UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

- - -

HYDRAULIC LABORATORY REPORT NO. HYD-2.1

- - -

Technical Memorandum No. 335

- - -

HYDRAULIC MODEL EXPERIMENTS FOR THE DESIGN OF HOOVER DAM BOOK 2 RESULTS OF VISUAL TESTS ON SEMIFINAL AND FINAL DESIGNS

By

E. W. LANE, RESEARCH ENGINEER

- - -

Denver, Colorado
May 12, 1933

UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: HYDRAULIC MODEL EXPERIMENTS

FOR THE DESIGN OF THE HOOVER DAM

BOOK 2

RESULTS OF VISUAL TESTS ON SEMIFINAL

AND FINAL DESIGNS

By E. W. LANE, RESEARCH ENGINEER

Under direction of

J. L. SAVAGE, CHIEF DESIGNING ENGINEER

TECHNICAL MEMORANDUM No. 335

Denver, Colorado

May 12, 1933

Price $1.00

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Denver, Colorado, May 12, 1933

MEMORANDUM TO CHIEF DESIGNING ENGINEER

By E. W. Lane, Research Engineer

Subject: Hydraulic Model Experiments for the Design of the Hoover Dam - Book 2 - Results of Visual Tests on Semifinal and Final Designs.

The experiments upon the first model types, and particularly the results obtained upon the first model constructed at the Montrose laboratory, showed that unusual care would be necessary if a spillway was to be developed which would be satisfactory, not only in the action in the spillway channel but also in the tunnels leading from the spillway proper back to the river.

Since no very satisfactory type was evolved by the tests on the first 1:20 and 1:100 models at the Montrose laboratory, nor by the addition to them of various forms of baffles, a new model was installed at the Colorado Agricultural Laboratory which embodied the pertinent results of the observations on the previous models. The principal difference between this model as originally constructed, and the first Montrose model (M-1) was that the slope of the channel bottom in the new model was flatter, in order that the depth of water in it would be greater and the turbulence therefore reduced.

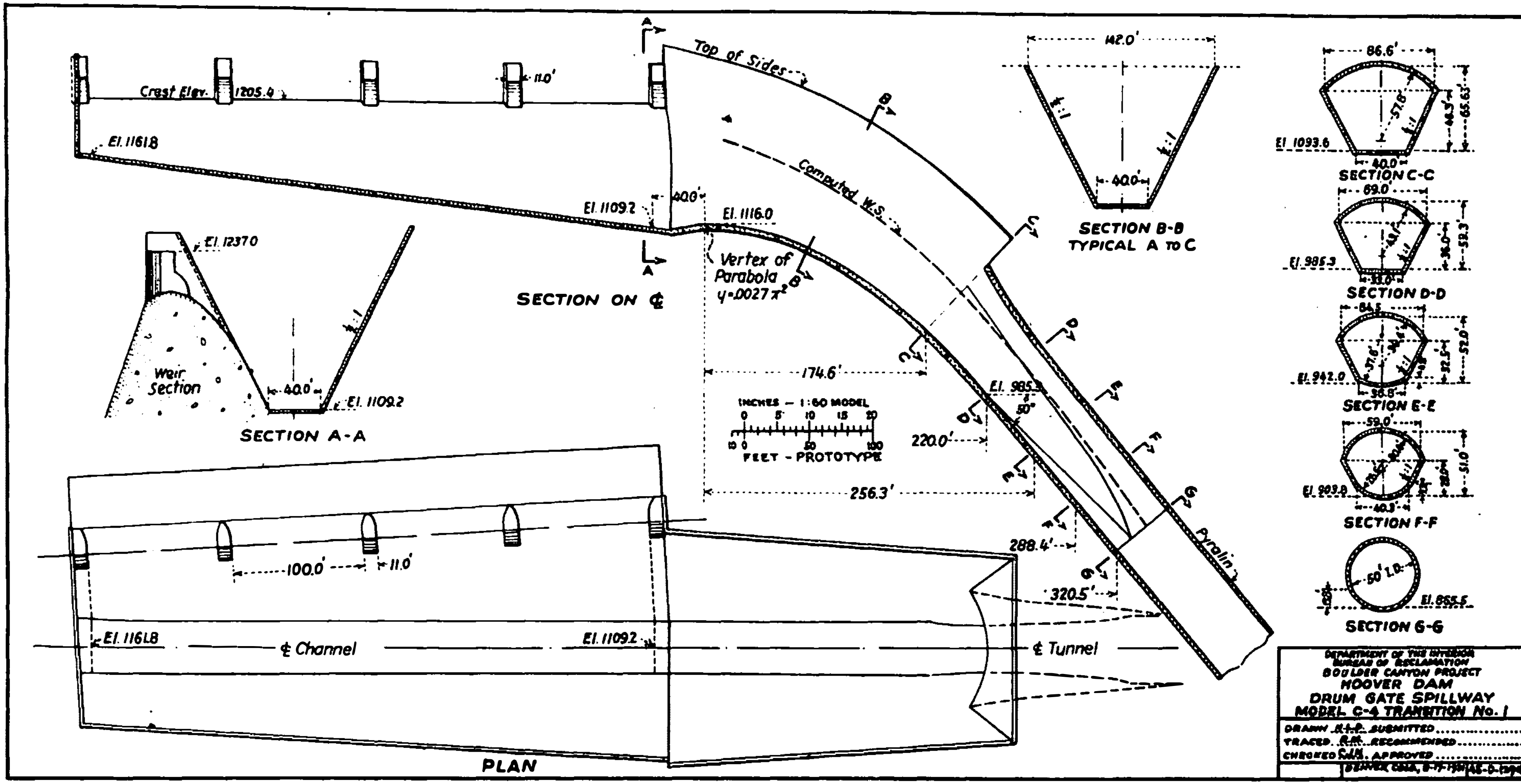

Crest Elev. 1205.4
11.0'
El. 1161.8
El. 1109.2
40.0'
El. 1116.0
Top of Sides
Computed W.S.
Vertex of Parabola $y = .0027x^2$
SECTION ON ℄
El. 1237.0
Weir Section
40.0'
El. 1109.2
SECTION A-A
174.6'
220.0'
256.3'
288.4'
320.5'
El. 985.3
50'
INCHES — 1:60 MODEL
FEET - PROTOTYPE
Pyralin
142.0'
40.0'
SECTION B-B
TYPICAL A TO C
86.6'
El. 1093.6
SECTION C-C
69.0'
El. 985.3
SECTION D-D
El. 942.0
SECTION E-E
59.0'
El. 903.8
SECTION F-F
El. 865.5
SECTION G-G
100.0'
11.0'
El. 1161.8
℄ Channel
El. 1109.2
℄ Tunnel
PLAN
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM
DRUM GATE SPILLWAY
MODEL C-4 TRANSITION No. 1
DRAWN ..... SUBMITTED
TRACED ..... RECOMMENDED
CHECKED ..... APPROVED

FIG. 13

Drum Gate Side Channel Spillway Model C-4

The prototype of the C-4 model is shown on Figure 13. The model was built on a scale of 1:60 or 1 inch on the model equal to 5 feet on the prototype. It had four drum gates, each 100 feet long, and a side channel trough approximately 45 feet deep at the upper end and 95 feet at the lower end. The crest and side channel were constructed of wooden frames covered with galvanized iron. In the first tests the model did not have movable gates, the solid crest being shaped to represent the condition with the drum gates down. Gates which could be regulated were added later. The transition from the trapezoidal channel to the circular 50-foot diameter tunnel was made by running laths between accurately cut and spaced collars and plastering over them with a mixture of quick-setting cement, lime and sand. The top of the transition was left off for some distance in order that the flow in it might be observed. Unfortunately no satisfactory pictures of this flow could be obtained, due to interference of the framing and lack of light.

The flow over the model was measured on a 2-foot Cipolletti weir, previously described. The location of the model in the laboratory was practically the same as that of the C-2 model shown on Figure 4. The height of the model crest was sufficient to submerge the measuring weir at high discharges, and an extensive series of volumetric measurements were made to accurately calibrate the measuring weir under this submerged condition. The maximum discharge over the model was about 7.2 second-feet and the corresponding depth on the model crest about 5 inches. The head on the model crest was observed by means of float gages, as previously described.

In the tests made upon this model, except in a few instances which will be noted, no major changes were made in the shape of either side of the channel or in their position with respect to each other. The principal changes were made in the transition from the trapezoidal channel to tunnel section, usually spoken of as the "transition," in the addition of baffles, and in the presence or absence of the model topography of the hillside.

The main object of the experiments was to develop a design which would allow the water to flow down the tunnel as smoothly as possible without completely filling the tunnel section. A large number of tests was also performed to investigate the effect of various devices on the flow. In order not to unduly increase the size of this report, the details of most of these setups are not presented in it, but a copy of a sketch of each one is filed with the office file copies of this report.

Considerable quantitative data was also observed on this model. Cross sections of the flow in the channel were observed for a large number of conditions. A number of observations were made in the transition on the depth of flow. Determinations were also made of the discharge coefficients of the ogee crest forms used and of the flow over the crest gates at various positions. The results of these quantitative observations are discussed in later sections of this report dealing with these particular features of spillway design.

Results of the Tests on the C-4 Model

The condition in the original design of the C-4 drum gate spillway is shown on Plate 53. These show that the water entering the tunnel was much higher against the rear wall, which caused a transverse flow in the upper end of the tunnel and produced undesirably rough conditions of flow down the inclined shaft. A similar transverse flow action is well shown on Plate 57. It was believed that by blocking off the downstream 60 feet of the spillway crest this condition would be improved. This was tried, and the reduction in flow over the crest was compensated for by a gate at the upper end of the channel which permitted the water to flow directly into the channel along its axis. The results of this experiment indicated that if a space of 60 feet was left between the end of spillway section and the entrance to the steep slope of the transition it would allow the difference in elevation on the two sides of the channel to equalize upstream from the transition and eliminate the cross flow at the tunnel entrance which would result in much better conditions of flow down the tunnel.

A-MODEL WITH TRANSITION NO.1

B-DISCHARGE 80,000 SEC. FT.

C-DISCHARGE 160,000 SEC. FT

D-DISCHARGE 200,000 SEC. FT.

ORIGINAL DESIGN OF DRUM GATE SPILLWAY MODEL C-4
TRANSITION NO.1

A-MODEL WITH TRANSITION NO. 1A

B-DISCHARGE 80,000 SEC. FT.

C-DISCHARGE 160,000 SEC FT

D-DISCHARGE 200,000 SEC FT

DRUM GATE SPILLWAY MODEL C-4
WITH 60 FT. CHANNEL EXTENSION-TRANSITION NO. 1A

A-15 FT. WEIR AT END OF CHANNEL

B-20 FT. WEIR AT END OF CHANNEL

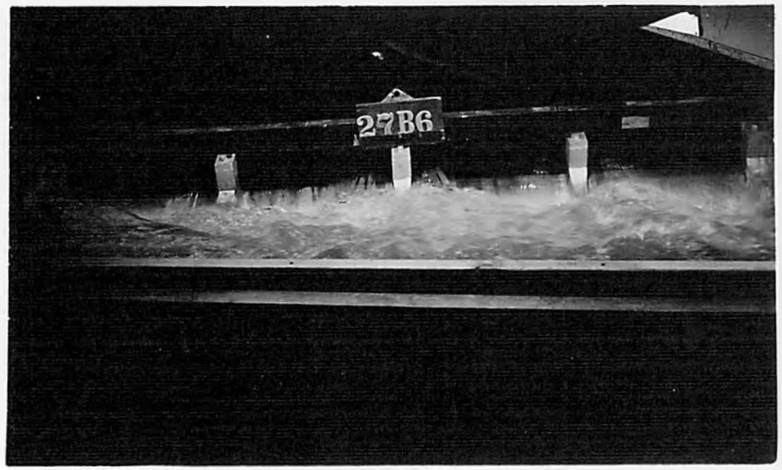
C-30 FT. WEIR AT END OF CHANNEL

DRUM GATE SPILLWAY MODEL C-4
EFFECT OF CROSS WEIRS OF VARIOUS HEIGHTS AT
LOWER END OF CHANNEL WITH 200,000 SEC. FT. DISCHARGE

PLATE 55

A-MODEL WITH 21 FT. OFFSET

B-DISCHARGE 200,000 SEC. FT.-LOOKING DOWNSTREAM

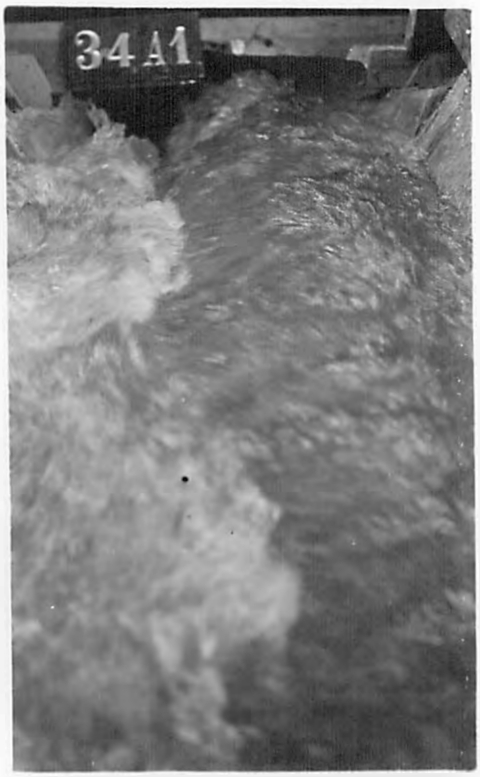


C-DISCHARGE 200,000 SEC. FT.-SIDE VIEW

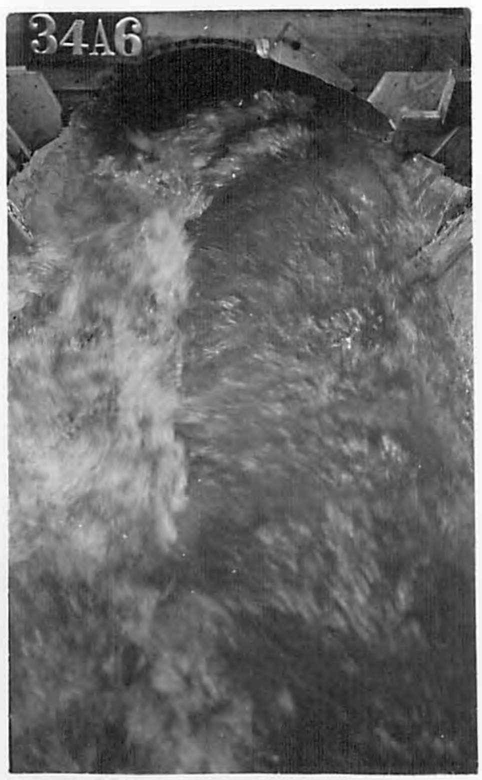
DRUM GATE SPILLWAY MODEL C-4
EFFECT **OF** OFFSET IN CHANNEL SIDE

A - DISCHARGE 120,000 SEC FT

B - DISCHARGE 160,000 SEC. FT.



C - DISCHARGE 200,000 SEC FT



D - DISCHARGE 200,000 SEC. FT.
LOOKING DOWN THE TUNNEL

DRUM GATE SPILLWAY MODEL C-4 TRANSITION NO. 2

Channel Extension of 60 Feet

The spillway model was therefore modified by moving the transition 60 feet downstream, with a straight section, having relatively level bottom, inserted between the end of the spillway section and the transition, as shown in Fig. 14 and Plate 54. The improvements resulting from the addition of the 60-foot section may be seen from a comparison of the views on Plates 54 and 53. The elongated transition also caused a greater depth of the water throughout the channel, and resulted in a smoother flow of the water all along the channel and as it entered the sloping section of the transition. This greater depth of water in the channel was not sufficient to reduce the coefficient of discharge by creating too great a submergence of the crest at the upper end.

Cross Weirs of Various Heights

The extension of the channel section below the spillway crest was considered extremely beneficial and was incorporated in the successive steps leading to the final design. The increased depth of the water in the channel seemed advantageous and an investigation was made of the possibility of improving the flow conditions by causing still greater depth of channel flow by means of a weir across the channel at the lower end. A set of experiments was tried with weirs of 15, 20 and 30-foot height at the end of the 60-foot extension in the channel. These tests indicated that the flow con-

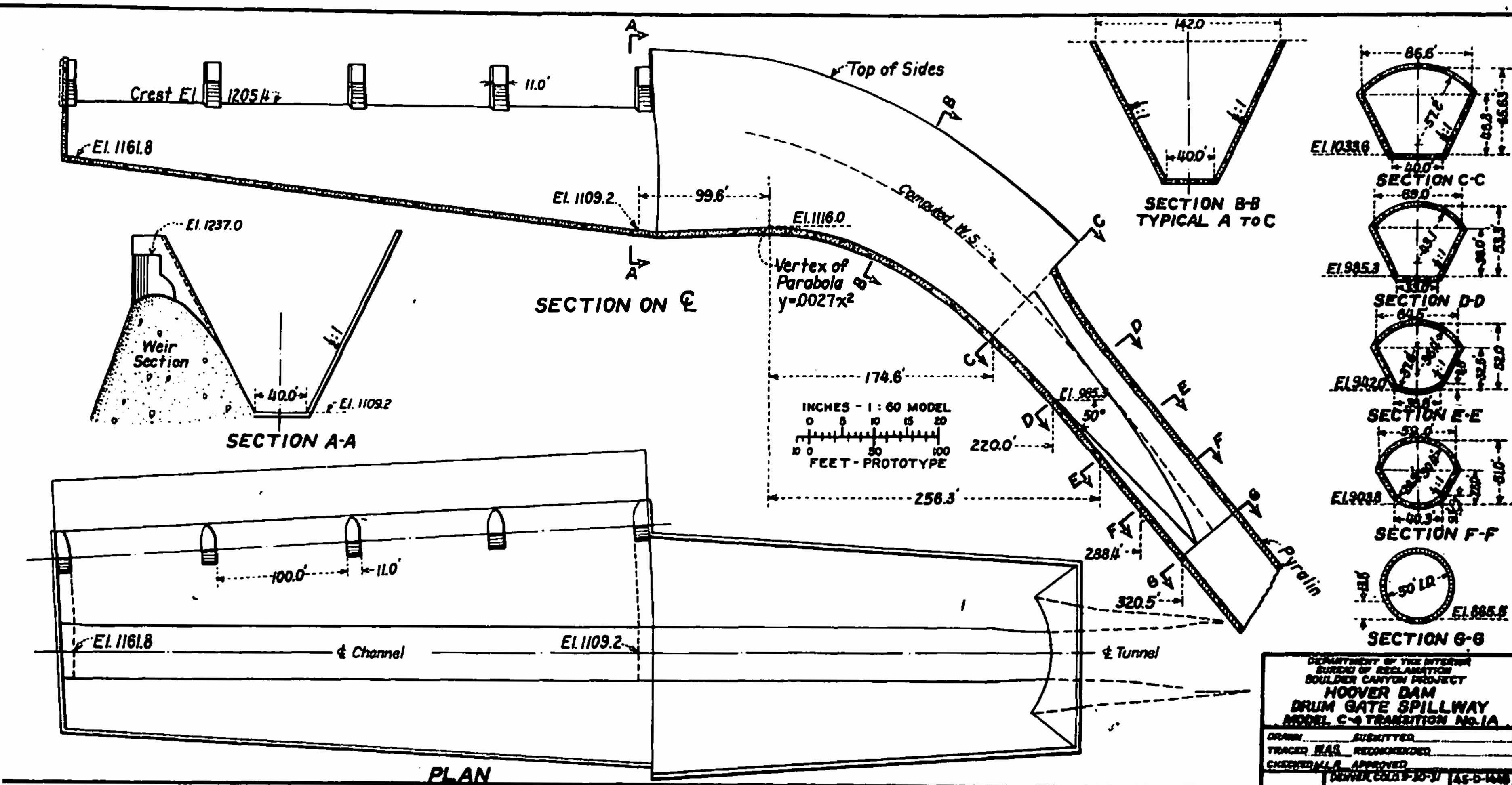

Crest El. 1205.4
11.0'
Top of Sides
El. 1161.8
El. 1109.2
99.6'
El. 1116.0
Computed W.S.
El. 1237.0
Weir Section
Vertex of Parabola $y=.0027x^2$
SECTION ON ℄
40.0'
El. 1109.2
SECTION A-A
174.6'
INCHES - 1 : 60 MODEL
FEET - PROTOTYPE
220.0'
256.3'
288.4'
320.5'
50°
Pyralin
142.0
40.0'
SECTION B-B
TYPICAL A TO C
86.6'
El. 1033.6
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
50' I.D.
SECTION G-G
100.0'
11.0'
El. 1161.8
℄ Channel
El. 1109.2
℄ Tunnel
PLAN
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM
DRUM GATE SPILLWAY
MODEL C-4 TRANSITION No. 1A
DRAWN
SUBMITTED
TRACED W.A.S.
RECOMMENDED
CHECKED
APPROVED
DENVER, COLO.

FIG. 14

ditions improved as the weir increased in height, as shown on Plate 55.

Offset in Channel Wall on Crest Side

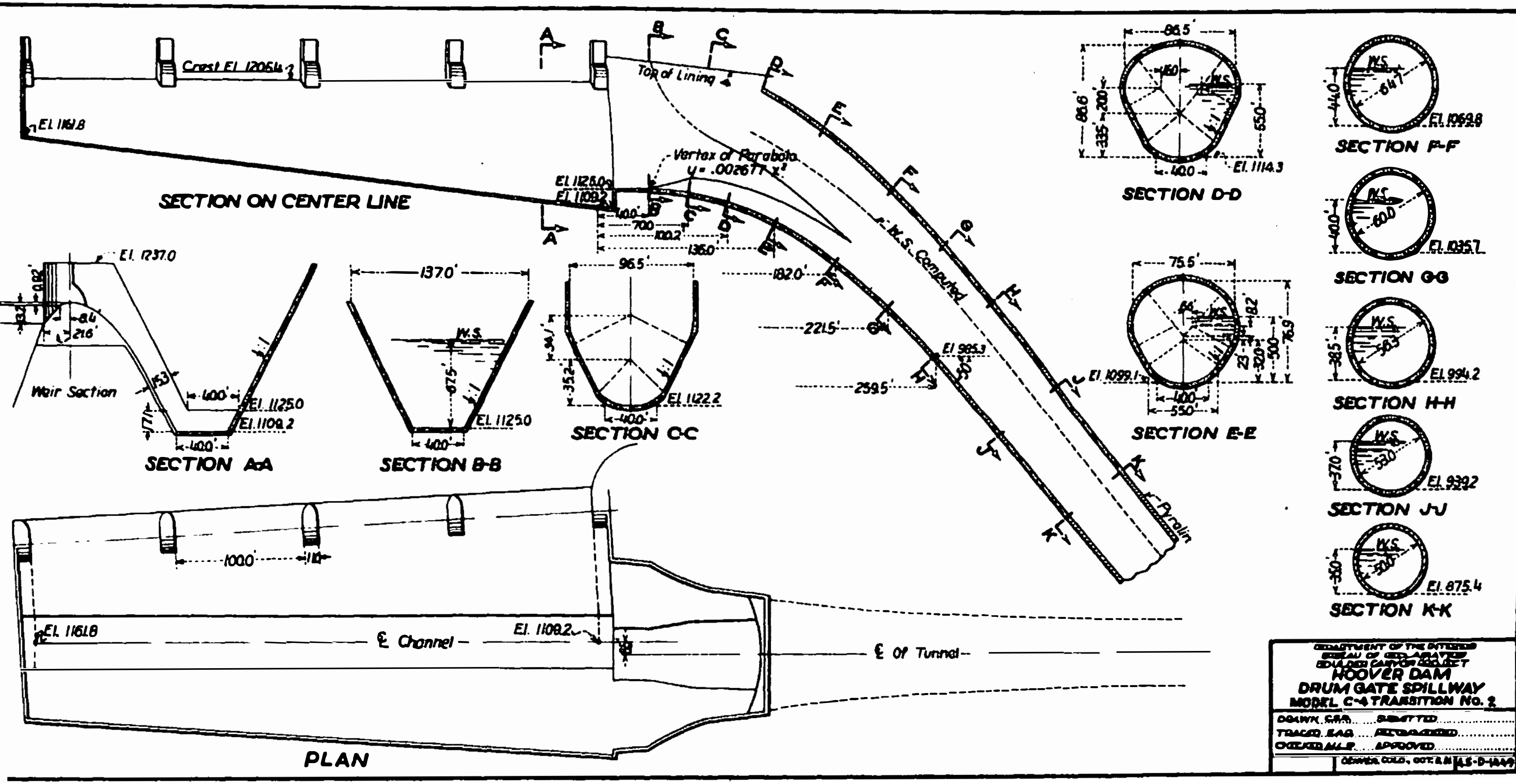
For all conditions of flow in the spillway, part of the channel opposite the ogee crest was taken up by the water flowing over the crest which had a very small component of flow in the direction of the channel. The space occupied by the water flowing along the channel was therefore practically that between the rear wall and the outer face of this nappe from the weir. At the downstream end of the ogee section the effective channel area suddenly increased to the full width of the channel, since there was no nappe there to reduce the section. This abrupt enlargement caused a whirl on the crest side of the channel where it occurred and a cross movement of the water from the opposite side of the channel took place as the water adjusted itself to the new channel shape. Both of these actions resulted in undesirable conditions of flow down the tunnel.

In order to remedy this condition an offset was constructed on the weir side of the transition, beginning just below the ogee section (Plate 56-A), which tended to make the side of this portion of the channel more nearly a continuation of the effective side of the channel upstream from it; i. e., the upper face of the nappe from the ogee weir. This offset also had the effect of reducing the channel section in the transition and thus producing a greater depth of flow in the channel. Both of these effects acted together to improve the nature of the flow in the channel (Plates 56 and 57-D) and in the transition and tunnel.

Transition No. 2

This action was further tested by the construction of transition No. 2 (Figure 15) which incorporated a 15.3-foot offset on the crest side and a cross weir with crest at El. 1125 at the entrance to the transition. This caused an improvement in the flow entering the tunnel, as may be seen by a comparison of Plate 57 with Plate 53. The flow down the tunnel with this setup, although fairly smooth, was less desirable than was secured in the final design, as it filled the shaft to a greater extent.

By raising or lowering the entire transition section, keeping the rear wall of the transition in line with the rear wall of the channel, the height of the cross weir could be changed and at the same time the offset on the crest side varied, the offset increasing as the cross weir height increased. An offset of 10 feet was found to give the best conditions and a greater distance was found to be detrimental. When the transition was raised to sufficient height to produce a cross weir of enough height to give the best conditions in the channel, however, the offset produced was too large.



SECTION ON CENTER LINE
Crest El. 1206.4
El. 1161.8
Top of Lining
Vertex of Parabola
y = .00267 x²
El. 1125.0
El. 1109.2
W.S. Computed
Pyralin
SECTION A-A
Weir Section
El. 1237.0
El. 1125.0
El. 1109.2
SECTION B-B
137.0'
El. 1125.0
SECTION C-C
96.5
El. 1122.2
SECTION D-D
86.5'
El. 1114.3
SECTION E-E
75.5'
El. 1099.1
SECTION F-F
El. 1069.8
SECTION G-G
El. 1035.7
SECTION H-H
El. 994.2
SECTION J-J
El. 939.2
SECTION K-K
El. 875.4
PLAN
℄ Channel
℄ Of Tunnel
El. 1161.8
El. 1109.2
HOOVER DAM
DRUM GATE SPILLWAY
MODEL C-4 TRANSITION No. 2

FIG. 15

Transitions Nos. 3 and 3A

Transition No. 2 did not include the 60-foot length between the ogee crest and the beginning of the steep section, and the lack of it was evident in the results obtained. In order to incorporate all the points tending toward good results which had been discovered in the previous tests, another transition, No. 3, was built which included the 60-foot extension, the 10-foot offset at the end of the ogee crest and a cross weir 43 feet high, with crest at El. 1145.

The dimensions of the prototype of this transition are given in Fig. 16. Plate 59 shows the model and the conditions of flow. This form of transition gave exceptionally smooth flow into the tunnel at the maximum discharge. However, at this discharge it backed the water up in the channel causing sufficient submergence of the crest to reduce the spillway capacity. This transition (No. 3) with minor changes was incorporated in the final design.

