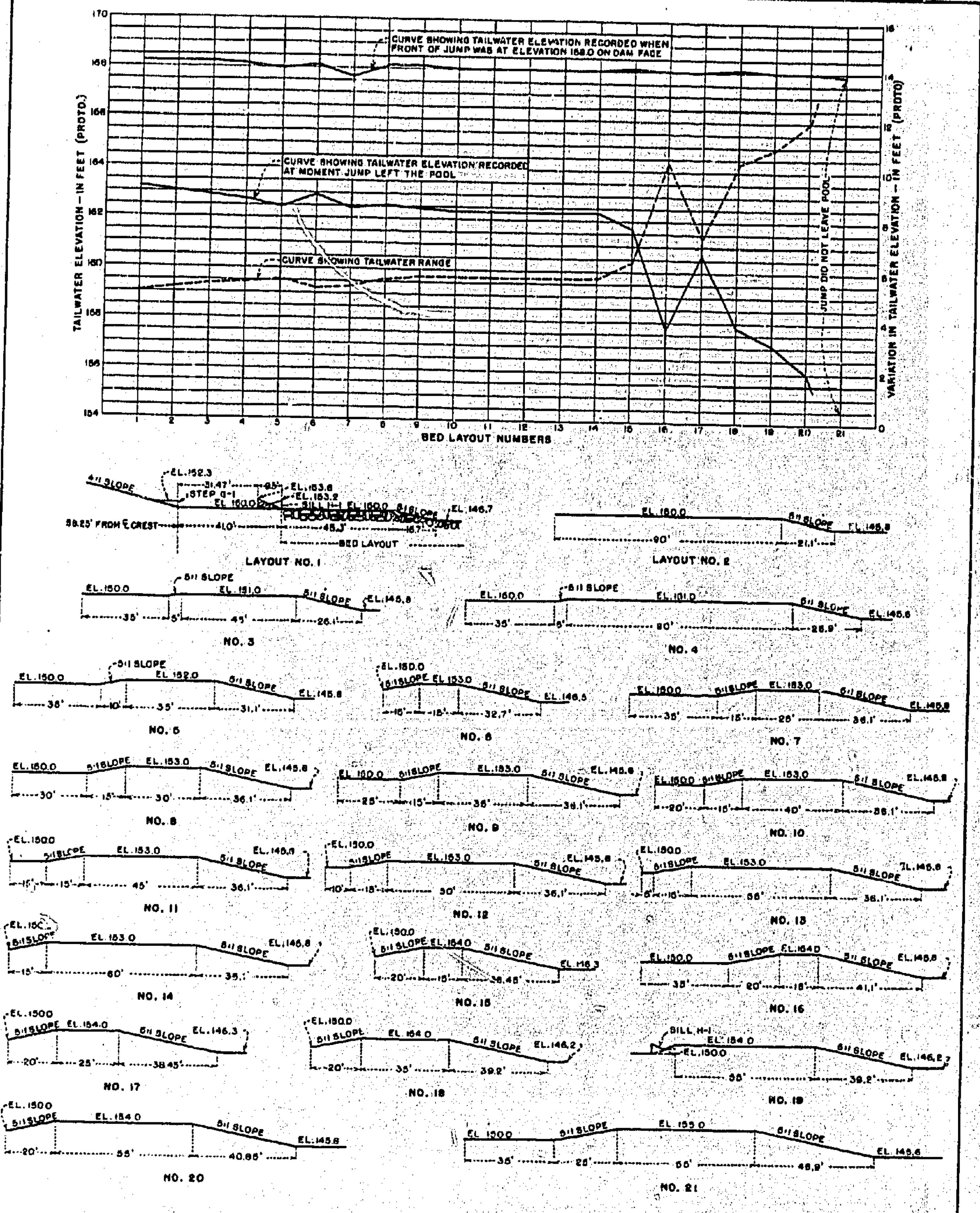
HYDRAULIC MODEL STUDIES
IMPERIAL DAM (REVISED)
EFFECT PRODUCED ON HEAD AND COEFFICIENT OF DISCHARGE BY VARYING ELEVATION OF LAKE BOTTOM

DRAWN R.K.V.	SUBMITTED J. N. Bradley
TRACED O.R.S.	RECOMMENDED J. E. Warnock
CHECKED J.N.B.	APPROVED J. L. Savage
DENVER, COLO. 7-17-35	212-D-565

FIGURE 28



NOTE

The stilling pool layout was the same for all of these tests.
All comparative tests were made at a discharge of 150,000 c.f.s.

All measurements are in feet prototype.

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BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM (REVISED)
CURVES SHOWING TAILWATER RANGES FOR COMPARATIVE RUNS ON VARIOUS BED LAYOUTS

DRAWN R.K.V. ...... SUBMITTED ......
TRACED H.S. D.P.B. ... RECOMMENDED ......
CHECKED J.M.S. ... APPROVED ......
DENVER, COLO., APR. 24, 1935
212-D-566

plotted on the same sheet. The upper line indicates the tailwater elevation recorded when the front of the jump advanced to elevation 158.0 on the dam, and the lower full line indicates the tailwater elevation recorded just as the jump left the pool. The dotted line, the scale for which is on the right-hand side of the graph, shows the actual tailwater range for each bed layout.

Layout 1 (fig. 28) had a bed 45 feet long with its surface at elevation 150.0. The jump left the pool at a tailwater elevation of 163.2 and the tailwater range was 5.0 feet. In layout 2, the bed was at the same elevation, but its length was increased to 90 feet. The tailwater range was slightly increased due to the increased friction offered by the additional 45 feet of bed. Incidentally, all beds were constructed of riprap so that their shapes could not change during any one run. Layouts 3 and 4 were similar to layouts 1 and 2, except that the elevation of the bed was raised to 151.0. The results obtained with these two were similar to those for layouts 1 and 2. Raising the bed one foot increased the tailwater range slightly.

The bed was raised to elevation 152.0 in layout 5 with the result that the tailwater range again showed a slight increase.

Layouts 6 to 14, inclusive, consisted of beds of various shapes and lengths with their controlling portions at elevation 153.0. For beds 35 feet and longer (layouts 9 to 14), the curve shows the tailwater range to be practically constant, while for the shorter beds (layouts 6 to 8) the tailwater range dropped off as the length of bed decreased.

Layouts 15 to 20, inclusive, were beds of various shapes and lengths with their highest portions at elevation 154.0. The curves show the stilling pool characteristics to vary greatly with the shape and length of this type of bed. With the higher beds the velocity over them was increased considerably; naturally the frictional resistance offered to the flow was increased. For this reason, the longest beds showed the greatest tailwater ranges.

In layout 21, 55 feet of the bed were raised to elevation 155.0. The jump refused to leave the pool for any tailwater elevation. The velocities over the higher portion of the bed, however, were exceedingly high, and it was necessary to use larger riprap than usual to keep the shape of the bed from changing.

The advantages and disadvantages for the extreme cases are sensibly equal. If the bed is at one of the lower elevations, the tailwater range is small. If the controlling portion of the bed is high, the tailwater range is increased considerably, but the velocities over the bed are very high, which is equally undesirable. It is difficult to choose a bed between the two extremes as the stilling-pool characteristics for beds at elevations

150.0, 151.0, 152.0, and 153.0 show very little variation, while the beds at elevations 154.0 and 155.0 give the desired tailwater range but are undesirable. The solution to this phase of the problem then would be to choose a bed at one of the lower elevations and develop a sill that would be effective in confining the jump to the stilling pool for a wide range of tailwater depths.

11. TESTS ON STILLING POOL (REVISED DESIGN)

A. Crest-length 1,335 Feet, Pool Floor at Elevation 150.0

a. Comparative Tests

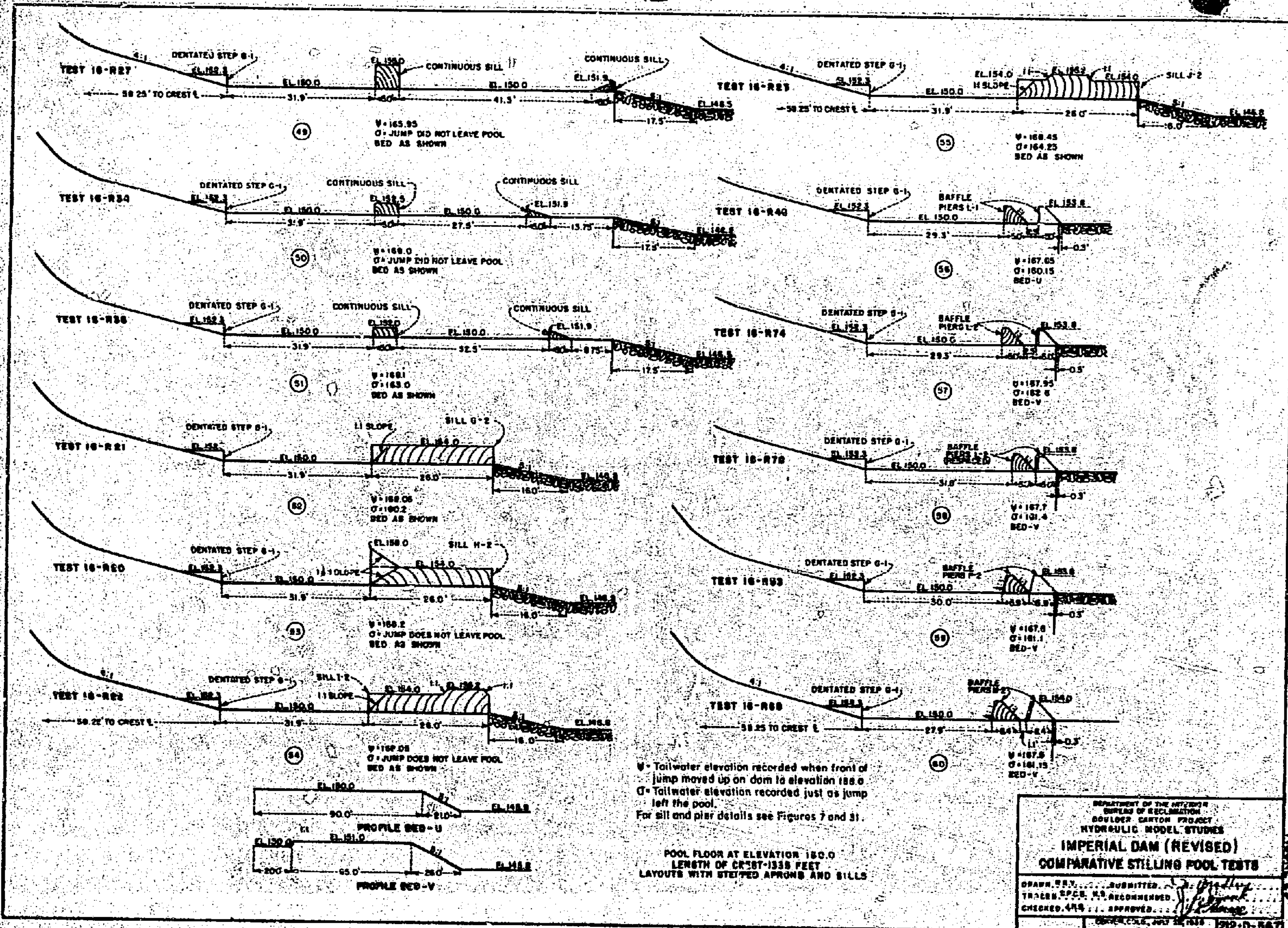
The design section was in favor of using one of the lower beds downstream from the stilling pool and suggested that further testing be continued on variations of layouts 42 and 40, shown on figure 14, and any other untried layouts that might appear promising. In response to this suggestion some eighty comparative stilling-pool layouts were tried, twenty-four of which are shown on figures 29 and 30. Some of the sills and stepped aprons used during these tests are shown in detail on figures 7 and 31. Curves showing the stilling-pool characteristics for the group of twenty-four representative layouts are shown on figure 32. All comparative runs were made at the maximum discharge of 150,000 second-feet for a 1,335-foot crest-length.

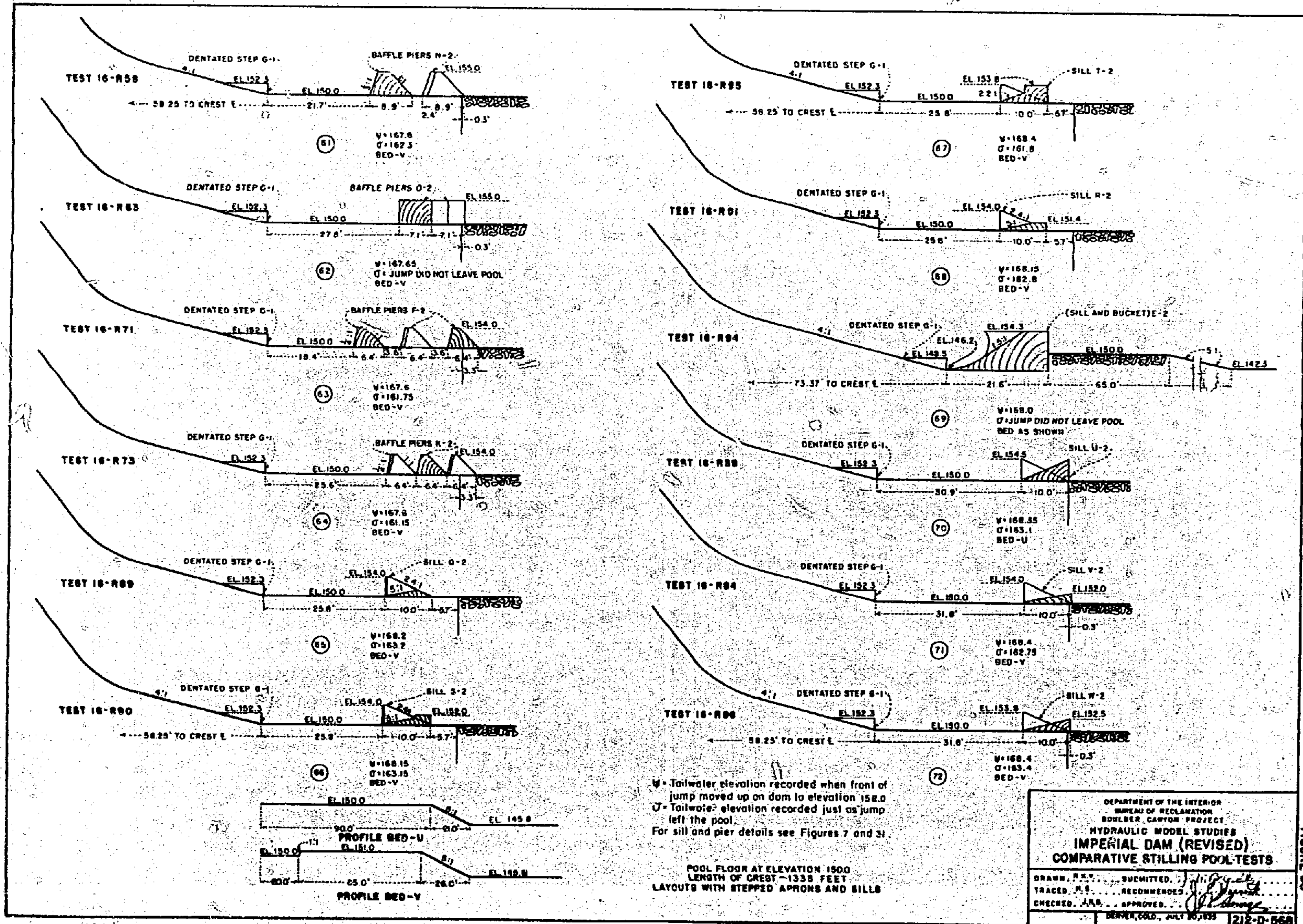
Layouts 49, 50, and 51 (fig. 29) were made purposely to form a double jump. These pools were quite satisfactory from a hydraulic viewpoint. Both jumps were effective and remained in the pool for all tailwater depths in layouts 49 and 50. These layouts were objectionable, however, in that an unnecessarily long apron was required for the double-jump pool.

A new type of sill was used in layouts 52, 53, 54, and 55. These sills are shown in detail on figure 31. The curves on figure 32 show these layouts had a wide tailwater range. The action in the pool, however, was undesirable as a large boil formed over the sill in each case and a secondary jump formed about 15 feet downstream from the sill when the tailwater was dropped to the vicinity of elevation 163.0. The secondary jump accounts for the wide tailwater range recorded for these layouts on figure 32.

Layout 56 (fig. 29) was a duplicate of layout 42 (fig. 14), except that the bed was dropped to elevation 150.0 which reduced the tailwater range from 11 to 7.5 feet (figs. 15 and 32). These piers are shown as L-1 on figure 7.

FIGURE 29


TEST 16-R27
DENTATED STEP G-1
EL. 152.3
EL. 150.0
EL. 153.0
CONTINUOUS SILL
CONTINUOUS SILL
EL. 151.9
EL. 148.5
58.25' TO CREST ℄
31.9'
41.3'
17.5'
49
V = 165.95
σ = JUMP DID NOT LEAVE POOL
BED AS SHOWN
TEST 16-R34
50
V = 169.0
σ = JUMP DID NOT LEAVE POOL
BED AS SHOWN
27.5'
13.75'
TEST 16-R36
32.5'
8.75'
51
V = 169.1
σ = 163.0
BED AS SHOWN
TEST 16-R21
1:1 SLOPE
SILL G-2
26.0'
16.0'
52
V = 168.05
σ = 160.2
BED AS SHOWN
TEST 16-R20
SILL H-2
EL. 158.0
EL. 154.0
53
V = 168.2
σ = JUMP DOES NOT LEAVE POOL
BED AS SHOWN
TEST 16-R22
SILL I-2
1:1 SLOPE
EL. 154.0
EL. 156.2
58.25' TO CREST ℄
54
V = 169.05
σ = JUMP DOES NOT LEAVE POOL
BED AS SHOWN
TEST 16-R23
EL. 154.0
1:1 SLOPE
EL. 156.2
EL. 154.0
SILL J-2
26.0'
55
V = 168.45
σ = 164.25
BED AS SHOWN
TEST 16-R40
BAFFLE PIERS L-1
EL. 153.8
29.3'
0.5'
56
V = 167.65
σ = 160.15
BED-U
TEST 16-R74
BAFFLE PIERS L-2
29.5'
57
V = 167.95
σ = 162.6
BED-V
TEST 16-R78
BAFFLE PIERS L-2 (REVERSED)
31.0'
58
V = 167.7
σ = 161.4
BED-V
TEST 16-R93
BAFFLE PIERS P-2
30.0'
59
V = 167.6
σ = 161.1
BED-V
TEST 16-R68
BAFFLE PIERS P-2
EL. 154.0
58.25 TO CREST ℄
27.9'
60
V = 167.8
σ = 161.15
BED-V
EL. 150.0
90.0'
21.0'
EL. 148.5
PROFILE BED-U
EL. 150.0
EL. 151.0
20.0'
65.0'
26.0'
EL. 148.5
PROFILE BED-V
V = Tailwater elevation recorded when front of jump moved up on dam to elevation 158.0
σ = Tailwater elevation recorded just as jump left the pool.
For sill and pier details see Figures 7 and 31.
POOL FLOOR AT ELEVATION 150.0
LENGTH OF CREST-1338 FEET
LAYOUTS WITH STEPPED APRONS AND SILLS
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM (REVISED)
COMPARATIVE STILLING POOL TESTS
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
DENVER, COLO.
212-D-567


TEST 16-R58
DENTATED STEP G-1
BAFFLE PIERS N-2
EL 152.3
EL 150.0
EL 155.0
58.25 TO CREST ℄
21.7'
8.9'
2.4'
0.3'
61
V=167.6
Ʊ=162.3
BED-V
TEST 16-R63
DENTATED STEP G-1
BAFFLE PIERS O-2
EL 152.3
EL 150.0
EL 155.0
27.8'
7.1'
0.3'
62
V=167.65
Ʊ= JUMP DID NOT LEAVE POOL
BED-V
TEST 16-R71
DENTATED STEP G-1
BAFFLE PIERS F-2
EL 152.3
EL 150.0
EL 154.0
18.4'
6.4'
3.6'
63
V=167.6
Ʊ=161.75
BED-V
TEST 16-R73
DENTATED STEP G-1
BAFFLE PIERS K-2
EL 152.3
EL 150.0
EL 154.0
25.6'
6.4'
3.3'
64
V=167.6
Ʊ=161.15
BED-V
TEST 16-R89
DENTATED STEP G-1
SILL O-2
EL 152.3
EL 154.0
EL 150.0
25.8'
10.0'
5.7'
65
V=168.2
Ʊ=163.2
BED-V
TEST 16-R90
DENTATED STEP G-1
SILL S-2
EL 152.3
EL 156.0
EL 150.0
EL 152.0
58.25' TO CREST ℄
25.8'
10.0'
5.7'
66
V=168.15
Ʊ=163.15
BED-V
EL 150.0
90.0'
20.0'
EL 145.8
PROFILE BED-U
EL 150.0
EL 151.0
20.0'
25.0'
26.0'
EL 148.8
PROFILE BED-V
TEST 16-R85
DENTATED STEP G-1
SILL T-2
EL 152.3
EL 153.8
EL 150.0
58.25' TO CREST ℄
25.8'
10.0'
5.7'
67
V=168.4
Ʊ=161.8
BED-V
TEST 16-R91
DENTATED STEP G-1
SILL R-2
EL 152.3
EL 154.0
EL 150.0
EL 151.4
25.8'
10.0'
5.7'
68
V=168.15
Ʊ=162.8
BED-V
TEST 16-R94
DENTATED STEP G-1
(SILL AND BUCKET) E-2
EL 146.2
EL 148.5
EL 154.3
EL 150.0
EL 142.5
73.37' TO CREST ℄
21.6'
65.0'
69
V=158.0
Ʊ=JUMP DID NOT LEAVE POOL
BED AS SHOWN
TEST 16-R88
DENTATED STEP G-1
SILL U-2
EL 152.3
EL 154.5
EL 150.0
30.9'
10.0'
70
V=166.55
Ʊ=163.1
BED-U
TEST 16-R84
DENTATED STEP G-1
SILL V-2
EL 152.3
EL 154.0
EL 150.0
EL 152.0
31.8'
10.0'
0.3'
71
V=168.4
Ʊ=162.75
BED-V
TEST 16-R86
DENTATED STEP G-1
SILL W-2
EL 152.3
EL 153.8
EL 150.0
EL 152.5
58.25' TO CREST ℄
31.8'
10.0'
0.3'
72
V=168.4
Ʊ=163.4
BED-V
V = Tailwater elevation recorded when front of jump moved up on dam to elevation 158.0
Ʊ = Tailwater elevation recorded just as jump left the pool.
For sill and pier details see Figures 7 and 31.
POOL FLOOR AT ELEVATION 150.0
LENGTH OF CREST—133.5 FEET
LAYOUTS WITH STEPPED APRONS AND SILLS
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM (REVISED)
COMPARATIVE STILLING POOL TESTS
DRAWN
SUBMITTED
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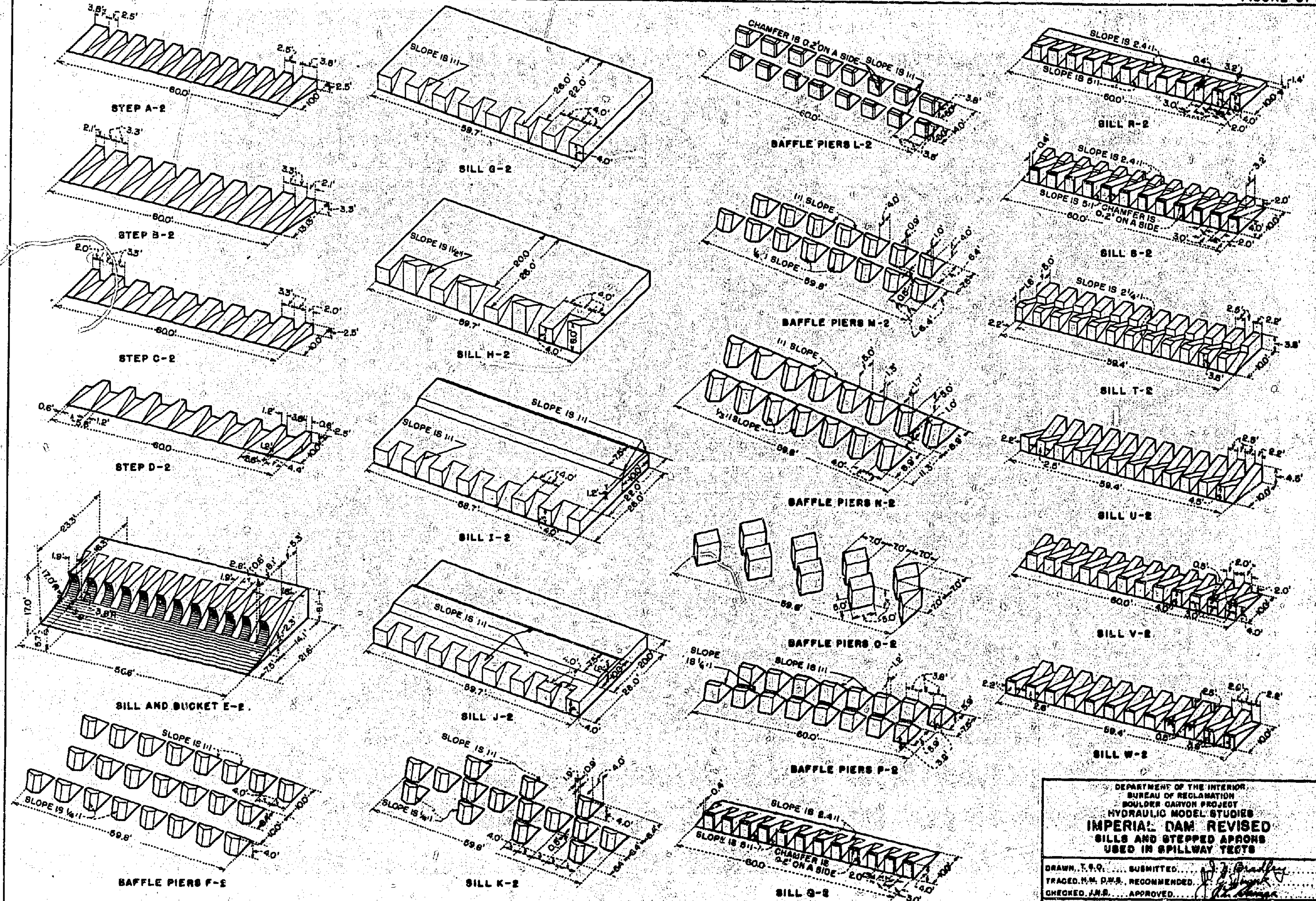
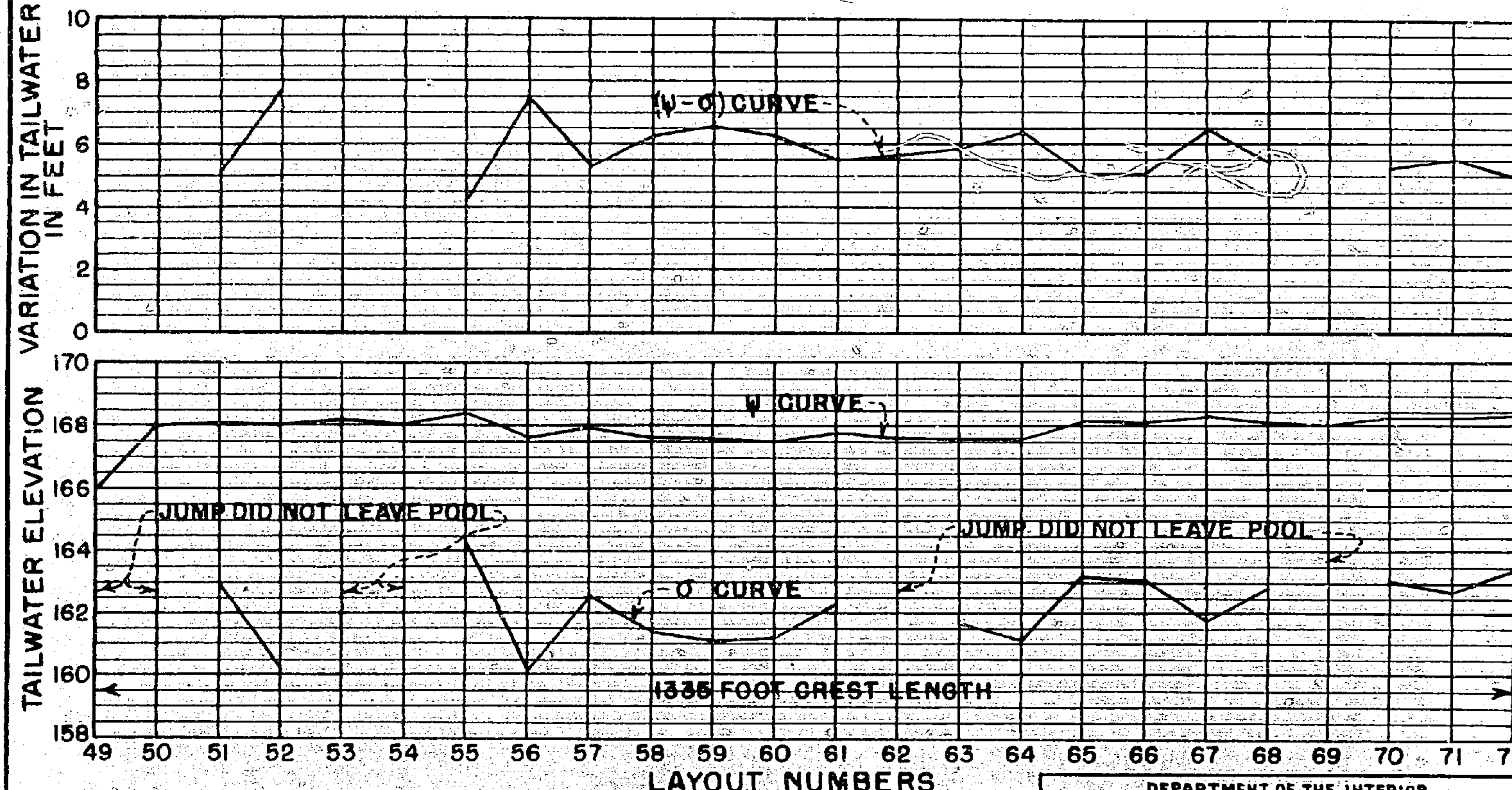
CHECKED
APPROVED
DENVER, COLO.
212-D-568
FIGURE 30

FIGURE 31


STEP A-2
STEP B-2
STEP C-2
STEP D-2
SILL AND BUCKET E-2
BAFFLE PIERS F-2
SILL G-2
SILL H-2
SILL I-2
SILL J-2
SILL K-2
BAFFLE PIERS L-2
BAFFLE PIERS M-2
BAFFLE PIERS N-2
BAFFLE PIERS O-2
BAFFLE PIERS P-2
SILL Q-2
SILL R-2
SILL S-2
SILL T-2
SILL U-2
SILL V-2
SILL W-2
SLOPE IS 1:1
CHAMFER IS 0.2' ON A SIDE
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM REVISED
SILLS AND STEPPED APRONS
USED IN SPILLWAY TESTS
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
DENVER, COLO.
212-D-569



For stilling pool layouts see Figures 28 and 29.

ψ = Tailwater elevation recorded when front of jump moved up on dam face to elevation 158.0.

σ = Tailwater elevation recorded just as jump left the pool.

ψ - σ = Permissible tailwater range.

All comparative runs were made at the maximum designed discharge of 150,000 c.f.s.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM (REVISED)
CURVES SHOWING TAILWATER
RANGES FOR COMPARATIVE RUNS

DRAWN J.N.B. SUBMITTED J. N. Bradley
TRACED J.O'K. RECOMMENDED J. E. Warnock
CHECKED J.D.M. APPROVED J. L. Savage

212-D-570

FIGURE 32

It was feared that the sharp corners on the prototype piers would be knocked off once the spillway was in operation, and a question arose as to whether the piers would be as effective without the sharp corners. For this reason, a 3-inch chamfer was put on the upstream faces, as shown in layout L-2 (fig. 31), and these were installed in the same positions in the pool as in the previous test. Layout 57 (fig. 29) shows the set-up. The curves on figure 32 show that chamfering the corners reduced the tailwater range from 7.5 to 5.4 feet. The chamfered piers were then respaced as shown in layout 58 with the result that a portion of this difference was regained. Figure 32 shows layout 58 to have a tailwater range of 6.3 feet.

