UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: REPORT ON HOOVER DAM SPILLWAY MODEL TESTS

FORT COLLINS LABORATORY - JULY-NOV., 1931

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by

R. R. RANDOLPH, JR., ASSISTANT ENGINEER

Under direction of

B. W. STEELE, CIVIL ENGINEER ON DAMS

TECHNICAL MEMORANDUM NO. 281

Denver, Colorado

November, 1931

(PRICE $)

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THE DRUM GATE DESIGN

SIDE CHANNEL SPILLWAY

Tested August-Nov., 1931

PHOTOGRAPH INDEX

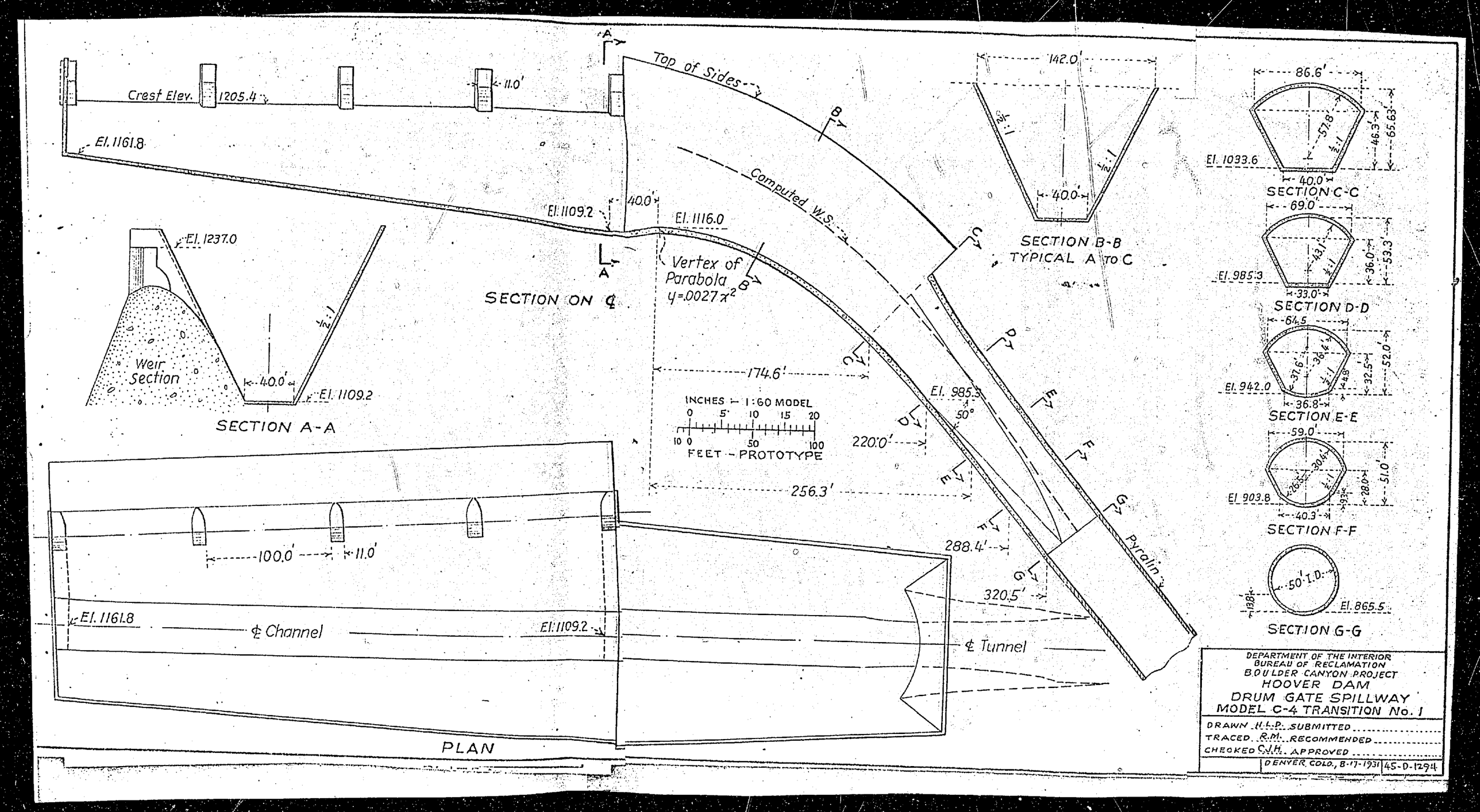
Photograph Number	Page	Description
		MODEL NO. 1.
2-A-0	27	False floor normal to back side.
2-A-1	27	Dentated Sill against Crest face.
6-A-0	27	False floor normal to back side
6-A-5	27	with no sill.
7-A-0	28	Offset Ledge in channel bottom
7-A-4	28	
12-A-0	5	As designed
12-A-1	5	
12-A-3	5	
12-A-5	5	
13-A-0	6	End Gate and Last Sixty feet of
13-A-1	7	Crest blocked off. Weir across
13-A-2	7	end of chennel.
		MODEL NO. 1-A
24-A-0	9	Diagonal overhanging dentated
24-A-1	9	baffle and various height weirs.
24-A-2	9	
24-A-3	9	
25-A-0	29	Right channel wall pulled in
25-A-4	29	and weir across end of chennel.
		MODEL NO. 2.
35-C-1	16	As designed with diagonal over-
35-D-6	16	hanging dentated baffle.
		MODEL NO. 3.
38-A-0	10	As designed
38-B-5	10	
38-A-1	11	
38-B-1	11	
38-A-3	11	
38-B-3	11	
		MODEL NO. 4.
41-A-1	19	As designed
41-A-2	19	
41-A-3	18	

MODEL NO. 3-A

43-A-0	17	As designed.
43-A-1	19	
43-A-2	19	
43-A-3	18	
43-A-4	18	
43-A-5	18	
44-A-0	20	As designed, with diagonal over-
44-C-1	20	hanging dentated baffle along the
44-A-1	21	bottom.
44-B-1	21	
44-A-3	21	
44-B-3	21	
44-A-4	20	
44-A-5	20	

MODEL NO. 5

52-A-0	13	As designed.
52-A-1	14	
52-B-1	14	
52-A-3	14	
52-B-3	14	
53-A-0	15	As designed with diagonal over-
53-A-1	16	hanging dentated baffle along the
53-B-1	16	bottom.
53-A-3	15	
53-B-3	15	
54-A-0	25	As designed, with dentated
54-A-1	25	buckets along the crest face.


Crest Elev. 1205.4
11.0'
El. 1161.8
Top of Sides
Computed W.S.
El. 1109.2
40.0'
El. 1116.0
Vertex of Parabola y=.0027x²
SECTION ON ℄
El. 1237.0
Weir Section
½:1
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
0 5 10 15 20
10 0 50 100
FEET — PROTOTYPE
100.0'
11.0'
El. 1161.8
℄ Channel
El. 1109.2
℄ Tunnel
PLAN
142.0'
½:1
40.0'
SECTION B-B
TYPICAL A to C
86.6'
57.8'
65.63'
46.3'
El. 1033.6
40.0'
SECTION C-C
69.0'
43.1'
53.3'
36.0'
El. 985.3
33.0'
SECTION D-D
64.5'
36.4'
52.0'
37.6'
32.5'
El. 942.0
36.8'
SECTION E-E
59.0'
30.4'
51.0'
26.5'
28.0'
El. 903.8
40.3'
SECTION F-F
50' I.D.
138'
El. 865.5
SECTION G-G
Pyralin
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM
DRUM GATE SPILLWAY
MODEL C-4 TRANSITION No. 1
DRAWN H.L.P. SUBMITTED
TRACED R.M. RECOMMENDED
CHECKED C.H. APPROVED
DENVER, COLO., 8-17-1931
45-D-1294

UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

REPORT ON

HOOVER DAM SPILLWAY MODEL TESTS

DRUM GATE SIDE CHANNEL DESIGN

MADE AT THE

HYDRAULIC LABORATORY OF THE COLORADO AGRICULTURAL COLLEGE AT FORT COLLINS, COLORADO.

August, September, October and November 1931.

Submitted by R. R. Randolph Jr.

The characteristics of this design may be seen on Plate No. 1 which shows the first model set up. In all the tests the crest and side channel relation remained the same but several different designs of the tunnel transition were tried.

The model was built on a 1:60 ratio or a scale of 1" on the model representing 5' on the prototype. This gave four drum gate openings of 20 inches each and a side channel trough approximately 9 inches deep at the upper end and 19 inches at the lower end. The crest and side channel were constructed of wood frames covered with galvanized iron. The transition to the tunnel was made by running laths, between collars at various sections, and plastering over them with a mixture of quick setting cement, lime and sand. The circular tunnel section below was made of transparent pyralin tubing 10 inches in diameter, which after making a vertical bend of 50 degrees, ran into a section of cast iron pipe in which the horizontal bend of the tunnel was accomplished. The top of this pipe was cut away as much as possible to obtain a view of the water flow around the bend.

The head of water over the crest was approximately 5 inches at the maximum flow and was measured by means of a float gage in a well connected to a pipe that ran out in front of the crest about 30 inches upstream therefrom.

The maximum flow over the model was about 7-1/2 cubic feet per second and was measured by means of a two foot Cipolletti weir, previously volumetrically calibrated in position, located upstream in the channel of approach to the crest.

The Cipolletti measuring weir was submerged for all but the lowest flows as the forebay was backed up over it, due to placing the model crest too high in the tanks. This introduced a probability of error in the flow measurement, for although the weir had been calibrated when submerged the measurements were not made at exactly the range used in the model tests, and the quantities had to be taken from exterpolated calibration curves. The difficulty was caused by the unfamiliarity of the Denver Office, where the model was designed and constructed, with the Laboratory set up and could have been overcome by lowering the model crest. This meant practically reconstruction of the model and, as the co-efficient looked reasonable, it was decided not to take the time for the alteration. As stated above, the model was built in Denver and shipped to Fort Collins by truck. The first model was received at the Laboratory on August 7th., and installed by August 8th.

The main object of the experiments was to develop a design that would carry the water down the tunnel, without completely filling it, in as smooth and straight line flow as possible.

The principal experimental methods followed to accomplish this were:

I. By Blocking off Transverse Flow from Crest at the Transition Entrance.

A. By blocking off the last 60 feet of the crest and placing a 60 foot gate on the center line of the channel at the upstream end to maintain the capacity.

Test No. 13. Compare with Test No. 28 to show similarity of action to B.

B. By moving the Transition Entrance 60 feet downstream.

Test No. 16: compare with Test No. 12 which was made on the original desigh.

II. By Placing a Weir across the Lower End of the Channel.

A. To create a dissipation pool and overflow crest that would level off the water surface at the Transition Entrance.

Test No. 24 shows the effect of the different height weirs.

Test No. 28: compare with Test No. 16 to show the effect of the weir on the channel water surface.

III. By Use of Weir and Offset in Tunnel Entrance.

A. Offset to prevent high velocity along the crest face and fill in water surface depression there.

1. With a 70 foot width weir and a 10 foot offset.

Test 38: compare with Test 28 to show the effect of offset and weir.

2. With a 40 foot width weir and a 14 foot offset.

Tests 34 & 35: compare with Tests 43 & 44 which have about the same water surface elevations.

IV. By Giving a Flatter Slope to the Transition Floor.

A. To check high velocity fall and level off surface.

Tests 43 & 44: compare with Tests 41 & 42 which werd made on similar transition that had a steeper floor slope.

Also Tests 34 & 35: compare with Tests 52 & 53.

V. By Placing Baffles along Channel Floor or on the Crest Face.

A. By impact and reversing the flow, to dissipate the energy of the overflow from the crest.

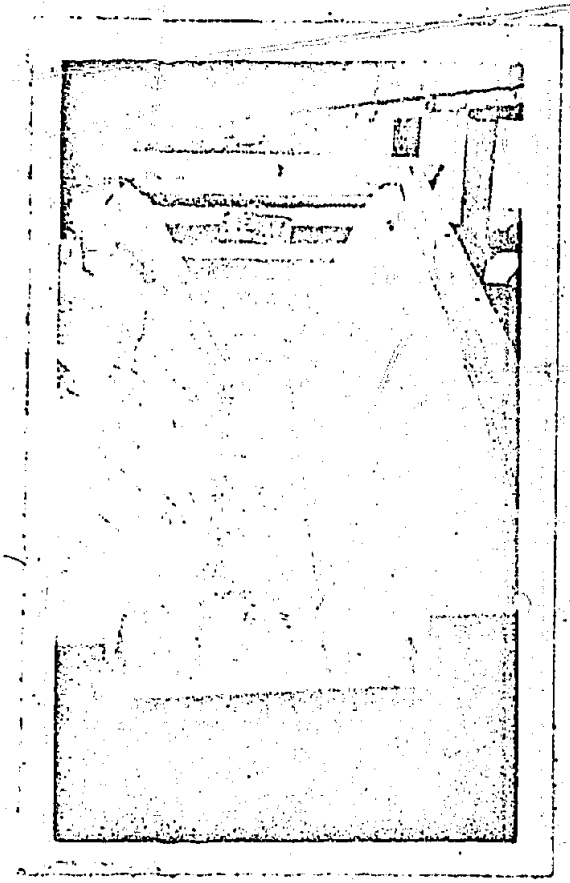
Test 44: compare with Test 43 which was made without baffles.

B. By creating two opposing rolls to dissipate the energy of overflow.

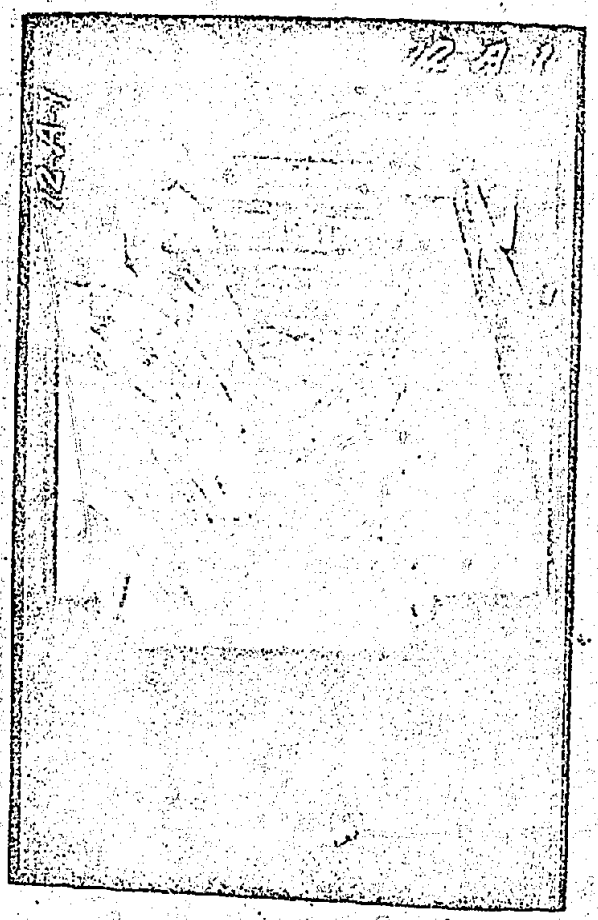
Test 54: compare with Test 52 which was made without baffles: compare with Test 44 to check flow conditions in the channel.

MODEL NO. 1.

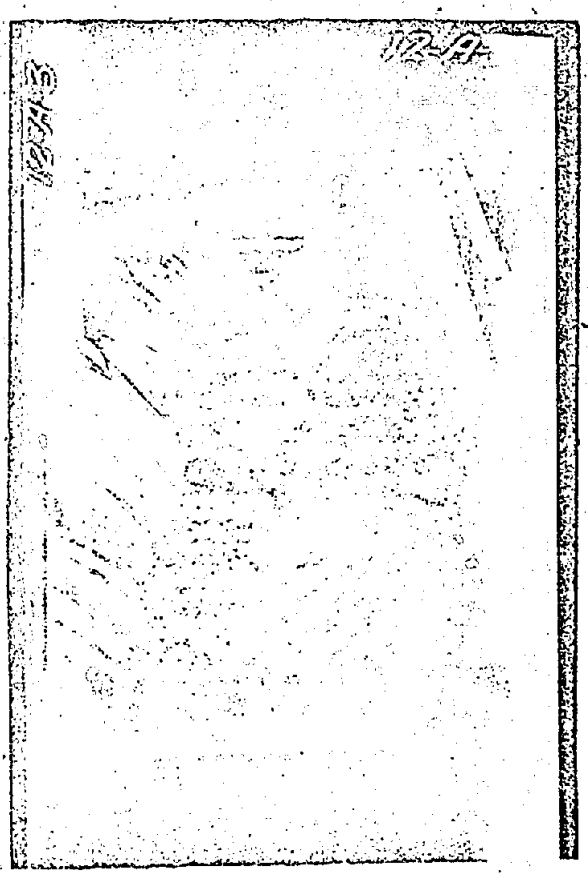
The layout of the original design is shown on Plate No. 1. It will be noted that the roof of the transition on the Model is left off for a distance down so that observations of the flow could be made. The action of the flow down the tunnel, as observed here, whether it was symmetrical or not, and the ~~ext~~ extent to which it filled the tunnel was the main criterion for judgment of the worth of the set up being tested. It is regrettable that no satisfactory pictures could be obtained of views down the tunnel, due to interference of the framing cross pieces and the lack of light. The accompanying pictures show the conditions existing in the channel and only indicate in a general way what is happening down the tunnel. As a general rule, the more level the water surface at the lower end of the channel, the better the flow down the incline and the comparison in this way can be made of many of the photographs. In the following pictures of Model No. 1 design, the piling up of the water against the right side wall will be noted, giving an unbalanced water surface which produces a whirl and tends to clog the flow down the tunnel. Water surface measurements made in the channel and down the transition are shown on Curves No. in the appendix.



Set up.



Flow 40,000 c.f.s.



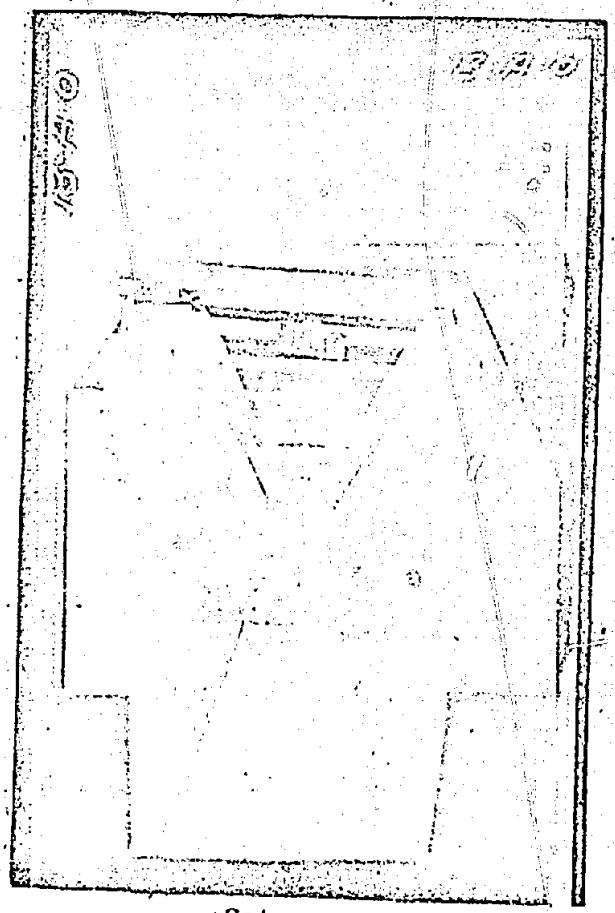
Flow 120,000 c.f.s.

Flow 200,000 c.f.s.

It was thought that if a length of channel was allowed below the crest, the water surface would have more chance to level off before going down the tunnel. This extension would also eliminate the transverse flow kick just at the tunnel entrance.

To test the idea, the last sixty feet of the crest was blocked off and in order to maintain the same capacity, a gate sixty feet wide was cut in the upstream end of the channel as shown in Photograph 13-A-0 below. This materially improved the flow as anticipated, and to apply the idea to the original design the tunnel transition was moved sixty feet further downstream from the last gate as shown on Plate No. 2.

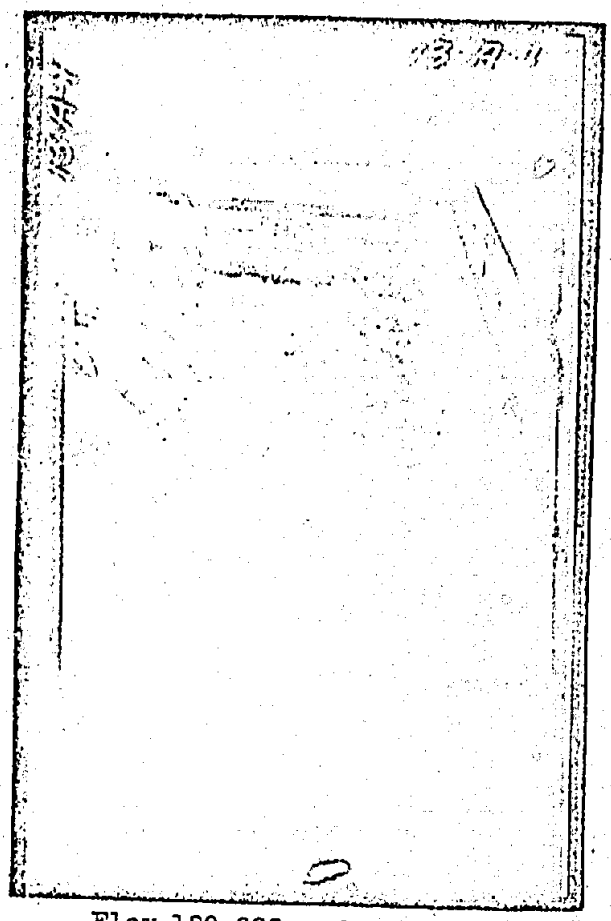
The Pictures on the following page illustrate the flow in the set up with the end gate and the last sixty feet of the crest blocked off, but in this instance there was also a 30 foot weir installed across the channel at the lower end (discussed later). This test may be likened to Test 28, in which the same height of weir was used in the channel after the transition had been moved sixty feet downstream, in order to show the similarity of operation between this set up and Model 1-A. See curves in Appendix.



Set up

MODEL NO. 1.

With End Gate and last 60 feet of Crest Blocked Off.



Flow 120,000 c.f.s.

Flow 200,000 c.f.s.

MODEL NO. 1-A.

To obtain the same effect as blocking off the flow from the last sixty feet of the crest, the Tunnel Transition Entrance was moved sixty feet downstream as shown on Plate No. 2. The photographs of the flow in the channel for this set up showed so little variation from those of Test 12, Page 5 that they will not be included here. It was hardly possible to discern a difference in the pictures and to tell what was actually happening to the flow down the shaft. It is more readily seen, from contrasting the water surface curves Nos and in the appendix, that there is a leveling off and greater depth of the water surface at the lower end of the channel, which consequently resulted in a smoother flow down the transition. This greater depth of water in the channel for the same quantity of water flowing was only at the lower end and did not reduce the co-efficient of discharge by creating a submergence of the crest.

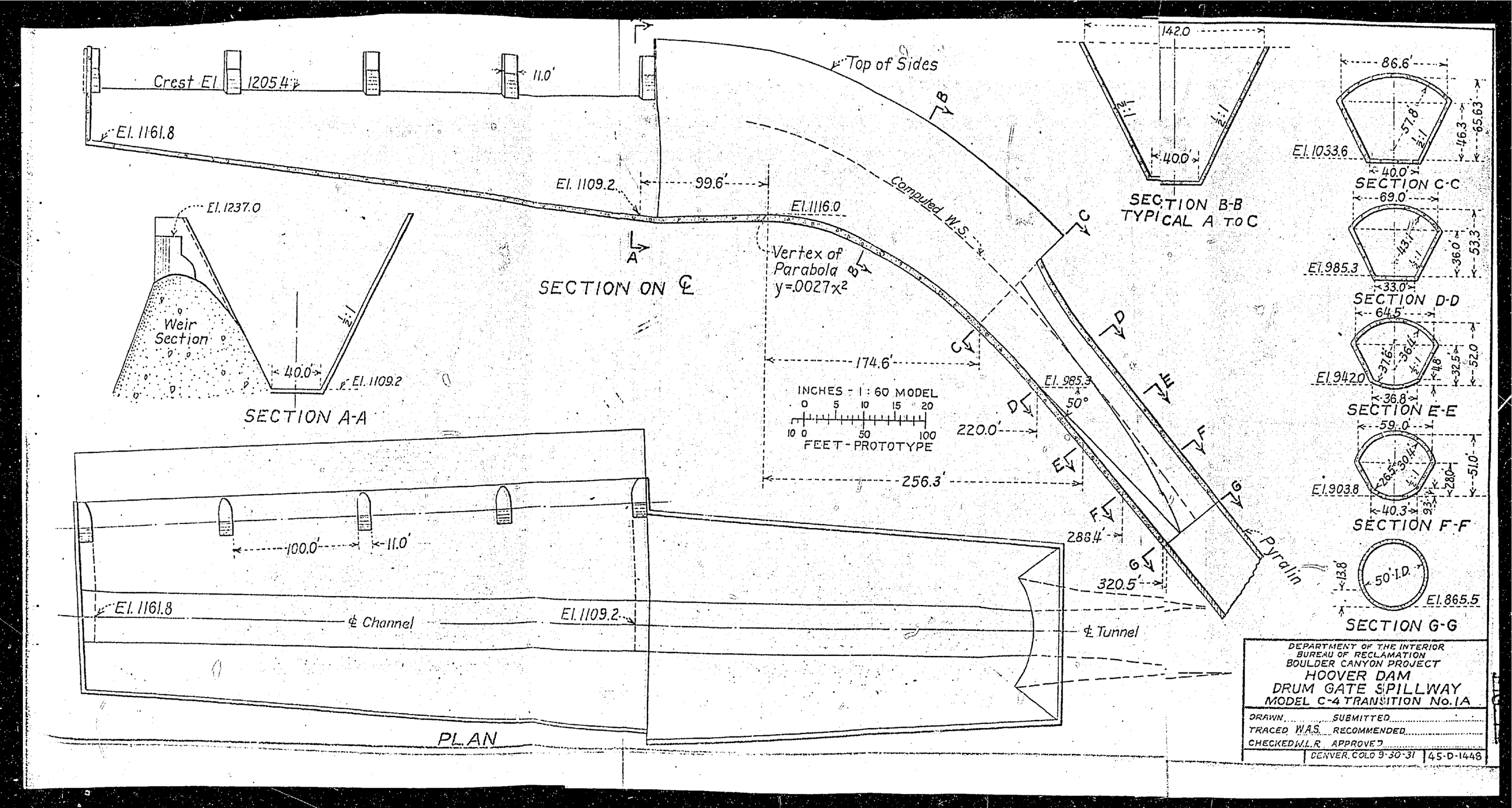
The extension of the channel below the spillway crest was considered extremely beneficial, if not absolutely necessary, and was therefore incorporated in most of the setups following.

And also, as the increased depth of the water in the channel seemed advantageous, the idea was carried further by trying weirs of various height across the channel at the lower end. This created a pool in which some of the energy of the spillway overflow was dissipated and the weir afforded a barrier which tended to smooth out the overflow from it.