In transition No. 3-A, shown on Fig. 17 and Plates 60 and 61, the No. 3 transition was lowered 5 feet, making the weir at the entrance at elevation 1140, which decreased the submergence of the crest and increased the discharge capacity. The action in the spillway channel and transition, however, were not as favorable as with transition No. 3.

Transition No. 3-C, shown by Fig. 18, was made from transition No. 3 by adding a level section of channel bottom at El. 1110

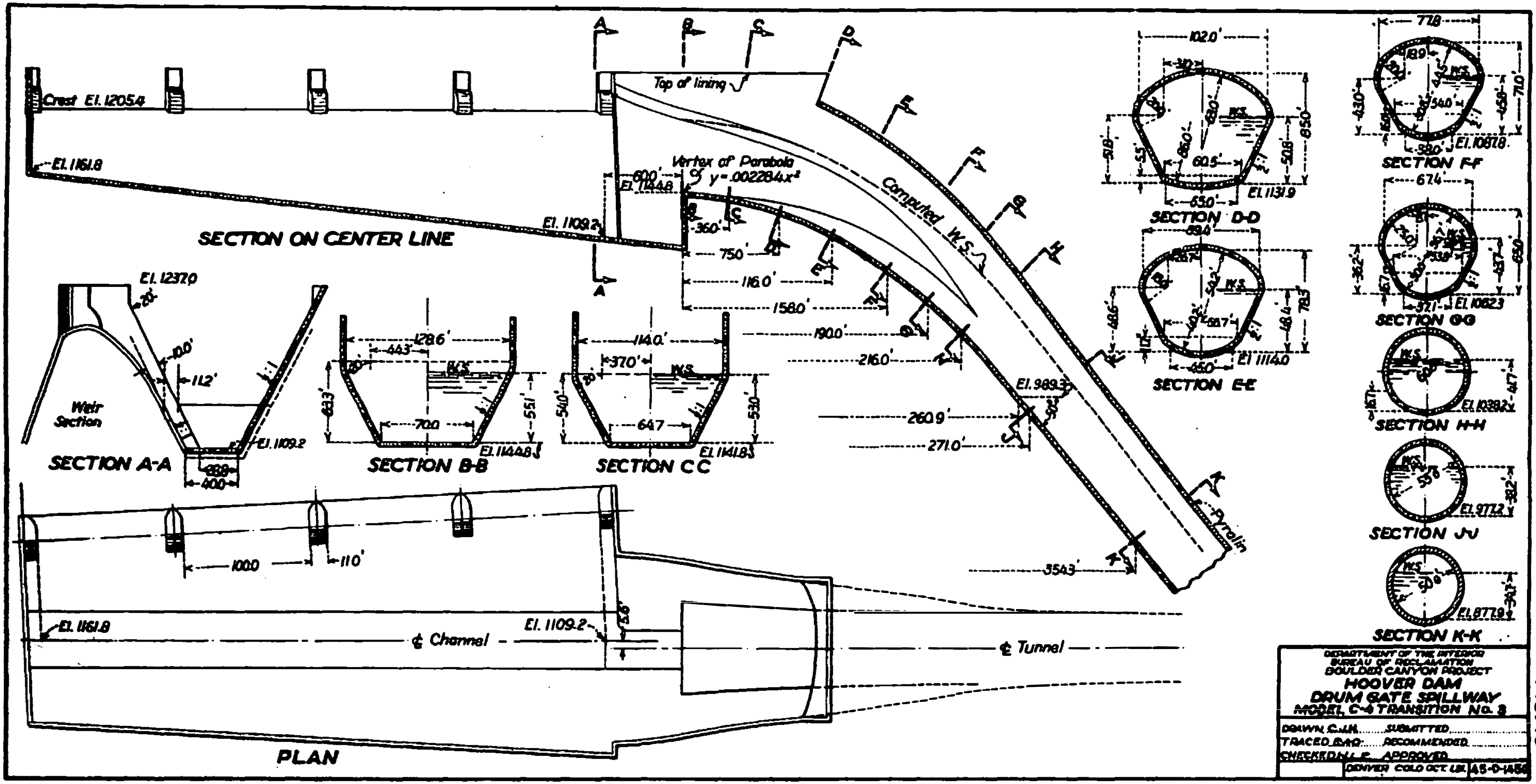

SECTION ON CENTER LINE
Crest El. 1205.4
El. 1161.8
El. 1109.2
El. 1144.8
Top of lining
Vertex of Parabola
y = .002284x²
Computed W.S.
El. 989.3
Pyralin
SECTION A-A
El. 1237.0
Weir Section
SECTION B-B
El. 1144.8
SECTION C-C
El. 1141.83
SECTION D-D
El. 1131.9
SECTION E-E
El. 1114.0
SECTION F-F
El. 1087.8
SECTION G-G
El. 1062.3
SECTION H-H
El. 1039.2
SECTION J-J
El. 977.2
SECTION K-K
El. 877.9
PLAN
El. 1161.8
El. 1109.2
℄ Channel
℄ Tunnel
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM
DRUM GATE SPILLWAY
MODEL C-4 TRANSITION No. 3
DRAWN C.J.H. SUBMITTED
TRACED B.A.G. RECOMMENDED
CHECKED APPROVED
DENVER COLO OCT. 1931 45-D-1456

FIG. 10

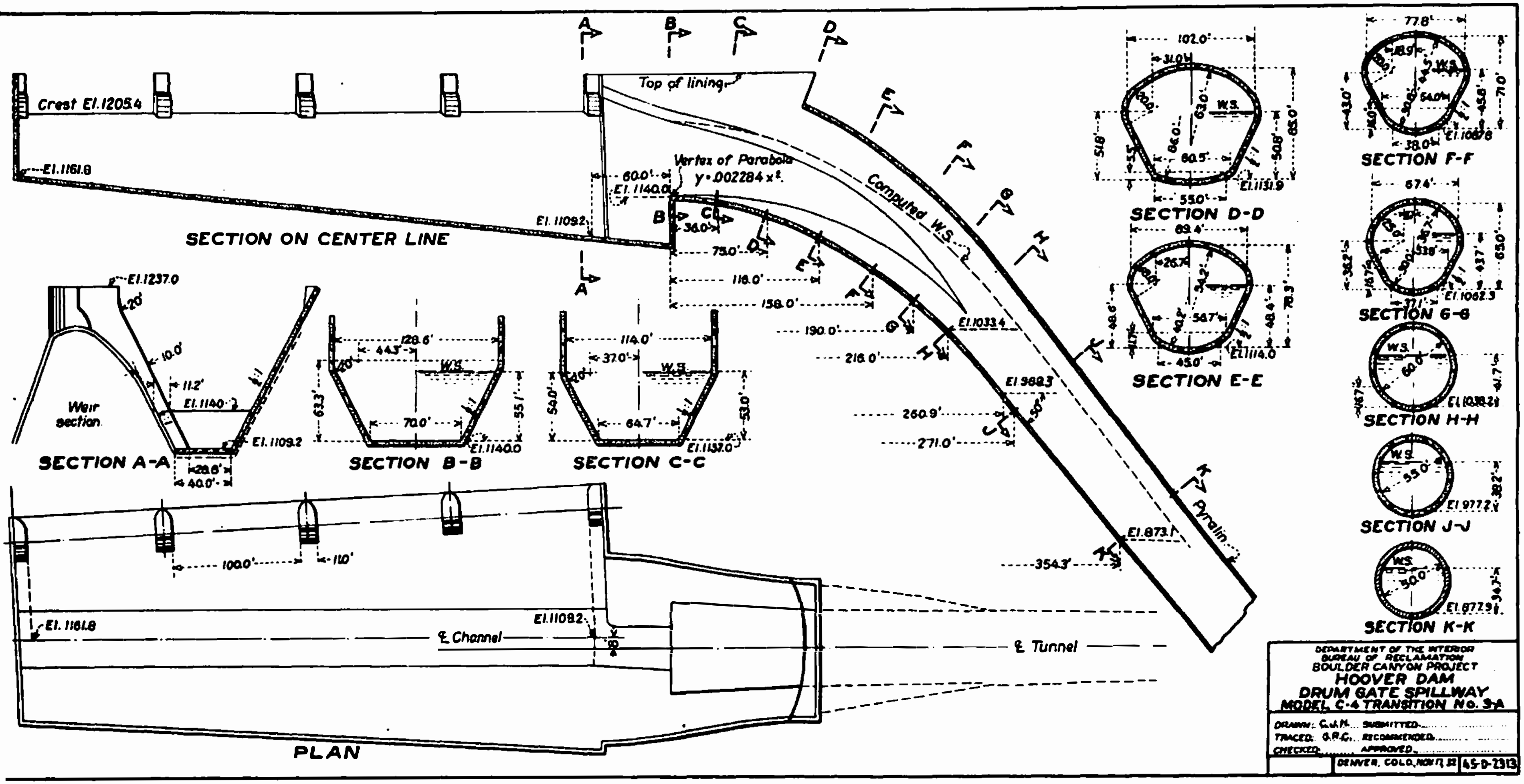

SECTION ON CENTER LINE
Crest El. 1205.4
El. 1161.8
El. 1109.2
El. 1140.0
Top of lining
Vertex of Parabola
y = .002284 x²
Computed W.S.
60.0'
36.0'
75.0'
116.0'
158.0'
190.0'
216.0'
260.9'
271.0'
354.3'
El. 1033.4
El. 968.3
El. 873.1
Pyralin
SECTION A-A
El. 1237.0
Weir section
El. 1140
El. 1109.2
28.8'
40.0'
SECTION B-B
128.6'
44.3'
70.0'
W.S.
El. 1140.0
SECTION C-C
114.0'
37.0'
64.7'
W.S.
El. 1137.0
SECTION D-D
102.0'
55.0'
60.5'
W.S.
El. 1131.9
SECTION E-E
89.4'
45.0'
56.7'
El. 1114.0
SECTION F-F
77.8'
54.0'
38.0'
W.S.
El. 1087.8
SECTION G-G
67.4'
El. 1062.3
SECTION H-H
W.S.
60.0'
El. 1038.2
SECTION J-J
W.S.
55.0'
El. 977.2
SECTION K-K
W.S.
50.0'
El. 877.9
PLAN
100.0'
11.0'
El. 1161.8
El. 1109.2
℄ Channel
℄ Tunnel
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM
DRUM GATE SPILLWAY
MODEL C-4 TRANSITION No. 3-A
DRAWN: C.J.H. SUBMITTED
TRACED: G.R.C. RECOMMENDED
CHECKED APPROVED
DENVER, COLO., NOV. 17, 32
45-D-2313

FIG. 17

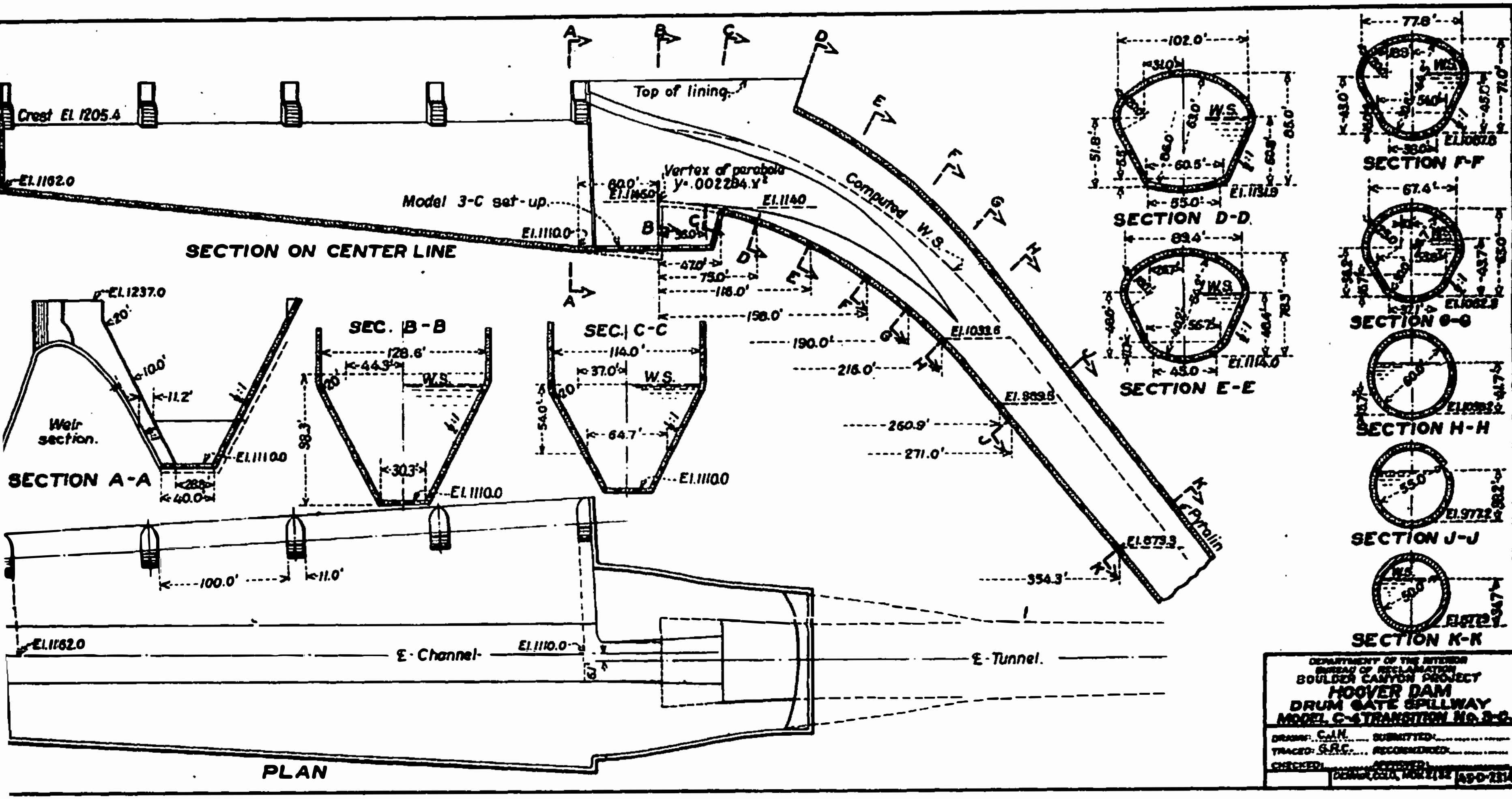
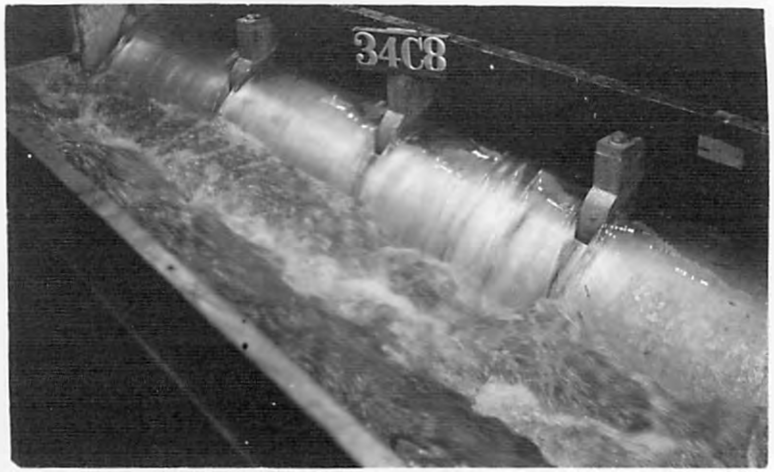
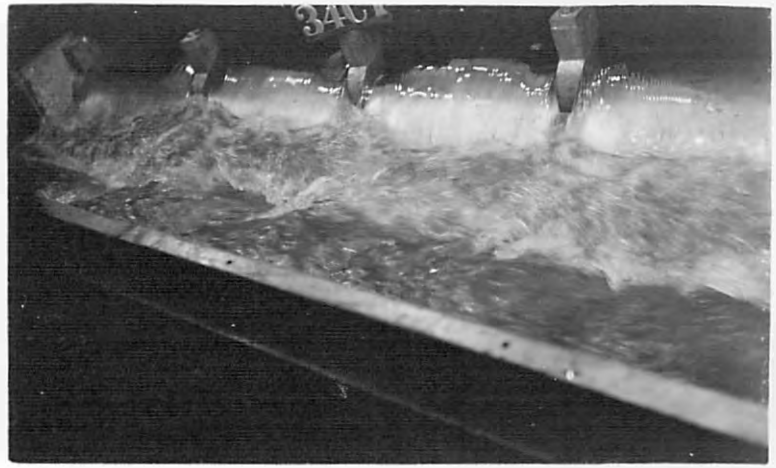

SECTION ON CENTER LINE
Crest El. 1205.4
El. 1162.0
Model 3-C set-up.
Top of lining
Vertex of parabola
y=.002284 x²
El. 1140
El. 1110.0
Computed W.S.
El. 1033.6
El. 989.8
El. 879.3
SECTION A-A
Weir section.
El. 1237.0
El. 1110.0
SEC. B-B
SEC. C-C
W.S.
SECTION D-D
SECTION E-E
SECTION F-F
SECTION G-G
SECTION H-H
SECTION J-J
SECTION K-K
PLAN
℄ Channel
℄ Tunnel.
El. 1162.0
El. 1110.0
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM
DRUM GATE SPILLWAY
MODEL C-4 TRANSITION No. 3-C
DRAWN: C.J.H.
TRACED: G.R.C.
CHECKED:
SUBMITTED:
RECOMMENDED:
APPROVED:

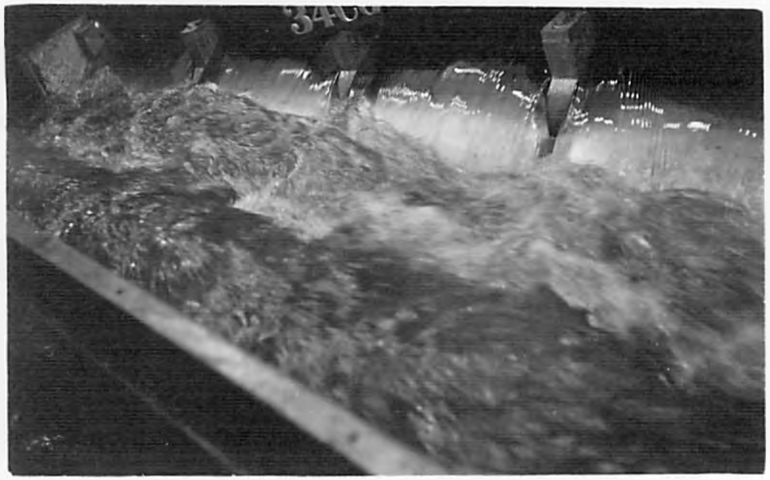
FIG. 18



A-DISCHARGE 120,000 SEC FT WITH TRANSITION NO 2



B-DISCHARGE 160,000 SEC FT WITH TRANSITION NO 2



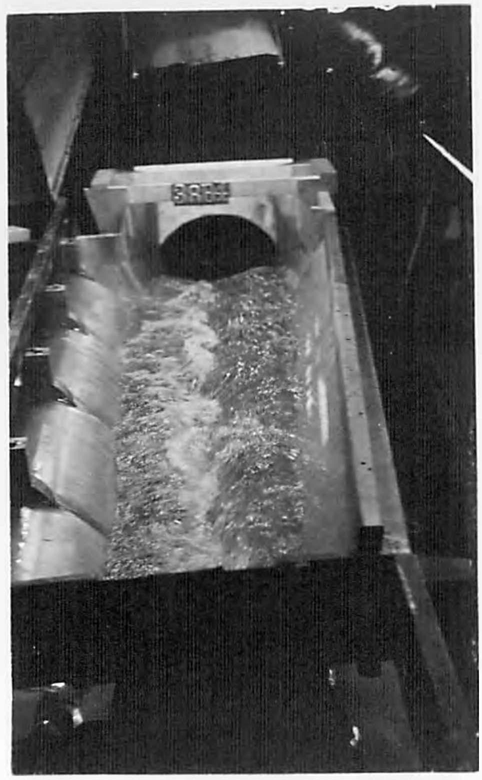
C-DISCHARGE 200,000 SEC FT WITH TRANSITION NO 2

C-DISCHARGE 200,000 SEC. FT.
WITH TRANSITION NO 1A AND CROSS WEIR

DRUM GATE SPILLWAY MODEL C-4

PLATE 58

A-MODEL WITH TRANSITION NO 3



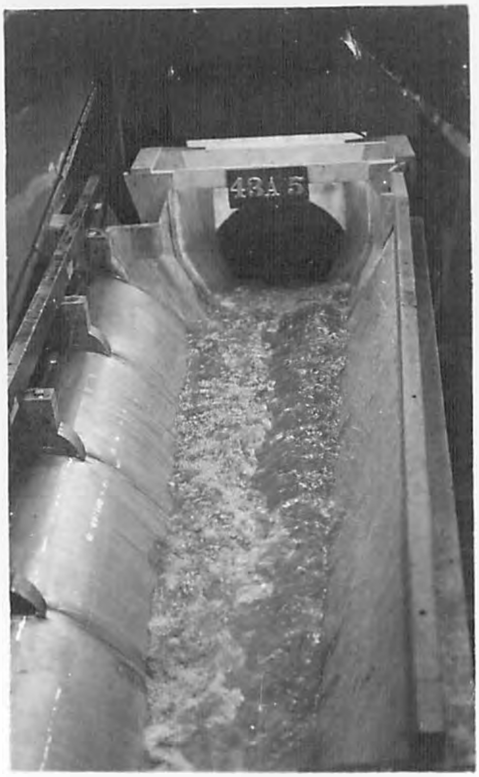
B-DISCHARGE 80,000 SEC FT

C-DISCHARGE 160,000 SEC FT

D-DISCHARGE 200,000 SEC FT

DRUM GATE SPILLWAY MODEL C-4 WITH TRANSITION NO. 3

A-MODEL WITH TRANSITION NO. 3A



B-DISCHARGE 40,000 SEC. FT.

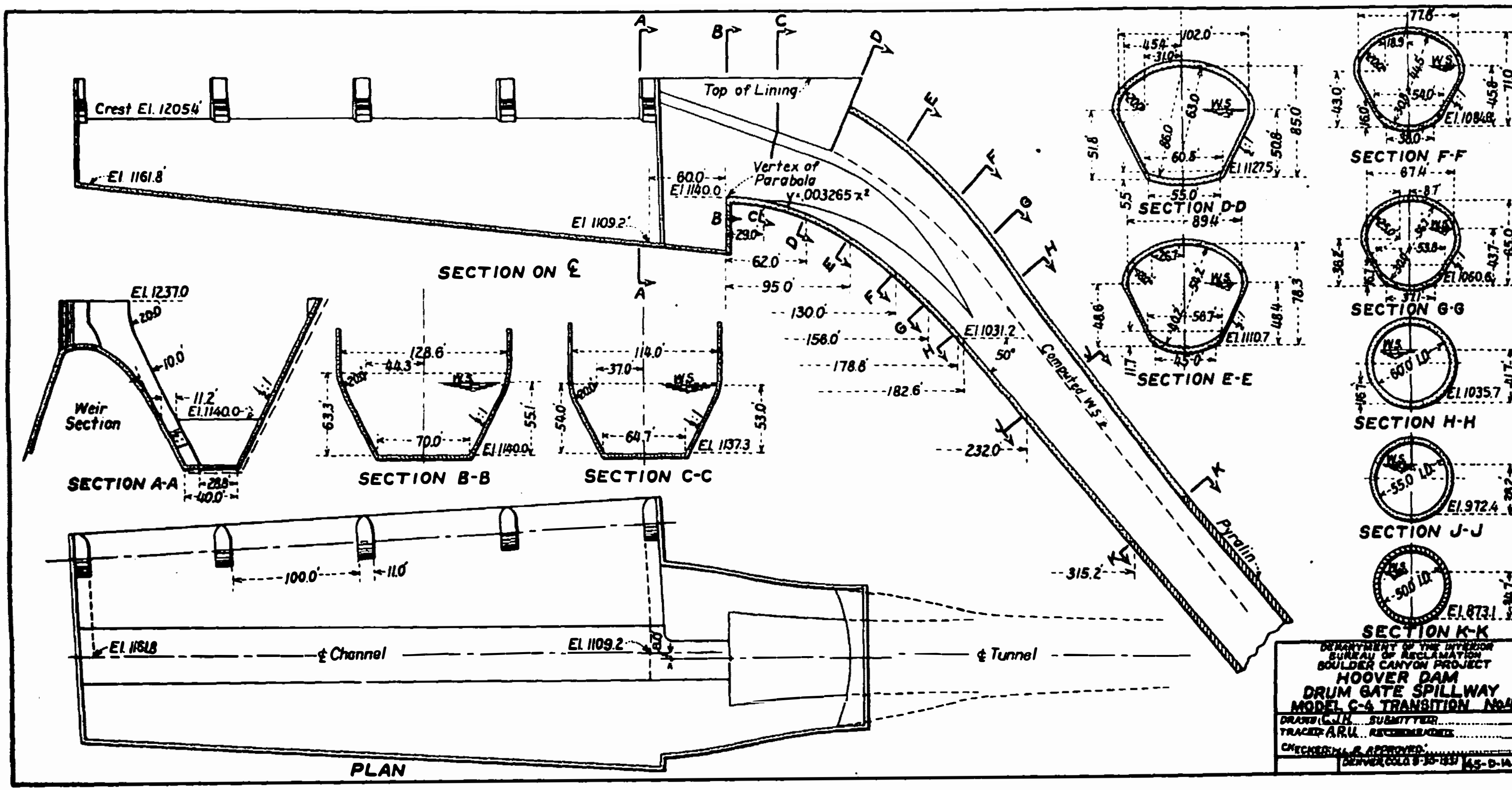
C-DISCHARGE 80,000 SEC FT

D-DISCHARGE 120,000 SEC FT

DRUM GATE SPILLWAY MODEL C-4 WITH TRANSITION NO 3A from the end of the spillway section 107 feet downstream to the cross weir, which was at El. 1140. This was done to test the advantage of a longer section than 60 feet between the weir crest and inclined portion of the transition. The increased length was of no advantage and no further tests were made with it.

Transitions Nos. 4 and 5

Two other forms of transition were experimented upon. One of these, No. 4, was very similar to No. 3-A except the parabola of the bottom of the transition was much steeper in No. 4, as shown in Fig. 19. The results of the steeper parabola were not satisfactory. Transition No. 5 (Fig. 20) had a low cross weir at El. 1125 and an offset on the crest side of the transition, the same as transition No. 2, but had a very much flatter parabolic slope for the bottom of the transition. This transition did not improve the flow down the tunnel, and seemed to indicate that the high cross weir was necessary with a flat parabolic curve to give good flow down the tunnel. The conditions of flow with transitions Nos. 4 and 5 are shown in Plates 62 and 63. To improve the approach to the spillway in tests using transition No. 4 a curved guide wall was placed upstream from the crest at each end as shown in Plate 61-C. This curved wall improved the flow and was retained in the final design.