In layout 59, the upstream faces of these piers were beveled in a vertical direction as shown in P-2 (fig. 31). The tailwater range for this layout was 6.6 feet.

A set of piers similar in type but with pointed noses, shown in M-2 (fig. 31), were used in layout 60 (fig. 29). Another set of piers similar to these, but larger, shown as N-2 (fig. 31), were used in layout 61 (fig. 30). The large piers are shown in plate VII-B and the small piers are shown in plate VIII-A. Plate VIII-B shows the pool in action with the small piers installed with the maximum discharge and a tailwater elevation of 166.0. Photograph C on the same plate shows the pool in operation at the maximum discharge with the tailwater dropped to elevation 160.6 and the jump forming downstream from the pool. Figure 32 shows that the jump left the pool for a tailwater elevation of 161.2. The small sharp-nosed piers (M-2, fig. 31) gave the best results in that they had a wider tailwater range and produced a smoother action in the pool than the larger ones (N-2).

The small sharp-nosed piers were respaced and a third row was added as shown in F-2 and K-2 (fig. 31) for layouts 63 and 64, respectively, (fig. 30). Both gave very good results. Layout 63 showed a tailwater range of 5.9 feet and layout 64 gave a slightly wider range of 6.4 feet. Layout 63 is shown on plate IX-A, and photographs B and C show this pool in action for the maximum discharge and tailwater elevations of 166.0 and 161.8, respectively.

The cubic blocks O-2 (fig. 31) used in layout 62 (fig. 30) were not satisfactory as a large boil formed above them.

Layouts 65, 66, 67, and 68 were made using modifications of the Rehbock sill. The sills are shown as Q-2, S-2, T-2, and R-2 on figure 31. With the exception of layout 67, the tailwater ranges were quite small and the sills showed no exceptional qualities otherwise. Sill T-2 used in layout 67, which had the widest

A. VIEW OF WINDOW BELOW DAM.

B. VIEW OF LARGE SHARP NOSED PIERS. SET-UP (61).

C. VIEW OF SILL T-2, SET-UP (67).

REVISED DAM.
CREST LENGTH 1536 FEET. POOL FLOOR AT ELEVATION 150.0.

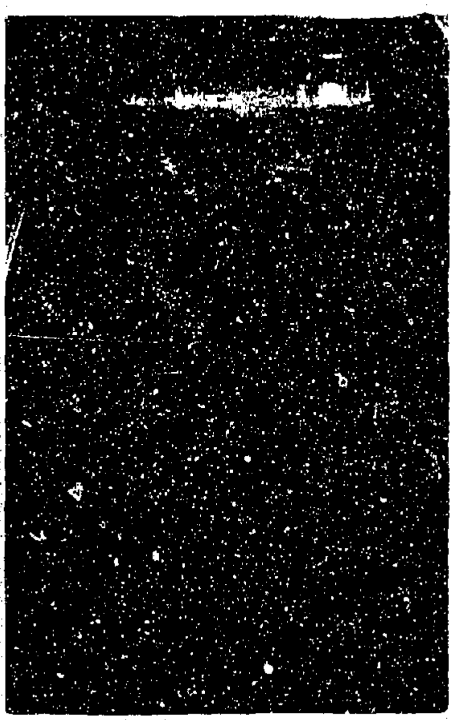
A. SMALL SHARP NOSED PIERS.

B. MAXIMUM DISCHARGE 112.4
SECOND-FEET PER FOOT OF CREST
TAILWATER ELEVATION 166.0.

C. MAXIMUM DISCHARGE 112.4
SECOND-FEET PER FOOT OF CREST.
TAILWATER ELEVATION 160.6.

REVISED DAM.
CREST LENGTH 1335 FEET. POOL FLOOR AT ELEVATION 150.0.

A. THREE ROWS OF SMALL SHARP
NOSED PIERS.



B. MAXIMUM DISCHARGE 112.4
SECOND-FEET PER FOOT OF CREST.
TAILWATER ELEVATION 166.0.

C. MAXIMUM DISCHARGE 112.4
SECOND-FEET PER FOOT OF CREST.
TAILWATER ELEVATION 161.8.

REVISED DAM.
CREST LENGTH 1335 FEET. POOL FLOOR AT ELEVATION 150.0.

tailwater range of the four, was objectionable as it created a moderate amount of boiling action above the sill. This sill is shown on plate VII-C.

Layout 69 was made using a diffuser sill, shown as E-2 (fig. 31) and plate X-A. One of the requirements of a sill of this type is a large tailwater depth. It was, therefore, necessary to drop the bucket, as shown in layout 69 (fig. 30). Plate X-B and -C shows the stilling pool in action using this layout for the maximum discharge and the tailwater at elevations 168.0 and 163.0, respectively. The jump refused to leave the pool when the tailwater was lowered but a secondary jump formed when the tailwater was dropped to about elevation 163.0. To eliminate this, it would be necessary to lower the bucket and sill still more. One of the outstanding advantages of a sill of this type, when properly installed, is the omission of the customary long paved apron. In this case, however, a large amount of excavation would be necessary and the increased depth of water over it would require an increased thickness of the concrete in the bucket to withstand the additional uplift pressures. In addition, the design department did not wish to shorten the length of the apron as it will serve an important part in increasing the length of path of underseepage beneath the dam.

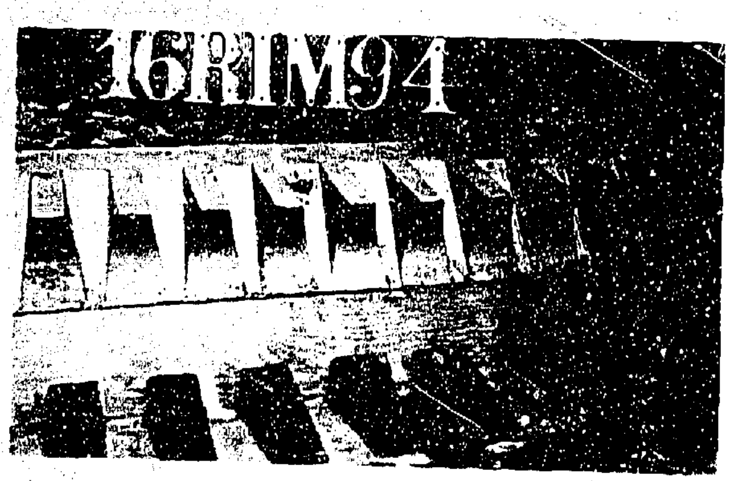
Compound Rehbock sills of various dimensions (U-2, V-2, and W-2, fig. 31) were tried in layouts 70, 71, and 72 (fig. 30). The action in the pool was excellent, the jump was very effective, and the water leaving the pool was quiet for all three layouts. The maximum tailwater range obtained using these sills and the bed at elevation 150.0 was 5.5 feet. Plate XI-A shows the model as in layout 72, and the photographs, B, C, and D illustrate the pool in action for the maximum discharge, using three tailwater depths; namely, elevations 168.4, 166.0, and 163.4, respectively. Photograph D shows the jump just on the verge of leaving the pool.

b. Stepped Aprons

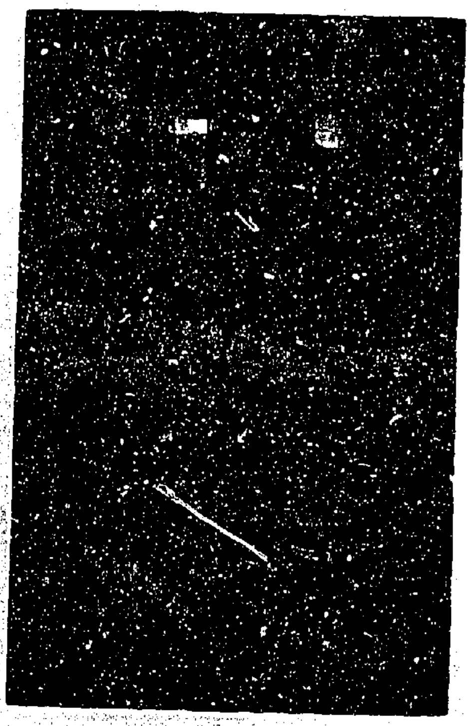
During a portion of the above tests, the various stepped aprons shown as A-2 to D-2, inclusive, (fig. 31) and step G-1 (fig. 7) were intermittently installed on the sloping apron to determine which gave the best results. Step G-1 (fig. 7) was decidedly the best of the group, and it is shown incorporated in the final design on figure 23.

c. Conclusions on Comparative Tests

Summing the second set of tests on the stilling pool,



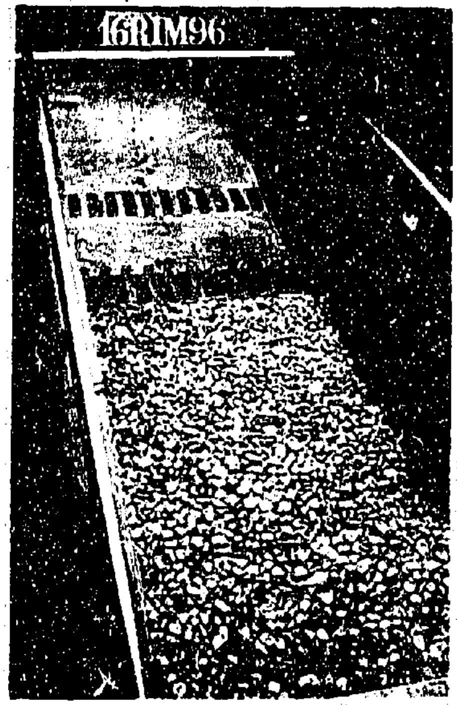
A. VIEW OF HORNSBY DIFFUSER SILL.



B. MAXIMUM DISCHARGE 112.4
SECOND-FEET PER FOOT OF CREST.
TAILWATER ELEVATION 168.0.

C. MAXIMUM DISCHARGE 112.4
SECOND-FEET PER FOOT OF CREST.
TAILWATER ELEVATION 163.0.

REVISED DAM.
CREST LENGTH 1335 FEET. POOL FLOOR AT ELEVATION 150.0.



A. DENTATED STEP AND COMPOUND REHBOCK SILL.

B. MAXIMUM DISCHARGE 112.4 SECOND-FEET PER FOOT OF CREST. TAILWATER ELEVATION 168.4.

C. MAXIMUM DISCHARGE 112.4 SECOND-FEET PER FOOT OF CREST. TAILWATER ELEVATION 166.0.

D. MAXIMUM DISCHARGE 112.4 SECOND-FEET PER FOOT OF CREST. TAILWATER ELEVATION 163.4.

REVISED DAM.
CREST LENGTH 1335 FEET. POOL FLOOR AT ELEVATION 150.0.

it was again found that the baffle piers (or some variation of them) and the compound Rehbock sills gave the most satisfactory results. With the river bed at elevation 150.0 the piers showed tailwater ranges from 5.4 to 7.5 feet while the compound Rehbock sill showed a range from 5.0 to 5.5 feet. The best pier layout was 56 (fig. 29), and the best layout with the compound Rehbock sill was 71 (fig. 30). Some doubt was expressed as to the practicability of the baffle-pier arrangements and the compound Rehbock sill was selected in spite of the additional tailwater range offered by the first.

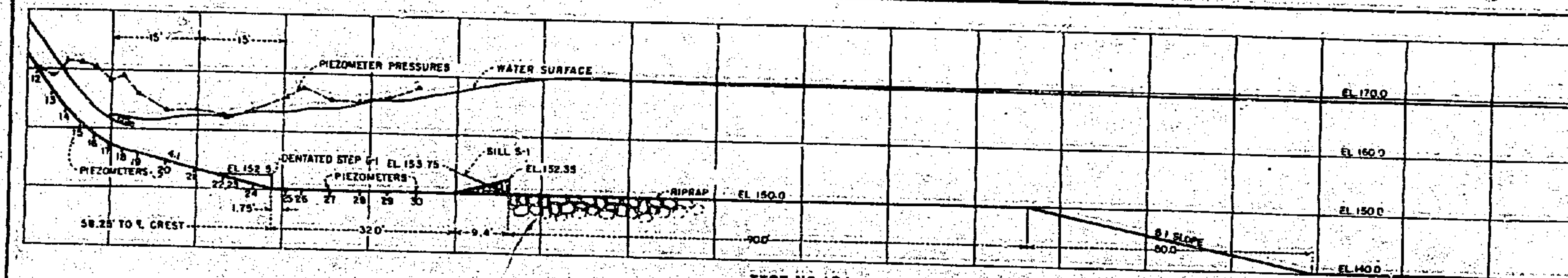
During the tests on these two types of sills, small sticks with nails driven in their ends, to increase their density, were floated over the model. These were intended to represent large logs in the prototype. In no case did the sticks strike the piers or sills. Some of them remained for a considerable length of time circulating about the stilling pool, and occasionally one would thump against the face of the dam. In passing over the sill, the sticks were always in an upright position, which accounts for their regularity in avoiding the piers. When caught in the roller and moved upstream, the sticks assumed a position normal to the direction of flow, and upon striking the dam were usually in this position.

d. Tests on the Final Stilling Pool Design

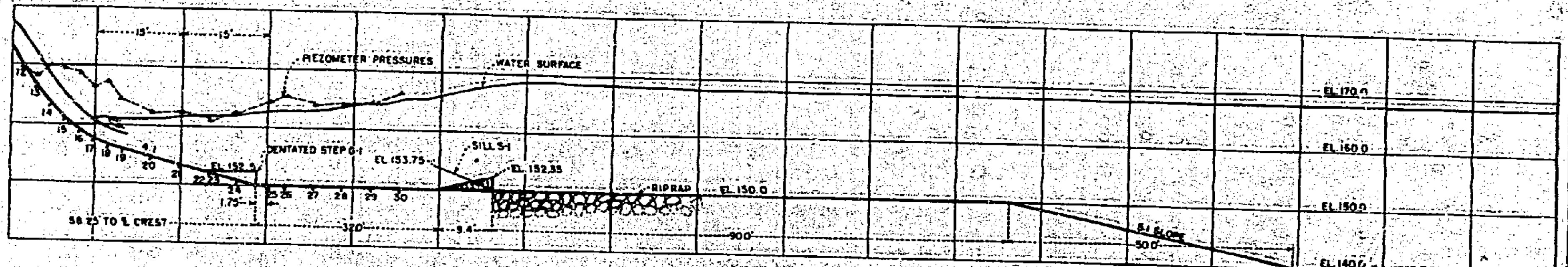
The model as finally built is shown on plate XI. Dentated step G-1 was installed on the downstream end of the sloping apron and sill S-1 (fig. 7) was placed on the end of a pool floor 41.5 feet long. Water surface profiles and piezometer pressures on the pool floor are shown for eight discharges, using different tailwater depths on figures 33, 34, and 35. The plotted points on these profiles represent prototype values obtained by conversion from the model results. Water surface profiles and piezometer pressures in the bucket are shown on figure 36. These and the stilling pool profiles were made to aid in designing the thickness of these portions of the structure.

e. Paint Tests on the Final Stilling Pool

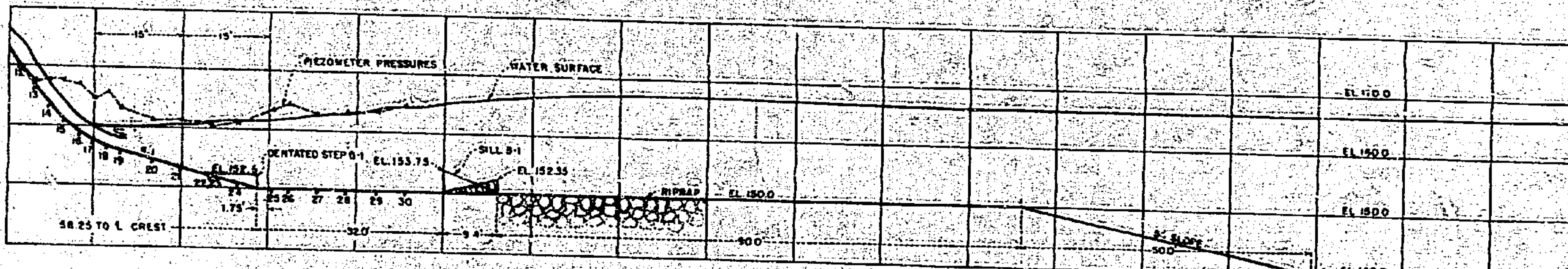
A series of paint tests were made on the final design, using the maximum discharge. These are shown on plates XII and XIII. Plate XII-A shows the pool looking downstream and plate XII-B shows the nature of the flow lines along a side wall of the flume. The extent to which the jet is flared by the dentated steps and how the flow rises to nearly vertical immediately upstream from the sill can be seen. Plate XII-C is an excellent picture of the



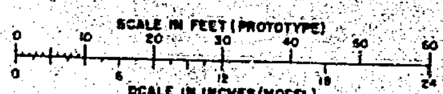
TEST NO. 1R1
HEAD 10.83 FT.; DISCHARGE 135.3 C.F.S. PER FT. OF CREST; TAILWATER EL. 168.8



TEST NO. 2R1
HEAD 9.58 FT.; DISCHARGE 113.0 C.F.S PER FT. OF CREST; TAILWATER EL. 168.0



TEST NO. 3R1
HEAD 8.36 FT.; DISCHARGE 90.06 C.F.S. PER FT. OF CREST; TAILWATER EL. 166.4



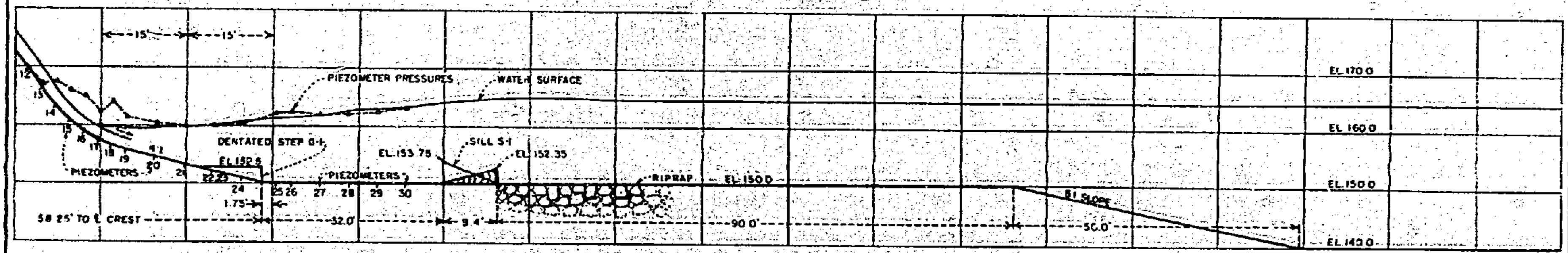
LENGTH OF CREST - 1338 FT.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM (REVISED)
PIEZOMETER PRESSURES AND WATER SURFACE PROFILES IN STILLING POOL

DRAWN R.E.V. SUBMITTED J.R. Bradley
TRACED E.F.J. H.S. RECOMMENDED
CHECKED J.N.B. APPROVED
DENVER, COLO., JUNE 3, 1935

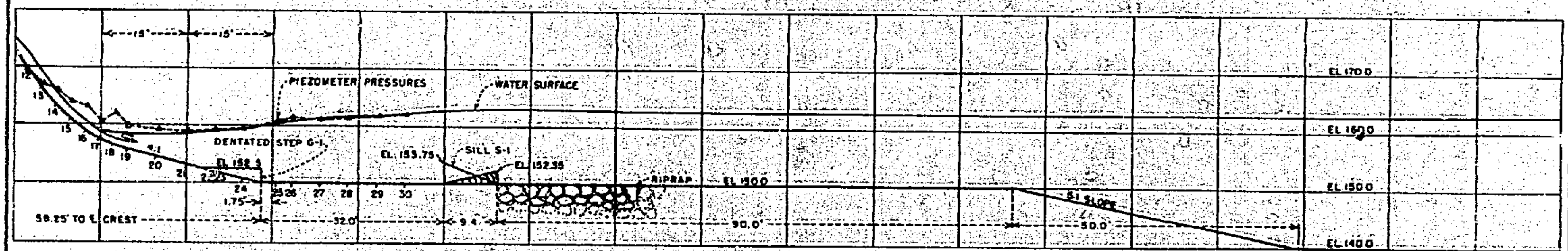
212-D-871

FIGURE 33



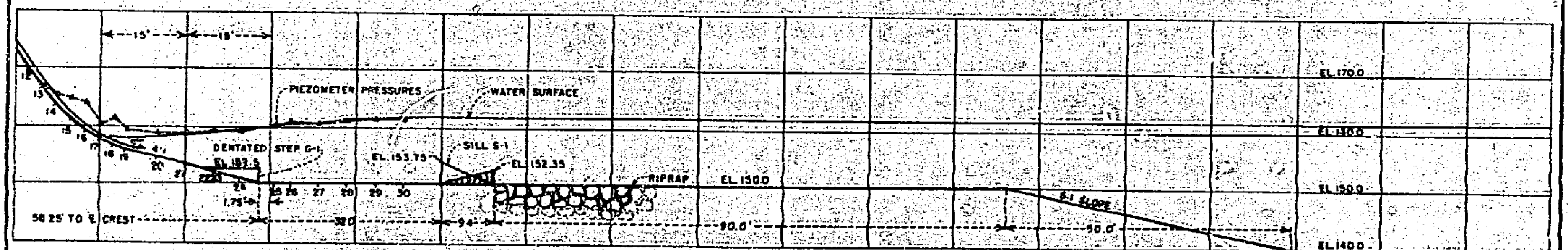
TEST NO. 4R1

HEAD 6.89 FT.; DISCHARGE 67.15 C.F.S. PER FT. OF CREST; TAILWATER EL. 164.6



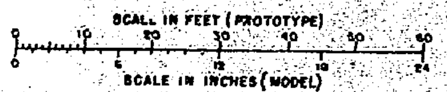
TEST NO. 5R1

HEAD 5.43 FT.; DISCHARGE 44.74 C.F.S. PER FT. OF CREST; TAILWATER EL. 162.7



TEST NO. 6R1

HEAD 4.86 FT.; DISCHARGE 33.74 C.F.S. PER FT. OF CREST; TAILWATER EL. 161.7



LENGTH OF CREST - 1336 FT.

DEPARTMENT OF THE INTERIOR
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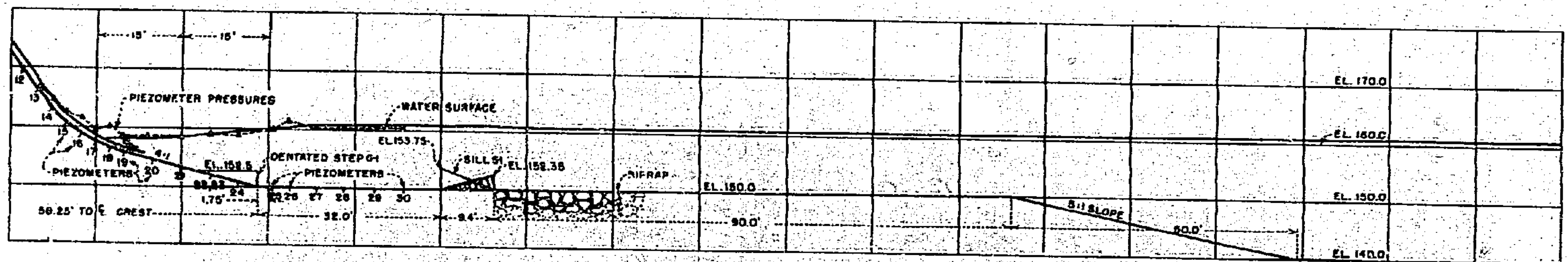
HYDRAULIC MODEL STUDIES

IMPERIAL DAM (REVISED)

PIEZOMETER PRESSURES AND WATER SURFACE PROFILES IN STILLING POOL

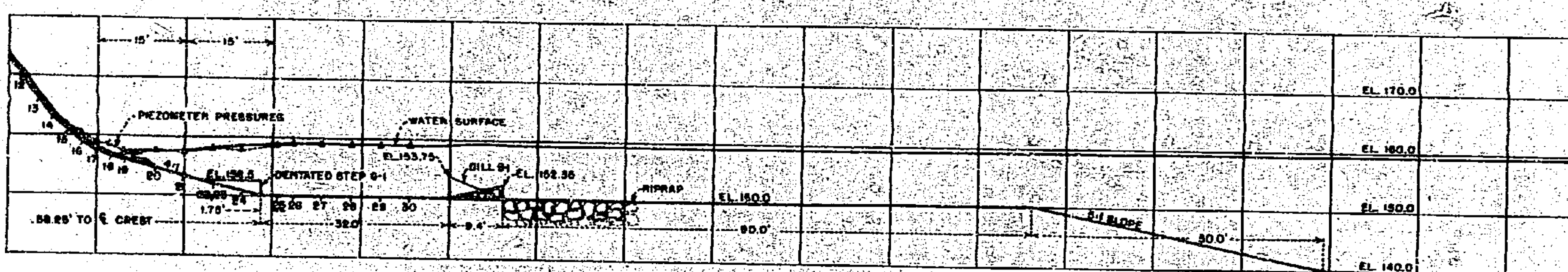
DRAWN: B.E.V. ... SUBMITTED: ...
TRACED: S.P.C.B., H.S. RECOMMENDED: ...
CHECKED: J.M.B. ... APPROVED: ...
DENVER, COLO., JUNE 1, 1939

2I2-0-572



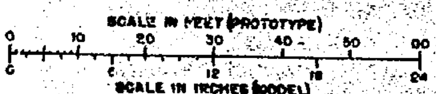
TEST NO. 7-RI

HEAD 3.46 FT.; DISCHARGE 22.06 C.F.S. PER FT. OF CREST; TAILWATER EL. 160.5



TEST NO. 8-RI

HEAD 2.31 FT.; DISCHARGE 11.41 C.F.S. PER FT. OF CREST; TAILWATER EL. 155.1



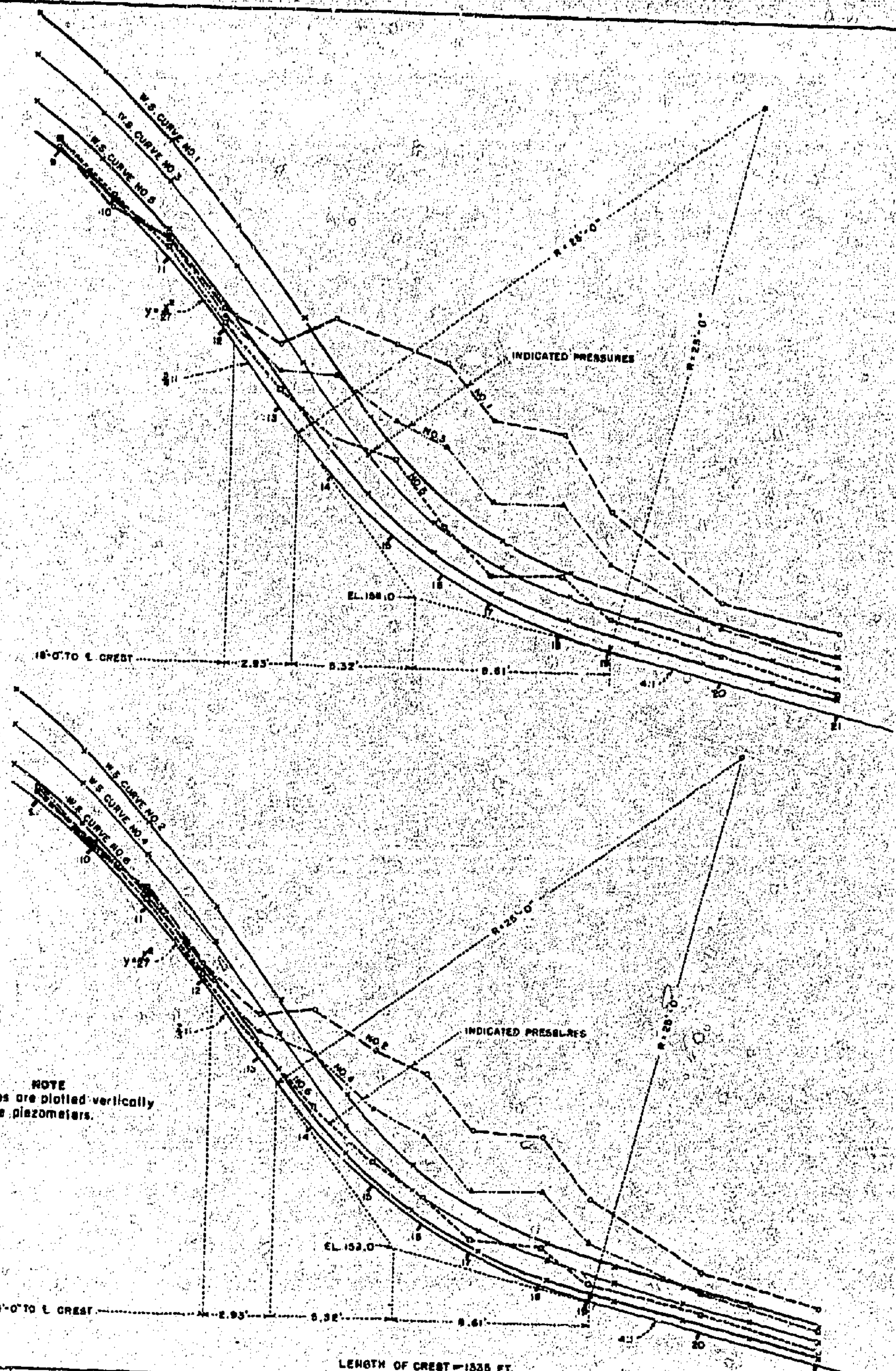
LENGTH OF CREST – 1338 FT.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM (REVISED)
PIEZOMETER PRESSURES AND WATER SURFACE PROFILES IN STILLING POOL

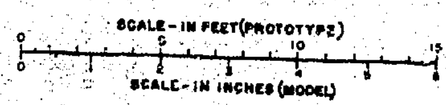
DRAWN R.S.V. ... SUBMITTED ...
TRACED H.S. E.P.S. ... RECOMMENDED ...
CHECKED J.H.S. ... APPROVED ...
DENVER, COLO., JUNE , 1938 | 212-D-573

FIGURE 38

FIGURE 36



TEST NO.	CURVE NO.	APPROX. TOTAL-Q IN C.F.S.	Q IN C.F.S. PER FT. CREST
17-3	1	150,000	112.06
17-2	2	105,000	78.04
17-4	3	90,000	63.96
17-5	4	60,000	45.02
17-6	5	30,000	22.18
17-7	6	15,000	11.38



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

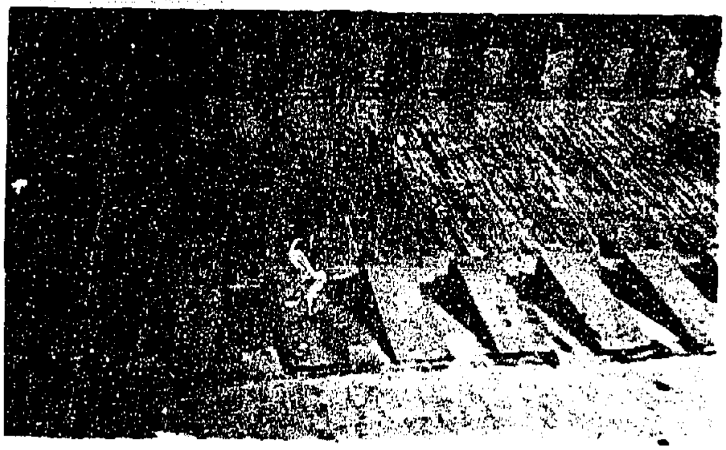
IMPERIAL DAM (REVISED)

PIEZOMETER PRESSURES AND WATER SURFACE PROFILES IN BUCKET

DRAWN. R.E.V. ... SUBMITTED ...
TRACED. J.R.S., M.S. RECOMMENDED ...
CHECKED. J.P.S. ... APPROVED ...