The effect of the various height weirs may be seen in the following photographs. Although this set up had a dentated offset in the channel floor (discussed later), the smoother flow, in comparison, at the tunnel entrance is caused by the use of a higher weir. Compare to Photograph 12-A-5 on Page 5.

Test No. 28 Curves Nos. in which a 35 foot weir was installed across the channel at the lower end may be compared to Test No. 16 Curves Nos. which was made without a weir to note the effect of the water surface. The increased depth in the channel caused a submergence of the crest at the upper end that would necessitate a rise of 0.5 feet in the forebay level to get the maximum of 200,000 c.f.s. over the crest.

Water surface Curves No. of this test (No. 24) show the action of the higher weir. Although naturally the water surface is higher over the 30 foot weir than the others at the entrance, further down the tunnel the water surface from the higher weir is below those of the lower weirs, showing the tendency of the flow over the higher weirs to flatten out down the incline.



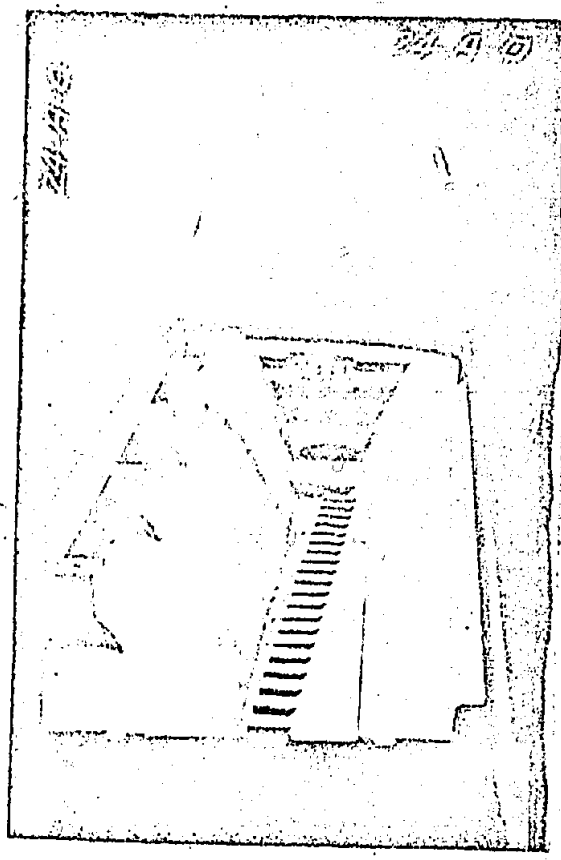
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT

HOOVER DAM
DRUM GATE SPILLWAY
MODEL C-4 TRANSITION No. 1A

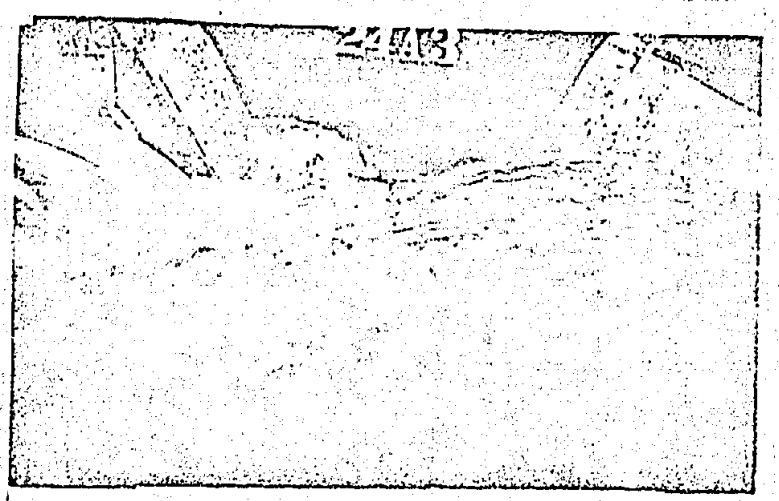
DRAWN ..... SUBMITTED .....
TRACED W.A.S. RECOMMENDED .....
CHECKED W.L.R. APPROVED .....

DENVER, COLO. 9-30-31 | 45-D-1448

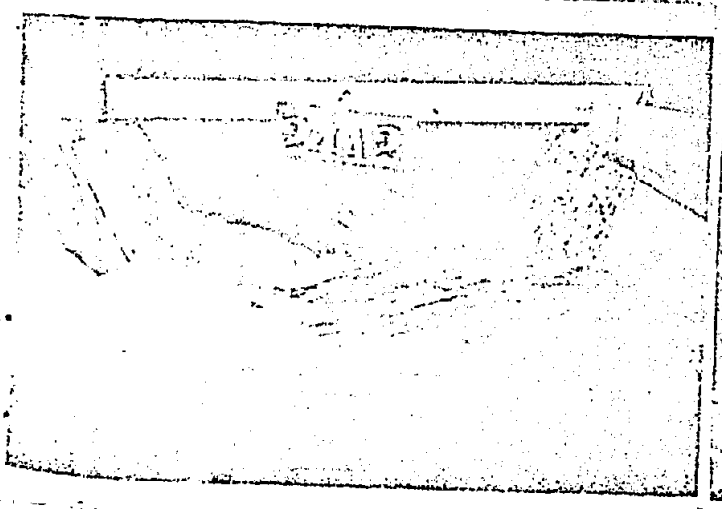
Dentated Sill - Various Height Weirs
Flow 200,000 c.f.s.



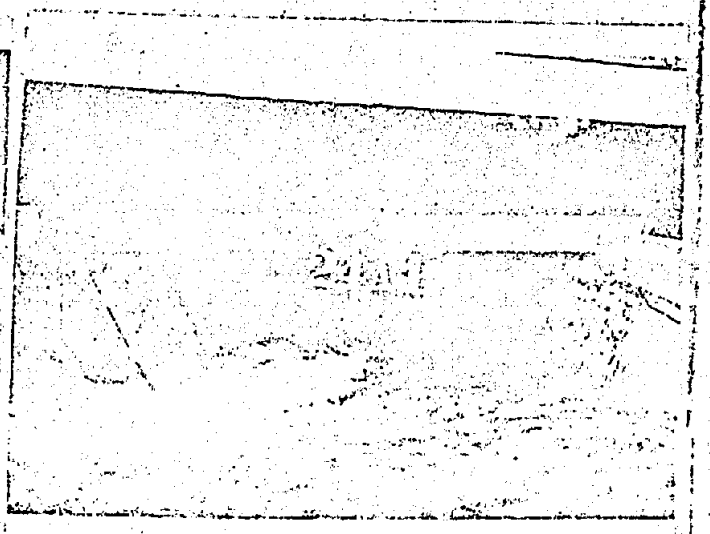
Set up



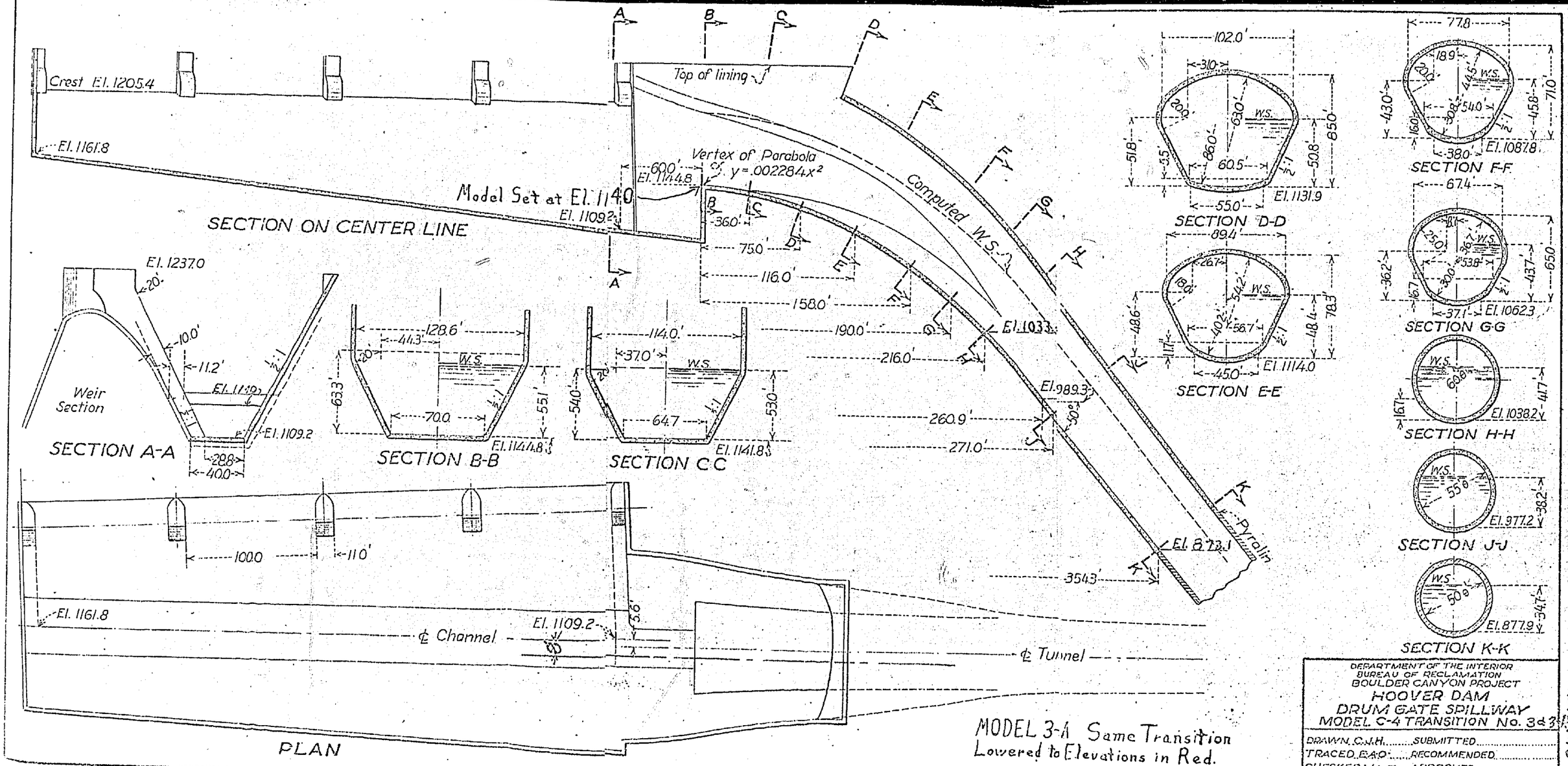
15 Foot Weir



20 Foot Weir

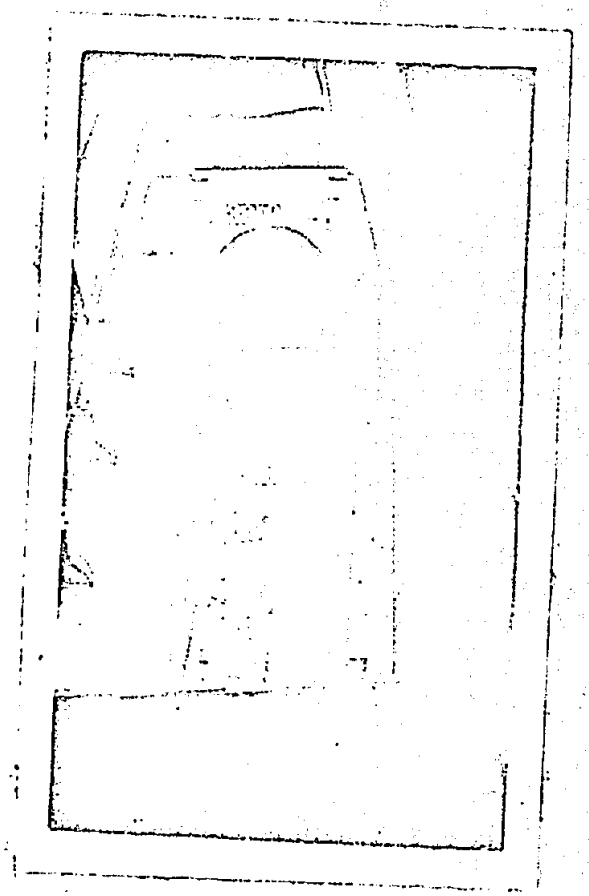


30 Foot Weir

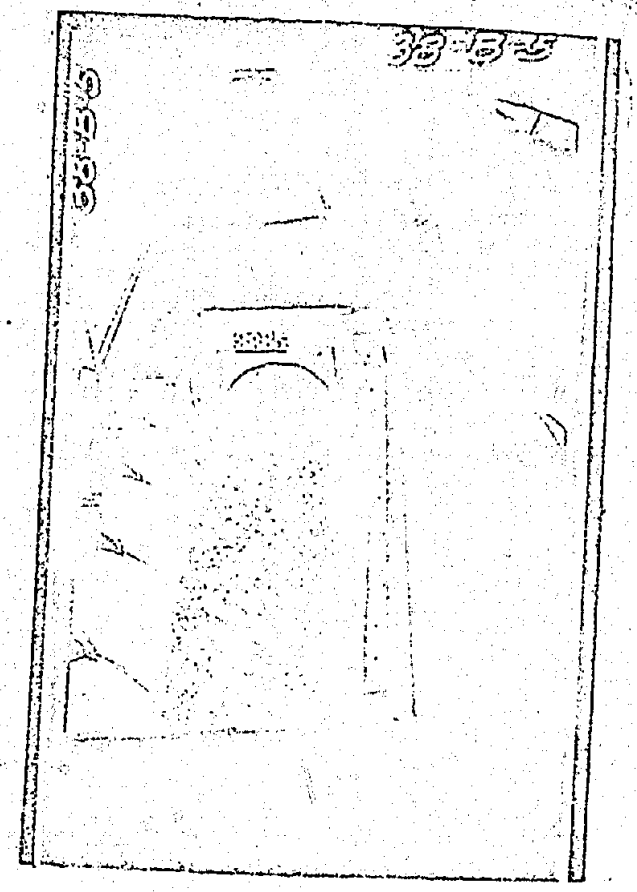

Crest El. 1205.4
El. 1161.8
Top of lining
Vertex of Parabola
y = .002284x²
El. 1144.8
Model Set at El. 1140
El. 1109.2
SECTION ON CENTER LINE
Computed W.S.
El. 1033
El. 989.3
El. 873.1
Pyralin
600'
360'
750'
1160'
1580'
1900'
2160'
2609'
2710'
3543'
El. 1237.0
20'
10.0'
11.2'
Weir Section
El. 1149
El. 1109.2
28.8'
40.0'
SECTION A-A
128.6'
44.3'
W.S.
20'
63.3'
70.0
55.1'
El. 1144.8
SECTION B-B
114.0'
37.0'
54.0'
64.7
53.0'
El. 1141.8
SECTION C C
102.0'
31.0'
20.0'
63.0'
W.S.
86.0'
60.5'
51.8'
55'
50.8'
85.0'
55.0'
El. 1131.9
SECTION D-D
89.4'
26.7'
18.8'
54.2'
W.S.
40.2'
56.7'
48.6'
11.7'
48.4'
78.3'
45.0'
El. 1114.0
SECTION E-E
77.8'
18.9'
20.0'
44.5'
W.S.
54.0'
30.8'
43.0'
16.0'
45.8'
71.0'
38.0'
El. 1087.8
SECTION F-F
67.4'
25.1'
25.0'
36.7'
W.S.
53.8'
30.0'
36.2'
16.7'
43.7'
65.0'
37.1'
El. 1062.3
SECTION G-G
W.S.
60.8'
16.7'
41.7'
El. 1038.2
SECTION H-H
W.S.
55.0'
38.2'
El. 977.2
SECTION J-J
W.S.
50.0'
34.7'
El. 877.9
SECTION K-K
100.0
110'
El. 1161.8
℄ Channel
El. 1109.2
5.6'
℄ Tunnel
PLAN
MODEL 3-A Same Transition
Lowered to Elevations in Red.
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM
DRUM GATE SPILLWAY
MODEL C-4 TRANSITION No. 3&3
DRAWN C.J.H. SUBMITTED
TRACED E.A.O. RECOMMENDED
CHECKED W.E. APPROVED
DENVER COLO OCT. 1,31. 45-D-1450

MODEL NO. 3.

It will be noted from the photographs on Page 9 that there is a depression in the water surface on the crest side and that the bulk of the flow seems to be down the right. This suggested an offset in the center line of the tunnel which would project the end wall from the crest face. The projecting wall tends to, check the velocity along the crest face, fill in the depression and raise the water surface at this point. A layout with the combination of a 35 foot weir located 60 feet downstream from the end of the crest and a 10 foot projecting end wall as shown on Plate No. 3 was built and tested. The following photographs illustrate flow conditions in the channel.



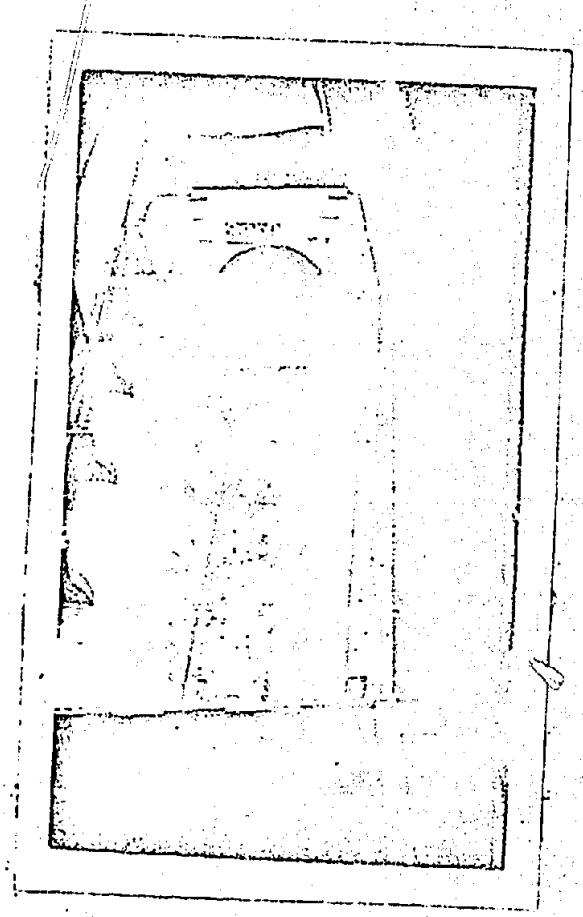
Set up



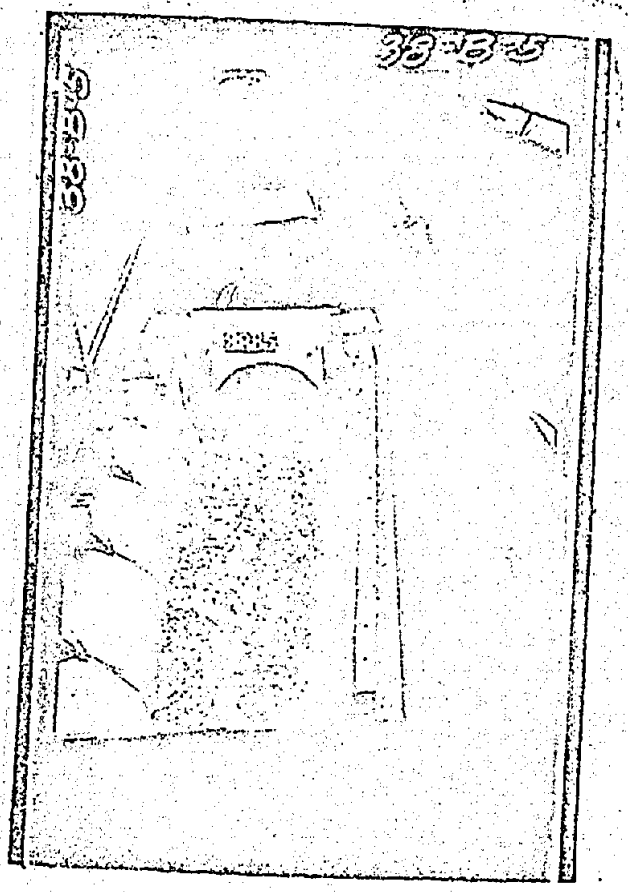
Flow 40,000 c.f.s.

MODEL NO. 3.

It will be noted from the photographs on Page 9 that there is a depression in the water surface on the crest side and that the bulk of the flow seems to be down the right. This suggested an offset in the center line of the tunnel which would project the end wall from the crest face. The projecting wall tends to, check the velocity along the crest face, fill in the depression and raise the water surface at this point. A layout with the combination of a 35 foot weir located 60 feet downstream from the end of the crest and a 10 foot projecting end wall as shown on Plate No. 3 was built and tested. The following photographs illustrate flow conditions in the channel.

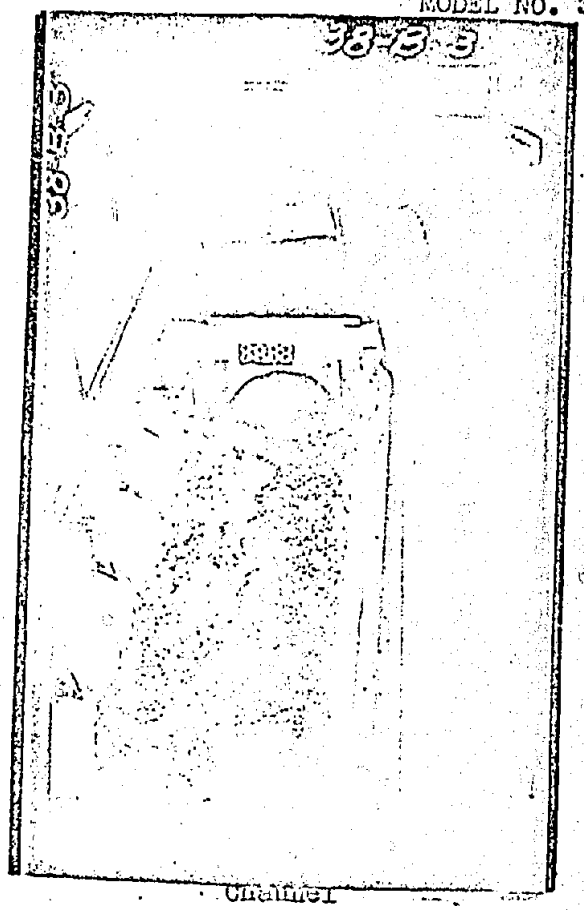


Set up

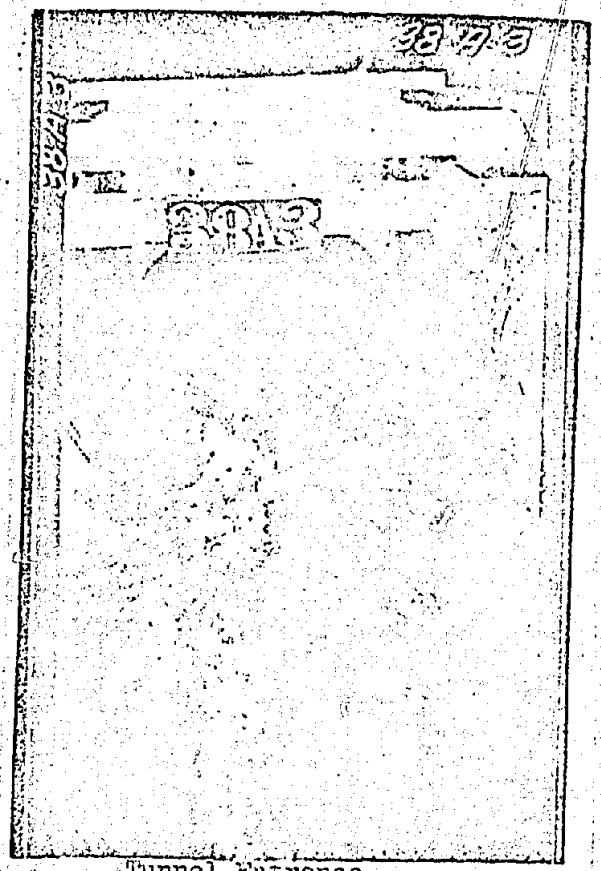


Flow 40,000 c.f.s.

MODEL NO. 3

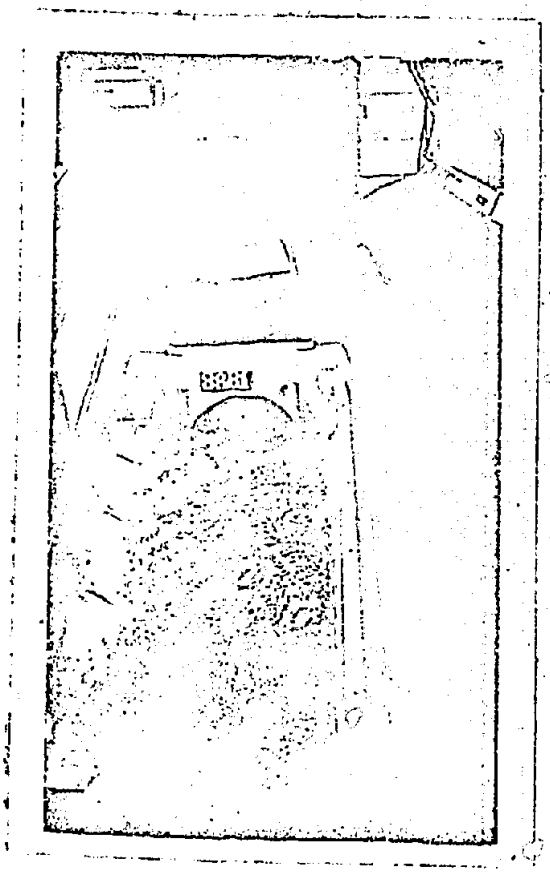


Channel

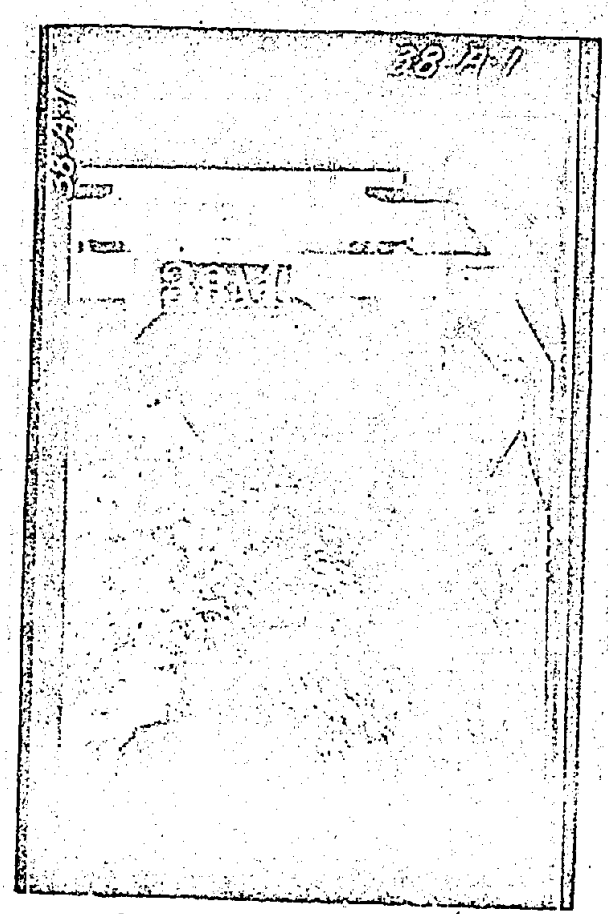


Tunnel Entrance

Flow 120,000 c.f.s.