SECTION ON ℄
Crest El. 1205.4'
El. 1161.8'
El. 1109.2'
Top of Lining
Vertex of Parabola
y = .003265 x²
El. 1140.0
El. 1031.2
Computed W.S.
Pyralin
SECTION A-A
Weir Section
El. 1237.0
El. 1140.0
SECTION B-B
El. 1140.0
SECTION C-C
El. 1137.3
SECTION D-D
El. 1127.5
SECTION E-E
El. 1110.7
SECTION F-F
El. 1084.8
SECTION G-G
El. 1060.6
SECTION H-H
60.0 I.D.
El. 1035.7
SECTION J-J
55.0 I.D.
El. 972.4
SECTION K-K
50.0 I.D.
El. 873.1
PLAN
℄ Channel
℄ Tunnel
El. 1161.8
El. 1109.2
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM
DRUM GATE SPILLWAY
MODEL C-4 TRANSITION No. 4
DRAWN C.J.H.
TRACED A.R.U.
DENVER, COLO.
45-D-1431

FIG. 19

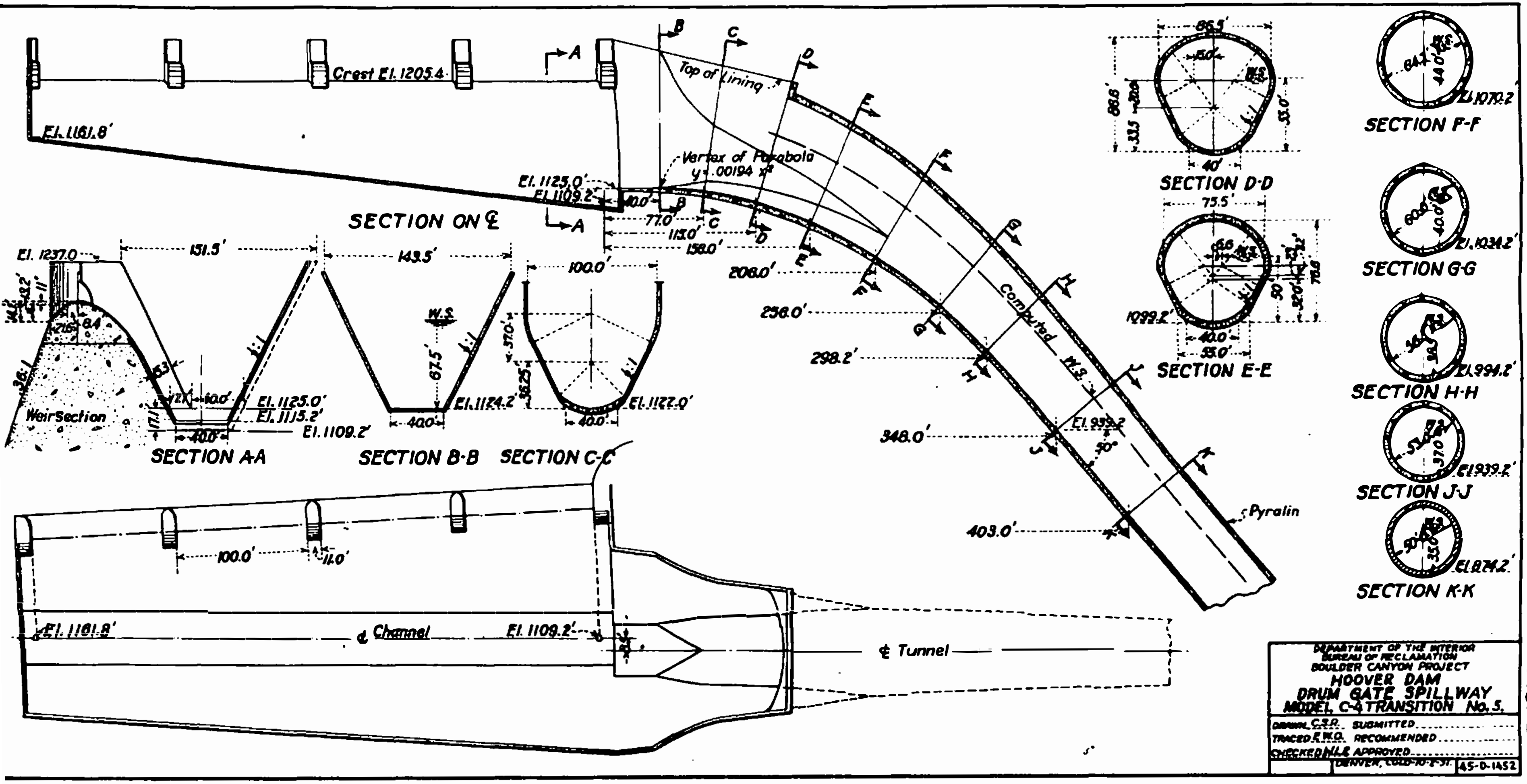
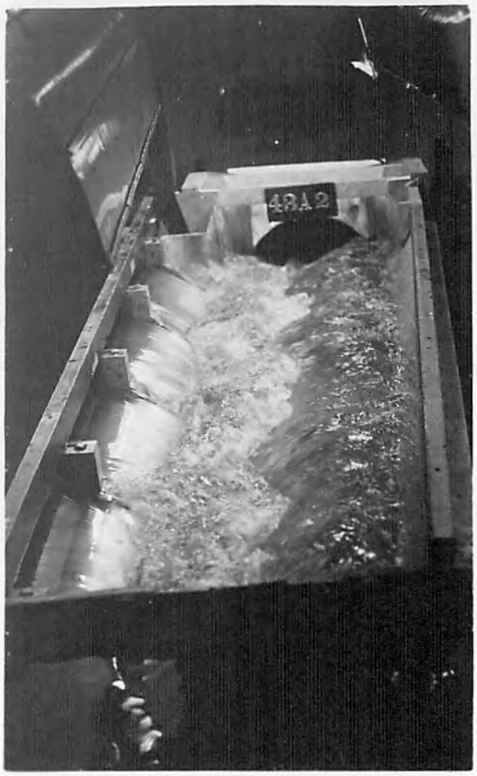

Crest El. 1205.4
El. 1161.8'
El. 1125.0'
El. 1109.2'
SECTION ON ℄
Top of Lining
Vertex of Parabola
y = .00194 x²
SECTION A-A
SECTION B-B
SECTION C-C
Weir Section
SECTION D-D
SECTION E-E
SECTION F-F
SECTION G-G
SECTION H-H
SECTION J-J
SECTION K-K
Computed W.S.
Pyralin
℄ Channel
℄ Tunnel
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM
DRUM GATE SPILLWAY
MODEL C-4 TRANSITION No. 5.
SUBMITTED
RECOMMENDED
APPROVED
45-D-1452

Fig. 20

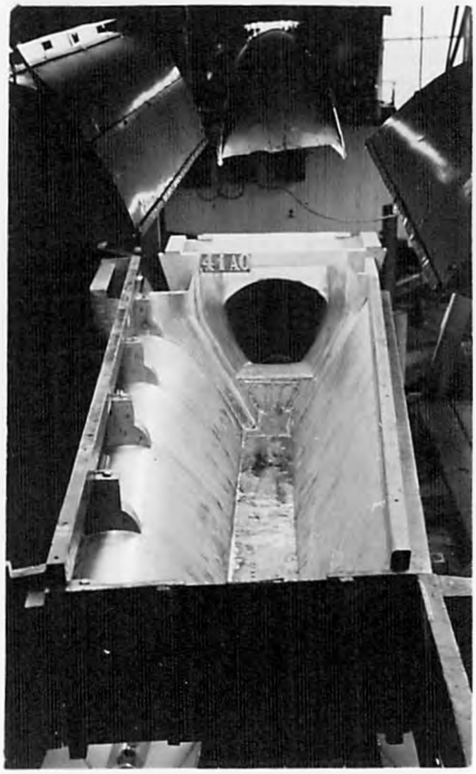


A-DISCHARGE 160,000 SEC. FT.

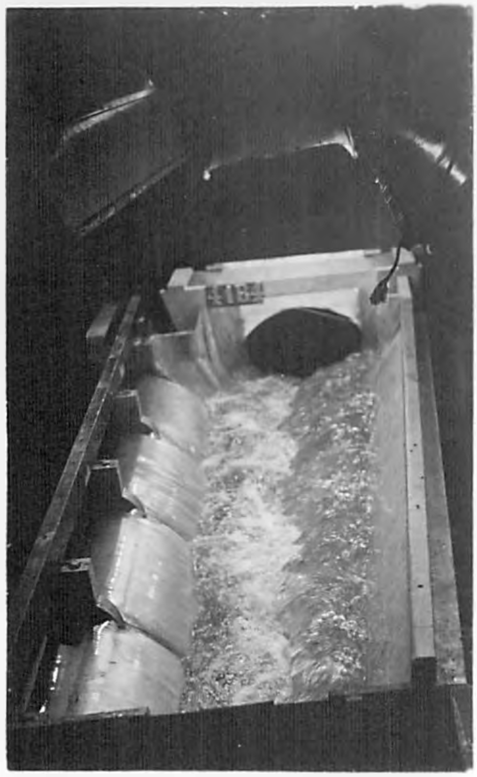
B-DISCHARGE 200,000 SEC. FT.

C-CURVED GUIDE WALL AT END OF SPILLWAY CREST

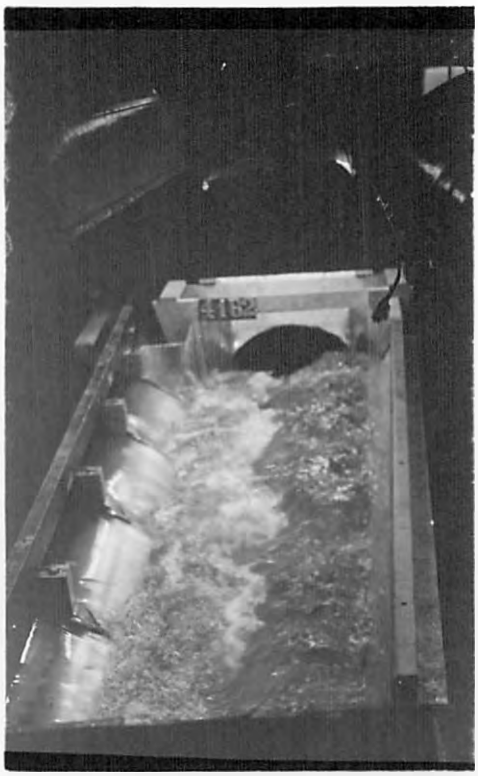
DRUM GATE SPILLWAY MODEL C-4 WITH TRANSITION NO. 3A



A-MODEL WITH TRANSITION NO. 4



B-DISCHARGE 80,000 SEC FT



C-DISCHARGE 160,000 SEC FT

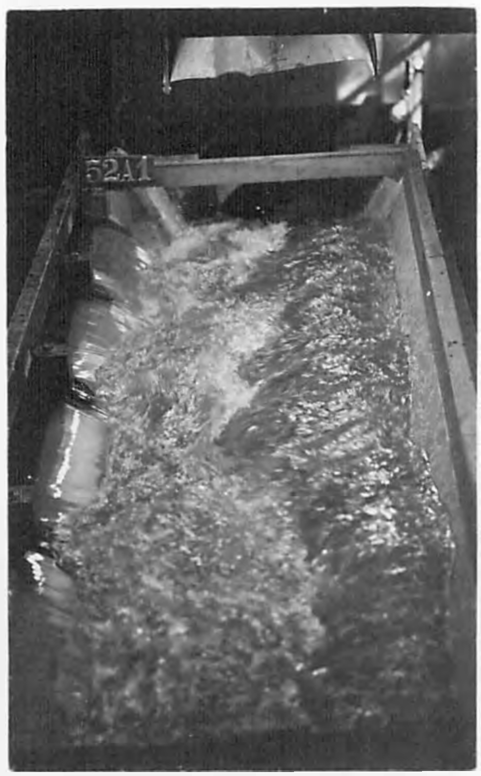
D-DISCHARGE 200,000 SEC FT

DRUM GATE SPILLWAY MODEL C-4 WITH TRANSITION NO. 4

A-MODEL WITH TRANSITION NO. 5

B-DISCHARGE 100,000 SEC. FT.

C-DISCHARGE 150,000 SEC FT



D-DISCHARGE 200,000 SEC FT

DRUM GATE SPILLWAY MODEL C-4 WITH TRANSITION NO. 5

Curved Wall at Upper End of Channel

Since transitions Nos. 4 and 5 proved less satisfactory than No. 3, the latter was replaced in position and future tests continued with it. Curved walls were introduced from the upstream end of the spillway face to the back of the channel to smooth out the flow in the upper end of the channel as shown in Plates 64 and 65 and Fig. 25. The condition with the square end in the channel is shown on Plate 66. At low flows an undesirable wave was formed at the upper end of the channel (Plates 64-B and 65-B) similar to that found on the M-1 model (Plate 34). At high flows the curved wall had little effect. The general appearance of the spillway was much better with a curved upstream end, and by the proper gate manipulation it would never be necessary to form this undesirable wave. The curved wall was therefore incorporated in the final design.

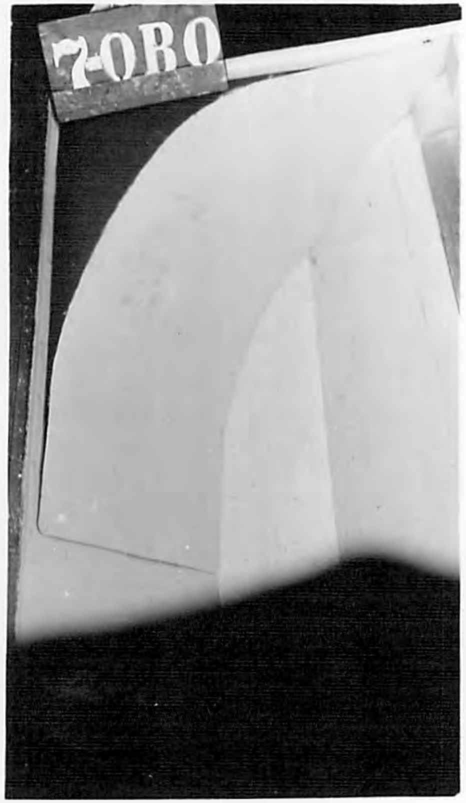
In testing model C-4, three different forms of spillway crest were used in an attempt to improve the discharge coefficients. The use of the three types had no effect apparent to the eye on the action of the spillway. Their quantitative effect on the discharge will be discussed in the later section of this report dealing with the flow over ogee crests.

A-MODEL WITH SHORT RADIUS CURVE

B-DISCHARGE 80,000 SEC. FT.
LOOKING UPSTREAM

C-DISCHARGE 200,000 SEC. FT.
LOOKING UPSTREAM

DRUM GATE SPILLWAY MODEL C-4
SHORT RADIUS CURVE AT UPPER END OF CHANNEL

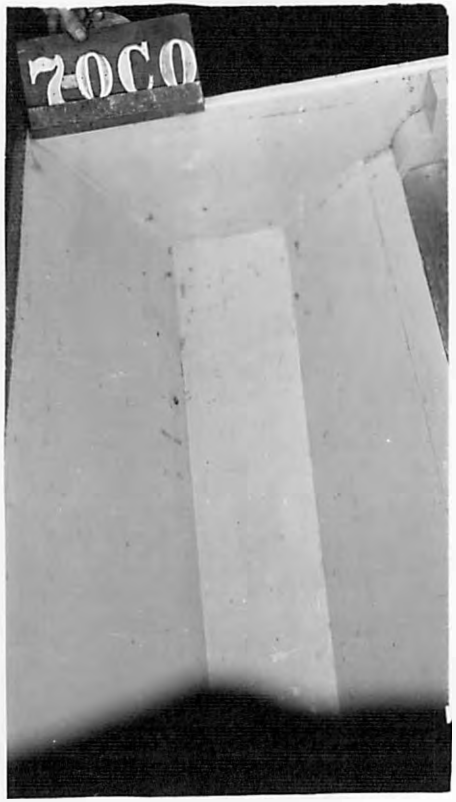


A-MODEL WITH LONG RADIUS CURVE

B-DISCHARGE 80,000 SEC. FT
LOOKING UPSTREAM

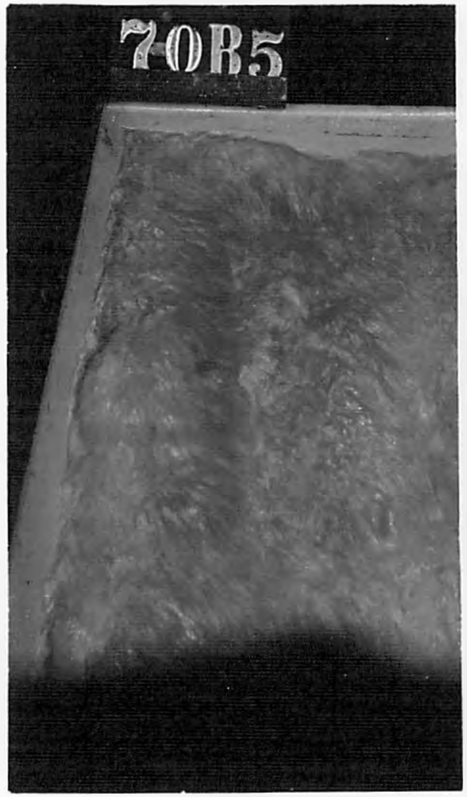
C-DISCHARGE 200,000 SEC. FT.
LOOKING UPSTREAM

DRUM GATE SPILLWAY MODEL C-4
LONG RADIUS CURVE AT UPPER END OF CHANNEL



A-MODEL WITH SQUARE END

B-DISCHARGE 80,000 SEC. FT
LOOKING UPSTREAM



C-DISCHARGE 200,000 SEC. FT
LOOKING UPSTREAM

DRUM GATE SPILLWAY MODEL C-4
UPPER END OF CHANNEL WITHOUT CURVE

Tests of Baffles and Similar Devices on the C-4 Model

The form of spillway finally adopted contains no baffles or other devices to break up currents and smooth out the flow. The tests leading up to this selection, however, included very extensive experiments on such devices. Most of these tests were performed on the C-4 model. Although considerable progress was made in improving the flow conditions by this means, satisfactory results were secured without them and it was believed that the additional improvement did not warrant the extra expense involved in their construction. However, it is believed that a record of these experiments will be of value to future designers of side channel and other spillways and they are therefore briefly described herein.

The tests in this field were very comprehensive, including a variety of basic forms and a great number of minor changes and combinations of them. In all, about 100 different arrangements and combinations were tested. To include a discussion of all of these would unduly lengthen this report. Only a brief account has therefore been included, but to preserve a record of all the tests a set of sketches of all the baffle arrangements on all of the models has been drawn up and filed with the office file copies of this report.

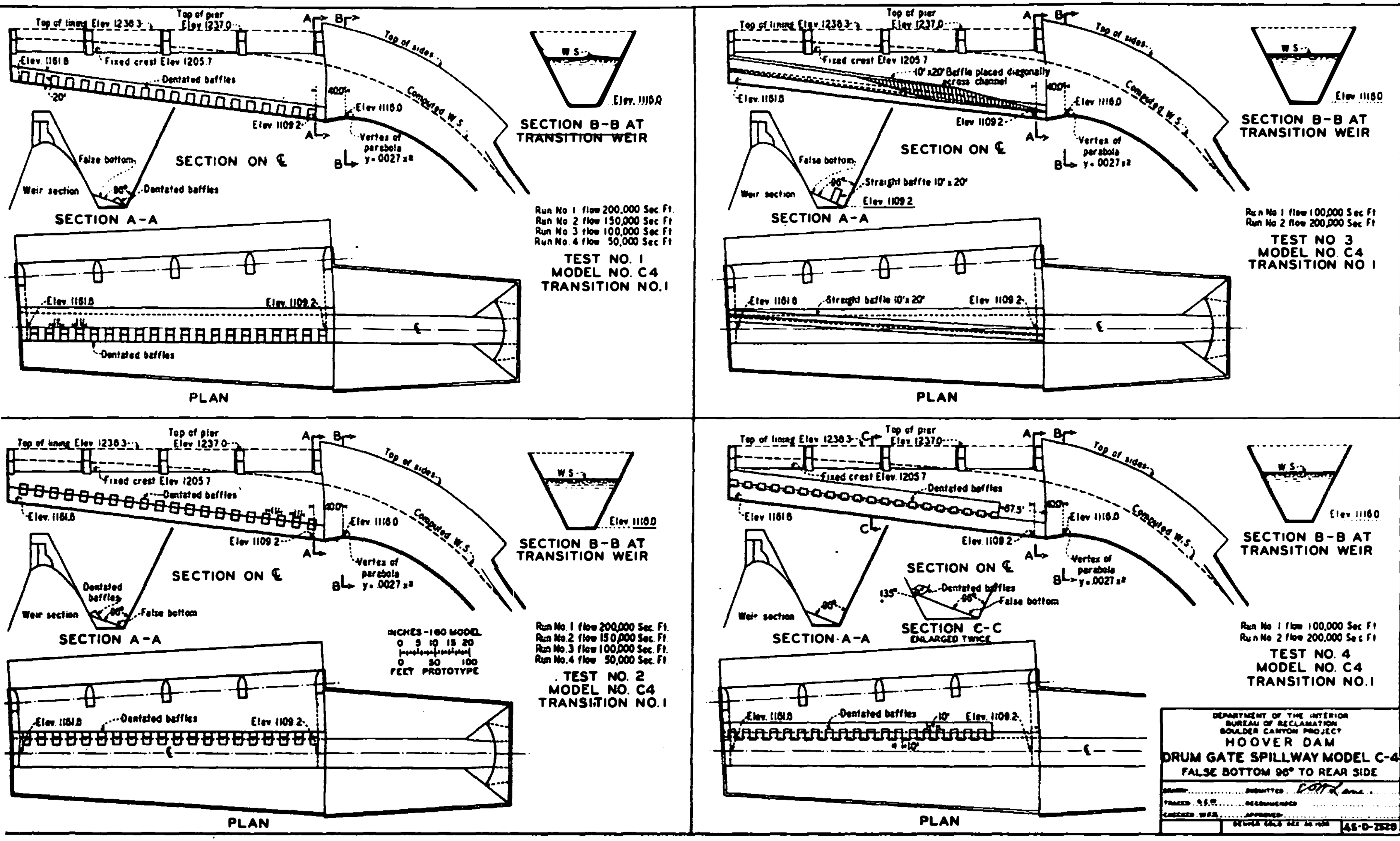
These tests were carried on simultaneously with the developments leading to the final design, and therefore include runs with baffles using all the various transition forms previously discussed.

In order that the developments leading to the final design might not be obscured, it was believed better to discuss these main steps separately from the tests with baffles, rather than to cover them both in a chronological order. In discussing the baffles, only the steps in the development of the principal forms will be described.

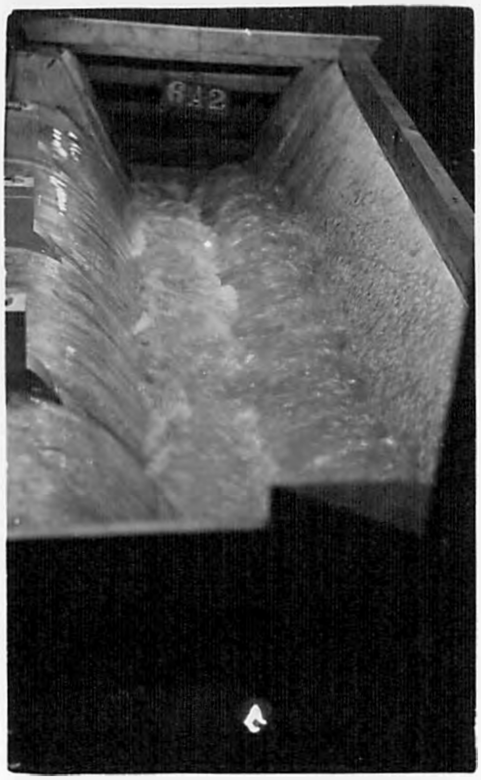
The purpose of the various baffle devices was to check the velocity produced by the fall over the spillway crest, as this would lessen the turbulence in the channel and reduce the height to which the water piled up on the rear side of the channel. The accomplishment of these results improved the flow conditions down the tunnel.

False Floor Sloping Across Channel

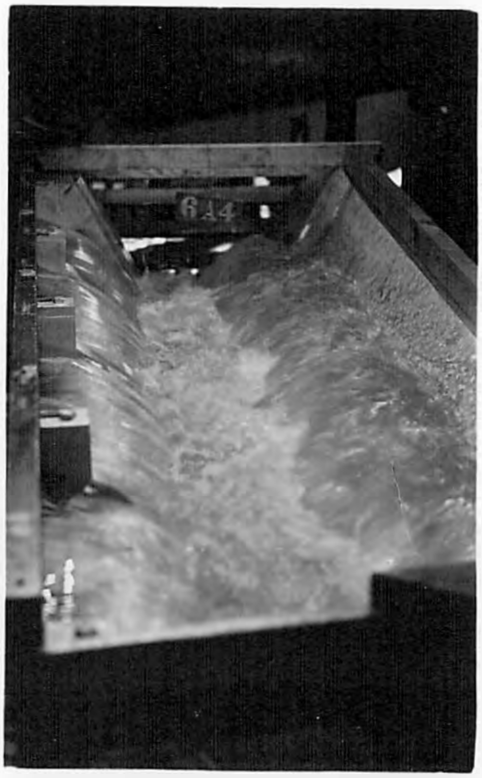
One of the first methods tested to accomplish these results was the installation of a false floor sloping across the channel, intersecting the rear side of the channel at an angle of 96° at the elevation of the channel bottom, as shown on Figure 21 and Plate 67. This alteration was expected to raise the water surface on the crest side and direct the jet against a normal surface, on which the tendency to rise would be less than in the case of the original form where the angle was obtuse. The results with this setup were but little improvement over the original form, as may be seen by a comparison of Plates 53 and 67. The effect of adding curved-faced baffles in three positions on the cross sloping floor; i. e., near the rear wall, on the center line, and near the crest side, were also


SECTION ON ℄
SECTION A-A
SECTION B-B AT TRANSITION WEIR
PLAN
Run No 1 flow 200,000 Sec Ft
Run No 2 flow 150,000 Sec Ft
Run No 3 flow 100,000 Sec Ft
Run No 4 flow 50,000 Sec Ft
TEST NO. 1
MODEL NO. C4
TRANSITION NO. 1
Run No 1 flow 100,000 Sec Ft
Run No 2 flow 200,000 Sec Ft
TEST NO 3
MODEL NO. C4
TRANSITION NO 1
INCHES - 1:60 MODEL
FEET PROTOTYPE
TEST NO. 2
MODEL NO. C4
TRANSITION NO. 1
SECTION C-C
ENLARGED TWICE
TEST NO. 4
MODEL NO. C4
TRANSITION NO. 1
Top of lining Elev 1238.3
Top of pier Elev 1237.0
Fixed crest Elev 1205.7
Dentated baffles
Elev 1161.8
Elev 1109.2
Elev 1116.0
Top of sides
Computed W.S.
Vertex of parabola y = .0027 x²
False bottom
Weir section
10' x 20' Baffle placed diagonally across channel
Straight baffle 10' x 20'
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM
DRUM GATE SPILLWAY MODEL C-4
FALSE BOTTOM 96° TO REAR SIDE
45-D-2828
FIG. 21

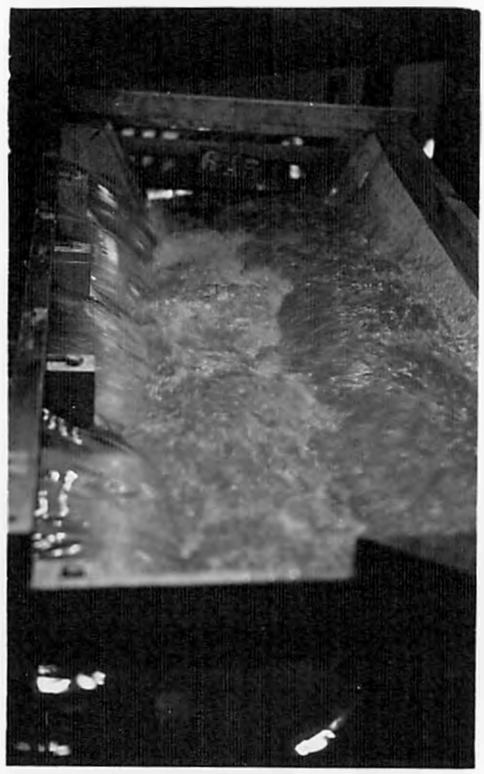
A-MODEL WITH FLOOR SLOPING ACROSS CHANNEL, 96° TO REAR WALL



B-DISCHARGE 80,000 SEC. FT.



C-DISCHARGE 160,000 SEC. FT.



D-DISCHARGE 200,000 SEC. FT.