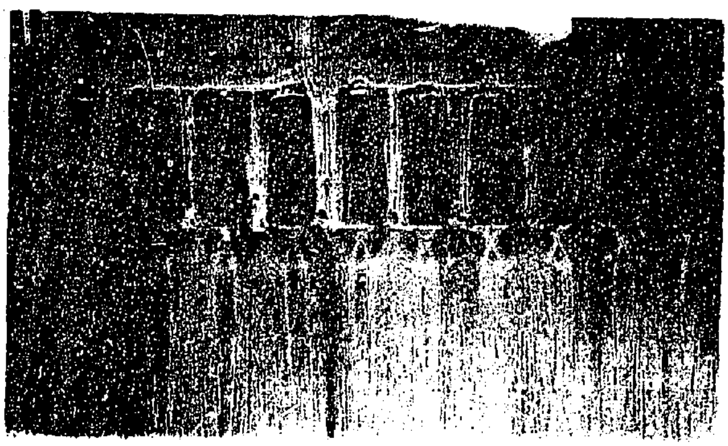
DENVER, COLO., JUNE 8, 1938

212-D-378



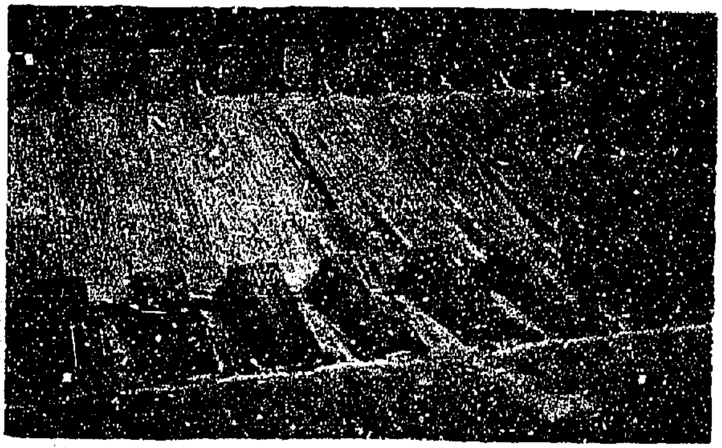
A. STILLING POOL.
LOOKING DOWNSTREAM.

B. STILLING POOL SHOWING LINES
OF FLOW ON SIDE OF FLUME.

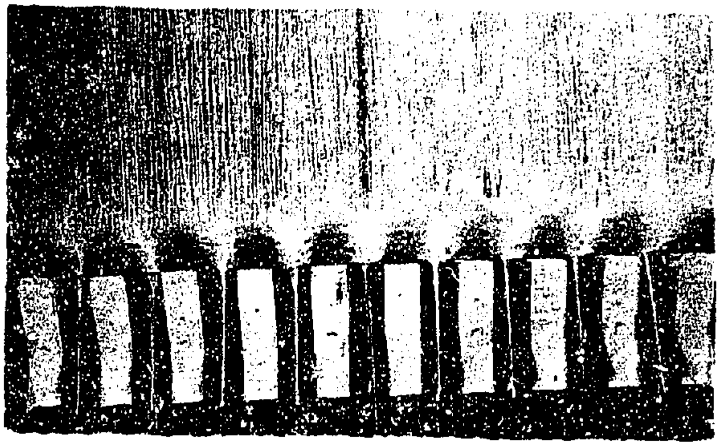


C. DENTATED STEPS - LOOKING UPSTREAM.

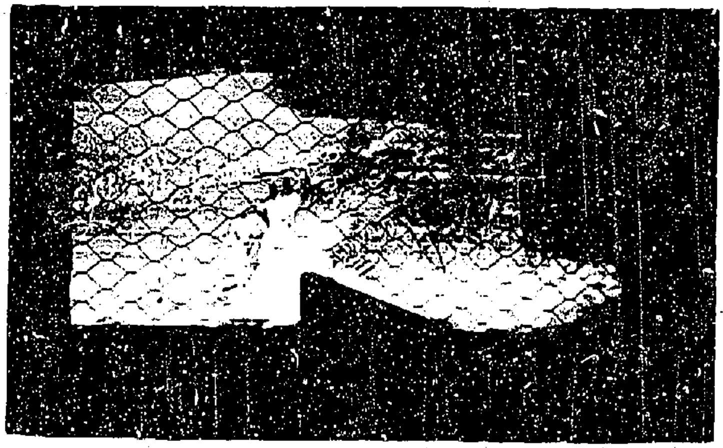
REVISED DAM.
RESULTS OF PAINT TESTS.



A. STILLING POOL.
LOOKING DOWNSTREAM.



B. COMPOUND REHBOCK SILL.
LOOKING UPSTREAM.



C. SIDE VIEW OF COMPOUND REHBOCK SILL.
LOOKING THROUGH RIGHT-HAND WINDOW.

REVISED DAM.
RESULTS OF PAINT TESTS.

pattern formed by the diverging jet as it flows over the dentated steps located on the sloping apron. The portion of the jet passing between the teeth spreads normal to the general direction of the flow as well as the portion that flows over the teeth. The function of the steps is to lift part of the high velocity jet off the floor and corrugate it, thus increasing its area and likewise increasing the internal friction in the stilling pool. As a result of these steps, the length of the jump was shortened to about two-thirds of its original length making possible a shorter length of pool with a corresponding saving in the cost of its construction.

Plate XIII-A is a view of the stilling pool looking downstream and B is a close-up of the compound Rehbock sill. Only the teeth having vertical upstream faces were painted before the run. The pattern in the region at the base of the teeth can be seen on plate XIII-B.

Plate XIII-C, a view looking through the right window of the flume after a paint test, illustrates very well the effectiveness of the sill. The high-velocity water is lifted from the floor and dispersed in various directions above the sill. The absence of these lines near the downstream end of the sill should be noted.

12. THE FINAL SPILLWAY DESIGN

Subsequent to the completion of the test program and the dismantling of the model, minor changes were made in the design of the spillway. The over-all length was reduced from 1335 to 1197.5 feet and the length of the stilling pool was shortened from 41.5 to 41.0 feet. The width of the teeth in the compound Rehbock sill was increased from 3.20 to 3.272 feet so that the expansion joints in the sill would match those in the pool floor. The final stilling pool design is shown on figure 23.

The effect of the two latter changes are, from experience, believed to be inconsequential as there is considerable latitude both in the length of the pool and the width of the teeth of the sill.

As previously designed, the maximum capacity of the spillway was 150,000 second-feet, or 112.4 second-feet per foot of length of crest, and the maximum capacity of the six-gate sluiceway was 15,000 second-feet, making a total capacity of 165,000 second-feet.

At the time that the length of the spillway was reduced from 1335 to 1197.5 feet and its capacity from 150,000 to 134,500 second-feet, the number of gates in the sluiceway was increased from six to twelve and its capacity increased from 15,000 to 30,000 second-feet so that the combined capacity was 164,500 second-feet or practically the same as the combined capacity in the original design.

The maximum discharge of 112.4 second-feet per foot of crest used in the final model studies simulates the maximum discharge of 134,500 second-feet in the final design of the spillway and the stilling pool was designed for the desired tailwater range with that capacity which is believed to be the practical limit of the stilling pool.

Figures 33, 34, and 35 show the action in the model of the final design of the stilling pool aside from the minor changes described above.

13. LOG OF TESTS (ORIGINAL SPILLWAY DESIGN)

IMPERIAL DAM (ORIGINAL)
BOULDER CANYON PROJECT
LOG OF TESTS

Test No.	Discharge Sec.-Ft.	Crest Length	Length of Pool	El. Pool Floor	Stepped Apron	Sill	Bed	Purpose	Remarks
1-1	150,000	1,072'	75.0'	152.0	None	A-1	Sand	Investigate action of sill.	Set-up as designed - water surface and bed profiles taken.
2-1	150,000	1,072'	75.0'	152.0	"	A-1	"	"	Sill lowered 2.5'. Water surface and bed profiles taken.
3-1	150,000	1,072'	75.0'	152.0	"	Rect. 2.5x8.0'	"	"	Water surface and bed profiles taken.
4-1	150,000	1,072'	75.0'	152.0	"	B-1	"	"	Water surface and bed profiles taken.
5-1	150,000	1,072'	75.0'	152.0	"	B-1	"	"	Sill raised 2.2 feet. Water surface and bed profiles taken.
6-1	150,000	1,300'	72.5'	152.0	"	B-1 as in 5-1	"	"	Water and sand surface profiles taken.
6-2	150,000	1,300'	72.5'	152.0	"	"	"	"	Same as 6-1, except tailwater elevation varied.
7-1	150,000	1,300'	35.0'	152.0	"	"	"	"	Water surfaces and bed surfaces.
7-2	150,000	1,300'	35.0'	152.0	"	"	"	"	Same as 7-1, except tailwater was higher.
8-1	150,000	1,300'	40.2'	152.0	"	Rect. 5'x2.2'	"	"	Water surfaces and bed profiles.

LOG OF TESTS (continued)

Test No.	Discharge Sec.-Ft.	Crest Length	Length of Pool	Elev. Pool Floor	Stepped Apron	Sill	Bed	Purpose	Remarks
9-1	150,000	1,300'& 1,732'	39.7'	152.0	None	Rect. 5'x2.2'	Sand	Investigate action of sill.	Water surfaces and bed profiles.
10-1	150,000	1,300'	39.7'	152.0	"	"	"	"	Bed was changed in this test to El. 152.0 for 100.0' from the sill; sloping from there to El. 147.0 in the next 50.0'; level sand from there on.
10-2	150,000	1,300'	39.7'	152.0	"	"	"	"	Same as 10-1, except that tail-water was 166.0.
11-1	150,000	1,300'	49.7'	152.0	"	"	"	"	Jump rough, boiling and splash-ing; water choppy.
11-2	150,000	1,300'	49.7'	152.0	"	"	"	"	Same as 11-1, except tailwater was 166.0; jump rough, boil.
12-1	150,000	1,300'	49.6'	152.0	"	Rect. 4'x1.7'	"	"	Action same as 11-1.
13-1	150,000	1,300'	49.6'	152.0	"	Rect. 4' x 3'	Bed at 152.0	"	Bed at 152.0 for 90' from sill; sloping in next 50' to 147.0; level from there on. Jump rough, high velocity.
13-2	150,000	1,300'	49.6'	152.0	"	"	"	"	Same set-up as in 13-1, except that tailwater is 166. Jump rougher.
14-1	150,000	1,300'	49.6'	152.0	"	"	Bed at 155.0	"	Same as 13-1, except bed. Jump was fairly quiet. High vel. below sill

LOG OF TESTS (continued)

Test No.	Discharge Sec.-Ft.	Crest Length	Length of Pool	Elev. Pool Floor	Stepped Apron	Sill	Bed	Purpose	Remarks
14-2	150,000	1,300'	49.6'	152.0	None	Rect. 4' x 3'	Bed at 155.0	Investigate action of sill.	Same as 14-1, except that tail-water was 166. Jump rough; slight secondary.
———	150,000	1,300'	49.6'	152.0	"	"	Bed at 153.0	A comparative test.	Bed at 153.0 for 100'; sloping to 147.0 in next 50' (riprap - 1½"). Jump was fairly satisfactory between 168.0 and 168.7.
———	150,000	1,732'	49.6'	152.0	"	"	"	"	Same set-up as above. Jump was satisfactory between 168.0 & 166.1.
———	100,000	1,300'	49.6'	153.0	"	"	"	"	Same as previous run, except for crest length and discharge. Jump satisfactory at 165.1.
———	150,000	1,300'	49.6'	152.0	"	B-1 on a 5.0'x2.2' rect.	"	"	Jump was satisfactory at tail-water elevation of 169.0'.
15-1	150,000	1,300'	59.6'	152.0	"	Rect. 4' x 3'	Bed at 152.0	Water surface, bed & dam pressure investigation.	Bed was riprap at 152.0 for 100' from sill; sloping to 147.0 in next 50' level sand from there on. (Riprap 1½" gravel). Jump was rough; violent boil; jump left pool at El. 166.9.

LOG OF TESTS (continued)

Test No.	Discharge Sec.-Ft.	Crest Length	Length of Pool	Elev. Pool Floor	Stepped Apron	Sill	Bed	Purpose	Remarks
16-1 to 16-7	Various	Various	59.6'	152.0	None	Rect. 4' x 3'	Bed at 152.0'	To determine the coefficient of discharge.	Data for determining the coefficient of discharge.
17-1 to 17-27	150,000	1,732'	Various	152.0	"	Various	Various	Comparative tests.	Tailwater range was insufficient.
18-1 & 18-2	150,000	1,732'	70.5'	152.0	"	None	152.0	To obtain pressures, and water surface profiles.	The jump was quiet at 167.7; rough at 166.5.
19-1 & 19-2	150,000	1,732'	57.5'	152.0	"	B-1 on a 22' x 5' Rect.	Scale riprap 152.0	"	Jump quiet - no erosion at 167.3.
20-1 to 20-120	150,000	1,300'	Various	150.0	Various	Various	Various	These were comparative tests.	Rough, some boil but no erosion at 165.6. Best designs were tests 27-28 and 27-80 (fig. 14).
21-1 to 21-3	150,000	1,300'	40.0'	150.0	G-1	M-1	152.0	Comparative tests.	Bed is riprap at 150.0 for 50' from end of the apron; then slopes to 152.0 at 100' from apron; then slopes to 147.0 in next 50'.

LOG OF TESTS (continued)

Test No.	Discharge Sec.-Ft.	Crest Length	Length of Pool	Elev. Pool Floor	Stepped Apron	Sill	Bed	Purpose	Remarks
22-1	150,000	1,300'	40.0'	150.0	G-1	M-1	155.0	Comparative tests.	This set-up was unsatisfactory because of standing waves.
23-1 to 23-2	100,000	1,300'	40.0'	150.0	G-1	M-1	152.0	Investigate pressures at end of teeth of dentated stepped apron.	Tailwater 165.2 (normal for 100,000 second-feet.)
24-1 to 24-2	50,000	1,300'	40.0'	150.0	G-1	M-1	152.0	"	Tailwater 163.2 in run 1; and 162.0 in run 2.
25-1 to 25-5	150,000	1,300'	Various	150.0	G-1	Various	Various	Comparative tests.	Tailwater range insufficient.
26-1 & 26-2	150,000	1,300'	45.0'	150.0	G-1	I-1 & M-1	152.0	Erosion tests.	Bed material was coarse sand. Tailwater El. was 168.1.
27-1 to 27-34	150,000	1,300'	Various	150.0	G-1	Various	Various	Comparative tests.	Bed was scale riprap at 152.0. Unsatisfactory because of erosion, roughness, and insufficient tailwater range.
28-1	150,000	1,300'	40.0'	150.0	G-1	K-1	152.0'	Erosion test.	Sill as shown in sketch K-1 (fig. 7) but has vertical faces upstream. Bed was coarse sand.

LOG OF TESTS (continued)

Test No.	Discharge Sec.-Ft.	Crest Length	Length of Pool	Elev. Pool Floor	Stepped Apron	Sill	Bed	Purpose	Remarks
29-1	150,000	1,300'	40.5'	150.0	G-1	L-1	152.0	Erosion test.	Original and eroded bed profiles were taken. Coarse sand was used.
30-1	150,000	1,300'	40.5'	150.0	G-1	L-1	152.0	"	"
31-1	150,000	1,300'	39.1'	150.0	G-1	K-1	152.0	"	"
32-1	150,000	1,300'	45.0'	150.6	G-1	H-1	152.0	"	"
33-1	150,000	1,300'	45.0'	150.0	None	M-1	152.0	"	"
34-1	150,000	1,300'	45.0'	150.0	"	I-1	152.0	"	"
35-1	150,000	1,300'	53.9'	150.0	"	Q-1	152.0	"	"
36-1	150,000	1,300'	40.5'	150.0	"	L-1	152.0	"	Sill L-1 with its vertical faces upstream. Same data taken as above.
37-1	150,000	1,300'	40.5'	150.0	"	L-1	152.0	"	Sill L-1 with its sloping faces upstream. Same data taken as above.
38-1	150,000	1,300'	39.1'	150.0	"	K-1	152.0	"	Same data taken as before.
39-1	150,000	1,300'	45.0'	150.0	"	H-1	152.0	"	"

LOG OF TESTS (continued)

Test No.	Discharge Sec.-Ft.	Crest Length	Length of Pool	Elev. Pool Floor	Stepped Apron	Sill	Bed	Purpose	Remarks
40-1 to 40-15	150,000	1,300'	Various	150.0	None & G-1	Various	152.0	Comparative tests to investigate range of tailwater and action of sills.	Some set-ups were satisfactory; others the tailwater range was too small; erosion bad; jump too rough, or too much boil.
41-1 to 41-3	Varied	1,300'	58.5'	150.0	G-1	S-1	152.0	Investigate pressures on downstream face of dam.	Approach channel floor raised to an approx. El. of 172.0.
42-1 to 42-3	Varied	1,300'	58.5'	150.0	G-1	G-1	152.0	"	Approach channel raised to an El. of approx. 178.0.
43-1 to 43-5	Varied	1,300'	58.3'	150.0	G-1	G-1	152.0	Pressure investigation and coefficient runs.	Approach floor at elevation 154.0.
44-1 to 44-5	150,000	1,300'	Varied	150.0	G-1 in all but 5; none in 5	S-1	Various	Erosion tests.	Original bed and eroded bed profiles were taken.

14. LOG OF TESTS (REVISED SPILLWAY DESIGN)

IMPERIAL DAM (REVISED)
BOULDER CANYON PROJECT
LOG OF TESTS

Test No.	Discharge Sec.-Ft.	Crest Length	Length of Pool	Elev. Pool Floor	Stepped Apron	Sill	Bed	Purpose	Remarks
1-1 to 8-1	Various	1,335'	41.4'	150.0	G-1	S-1	150.0	Pressure & coefficient tests.	Run at normal tailwater for discharge (taken from rating curve).
9-1 to 15-1	Various	1,335'	41.4'	150.0	G-1	S-1	150.0	Coefficient test.	Run at tailwater corresponding to the discharge.
16-1 to 16-17	150,000	1,335'	41.4'	150.0	G-1	Various	Various	Comparative tests.	Tailwater range, erosion, and tailwater condition noted.
16-18	150,000	1,335'	57.9'	150.0	G-1	Similar to G-2	Bed as in layout 52 (fig.29)	"	"
16-19	150,000	1,335'	57.9'	150.0	G-1	"	Riprap at 150	"	"
16-20 to 16-24	150,000	1,335'	57.9'	150.0	G-1	Various	Bed as in layout 52 (fig.29)	"	"
16-25 & 26	150,000	1,335'	Various	150.0	G-1	Various	Riprap at 150	"	"

LOG OF TESTS (continued)

Test No.	Discharge Sec.-Ft.	Crest Length	Length of Pool	Elev. Pool Floor	Stepped Apron	Sill	Bed	Purpose	Remarks
16-27 to 16-37	150,000	1,335'	Various	150.0	G-1	Two sills Various combinations	Bed as in layout 49 (fig.29)	Comparative tests.	Tailwater range, erosion, and tailwater condition noted.
16-38 & 39	150,000	1,335'	40.9'	150.0	G-1	U-2	Riprap at 150	Comparative test.	"
16-40 to 16-44	150,000	1,335'	40.9'	150.0	Various	U-2	"	Comparative tests.	Tailwater kept constant and position of jump noted.
16-45	150,000	1,335'	40.9'	150.0	G-1	U-2	"	"	Dam, bed, sill, and step as in revised design.
16-46 & 47	150,000	1,335'	41.8'	150.0	G-1	L-1	Beds U & V (fig.29)	"	Good tailwater range.
16-48 to 16-51	150,000	1,335'	41.0'	150.0	G-1	H-1	Various	"	Bed only was varied.
16-52 to 16-65	150,000	1,335'	Various	150.0	G-1	Various	Bed V	"	Most set-ups fairly good. Bed and step were kept the same and sills were varied.
16-66 & 67	150,000	1,335'	37.5'	150.0	Various	Similar to L-2	"	"	Step changed - same sill and bed.

LOG OF TESTS (continued)

Sheet 3 of 4

Test No.	Discharge Sec.-Ft.	Crest Length	Length of Pool	Elev. Pool Floor	Stepped Apron	Sill	Bed	Purpose	Remarks
16-38 to 16-74	150,000	1,335'	Various	150.0	G-1	Various baffle piers	Bed V	Comparative tests.	Piers changed - step and bed the same.
16-75	150,000	1,335'	54.5'	150.0	G-1	K-2	Bed V	Check run on test 16-47.	Jump went out at a higher tail-water elevation than in test 16-47 - about 2 feet higher.
16-76 to 16-92	150,000	1,335'	Various	150.0	G-1	Various	"	Comparative tests.	Piers and sills varied - step and bed the same. A few runs were satisfactory.
16-93	150,000	1,335'	21.6'	150.0	G-1	E-2	Shown in layout 69 (fig.30)	"	Same step, bed relatively the same, sill different.
16-94	150,000	1,335'	21.6'	150.0	G-1	E-2	"	"	Same step, bed relatively the same, sill the same but raised.
16-95	150,000	1,335'	35.8'	150.0	G-1	T-2	Bed V (fig.29)	"	Bed and step the same, sill changed.
16-96	150,000	1,335'	41.8'	150.0	G-1	W-2	"	Comparative test.	Very satisfactory results.
17-1 to 17-7	Various	1,335'	43.3'	150.0	G-1	L-2	Bed V	Investigation of pressure on downstream face of dam.	Test made after sanding down spillface of dam.

LOG OF TESTS (continued)

Test No.	Discharge Sec.-Ft.	Crest Length	Length of Pool	Elev. Pool Floor	Stepped Apron	Sill	Bed	Purpose	Remarks
18-1 to 18-14	Various	1,335'	43.3'	150.0	G-1	T-1	Bed V	Coefficient of discharge with various approach El. and piez. press.	Head, discharge, piez. press., and water surface profiles taken.
19-1	150,000	1,335'	41.5'	150.0	G-1	S-1	Bed V	Study of flow lines in wet paint.	Sketches of flow lines in paint were made and photographs taken.
Special 1 to 6	Various	1,335'	41.5'	150.0	G-1	T-2	Bed V	Visual debris test.	Both tailwater and discharge varied.

III. THE IMPERIAL DAM SLUICEWAY

1. THE LABORATORY

A model of the Imperial Dam sluiceway was constructed and tested in the same laboratory as the dam but in a different location. A plan of this portion of the laboratory is shown on figure 37.

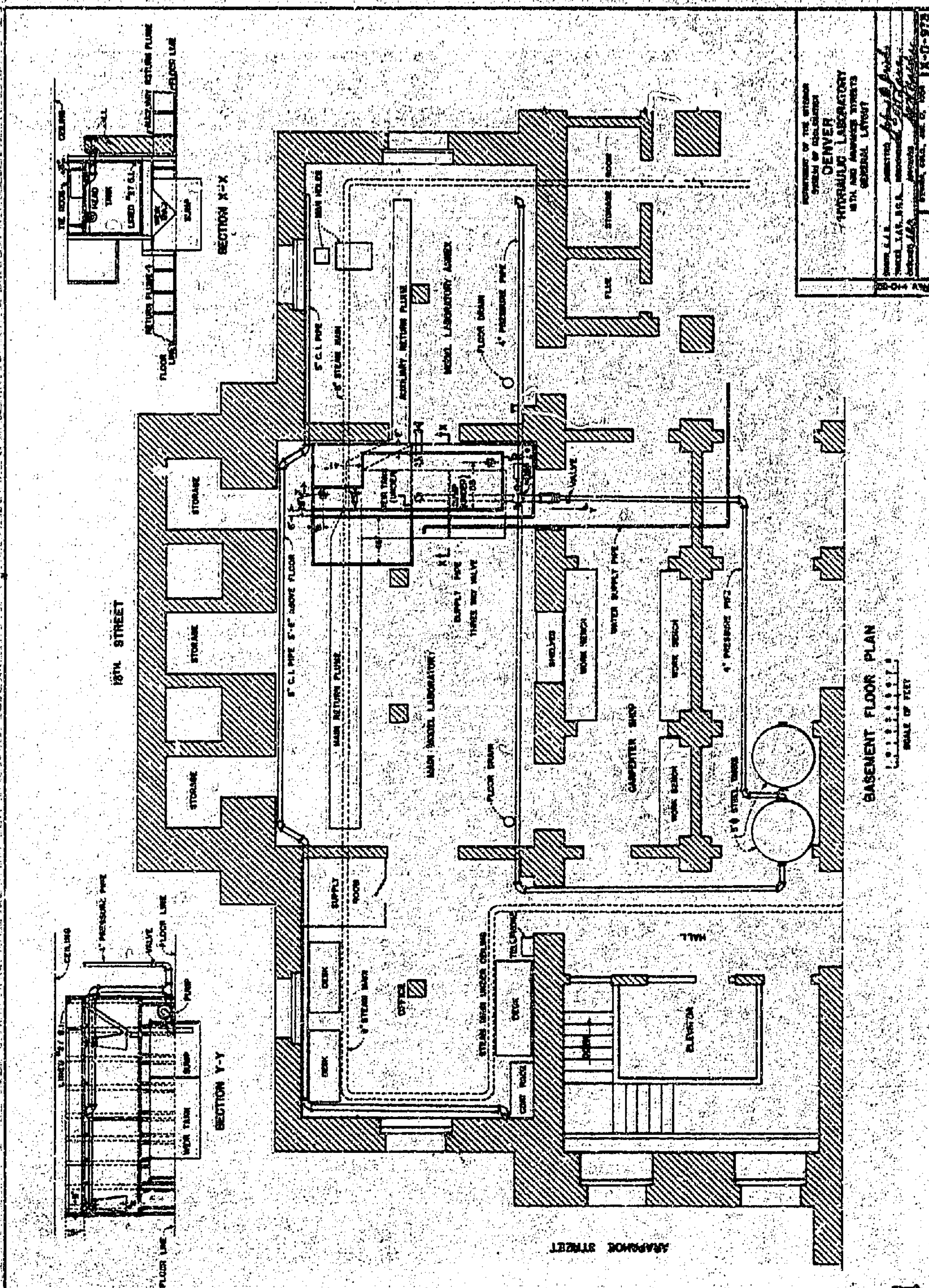
The water for the models was measured over a 90-degree, V-notch weir located in the end of a weir tank 6 by 12 by 4 feet deep, which was partially below the laboratory floor. From here, the water was pumped by a 6-inch centrifugal pump into a constant level tank located near the ceiling of the laboratory. A constant head of water was maintained in this tank by a stationary skimming weir. The water flowed from the constant level tank through two 8-inch calibrated gate valves, then through large expanding cones into two head reservoirs located directly below the constant level tank. Water was then supplied to the models directly from these head reservoirs. With this arrangement, two models could be operated simultaneously. The sluiceway model was supplied directly from one of these head reservoirs. After passing through the model, the water collected in a sheet-metal flume and returned to the weir tank where it was recirculated.

2. THE SLUICEWAY MODEL

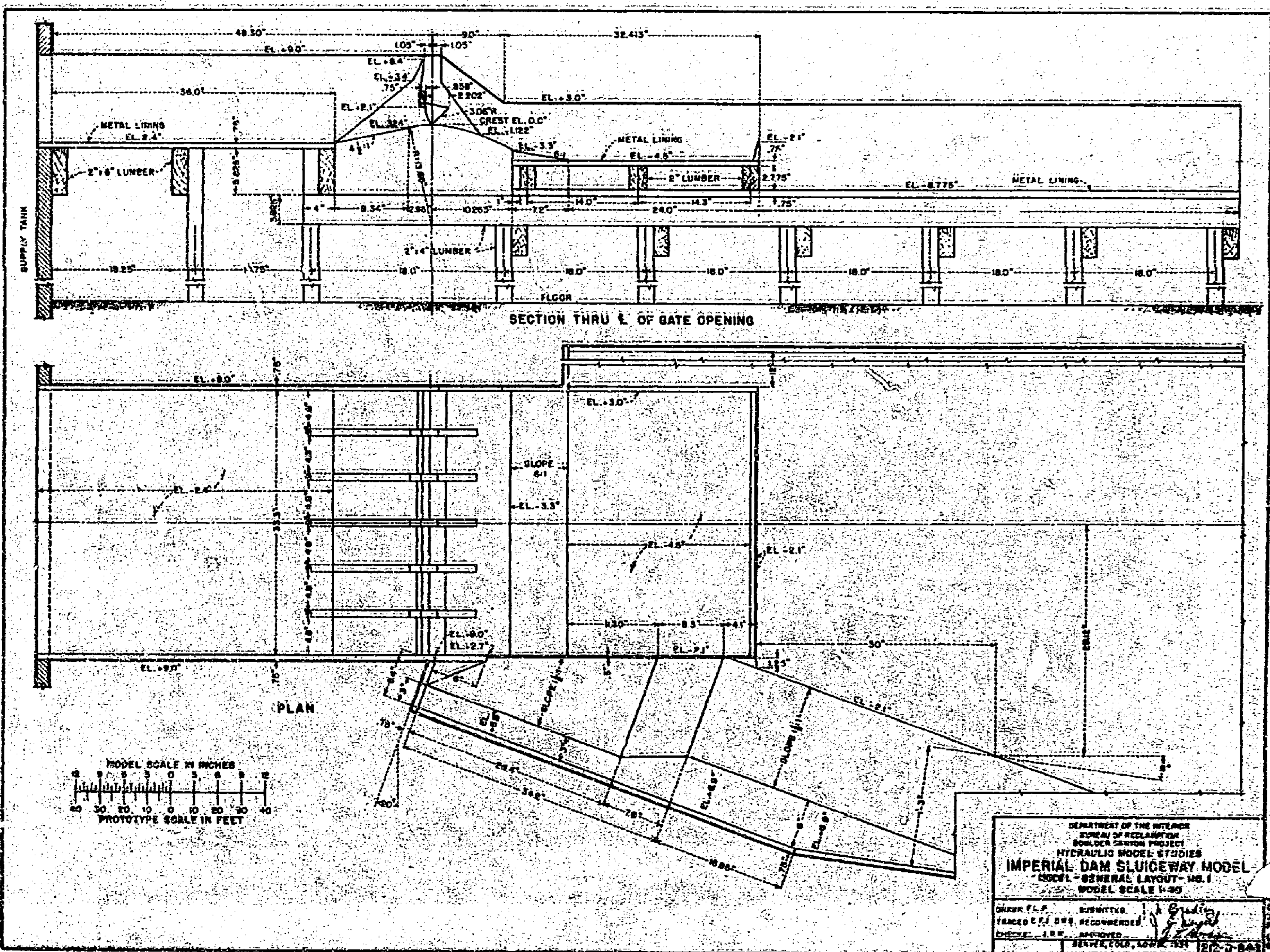
The original sluiceway model (fig. 38) was constructed in the laboratory on a scale of 1 to 40. The overflow section was by shaping a piece of 20-gage sheet metal over five heavy metal ribs and soldering it in place. The ribs in turn were mounted on small steel angles. The five piers on the original design were made of redwood and waterproofed with oil and varnish. The gates were constructed of one piece of 18-gage sheet metal extending the full length of the crest and bent radially to the correct curvature. The gate was pivoted on a 1/4-inch brass rod by means of arms which extended from the rod to the gate. Two lock nuts made it possible to lock the gate in any position.

The model was constructed in a wooden flume lined with sheet metal. The upstream apron was represented by the floor of the box. The downstream apron, made of wood and sheet metal, was built so that changes could be made in this portion of the structure. A sand box was provided downstream from the stilling pool so that the effect of erosion for various layouts could be compared. An adjustable weir was installed at the downstream end of the sand box to regulate the tailwater depth. A piezometer connected to the box registered the tailwater elevation. Piezometers having 3/16-

FIG. 37



19TH STREET
ARAPAHOE STREET
BASEMENT FLOOR PLAN
SECTION X-X
SECTION Y-Y
STORAGE
MAIN MODEL LABORATORY
MODEL LABORATORY ANNEX
MAIN RETURN FLUME
AUXILIARY RETURN FLUME
CARPENTER SHOP
WORK BENCH
SUPPLY ROOM
OFFICE
DESK
HALL
ELEVATOR
FLUE
FLOOR DRAIN
4" PRESSURE PIPE
WATER SUPPLY PIPE
VALVE
DENVER
HYDRAULIC LABORATORY
GENERAL LAYOUT



SUPPLY TANK
METAL LINING
2"x4" LUMBER
2" LUMBER
FLOOR
CREST EL. 0.0"
SECTION THRU ℄ OF GATE OPENING
SLOPE 6:1
PLAN
MODEL SCALE IN INCHES
PROTOTYPE SCALE IN FEET
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY MODEL
MODEL - GENERAL LAYOUT - NO. 1
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED

inch holes were located on the overflow section of the sluiceway for observing the pressures on the face. These were connected by rubber hoses to a reading board. Water-surface measurements were made with a point gage mounted on a carriage that operated along two level steel angles, one on each side of the flume. The head on the model was observed from a hook gage connected to the head reservoir.