Channel



Tunnel Entrance

Note the exceptionally smooth flow into the tunnel at the maximum discharge as seen in Photograph 38-A-1. Down the incline the flow was well on the bottom leaving the roof clear, with only an occasional splash upwards. This setup gave better flow conditions down the tunnel than any yet tested but backed the water up in the channel causing a submergence of the crest that reduced its capacity. It would require a pond 0.60 feet above the normal Elevation 1232 to pass the 200,000 c.f.s. Consequently in the final design, that is, the best design developed to date, the tunnel transition was dropped 4.8 feet making the weir at the entrance at Elevation 1140, See Model 3-A. The use of the lower weir decreased the submergence on the crest and increased its capacity, which, however, was not yet quite up to the maximum required. This was later obtained by an alteration of the crest that increased the coefficient of discharge.

It would seem that the higher the weir the smoother the flow over it, and it is the belief of the writer that the elevation of the channel floor at the upper end could be decreased, even dropped to make the floor level, to cut down the submergence on the crest and a higher weir used which would result in improved flow conditions.

By comparison with the water surface curves Nos. of Test 28, the effect of the offset in the tunnel can be seen. A slight rise in water surface especially against the crest face was noted. This however, did not decrease the capacity of the spillway but the rise on the left side tended to level off the surface which was beneficial.

Comparison with Test 16 may be made to show the benefits obtained from the use of a weir across the lower end of the channel. Compare Photographs 38-B-1 on Page 11 to 12-A-5 on Page 5.

MODEL NO. 2

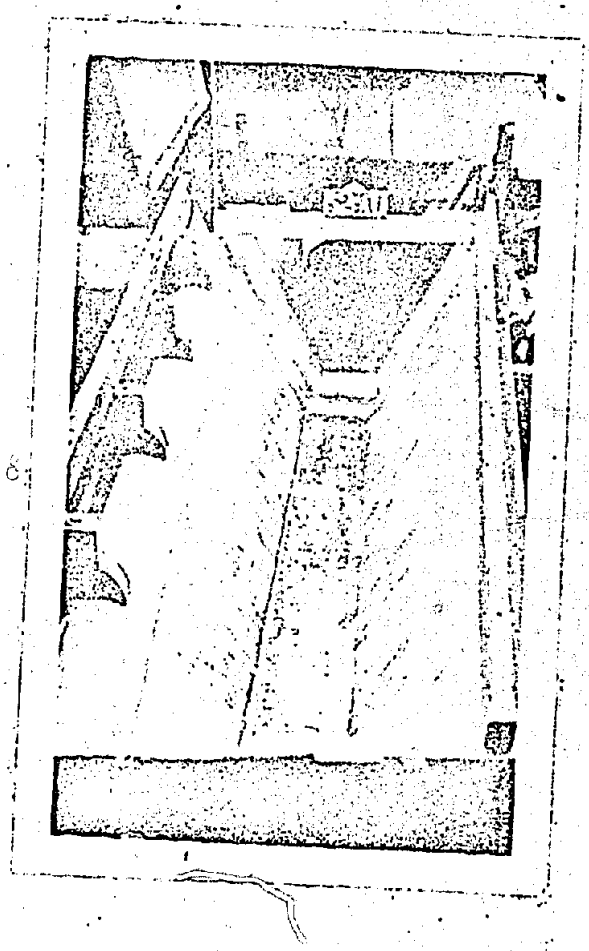
It will be noted that in the set up just discussed above, see Plate No. 3, the weir was raised across the end of the channel, making a length of seventy feet along its crest and the transition narrowed into the tunnel from this width.

It was seen that considerable saving in the cost of construction could be made if the original forty foot width of bottom could be held. In the set up for Model No. 2, see Plate No. 4, the original design of the transition, with respect to width, was slid up the right wall to give a weir and offset as large as possible without backing the water

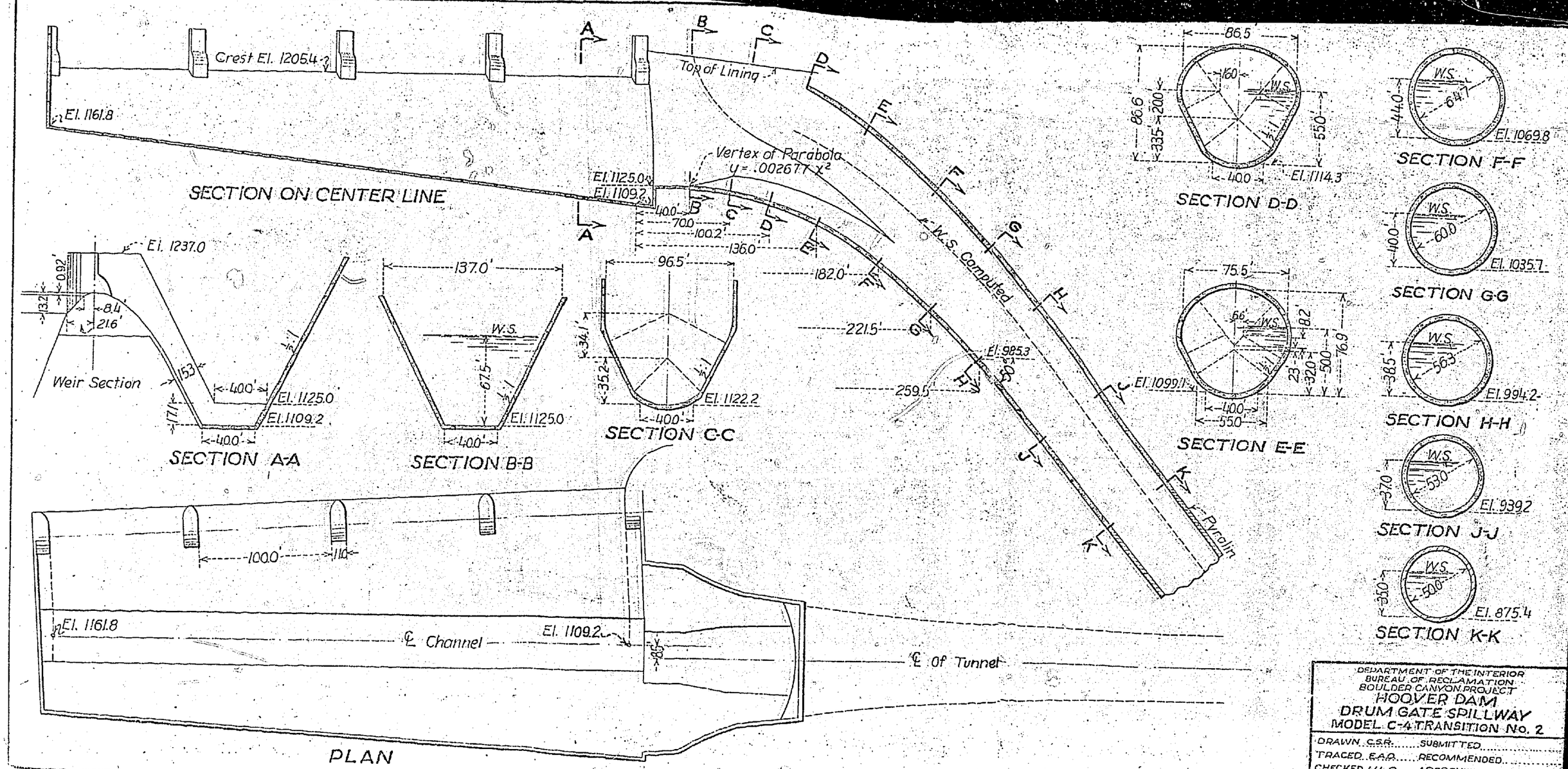
over the crest and cutting down the capacity. Photographs of the flow, some of which were taken when a dentated baffle (discussed later) was installed in the channel are shownmon the following pages. The improvement made by the use of the baffles was very marked in this set up as seen by comparison of the photographs.

MODEL NO. 2.

Following pictures are of Model No. 5 which do not differ materially from those taken of Model 2 and are included because of the better views obtained.



Set up.

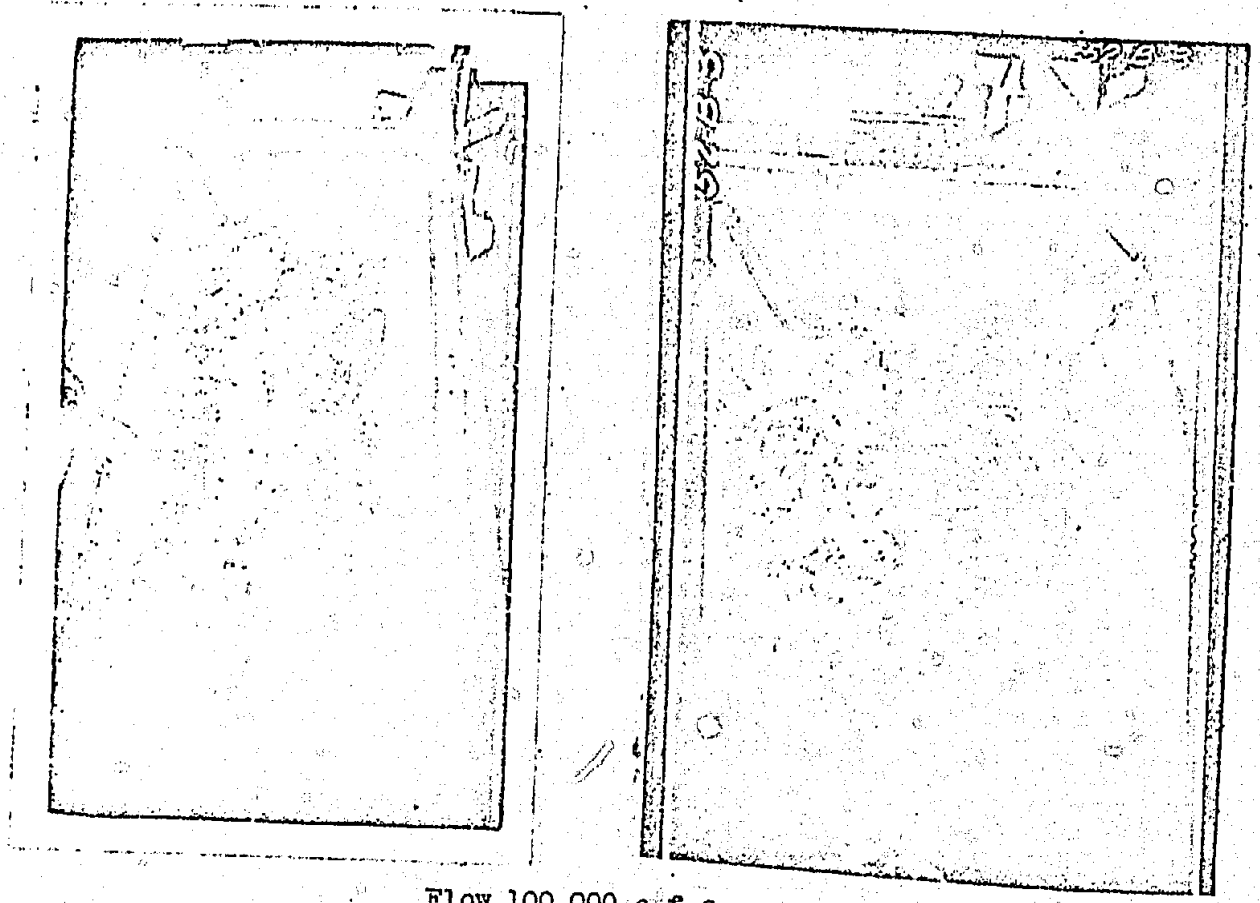


DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT

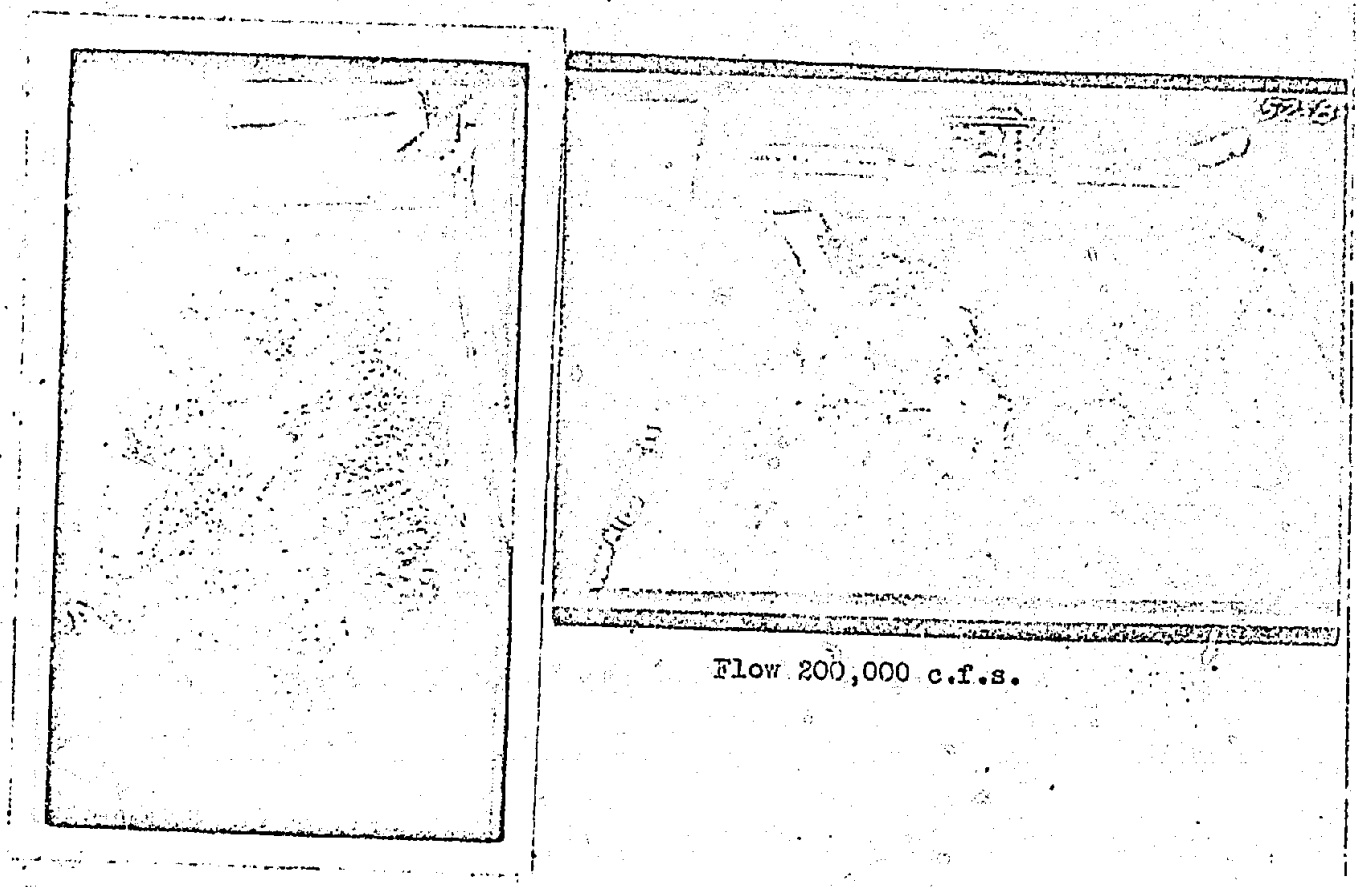
HOOVER DAM
DRUM GATE SPILLWAY
MODEL C-4 TRANSITION No. 2

DRAWN C.S.R. SUBMITTED
TRACED E.A.P. RECOMMENDED
CHECKED W.A.P. APPROVED

DENVER, COLO., OCT. 3, 31 | 4-S-D-1449



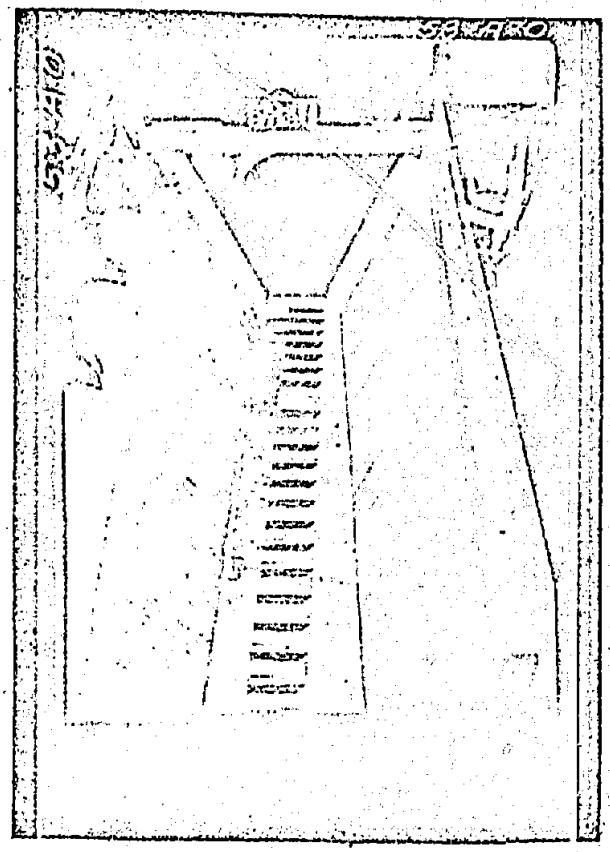
Flow 100,000 c.f.s.



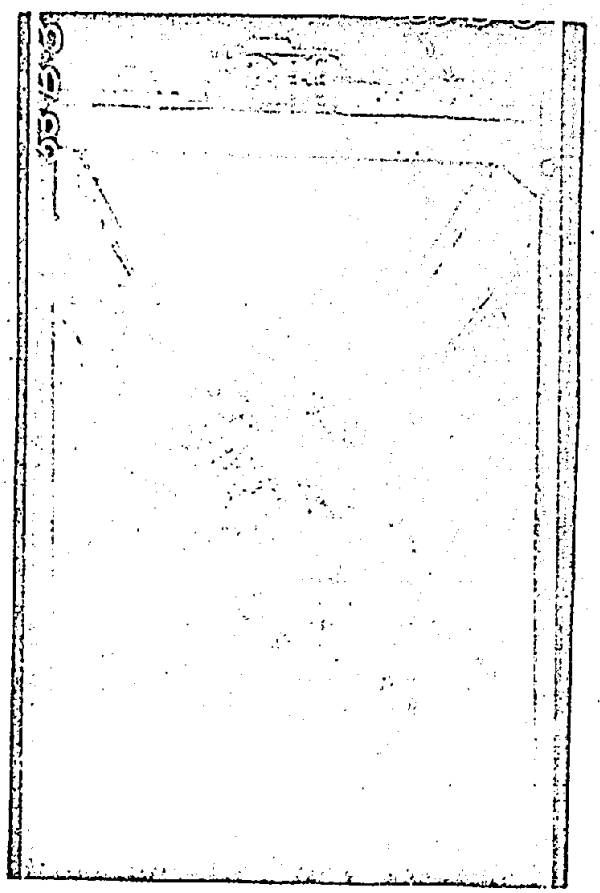
Flow 200,000 c.f.s.

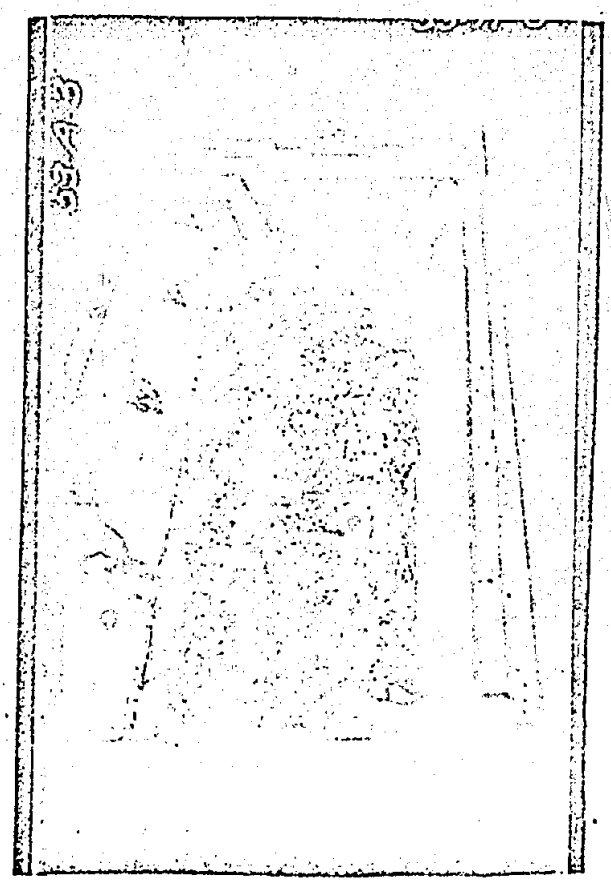
Flow 200,000 c.f.s.

With Baffles.

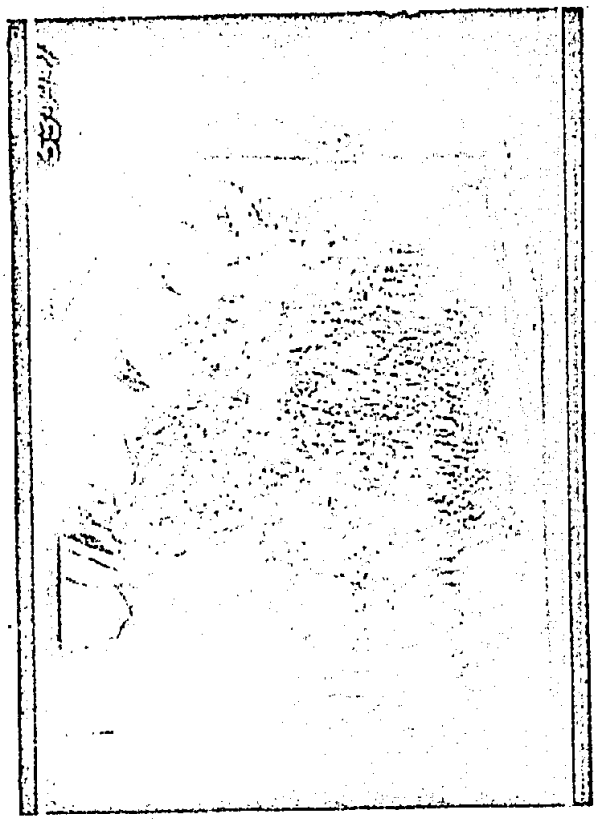


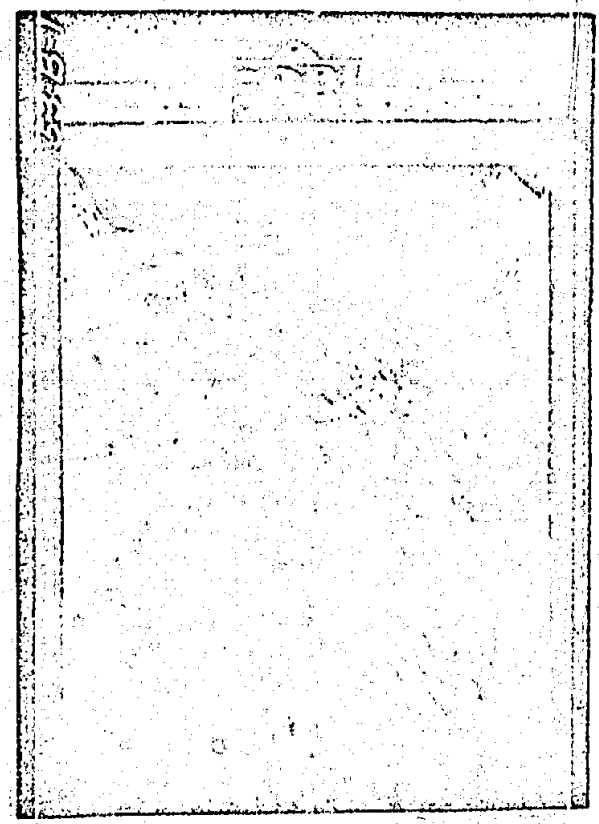
Set up.





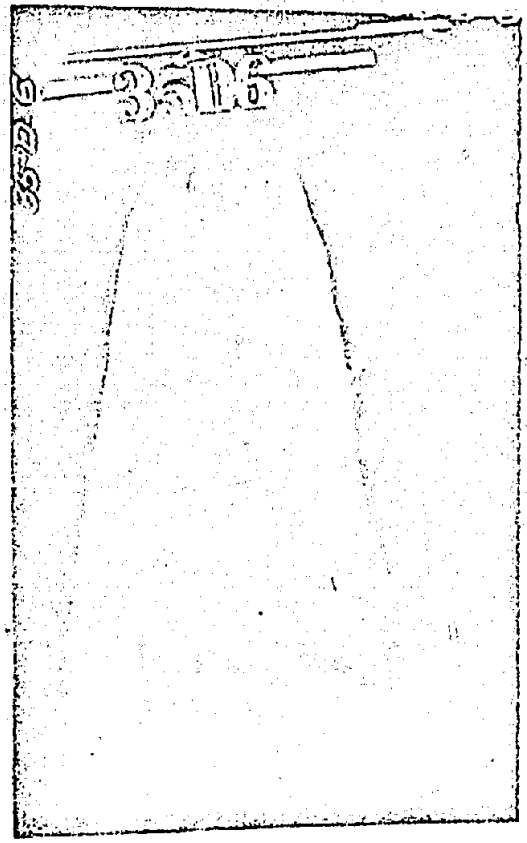
Flow 100,000 c.f.s.



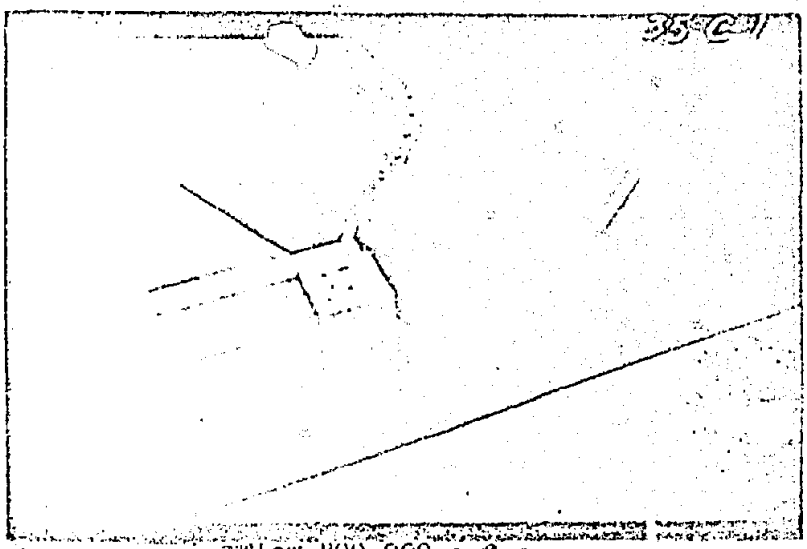


Flow 200,000 c.f.s.

End of Transition
Tunnel Pipe Removed



In Tunnel at End of Transition



Flow 200,000 c.f.s.