DRUM GATE SPILLWAY MODEL C-4 TRANSITION NO. 1
EFFECT OF FLOOR SLOPING ACROSS CHANNEL

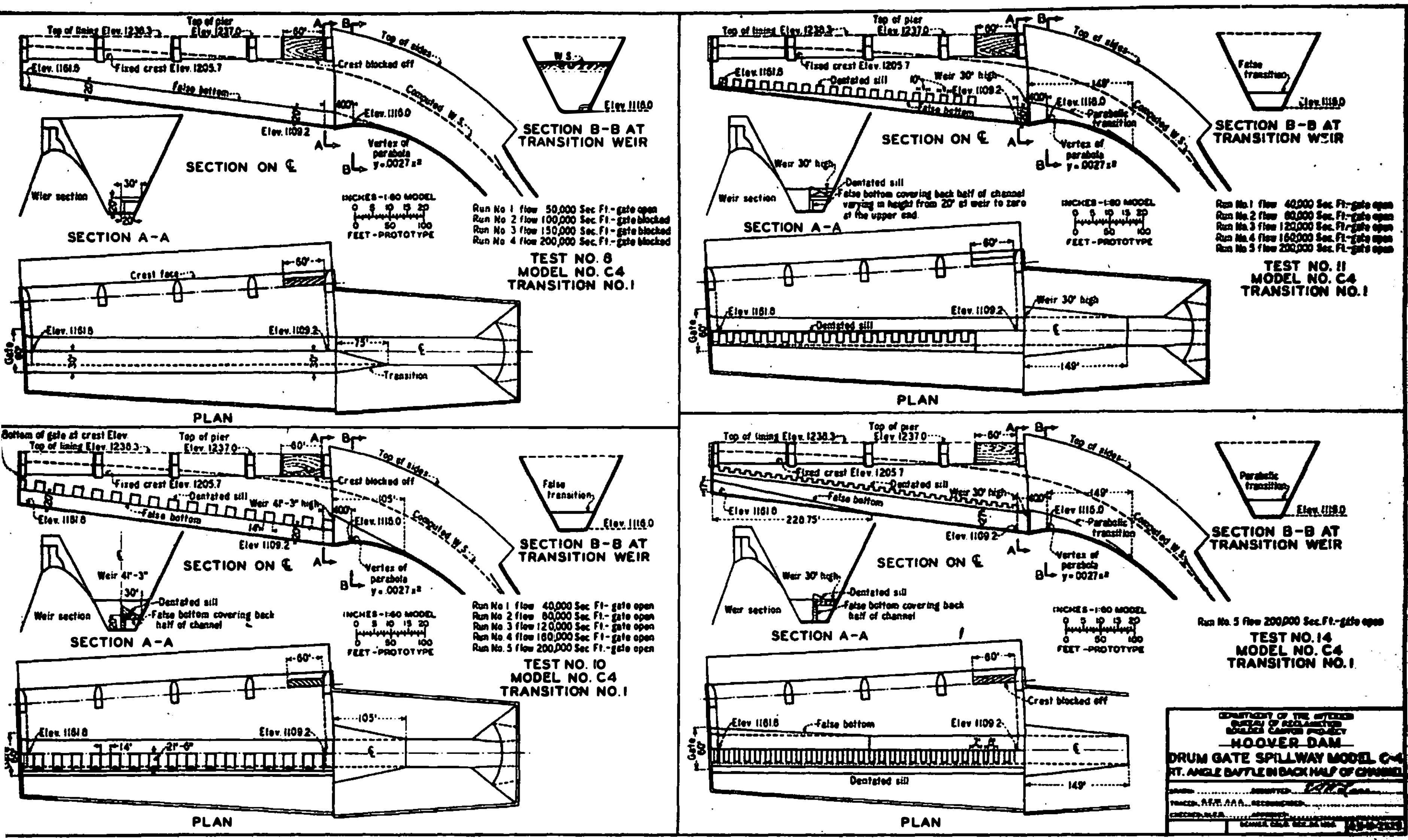
tried. The latter position was most beneficial as the baffles tended to even out the flow across the channel at all flows except the very low ones, as shown on Plate 68. Some of the other minor changes of this general form are shown on Figure 21.

Trough in Front Half of Channel

Another form of baffle tested was a ledge on the rear half of the channel, leaving a trough on the crest side as shown on Figure 22 and Plate 69-A. This is approximately the same form as tested on the M-1 model and shown on Plate 43. At high flows the effect of the trough was beneficial, but for low flows it was probably less desirable than the original design. The details of some of the variations of this major form which were tested are shown on Figure 22.

Dentated baffles on the front edge of the ledge (Plate 69-C) resulted in improved conditions. This form led to cutting the dentates in the ledge itself and then to the addition of the projecting blocks, which made up the best form of baffle devised. This form of baffle is shown on Plates 70 and Figure 23. The effect of the dentated baffle may be seen by comparing Plates 61 and 70. A few of the many varieties of this baffle are shown on Figure 23.

In its best form this baffle was 20 feet high at the upper end of the channel and 30 feet high at the lower end, and was placed diagonally across the channel bottom from a position 10 feet in front of channel center line at upper end to 10 feet in rear of center line



SECTION ON ℄
SECTION A-A
SECTION B-B AT TRANSITION WEIR
PLAN
Top of lining Elev. 1238.3
Top of pier Elev. 1237.0
Fixed crest Elev. 1205.7
Crest blocked off
Top of sides
Computed W.S.
False bottom
Elev. 1161.8
Elev. 1109.2
Elev. 1116.0
Vertex of parabola y = .0027x²
Weir section
Transition
INCHES - 1:60 MODEL
FEET - PROTOTYPE
Run No 1 flow 50,000 Sec Ft - gate open
Run No 2 flow 100,000 Sec Ft - gate blocked
Run No 3 flow 150,000 Sec Ft - gate blocked
Run No 4 flow 200,000 Sec Ft - gate blocked
TEST NO. 8
MODEL NO. C4
TRANSITION NO. 1
Dentated sill
Weir 30' high
False bottom covering back half of channel varying in height from 20' at weir to zero at the upper end.
False transition
Parabolic transition
Run No. 1 flow 40,000 Sec. Ft. - gate open
Run No. 2 flow 80,000 Sec. Ft. - gate open
Run No. 3 flow 120,000 Sec. Ft. - gate open
Run No. 4 flow 160,000 Sec. Ft. - gate open
Run No. 5 flow 200,000 Sec. Ft. - gate open
TEST NO. 11
MODEL NO. C4
TRANSITION NO. 1
Bottom of gate at crest Elev.
Weir 41'-3" high
False bottom covering back half of channel
TEST NO. 10
MODEL NO. C4
TRANSITION NO. 1
Run No. 5 flow 200,000 Sec. Ft. - gate open
TEST NO. 14
MODEL NO. C4
TRANSITION NO. 1
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM
DRUM GATE SPILLWAY MODEL C-4
RT. ANGLE BAFFLE IN BACK HALF OF CHANNEL

FIG. 22

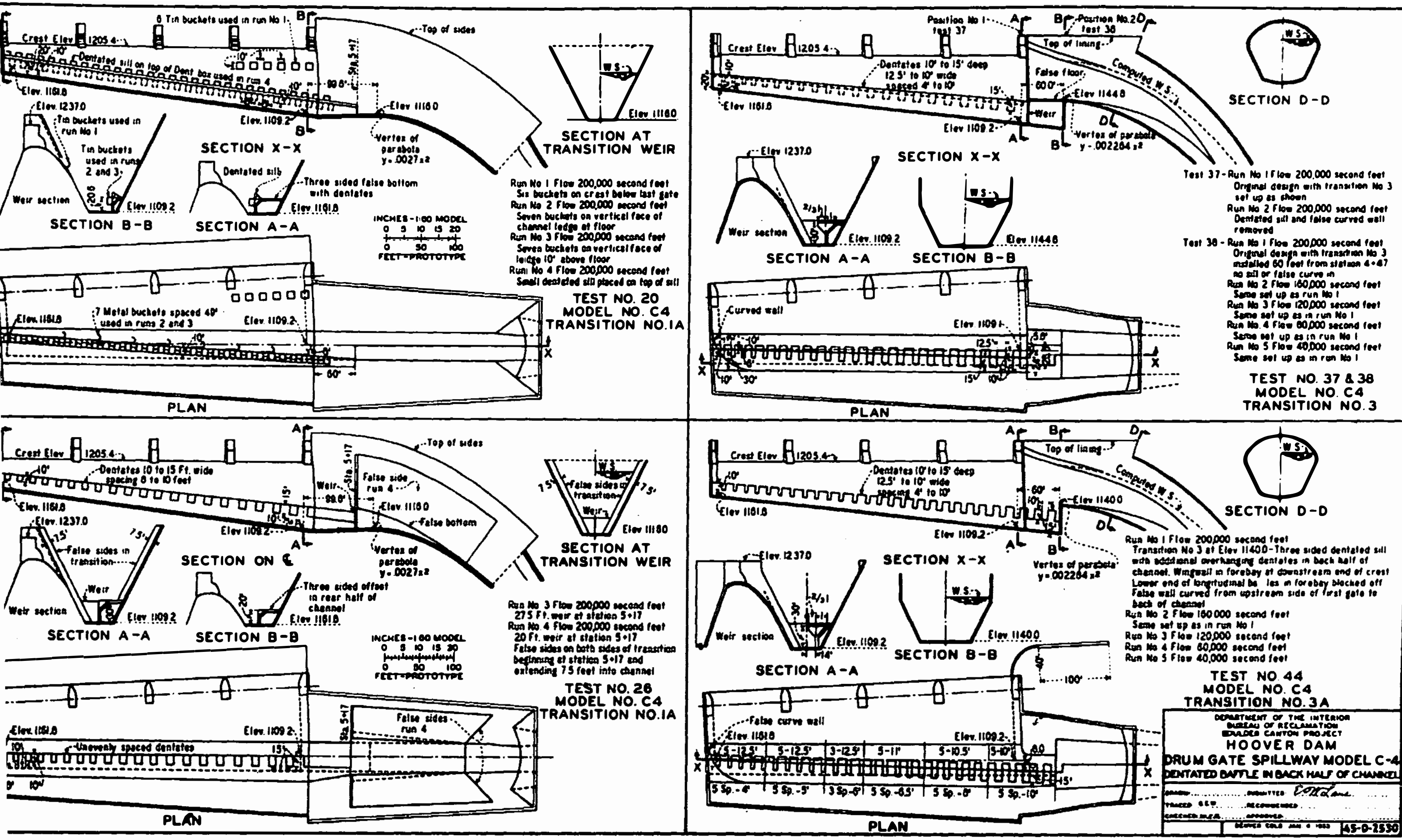

TEST NO. 20
MODEL NO. C4
TRANSITION NO. 1A
Run No 1 Flow 200,000 second feet
Six buckets on crest below last gate
Run No 2 Flow 200,000 second feet
Seven buckets on vertical face of channel ledge at floor
Run No 3 Flow 200,000 second feet
Seven buckets on vertical face of ledge 10' above floor
Run No 4 Flow 200,000 second feet
Small dentated sill placed on top of sill
SECTION AT TRANSITION WEIR
SECTION B-B
SECTION A-A
SECTION X-X
PLAN
TEST NO. 37 & 38
MODEL NO. C4
TRANSITION NO. 3
Test 37 - Run No 1 Flow 200,000 second feet
Original design with transition No 3 set up as shown
Run No 2 Flow 200,000 second feet
Dentated sill and false curved wall removed
Test 38 - Run No 1 Flow 200,000 second feet
Original design with transition No 3 installed 60 feet from station 4+47 no sill or false curve in
Run No 2 Flow 160,000 second feet
Same set up as run No 1
Run No 3 Flow 120,000 second feet
Same set up as in run No 1
Run No 4 Flow 80,000 second feet
Same set up as in run No 1
Run No 5 Flow 40,000 second feet
Same set up as in run No 1
SECTION D-D
TEST NO. 28
MODEL NO. C4
TRANSITION NO. 1A
Run No 3 Flow 200,000 second feet
27.5 Ft. weir at station 5+17
Run No 4 Flow 200,000 second feet
20 Ft. weir at station 5+17
False sides on both sides of transition beginning at station 5+17 and extending 75 feet into channel
SECTION ON ℄
TEST NO. 44
MODEL NO. C4
TRANSITION NO. 3A
Run No 1 Flow 200,000 second feet
Transition No 3 at Elev 1140.0 - Three sided dentated sill with additional overhanging dentates in back half of channel. Wingwall in forebay at downstream end of crest. Lower end of longitudinal baffles in forebay blocked off. False wall curved from upstream side of first gate to back of channel
Run No 2 Flow 160,000 second feet
Same set up as in run No 1
Run No 3 Flow 120,000 second feet
Run No 4 Flow 80,000 second feet
Run No 5 Flow 40,000 second feet
INCHES - 1:60 MODEL
FEET - PROTOTYPE
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM
DRUM GATE SPILLWAY MODEL C-4
DENTATED BAFFLE IN BACK HALF OF CHANNEL
45-D-2530

FIG. 23

A-MODEL WITH DENTATED DEFLECTORS ON CREST SIDE OF SLOPING FLOOR

B-DISCHARGE 50,000 SEC. FT.

C-MODEL WITH DENTATED BUCKETS ON CREST SIDE OF SLOPING FLOOR

D-DISCHARGE 200,000 SEC. FT

DRUM GATE SPILLWAY MODEL C-4 TRANSITION NO. I
EFFECT OF DENTATED DEFLECTORS & BUCKETS ON SLOPING FLOOR

A-MODEL WITH TROUGH IN FRONT HALF OF CHANNEL

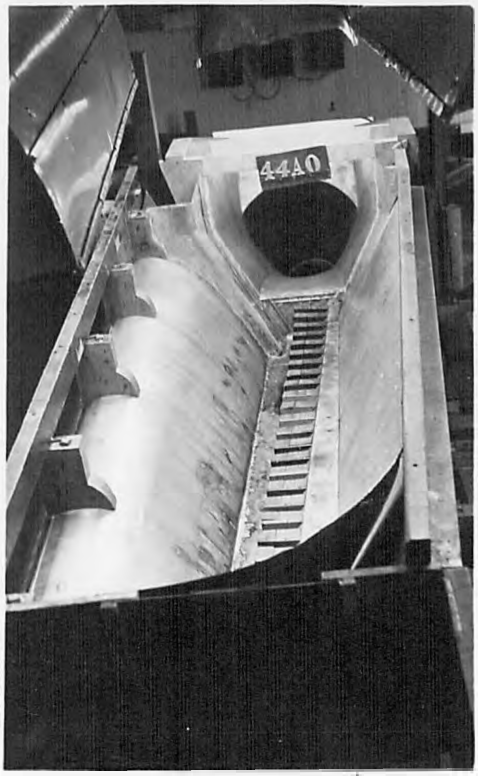
B-DISCHARGE 200,000 SEC. FT PLAIN OFFSET

C-MODEL WITH TROUGH IN FRONT HALF OF CHANNEL AND DENTATED SILL

D-DISCHARGE 200,000 SEC. FT. OFFSET WITH DENTATED SILL

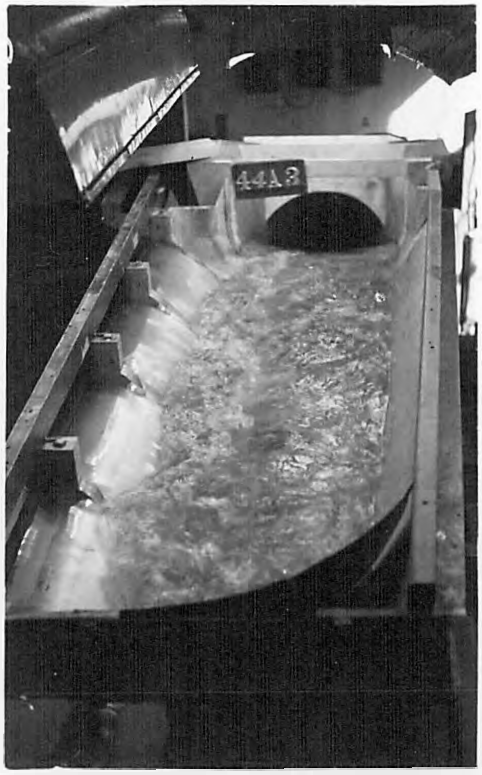
DRUM GATE SPILLWAY MODEL C-4 TRANSITION NO. I

EFFECT OF TROUGH IN FRONT HALF OF CHANNEL

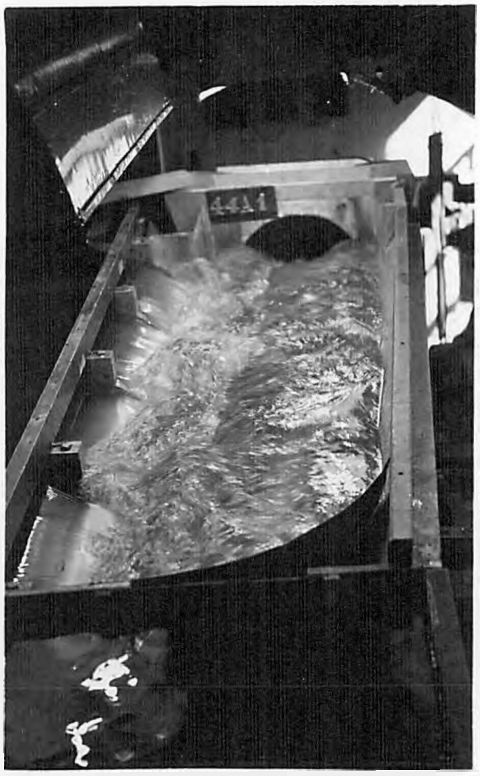


A-MODEL WITH DENTATED BAFFLE

B-DISCHARGE 80,000 SEC. FT.



C-DISCHARGE 120,000 SEC. FT.



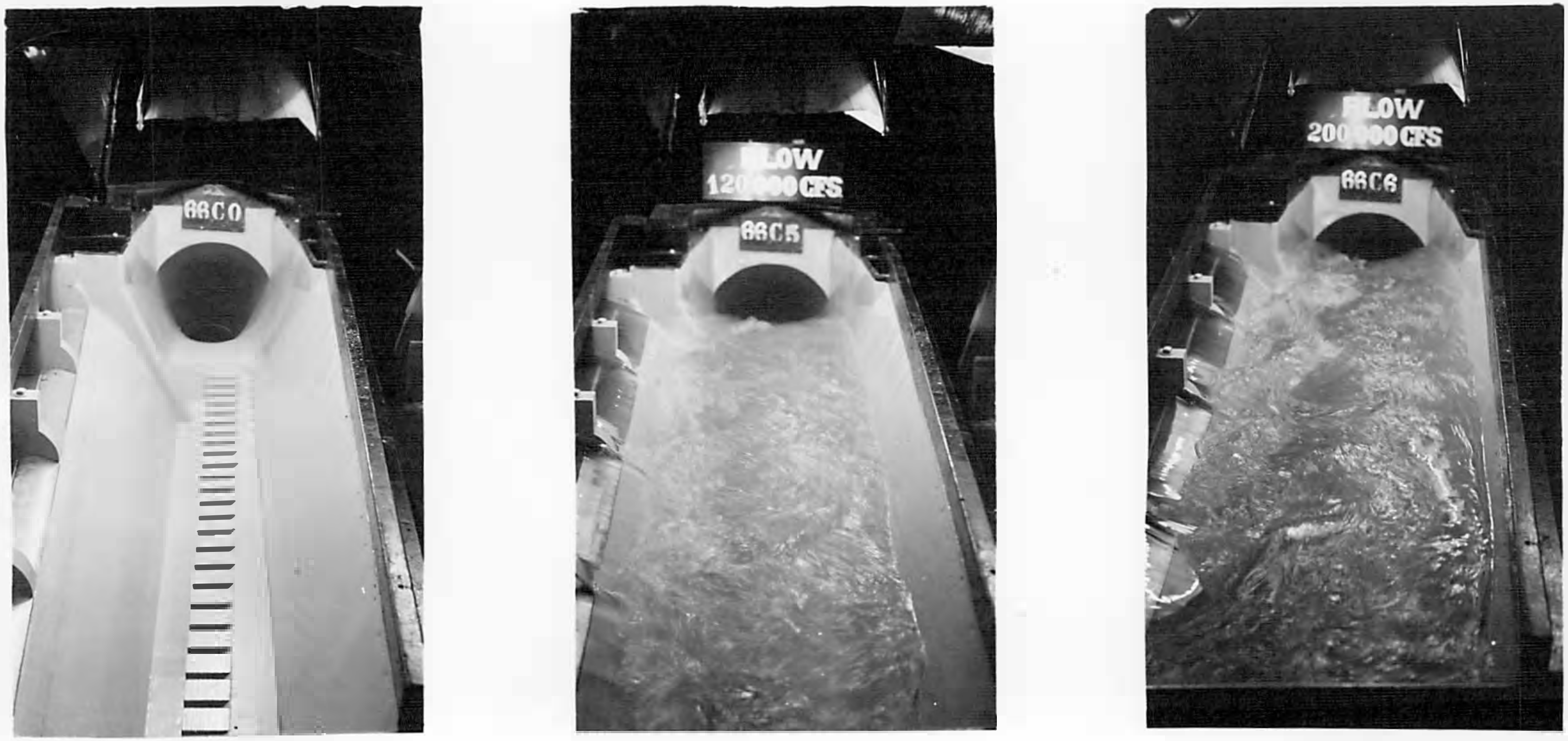
D-DISCHARGE 200,000 SEC. FT.

DRUM GATE SPILLWAY MODEL C-4 TRANSITION NO. 3A
EFFECT OF DENTATED BAFFLES & OF CURVE IN UPPER END OF CHANNEL

at beginning of transition. The dentates were made by cutting notches in the leading edge of the baffle, varying from 10 feet to 15 feet deep at an angle of 45° with the vertical, spaced from 8 feet to 10 feet apart. The overhanging blocks were about two-thirds the width of the dentates. This type of baffle was tested with all the different transitions and cross weirs.

On Plate 71 is shown this form of baffle with the 3-A transition, which was the best form developed using the baffles. The flow conditions for 120,000 second-feet and 200,000 second-feet are given on views B and C. The improvement due to the baffle may be observed by comparing these views with those given on Plates 60-D and 61-B. As will be seen, the baffles caused a material smoothing out of the flow.

By the action of this baffle, part of the water falling over the crest was deflected back toward the crest side and thus tended to make the water level more nearly equal on the two sides of the channel. The baffle face was set somewhat at an angle with the direction of the center line of the channel since with the face set on the center line there was a tendency of the water in the channel to pulsate back and forth across the channel in a sort of tidal motion, and this did not occur with the baffle set at an angle. At 200,000 second-feet discharge the weir at the upper end was submerged so deeply that the overflowing stream did not dive down to the bottom of the channel but rather it passed over the top and



A-MODEL WITH BAFFLES

B-DISCHARGE 120,000 SEC FT

C-DISCHARGE 200,000 SEC FT

DRUM GATE SPILLWAY MODEL C-4 TRANSITION NO. 3A
BEST FORM OF CHANNEL AND BAFFLE DEVELOPED

PLATE [illegible]

did not come into contact with the baffles. Their effect was, therefore, not as great at the maximum discharge as at somewhat lower flows.

Deflectors Attached to Crest Side of Channel

Plates 72 and 73 show several other forms of baffles and deflectors which were experimented upon. The details of these setups are given on Figure 24. The first of these (Plate 72-A) was a straight deflector with curved upper surface attached to the ogee 20 feet below the crest elevation. The deflecting action at low flow is shown on Plate 72-B.

The form shown on Plates 72-C and D gave better results. This form caused two opposing currents which impinged on each other. The portion of the overfalling nappe which passed between the teeth followed around the channel perimeter and that meeting the top of the teeth was deflected more or less horizontally across the channel. These two streams tend to meet in the channel and much of the energy was dissipated by impact. The blocks had to be set high enough to allow the under roll to take place beneath them. This is somewhat objectionable at low flows, particularly at the upper end of the channel as there is no pool there to receive the impact of the jet.

On Plates 73-A and B is shown a combination of these curved deflectors with a coping baffle somewhat similar to that tested on the M-1 model. This combination gave a very satisfactory dissipation

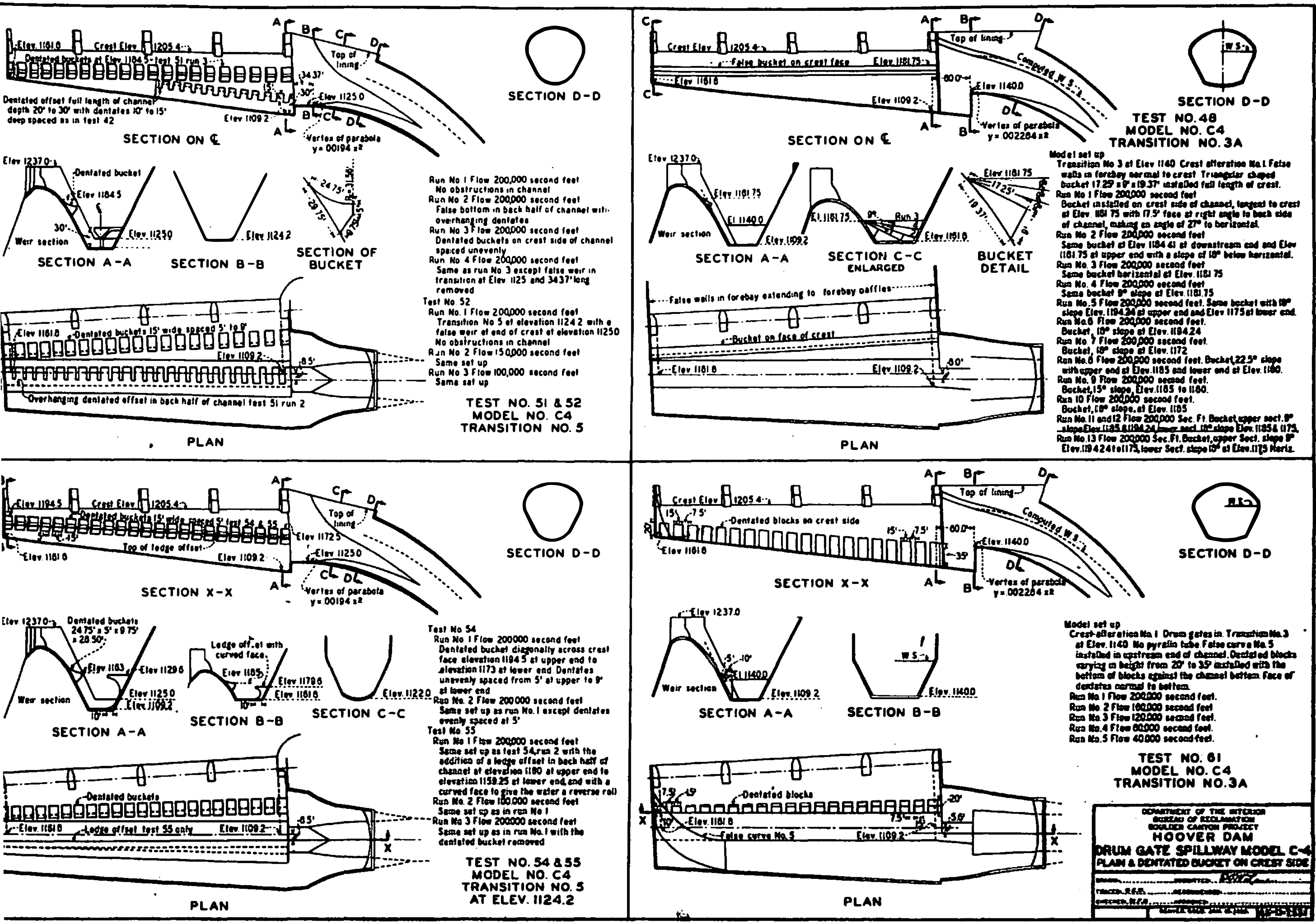
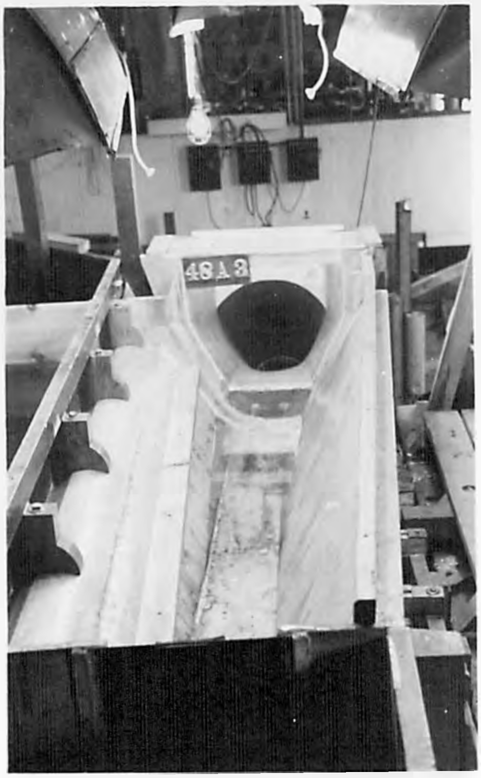