3. THE ORIGINAL DESIGN

A plan and section of the sluiceway as originally designed is shown on figure 39. The crest was at elevation 162.0, the upstream apron at 154.0, and the downstream apron at elevation 147.0. Flow through the sluiceway was to be controlled by six radial gates each 16 feet in length. An apron on a 6 to 1 slope was provided just downstream from the rounded overflow section to keep the front of the jump in this region for a wide range of discharges and tailwater depths. A continuous sill 8 feet high with a beveled upstream face was to be used on the end of the downstream apron to aid in the formation of the jump. Photographs of the model constructed according to the original design are shown on plate 1. Photograph A shows the original model and sand bed before a run; B, the sluiceway operating at a partial discharge; and C, taken after the run, shows the erosion of the sand bed.

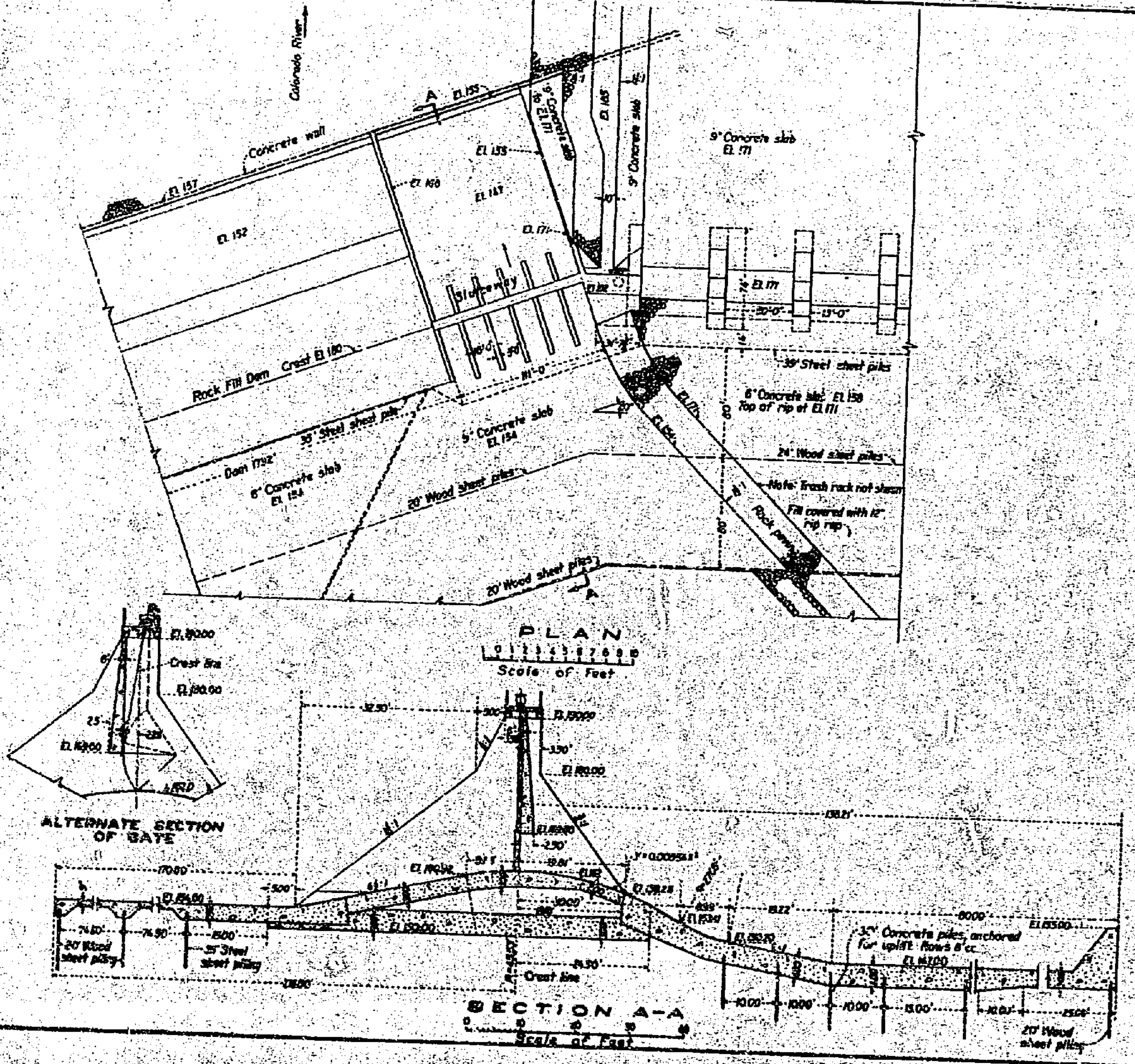
No measurements were recorded on the original design. The model showed the pool to be quite rough with a large boil over the sill for the maximum discharge and tailwater depth. With the sand bed at elevation 155.0 the velocity of the water flowing over it was quite high. Energy dissipation was not confined entirely to the stilling pool and further model tests were planned on this phase of the structure.

4. STILLING POOL TESTS

A. Six 16-Foot Gates - Piers 3.0 Feet Wide

a. Original Single-Jump Pool

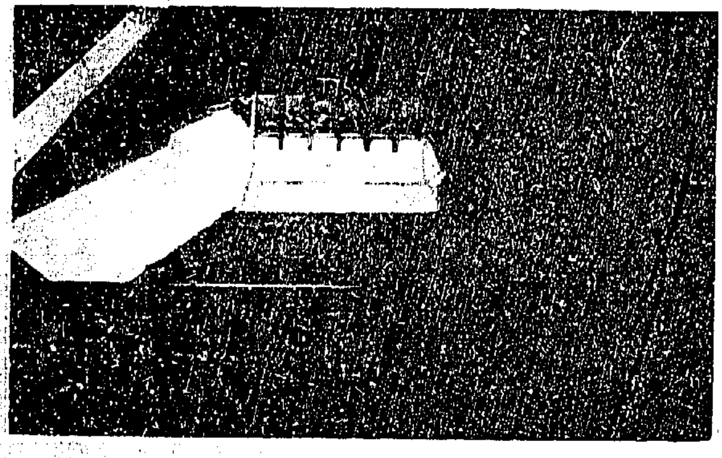
Different designs of sills (fig. 40) were tried at the end of the horizontal apron in an effort to improve the action in the stilling pool and reduce erosion downstream. It was found that stepped aprons (A-3 to G-3, fig. 40) installed at the 6:1 sloping apron were an asset and a number of these were intermittently tried in combination with the various sills throughout the following tests.



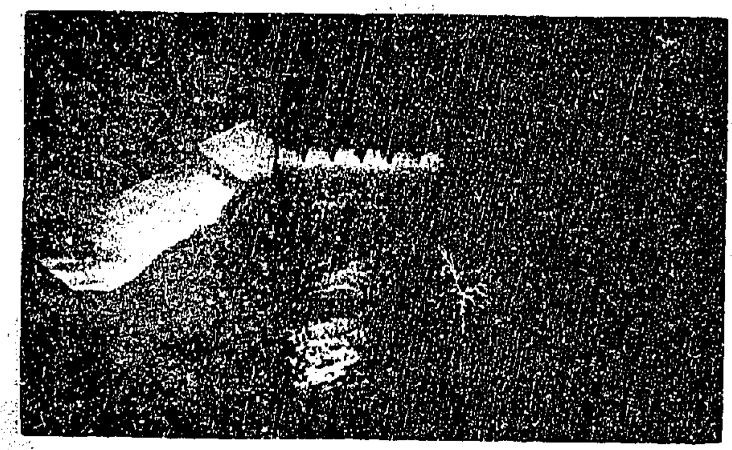
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

IMPERIAL DAM SLUICEWAY
ORIGINAL PLAN
AND SECTION

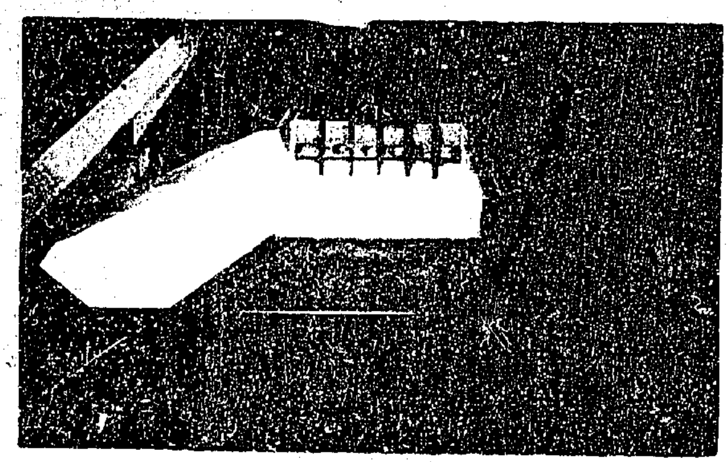
FIGURE 39



A. SAND BED BEFORE RUN.



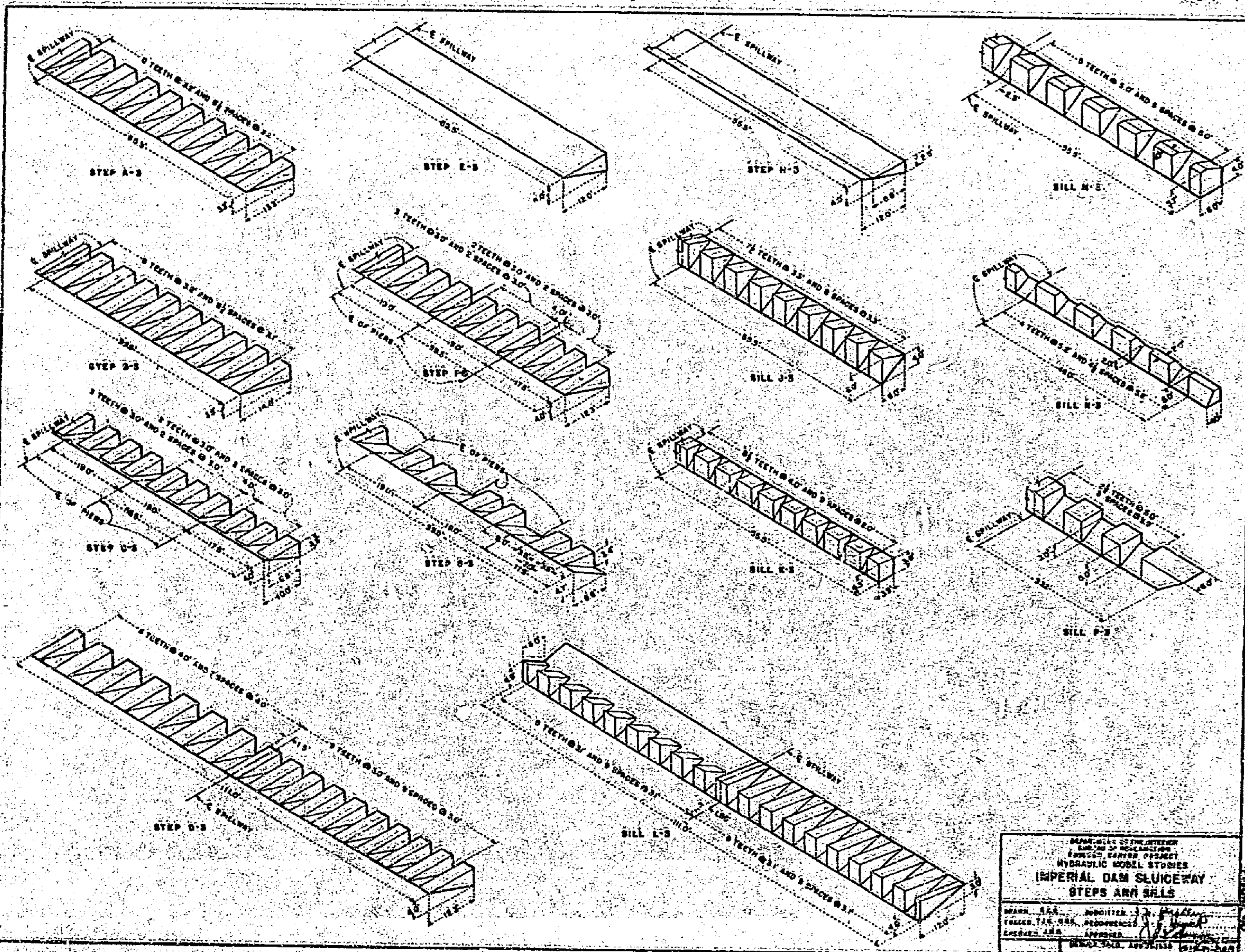
B. DISCHARGE 2,140 SECOND-FEET.
TAILWATER ELEVATION 158.0.



C. SAND BED AFTER RUN.

ORIGINAL DESIGN.

FIGURE 40


STEP A-3
STEP E-3
STEP H-3
SILL M-3
STEP B-3
STEP F-3
SILL J-3
SILL K-3
STEP D-3
STEP G-3
SILL E-3
SILL P-3
STEP O-3
SILL L-3
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
STEPS AND SILLS

Tests 4-1 and 4-2 (fig. 41) were made with the stepped apron, F-3, placed at the end of the sloping apron and sill L-3 installed on the end of a pool floor 45.5 feet long[1]. A smooth

[1]The length of the pool floor as referred to throughout this report will be defined as that length of horizontal paving from the point at which the sloping apron intersects it to the end of the sill.

paving, 58 feet in length and at elevation 150.0, was placed immediately downstream from the sill, and below this the river was paved with riprap for a distance of 70 feet. The riprap started at elevation 150.0 and sloped downward to elevation 140.0. Plate II-A shows this layout and B is a view of the model in operation at a discharge of 12,042 second-feet with a tailwater elevation of 155.4. The jump was on the verge of leaving the pool for this depth of tailwater. For the purpose of comparison, the teeth were different on the two halves of the sill (sill L-3, fig. 40). The larger teeth gave slightly better results than the smaller ones. Flow conditions were fairly satisfactory for the maximum tailwater elevation of 158.0 (test 4-1, fig. 41) but when the tailwater was dropped to elevation 155.4 as in test 4-2, the jump threatened to leave the pool. In addition, a large boil formed over the sill and a series of stationary waves, created by the high velocity water, were present downstream from the pool. The front of the jump formed near the center of the stilling pool for both tailwater depths. This layout was unsatisfactory for the purpose desired as the tailwater range was much too small and the velocities downstream from the pool too high.

A predicted tailwater rating curve is shown on figure 8. There is some uncertainty concerning this curve as it is impossible to ascertain the effect Boulder Dam and the dumping of silt into the river from the All-American canal desilting works will have on the future regime of the river. In order to be prepared for any unexpected tailwater conditions that might be encountered, it was thought best to design a stilling pool for the sluiceway, as well as for the dam, that would operate satisfactorily for a wide range of tailwater depths. Further experimentation was carried on to this end.

Tests 5-1 and 5-2 (fig. 41) were similar to those previously described, except that a portion of the smooth paving below the sill was raised one foot to elevation 151.0. The water-surface profiles for these runs show that the higher paving below the sill increased the tailwater range with the result that the front of the jump moved upstream. Conditions downstream from the pool were worse than in test 4, as raising the paving increased the velocity over it and this in turn caused very large stationary

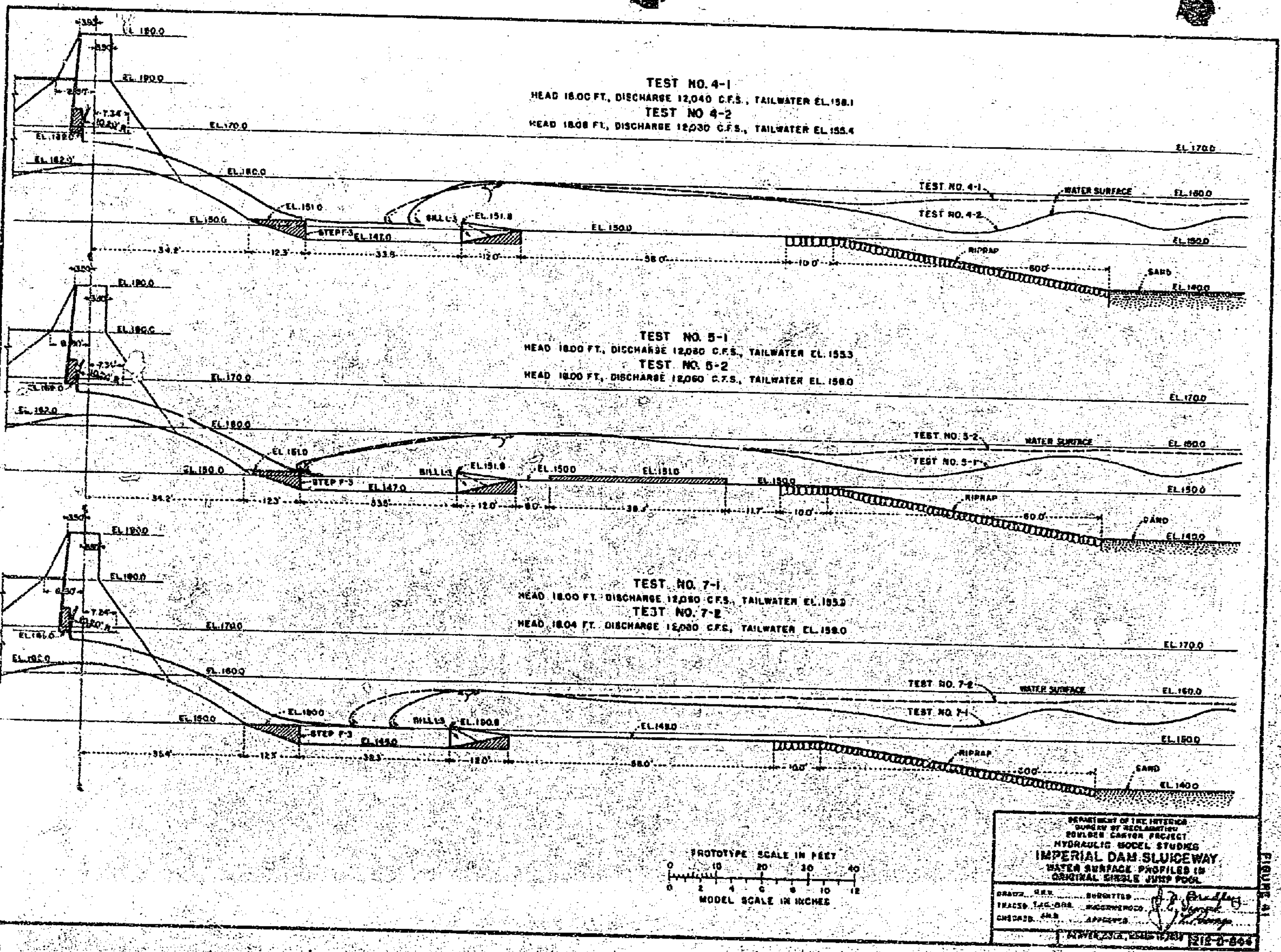
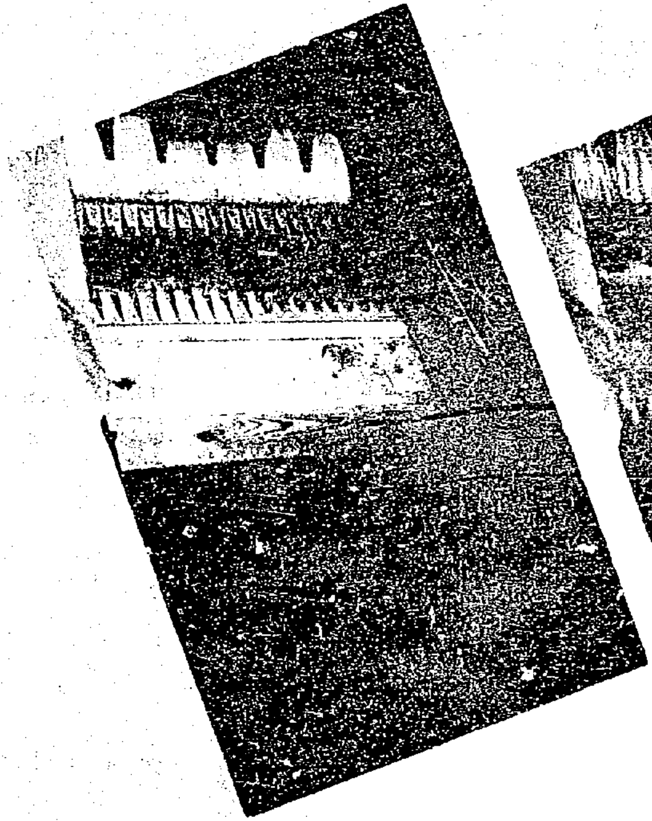
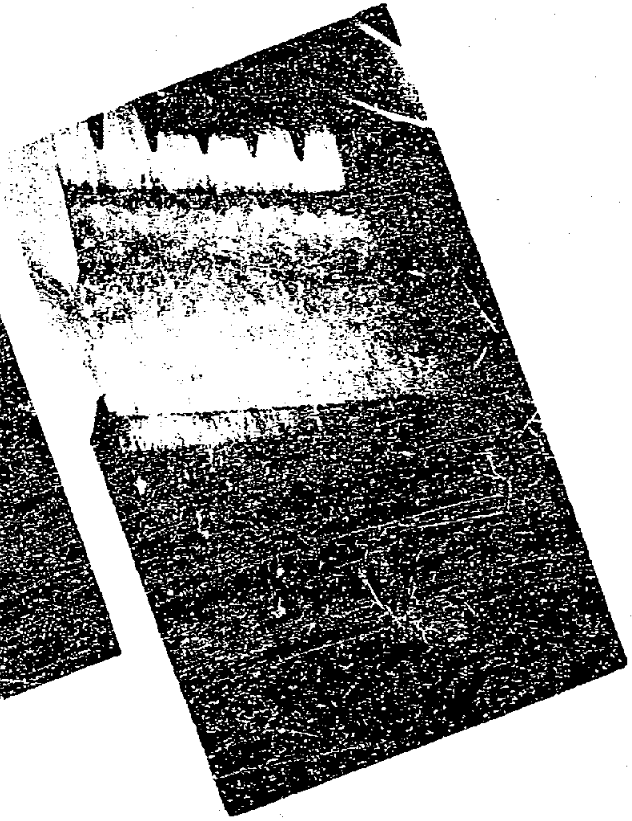

TEST NO. 4-1
HEAD 18.00 FT., DISCHARGE 12,040 C.F.S., TAILWATER EL. 158.1
TEST NO 4-2
HEAD 18.08 FT., DISCHARGE 12,030 C.F.S., TAILWATER EL. 155.4
TEST NO. 5-1
HEAD 18.00 FT., DISCHARGE 12,080 C.F.S., TAILWATER EL. 155.3
TEST NO. 5-2
HEAD 18.00 FT., DISCHARGE 12,060 C.F.S., TAILWATER EL. 158.0
TEST NO. 7-1
HEAD 18.00 FT. DISCHARGE 12,050 C.F.S., TAILWATER EL. 155.0
TEST NO. 7-2
HEAD 18.04 FT. DISCHARGE 12,080 C.F.S., TAILWATER EL. 158.0
WATER SURFACE
RIPRAP
SAND
STEP F-3
SILLS
PROTOTYPE SCALE IN FEET
MODEL SCALE IN INCHES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
WATER SURFACE PROFILES IN ORIGINAL SINGLE JUMP POOL
212-D-844

FIGURE 41



A. LAYOUT AS FOR TEST 4-1.

B. DISCHARGE 12,042 SECOND-FEET.
TAILWATER ELEVATION 155.4.



C. DISCHARGE 12,062 SECOND-FEET.
TAILWATER ELEVATION 155.3.

ORIGINAL SINGLE JUMP POOL

waves to form. Plate II-C shows this pool in action for a discharge of 12,062 second-feet and a tailwater elevation of 155.3.

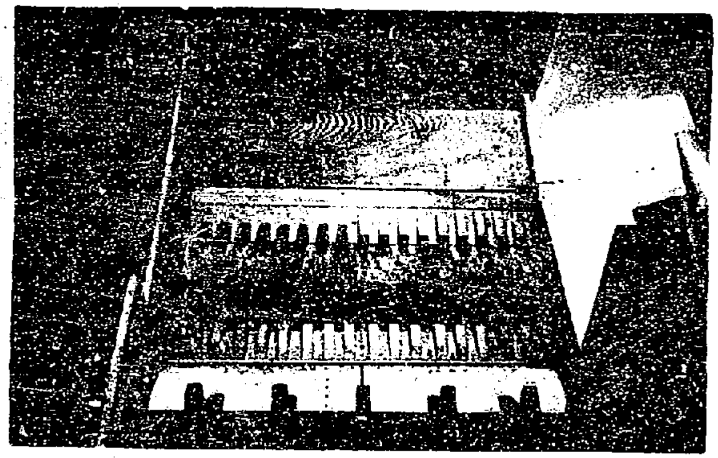
For tests 7-1 and 7-2 (fig. 41) the layout was similar to that in the previous tests, except that the pool floor was lowered to elevation 146.0 and the 58 feet of smooth paving below the sill was dropped to elevation 149.0. Plate III-A is a view of this layout and B shows the pool in operation for a discharge of 12,082 second-feet with a tailwater elevation of 158.0. The lowering of the pool floor one foot was compensated by dropping the paving an equal amount, and as a net result, flow conditions were very similar to those in test 4. The profile on figure 41 shows that the front of the roller moved back to the center of the pool. The action in the pool was somewhat improved in that the boiling action was reduced, but the stationary waves continued to form downstream for the lower tailwater depths. In addition to these disadvantages, there was an insufficient tailwater range.

b. The Double-Jump Pool

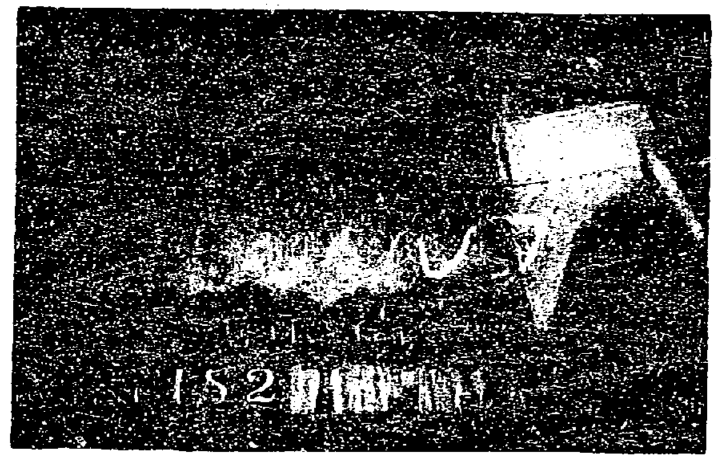
As the previous layouts failed to produce the desired results and other similar layouts did not appear promising, the stilling pool was rebuilt to form a double hydraulic jump. The first pool of this type to be tried is shown in profile for tests 8-1 and 8-2 on figure 42. The primary pool was shortened to 31 feet and left at elevation 146.0. Sill L-3 and dentated stepped apron F-3 (shown in detail on fig. 40) were used in combination and the smooth paving was extended downstream as shown. Plate III-C is a view of this layout and D and E show the pool in action for a discharge of 12,062 second-feet and tailwater elevations of 158.0 and 155.5, respectively. The secondary jump can be seen in photograph E. Referring to the water surface profiles for tests 8-1 and 8-2 (fig. 42), it can be seen that the flow conditions were much improved with the double-jump pool. The surface waves downstream from the stilling pool were eliminated and the tailwater range was increased.

For tests 10-1 and 10-2 (fig. 42), sill L-3 was removed and the pool shortened. The paving under the secondary jump was shortened considerably and a small continuous rectangular sill was installed on the end of it. Plate IV-A shows this pool in action for a discharge of 12,102 second-feet and a tailwater elevation of 155.2 and B is a view of the layout taken after the run. The action of the double jump was very effective, the water leaving the secondary roller was quiet and erosion of the sand bed was slight (plate IV-B).

A layout was desired which would produce a double jump for all tailwater elevations below 158.0 and one in which the

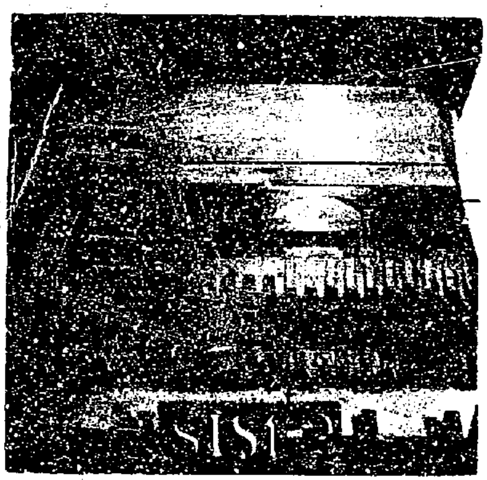


A. LAYOUT AS FOR TEST 7-2.

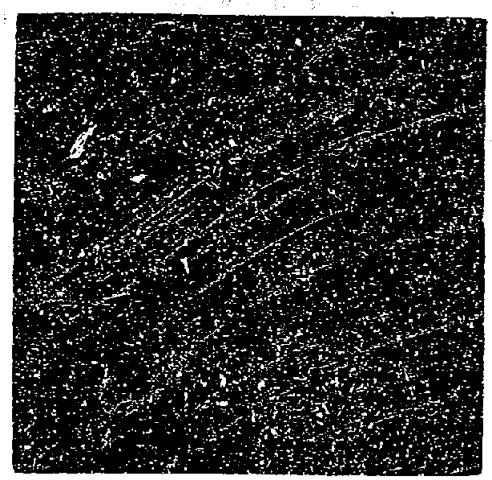


B. DISCHARGE 12,062 SECOND-FEET.
TAILWATER ELEVATION 158.0.

ORIGINAL SINGLE JUMP POOL



C. LAYOUT FOR TEST 8.

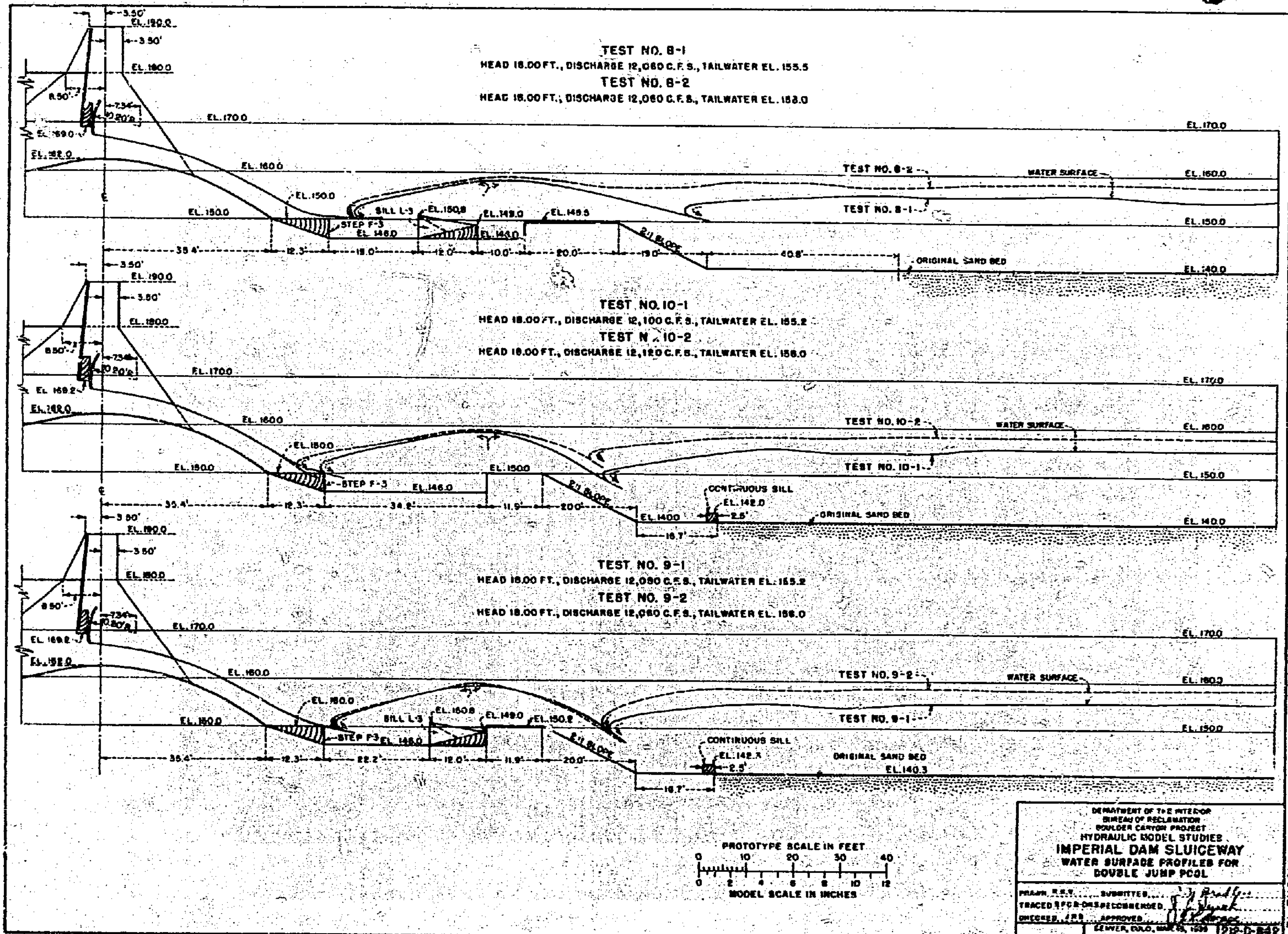


D. DISCHARGE 12,062 SECOND-FEET.
TAILWATER ELEVATION 158.0.

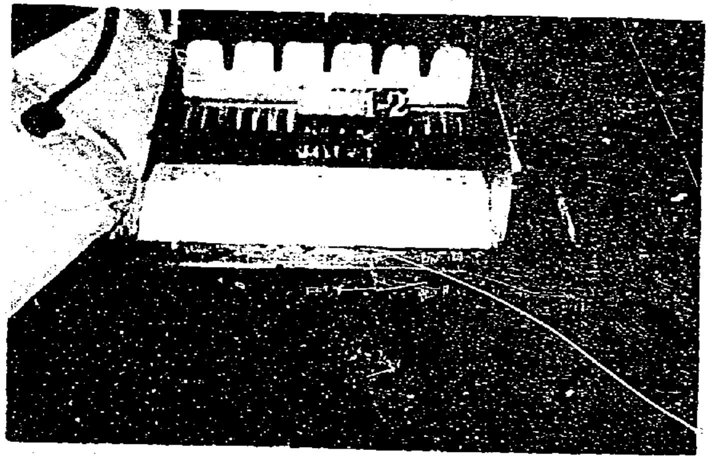
E. DISCHARGE 12,062 SECOND-FEET.
TAILWATER ELEVATION 155.5.