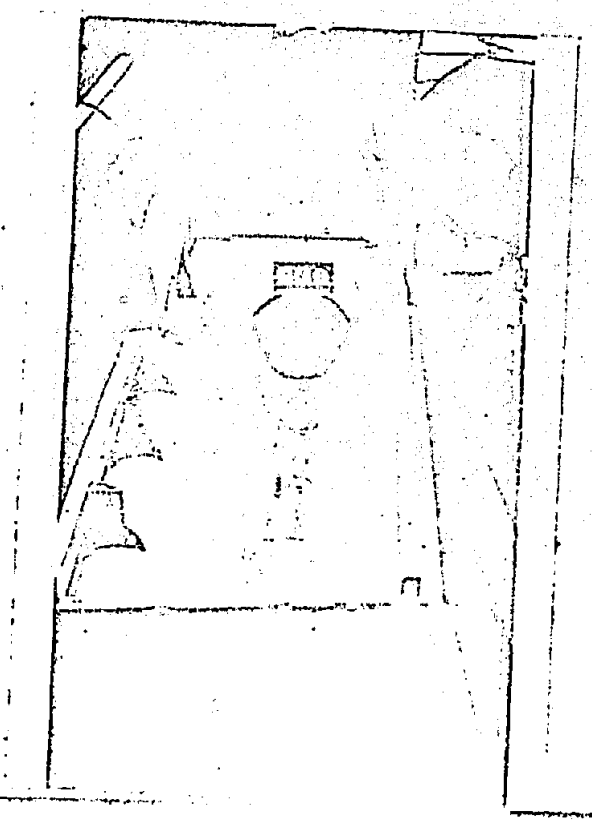
The flow down the tunnel with this set up was a shade less desirable, filling the shaft more than in the final design (Model 3-a), but appeared to be satisfactory. With the dentated baffles set in along the floor, conditions of flow were about as good as any we obtained with any set up, although they caused a higher water surface in the channel that cut the co-efficient of discharge down from 3.64 (required) to 3.57. The alteration made to the crest later, however, would allow this set up to pass the required quantity.

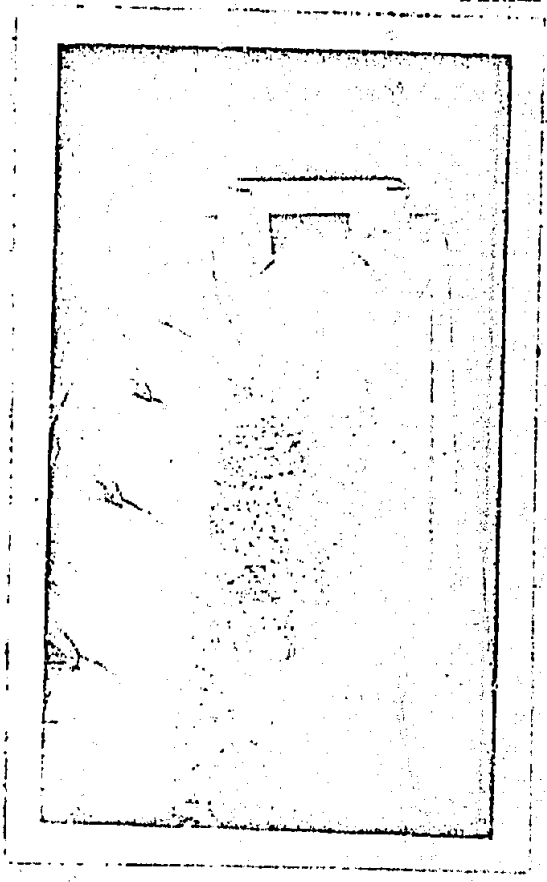
Comparison of these tests can be made with Tests 43 & 44, Page Model 3-A to check flow action in the designs using different weir lengths. From the photographs there seems to be little choice according to the behavior in the channel, although for mModel 3-A the flow down the tunnel transition was a bit more satisfactory.

MODEL NO. 3-A.

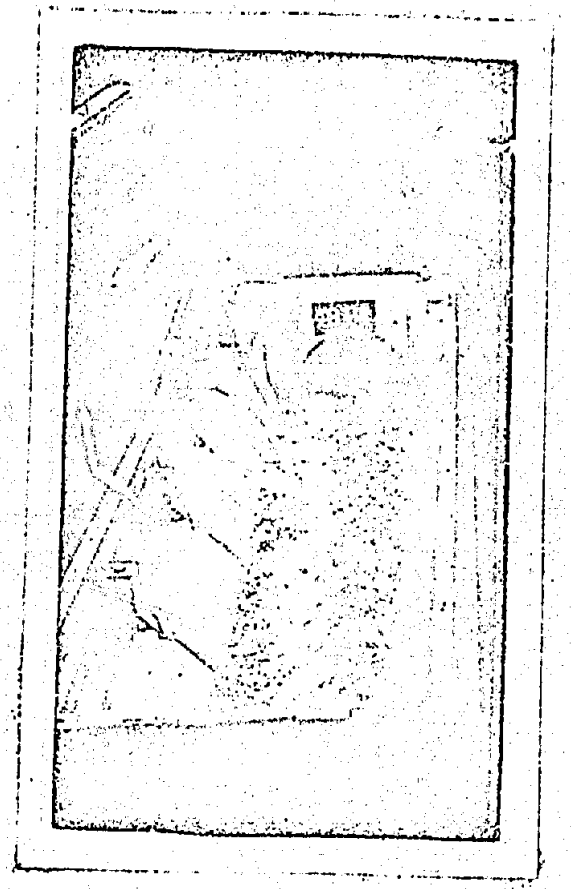
This set up produced the best flow conditions of any yet tested, that is, without cutting down the spillway capacity by excessive submergence of the crest, and incorporates the most beneficial features of design developed by the investigations, i.e., the weir located downstream from the end of the spillway and the offset in the tunnel entrance, as well as the flatter transition floor parabola discussed later.

With the baffles in along the floor of the channel, an improvement in the flow down the tunnel was noted, especially at the lower flows.

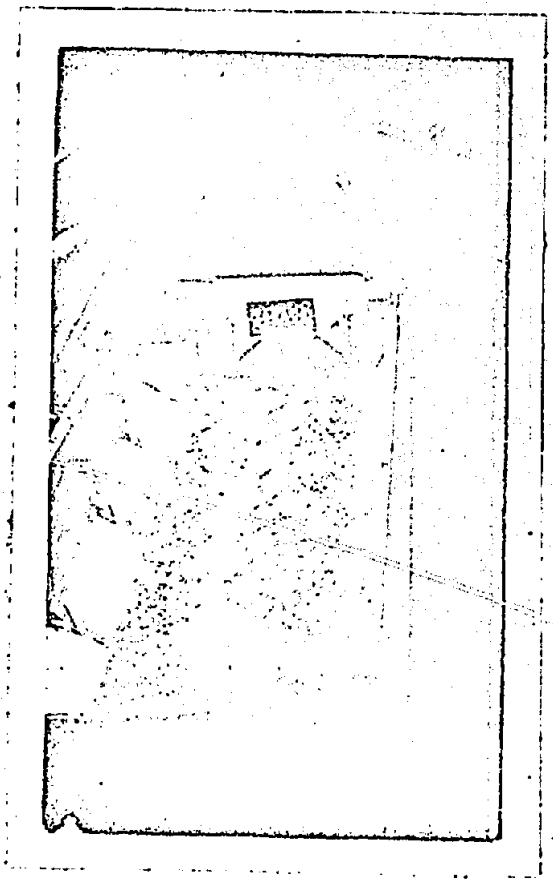


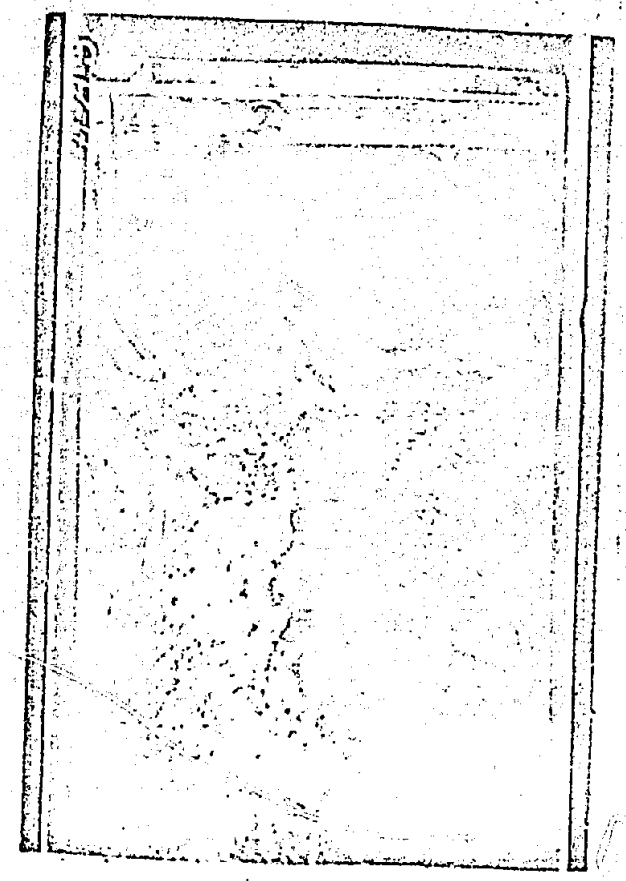


Flow 40,000 c.f.s.



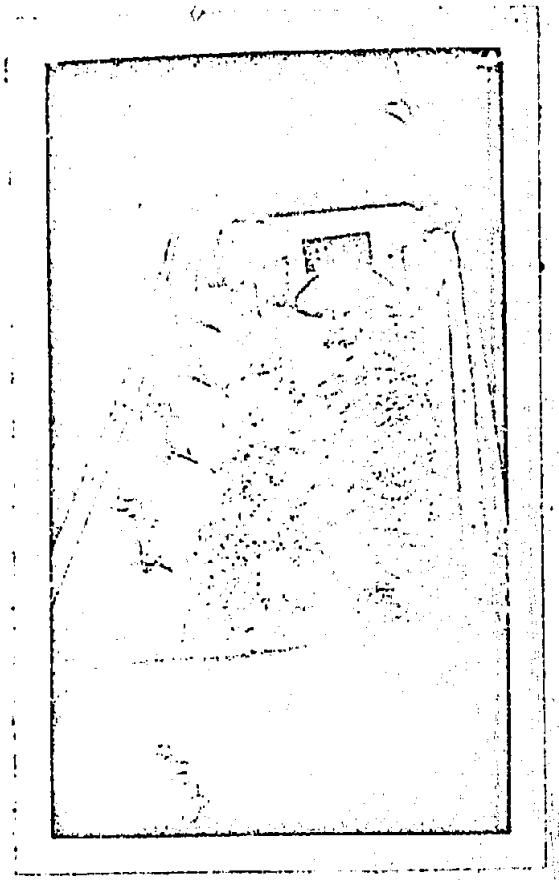
Flow 80,000 c.f.s.



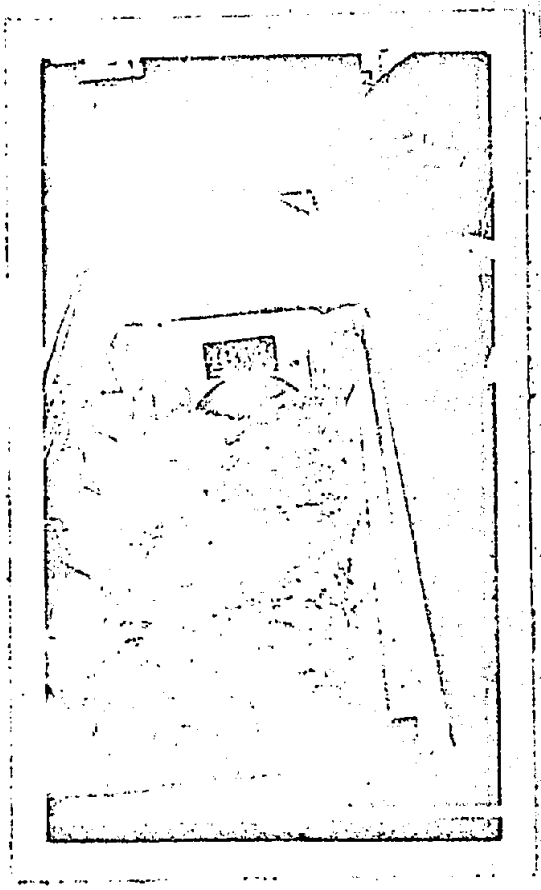


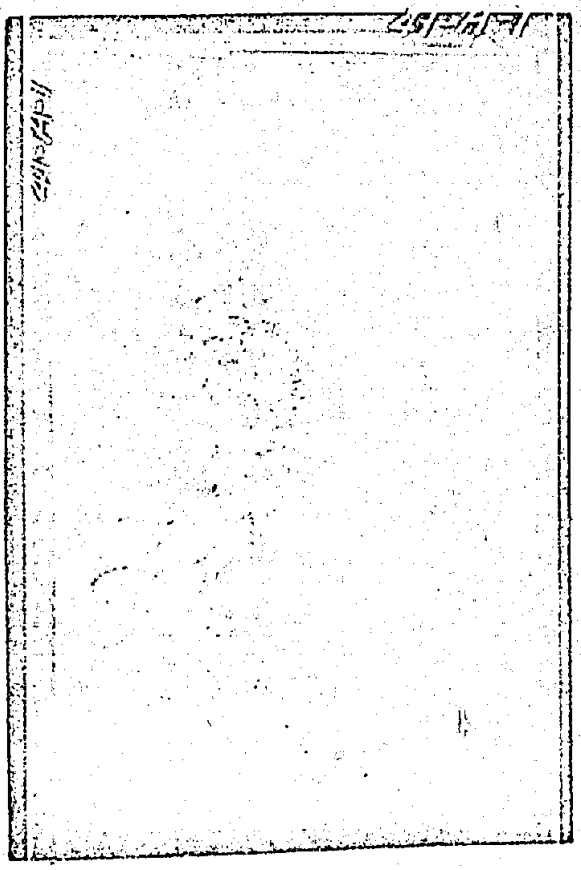
Flow 120,000 c.f.s.

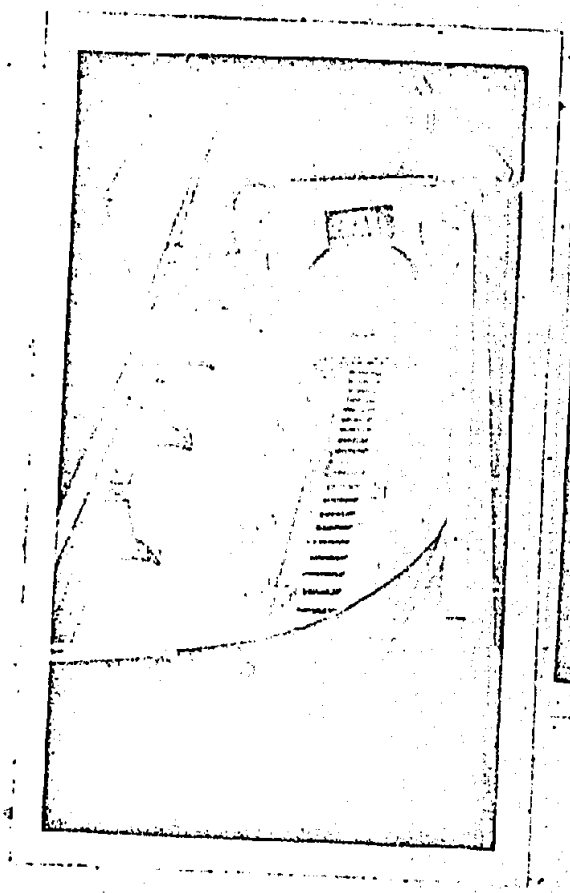
MODEL NO. 3-A FINAL DESIGN

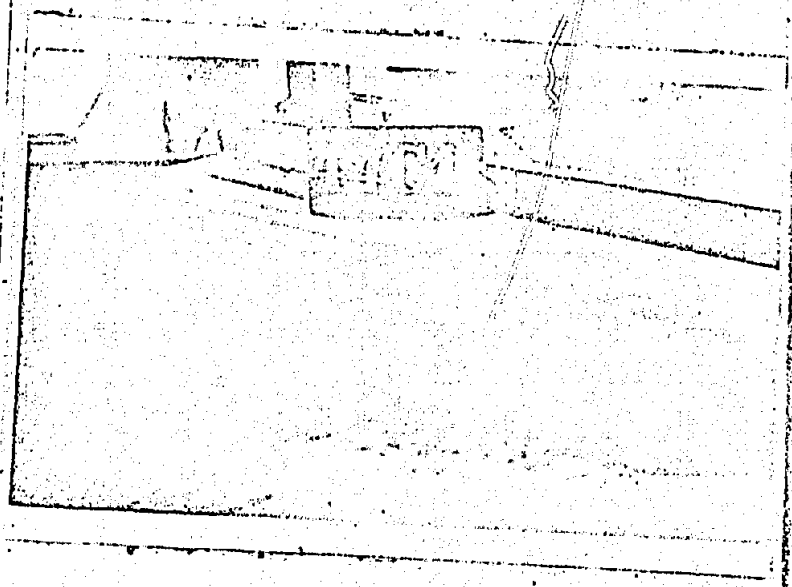


Flow 160,000 c.f.s.



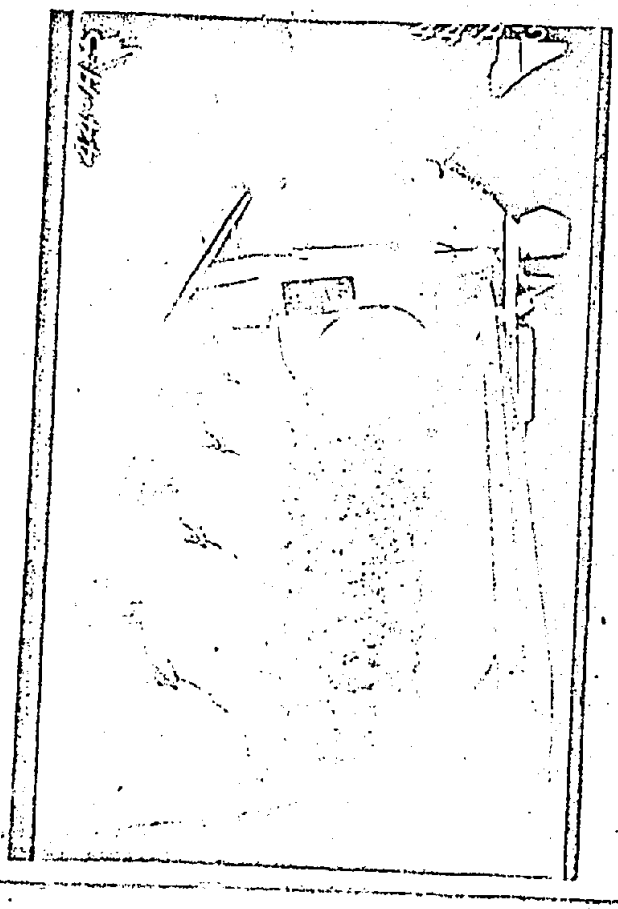




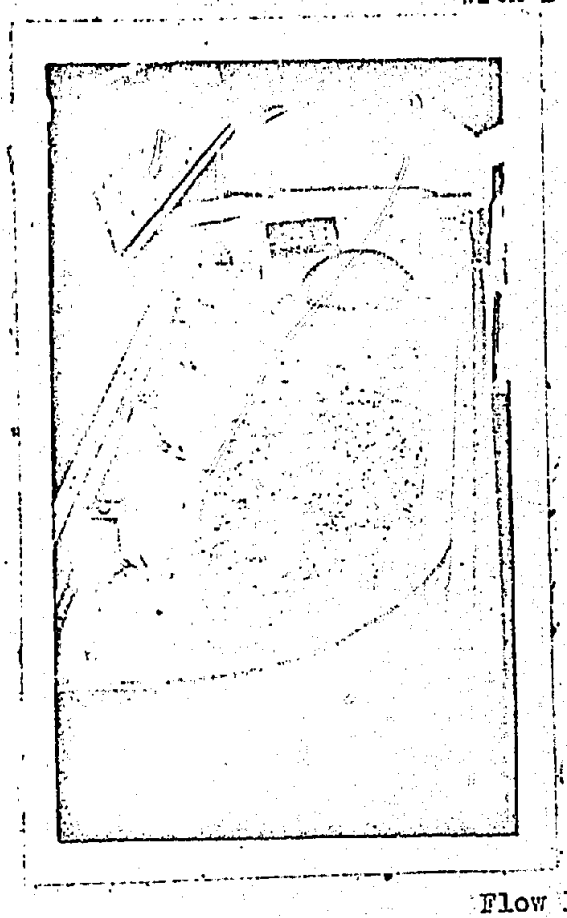


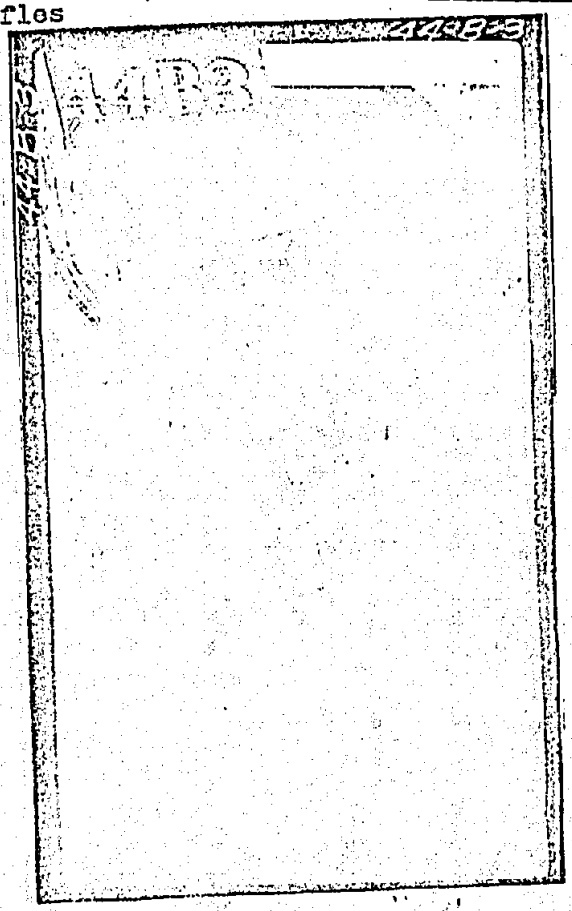
Set up

End Wing Wall - Flow 200,000 c.f.s.

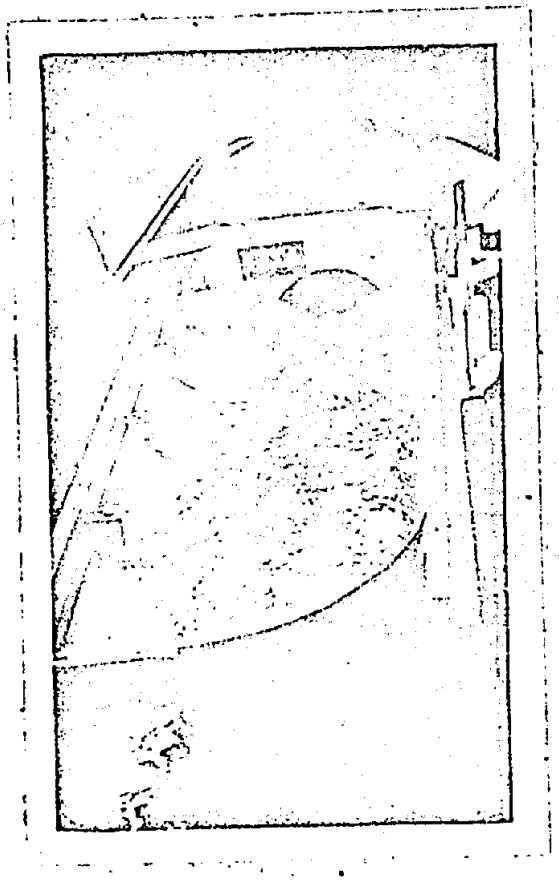


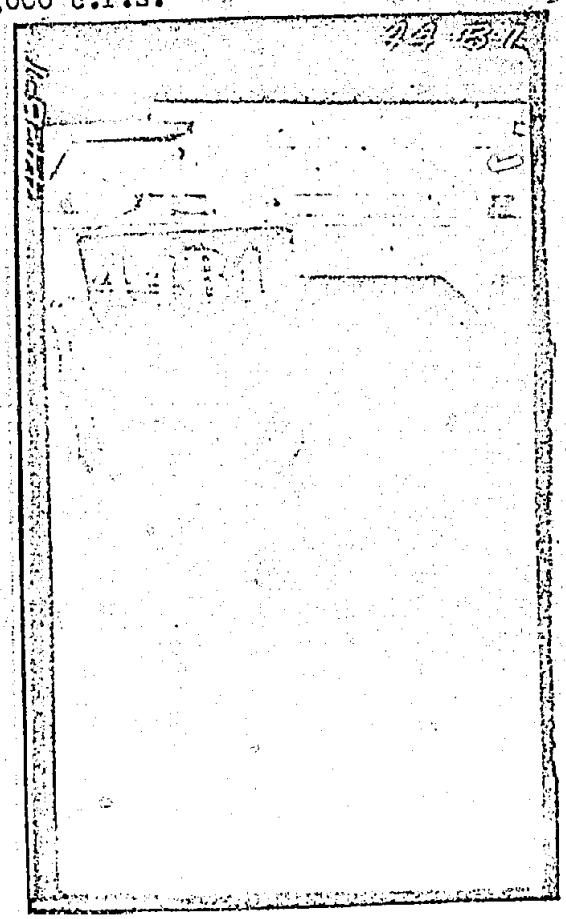
With Baffles





Flow 120,000 c.f.s.





Flow 200,000 c.f.s.

Compare these pictures with those of Test 38 Pages 10 & 11 in which the same set up was used except that the weir was 4.8 feet higher, See Plate No. 3. There is seen to be a marked improvement in flow conditions in the channel, according to the photographs, in the set up with the weir only slightly higher, but the apparent decided difference was not manifested in greatly improved flow conditions down the tunnel transition, although there was some improvement noted. The use of the higher weir is in the right direction but as previously stated, the set up for Model No. 3 necessitated a forebay elevation of about 1232.6 to pass the required 200,000 c.f.s. With the crest alteration made later, however, it was found that the capacity would be amply carried, if no baffles were used along the floor, and would just pass the required flow with them installed.

MODEL NO. 4

The set up for Model No. 4 is shown on Plate No. 5 and differs from Model No. 3-A, Plate No. 3, only in the slope of the transition floor, which was steeper for this set up. The pictures of the flow in the channel for this model do not differ from those of Tests 43 & 44, on Pages 19, 20 & 21, enough to include here.