SECTION ON ℄
SECTION D-D
SECTION A-A
SECTION B-B
SECTION OF BUCKET
PLAN
Dentated offset full length of channel depth 20' to 30' with dentates 10' to 15' deep spaced as in test 42
Overhanging dentated offset in back half of channel test 51 run 2
Run No 1 Flow 200,000 second feet
No obstructions in channel
Run No 2 Flow 200,000 second feet
False bottom in back half of channel with overhanging dentates
Run No 3 Flow 200,000 second feet
Dentated buckets on crest side of channel spaced unevenly
Run No 4 Flow 200,000 second feet
Same as run No 3 except false weir in transition at Elev. 1125 and 34.37' long removed
Test No 52
Run No 1 Flow 200,000 second feet
Transition No 5 at elevation 1124.2 with a false weir at end of crest at elevation 1125.0
No obstructions in channel
Run No 2 Flow 150,000 second feet
Same set up
Run No 3 Flow 100,000 second feet
Same set up
TEST NO. 51 & 52
MODEL NO. C4
TRANSITION NO. 5
TEST NO. 48
MODEL NO. C4
TRANSITION NO. 3A
SECTION C-C ENLARGED
BUCKET DETAIL
False walls in forebay extending to forebay baffles
Bucket on face of crest
Model set up
Transition No 3 at Elev 1140 Crest alteration No. 1 False walls in forebay normal to crest. Triangular shaped bucket 17.25' x 9' x 19.37' installed full length of crest.
Run No 1 Flow 200,000 second feet
Bucket installed on crest side of channel, tangent to crest at Elev. 1181.75 with 17.5' face at right angle to back side of channel, making an angle of 27° to horizontal.
Run No 2 Flow 200,000 second feet
Same bucket at Elev 1184.41 at downstream end and Elev 1181.75 at upper end with a slope of 10° below horizontal.
Run No. 3 Flow 200,000 second feet
Same bucket horizontal at Elev. 1181.75
Run No. 4 Flow 200,000 second feet
Same bucket 9° slope at Elev. 1181.75
Run No. 5 Flow 200,000 second feet. Same bucket with 18° slope Elev. 1194.24 at upper end and Elev 1175 at lower end.
Run No. 6 Flow 200,000 second feet.
Bucket, 10° slope at Elev. 1194.24
Run No. 7 Flow 200,000 second feet.
Bucket, 18° slope at Elev. 1172
Run No. 8 Flow 200,000 second feet. Bucket 22.5° slope with upper end at Elev. 1185 and lower end at Elev. 1160.
Run No. 9 Flow 200,000 second feet.
Bucket, 15° slope, Elev. 1185 to 1160.
Run 10 Flow 200,000 second feet.
Bucket, 18° slope, at Elev. 1185
Run No. 11 and 12 Flow 200,000 Sec. Ft. Bucket upper sect. 9° slope Elev. 1185 & 1194.24 lower sect. 10° slope Elev. 1185 & 1175.
Run No. 13 Flow 200,000 Sec. Ft. Bucket, upper Sect. slope 9° Elev. 1194.24 to 1175, lower Sect. slope 10° at Elev. 1175 Horiz.
SECTION X-X
SECTION C-C
Dentated buckets 24.75' x 5' x 9.75' x 28.50°
Ledge offset with curved face
Ledge offset test 55 only
Test No 54
Run No 1 Flow 200000 second feet
Dentated bucket diagonally across crest face elevation 1194.5 at upper end to elevation 1173 at lower end. Dentates unevenly spaced from 5' at upper to 9' at lower end
Run No. 2 Flow 200000 second feet
Same set up as run No. 1 except dentates evenly spaced at 5'
Test No. 55
Run No 1 Flow 200000 second feet
Same set up as test 54, run 2 with the addition of a ledge offset in back half of channel at elevation 1180 at upper end to elevation 1159.25 at lower end and with a curved face to give the water a reverse roll
Run No. 2 Flow 100,000 second feet
Same set up as in run No 1
Run No 3 Flow 200000 second feet
Same set up as in run No. 1 with the dentated bucket removed
TEST NO. 54 & 55
MODEL NO. C4
TRANSITION NO. 5
AT ELEV. 1124.2
Dentated blocks on crest side
Dentated blocks
False curve No. 5
Model set up
Crest alteration No. 1 Drum gates in. Transition No. 3 at Elev. 1140 No pyralin tube False curve No. 5 installed in upstream end of channel. Dentated blocks varying in height from 20' to 35' installed with the bottom of blocks against the channel bottom. Face of dentates normal to bottom.
Run No. 1 Flow 200,000 second feet.
Run No. 2 Flow 160,000 second feet
Run No. 3 Flow 120,000 second feet.
Run No. 4 Flow 80,000 second feet.
Run No. 5 Flow 40,000 second feet.
TEST NO. 61
MODEL NO. C4
TRANSITION NO. 3A
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM
DRUM GATE SPILLWAY MODEL C-4
PLAN & DENTATED BUCKET ON CREST SIDE

FIG. 24



A-MODEL WITH DEFLECTOR

B-DISCHARGE 100,000 SEC FT.

PLAIN DEFLECTOR ON CREST FACE-TRANSITION NO 3

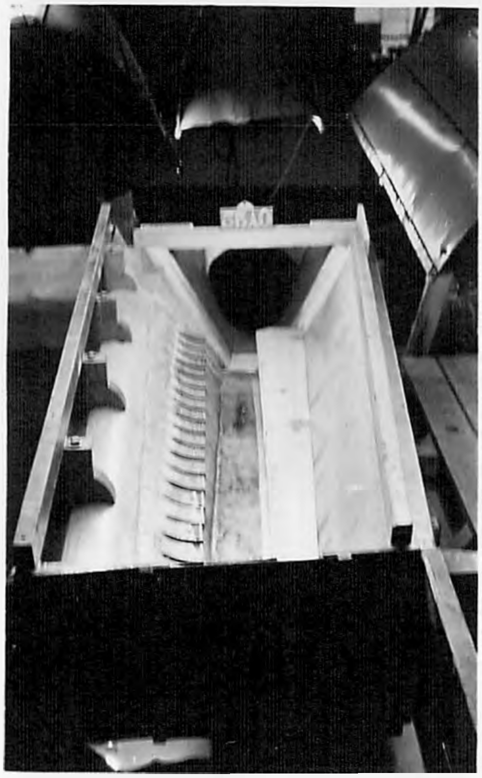
C-MODEL WITH DENTATED DEFLECTORS

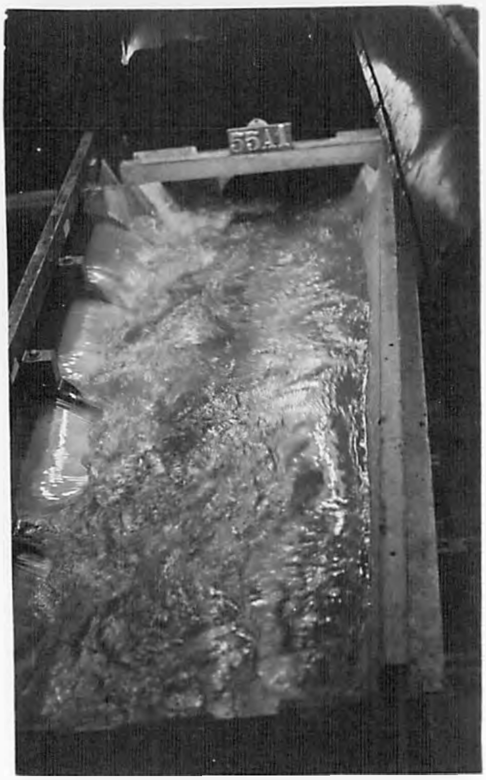
D-DISCHARGE 200,000 SEC FT

CURVED FACE DENTATED DEFLECTORS ON CREST-TRANSITION NO. 5

DRUM GATE SPILLWAY MODEL C-4

DEFLECTORS ON CREST SIDE OF CHANNEL

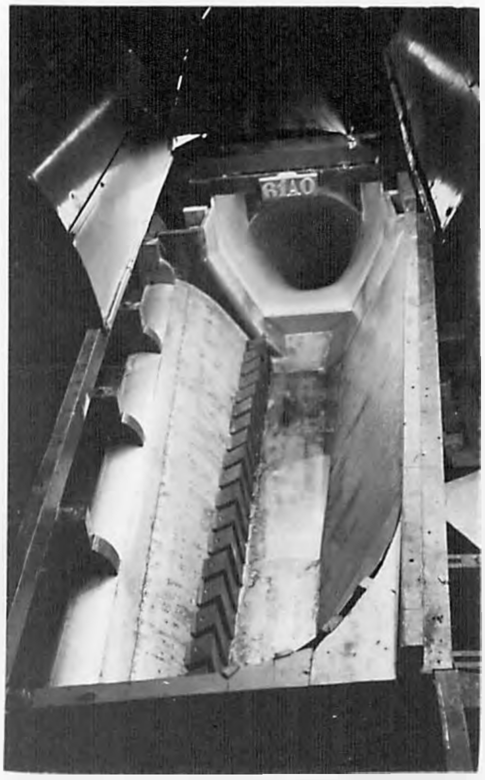




A-MODEL WITH DEFLECTOR

B-DISCHARGE 200,000 SEC. FT.

CURVED FACE DENTATED DEFLECTOR ON CREST AND COPING BAFFLE ON REAR WALL



C-MODEL WITH DENTATED BLOCKS

D-DISCHARGE 40,000 SEC. FT.

DENTATED BLOCKS ON CREST FACE AND CURVED WALL IN UPPER CHANNEL

DRUM GATE SPILLWAY MODEL C-4
DEFLECTORS ON CREST SIDE OF CHANNEL

of the energy of flow but introduced so much obstruction to the longitudinal flow of the water in the channel that the flow over the upstream end of the crest was badly obstructed. The form shown on Plates 73-C and D seemed fairly satisfactory for high flows but gave undesirable results for low flows.

A trough on the rear side of the channel as shown in Plate 74 was also tried. This was similar to one tested on the M-2 model and like it did not give very satisfactory results.

False Rear Wall in the Channel

In addition to the baffle studies a few tests were made to investigate the possibilities of changing the channel cross section. This was done by inserting a false rear wall in the channel, making an angle of 60° with the horizontal as shown on Plate 75. This narrowed the channel bottom to half the original width at the upstream end and full width at the lower end. This contraction improved the flow conditions for a given height of cross weir. Higher cross weirs were also tried, as shown on Plate 75, and the flow improved as the height of the cross weir increased. The result was not as good as that with the larger channel with weirs producing the same degree of submergence.

A-MODEL WITH TROUGH NEAR REAR WALL

[illegible]HARGE 75,000 SEC [illegible]

[illegible]O SEC [illegible]

D-DISCHARGE 20000 [illegible]

DRUM GATE SPILLWAY MODEL C-4 TRANSITION NO 5
TROUGH ON REAR SIDE OF CHANNEL

A-MODEL WITH FALSE BACK IN CHANNEL

B-DISCHARGE 200,000 SEC. FT
15 FT CROSS WEIR AT STA 5+17

C-DISCHARGE 200,000 SEC FT
20 FT. CROSS WEIR AT STA 4+57

D-DISCHARGE 200,000 SEC. FT
35 FT. CROSS WEIR AT STA. 4+57

DRUM GATE SPILLWAY MODEL C-4
FALSE BACK IN CHANNEL AND VARIOUS CROSS WEIR HEIGHTS

Drum Gate Side Channel Spillway, Model M-3, Experiments at Montrose Laboratory

In order to test out on a larger scale the results obtained on the 1:60 scale drum gate model at the Colorado Agricultural College laboratory, a similar model was constructed on a 1:20 scale at the laboratory at Montrose. This model, except for scale, was the same as that tested at Fort Collins, using the 3-A transition as shown by the prototype drawing, Figure 17. The construction was similar to that of the M-1 model previously described. In the rear wall of this model were placed three windows in order that the action of the water inside the spillway channel might be observed.

Flow in Original Design of M-3 Model

A number of experiments were carried out on the M-3 model to improve the conditions of flow in the spillway channel and through the tunnel. These will be discussed in the following paragraphs. The details of each setup are not given in this report but copies of sketches of all of them are filed with the office file copy of this report.

Extensive quantitative observations were made on this model. The cross sections of the channel flow for various conditions were determined and the pressures on the bottom and side walls of the channel and on the bottom of the transition were observed. The coefficients of discharge for the various forms of crest for a wide range of flows were observed and also for the drum gates in the various positions. Observations were also made of the air content in the spillway channel and of the velocity of flow in the spillway tunnel. These quantitative results are discussed in the later sections of this report dealing with the particular features.

The appearance of this model is shown on the three views of Plate 76. The action of this model for flows of 40,000, 80,000 and 120,000 second-feet are shown on Plate 77, and for 160,000 and 200,000 second-feet on Plate 78. The similarity of the action of the large scale model to that of the small scale may be seen by comparing these plates to the views shown on Plates 60 and 61. At the lower discharges the action of these spillways was very similar. The appearance for the 200,000 second-foot discharge does not show such exact similitude but this is because at this discharge there was a tendency for surging and the still pictures being taken at different points in the surge do not show the action under exactly the same conditions. Also, in a later part of this report the comparisons of the action for the two model scales will be made on a quantitative basis.

C-SIDE CHANNEL MODEL
LOOKING UPSTREAM

B-SIDE CHANNEL MODEL
LOOKING DOWNSTREAM

A-VIEW OF MODEL SETUP

DRUM GATE SIDE CHANNEL SPILLWAY MODEL M-3

PLATE 78

A-DISCHARGE 40,000 SEC. FT.

B-DISCHARGE 80,000 SEC. FT.

C-DISCHARGE 120,000 SEC. FT.

FLOW IN DRUM GATE SIDE CHANNEL SPILLWAY
MODEL M-3

A-DISCHARGE 160.000 SEC. FT.

B-DISCHARGE 200,000 SEC. FT.

C-DISCHARGE 200,000 SEC. FT.

FLOW IN DRUM GATE SIDE CHANNEL SPILLWAY
MODEL M-3

Curved Wall at Upstream End of the Channel

Experiments were made on this model with curved wall at the upper end of the channel similar to those investigated in the 1:60 model. Plate 79 shows one of these walls in place and the action of the spillway with a 200,000 second-foot discharge.

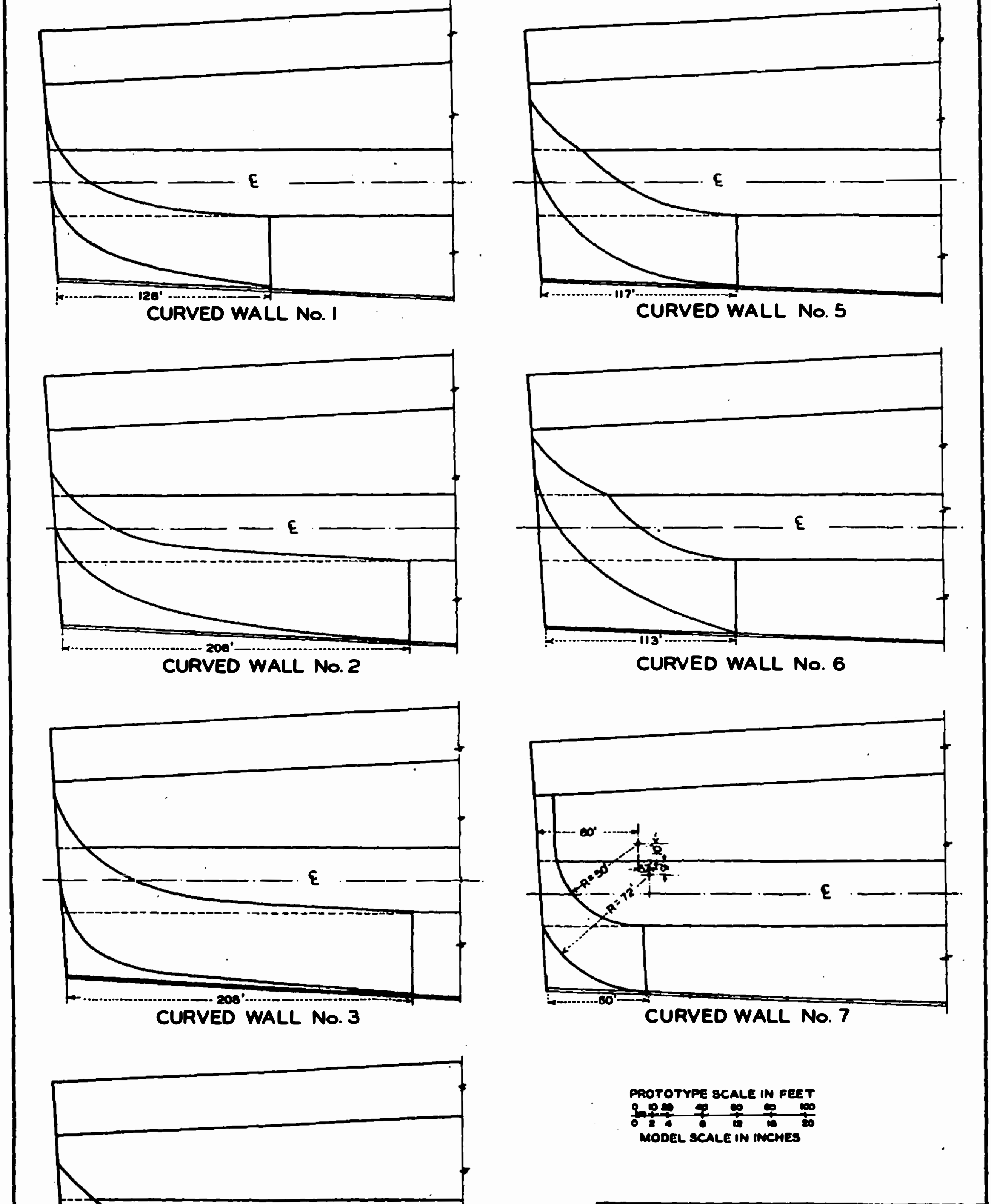
Experiment with Dentated Baffle

Two forms of dentated baffle were experimented upon in the M-3 model. These were similar to the overhanging dentated form experimented on in the 1:60 model, as described on page 13 and shown on Plates 70 and 71. The two forms tested on the M-3 model were similar except that in the second form the alternate teeth of the first form were removed. Experiments were also made with the closely-spaced teeth and the curved wall at the upper end of the channel.

Plate 80, view A, shows the first form of dentated baffle experimented upon. It is an exact duplicate of that shown on Plate 70 in the 1:60 model. The results of this model are shown on Plates 80 and 81 for discharges of 40,000 to 200,000 second-feet. The similarity of the action of this model with that of the 1:60 model may be seen by comparing these views with those shown on Plates 61 and 70.

The runs on Plates 80 and 81 were made with a square end on the channel, as shown on Plate 76. Those on Plates 82 and 83 were made with a curved wall at the upstream end of the channel. The second form of dentated baffle was made from the first by removing the

FIG. NO. 25.



BOULDER CANYON PROJECT

HOOVER DAM-HYDRAULIC EXPERIMENTS
CURVED WALL AT UPPER END OF
SPILLWAY CHANNEL MODEL C-4

SUBMITTED E. W. Lane

45-D-3129

A-NO FLOW

B-DISCHARGE 200,000 SEC. FT.
LOOKING DOWNSTREAM

C-DISCHARGE 200,000 SEC. FT.
LOOKING UPSTREAM

CURVED WALL AT UPPER END OF CHANNEL
DRUM GATE SPILLWAY MODEL M-3

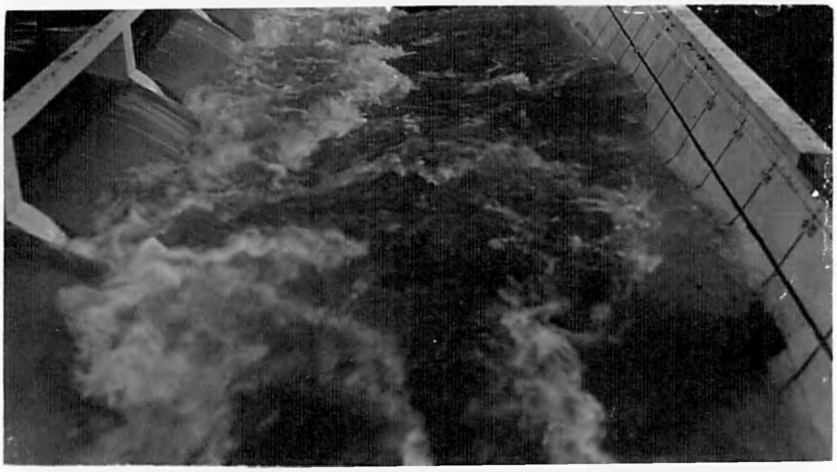
A-NO DISCHARGE

B-DISCHARGE 40,000 SEC. FT.

C-DISCHARGE 80,000 SEC. FT.

FLOW WITH FORM 3 OF DENTATED BAFFLE
IN DRUM GATE SPILLWAY MODEL M-3

A-DISCHARGE 120,000 SEC. FT.



B-DISCHARGE 160,000 SEC. FT.

C-DISCHARGE 200,000 SEC. FT.

FLOW WITH FORM 3 OF DENTATED BAFFLE
IN DRUM GATE SPILLWAY MODEL M-3

A-LOOKING DOWNSTREAM

B-LOOKING UPSTREAM

C-DISCHARGE 31,500 SEC FT

FORM 3 OF DENTATED BAFFLE WITH CURVED WALL AT
CHANNEL END. DRUM GATE SPILLWAY MODEL M-3

PLATE 82

A-DISCHARGE 120,000 SEC. FT.

B-DISCHARGE 160,000 SEC. FT.
MODEL M-3

C-DISCHARGE 200,000 SEC. FT

D-DISCHARGE 200,000 SEC. FT.

FORM 3 OF DENTATED BAFFLE WITH CURVED WALL AT
CHANNEL END DRUM GATE SPILLWAY MODEL M-3

A-NO DISCHARGE

B-DISCHARGE 40,000 SEC. FT.

FLOW WITH FORM 2 OF DENTATED BAFFLE
IN DRUM GATE SPILLWAY MODEL M-3

alternate teeth. This baffle is shown on Plate 84, view A, and with a discharge of 40,000 second-feet on view B. The action of this baffle is quite similar to that having closer-spaced teeth. Both of these baffles resulted in the smoothing out of the water surface in the channel, but offered some obstruction to the flow. The improvement was not believed to be sufficient to justify the expensive construction necessitated by the baffle, and therefore none was used in the final design.

Flow with Drum Gates Raised

A series of experiments was made with the drum gates raised in order to determine the action of the spillway under these conditions and to see if it were possible to obtain better conditions of flow at low discharges by means of adjusting the various gates. Plate 85, view A, shows the conditions in the spillway when discharging 31,500 second-feet with all the gates at their maximum elevation (1221.7). This is the condition which it was estimated would be reached by the peak of a flood equal to the 1884 flood if the flow was distributed equally between the two spillways. This is the largest flood of which there is a usable record. Views B anc C of Plate 85 show the effect of different gate levels at the different ends of the spillway. In view B the greatest part of the discharge came from the upstream gates. The upstream gate (No. 1) was entirely down.

A-DISCHARGE 31,500 SEC. FT.
ALL GATE CRESTS AT EL. 1221.7

B-DISCHARGE 144,000 SEC. FT.
LARGEST FLOW FROM UPSTREAM GATES

C-DISCHARGE 144,000 SEC. FT.
LARGEST FLOW FROM DOWNSTREAM GATES

FLOW WITH DRUM GATES UP. SPILLWAY MODEL M-3

Gate 2 was one-fourth up, gate 3 one-half up, and gate 4 three-fourths of its full height up. The discharge was 144,000 second-feet, which was the greatest that would flow over the spillway crest under these conditions with a water level at the maximum flood line, elevation 1232. In view C the discharge was largest over the downstream gates. Gate 4, the downstream gate, was entirely down, gate 3 one-fourth up, gate 2 one-half up, and gate 1 three-fourths up. These experiments showed that at low discharges improvement in the flow conditions could be secured by having the greatest flow over the downstream end of the spillway but at larger flows the best results were obtained with greater flows over the upstream end of the crest. This is because for small discharges the depth of water at the lower end of the channel is relatively much greater, with respect to that at the upper end, than at large flows on account of the pool formed just upstream from the cross weir of the channel. This greater depth can dissipate the energy of the small flows with relatively small disturbance, while the water passing over the upper end of the weir does not fall into this pool. At larger discharges the depths at the two ends of the channel become more nearly equal, but the drop from reservoir level to channel level is less at the upper end and the disturbance there is therefore less.

The flow conditions for gates uniformly raised one-fourth of the way up are shown on Plates 86 and 87. In this case, the tur-

A-DISCHARGE 31,500 SEC. FT.

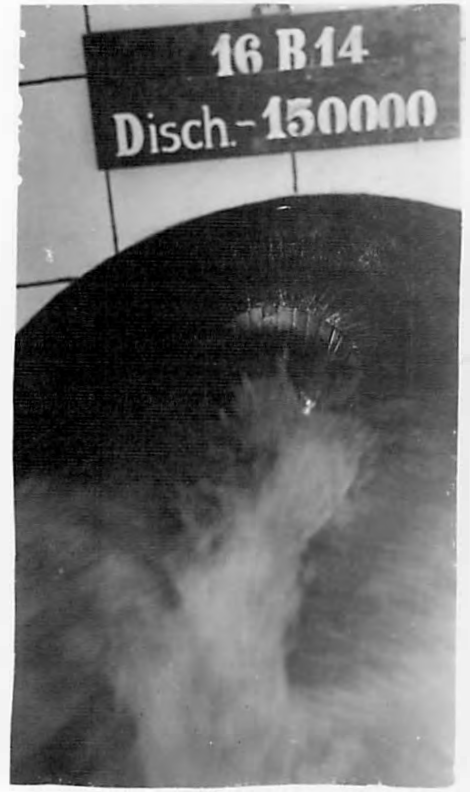
B-DISCHARGE 50,000 SEC. FT.

C-DISCHARGE 80,000 SEC. FT.

FLOW WITH DRUM GATES ONE-QUARTER UP
SPILLWAY MODEL M-3

A-DISCHARGE 120,000 SEC. FT.

B-DISCHARGE 150,000 SEC. FT.



C-DISCHARGE 150,000 SEC. FT.
LOOKING DOWN TUNNEL TRANSITION

FLOW WITH DRUM GATES ONE-QUARTER UP
SPILLWAY MODEL M-3

bulence in the channel is slightly greater than for the gates down, since the water level in the reservoir is higher with the gates up and therefore the drop between the reservoir surface and the water level in the channel is greater, causing more energy to be dissipated in the side channel and therefore more turbulence to be produced.

Direction of Currents in Side Channel Spillway

Observations were made on the direction of the current in the side channel by observing the path taken by a stream of colored water introduced into the flow in front of the windows which were in the rear side of the channel. Plate 88 shows the path for a 200,000 second-foot discharge at these three windows. It will be noted that in all cases the flow is diagonally upward in the direction of the flow down the channel. This confirms the results obtained on the C-2 model. The upward direction of flow at the downstream window is due to the water rising to pass over the weir at the entrance to the transition. The rising path at the other two windows is due to a combination of the rising stream on the back side of the channel, together with the longitudinal flow in the channel itself.