DOUBLE JUMP POOL.

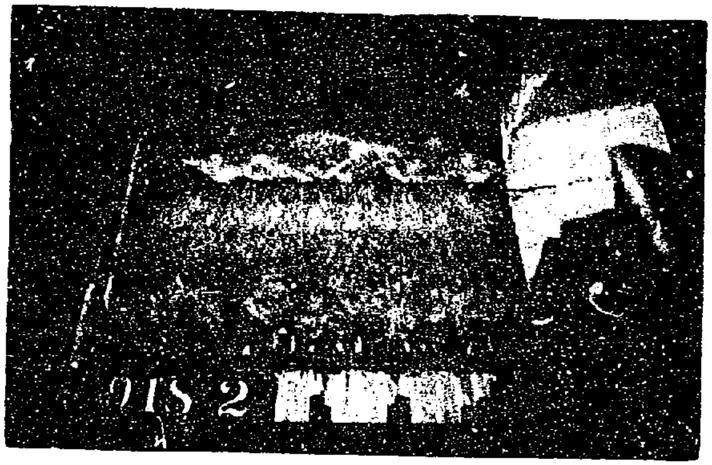
FIGURE 42


TEST NO. 8-1
HEAD 18.00 FT., DISCHARGE 12,060 C.F.S., TAILWATER EL. 155.5
TEST NO. 8-2
HEAD 18.00 FT., DISCHARGE 12,060 C.F.S., TAILWATER EL. 158.0
TEST NO. 10-1
HEAD 18.00 FT., DISCHARGE 12,100 C.F.S., TAILWATER EL. 155.2
TEST NO. 10-2
HEAD 18.00 FT., DISCHARGE 12,120 C.F.S., TAILWATER EL. 158.0
TEST NO. 9-1
HEAD 18.00 FT., DISCHARGE 12,080 C.F.S., TAILWATER EL. 155.2
TEST NO. 9-2
HEAD 18.00 FT., DISCHARGE 12,060 C.F.S., TAILWATER EL. 158.0
WATER SURFACE
ORIGINAL SAND BED
CONTINUOUS SILL
STEP F-3
SILL L-3
2:1 SLOPE
PROTOTYPE SCALE IN FEET
MODEL SCALE IN INCHES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
WATER SURFACE PROFILES FOR
DOUBLE JUMP POOL
212-D-842

A. DISCHARGE 12,102 SECOND-FEET.
TAILWATER ELEVATION 155.2.



B. LAYOUT FOR TEST 10.
AFTER RUN.



C. DISCHARGE 12,082 SECOND-FEET.
TAILWATER ELEVATION 158.0.

D. LAYOUT FOR TEST 9.
AFTER RUN.

DOUBLE JUMP POOL

secondary jump would flood out for tailwater elevations above 158.0. Tests were made to develop a pool that would have these characteristics. In test 10 (fig. 42), the secondary jump did not flood out until the tailwater reached elevation 164.4.

A layout identical to test 10 was used in test 9 (fig. 42), except that sill L-1 was reinstalled on the pool floor. Plate IV-C shows the pool in action for a discharge of 12,082 second-feet and a tailwater elevation of 158.0, and D shows a view of the layout and sand bed taken after the run. The hydraulic action in the pool was satisfactory but the secondary jump did not flood out until the tailwater reached elevation 159.3.

A material change was made in the stilling pool for tests 13, 15, and 16 (fig. 43). Sill K-3 (fig. 40) was used on the stilling pool floor for tests 13-1 and 13-2. Plate V-A shows the pool in action for a discharge of 12,060 second-feet and a tailwater elevation of 155.0, and B is a view of the layout taken after the run. In this case, the secondary jump flooded out for a tailwater elevation of 160.5.

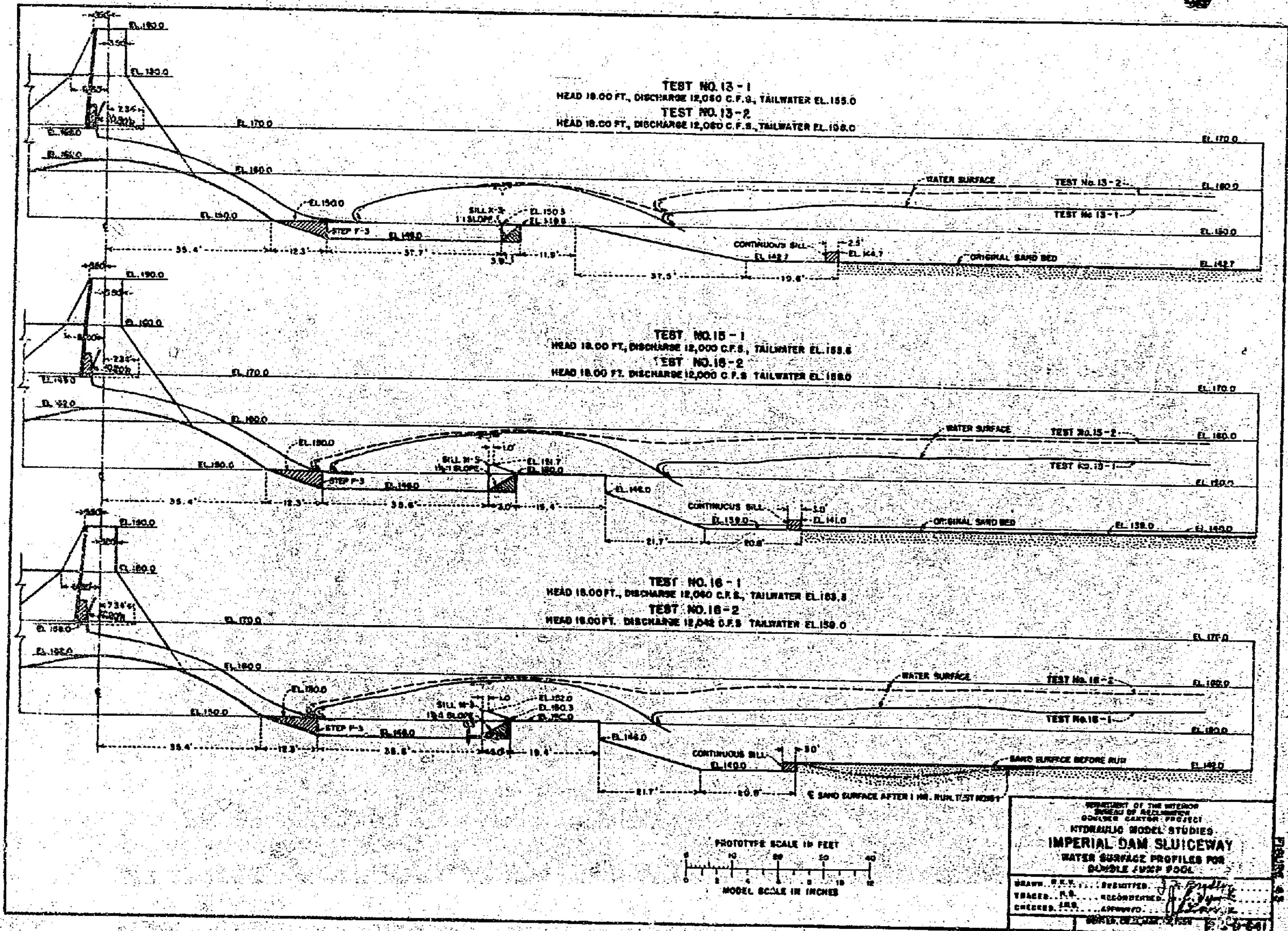
In tests 15-1 and 15-2, sill M-3 was installed in the primary pool and the secondary pool floor was shortened and dropped to elevation 139.0. Plate VI-A shows the layout, and B and C show the pool in action for a discharge of 12,000 second-feet and tailwater elevations of 158.0 and 153.6, respectively. The secondary jump flooded out at a tailwater elevation of 156.8.

A pool which had the desired characteristics was developed in tests 16-1 and 16-2 (fig. 43). Stepped apron F-3 was again used in combination with sill M-3 in the primary pool. The secondary pool floor was raised a foot to elevation 140.0 and the sand bed was elevated to 142.0. Plate V-C shows the pool in action for a discharge of 12,060 second-feet and a tailwater elevation of 153.5, and D shows a view of the layout and sand bed taken after the run. Erosion was somewhat excessive near the ends of the small rectangular sill. The secondary jump flooded out for a tailwater elevation of 157.5. The hydraulic action in the pool was very satisfactory for tests 13, 15, and 16, as can be seen from the profiles on figure 43. A profile of the sand surface on the center line of the sluiceway is shown after the run for test 16-2 on the same figure.

B. Eight 16-Foot Gates - Piers 3.5 and 6.0 Feet Wide

a. Revised Double-Jump Pool

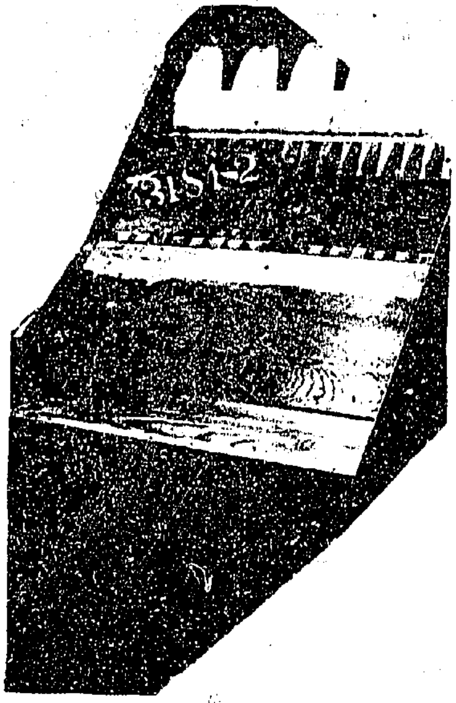
The consulting board at a meeting in January 1935, recommended that the height of Imperial Dam be increased one foot and



TEST NO. 13 - 1
HEAD 18.00 FT., DISCHARGE 12,050 C.F.S., TAILWATER EL. 155.0
TEST NO. 13 - 2
HEAD 18.00 FT., DISCHARGE 12,050 C.F.S., TAILWATER EL. 158.0
TEST NO. 15 - 1
HEAD 18.00 FT., DISCHARGE 12,000 C.F.S., TAILWATER EL. 153.6
TEST NO. 15 - 2
HEAD 18.00 FT. DISCHARGE 12,000 C.F.S. TAILWATER EL. 158.0
TEST NO. 16 - 1
HEAD 18.00 FT., DISCHARGE 12,050 C.F.S., TAILWATER EL. 153.8
TEST NO. 16 - 2
HEAD 18.00 FT. DISCHARGE 12,048 C.F.S. TAILWATER EL. 159.0
WATER SURFACE
ORIGINAL SAND BED
CONTINUOUS SILL
STEP F-3
SAND SURFACE BEFORE RUN
SAND SURFACE AFTER 1 HR. RUN, TEST NO. 16-1
PROTOTYPE SCALE IN FEET
MODEL SCALE IN INCHES
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
WATER SURFACE PROFILES FOR
DOUBLE JUMP POOL

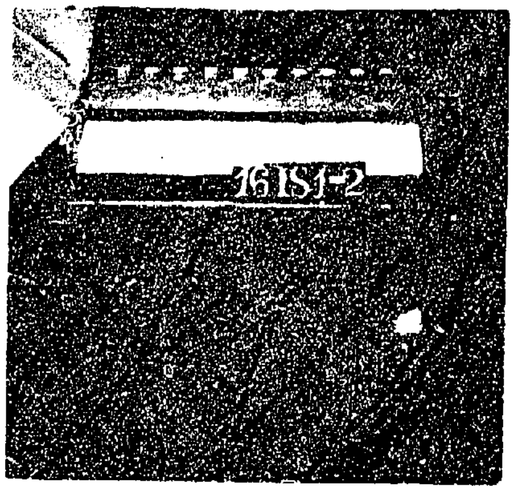
FIGURE 43

A. DISCHARGE 12,062 SECOND-FEET.
TAILWATER ELEVATION 155.0.



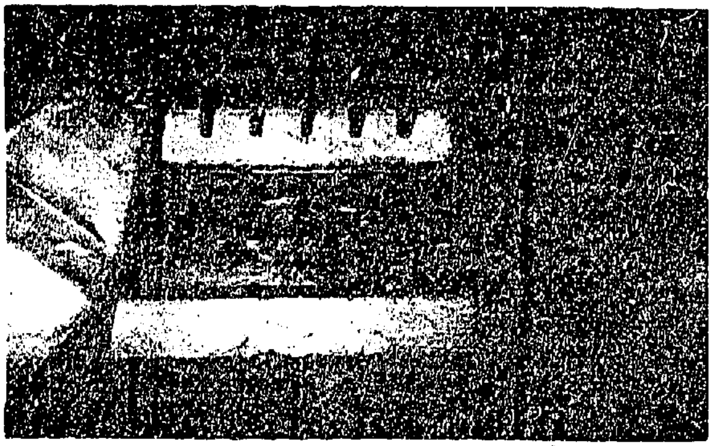
B. LAYOUT FOR TEST 13.
AFTER RUN.

C. DISCHARGE 12,062 SECOND-FEET.
TAILWATER ELEVATION 153.5.

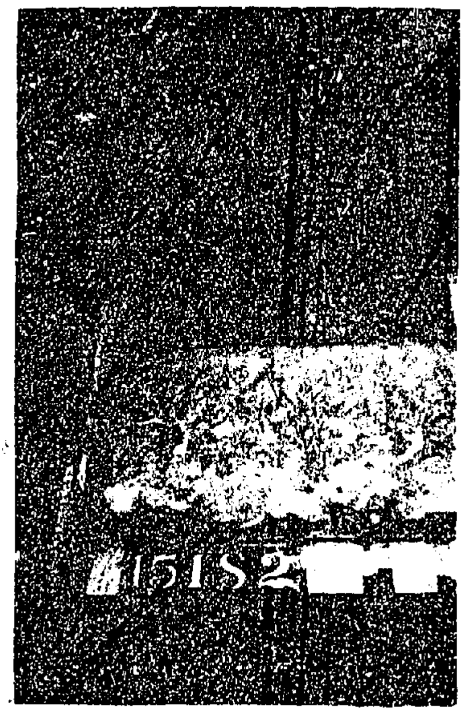


D. LAYOUT FOR TEST 16.
AFTER RUN.

DOUBLE JUMP POOL



A. LAYOUT FOR TEST 15.



B. DISCHARGE 12,000 SECOND-FEET.
TAILWATER ELEVATION 156.0.

C. DISCHARGE 12,000 SECOND-FEET.
TAILWATER ELEVATION 153.6.

DOUBLE JUMP POOL

that the sluiceway be raised a like amount. This established the new sluiceway crest at elevation 163.0. The shape of the overflow section was changed to that shown on figure 44. The upstream slope was changed from $4\frac{1}{2}$:1 to $1\frac{1}{2}$:1 with the result that the crest portion was flattened considerably. In addition, it was recommended that eight gates 16 feet in length be used (fig. 44) instead of six as originally planned, which increased the total capacity of the sluiceway by one-third. The width of the piers was increased from 3 feet to 3 feet 6 inches, except the center pier, the width of which was increased to 6 feet.

The model was partly rebuilt to simulate the change of design. The approach and stilling pool floors were lowered to correct for the change in elevation. Warped walls were installed on the sides of the secondary stilling pool to form a transition from the rectangular pool to the trapezoidal channel downstream.

The shape of the overflow section was not changed from that of the original design. The number of gates was not increased from six to eight, instead, the model was considered to represent the prototype with the two center gates and the wide center pier removed. The model discharge represented a flow of approximately 2,000 second-feet per gate. The width of the piers in the model remained at 3.0 feet as in the original design.

A comparison of figure 44 with figure 45 will show the difference between the prototype and the model. Plate VII-A is a view of the revised double-jump pool. Photograph B shows it in operation for a discharge of approximately 2,000 second-feet per gate and a tailwater elevation of 158.0 and C shows the pool in action for the same discharge and a tailwater elevation of 150.5. Profiles of the water surfaces for this pool are shown for a variety of conditions on figures 46 and 47. Pressures on the pool floor are indicated by the broken lines on the same figures. The action in the pool was very satisfactory for all conditions of flow. The secondary jump flooded out for a tailwater elevation of about 158.0 and a wide tailwater range was afforded by this layout. Energy dissipation was very effective and flow below the secondary jump was comparatively quiet. This layout had one distinct disadvantage, however, in that it necessitated a long length of concrete paving. For this reason, another type of pool was investigated.

b. Single-Jump Pool with Long Sloping Apron

The stilling pool was revised as shown on figures 48 and 49 and plate VIII-A. A long apron with a slope of 4:1 commenced 17.9 feet downstream from the center line of the crest and extended

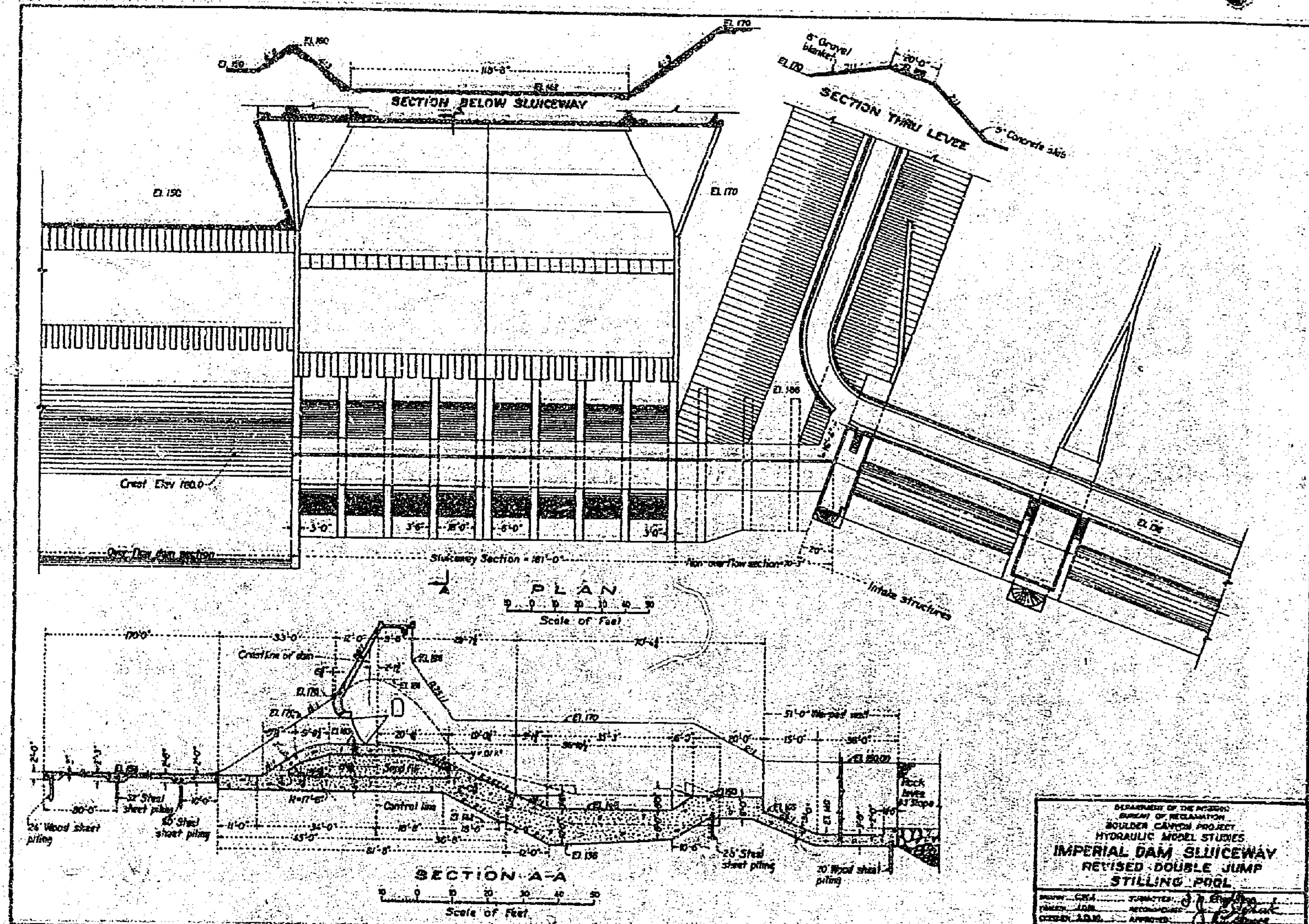

SECTION BELOW SLUICEWAY
SECTION THRU LEVEE
El. 150
El. 160
El. 170
110'-0"
5" Gravel blanket
5" Concrete slab
20'-0"
Crest Elev 180.0
Over-flow dam section
Sluiceway Section = 181'-0"
Non-overflow section
Intake structures
El. 186
El. 136
3'-0"
PLAN
Scale of Feet
Crestline of dam
Control line
Sand fill
51'-0" Warped wall
Rock levee
24" Wood sheet piling
32' Steel sheet piling
20' Wood sheet piling
25' Steel sheet piling
SECTION A-A
Scale of Feet
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
REVISED DOUBLE JUMP
STILLING POOL

FIGURE 44

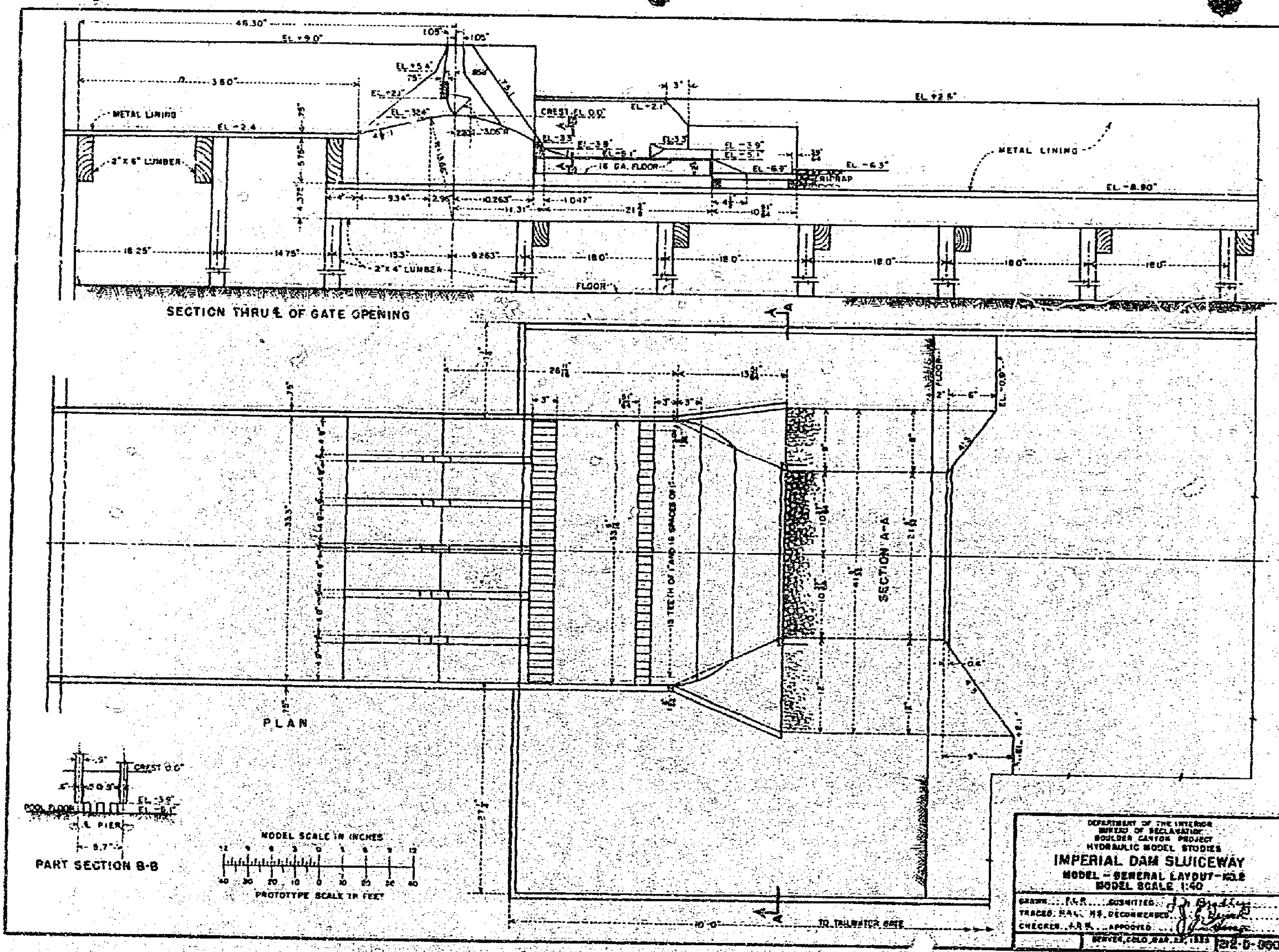
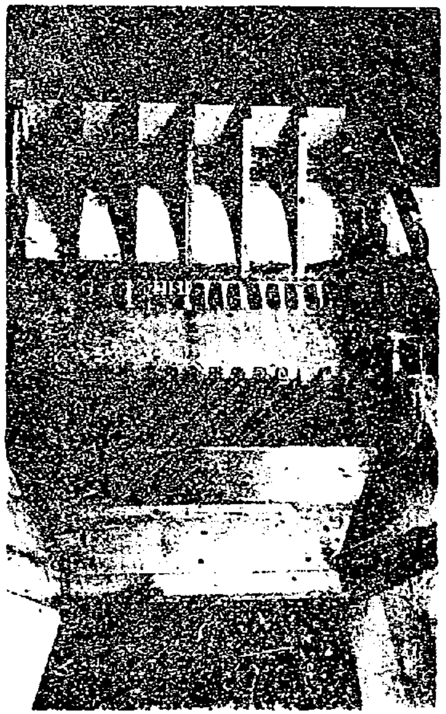
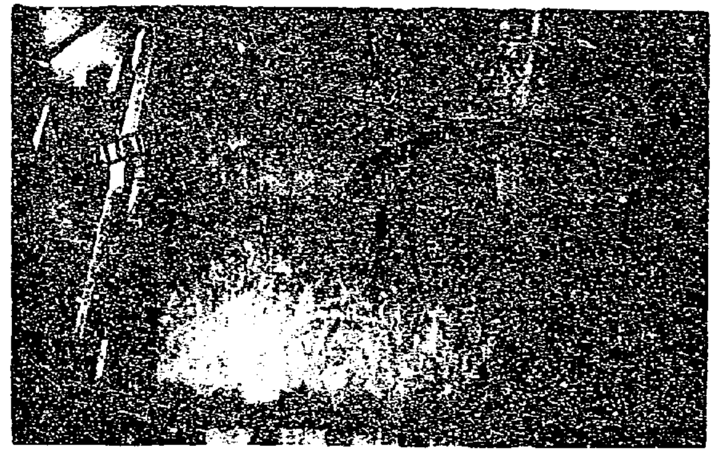

SECTION THRU ℄ OF GATE OPENING
METAL LINING
2"x 6" LUMBER
2"x 4" LUMBER
16 GA. FLOOR
CREST EL 0.0"
RIPRAP
FLOOR
EL +9.0"
EL +2.5"
EL -2.4
EL -8.90"
SECTION A-A
15 TEETH OF 1" AND 16 SPACES OF 1"
PLAN
PART SECTION B-B
POOL FLOOR
℄ PIER
MODEL SCALE IN INCHES
PROTOTYPE SCALE IN FEET
TO TAILWATER GATE
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
MODEL - GENERAL LAYOUT - NO.2
MODEL SCALE 1:40
DENVER, COLO. MAR. 23, 1935
212-D-860

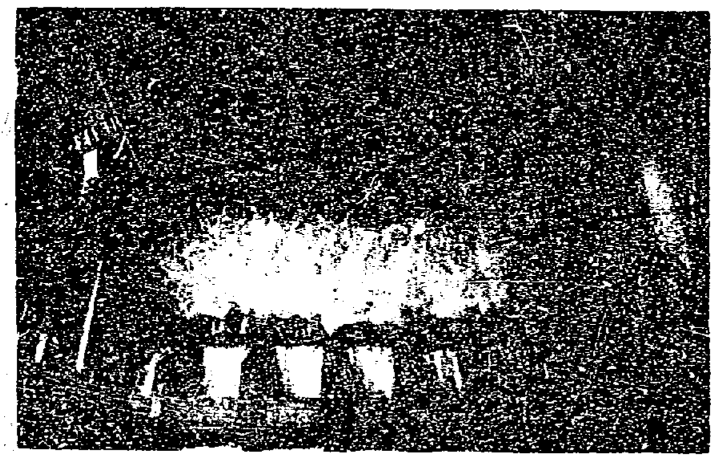
FIGURE 45



A. LAYOUT AS FOR TEST 33.

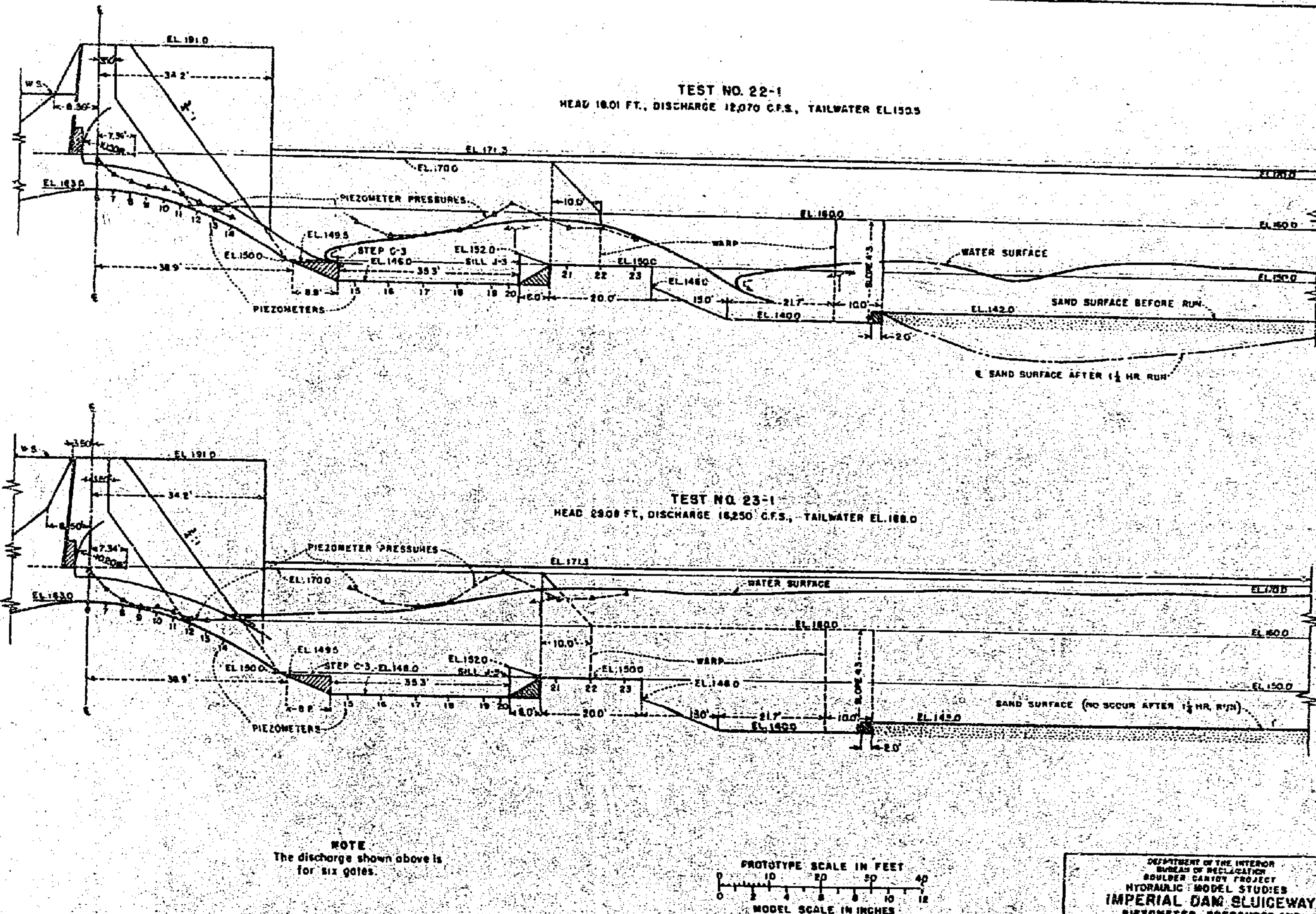


B. DISCHARGE 11,970 SECOND-FEET.
TAILWATER ELEVATION 158.0.



C. DISCHARGE 12,070 SECOND-FEET.
TAILWATER ELEVATION 150.5.

REVISED DOUBLE JUMP POOL



NOTE
The discharge shown above is for six gates.