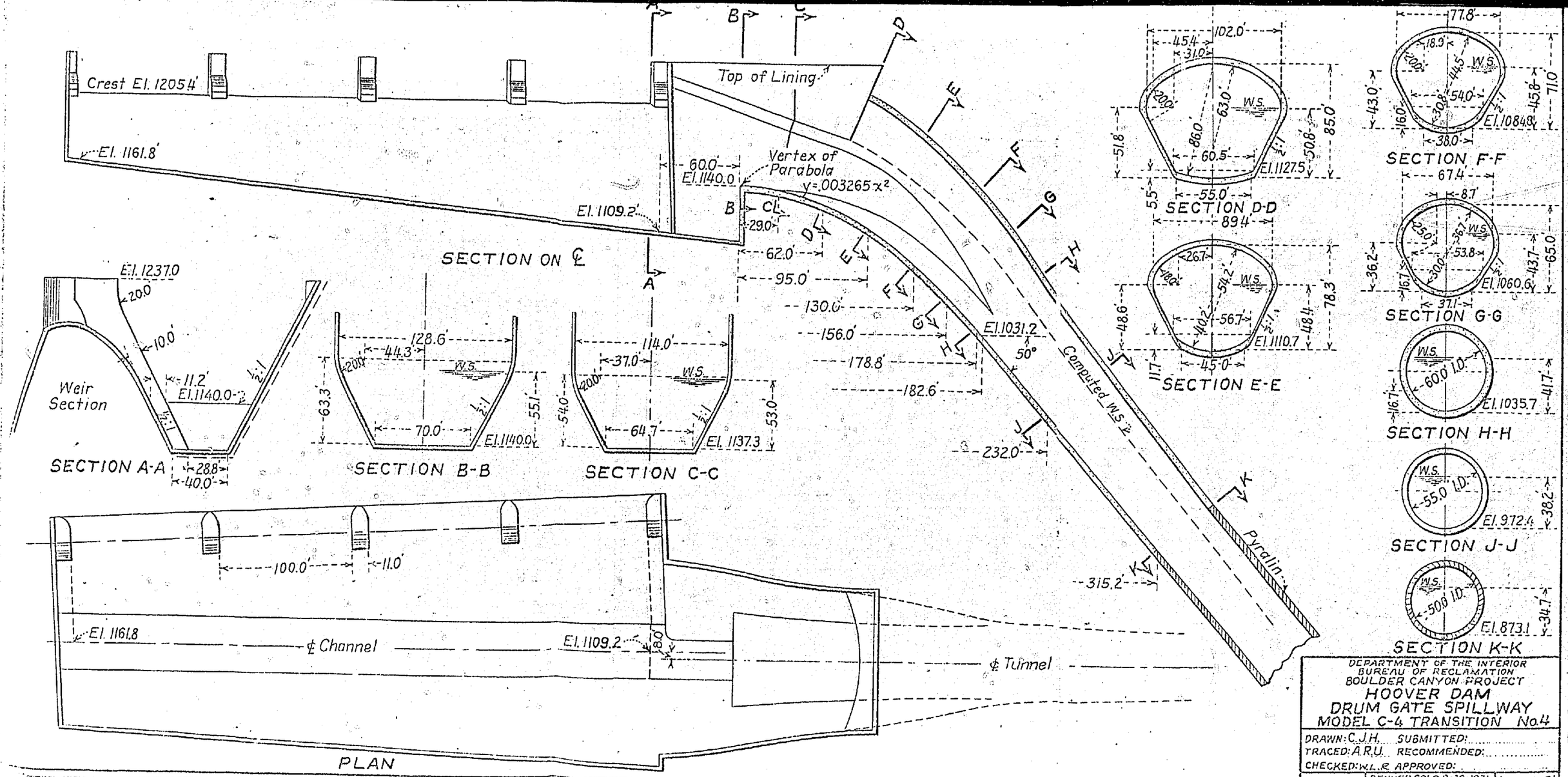
The water surface measurements are included in the appendix.

The flow down the tunnel for this set up was not as satisfactory as in Model 3-A, tending to splash more and fill the shaft to a greater depth. It was indicated that if the jet could be supported to a greater extent, that is, if the inclination of the shaft could be made flatter, better flow conditions down it would result.

MODEL NO. 5

Model No. 5, Plate No. 6, differs from Model No. 2, Plate No. 4, in that the floor slope of the transition was made flatter to check the result of the tendencies indicated in the tests of Models 3-A and 4 - that to lessen the abruptness of drop into the tunnel would be beneficial. The result was somewhat disappointing as very little improvement in the flow down the tunnel over the Model No. 2 set up was apparent, and the conditions of flow were still not as satisfactory as those of Model No. 3-A.

It would seem that the high weir does the work, the higher the better, which feature is the outstanding difference between this model and Model 3-A.



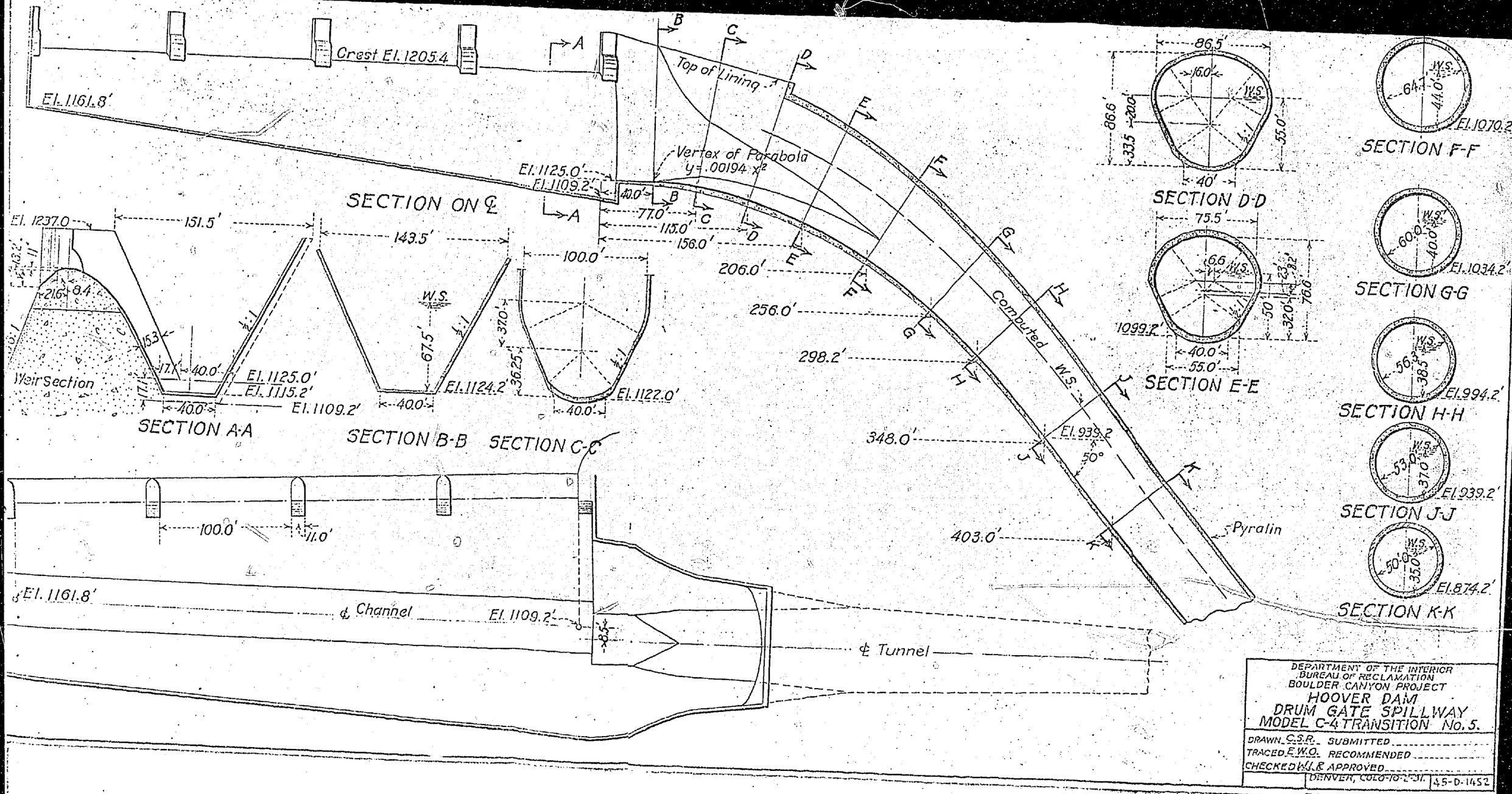
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT

HOOVER DAM
DRUM GATE SPILLWAY
MODEL C-4 TRANSITION No.4

DRAWN: C.J.H. SUBMITTED:
TRACED: A.R.U. RECOMMENDED:
CHECKED: W.L.R APPROVED:

DENVER, COLO 9-30-1931 | 45-D-1451

PLATE No. 5


Crest El. 1205.4
El. 1161.8'
Top of Lining
Vertex of Parabola
y = .00194 x²
El. 1125.0'
El. 1109.2'
SECTION ON ℄
Computed W.S.
Pyralin
El. 939.2
50°
El. 1237.0
151.5'
143.5'
100.0'
W.S.
Weir Section
El. 1125.0'
El. 1115.2'
El. 1109.2'
El. 1124.2'
El. 1122.0'
SECTION A-A
SECTION B-B
SECTION C-C
100.0'
11.0'
El. 1161.8'
℄ Channel
El. 1109.2'
℄ Tunnel
SECTION D-D
SECTION E-E
SECTION F-F
SECTION G-G
SECTION H-H
SECTION J-J
SECTION K-K
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HOOVER DAM
DRUM GATE SPILLWAY
MODEL C-4 TRANSITION No. 5.
DRAWN C.S.R. SUBMITTED
TRACED E.W.O. RECOMMENDED
CHECKED W.L.R APPROVED
DENVER, COLO. 10-2-31. 45-D-1452

Photographs of flow in this set up differ little from those of Tests No. 34 & 35 for Model No. 2, Page 16. Photographs of the maximum flow will be found on Page 16.

Water surface measurements curves will be found in the appendix.

BAFFLES.

Numerous and various types of baffles were tried in the channel to check the velocity of the spillway overflow and prevent it from piling up along the right wall, producing unbalanced flow down the tunnel.

Tests on some of the set ups will be discussed briefly later and only the two types that gave the best results will be considered now.

Sketch No. 1, Page shows a dentated baffle built along the channel bottom that gave very good results. Photographs 52-A-0, Page 13 and 44-A-0, Page 20 illustrate the arrangement.

This type of baffle is merely an offset ledge left in the bottom excavation, with overhanging blocks built projecting out from it, and is quite feasible structurally and economically.

In operation, the overflow jet is reversed back toward the spillway face, causing greater depth of flow along that side, which tends to level off the water surface, with consequent smoother and more symmetrical flow down into the tunnel. The dentates allow an enfiltration of flow on the right side that has very little transverse velocity to cause piling up on the wall.

The face of the baffle or ledge was set diagonally out across the channel to give a deflecting surface downstream, tending to cause more flow along the crest side. This also eliminates a tendence of the water in the channel to slosh back and forth in a regular recurring roll that was noticed when the baffle face was set on the center line. See Test No. 17.

The diagonal baffle, at the lower end of the channel, draws away from the weir face leaving a barrier across the full width of the channel over which the flow is symmetrical. (Patents pending - McConaughy & Randolph)

Operation of the baffle at the different stages of flow can best be seen from the 44 series pictures on Pages 20 & 21 and the 53 series on Pages 15 & 16. At the low flow of 40,000 c.f.s. the baffles are barely covered, but at 80,000 and 120,000 c.f.s. the beneficial flow results are beginning to be seen. Note the

leveling off of the channel water surface and the comparatively smooth flow. Contrast Photographs 44-A-3 with 43-A-3 which is the same set up without baffles. Note in Photograph 44-B-3 the straight line transparent flow at the tunnel entrance as compared to the turbulence seen in Photograph 43-B-3.

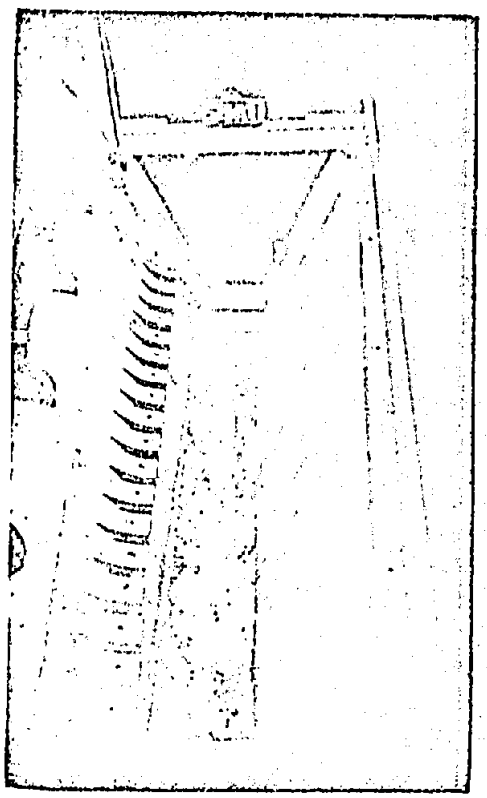
At the maximum flow of 200,000 c.f.s. the water in the channel backs up on the crest to such an extent as to deflect the overflowing sheet of water over the baffles so that they do not operate as effectively as at the lower discharges. Their beneficial action at this high flow, however, may be readily seen by contracting photographs 43-A-1 and 44-A-1.

Another type of baffle, or means of breaking the energy of the overflow, that gave very good results, is pictured in photograph 54-A-0 on Page 25. It consists of a false bucket located rather high up on the crest with dentated openings one third the bidth of the block.

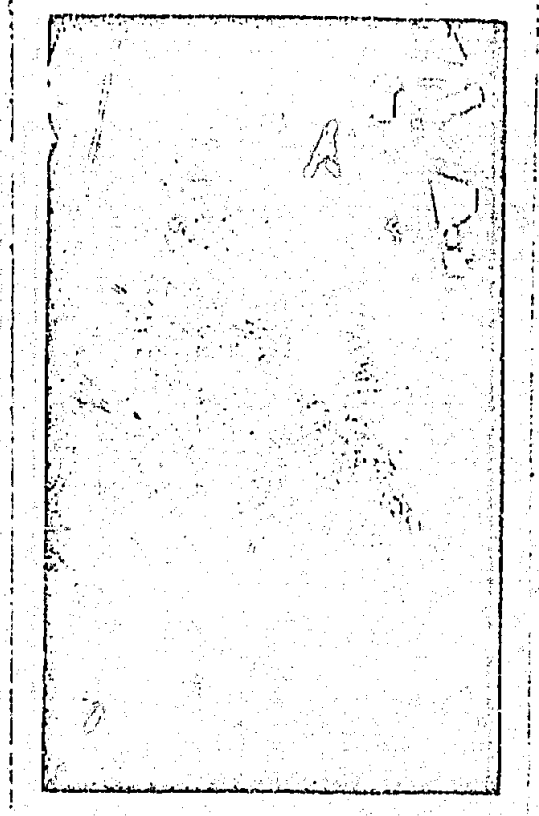
The theory of operation is to create two opposing rolls that break the energy of the overflow. The horizontal bucket blocks turn some of the overflow out across the channel where it strikes the back wall and is deflected downward meeting the upward flow that passed through the dentates which had traveled to the bottom and up the back wall.

The blocks must be set high on the crest in order to allow room for the reverse roll to form under them. This is somewhat objectionable at low flows as the jet sprays off them to the channel floor. For about half the length of the crest, however, there is a pool formed by the weir below, to receive the impact of the overflow sheet. The pool rapidly becomes deeper as the flow increases and it is only at exceptionally low flows that the bottom is exposed. It does not seem that the impact on the floor, even if exposed, would be greater than the impact on the back wall in the operation without the baffles.

The following photographs may be contrasted to check flow conditions without and with the two types of baffles discussed above. Flow down the tunnel was materially improved by the use of either baffle, conditions being more favorable with the baffle in the floor. See photographs 52-A-0 and 53-A-1 on pages 13 & 14 for flow without baffles. See photographs 53-A-0 and 53-A-1, Pages 15 & 16 for flow with the floor baffles set in.



Set up - Crest Baffles



Flow 200,000 c.f.s.

CREST ALTERATION.

The spillway crest as first built gave a coefficient of discharge slightly less than than required to allow a flow of 200,000 c.f.s. at a head of 266 feet over the crest with the set up as shown in Model 3-A. This was due to some extent to the submergence on the upper end of the crest but as this submergence seemed beneficial in smoothing out the flow in the channel, as attempt was made to increase the coefficient by an alteration to the crest. This consisted of slicing away the upstream nose of the crest on a 45 degree slope as shown on Sketch No. in the appendix. An increase of the coefficient from 3.60 to 3.76 was obtained from tests on the Model 3-A set up. A slight loss was indicated when the drum gates were installed on the crest, as shown on Curve Sheet No.

The use of the baffles along the channel bottom in Model 3-A cause an increased depth of water along the crest side, cutting the coefficent from to about 3.67. Which this coefficient the capacity is obtained, however, as the "C" required is 3.64.

With the dentated buckets along the crest face, the coefficient is not decreased perceptibly.

If the baffles in the bottom are not going to be used in the final design, the indications are that a slightly higher weir could be used at the transition entrance, which would aid flow conditions down the incline. A test made with a false addition to the top of the weir in Model 3-A, bringing it up to El. 1144.8, indicated a coefficient of 3.70 which is ample to allow the maximum discharge to pass.

Or perhaps, the right back wall could be moved in at the upper end raising the water surface, to improve flow conditions, but not enough so that the submergence causes a decrease in the maximum capacity required.

Tests up to Test 46 were made with the original crest; from Test 46 to Test 56 with the altered crest; and from Test 57 on, with drum gates installed in the crest.

The whole of the above discussion treats with the main alterations only, made during the investigations, and comments on each of the seven transition models tested, but there were numerous and various experiments performed on each of these models, alterations in the form of false weirs, bottoms and sides and varied designs of baffles that have not as yet been touched upon.

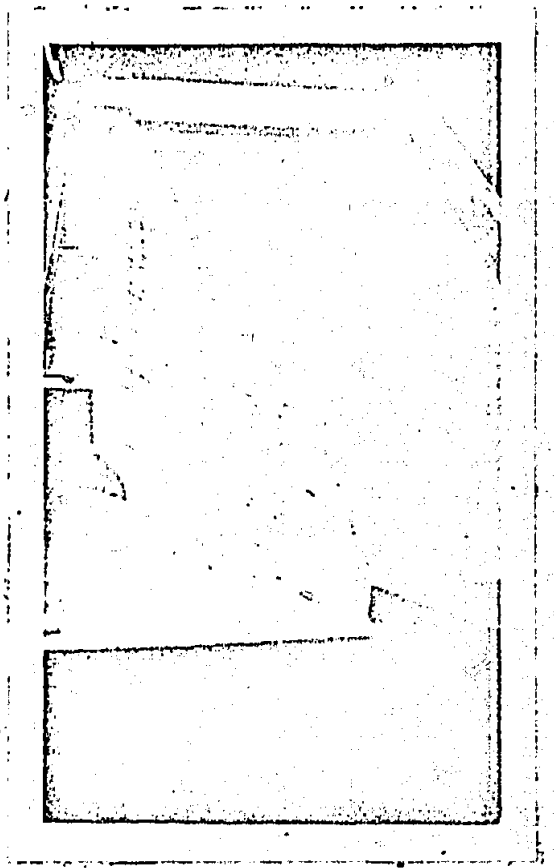
Some of these experiments were good and gave vital leads to the development of the final design, some, naturally were in the wrong direction. In the appendix will be found an entire list of the experiments performed to date, arranged in outline form. Data on those not included in this report may be found in the Laboratory files for reference, if necessary.

Following is a brief comment on some of the minor experiments. Sometimes it is as valuable to know what not to do as it is to know what to do.

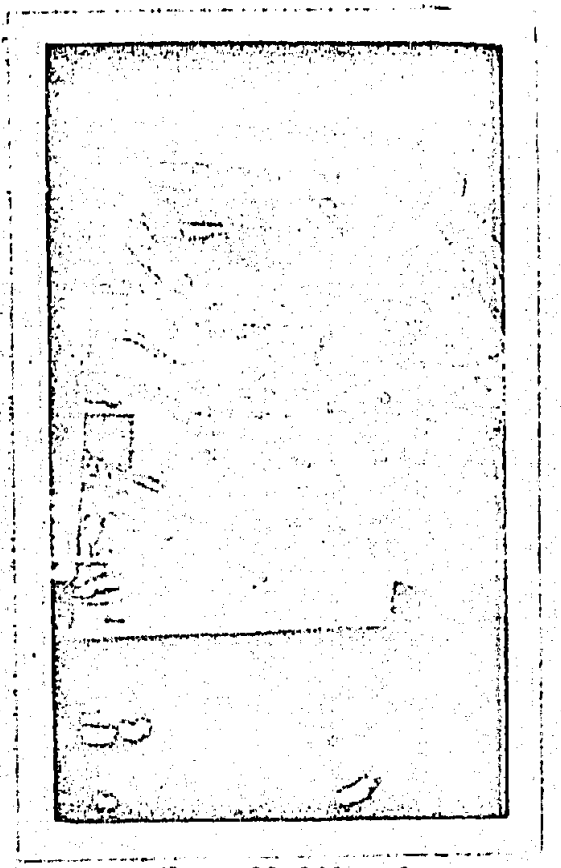
MODEL NO. 1.

The picture below shows a false floor set perpendicular to the back side. The theory was that this would raise the water surface on the crest side as well as direct the overflow jet against a normal surface on which the tendency to ride up it would be less than if the wall was at an obtuse angle.

The photograph of the maximum flow shows that there was little improvement in the conditions. Compare with 12-A-5 on Page 5.

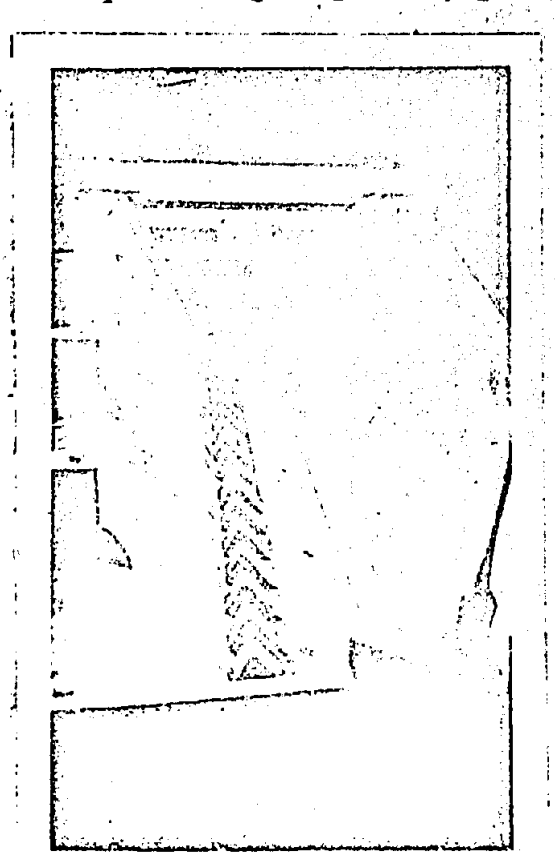


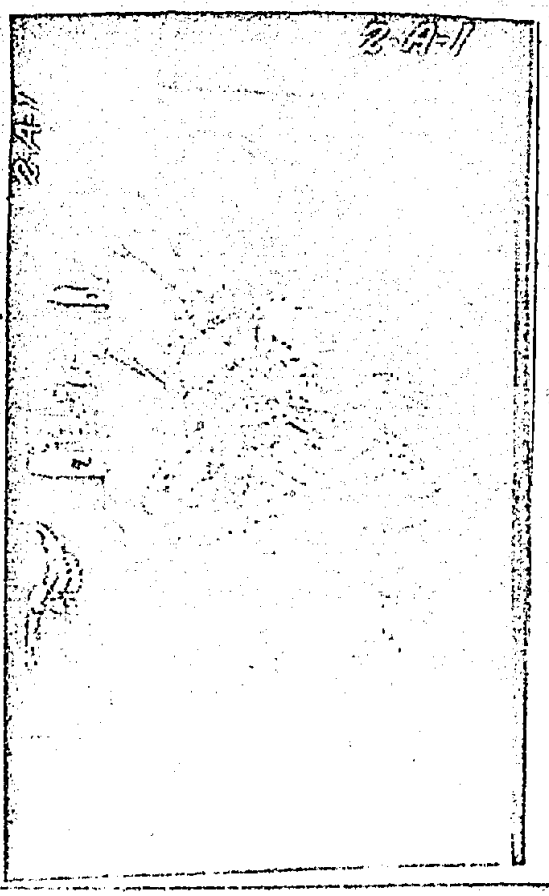
Set up



Flow 200,000 c.f.s.

Dentate blocks were tried on the floor, at positions, against the back wall, on the center line, and against the crest face. The latter position giving fairly good results, as pictured below.





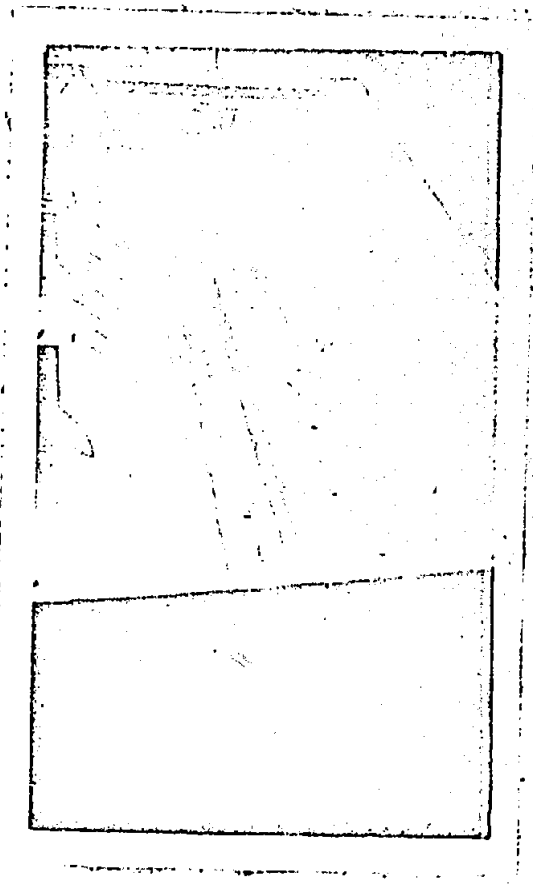
A solid sill in place of the dentates was tried, but the deflected jet created too much turmoil for satisfactory performance.