Reference to Air Content in the Channel

Extensive experiments were made on the M-3 model to determine the air content in the water passing down the side channel and

A-UPSTREAM WINDOW

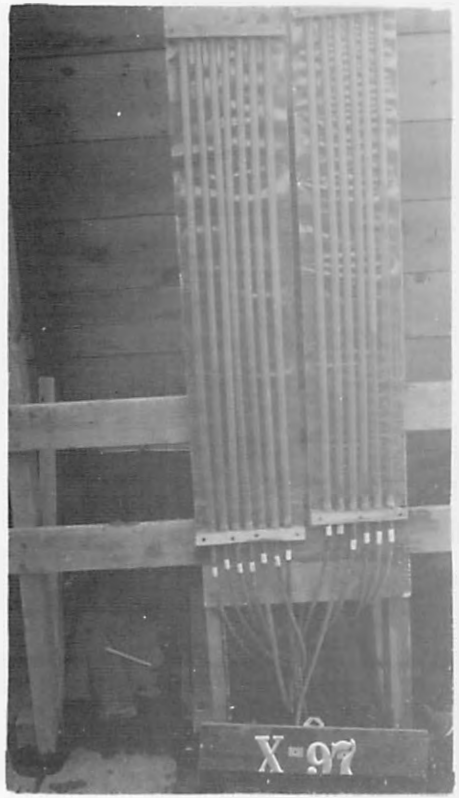
B-MIDDLE WINDOW

C-DOWNSTREAM WINDOW

DIRECTION OF CURRENTS IN SIDE CHANNEL SPILLWAY FOR 200,000 SEC. FT. DISCHARGE OBSERVED THROUGH WINDOWS IN REAR WALL OF MODEL M-3

A-METHOD OF OBSERVING CREST ELEVATIONS

B-APPARATUS FOR MEASURING AIR CONTENT



C-PIEZOMETERS FOR OBSERVING PRESSURE ON WALLS AND BOTTOM

INSTRUMENTS AND METHODS USED IN MAKING MEASUREMENTS
DRUM GATE SPILLWAY MODEL M-3

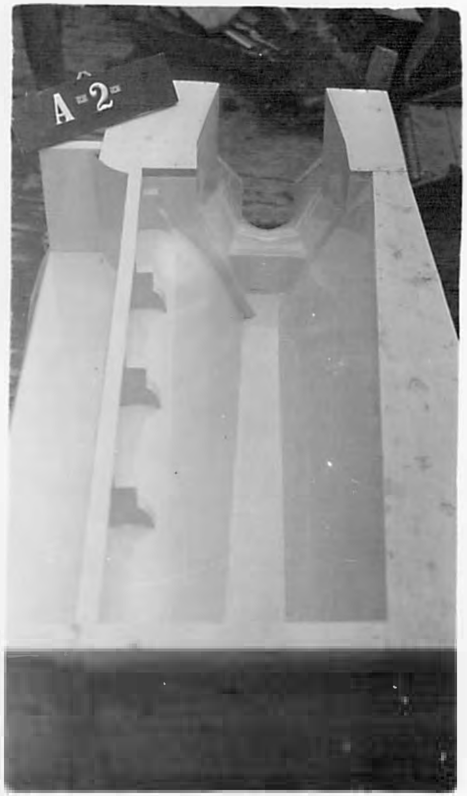
the pressure at numerous points on the side walls and in the transition section. Plate 89, view B, shows the apparatus used to determine the air content. View C shows a set of monometer tubes used to observe the pressure of the water on the bottom of the transition. Detailed results of these experiments are given in a later part of this report.

Experiments on 1:100 Scale Model, M-4

A model on 1:100 scale was constructed of the same shape as that on the 1:20 scale previously described, and the 1:60 scale at Fort Collins laboratory with the 3-A transition. The prototype dimensions are given on Figure 17. In this model the transition was constructed with an open top so that the flow could be readily observed. The condition for various discharges are shown on Plates 90 and 91. The results were very similar to those on the 1:20 and 1:60 models. The quantitative comparison of these results is given in a later part of this report.

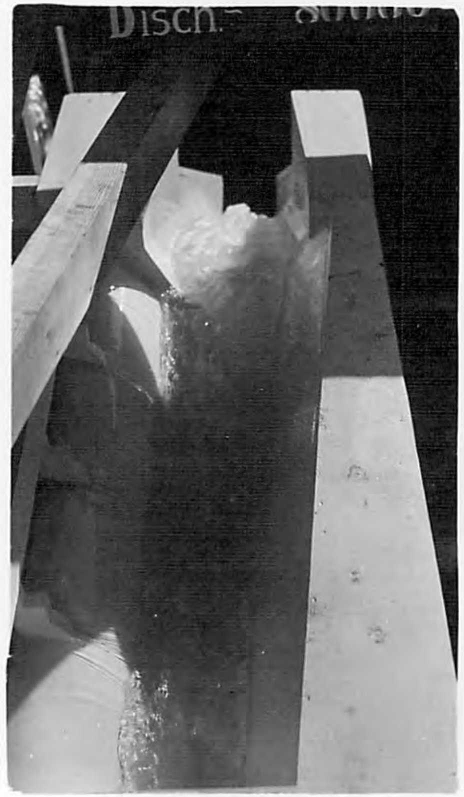
Similitude of Results on C-4 and M-3 Models

The similarity of the results obtained on the models M-4, C-4 and M-3 was so close that great confidence was felt in the principles of model testing and that the results obtained on the models could be extended to the action of the prototype. A comparison of these results on a quantitative basis is given in Book 3. The ap-



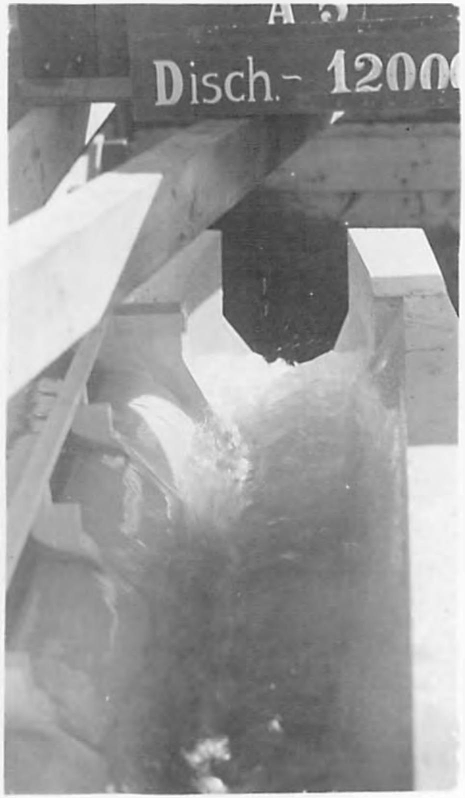
A-NO DISCHARGE

B-DISCHARGE 40,000 SEC. FT.

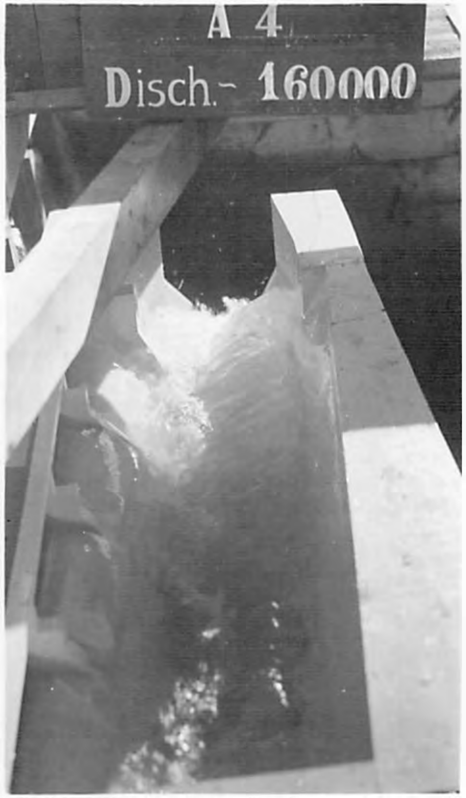


C-DISCHARGE 80,000 SEC. FT.

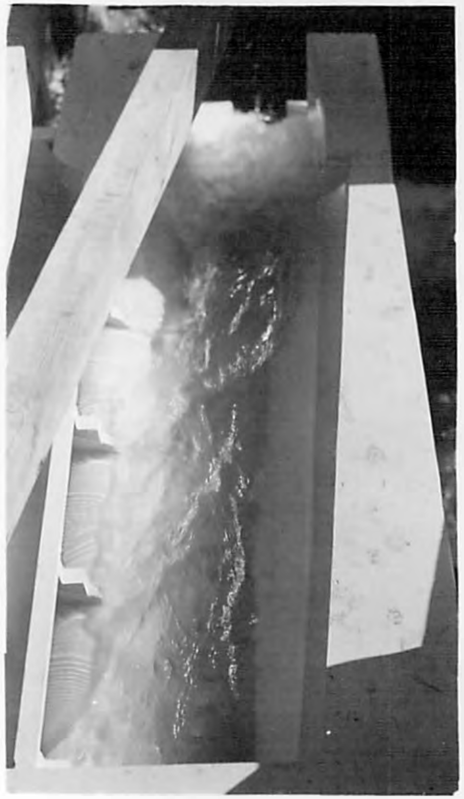
FLOW IN 1:100 SCALE SPILLWAY MODEL M-4



A-DISCHARGE 120,000 SEC. FT



B-DISCHARGE 160,000 SEC. FT.

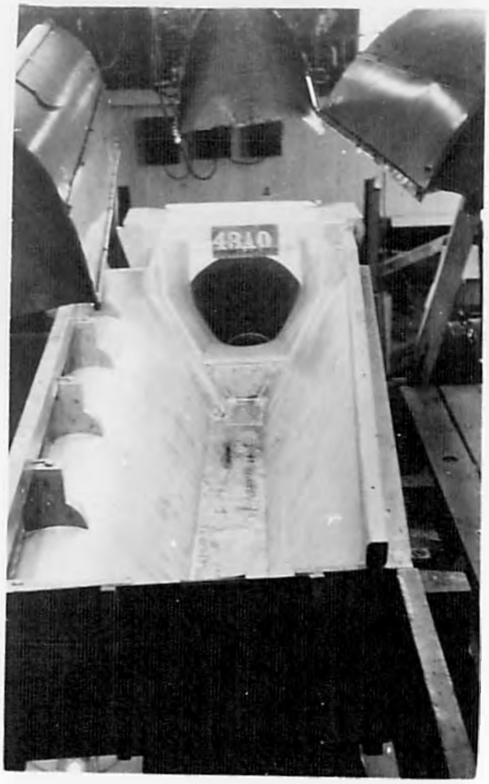


C-DISCHARGE 200,000 SEC. FT.

FLOW IN 1:100 SCALE SPILLWAY MODEL M-4

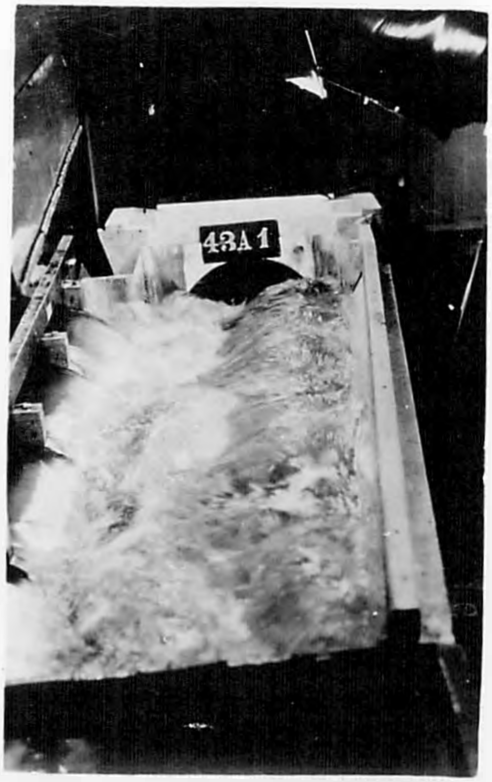
pearance of comparable tests for all cases where good photographs are available are shown on Plates 92 to 94 inclusive. Plate 92, views A and B, shows the C-4 and M-3 models without baffles and views C and D show the appearance with flows corresponding to 200,000 second-feet. The actions are seen to be very similar, there being a strong resemblance between the two even in the case of the minor wave formations. In the 1:20 model the water surface is more frothy, as a result of the fact that the surface tension, being of the same magnitude in both models, is relatively smaller in the case of the larger model. Comparison of model and prototype results on other structures where available also show a similar relation, as there was more spray and foam in the case of the prototype.

The same models with curved upstream ends and dentated baffles are shown on Plates 93-A and B. Comparable views for flows of 200,000 second-feet are shown on views C and D. The general agreement in appearance is close but there is some difference in detail. The flow conditions from the standpoint of these minor differences go through a certain rough cycle and unless the two photographs were taken at the same position in the cycle, they would differ somewhat in appearance, although the action in the two spillways might be exactly similar. For this reason the comparison on Plate 93 gives an impression of less exact agreement than really existed. Comparisons of the conditions for flows of 160,000 and 120,000 second-feet are shown on Plate 94. The agreement



A-FORT COLLINS 1:60 MODEL
C-4

B-MONTROSE 1:20 MODEL
M-3



C-DISCHARGE 200,000 SEC. FT
MODEL C-4

D-DISCHARGE 200,000 SEC FT
MODEL M-3

COMPARISON OF FLOW CONDITIONS IN C-4 AND M-3 MODELS
NO BAFFLE IN CHANNEL

A-FORT COLLINS' 1:60 MODEL
C-4

B-MONTROSE 1:20 MODEL
M-3

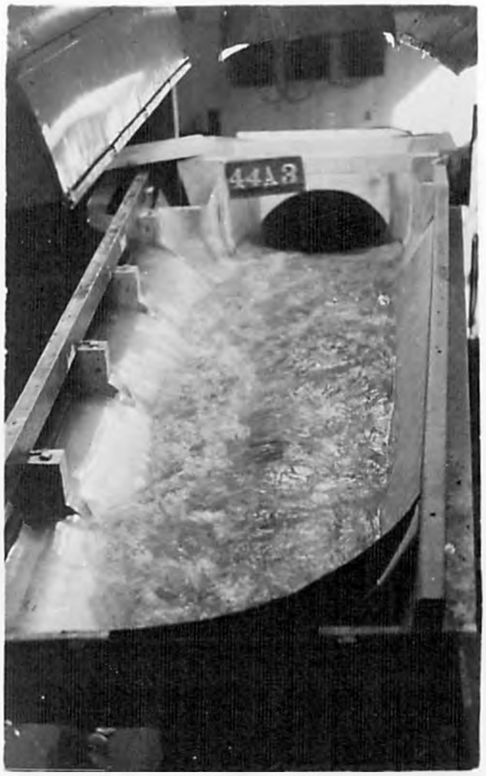
C-DISCHARGE 200,000 SEC FT
MODEL C-4

D-DISCHARGE 200,000 SEC FT
MODEL M-3

COMPARISON OF FLOW CONDITIONS IN C-4 AND

A-DISCHARGE 160,000 SEC. FT.
MODEL C-4

B-DISCHARGE 160,000 SEC. FT.
MODEL M-3



C-DISCHARGE 120,000 SEC. FT.
MODEL C-4

D-DISCHARGE 120,000 SEC. FT.
MODEL M-3

COMPARISON OF FLOW CONDITIONS IN C-4 AND
M-3 MODELS WITH DENTATED BAFFLE IN CHANNEL

here is also very good. It is believed that these three plates show that very satisfactory agreement was secured between the results of these two models. Very close similarity was also obtained with the quantitative comparisons of the 1:100, 1:60 and 1:20 scale models, as will be shown in Book 3. Visual comparison was not possible in the case of the 1:100 model on account of the lack of satisfactory photographs.

The Final Spillway Design

As a result of the tests of the weir nappe shapes, and the flow over various ogee shapes, described in Book 4 of this report, a form of ogee crest was developed which permitted a greater flow over it than the forms used on the C-4 and M-3 models. This improved form was incorporated in the final design. The other principal difference between the final design and the semifinal design, represented by the C-4, M-3 and M-4 models, was in the height of the cross weir in the spillway channel. In the semifinal designs the crest of this weir was at elevation 1140. To use a higher weir with these models backed the water up in the channel for discharges of 200,000 second-feet to such an extent that the flow over the upper end of the spillway weir was considerably reduced. The tests of the C-4 model, with the No. 3 transition, which had a cross weir at elevation 1145, showed however that better flow conditions were obtained in the spillway channel and the tunnel than with a weir at elevation 1140. This was a considerable advantage as it made the pulsating conditions which were experienced with the M-1 model still less likely to occur in the prototype. It was found that with the improved crest form the discharge would be practically the same with the higher cross weir as with the former crest form and lower weir. Slightly lower levels would be obtained in the reservoir by using both the improved crest and lower weir, but this difference was so small that the advantage of better flow conditions predominated and the cross weir at elevation 1145 was adopted. The effect of the changes incorporated in the final design was therefore an improved condition of flow rather than an increase in discharge capacity.

Tests on Models of the Final Design

Extensive tests were made on the models of the final design. These fall into two general classifications; visual tests and quantitative tests. The visual tests consisted of:

1. Observation of the flow conditions with all gates down and with gates partly and completely raised.

2. Tests to determine the best form of downstream end of the piers on the crest.

3. Test of a device for improving flow conditions at the upstream end of the channel.

4. Tests to determine the best operating program for the gates during a flood.

The quantitative tests consisted of:

1. Determination of crest discharge coefficients with gates closed, partly raised, and fully raised, and comparison of the results on the three models.

2. Observation on the depths of flow in the spillway channel and transition, and comparison of the results on the different models.

3. Determination of pressures on the bottom and sides at various points on the crest, channel and transition and comparison of the results on the three models.

4. Measurement of air content of the water flowing in the side channel.

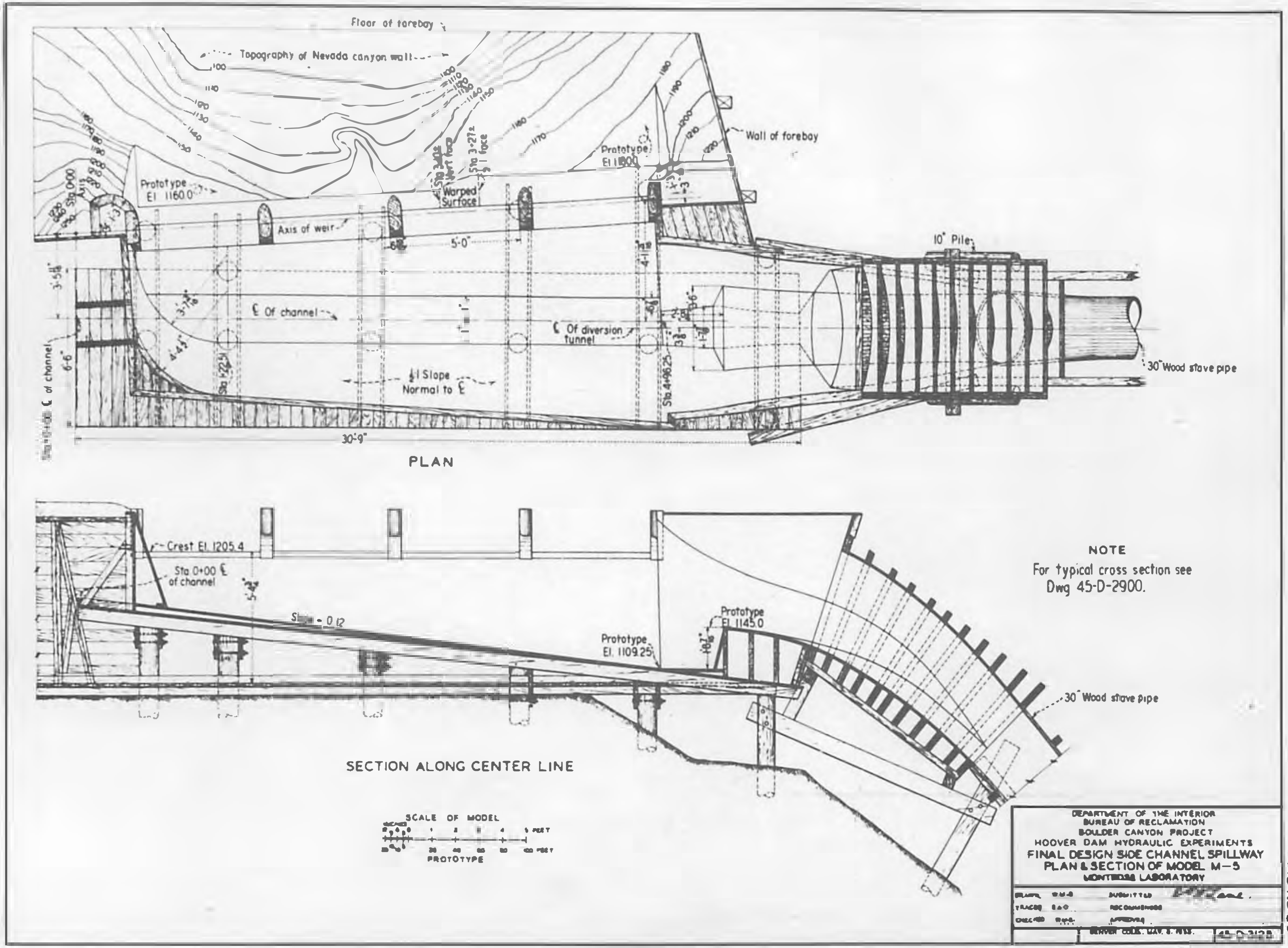
Visual determination of flow conditions were made on all three models and comparisons of the action of the various models was made by means of photographs to determine the reliability of the principles of similitude.

The operating program was worked out principally on the 1:60 model as it was easier to manipulate the gates on it. Some tests, however, were made on the 1:20 model. The tests of the gate piers were made on both 1:60 and 1:20 scales. The test for the device for improving the flow at the upper end of the channel was made only on the 1:20 model.

Of the quantitative tests, the crest coefficient determinations were made on all three models and the observations of pressures on the crest, channel and transition, were made on the 1:20 and 1:60 models. The observations on the depth of flow in the channel and transition were made on all models. The air content was determined only on the 1:20 model. The results of the quantitative tests and the comparison of them from the standpoint of similitude are given in Book 3 of this report.

Final Design Models M-5, C-5 and C-6

The final design 1:20 scale model M-5 at the Montrose laboratory was constructed of galvanized sheet iron over a wood frame in a manner somewhat similar to that of the M-1 and M-3 models previously described. Advantage was taken, however, of the experience gained on the early ones and the framing was designed somewhat differently. A plan and vertical section of this model is shown on Figure 26. A cross section of the model with the adjacent topography is shown on Figure 27. Two views showing different stages of the construction are shown on Plate 95. This plate also shows views of the completed model. Other views of the model are shown in connection with a comparison of the views of the three models on Plates 97 and 98. The gates of this model could be raised to any desired height by means of screws operated from the inside. The entire shape of the gates was not built, and a canvas diaphragm was used to prevent the water from passing through the space beneath



Floor of forebay
Topography of Nevada canyon wall
Wall of forebay
Prototype El 1160.0
Prototype El 1180.0
Axis of weir
Warped Surface
5'-0"
10" Pile
℄ Of channel
℄ Of diversion tunnel
½:1 Slope Normal to ℄
30" Wood stave pipe
30'-9"
PLAN
Crest El. 1205.4
Sta 0+00 ℄ of channel
Slope = 0.12
Prototype El. 1109.25
Prototype El. 1145.0
30" Wood stave pipe
SECTION ALONG CENTER LINE
NOTE
For typical cross section see Dwg 45-D-2900.
SCALE OF MODEL
PROTOTYPE
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM HYDRAULIC EXPERIMENTS
FINAL DESIGN SIDE CHANNEL SPILLWAY
PLAN & SECTION OF MODEL M-5
LABORATORY
SUBMITTED
RECOMMENDED
APPROVED

FIG No. 26

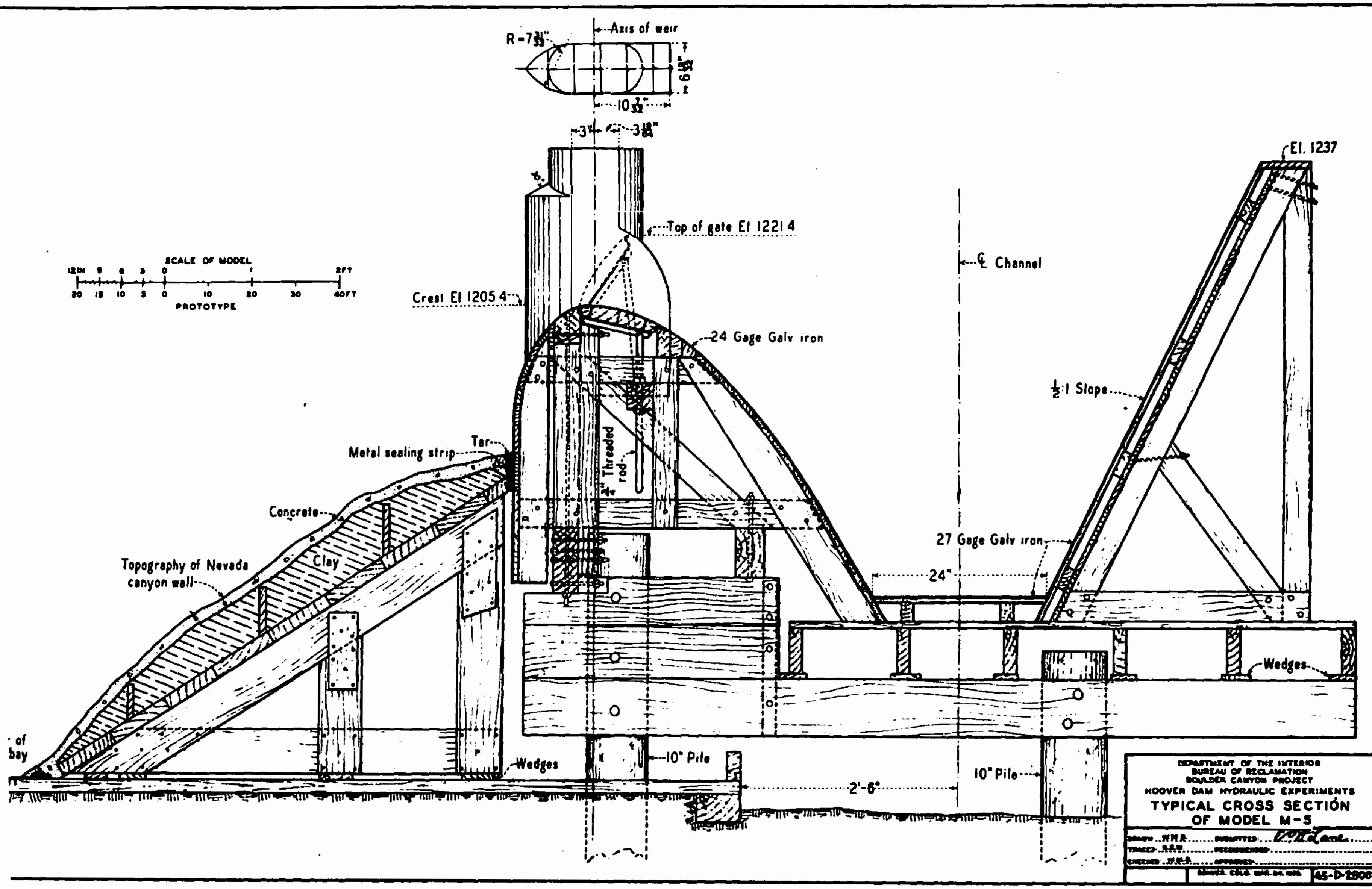
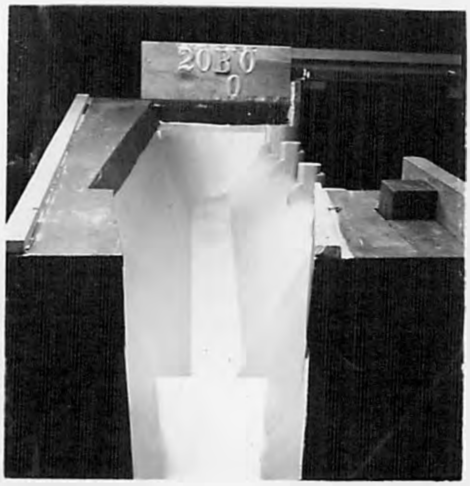

Axis of weir
Top of gate El 1221.4
℄ Channel
Crest El 1205.4
SCALE OF MODEL
PROTOTYPE
24 Gage Galv iron
El. 1237
½:1 Slope
Threaded rod
Tar
Metal sealing strip
Concrete
Clay
Topography of Nevada canyon wall
27 Gage Galv iron
24"
Wedges
10" Pile
2'-6"
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM HYDRAULIC EXPERIMENTS
TYPICAL CROSS SECTION
OF MODEL M-5
45-D-2900

FIG. 27

1: 20 MODEL RATIO

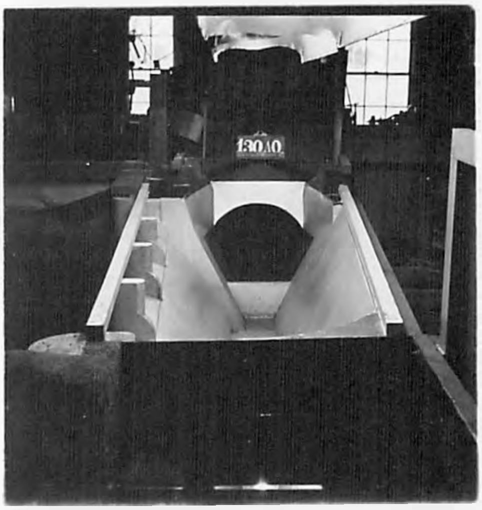
1:60 MODEL RATIO



1:100 MODEL RATIO

COMPARISON OF SPILLWAY MODELS, FINAL DESIGN
LOOKING UPSTREAM

1: 20 MODEL RATIO



1 60 MODEL RATIO

1·100 MODEL RATIO

COMPARISON OF SPILLWAY MODELS, FINAL DESIGN
LOOKING DOWNSTREAM

the top of the gate. This model was provided with windows in the side channel to observe the flow. It was painted with a very light gray paint and lines were painted on to show the stationing along the channel and the elevations. The same transition, slightly modified, was used for this as for the M-3 model and the model of the tunnel was the same as for the M-1 and M-3 models.