DEPARTMENT OF THE INTERIOR
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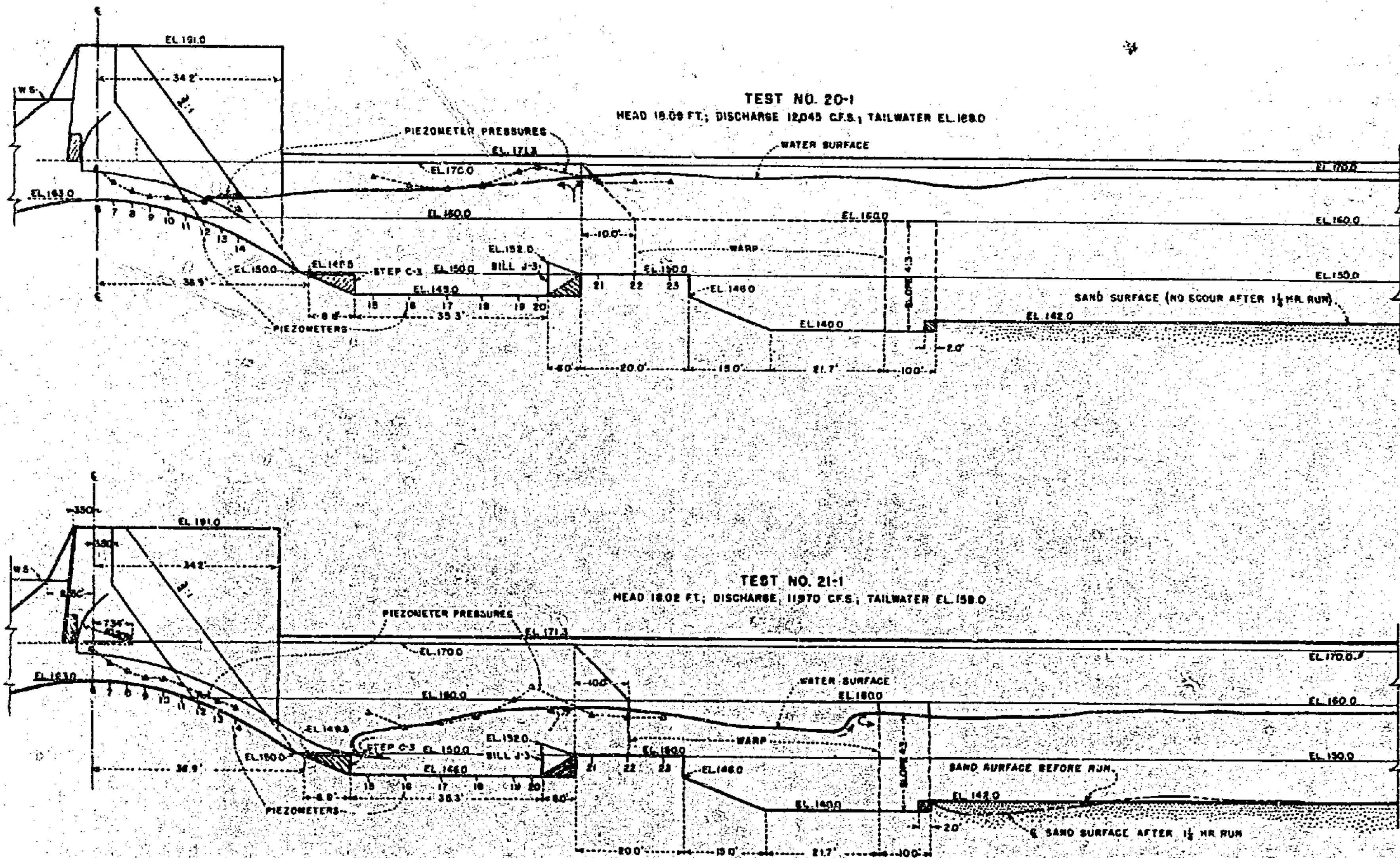
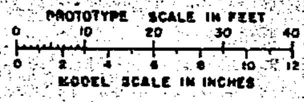
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
PIEZOMETER PRESSURES AND WATER-SURFACE PROFILES FOR REVISED DOUBLE JUMP POOL

DRAWN R.K.K. SUBMITTED
TRACED S.P.O.G., O.R.S. RECOMMENDED
CHECKED J.B.M. APPROVED
DENVER, COLO.
212-D-955

FIGURE 46



NOTE
The discharge shown above is for six gates.



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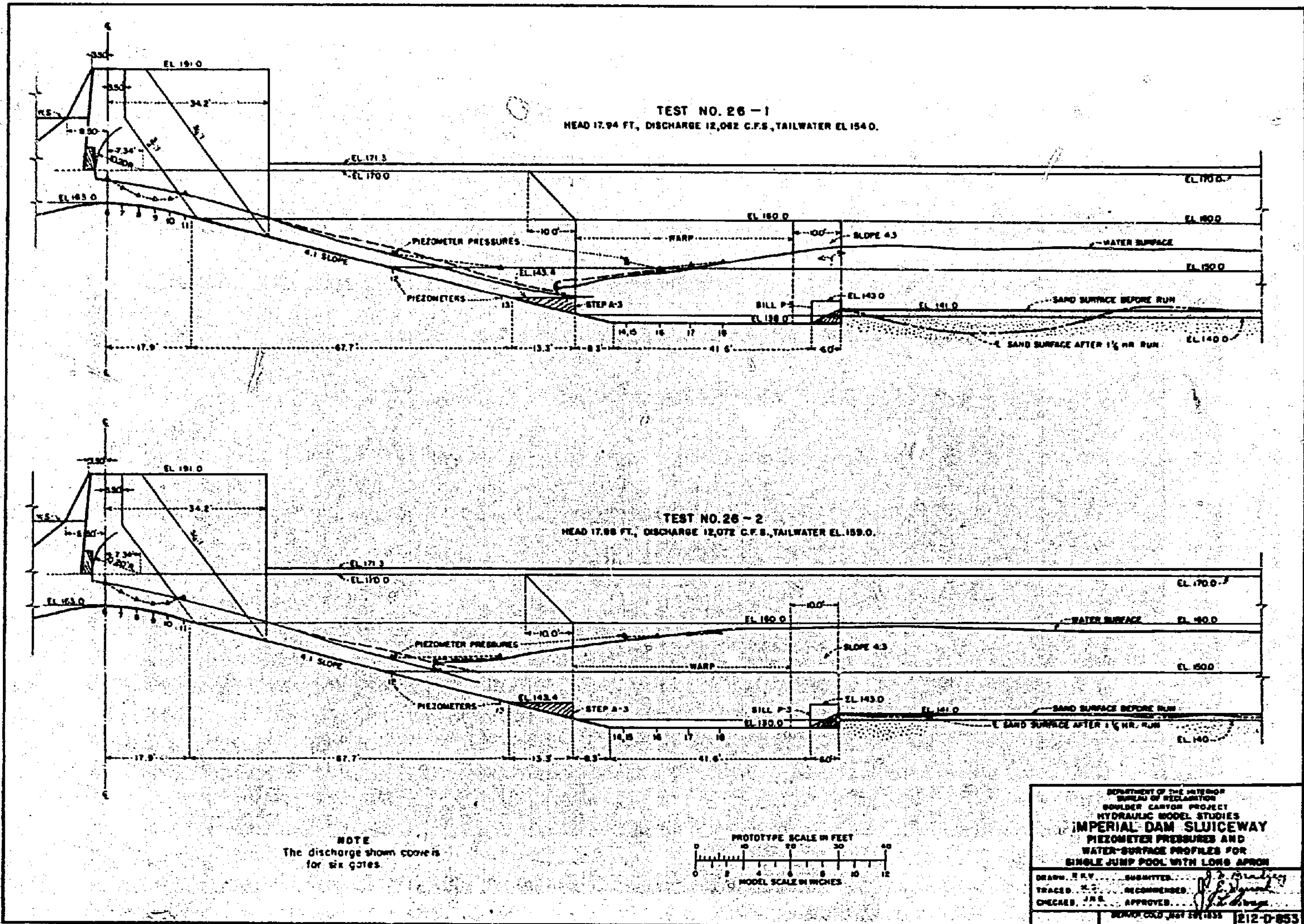
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
PIEZOMETER PRESSURES AND
WATER-SURFACE PROFILES FOR REVISED
DOUBLE JUMP POOL

DRAWN R.B.Y. SUBMITTED
TRACED R.S. O.P.S. RECOMMENDED
CHECKED J.D.M. APPROVED
DENVER, COLO. 212-D-254

FIGURE 47



TEST NO. 26 – 1
HEAD 17.94 FT., DISCHARGE 12,062 C.F.S., TAILWATER EL 154.0.
TEST NO. 26 – 2
HEAD 17.98 FT., DISCHARGE 12,072 C.F.S., TAILWATER EL 159.0.
EL 191.0
EL 171.3
EL 170.0
EL 163.0
EL 160.0
EL 150.0
EL 143.4
EL 143.0
EL 141.0
EL 140.0
PIEZOMETER PRESSURES
PIEZOMETERS
WARP
SLOPE 4:3
4:1 SLOPE
STEP A-3
SILL P-3
WATER SURFACE
SAND SURFACE BEFORE RUN
SAND SURFACE AFTER 1½ HR. RUN
NOTE
The discharge shown above is for six gates.
PROTOTYPE SCALE IN FEET
MODEL SCALE IN INCHES
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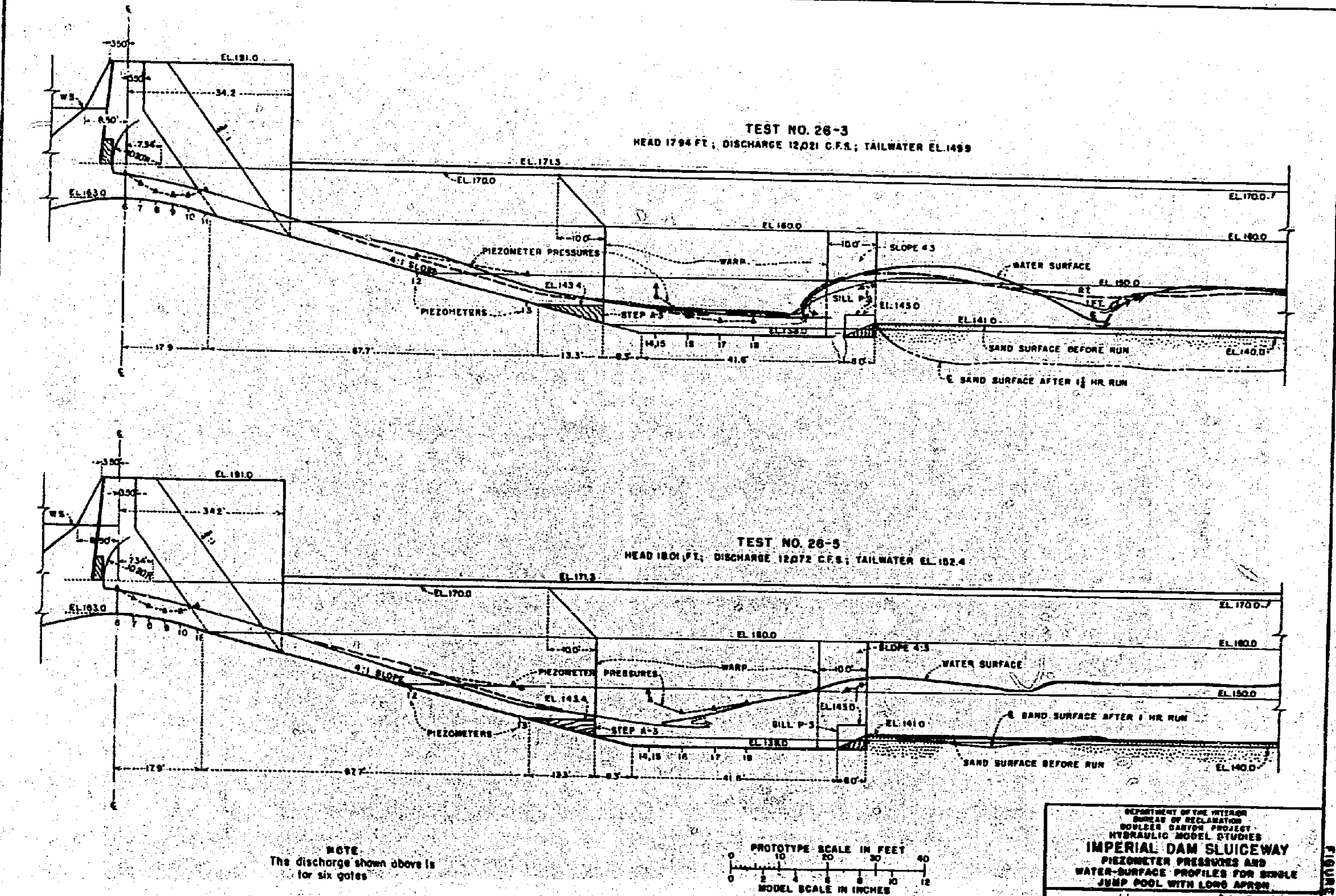
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
PIEZOMETER PRESSURES AND
WATER-SURFACE PROFILES FOR
SINGLE JUMP POOL WITH LONG APRON
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLO.
212-D-853

FIGURE 48



NOTE:
The discharge shown above is for six gates

DEPARTMENT OF THE INTERIOR
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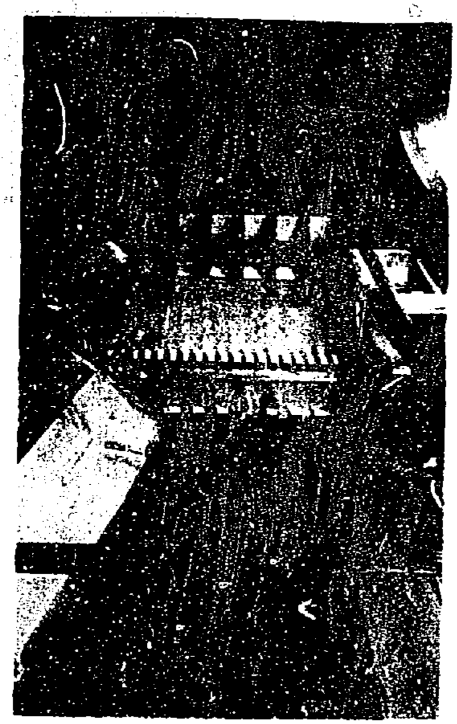
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
PIEZOMETER PRESSURES AND
WATER-SURFACE PROFILES FOR SINGLE
JUMP POOL WITH LONG APRON

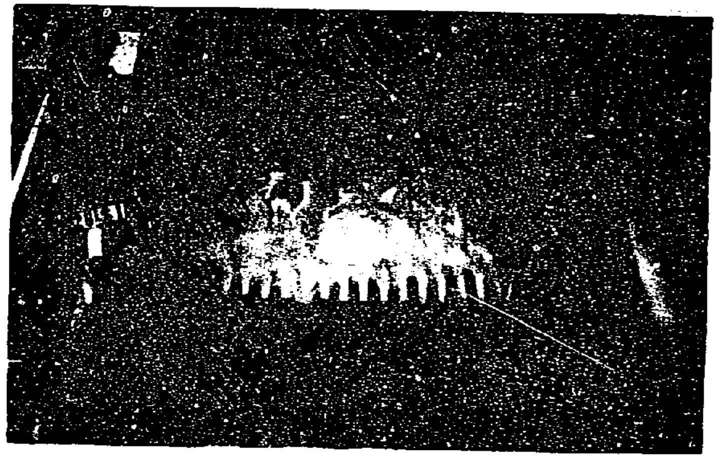
DRAWN... SUBMITTED...
TRACED... RECOMMENDED...
CHECKED... APPROVED...
DENVER, COLO.

212-D-892

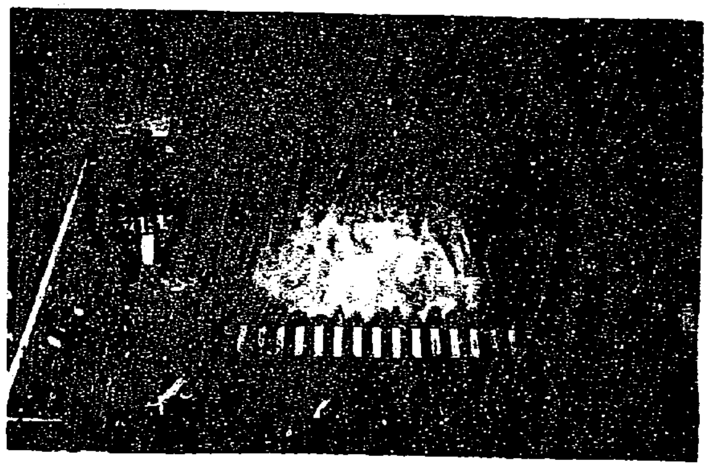
FIGURE 40



A. LAYOUT AS FOR TEST 26.



B. DISCHARGE 12,062 SECOND-FEET.
TAILWATER ELEVATION 154.0.



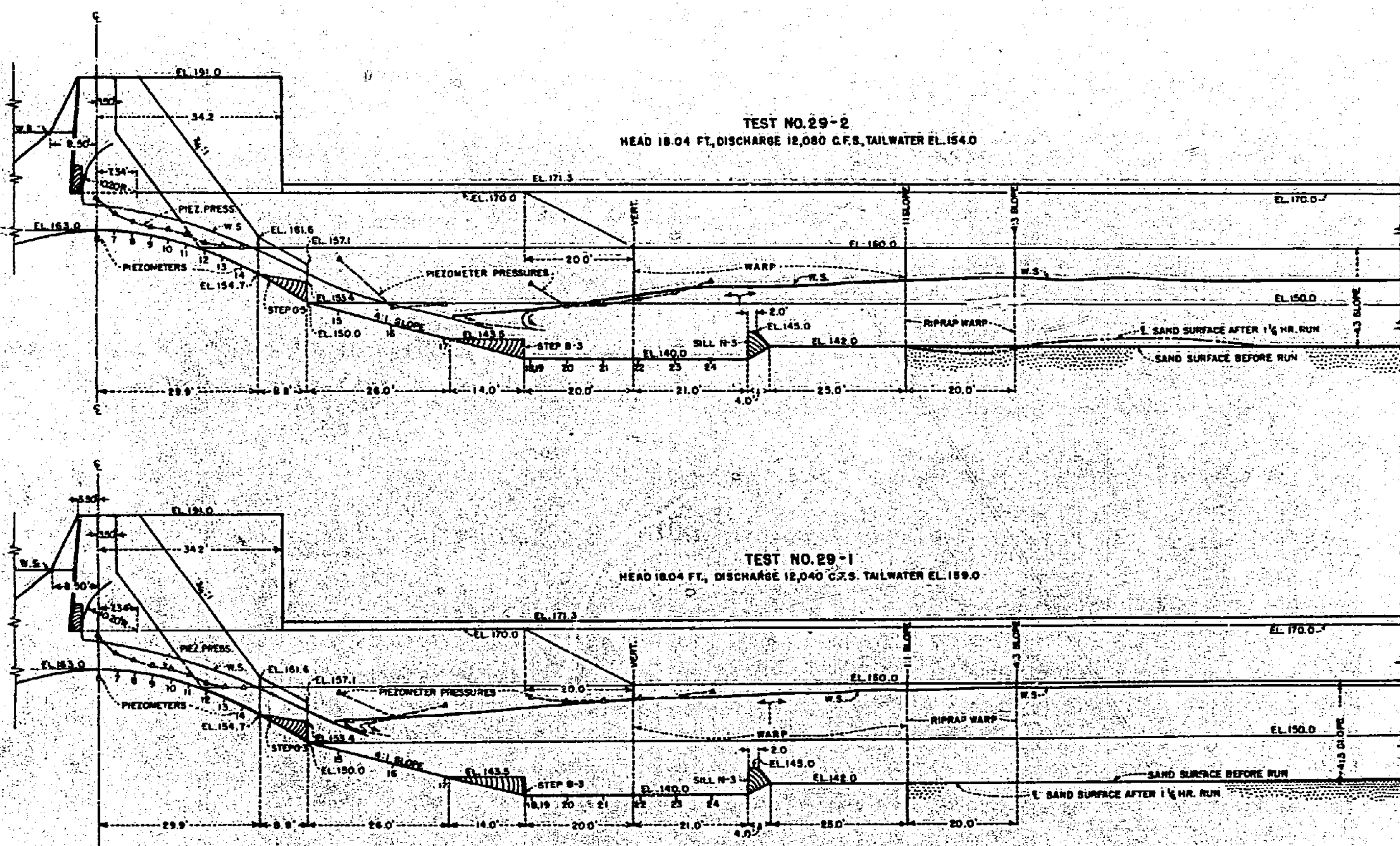
C. DISCHARGE 12,072 SECOND-FEET.
TAILWATER ELEVATION 152.4.

SINGLE JUMP POOL WITH LONG SLOPING APRON

89.3 feet downstream to the floor of the stilling pool which in this case was at elevation 138.0. Stepped apron A-3 was installed on the sloping apron as shown, and sill P-3 (shown in detail on figure 40) was placed at the end of the horizontal pool floor, and the sand bed below the sill was leveled off to elevation 141.0. The warped stilling-pool walls remained the same as in the revised double-jump layout. Profiles of the water surfaces and piezometer pressures are plotted on figures 48 and 49 for a discharge of approximately 2,000 second-feet per gate with variations in the tailwater depth. The jump, as a means of dissipating the energy, was very effective, and this type of pool exhibited a wider tailwater range for the maximum discharge than did the double-jump pool. It can be noted in test 26-3 (fig. 49) that the front of the jump is still in the pool for a tailwater elevation of 149.9. The single-jump pool with long sloping apron was quite satisfactory in all respects. The dentated steps on the sloping apron were very effective in this design. Plate VIII-B and C show the pool in action for a discharge of 2,000 second-feet per gate with tailwater elevations of 154.0 and 152.4, respectively.

c. The Final Stilling-Pool Design

As the single-jump pool discussed above required a very long length of paving similar to the double-jump pool, an attempt was made to shorten this portion of the structure. The stilling pool was revised as shown in the profiles on figure 50 and plate IX-A. The 4:1 sloping apron in this case commenced 38.7 feet downstream from the center line of the crest and extended 40 feet downstream at which point it intersected the horizontal stilling-pool floor which was raised 2 feet to elevation 140.0. Stepped apron B-3 was installed on the end of the sloping apron, sill N-3 (fig. 40) was placed at the end of the stilling pool, and the sand bed was leveled to elevation 142.0. This change shortened the sluiceway structure 31 feet. Two additional features were also incorporated in this final design. First, a second set of dentated steps (G-3 fig. 40) was installed on the overflow crest upstream from the first set. These gave additional corrugations to the jet of water flowing over them, making possible the shorter length of concrete apron downstream from the crest and a shallower stilling pool. Second, additional tail pieces were placed on the downstream ends of the gate piers as shown on plate IX-A to eliminate the fins that were formerly present below these piers. Profiles of the water surfaces and piezometer pressures are shown for two runs for the final stilling pool design on figure 50. The action in the pool was very satisfactory for all conditions of flow and tailwater depth. For ~~the maximum~~ discharge of 2,000 second-feet per gate, the jump remained in the pool for a tailwater elevation of 150.0. This pool would operate satisfactorily for a lower tailwater elevation than this but mechanical



NOTE
The discharge shown above is for six gates

PROTOTYPE SCALE IN FEET
0 10 20 30 40
0 2 4 6 8 10 12
MODEL SCALE IN INCHES

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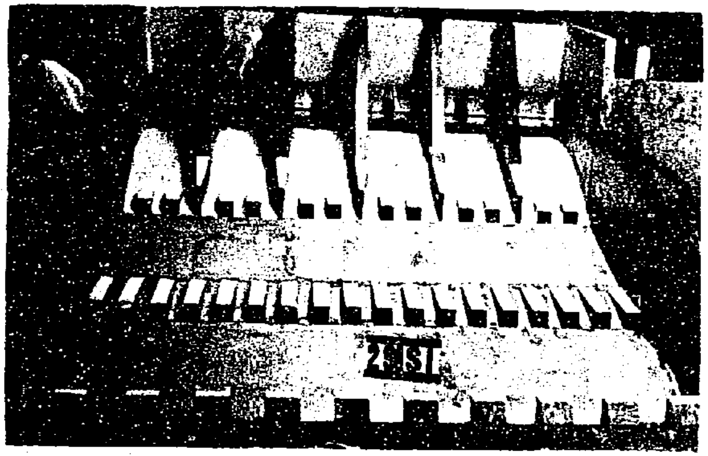
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
PIEZOMETER PRESSURES AND
WATER-SURFACE PROFILES FOR
FINAL STILLING POOL DESIGN

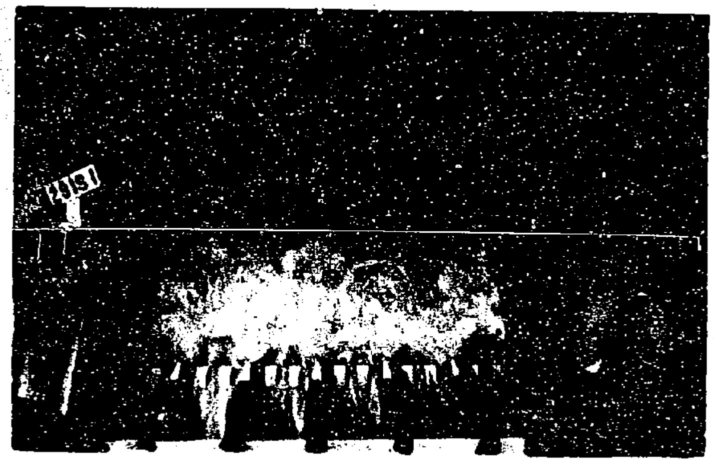
DRAWN ... SUBMITTED ...
TRACED ... RECOMMENDED ...
CHECKED ... APPROVED ...
DENVER, COLO., JULY 12, 1938
212-D-851

FIGURE 50

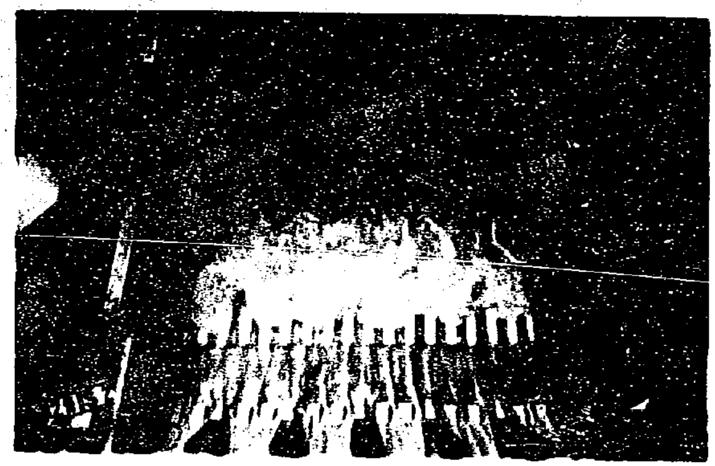


A. FINAL STILLING POOL LAYOUT

B. DISCHARGE 12,000 SECOND-FEET.
TAILWATER ELEVATION 165.0.



C. DISCHARGE 12,042 SECOND-FEET
TAILWATER ELEVATION 159.0.



D. DISCHARGE 12,042 SECOND-FEET.
TAILWATER ELEVATION 164.0.

THE FINAL STILLING POOL DESIGN

difficulties prohibited dropping of the tail water farther in the model. The final stilling-pool design is shown on plates IX and X. Photograph IX-A shows the layout and B, C, and D show the pool in operation for a discharge of 2,000 second-feet per gate with tail-water elevations of 165.0, 159.0, and 154.0, respectively.

C. Twelve 16-Foot Gates - Piers 3.5 and 6.0 Feet Wide

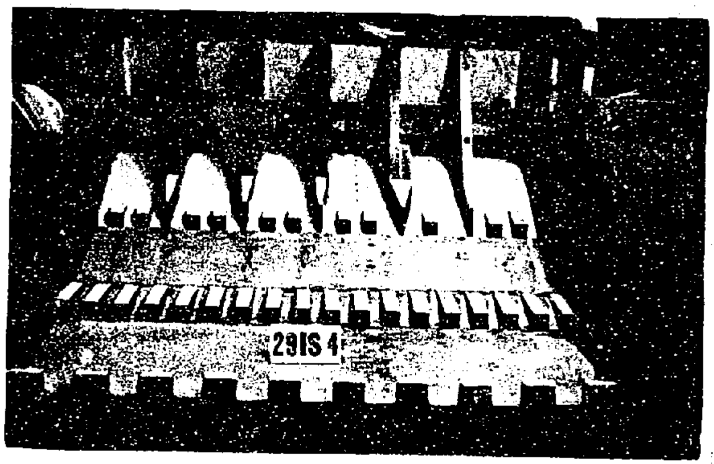
a. The Final Sluiceway Design

At a meeting of the consulting board in August 1935, the above stilling-pool design was approved. A section of the prototype structure is shown on figure 51. The board at this meeting, however, recommended that twelve gates, 16 feet in length, be used instead of eight as formerly decided. The additional gates will undoubtedly increase the flexibility of the sluiceway and make possible more efficient flushing. A plan of the latest sluiceway design is shown on figure 52. A drawing of the final Denver model is included as figure 53. In this case, the model represented one-half of the sluiceway. With twelve gates, the final sluiceway will have a maximum capacity of about 43,000 second-feet.

b. Addition of Tailpieces on Piers

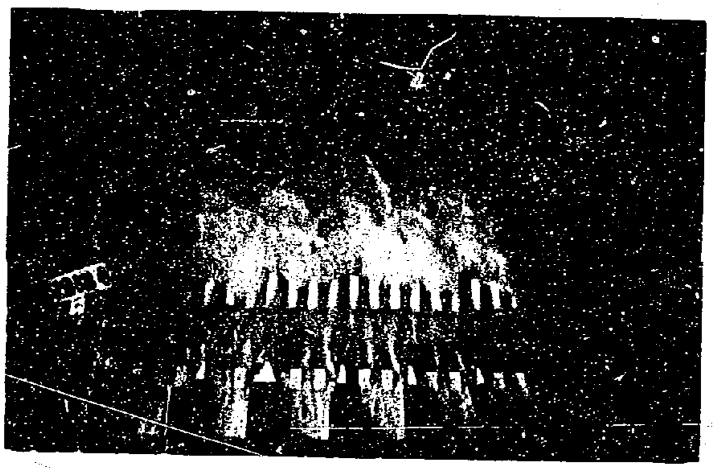
During the tests on the final design various tailpieces were installed on the downstream ends of the piers in an attempt to iron out the fins created in that locality by the original piers. The best of these are shown on plates IX and X. A comparison of plate VIII-B (without the tapered tailpieces) with plate IX-D (with the tailpieces installed) justifies the addition of these on the small piers. A sketch of this tailpiece is shown on figure 54 for a pier 3.0 feet wide. In the final design the width of the small piers was increased to 3.5 feet but this latter width was never used on the model.