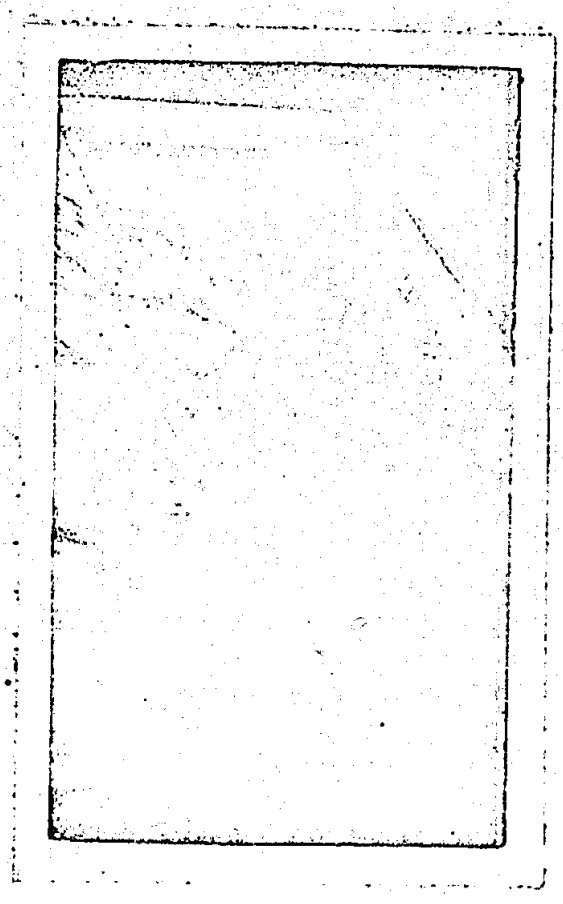
A plain offset in the channel floor on the right side as pictured below, smoothed out the surface flow considerably. With a dentated sill set along the front edge, conditions of flow were even better. This led to cutting the dentates in the offset ledge itself and projecting the blocks out over the channel as seen in photographs 44-A-0 and 53-A-0 with marked improvement.

With the shelf on the left or crest side there was not improvement in the flow discernible.

MODEL NO. 1

Offset Ledge in Channel Bottom



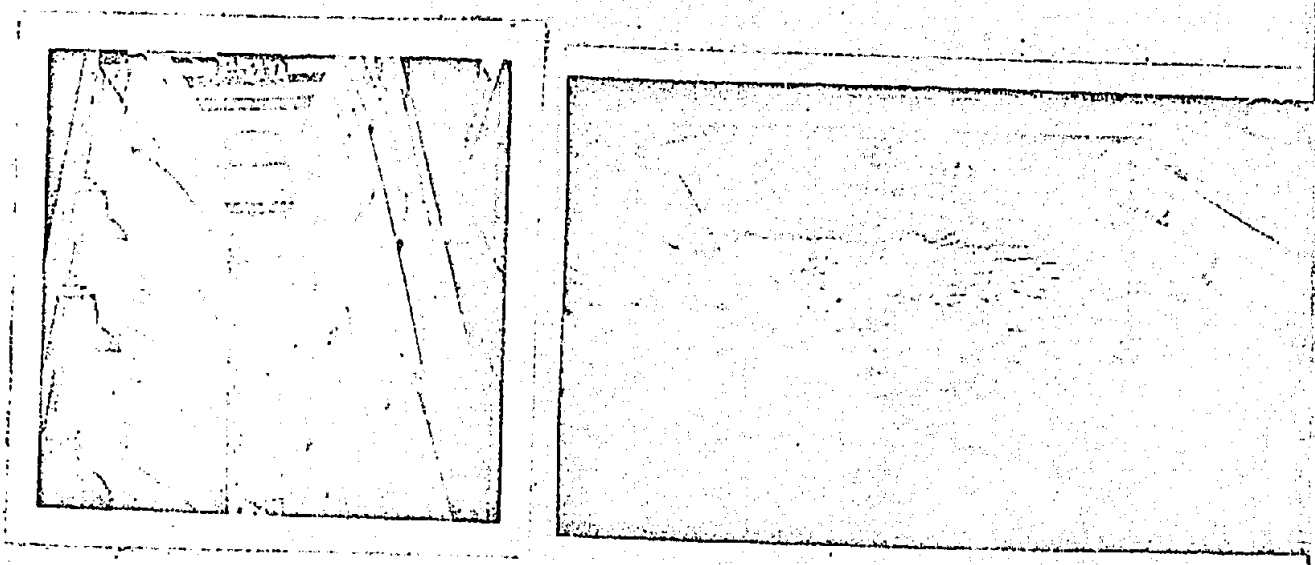


MODEL NO. 1-A

A false right wall was placed in the channel, on the center at the upper end, and coming tangent to the original wall at the lower end. This, of course, decreased the capacity of the trough and raised the water surface which improved conditions of flow down the tunnel. However, in this instance the channel was narrowed too much and the submergence of the crest was great enough to choke the capacity discharge.

Indications were that the channel should be made narrow at the upper end with a flatter bottom slope than the original design, or in other words leave the back wall where it is and flatten the floor slope.

False side wall & Weir at El. 1145



Set up Flow 200,000 c.f.s.

Photograph 25-A-4 pictures almost ideal flow conditions at the tunnel entrance.

MODEL NO. 1-A

A false right wall was placed in the channel, on the center at the upper end, and coming tangent to the original wall at the lower end. This, of course, decreased the capacity of the trough and raised the water surface which improved conditions of flow down the tunnel. However, in this instance the channel was narrowed too much and the submergence of the crest was great enough to choke the capacity discharge.

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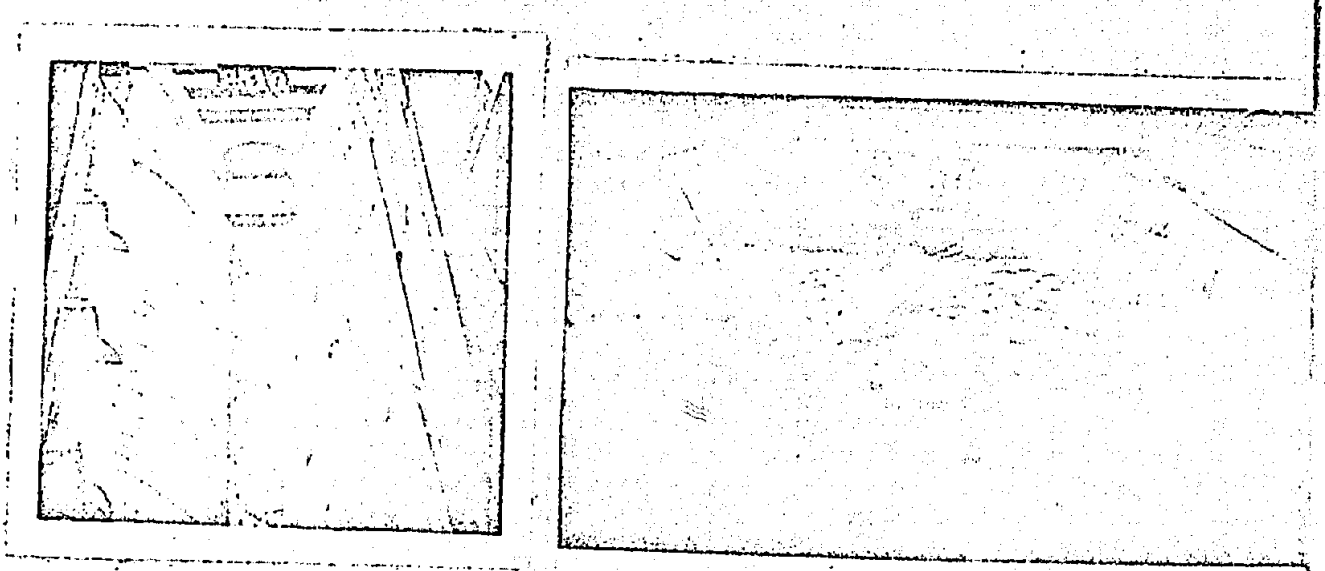
False side wall & Weir at El. 1145



Set up Flow 200,000 c.f.s.

Photograph 25-A-4 pictures almost ideal flow conditions at the tunnel entrance.

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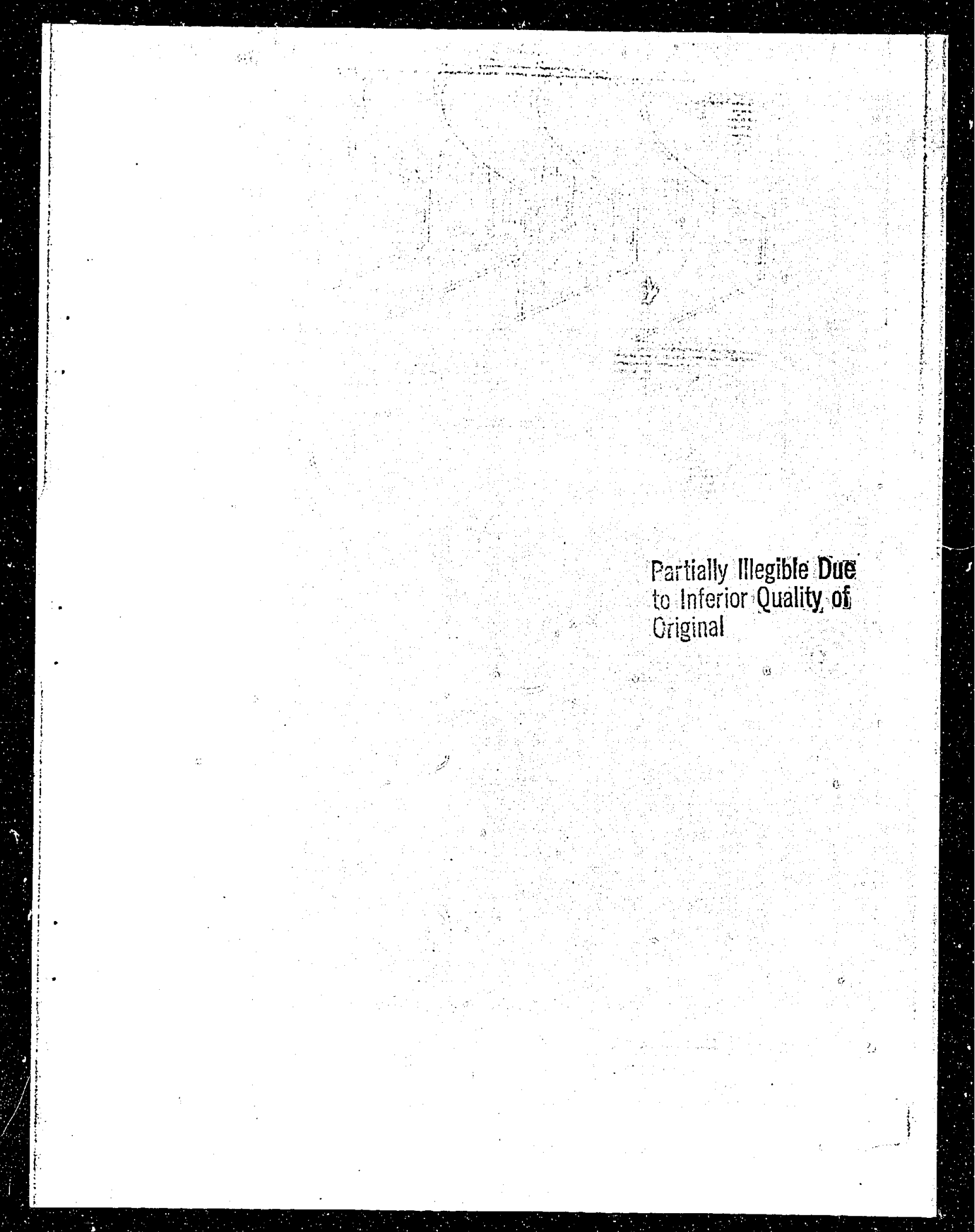

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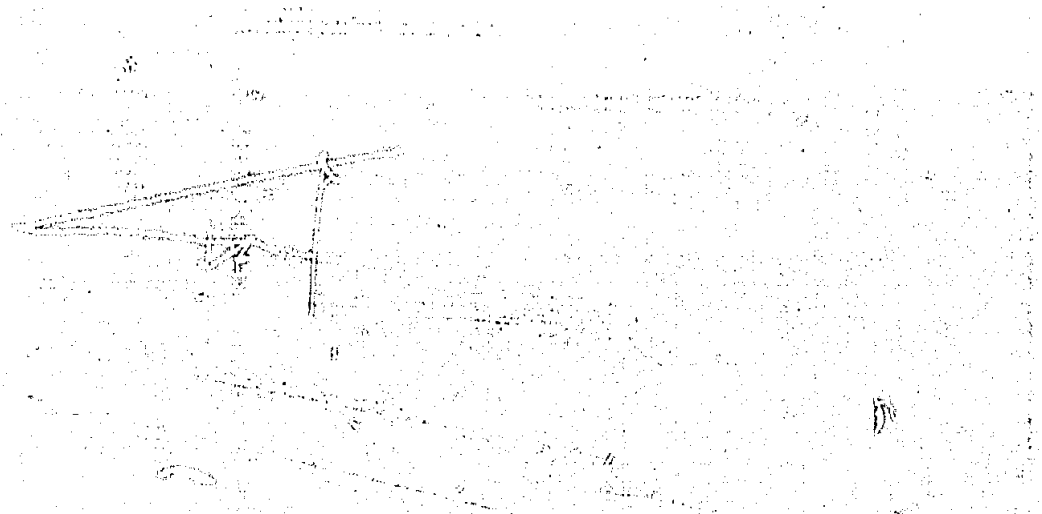

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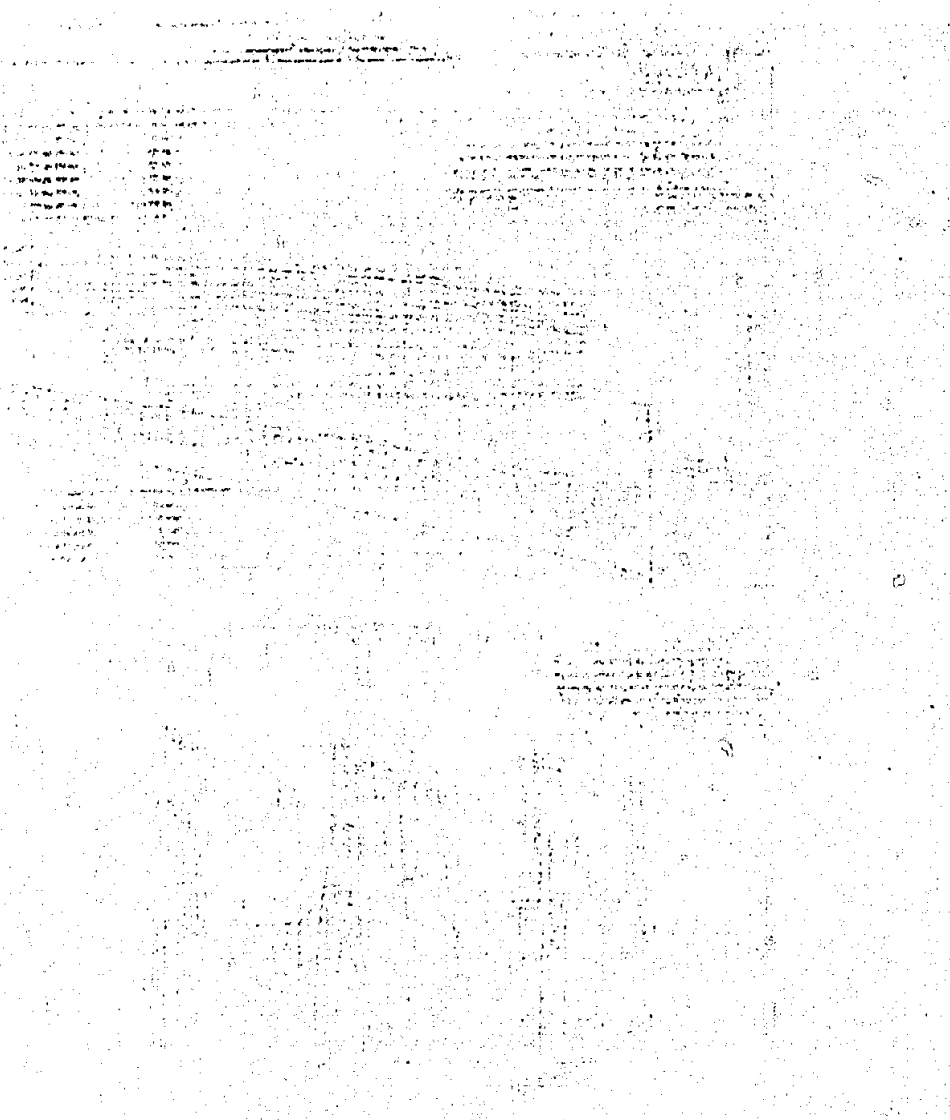

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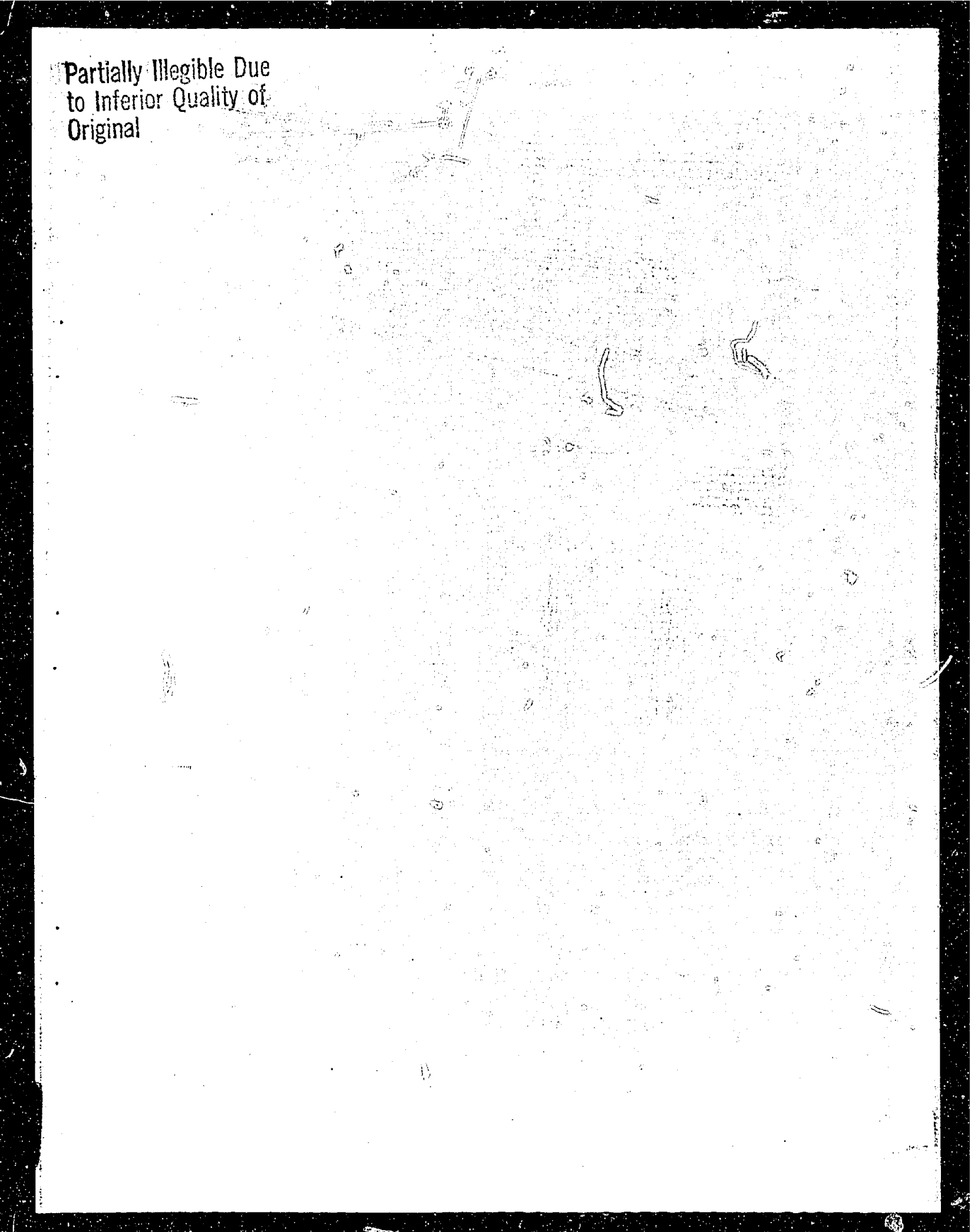

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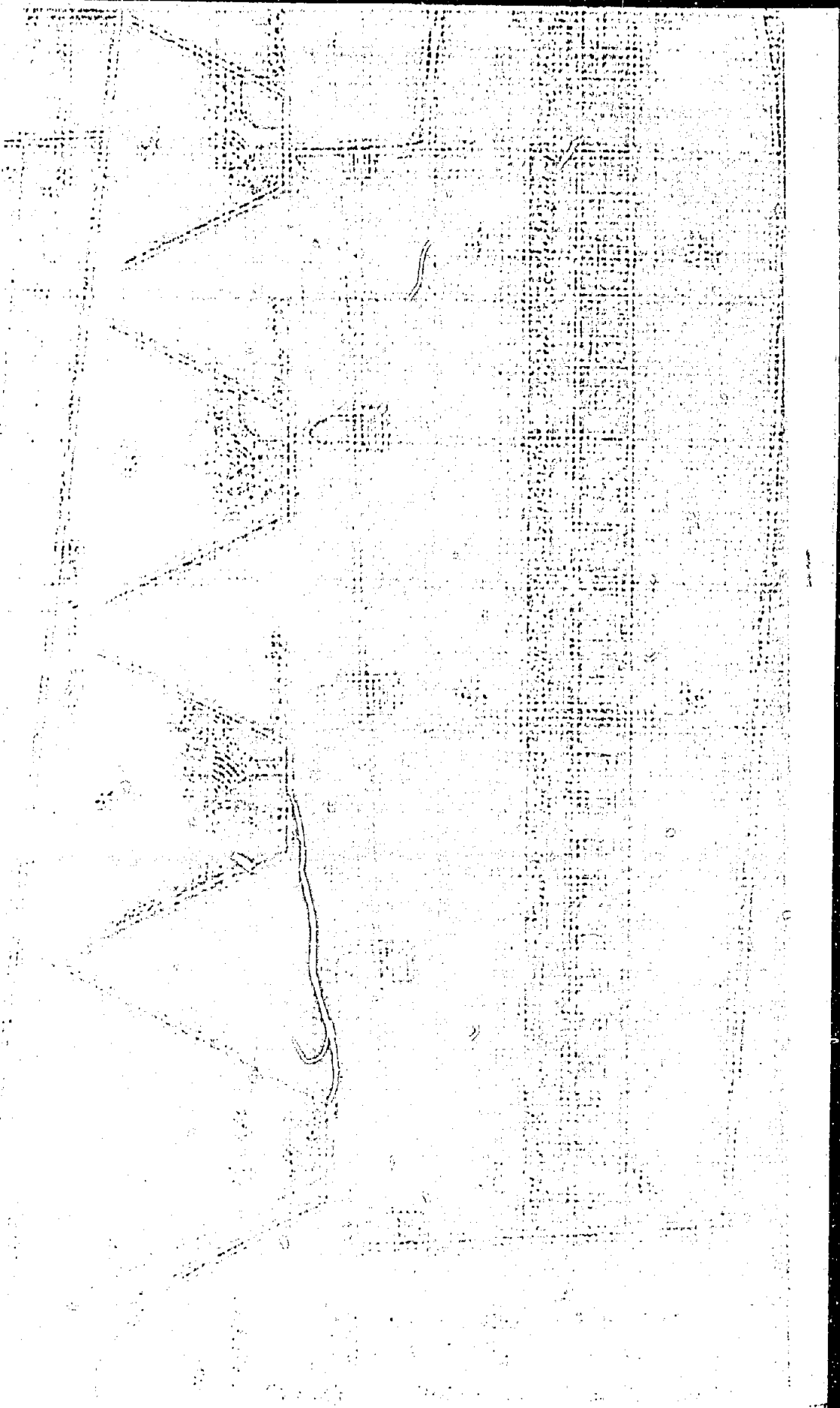

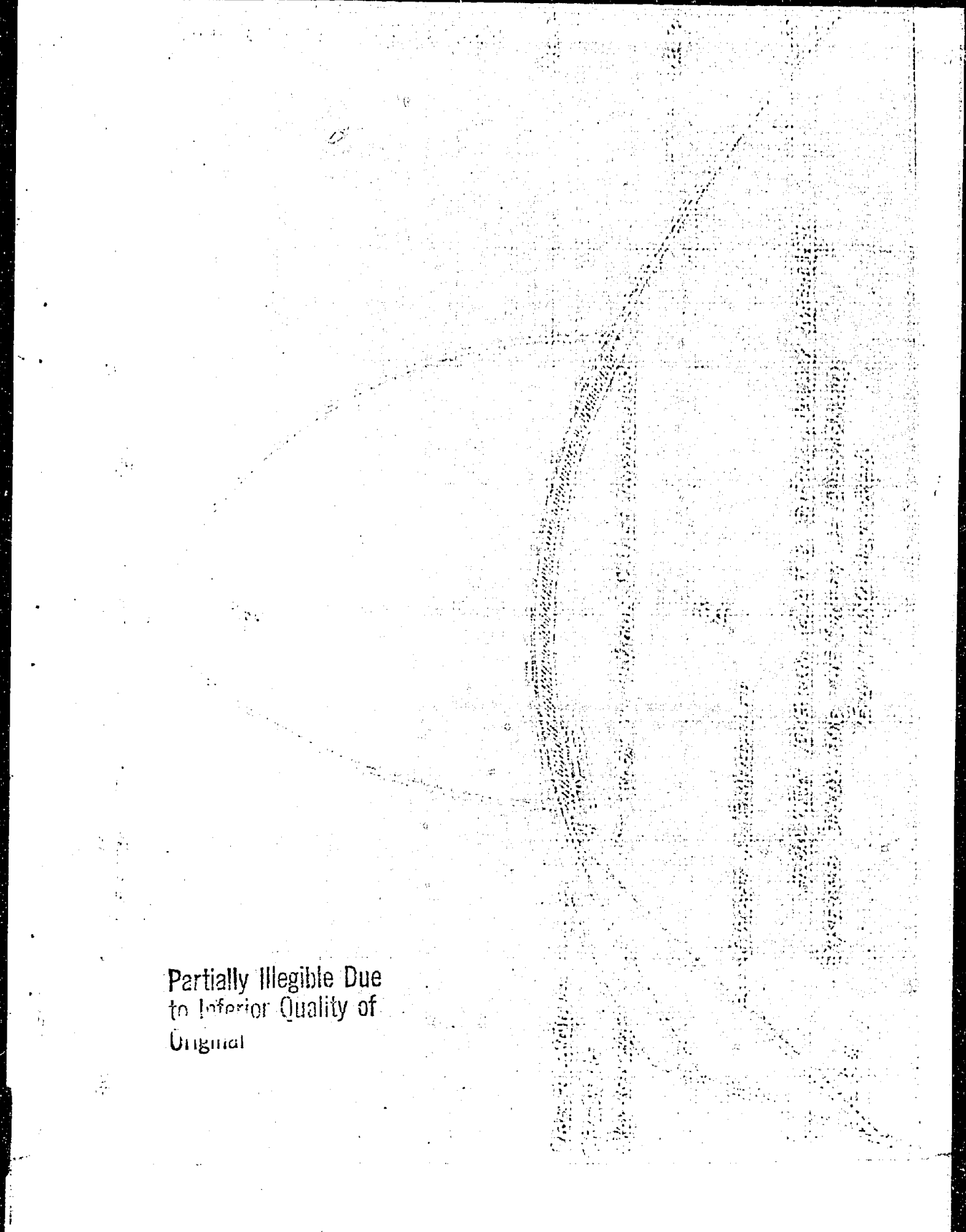

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to Inferior Quality of
Original

THE STONEY GATE DESIGN

SIDE CHANNEL SPILLWAY

Tested July-August, 1931

INDEX OF PHOTOGRAPHS.