The 1:60 model (C-5) of the final design of the spillway was constructed in a very similar manner to that of the C-4 model. The design of this model is shown in detail on Figure 28. It differs from the other models in having gates which could be quickly raised or lowered by means of push-rods actuated through a rack and pinion from the outside of the model. This arrangement greatly facilitated the experiments to determine the effect of gates in various positions. The topography in front of the model was constructed of a lean cinder concrete. Views of this model from the upstream side showing the topography are given on Plate 96. An idea of the very large size of the prototype of this spillway may be gained by comparison of the size of the model of the spillway with the miniature automobile and truck in front of the left end of the crest in the upper view. Other views of this model are shown on Plates 97 and 98.

The 1:100 model was also constructed of galvanized iron over a wooden frame. Great care was taken to secure an accurate

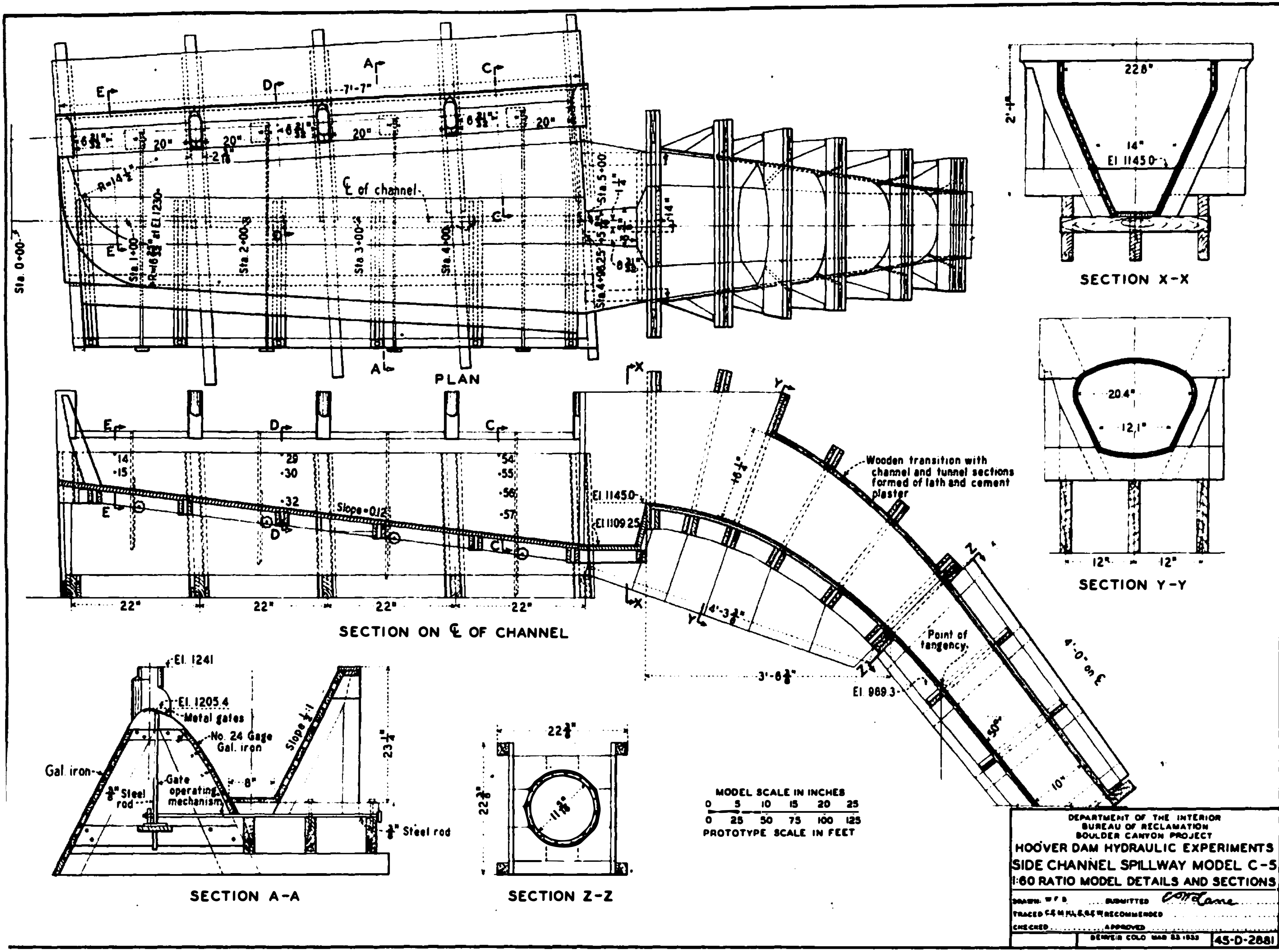
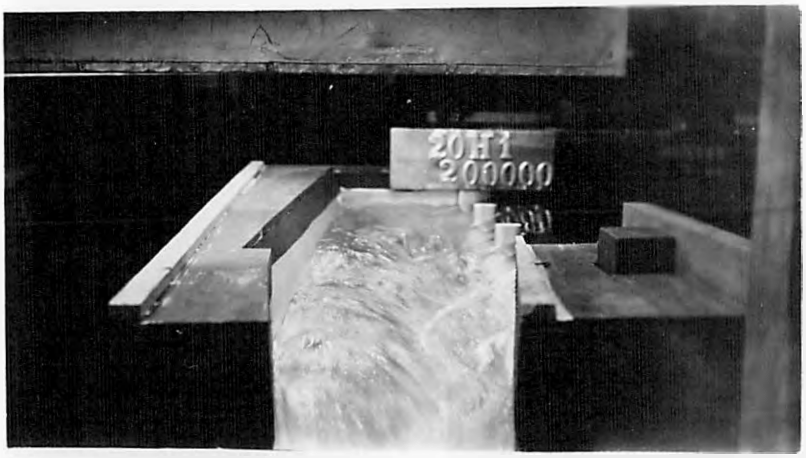

PLAN
SECTION X-X
SECTION Y-Y
SECTION ON ℄ OF CHANNEL
SECTION A-A
SECTION Z-Z
℄ of channel
Wooden transition with channel and tunnel sections formed of lath and cement plaster
Point of tangency
4'-0" on ℄
El. 1241
El. 1205.4
Metal gates
No. 24 Gage Gal. iron
Gal. iron
Gate operating mechanism
3/8" Steel rod
Slope 1/2:1
Slope = 0.12
El 1145.0
El 1109.25
El 989.3
MODEL SCALE IN INCHES
0 5 10 15 20 25
0 25 50 75 100 125
PROTOTYPE SCALE IN FEET
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM HYDRAULIC EXPERIMENTS
SIDE CHANNEL SPILLWAY MODEL C-5
1:60 RATIO MODEL DETAILS AND SECTIONS
DENVER COLO
45-D-2881

FIG. 28

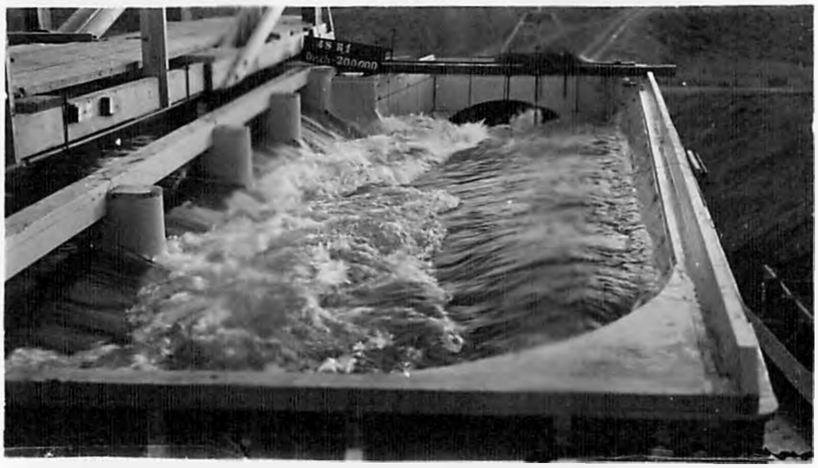
I: 20 MODEL RATIO

I: 60 MODEL RATIO

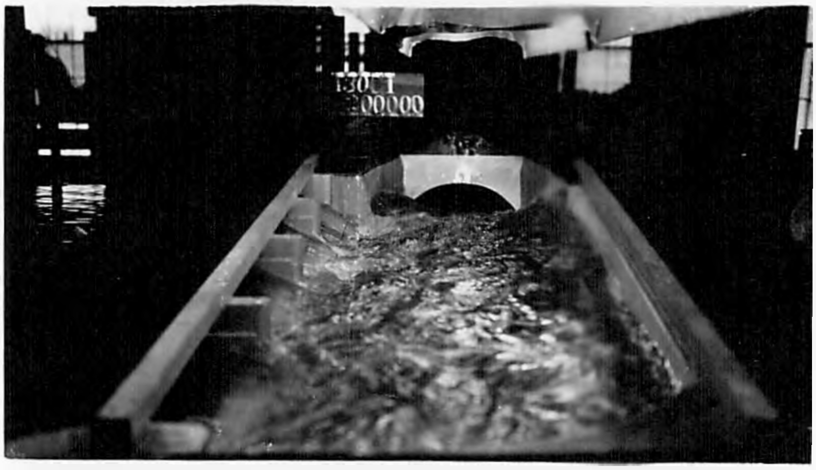


I:100 MODEL RATIO

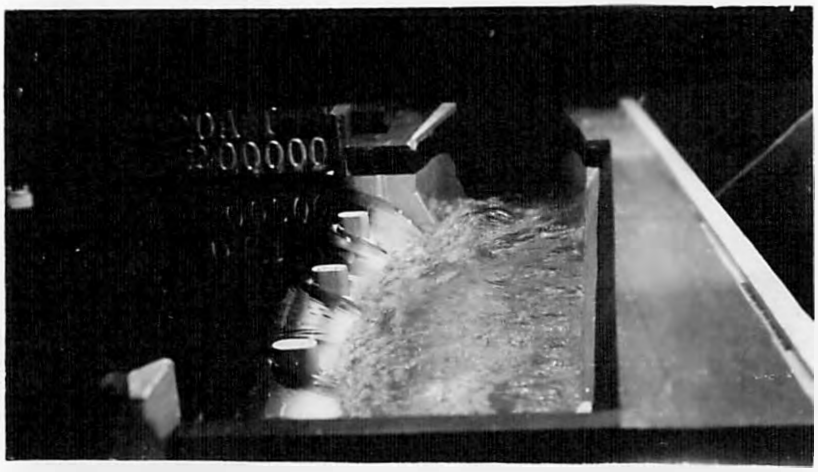
COMPARISON OF RESULTS OF EXPERIMENTS ON
SPILLWAY MODELS, FINAL DESIGN. LOOKING UPSTREAM
DISCHARGE 200,000 SEC. F'I
THE DESIGN CAPACITY



1:20 MODEL RATIO



1:60 MODEL RATIO



1:100 MODEL RATIO

COMPARISON OF RESULTS OF EXPERIMENTS ON SPILLWAY MODELS, FINAL DESIGN. LOOKING DOWNSTREAM

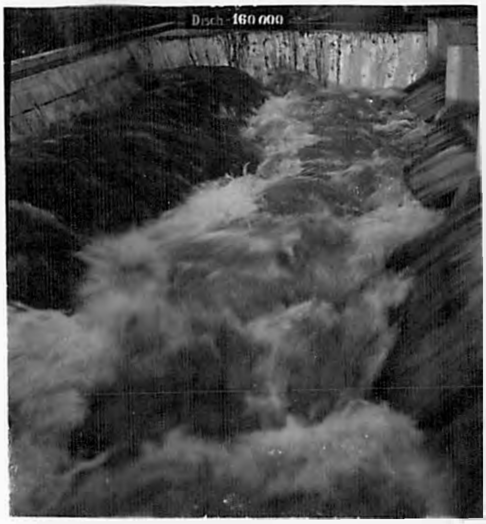
DISCHARGE 200,000 SEC. FT.
THE DESIGN CAPACITY

reproduction in order that the results of the three models would be comparable. No gates were used on this model, and the crest was shaped to represent the shape with the drum gates down. Views of this model are also shown on Plates 97 and 98.

Similarity of Visual Results on the Three Final Design Models

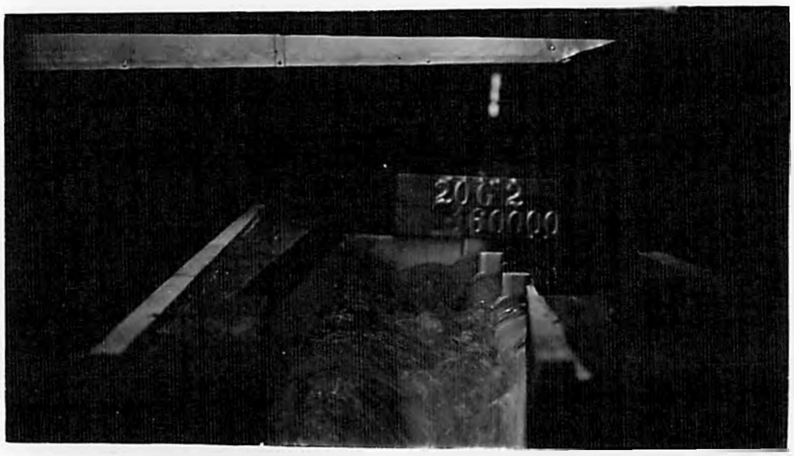
The action of all three models for all the conditions experimented upon was found to be surprisingly similar. This is strikingly shown by comparing the photographs of the flow in the three models for the corresponding discharges and gate settings, as shown on Plates 97 to 112 inclusive. Plates 97 and 98 are comparable views of the three models with no flow. Plates 99 and 100 show the three models with discharges corresponding to 200,000 second-feet, the former looking upstream and the latter downstream. A very close correspondence in the general features is noted, and in most cases this extends to the details of the wave action as well. This is particularly true in Plate 100 as shown by the close correspondence between the wave action below each of the corresponding gates.

The flow conditions in the channel for discharges of 160,000 second-feet and over went through a series of rough cycles, in which certain forms of flow appeared at intervals. Unless the photographs were taken at the same stage in the cycle they would appear to indicate different flow conditions, even if the conditions considering the whole cycle were exactly the same. For this reason



1:20 MODEL RATIO

1:60 MODEL RATIO



1:100 MODEL RATIO

COMPARISON OF RESULTS OF EXPERIMENTS ON SPILLWAY MODELS, FINAL DESIGN. LOOKING UPSTREAM DISCHARGE 160,000 SEC. FT.

1 20 MODEL RATIO

1 60 MODEL RATIO

1:100 MODEL RATIO

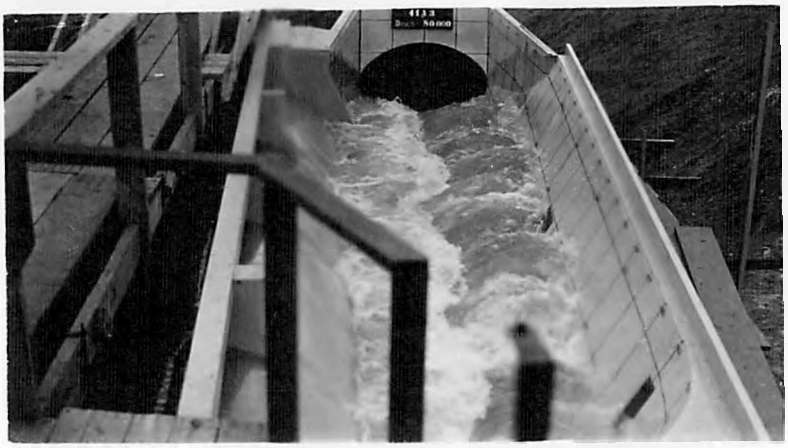
COMPARISON OF RESULTS OF EXPERIMENTS ON
SPILLWAY MODELS, FINAL DESIGN. LOOKING UPSTREAM
DISCHARGE 160,000 SEC. FT.

I: 20 MODEL RATIO

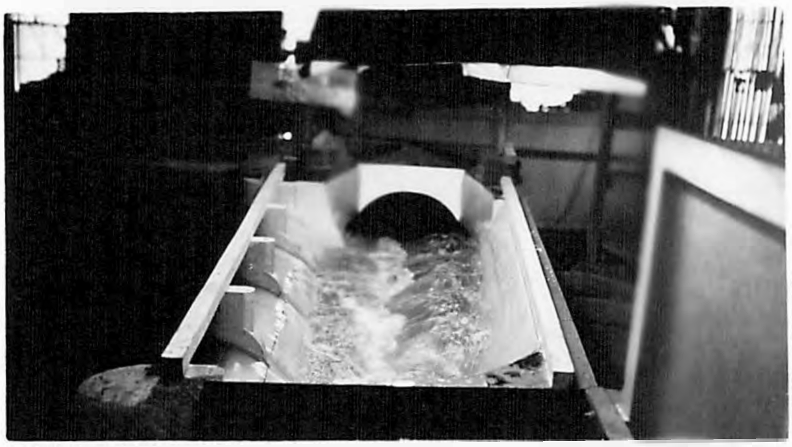
I: 60 MODEL RATIO

I:100 MODEL RATIO

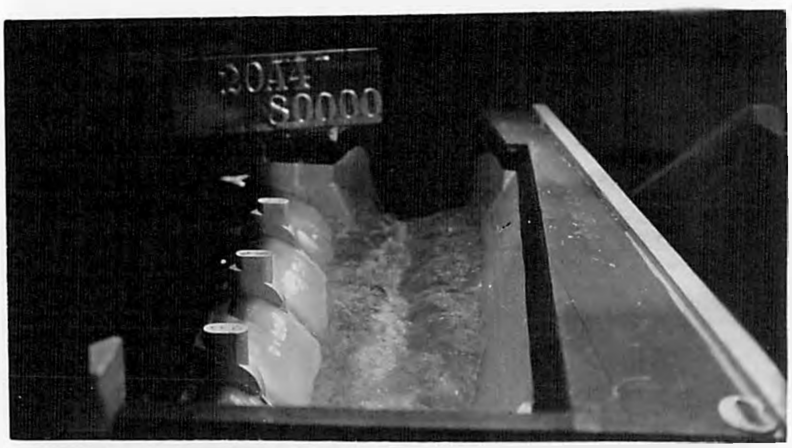
COMPARISON OF RESULTS OF EXPERIMENTS ON SPILLWAY MODELS, FINAL DESIGN. LOOKING UPSTREAM DISCHARGE 80,000 SEC. FT.



1:20 MODEL RATIO

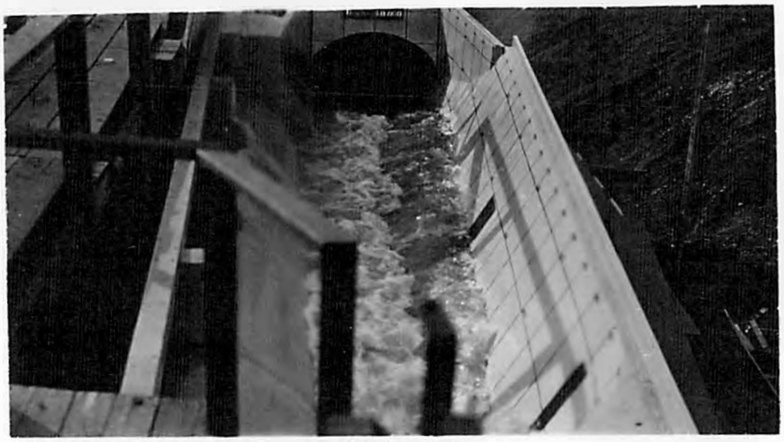


1:60 MODEL RATIO

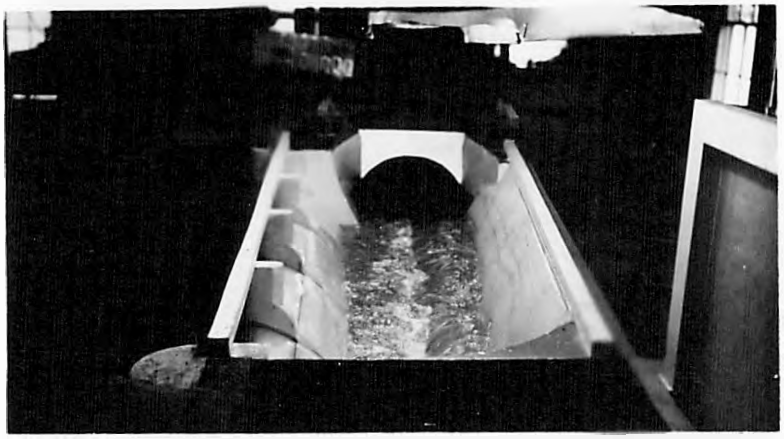


1:100 MODEL RATIO

COMPARISON OF RESULTS OF EXPERIMENTS ON SPILLWAY MODELS, FINAL DESIGN. LOOKING DOWNSTREAM DISCHARGE 80,000 SEC. FT.



1:20 MODEL RATIO

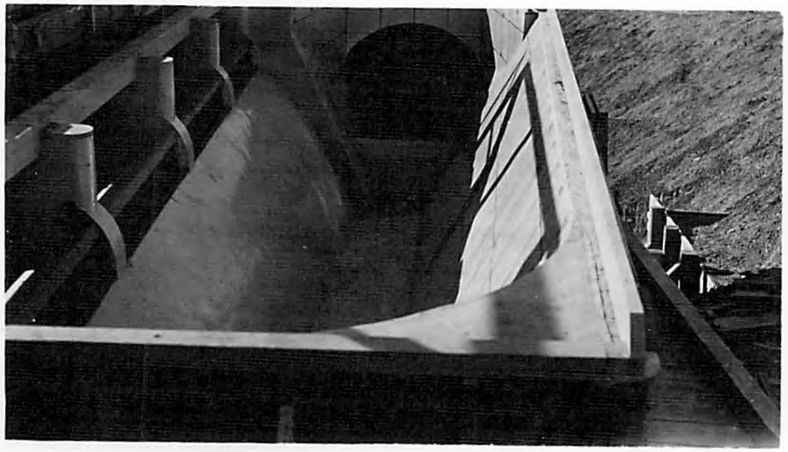


1:60 MODEL RATIO

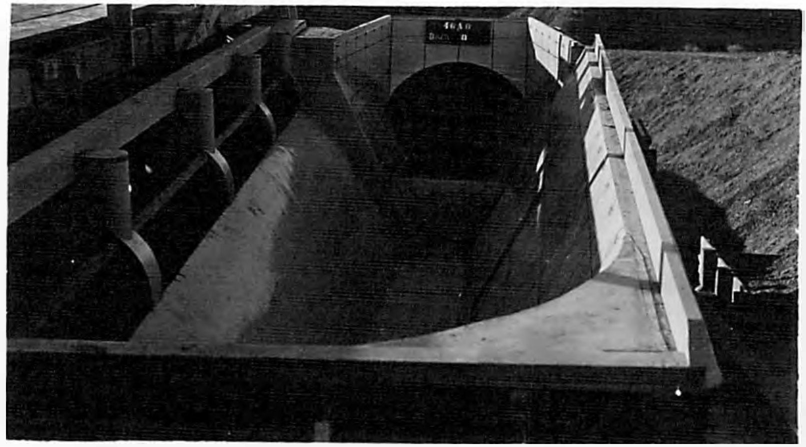
1:100 MODEL RATIO

COMPARISON OF RESULTS OF EXPERIMENTS ON SPILLWAY MODELS, FINAL DESIGN. LOOKING DOWNSTREAM

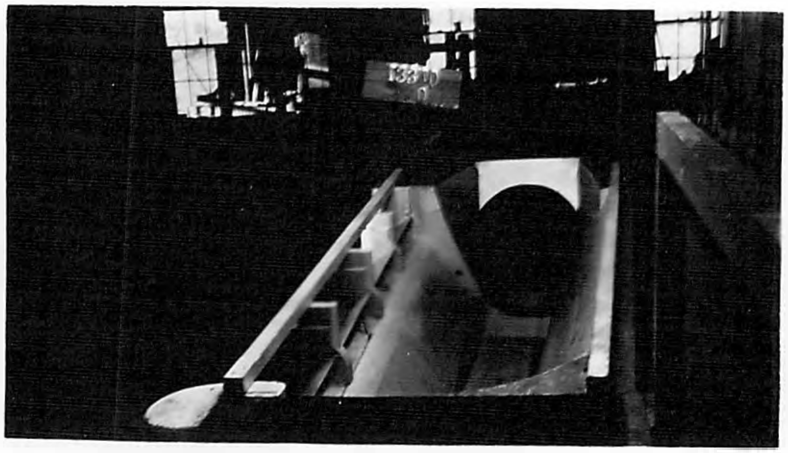
DISCHARGE 40,000 SEC. FT.