To simulate the large piers, one pier on the model was increased to 6.0 feet in width. The tailpiece producing the best results on this pier is shown on plate X-A and drawn in detail on figure 54. Plate X-B, C, and D, taken of the final stilling pool operating at a discharge of 2,000 second-feet per gate shows this tailpiece to be entirely satisfactory. Both tailpieces improve flow conditions and it is felt that they are worth the extra cost necessary for their installation.

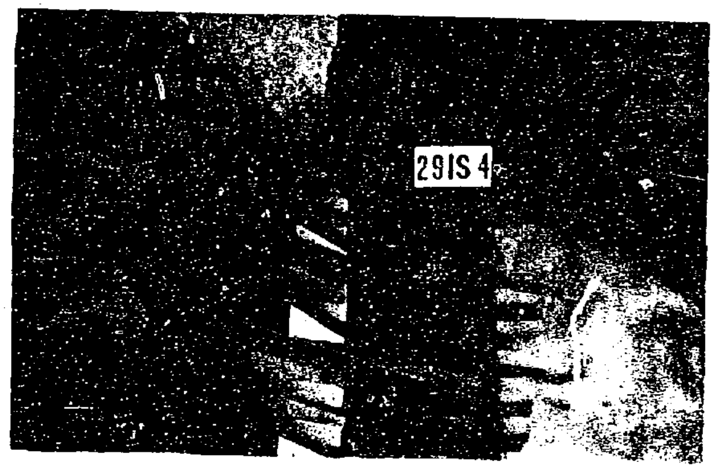


A. FINAL STILLING POOL LAYOUT WITH ONE 6.0-FOOT PIER

B. DISCHARGE 12,000 SECOND-FEET TAILWATER ELEVATION 154.0



C. DISCHARGE 12,000 SECOND-FEET TAILWATER ELEVATION 154.0

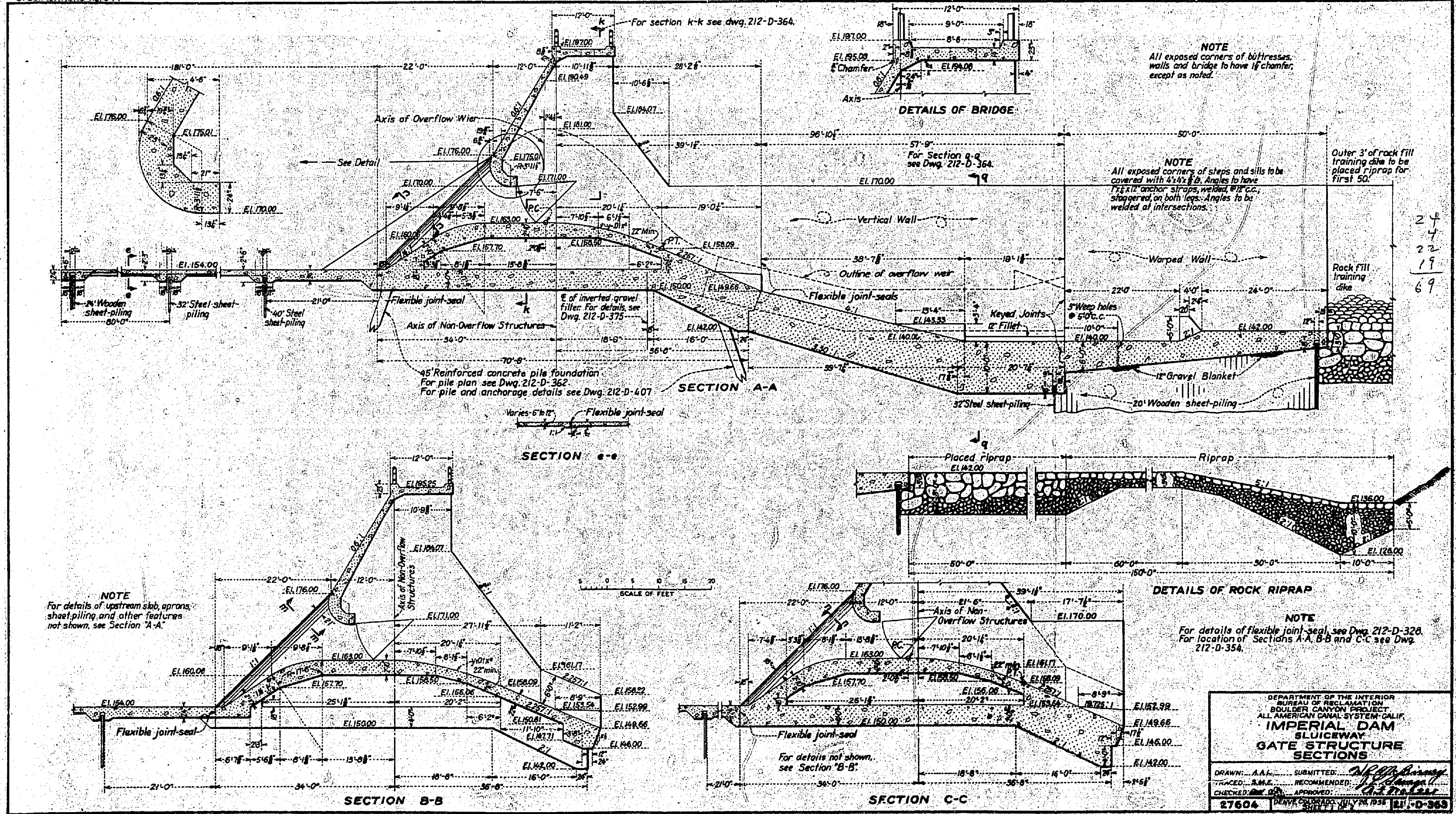


D. DISCHARGE 12,000 SECOND-FEET TAILWATER ELEVATION 154.0

THE FINAL STILLING POOL DESIGN

SPECIFICATIONS NO. 644

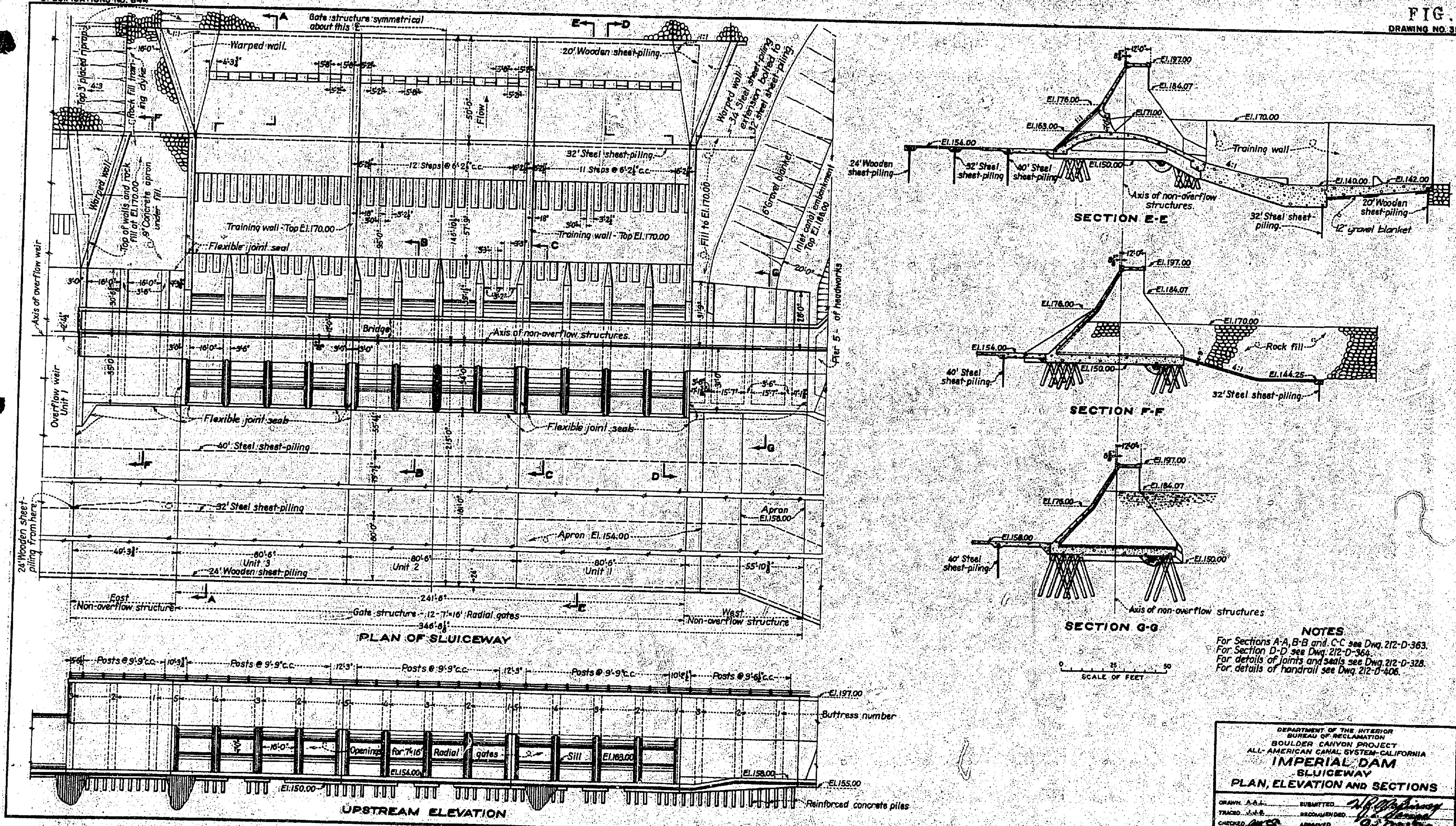
DRAWING NO. 44

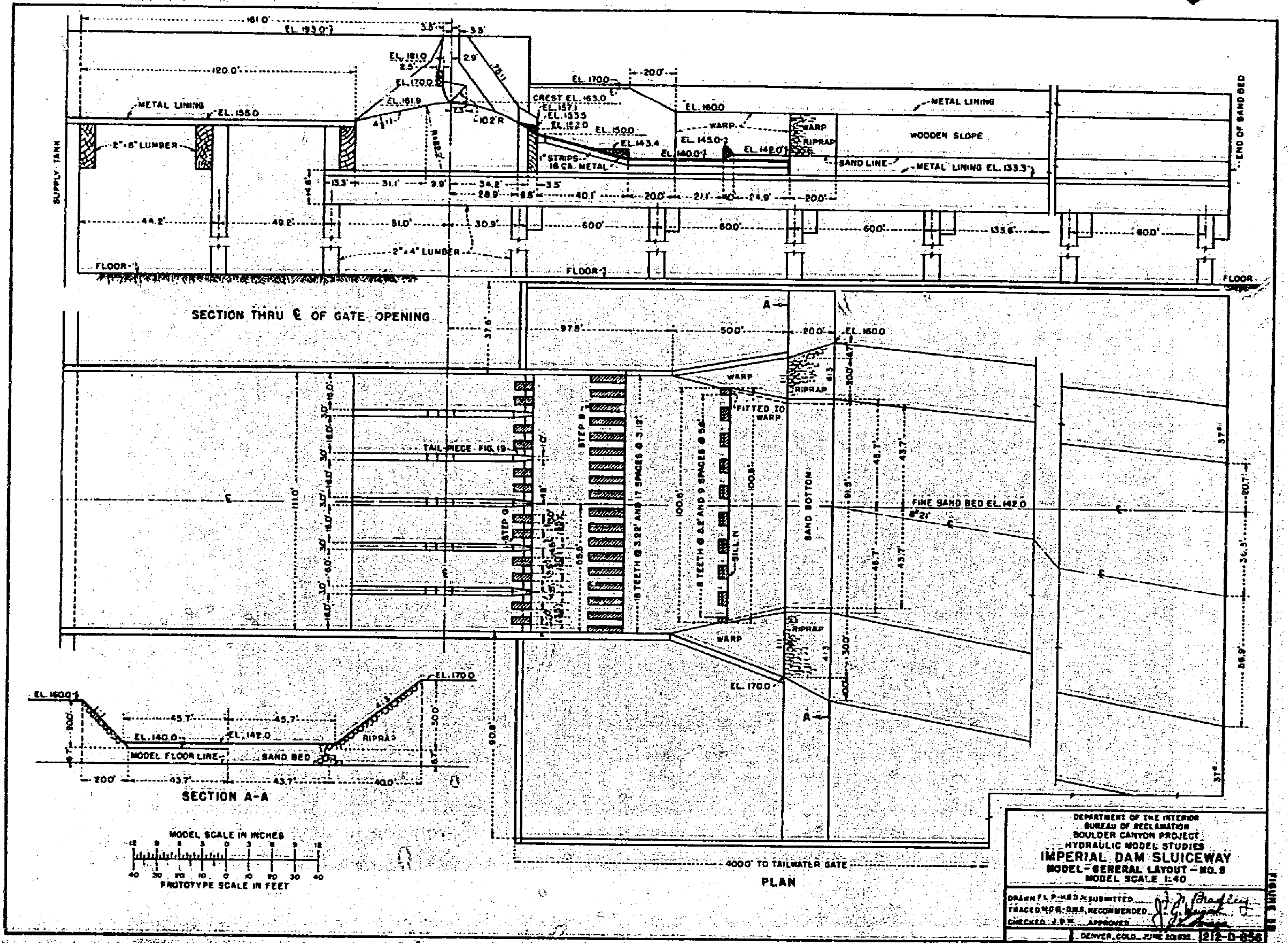


SPECIFICATIONS NO. 644

FIG. 52

DRAWING NO. 35





SECTION THRU ℄ OF GATE OPENING
SUPPLY TANK
METAL LINING
EL. 155.0
2" x 6" LUMBER
2" x 4" LUMBER
FLOOR
EL. 193.0
EL. 181.0
EL. 170.0
EL. 161.9
CREST EL. 163.0
EL. 157.1
EL. 153.5
EL. 152.0
EL. 150.0
EL. 143.4
EL. 145.0
EL. 140.0
EL. 142.0
EL. 160.0
1" STRIPS 16 GA. METAL
WARP
RIPRAP
WOODEN SLOPE
SAND LINE
METAL LINING EL. 133.3
END OF SAND BED
SECTION A-A
MODEL FLOOR LINE
SAND BED
MODEL SCALE IN INCHES
PROTOTYPE SCALE IN FEET
PLAN
TAIL-PIECE FIG. 19
STEP G
STEP B
18 TEETH @ 3.22' AND 17 SPACES @ 3.12'
8 TEETH @ 6.2' AND 9 SPACES @ 5.6'
SILL N
FITTED TO WARP
SAND BOTTOM
FINE SAND BED EL. 142.0
400.0' TO TAILWATER GATE
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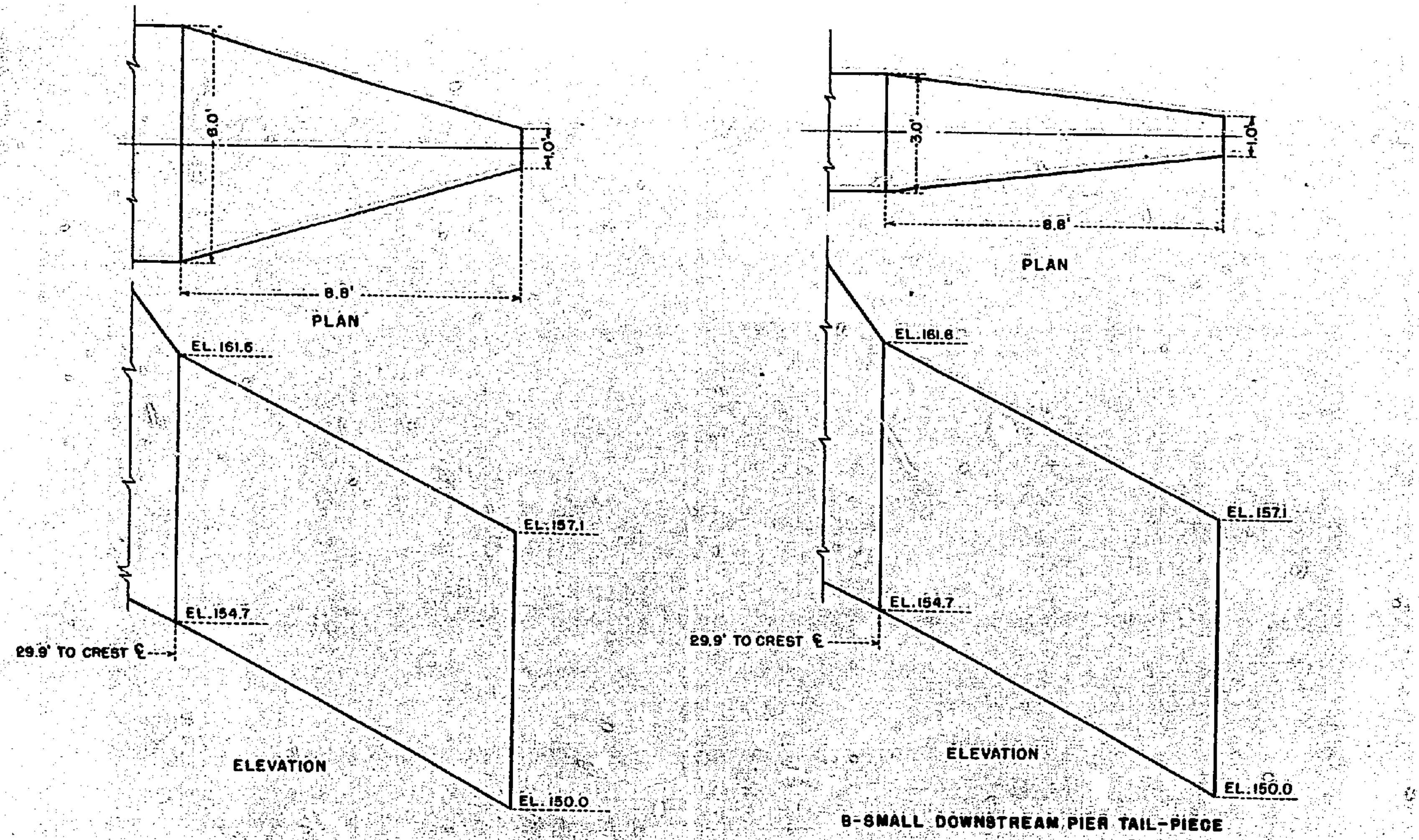
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
MODEL-GENERAL LAYOUT-NO. 8
MODEL SCALE 1:40
DRAWN F.L.P.-H.B.D. SUBMITTED
TRACED M.D.G.-D.M.S. RECOMMENDED
CHECKED J.B.W. APPROVED
DENVER, COLO., JUNE 20, 1935.
212-D-856

FIGURE 54



A-LARGE DOWNSTREAM PIER TAIL-PIECE

B-SMALL DOWNSTREAM PIER TAIL-PIECE

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BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
PIER TAIL-PIECES FOR
MODEL EXPERIMENTS

DRAWN P.K.V. SUBMITTED J. E. Bradley
TRACED E.W.W. D.R.B. RECOMMENDED J. C. Savage
CHECKED J.D.M. APPROVED J. L. Savage
DENVER, COLO., SEPT. 4, 1935 212-D-850

c. Pressures on Overflow Face (Montrose Model)

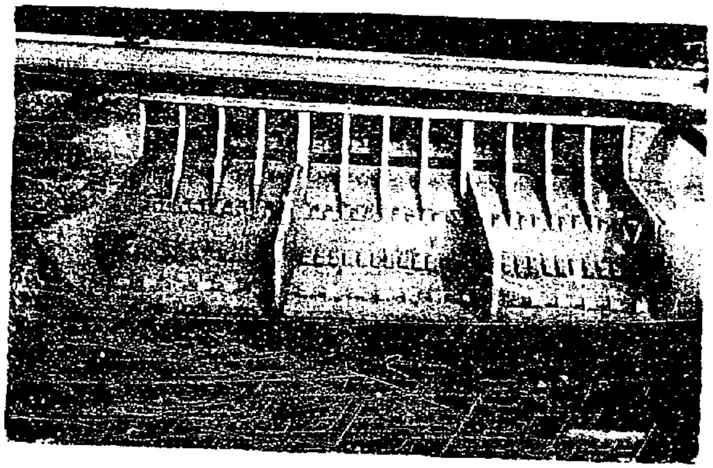
A complete model of Imperial Dam which had incorporated in it the final sluiceway design was constructed on a scale of 1:40 at the Bureau of Reclamation hydraulic laboratory at Montrose, Colorado, to study a phase of the silt problem in connection with the project. It was necessary to make the final gate calibration and obtain pressures on the overflow face of this model as the gate section of the Denver model was never revised to simulate the final design. A photograph of the Montrose model is shown on plate XI-A. Profiles of the water surfaces downstream from the gates and pressures on the overflow face obtained from this model are shown for various conditions of head, discharge and gate opening on figure 55. In each case all twelve gates were open the same amount. It is believed that the runs on figure 55 are representative of the range of conditions that can prevail on the prototype structure. In no case was a negative pressure recorded on the spill face. Test 41-4 was evidently the worst condition in the group with maximum head on the crest and a large discharge.

d. Action in Stilling Pool (Montrose Model)

In addition to the above tests, observations were made on the stilling pool to determine whether the action in the wide pool was as satisfactory as that in the pool of the six-gate Denver model. Plate XI-B, C, and D show the Montrose stilling pool in action for a few conditions of discharge and tail water. The Montrose pool differed from the Denver model in that it had twelve gates instead of six, and dividing walls extended downstream from the two large piers to the end of the stilling pool floor, which was not a feature in the Denver model.

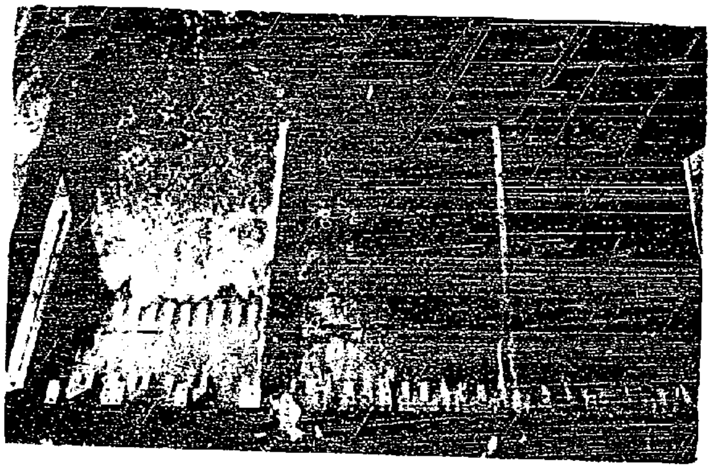
The dividing walls are undoubtedly advantageous when only one side of the sluiceway is in operation as is evident from photograph C. Each four-gate section acts as a unit and turbulence and whirling action is practically eliminated in adjacent units.

Plate XI-B shows all twelve gates operating at 24,000 second-feet with normal tail water and photograph D shows the same conditions of discharge with the tail water at elevation 150, at which point the jump threatens to leave the pool. A comparison of the photographs on plate XI with those on plates IX and X shows little difference in the stilling-pool action in the two models.

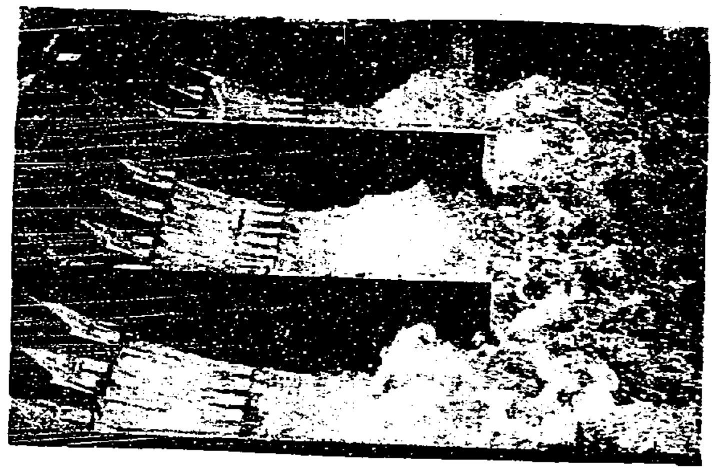


A. SLUICEWAY MODEL LOOKING UPSTREAM.

B. LOOKING DOWNSTREAM ON POOL
DISCHARGE 24,000 SECOND-FEET
TAILWATER ELEVATION 158.0.



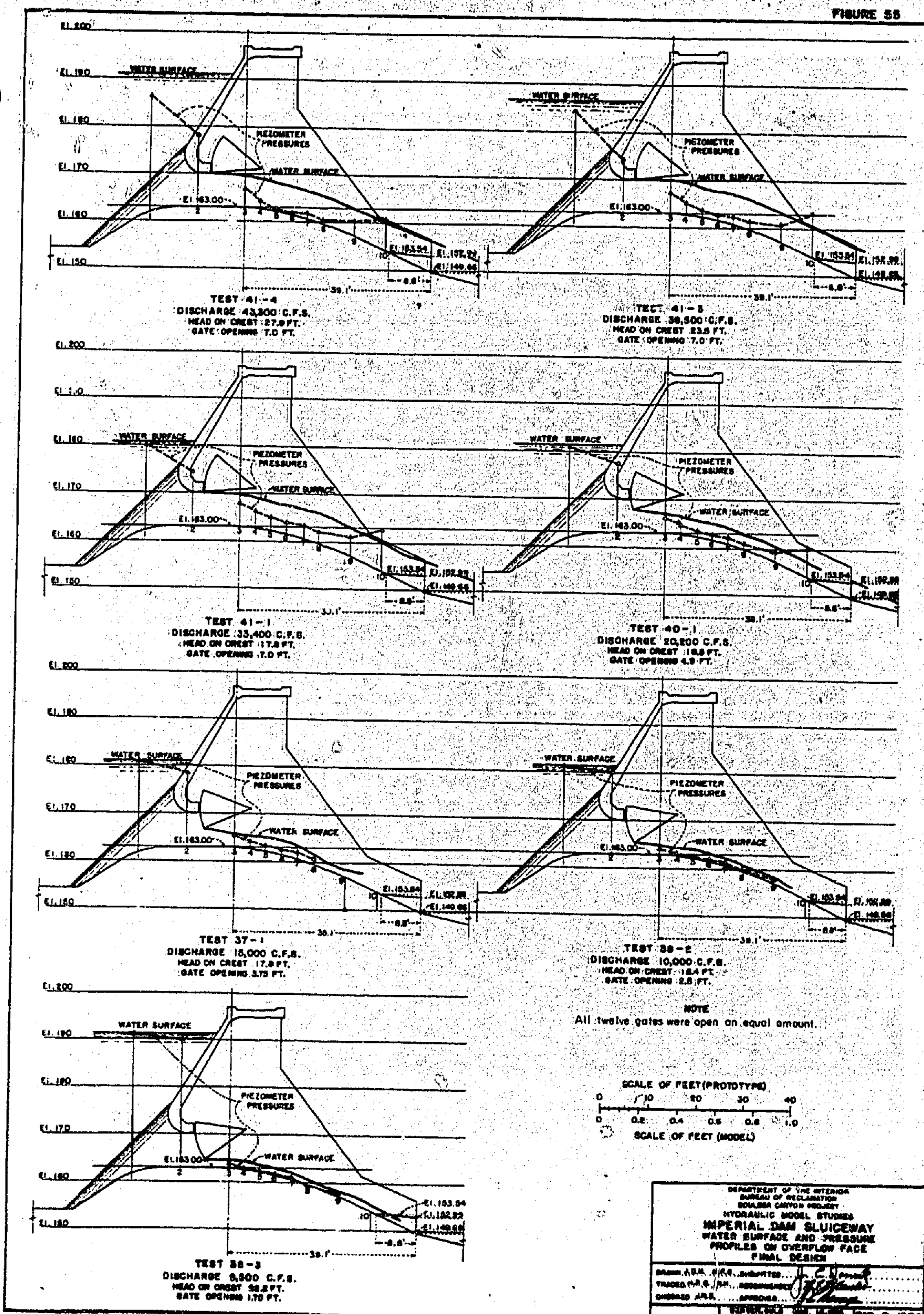
C. LOOKING DOWNSTREAM ON POOL
SIX GATES ON LEFT OPEN
DISCHARGE 12,000 SECOND-FEET
TAILWATER ELEVATION 154.0.