Photograph Number	Page.
H	2
K	2
K-7	3
K-13	3
Point gage	3
Piezometers	4
6-B-6	9
6-A-10	10
6-B-11	9
6-A-16	11
6-B-16	11
6-A-20	11
6-B-20	111
7-A-3	7
7-B-3	7
8-A-1	17
9-A-1	8
9-B-1	8
11-A-3	6
11-A-5	15
11-A-6	6
13-D-1	15
13-B-5	15
13-A-5	15
13-B-6	16
14-B-1	21
14-C-1	21
14-A-3	21
17-A-1	17
17-A-4	17
18-A-1	18
18-A-4	18
19-A-1	13
19-A-2	13
20-A-1	12
20-A-5	12
20-D-6	12
21-D-1	17
21-B-1	19
21-C-1	19

INDEX OF PHOTOGRAPHS.

Photograph Number	Page.
H	2
K	2
K-7	3
K-13	3
Point gage	3
Piezometers	4
6-B-6	9
6-A-10	10
6-B-11	9
6-A-16	11
6-B-16	11
6-A-20	11
6-B-20	11
7-A-3	7
7-B-3	7
8-A-1	17
9-A-1	8
9-B-1	8
11-A-3	6
11-A-5	15
11-A-6	6
13-D-1	15
13-B-5	15
13-A-5	15
13-B-6	16
14-B-1	21
14-C-1	21
14-A-3	21
17-A-1	17
17-A-4	17
18-A-1	18
18-A-4	18
19-A-1	13
19-A-2	13
20-A-1	12
20-A-5	12
20-D-6	12
21-D-1	17
21-B-1	19
21-C-1	19

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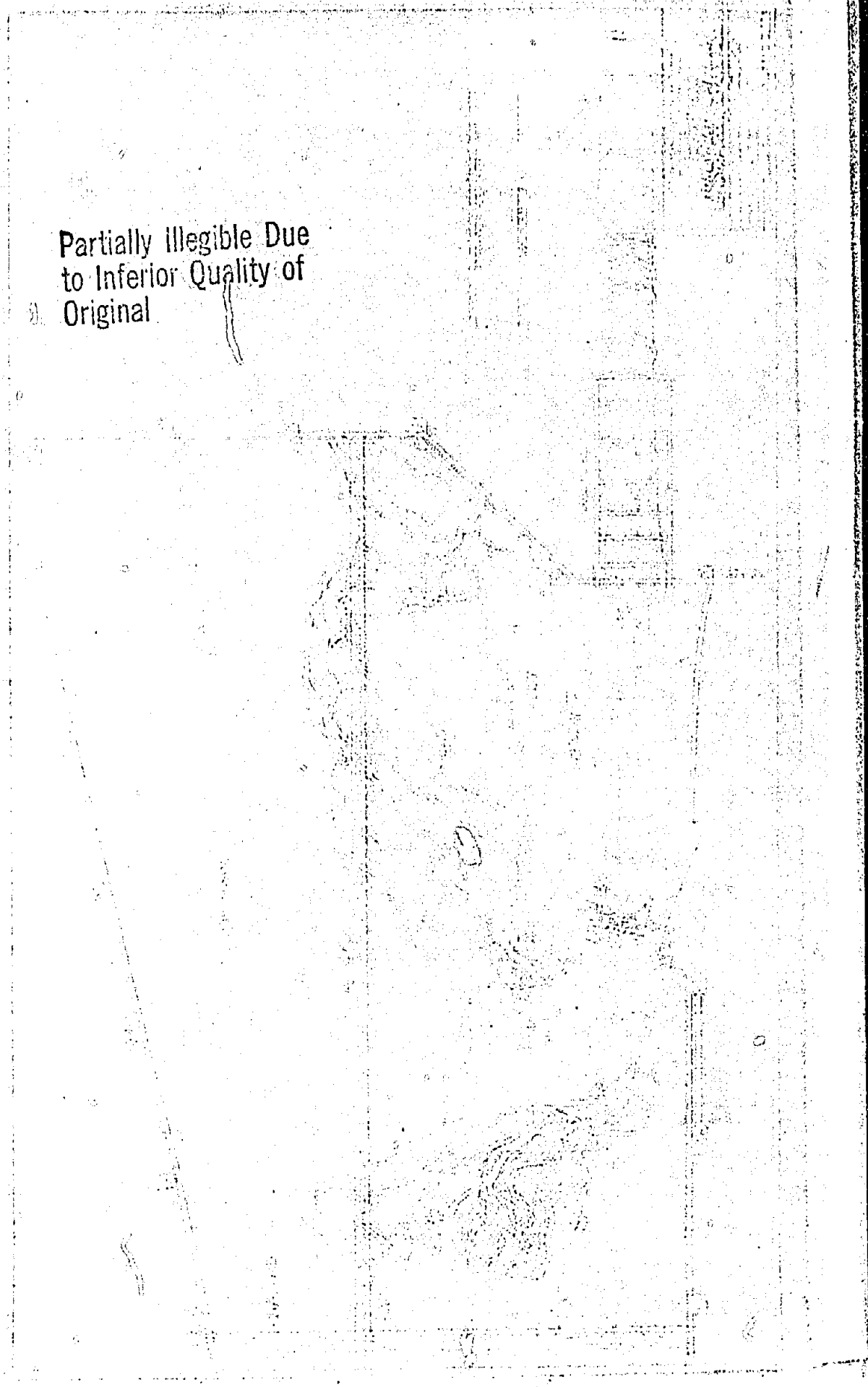

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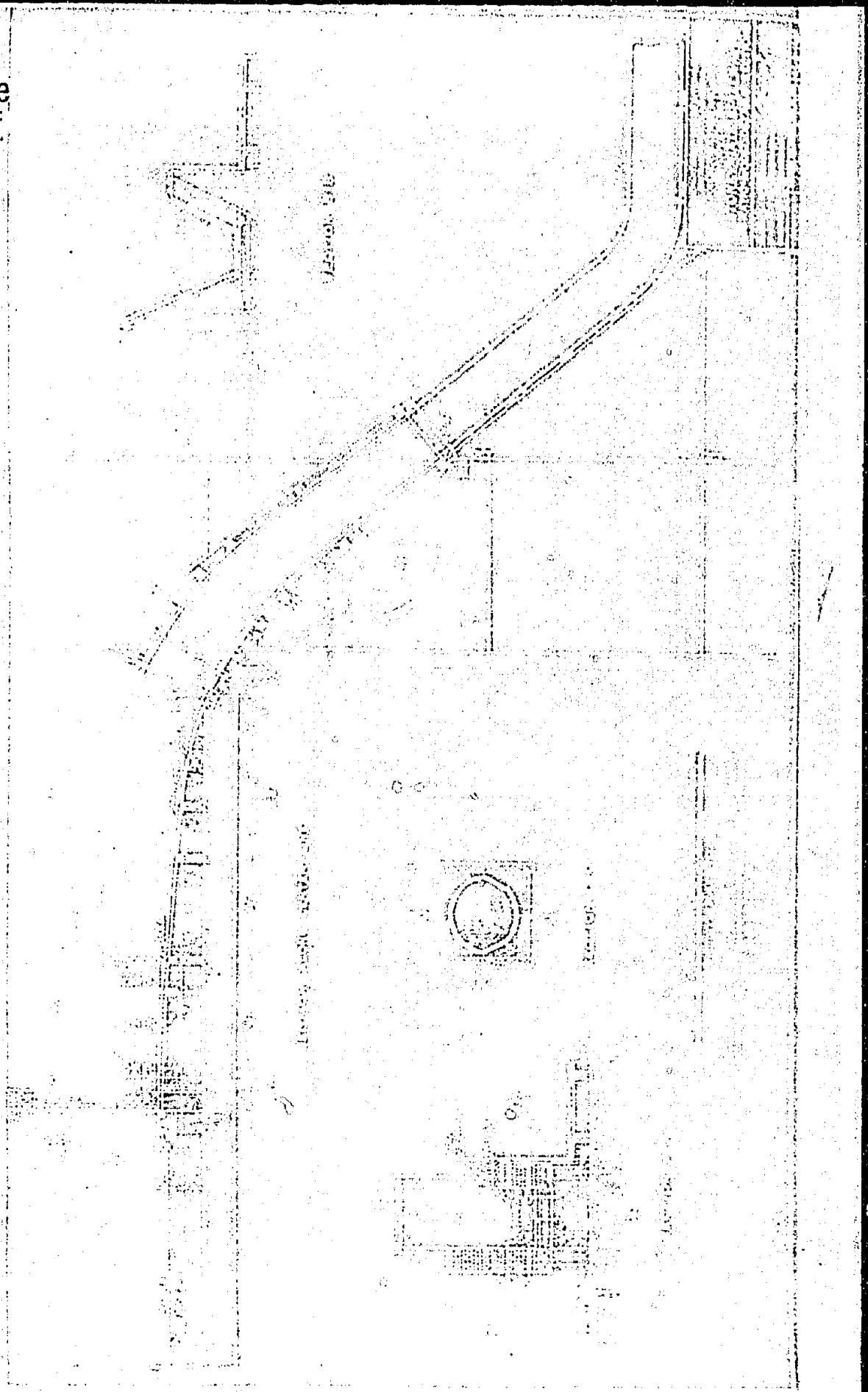


UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Denver, Colorado
September 28, 1931

Report on

HOOVER DAM SPILLWAY MODEL TESTS

STONEY GATE SIDE CHANNEL DESIGN

made at
the Hydraulic Laboratory of the Colorado Agricultural College at Fort Collins, Colo.

July - August, 1931

R. R. Randolph, Jr.

One of the contemplated designs for the Hoover Dam spillways was a side channel spillway layout with a large Stoney Gate at the entrance to the channel, details of which are shown on Plate No. 1.

In July of this year a model of this design was built on a scale of 1 - 60 or 1 inch equals 5 feet, and installed in the Hydraulic Laboratory of the Colorado Agricultural College at Fort Collins, Colo.

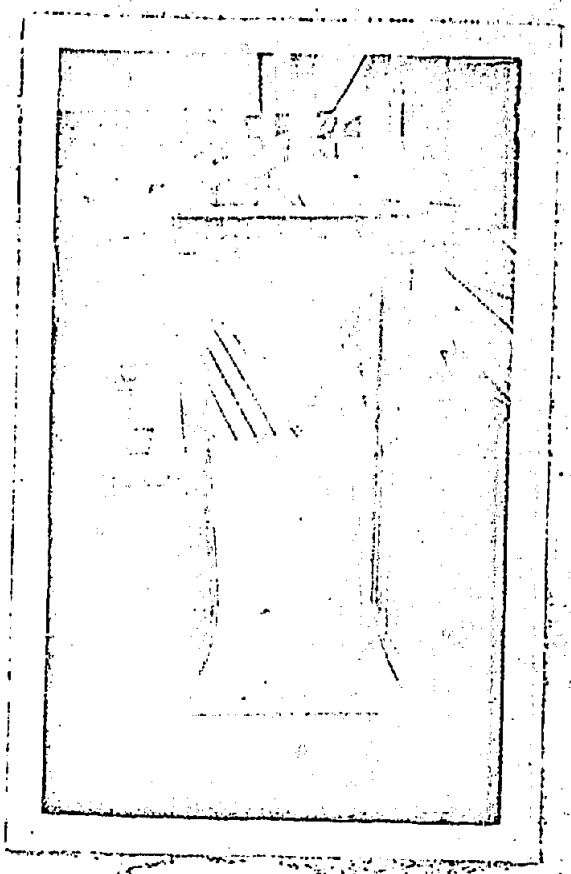
The scale proportions gave a model about seven feet long and one and a half feet in height, the width of the Stoney Gate being one foot. For maximum flow the depth of the water over the crest was approximately two inches and the quantity of water handled was around seven and one-half cubic feet per second.

The model was constructed of wood framing covered with galvanized iron for the most part but the accurate curve of the spillway crest was carved from a block of wood, also the warped section of the channel below the gate was shaped from boards stacked up and screwed together. After assembly the model was painted with gray Duco where the concrete was to be represented, other parts being blocked out with a red enamel, to contrast for picture taking.

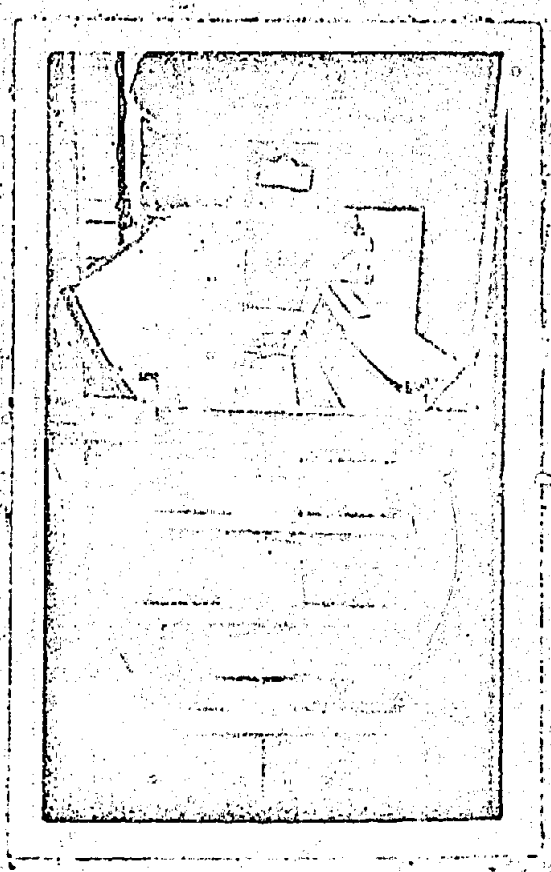
Representation of the rock topography in front of the spillway was obtained by cribbing up boards of a thickness corresponding to a four foot interval, which were cut along the contour lines.

The transition from the sloped wall side channel to the circular tunnel was shaped between collars at various intervals by wood staves which were then smoothed down and painted and the outside coated with a thick layer of paraffin to prevent swelling.

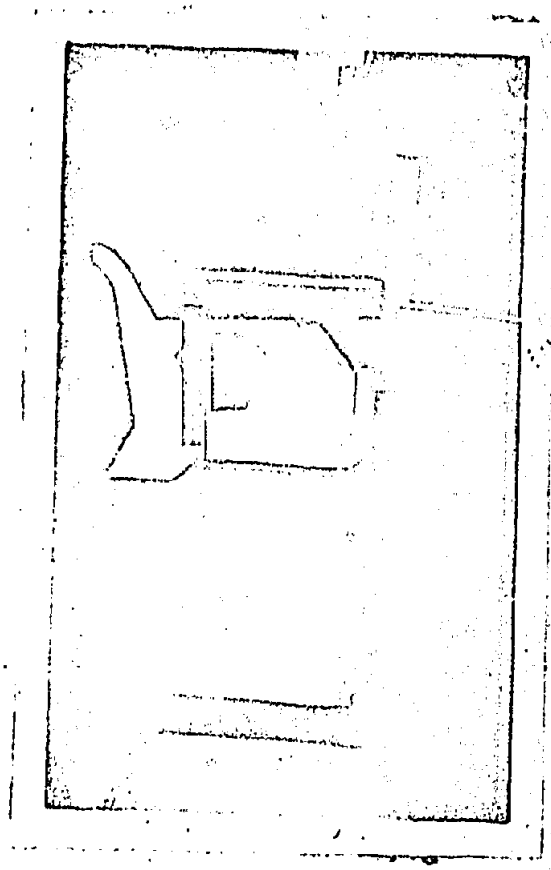
Construction of the model is indicated by the following photographs:-



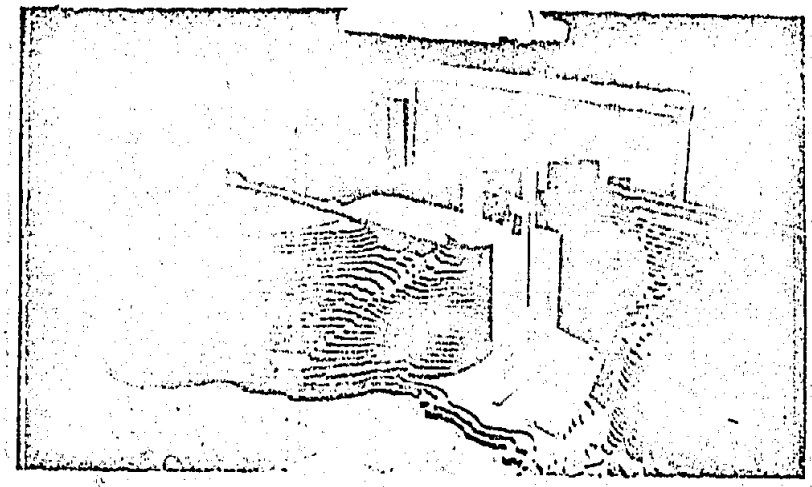
Looking downstream showing framing and channel transition.



Looking upstream showing crest block in place and tunnel transition.

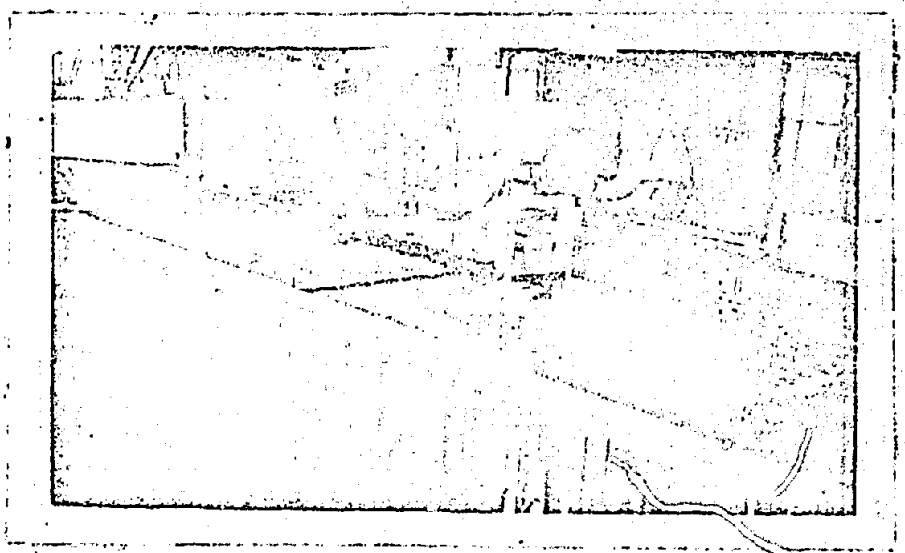


Completed model without contours.



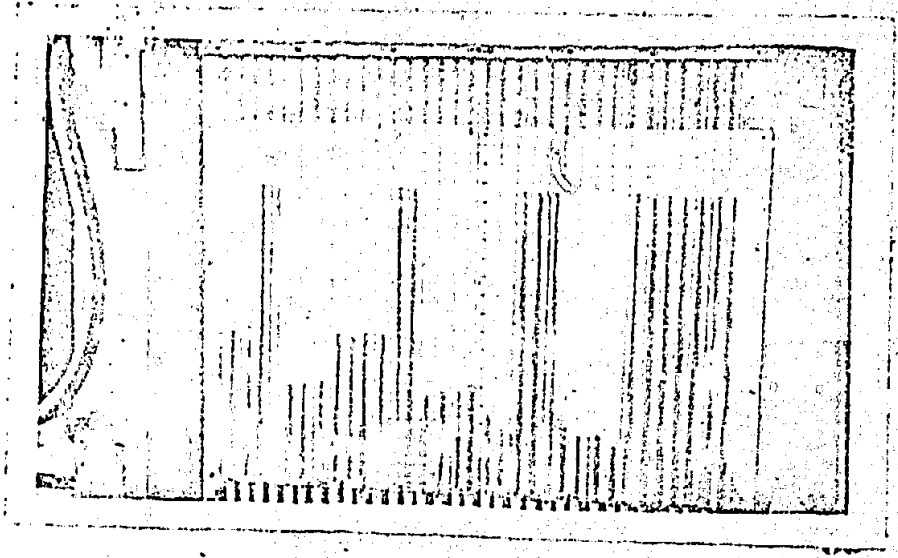
Completed model with contours

Measurements of water flow were obtained from a two foot Cipolleti weir which had previously been volumetrically calibrated in position, located upstream in the approach channel. Water surface elevations were measured by means of a point gage, as illustrated in the following photo.



Water surface measurements by point gage

Water surface elevations in the forebay and pressures at various points in the channel were obtained by piezometer openings, located as shown on Plate No. 1., which were connected by rubber hose to the glass tubes, mounted as shown in the following photograph:-



Piezometer gage board.

Investigations included experiments on:

I. The Original Design.

A. To check the theory.

1. Flow over crest only.

a. Co-efficient of discharge.

2. Flow under gate only.

a. Capacity at various openings.

3. Flow over crest and under gate during rising flood.

a. Observation and record of operation.

II. Alterations on the Original Design.

A. To improve flow conditions.

1. Placing dentated sill on channel floor.

2. Extending gate pier upstream.

3. Decreasing width of gate channel excavation.

4. Lengthening channel transition.

5. Extending end piers of the crest upstream.

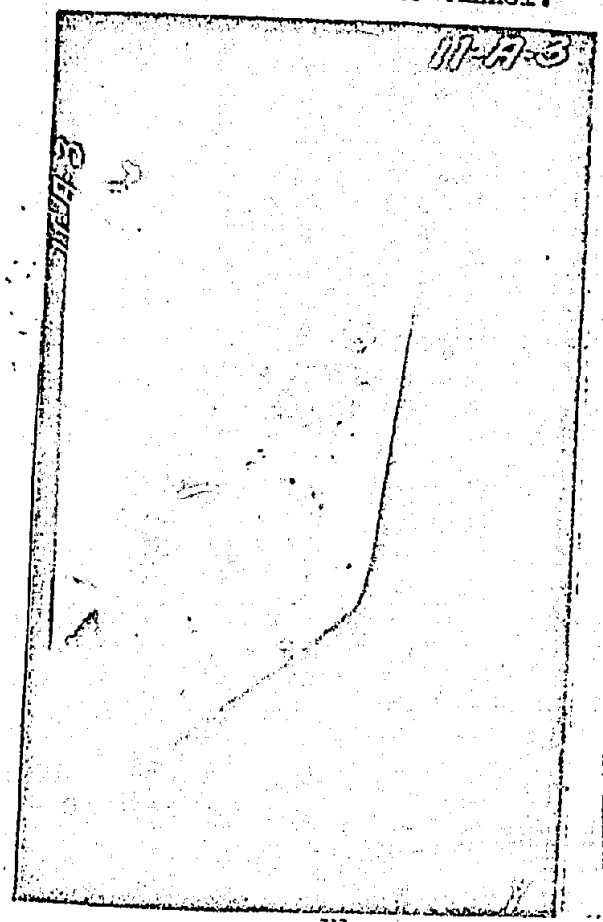
6. False floors in channel to obtain data for further design.

Flow over Crest Only.

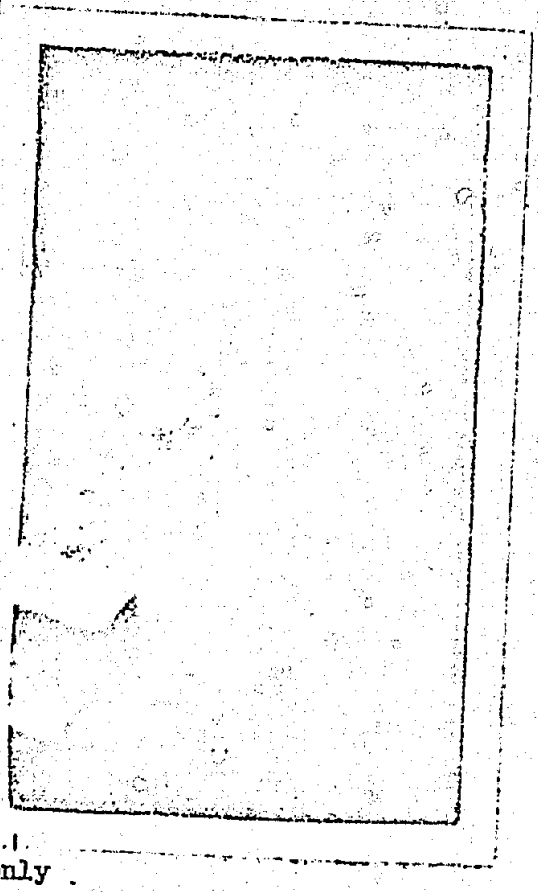
The flow from the Gate was blocked off and various discharges up to a flow corresponding to 200,000 c.f.s. were recorded. At the same time the depth of water over the crest was measured through piezometer openings located upstream therefrom, and a coefficient of discharge curve computed. (See appendix for all curves)

Water surface elevations were also taken in the channel by means of the point gage.

It will be noted in the following pictures that the water tends to pile up on the far wall of the channel and ride down the right side of the tunnel.



Flow over crest only
Discharge 55,000 c.f.s.
Pond El. 1232 approx.



Discharge 200,000 c.f.s.
Pond El. 1247 approx.

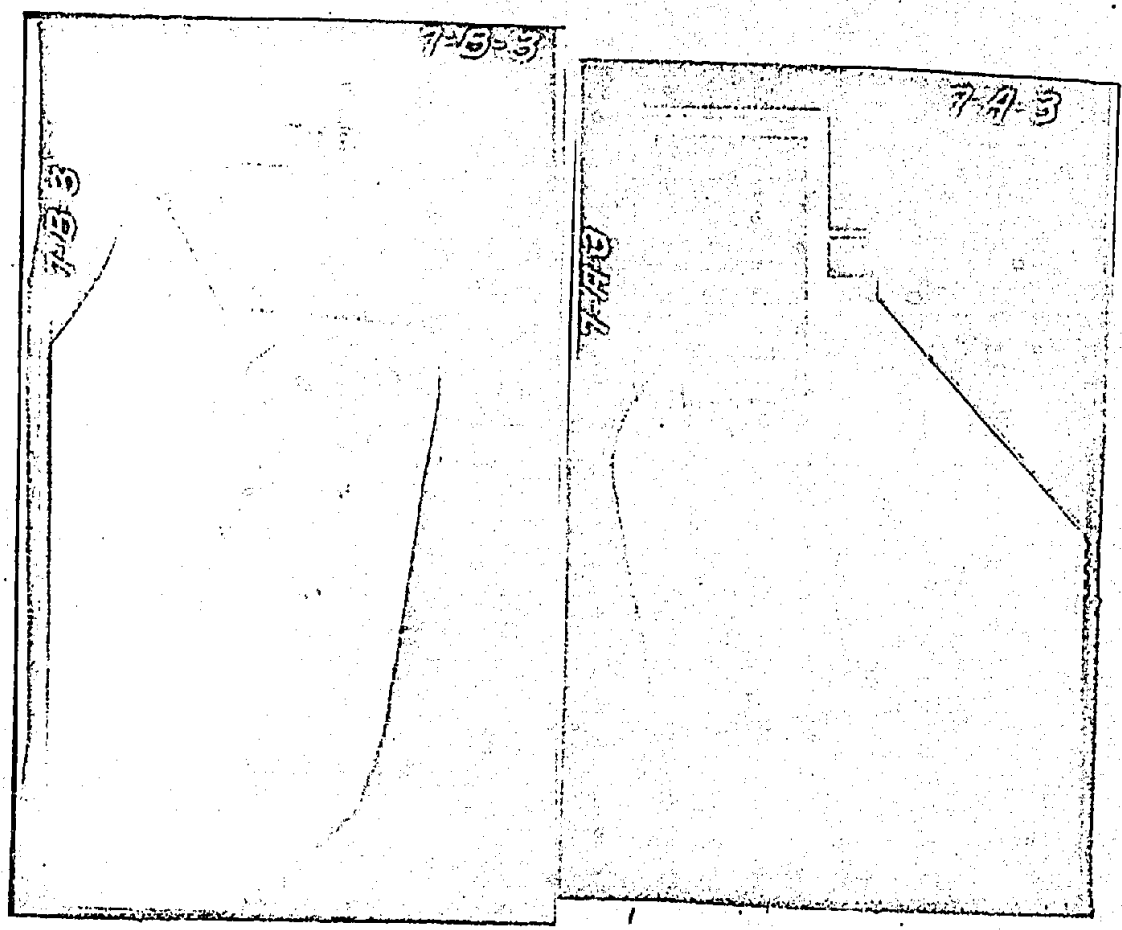
See also Photograph 11-A-5 on Page 15

Flow under Gate Only.