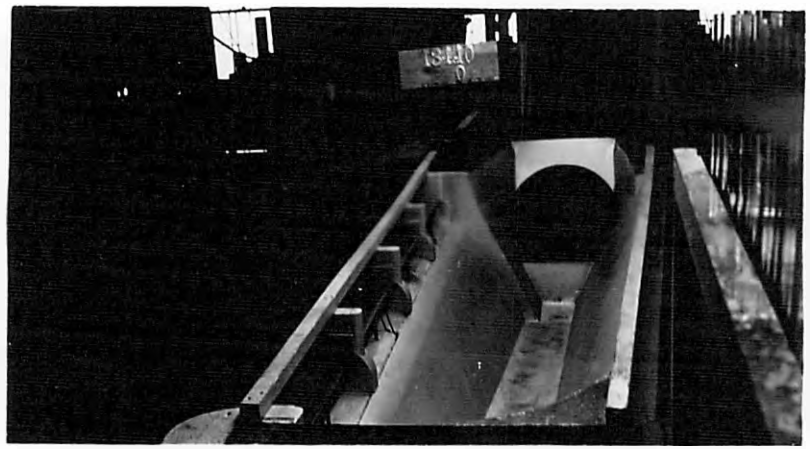
1:20 MODEL RATIO-GATES RAISED $\frac{3}{4}$



1:20 MODEL RATIO-GATES COMPLETELY RAISED

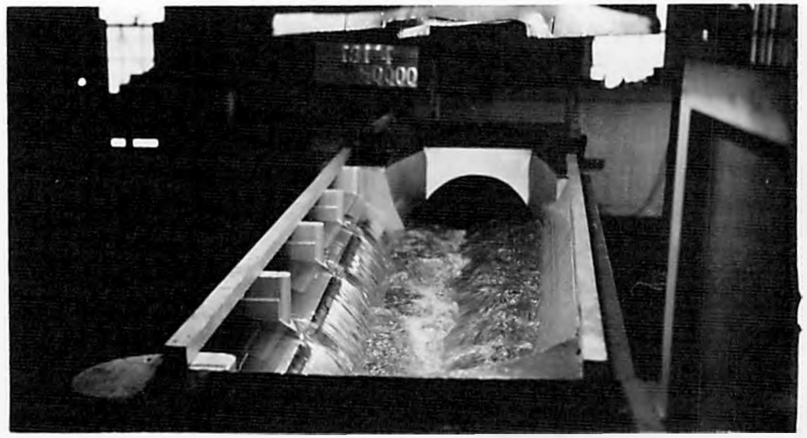


1:60 MODEL RATIO-GATES RAISED $\frac{3}{4}$



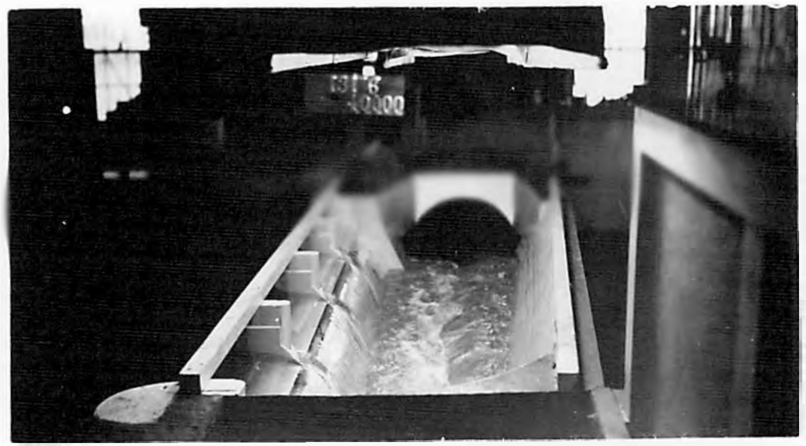
1:60 MODEL RATIO-GATES COMPLETELY RAISED

COMPARISON OF MODELS OF FINAL SPILLWAY DESIGN
GATES RAISED



1:20 MODEL RATIO 1:60 MODEL RATIO

DISCHARGE 80,000 SEC. FT.



1:20 MODEL RATIO 1:60 MODEL RATIO

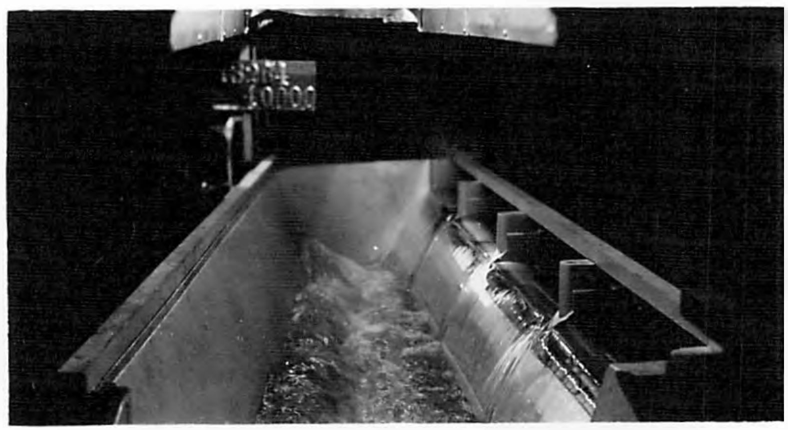
DISCHARGE 40,000 SEC. FT.

COMPARISON OF RESULTS OF EXPERIMENTS ON SPILLWAY MODELS, FINAL DESIGN, GATES RAISED $\frac{1}{4}$

PLATE 109

1:20 MODEL RATIO — 1:60 MODEL RATIO

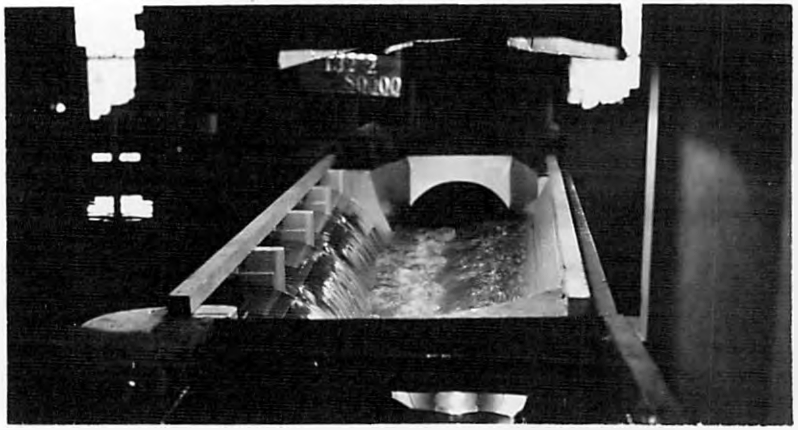
DISCHARGE 80,000 SEC. FT.



1:20 MODEL RATIO — 1:60 MODEL RATIO

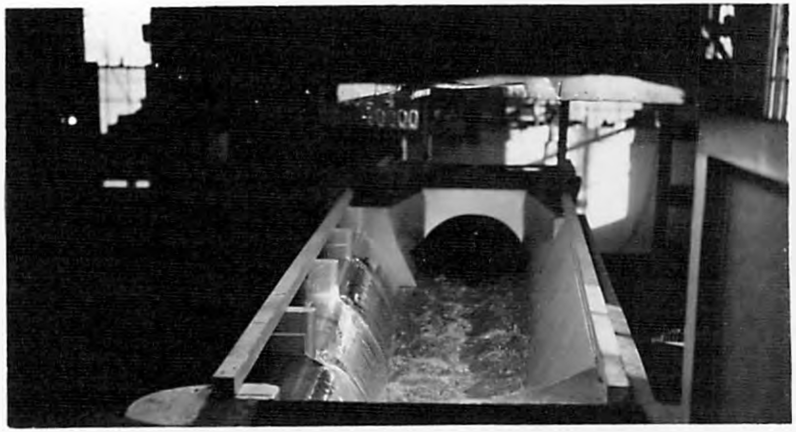
DISCHARGE 40,000 SEC. FT.

COMPARISON OF RESULTS OF EXPERIMENTS ON SPILLWAY MODELS, FINAL DESIGN, LOOKING UPSTREAM, GATES RAISED ½



1:20 MODEL RATIO 1:60 MODEL RATIO

DISCHARGE 80,000 SEC. FT.



1:20 MODEL RATIO 1:60 MODEL RATIO

DISCHARGE 40,000 SEC. FT.

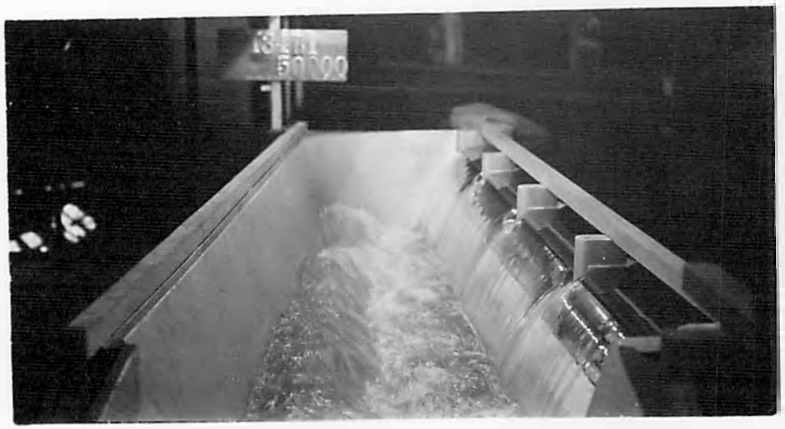
COMPARISON OF RESULTS OF EXPERIMENTS ON SPILLWAY MODELS,
FINAL DESIGN, LOOKING DOWNSTREAM, GATES RAISED $\frac{1}{2}$

PLATE III

1:20 MODEL RATIO

1:60 MODEL RATIO

GATES RAISED $\frac{3}{4}$ - DISCHARGE 40,000 SEC. FT.



1:20 MODEL RATIO

1:60 MODEL

GATES COMPLETELY RAISED - DISCHARGE 40,000 SEC. FT.

COMPARISON OF RESULTS OF EXPERIMENTS ON SPILLWAY MODELS. FINAL DESIGN, GATES RAISED

PLATE 112

the similarity of flow may have been even better than indicated by the photographs.

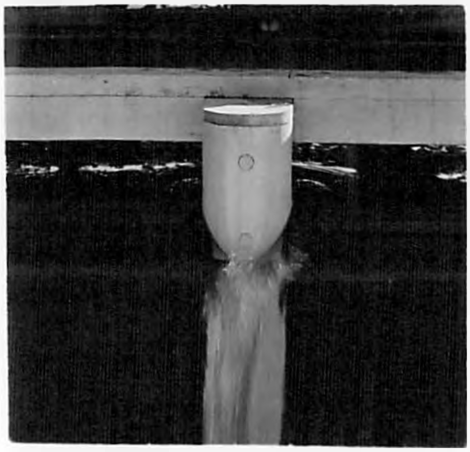
The effect of the same surface tension in the water in all three models is noticeable in the increase in surface roughness or frothiness as the size of the model is increased, and the surface tension therefore relatively reduced. Plates 101 and 102 show the conditions in the three models for flows corresponding to 160,000 second-feet with all the gates down. Here again the close similarity even in the wave forms is noticeable. This is also noticeable on Plates 103 and 104 which show the conditions for flows of 120,000 second-feet, in Plates 105 and 106 for 80,000, and in Plate 107 for 40,000.

The flow conditions with the drum gates in raised positions for the M-5 and C-5 models show the same close correspondence of flow conditions. Plate 108 shows the models with no flow. On Plate 109 are shown comparisons for flows of 40,000 and 80,000 second-feet with the gates raised one-quarter. A similar comparison is shown on Plates 110 and 111 for gates half raised. On Plate 112 is shown the conditions for discharges of 40,000 second-feet with gates three-quarters and fully raised. In all these conditions the correspondence is very close, in most cases extending to the minor wave forms.

It is believed that a detailed study of the results of the comparable runs on the three models as shown by these photographs will demonstrate conclusively the close similarity of the action of these models, the smallest of which is one-fifth the size of the largest. This fact, together with the fact that whenever it has been possible to obtain comparisons between models and their prototypes, a close similarity has always been found, is believed to be sufficient grounds for the conclusion that the spillways of the Hoover Dam will perform in a manner very close to that indicated by the model tests and that the great volumes of water involved will be safely handled. This conclusion is still further confirmed by the quantitative comparisons of the results obtained on these spillways, as given in Books 3 and 4 of this report.

Study of the Shape of Downstream End of Crest Piers

One of the valuable results of model tests is the check which they give of the performance of the details of the structures as well as of the main features. When the M-5 and C-5 models of the spillway were first tested, it was discovered that a partial vacuum formed under the nappe flowing over the gate with the gates in a partially raised position. At the ends of the gates, the water flowed around the pier in such a manner that no opening existed behind the pier through which air could flow to the space beneath the nappe, from which air was continually being carried away by the overflowing water. This condition is shown for various gate openings and flows on Plate 113. The water at the ends of the gate



GATES RAISED FULL HEIGHT
LAKE AT EL. 1232

GATES RAISED ¾-DISCHARGE 90,000 SEC FT

GATES DOWN-DISCHARGE 200,000 SEC FT

CONDITION AT DOWNSTREAM END OF GATE PIERS
ORIGINAL DESIGN M-5 MODEL

spread rapidly in a lateral direction and maintained a sheet of water one side of which was constantly in contact with the pier face. In order to cause this sheet to break contact with the pier, and form an open space through which aeration of the nappe could take place, the parallel sides of the pier were extended downstream and the cylindrical portion at the downstream end of the pier was made with a smaller radius than half the pier thickness. This resulted in an offset at the downstream edge of the parallel sides of the pier. Several combinations of radii and extension of parallel sides were tested. The results of several of them are shown on Plate 114. View A was taken looking down from the top of the pier. With an extension of the parallel sides of the pier 1.5 feet further downstream than in the original design, and a decrease of the radius of the cylindrical portion of 1.0 feet, which produced a 1.0-foot offset in the pier sides at this point. It shows a space between the edges of the nappes from the two gates and the face of the pier. Through this space air could pass to aerate the under side of the nappe. Views B and C show results with other extensions and pier radii. It was desirable to reduce the extension to a minimum, in order to reduce the volume of concrete in the piers. An extension of 1.33 feet and a decrease of pier radius of 1.0 feet were finally adopted. This shape closely approximates that shown on view A.

A-PARALLEL SIDES EXTENDED 1.5 FT.
CYLINDER RADIUS (1/2 PIER THICKNESS-1.0 FT.)

B-PARALLEL SIDES EXTENDED 2.0 FT.
CYLINDER RADIUS (1/2 PIER THICKNESS-1.0 FT.)

C-PARALLEL SIDES EXTENDED 1.5 FT.
CYLINDER RADIUS (1/2 PIER THICKNESS-1.5 FT.)

CONDITION AT DOWNSTREAM END OF GATE PIERS
SIDES EXTENDED, CYLINDER RADIUS DECREASED

A-PARALLEL SIDES EXTENDED 1.5 FT.
CYLINDER RADIUS (½ PIER THICKNESS-1.0 FT.)

B-PARALLEL SIDES EXTENDED 2.0 FT.
CYLINDER RADIUS (½ PIER THICKNESS-1.0 FT.)

C-PARALLEL SIDES EXTENDED 1.5 FT.
CYLINDER RADIUS (½ PIER THICKNESS-1.5 FT.)

CONDITION AT DOWNSTREAM END OF GATE PIERS
SIDES EXTENDED, CYLINDER RADIUS DECREASED

A-PARALLEL SIDES EXTENDED 1.5 FT.
CYLINDER RADIUS (1/2 PIER THICKNESS-1.0 FT.)

B-PARALLEL SIDES EXTENDED 2.0 FT.
CYLINDER RADIUS (1/2 PIER THICKNESS-1.0 FT.)

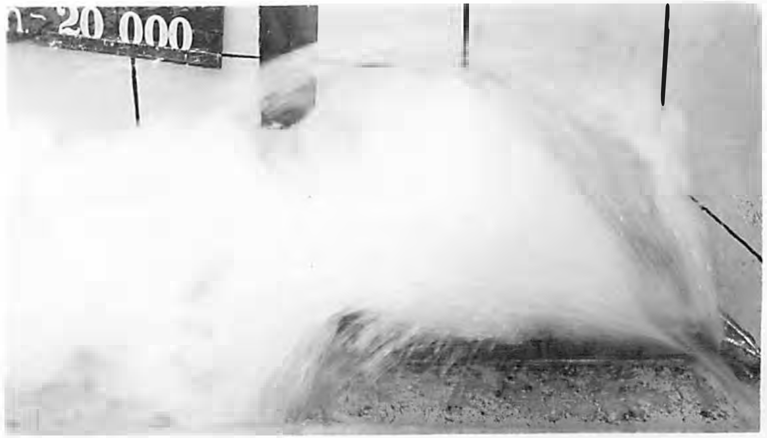
C-PARALLEL SIDES EXTENDED 1.5 FT.
CYLINDER RADIUS (1/2 PIER THICKNESS-1.5 FT.)

CONDITION AT DOWNSTREAM END OF GATE PIERS
SIDES EXTENDED, CYLINDER RADIUS DECREASED

Baffle at Upper End of Channel

At low discharges, with the gate near the upstream end of the crest at equal elevations, an undesirable wave formed at the upstream end of the channel, due to the effect of the curved wall at the upper end, as described on page 10. In order to remedy this condition a form of baffle was tested in the 1:20 scale model. It consisted of two steps, as shown on Plate 115. The baffle, however, did not remove the undesirable wave. The conditions for flows of 20,000, 40,000 and 80,000 second-feet are also shown on Plate 115. The action of the baffle became more effective at higher discharges, but even with no baffle the wave action tended to decrease as the discharge increased. Hence, little improvement was effected by the baffle at any discharge. Somewhat better results were obtained by removing the lower of the two steps and placing an overhanging coping on the higher step. By the proper operation of the drum gates during a flod, however, as described in the last paragraphs of this book, the undesirable wave was largely eliminated, except for such small discharges that no harm could result, and it was not considered worth while to make further search for a baffle form for this purpose.

BAFFLE WITH NO FLOW



DISCHARGE 20,000 SEC. FT.

DISCHARGE 40,000 SEC. FT.

DISCHARGE 80,000 SEC. FT.

TEST OF BAFFLE AT UPPER END OF CHANNEL

PLATE 115

EFFECT OF CROSS WEIR IN CHANNEL

At the conclusion of the experiments on the 1:20 model, to determine the discharge coefficient of the spillway crest without the submergence caused by the cross weir in the spillway channel, a portion of this weir was removed, which lowered the effective crest approximately 12 ft. The improvement in the flow conditions in the channel due to the higher weir is strikingly shown by a comparison of the conditions with the weir at the two heights, as shown on Plate 116.

Determination of Gate Operating Program

In order that the spillways might function in the best possible manner an extensive study was made on the C-5 model to determine the way in which the gates should be operated during a flood. Most of the previous experiments had been carried on with the gates all at the same elevation altho on the M-3 model (Plate 85) some studies were made with gates at various elevations. In all, 75 different operating programs were tried out. These combinations fell into five groups according to the action of the gates as the flow is increased, which were as follows: (1) all gates moving at the same rate and elevation; (2) each gate lowered entirely down before the next gate starts; (3) each gate lowered five ft. before the next successive gate starts, after which they all move down at the same rate; (4) same as group No. 3 except using 10 ft. drop instead of 5 ft.; and (5) some miscellaneous orders.

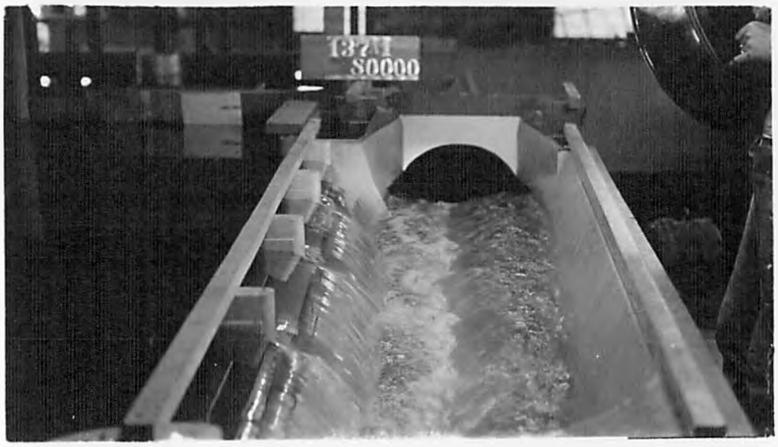
Of these seventy-five programs, three were nearly equally desirable, and were selected for further detailed study. In program

DISCHARGE 200,000 SEC. FT. DISCHARGE 160,000 SEC. FT.
CONDITIONS WITH CROSS WEIR AT FINAL DESIGN HEIGHT

CONDITIONS WITH CROSS WEIR LOWERED 12 FT.

EFFECT OF LOWERING CROSS WEIR ON
CHANNEL FLOW CONDITIONS

A of these three, gates 1 and 4 (numbering from the upstream end of the channel) lowered equally until they were down 5 ft., at which time the middle two gates, 2 and 3, started to drop and all four gates lowered at the same rate until they reached the fully open position. In program B the upstream gate, No. 1, lowered 5 ft., at which point the remaining three gates started to drop and all four gates continued to lower at the same rate. In program C all the gates dropped at the same time and rate. The action of the water for these various programs is shown on Plates 117 to 122 inclusive. The action is shown quantitatively on Figures 61 and 62 in Book 3. The action of the spillway for these three programs was so nearly equally desirable that it was difficult to decide which was best. Program C, in which all the gates move together, was finally selected for adoption, largely because of simplicity. This is the arrangement therefore which will be used in case it is necessary to discharge water over the spillways of the Boulder Dam.



A-DISCHARGE 80,000 SEC.FT.

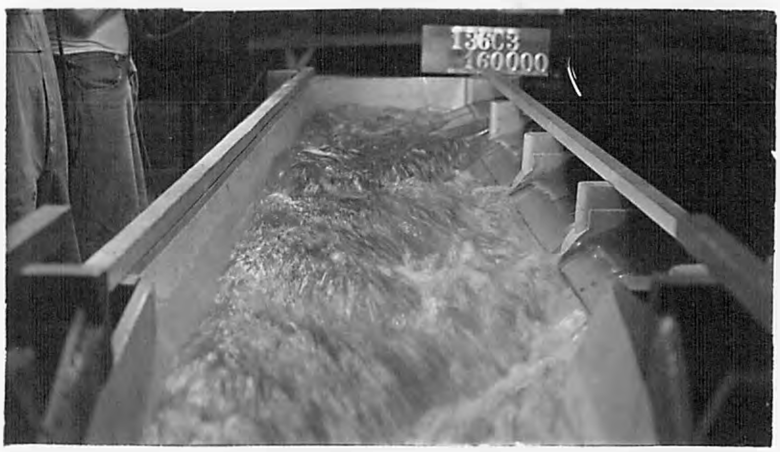
B-DISCHARGE 120,000 SEC.FT.

C-DISCHARGE 160,000 SEC.FT.

GATE OPERATING PROGRAM-A
GATES 1 AND 4 ARE 5 FT. ABOVE GATES 2 AND 3
LOOKING DOWNSTREAM

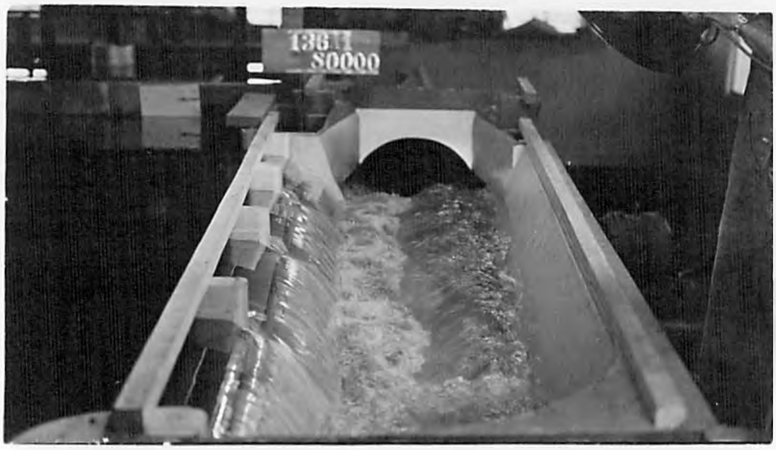
A- DISCHARGE 80,000 SEC.FT.

B-DISCHARGE 120,000 SEC.FT.

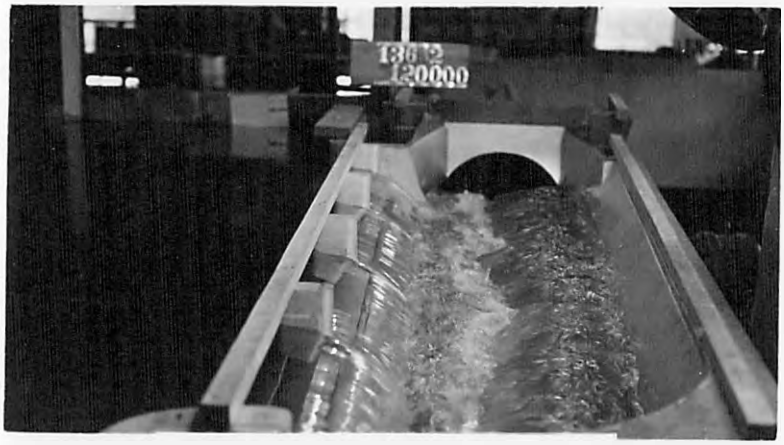


C-DISCHARGE 160,000 SEC. FT.

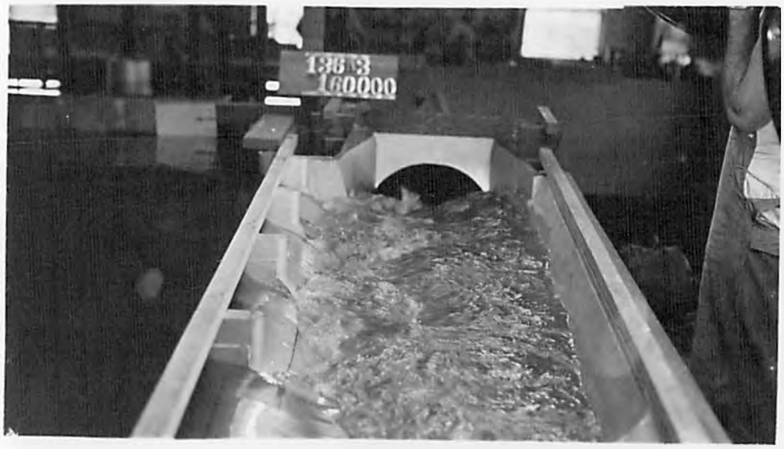
GATE OPERATING PROGRAM-B
UPSTREAM GATE 5 FT. ABOVE GATES 2, 3 AND 4
LOOKING UPSTREAM



A-DISCHARGE 80,000 SEC.FT.



B-DISCHARGE 120,000 SEC.FT.



C-DISCHARGE 160,000 SEC.FT.

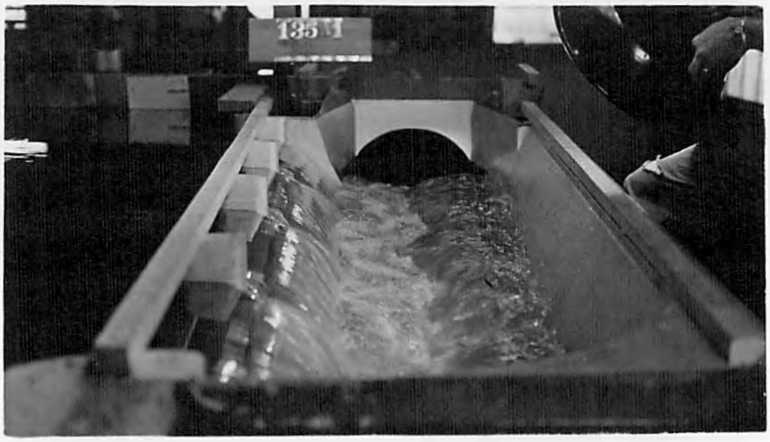
GATE OPERATING PROGRAM-B
UPSTREAM GATE 5 FT. ABOVE GATES 2, 3 AND 4
LOOKING DOWNSTREAM

A- DISCHARGE 80,000 SEC.FT.

B- DISCHARGE 120,000 SEC.FT.

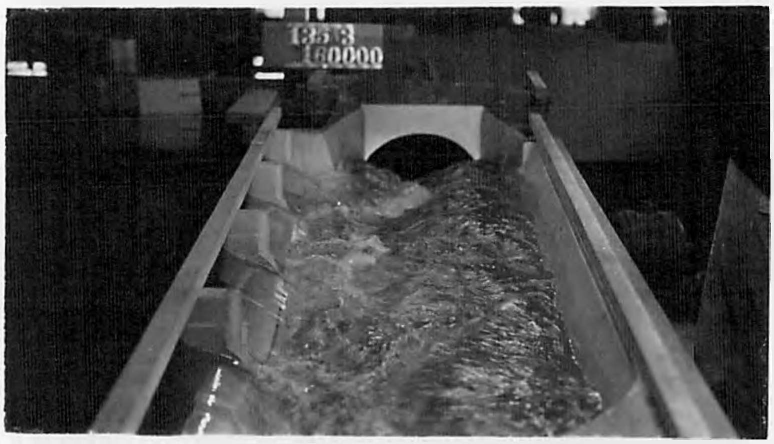
C- DISCHARGE 160,000 SEC.FT.

ADOPTED GATE OPERATING PROGRAM-C
ALL GATES AT THE SAME ELEVATION
LOOKING UPSTREAM



A-DISCHARGE 80,000 SEC.FT.

B-DISCHARGE 120,000 SEC.FT.



C-DISCHARGE 160,000 SEC. FT.

ADOPTED GATE OPERATING PROGRAM C
ALL GATES AT THE SAME ELEVATION
LOOKING DOWNSTREAM