D. DISCHARGE 24,000 SECOND-FEET
TAILWATER ELEVATION 150
JUMP ON VERGE OF LEAVING POOL.

FINAL SLUICEWAY DESIGN
MONTROSE MODEL

FIGURE 55



WATER SURFACE
PIEZOMETER PRESSURES
EL. 163.00
TEST 41-4
DISCHARGE 43,300 C.F.S.
HEAD ON CREST 27.9 FT.
GATE OPENING 7.0 FT.
TEST 41-3
DISCHARGE 38,500 C.F.S.
HEAD ON CREST 23.5 FT.
GATE OPENING 7.0 FT.
TEST 41-1
DISCHARGE 33,400 C.F.S.
HEAD ON CREST 17.8 FT.
GATE OPENING 7.0 FT.
TEST 40-1
DISCHARGE 20,200 C.F.S.
HEAD ON CREST 18.8 FT.
GATE OPENING 4.9 FT.
TEST 37-1
DISCHARGE 15,000 C.F.S.
HEAD ON CREST 17.8 FT.
GATE OPENING 3.75 FT.
TEST 38-2
DISCHARGE 10,000 C.F.S.
HEAD ON CREST 18.4 FT.
GATE OPENING 2.5 FT.
TEST 38-3
DISCHARGE 5,300 C.F.S.
HEAD ON CREST 32.2 FT.
GATE OPENING 1.70 FT.
NOTE
All twelve gates were open an equal amount.
SCALE OF FEET (PROTOTYPE)
0 10 20 30 40
0 0.2 0.4 0.6 0.8 1.0
SCALE OF FEET (MODEL)
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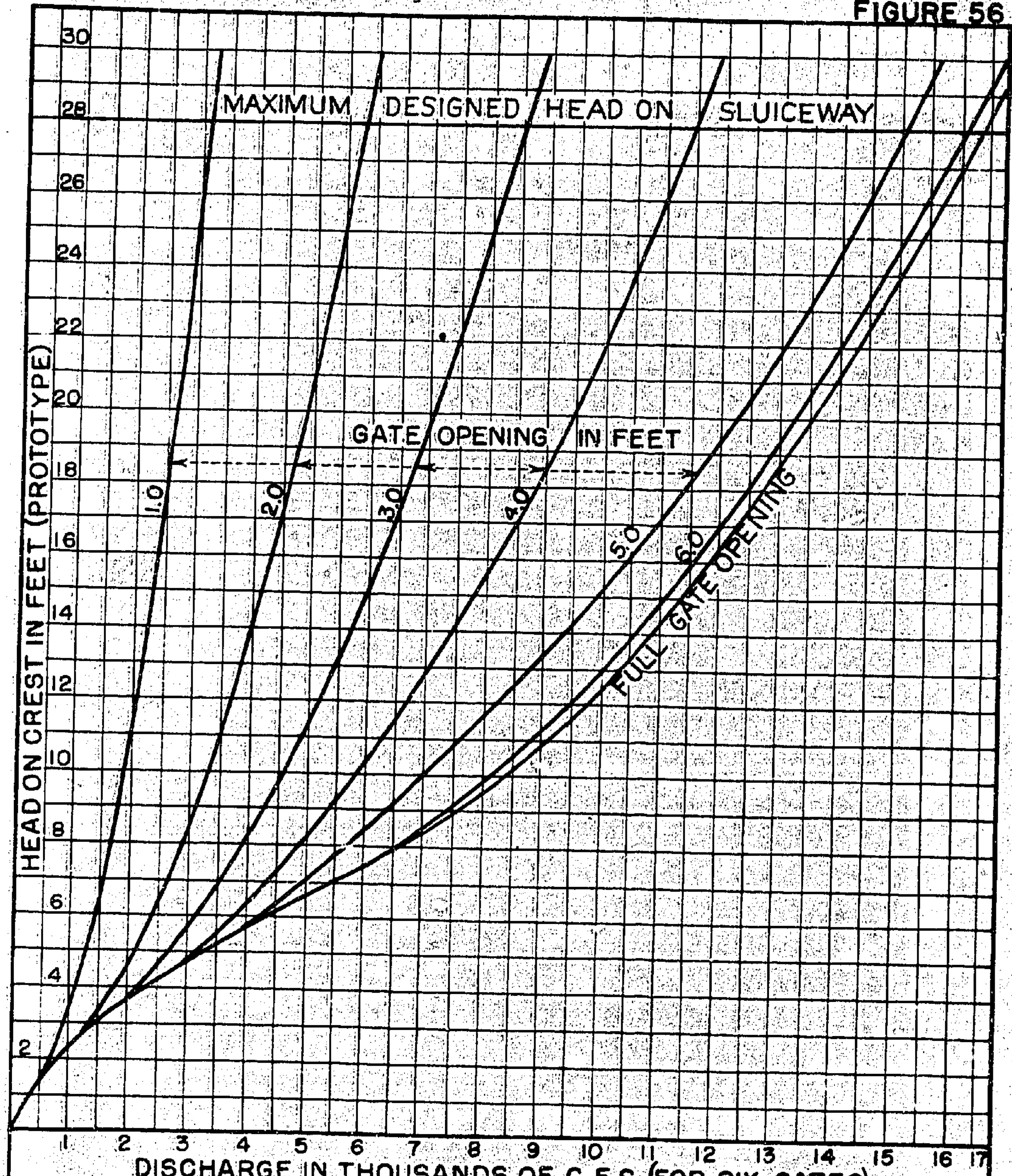
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
WATER SURFACE AND PRESSURE
PROFILES ON OVERFLOW FACE
FINAL DESIGN

FIGURE 56



NOTES

These curves were obtained from the original sluiceway shown on Figure 39

All gates were open an equal amount.

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BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY
GATE CALIBRATION CURVES FROM ORIGINAL SLUICEWAY MODEL

DRAWN R.K.V. SUBMITTED J. N. Bradley
TRACED O.R.S. RECOMMENDED [illegible]
CHECKED J.N.B. APPROVED [illegible]

DENVER, COLO., FEB. 24, 1936 212-D-849

5. CALIBRATION OF GATES

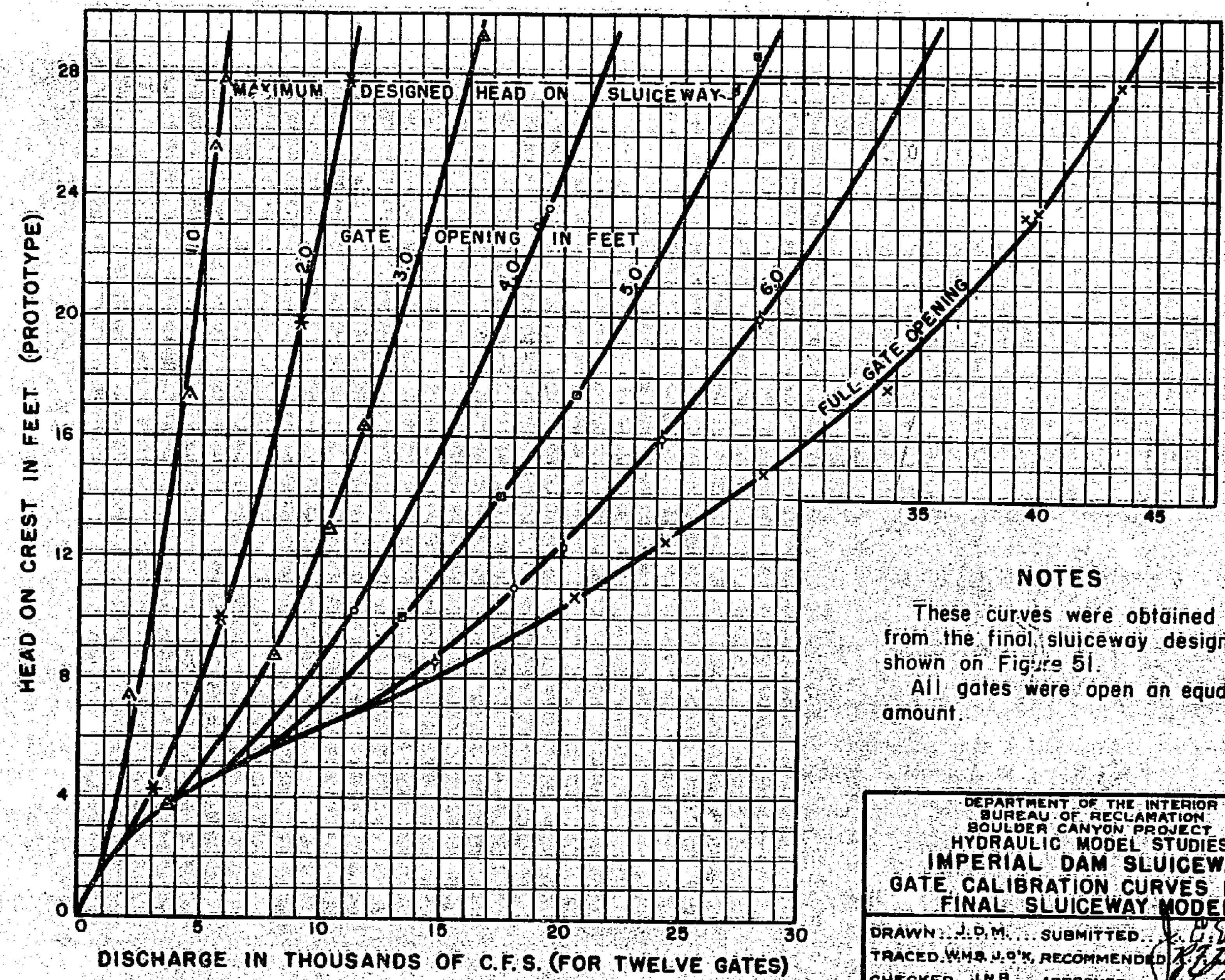
A. Original Design (Denver Model)

Near the commencement of tests on the sluiceway, the radial gates were calibrated for the original design (fig. 39) on the Denver model. The calibration curves converted into prototype values by Froude's law are shown on figure 56. All gates were open an equal amount for each run and the discharge indicated on figure 56 is for six gates. Aside from this the graph is self explanatory. It is interesting to note that the original sluiceway practically reaches its capacity for a gate opening of five feet.

B. The Final Design (Montrose Model)

A set of calibration curves for the final sluiceway design (fig. 51) obtained from the Montrose model is shown on figure 57. The discharge shown is for twelve gates, and for each run, all gates were open an equal amount. It was necessary to comply with some limitation such as this, otherwise the number of possible gate combinations would become endless.

A comparison of the calibration curves for the original design (fig. 56) and those for the final design (fig. 57) shows the two sets of curves to be in fair agreement for gate openings as large as five feet, the original model showing a slightly larger discharge for a given head in this range. For gate openings greater than five feet, the rounded entrance on the final design becomes effective and the capacity of the sluiceway is greatly increased over that of the original. The rounded entrance is evidently ineffective until the gate is practically wide open.



NOTES

These curves were obtained from the final sluiceway design shown on Figure 51.

All gates were open an equal amount.

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HYDRAULIC MODEL STUDIES

IMPERIAL DAM SLUICEWAY

GATE CALIBRATION CURVES FROM FINAL SLUICEWAY MODEL

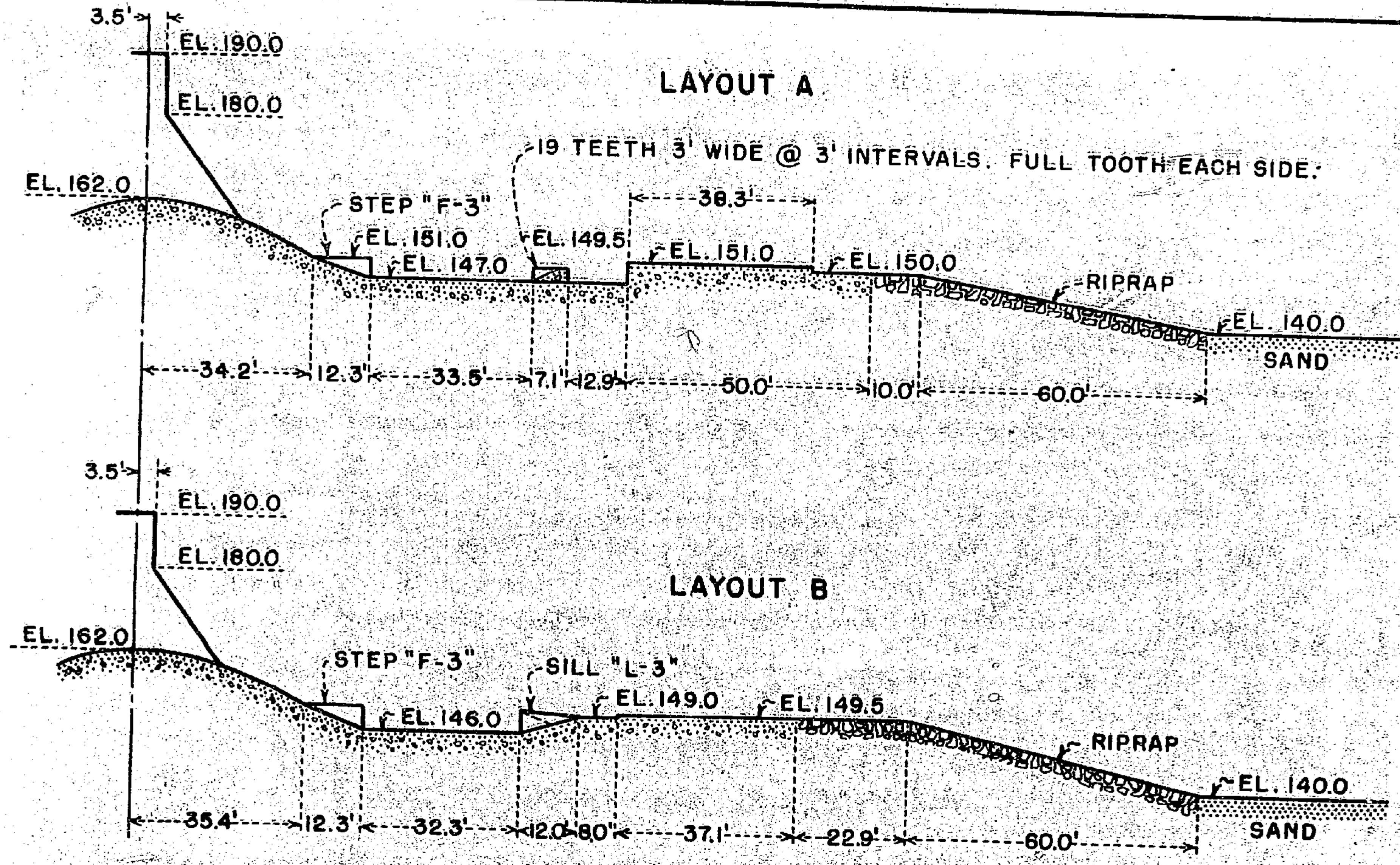
DRAWN J.D.M. SUBMITTED
TRACED W.M.S. J.O'K. RECOMMENDED
CHECKED J.N.B. APPROVED
DENVER, COLO. 6-5-36

212-D-1254

IMPERIAL DAM SLUICEWAY
BOULDER CANYON PROJECT
Log of Tests

SYMBOLS
TW = Tailwater
SJ = Single hydraulic jump pool
DJ = Double hydraulic jump pool
DS = Downstream

Test no.	Drawing no.	Discharge Sec. ft.	Head on Crest	Type Pool	Pool Elev.	Bed Elev.	TW Elev.	Remarks
1-1S-(1-16)	Figs. 39&56 Pl. I	0-16,000	0-30'	SJ	147	150	---	Original design without sill. Action not satisfactory for TW range. Gate calibration.
2-1S-(1-62)	Fig. 39	12,000 & 16,000	18'-28'	SJ	147	150	155-163	Original design modified by various combinations of steps, sills, and control sections. To determine best set-up for a low depth of TW
3-1S-1	Figs. 39 & 58A	12,000	18'	SJ	147	140	155.5	Hydraulic jump formed in pool; secondary jump at 200' DS from crest; erosion deep at 230' DS from crest.
3-1S-2	Figs. 39 & 58A	12,000	18'	SJ	147	140	158.0	Better looking pool and tailrace than 3-1S-1.
4-1S-1	Fig. 41 & Pl. II	12,000	18'	SJ	147	140	155.4	Same as 3-1S-1 except for sill and control section. Boil over sill. Heavy scour 240' from crest; secondary wave as 3-1S-1, and poor pool.
4-1S-2	Fig. 41	12,000	18'	SJ	147	140	158.0	Improved pool action with no secondary wave. Control section floods out at El. 158.
5-1S-1	Fig. 41 & Pl. II	12,000	18'	SJ	147	140	155.3	Set-up as 4-1S-1 except control section raised to El. 151. Floods out at El. 159.3. Action like 3-1S-1.
5-1S-2	Fig. 41	12,000	18'	SJ	147	140	158.0	Set-up as 5-1S-1. Pool action much improved, indicating TW 155.5 [illegible] TW range too small.
6-1S-1	Figs. 39 & 58B	12,000	18'	SJ	146	140	155.8	Good pool action. Secondary wave [illegible]' high at 215' from crest; tailrace not rough.
6-1S-2	Figs. 39 & 58B	12,000	18'	SJ	146	140	158.0	Control section floods out at El. 1[illegible]7.4. Pool and tailrace smoother.
7-1S-1	Fig. 41	12,000	18'	SJ	146	140	155.3	Set-up as 6-1S-1 except control section lowered to El. 149. Jump almost out of pool. Control floods out at 15[illegible].8.
7-1S-2	Fig. 41 Pl. III	12,000	18'	SJ	146	140	158.0	Action throughout pool and tailrace improved. Good flow action.



NOTE: Model ratio 1:90.

FIGURE 58

IMPERIAL DAM SLUICEWAY
VARIOUS POOL DESIGNS
DRAWN H.G.D. Jr. DATE 1-20-36

212-D-857

Test no.	Drawing no.	Discharge Sec. ft.	Head on Crest	Type Pool	Pool Elev.	Bed Elev.	TW Elev.	Remarks
8-1S-1	Fig. 42 Pl. III	12,000	18'	DJ	146 140	140	155.5	Scour 5' deep at end of floor. Good pool action. Control floods out at 157.8.
8-1S-2	Fig. 42 Pl. III	12,000	18'	DJ	146 140	140	158.0	Single jump action. Smoother flow through pool and tailrace.
9-1S-1	Fig. 42	12,000	18'	DJ	146 140.3	140.3	155.2	Erosion 20' DS from sill 15' deep. Action very much like 8-1S-1.
9-1S-2	Fig. 42 Pl. IV	12,000	18'	DJ	146 140.3	140.3	158.0	Control floods out at 159.3 - Two jump action as 9-1S-1. Better surface in 8-1S-2.
9-1S-3		16,000±	28'	DJ	146 140.3	140.3	163.0 to 156.5	Jump starts moving out at 161.5. No erosion at 159.8. Little erosion at 156.5. Quiet TW.
10-1S-(1-2)	Fig. 42 Pl. IV	12,000	18'	DJ	146 140	140	155.2 158.0	Action similar to 9-1S-(1 & 2). Erosion for low TW is 3' deep at 20' DS from sill. Control floods out at 164.4.
10-1S-(3-6)	Fig. 42 Pl. IV	12,000	18'	DJ	146 140	140		Tried various sets of rectangular blocks on floor between control section and piers. Best flow conditions with blocks (4' high, 3' wide, and 3' spacing) placed just upstream of control floor (El. 150.3). Control flooded out at 159.4
11-1S-(1-2)		12,000	18'	DJ	146 140	140	155.2 158.0	Set-up as 10-1S-1 except length of control section reduced to 3' and set of blocks (4' high, 3' wide, and 5' spacing) placed 88' DS from crest. Control flooded out at 161.5. High boil over sill; scour 3' deep at 20' DS from beginning of bed.
11-1S-(3-5)		12,000	18'	DJ	146 140	140	155.0 158.0	Set-up as 11-1S-1. Various spacing of blocks used. Jump stayed in with all blocks removed. Jump went out with blocks at 3' spacing.
12-1S-1		12,000	18'	DJ	146 140	140		Set-up as 10-1S-1 except control section cut down to El. 146 at 100' DS from where it sloped down to El. 140. Control would not flood out for TW less than 164.0

Test no.	Drawing no.	Discharge Sec. ft.	Head on Crest	Type Pool	Pool Elev.	Bed Elev.	TW Elev.	Remarks
12-1S-2		12,000	18'	DJ	146 140	140		Set-up as 12-1S-1 except control section 5' long at El. 150. Slope to El. 140 from control El. 150 added. Control section flooded out at El. 162.4. Boil in pool reduced. Little erosion.
13-1S-(1-2)	Fig. 43 Pl. V	12,000	18'	DJ	146 142.7	142.7	155.0 158.0	Double jump action. Control flooded out at 160.5. Very little erosion.
14-1S-(1-6)	Fig. 59A	12,000	18'	DJ	146	140- 142	154.2 158.1	"A" - Type "F" most effective in forming jump. "S" - Many toothed sills both as to size of teeth and spacing tried. Sill "M-3" most effective. "X" - of all lenghts of control tried. Minimum seemed to be 20' for low TW. "Z" - Varied from 100-110' with little effect "C" varied from El. 146-150. Most effective TW. 150 required to hold jump in pool. "G" - started from El. 146-150, with different lengths, ending at El. 140-142. Most effective slope from El. 146-140. "B" - found to be satisfactory at El. 140.
15-1S-1	Fig. 43 Pl. VI	12,000	18'	DJ	146 139	139	153.6	Good pool and tailrace action; scour 2' deep at 20' beyond rectangular sill. Control section flooded out at 156.8. Raising bed to 140 caused no change in flow.
15-1S-2	Fig. 43 Pl. VI	12,000	18'	DJ	146 139	139	158.0	Single jump pool action. Very little boil over sill. Good water surface; little scour.
15-1S-3	Fig. 43 Pl. VI	12,000	18'	DJ	146 139	139		El. of teeth of sill "M-3" changed to 151 and 152. Jump less stable with former.
16-1S-(1-5)	Fig. 43 Pl. V	12,000	18'	DJ	146 140	142	153.5 161.5	Tried various steps and lengths of apron at El. 140. Set-up 16-1S-1 showed most stable jump action for low TW. range.
17-1S-1		12,000	18'	DJ	146 140	142	168.0	Stream bed turns 8 deg. to right of center line with 4:3 side slopes. No scour. Good pool and tailrace.
18-1S-1		12,000	18'	DJ	146 140	142	158.0	Secondary jump on verge of forming. Pool action good. Little scour at end of pool.

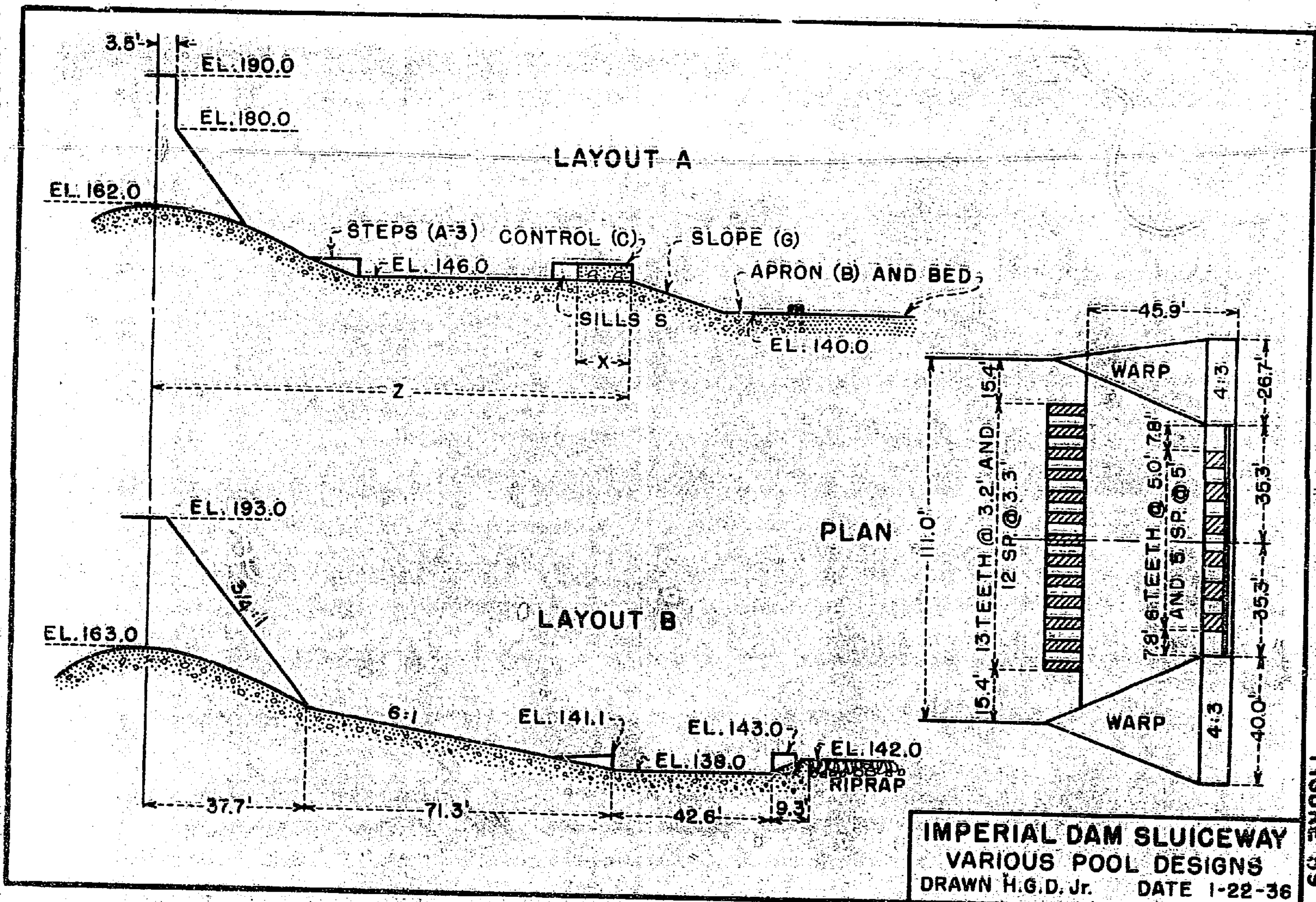


FIGURE 59

IMPERIAL DAM SLUICEWAY
VARIOUS POOL DESIGNS
DRAWN H.G.D. Jr. DATE 1-22-36

212-D-858

Test no.	Drawing no.	Discharge Sec. ft.	Head on Crest	Type Pool	Pool Elev.	Bed Elev.	TW Elev.	Remarks
18-1S-2		12,000	18'	DJ	146 140	142	---	Determination of TW for change in flow types. Secondary jump formed at TW 156; flooded out at TW 158 with steady primary jump at DS tip of piers.
19-1S-1		12,000	18'	DJ	146 140	142	150.3	Side slopes 4:3 in tailrace. Exit end of tailrace increased from 74.5' to 113.5'. Double jump action in pool. Tertiary jump in tailrace. High scouring velocities in tailrace; bad scour, 8.5' deep from 20' to 40' from end of pool.
20-1S-1	Fig. 47	12,000	18'	DJ	146 140	142	168.0	Set-up as 18-1S-1 except warps extend 10' DS with 4:3 side slopes. Good single jump action. No scour.
21-1S-1	Fig. 47 Pl. VII	12,000	18'	DJ	146 140	142	158.0	Good single jump action. Secondary jump was about to form. Deepest scour 2.25'.
22-1S-1	Fig. 46 Pl. VII	12,000	18'	DJ	146 140	142	150.5	TW too low; tertiary jump in tailrace; bad scour beyond warps. Material built against sill.
22-1S-2		12,000	18'	DJ	146 140	142	---	Good primary jump at piers - TW El. 159.0 Secondary jump starts at TW El. 158.0 Secondary jump stable at TW El. 156.5 Tertiary jump starts at TW El. 153.0 Tertiary jump stable at Tw El. 152.0 Determined by raising and lowering TW.
23-1S-1	Fig. 46 Pl. VII	16,250	28'	DJ	146 140	142	168.0	Single jump action. Rough. Jump at piers. No scour.
24-1S-(1-4)	Fig. 59B	12,000	18'	SJ	138	142	150.4 158.0	Secondary jump for low TW. Scour is bad. Flow throughout improved by sills. Action smoother than double jump pools.
25-1S-1	Fig. 60A	12,000	18'	SJ	138	141	152.4 168.0	Action about the same as 24-1S-Series. Scour medium for low tailwater.
25-1S-(2-14)	Fig. 60A	12,000	18'	SJ	138	141	154.0	Tried modifications of toothed rectangular and triangular sills at end of warps. On 4:1 slope. Tried various combinations of dentated steps. Most favorable set-up with dentated step at end of 4:1 slope and toothed sill at end of pool

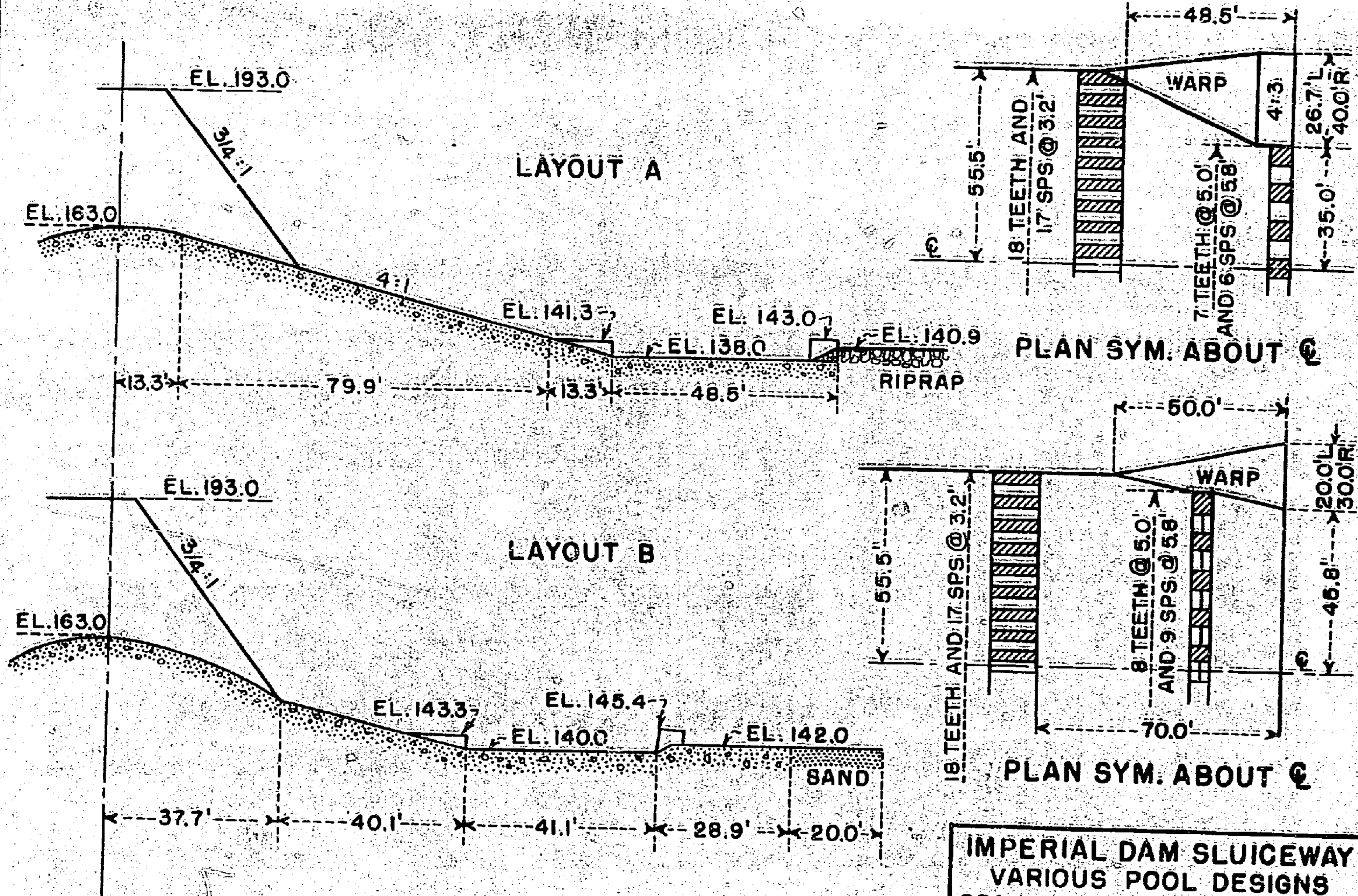


FIGURE 60

IMPERIAL DAM SLUICEWAY
VARIOUS POOL DESIGNS
DRAWN H.G.D.Jr. DATE 1-22-36

212-D-859

Test no.	Drawing no.	Discharge Sec. ft.	Head on Crest	Type Pool	Pool Elev.	Bed Elev.	TW Elev.	Remarks
26-1S-1	Fig. 48 Pl. VIII	12,000	18'	SJ	138	141	154.0	Scour not dangerous. Good flow in pool and tailrace.
26-1S-2	Fig. 48	12,000	18'	SJ	138	141	159.0	Jump moved up slope; very little scour; good flow conditions throughout model.
26-1S-3	Fig. 49	12,000	18'	SJ	138	141	150.0	Jump moved out to end of warps. Poor flow conditions and bad scour.
26-1S-4		12,000	28'	SJ	138	141	168.0	Set-up as 26-1S-3. Jump drowned. Good water surface. Very little scour.
26-1S-5	Fig. 49 Pl. VIII	12,000	18'	SJ	138	141	152.4	Jump moved down from end of slope. Scour in pool 7.5' deep. Not dangerous.
27-1S-(1-9)		12,000	18'	SJ	138	141	---	Double set of steps on 4:1 slope improved. Flow for low tailwater depths so that TW was 2' - 3' lower than previous run.
28-1S-1	Fig. 60B	12,000	18'	SJ	140	142	154.0	Floor at end of pool raised 2'. Good pool action; little scour. TW a minimum for good action.
28-1S-(2-5)	Fig. 60B	12,000	18'	SJ	140	142	154.0	Noses built on DS tip of dentated step. Proper shape nose does not disturb the flow. A dentated step set at DS tip of piers improved flow through pool.
28-1S-(6-7)	Fig. 60B	12,000	18'	SJ	140	142	154.0	Set-up as in fig. 60B plus dentated step between DS tip of piers and stream-lined tailpieces on DS tip of piers. Flow conditions greatly improved over previous runs.
29-1S-(1-3)	Figs. 50, 51 and 52 Pl. IX & X	12,000	18' 28'	SJ	140	142	154.0 159.0 165.0	Very good flow conditions with little scour. TW range taken for the final design.
29-1S-4	Figs. 53 and 54 Pl. X	12,000	18'	SJ	140	142	----	Tried tailpiece for double pier. Flow not as effective as in the case of single pier. Improvement in flow warrants installation.