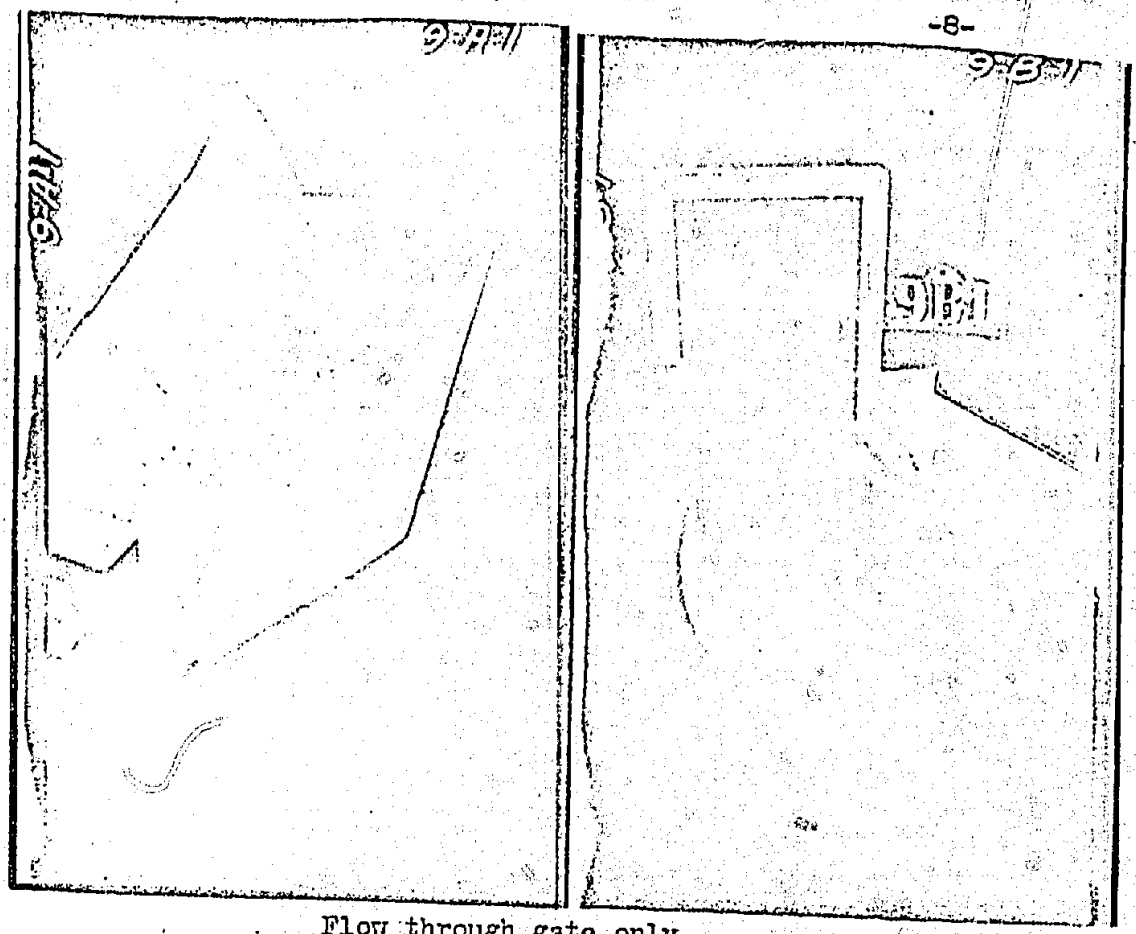
The crest was blocked off and the gate opened at different stages with the pond kept constant at Elevation 1232. The discharge capacity of the gate xx at various openings was plotted. Quite a vortex was noted in the forebay ahead of the gate.

It will be seen in the following pictures that the flow from the gate only is of high velocity and straight line flow except for the component across the channel given it by the curve in the transition below the gate.

Photograph 7-B-3 below may be contrasted to Photo 11-A-3 and 9-A-1 to 11-A-6 in the foregoing section for flow conditions of approximately the same quantity of water discharging.



Flow under gate only.
Discharge approximately 60,000. Pond at El. 1232.



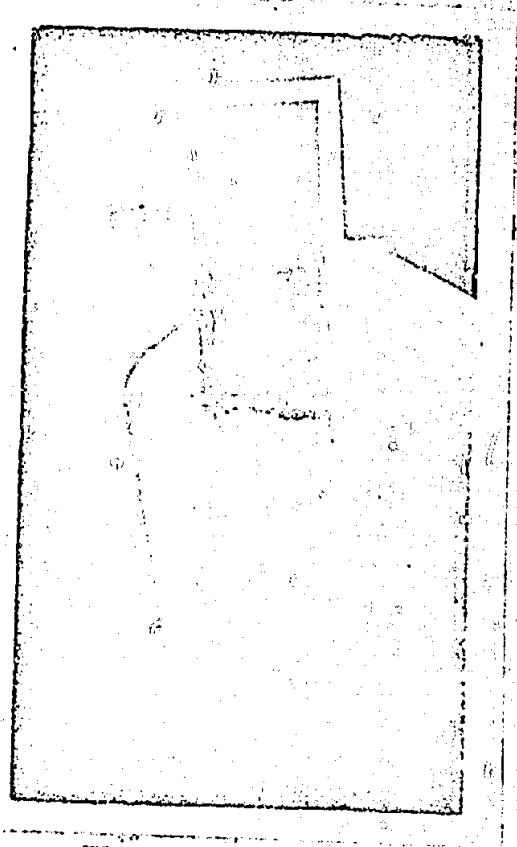
Flow through gate only
Approximately 190,000 c.f.s.

Flow over Crest and under Gate.

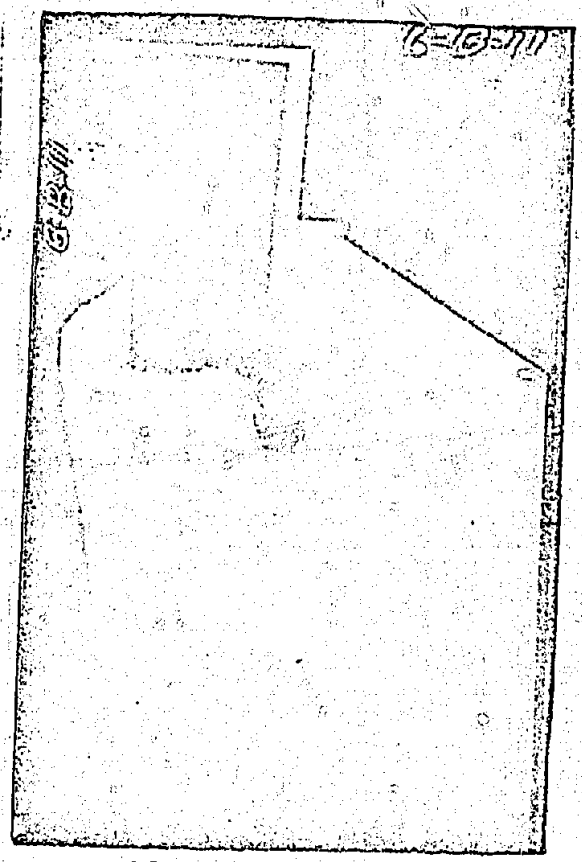
In this test rising flood conditions were simulated, that is, the flow was allowed to pass over the crest until the pond readhed Elevation 1232, where it was kept constant by raising the Stoney Gate until the full discharge representing 200,000 c.f.s. was reached. Flow quantities at various forebay elevations and gate openings were recorded and observation of conditions caused by raising the gate noted. Loss in head over the horizontal excavation in front of the crest was ascertained by means of a row of piezometers upstream normal to the crest. To check any tendency of the water to leap the floor of the tunnel transition a row of piezometers were located along the center line and readings taken at the various discharges. To obtain the vacuum under the nappe over the gate and also on the crest wall near the gate where the slope was steep, piezometers were located at these points and their readings recorded.

In the following picture (6-B-6) the flow over the gate may be seen, the gate still being closed at this stage.

When the gate is opened slightly, however, there is quite a disturbance due to the high velocity water shooting under it, as seen in the following photographs 6-B-11 and 6-A-10.

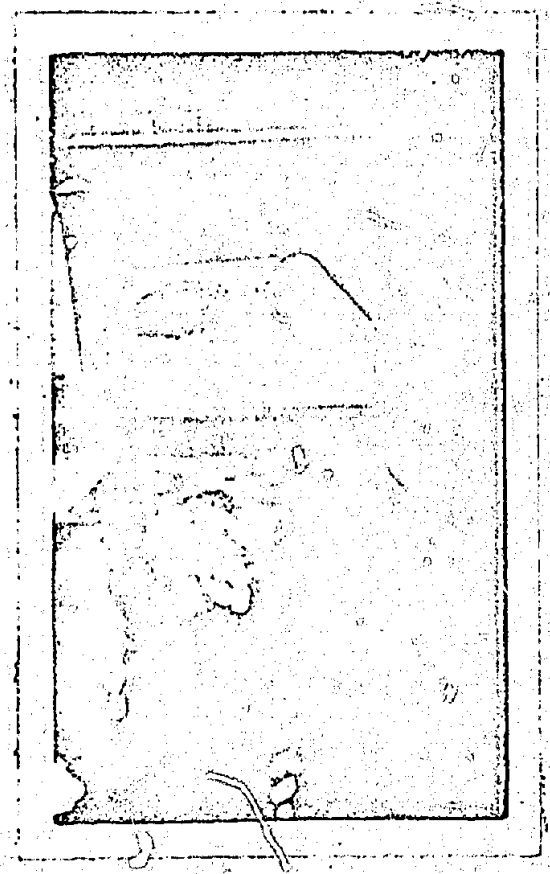


Flow over crest and gate. Approximately 60,000 c.f.s.



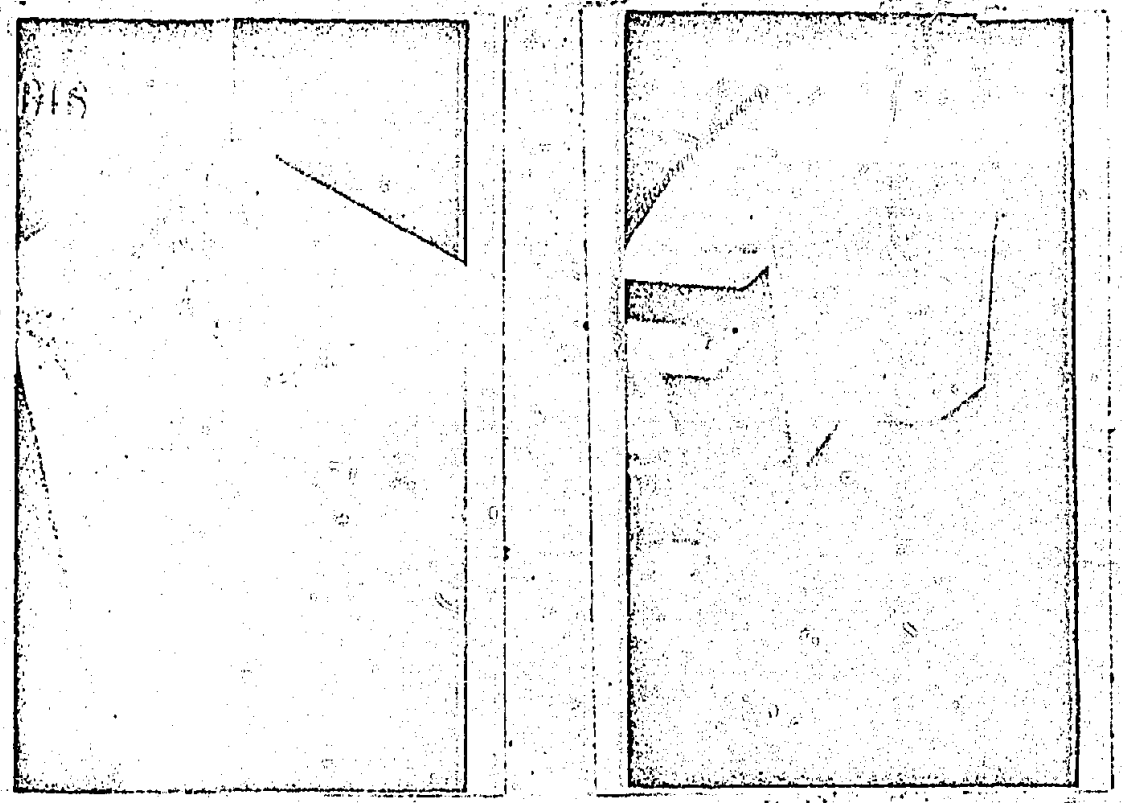
Flow over crest and under gate. Approximately 110,000 c.f.s.

Pond Elevation 1232.

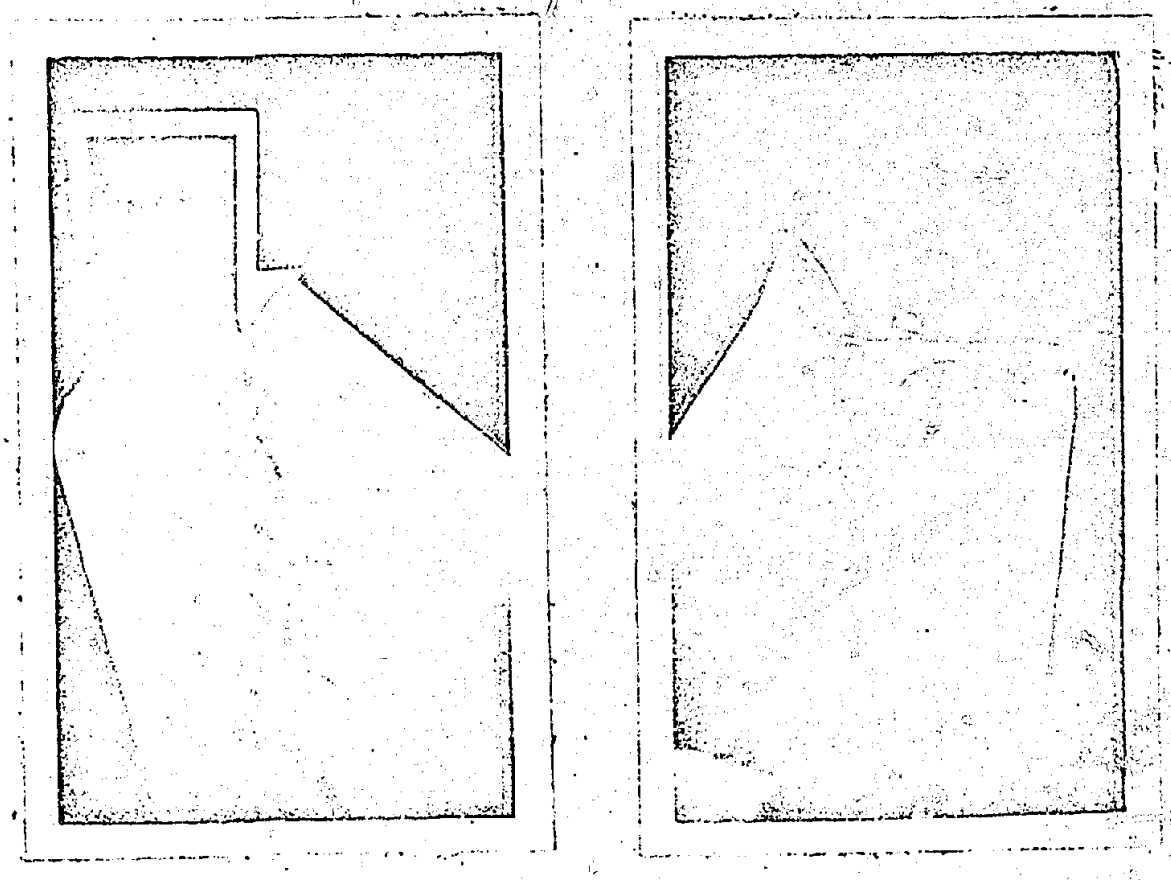


Flow over Crest and under Gate
Approximately 110,000
c.f.s. Pond El. 1232.

As the gate is raised further, however, the flow from it tends to counteract the component, of water from the crest, across the channel and sweep it downstream, as seen in the following pictures. It is on the smaller gate openings that the disturbance is worse.



Flow over the crest and under the gate.
Approximately 160,000. Pond El. 1232.



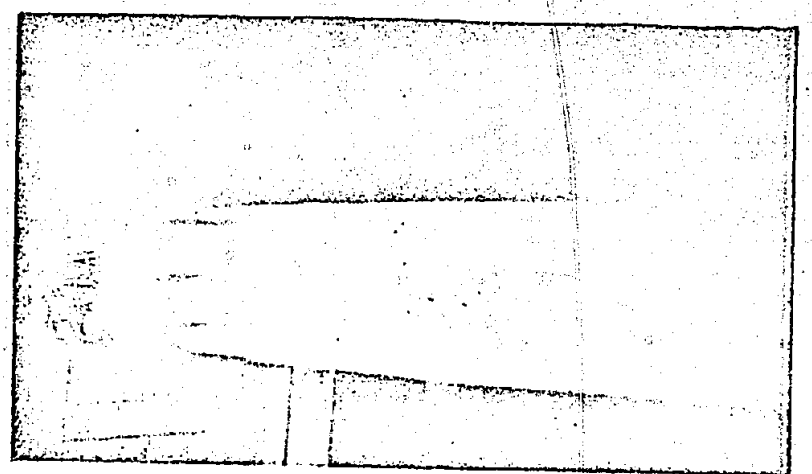
Flow over crest and under gate.
Approximately 200,000. Pond El. 1232.

illustrated in the following pictures. It will be noted in Photograph 20-A-5 that the flow from the crest which amounts to about 55,000 c.f.s. has imparted a twist to the jet and this is substantiated by observing the roll to the water when the entire flow is passed over the crest as seen in Photo 20-D-6.

It would seem by the pictures that the tunnel was running full, but the main bulk of the water is flowing in about the lower three quarters, the water on top being splash and spray. There is less when the flow is through the gate only as noted in Photo. 20-A-1.

Over crest only. Gate blocked.

Over crest and through gate.

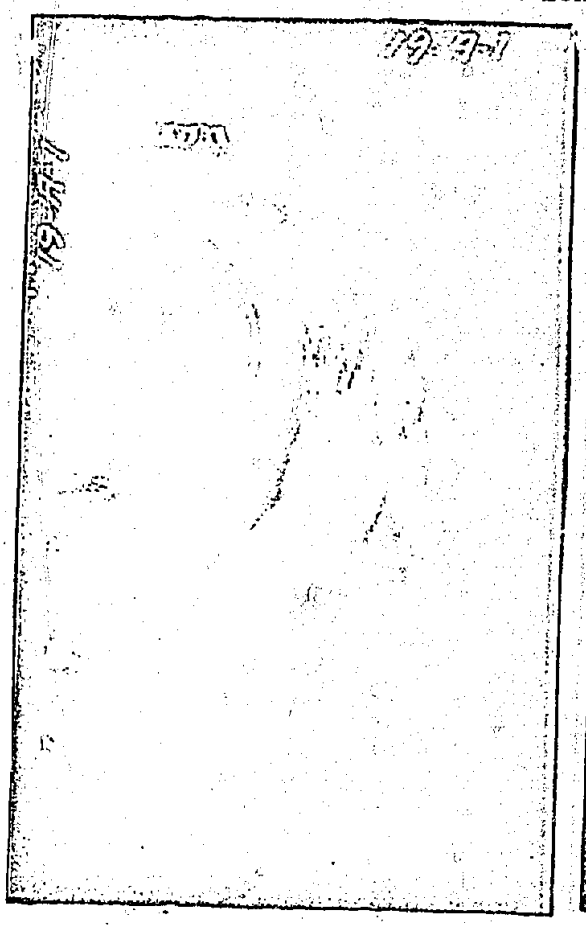


Through gate only. Crest blocked.

Flow from End of Tunnel Transition
200,000 c.f.s. in all cases.

The following pictures illustrate the action of the water in the horizontal bend of the tunnel. As much of the model pipe as possible was cut away to obtain a view inside. The flow action remains practically the same for all flows, whether coming over the crest alone, or gate alone, or combined; and for any type of alteration tried in the channel. It will be noted that when the jet strikes the curve there is a fold of water which rides the top of the tube for a ways and then falls back into the stream. By the time the water reaches the end of the tunnel, the surface seems fairly level, not quite filling the passage.

Horizontal Tunnel Bend, Looking upstream



Flow over crest
60,000 c.f.s.
approximately.

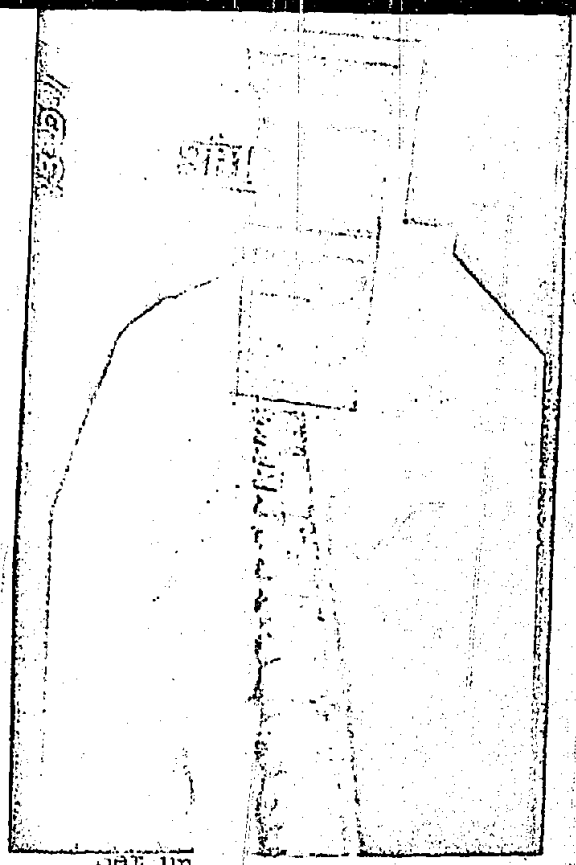
Flow over crest
and through gate.
200,000 c.f.s.
approximately.

Alterations to Improve Flow Conditions.

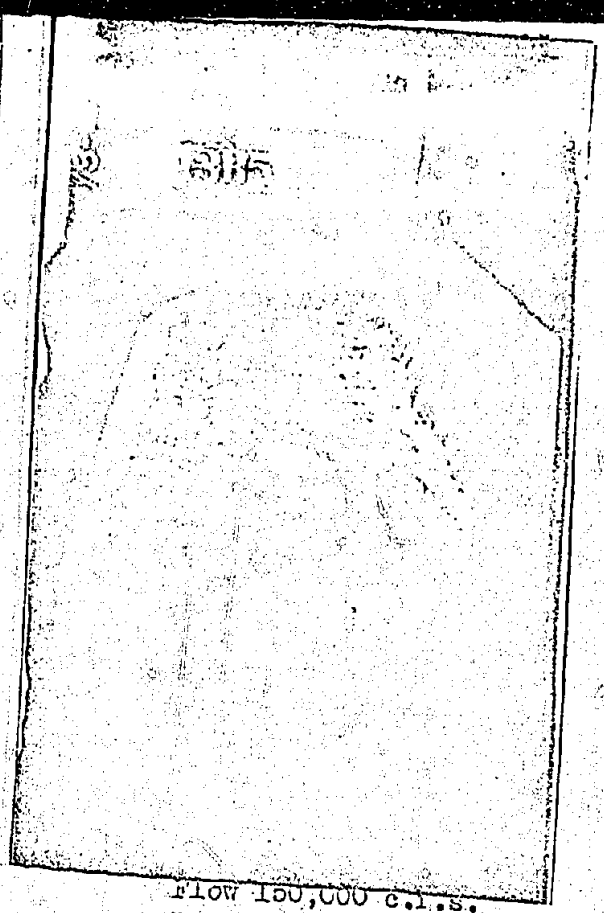
Dentated Sill Along Channel Floor.

In an attempt to check the flow over the crest from piling up along the right wall, two sets of curved dentates were tried along the channel floor, the larger representing fifteen feet height is shown in the following Photograph No. 13-D-1.

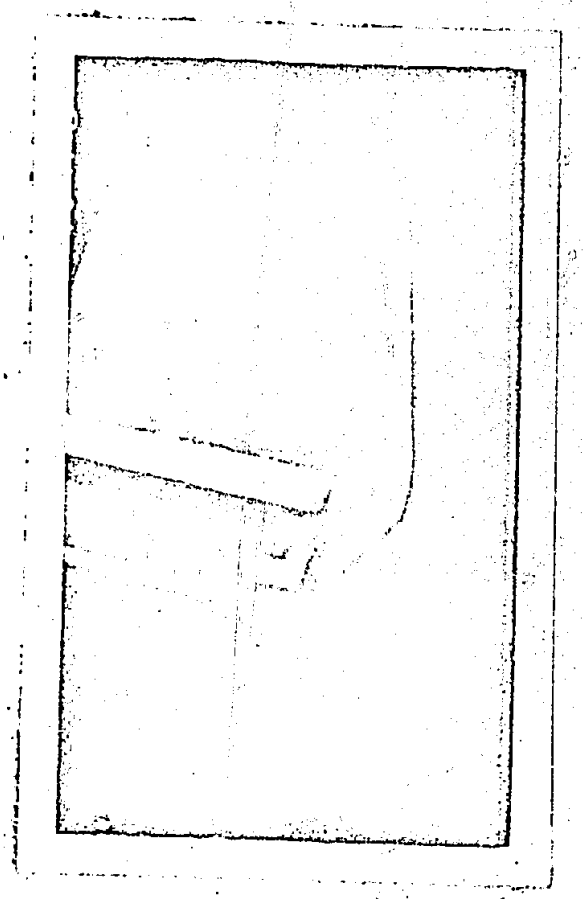
The action of the dentated buckets in leveling out the water surface was very satisfactory as shown by comparison of the two photographs on the following page, showing the same flow, with and without the sill. At the maximum discharge, however, the effect is almost lost due to the deep submergence of the baffles. Compare photographs 11-A-6 and 13-B-6.



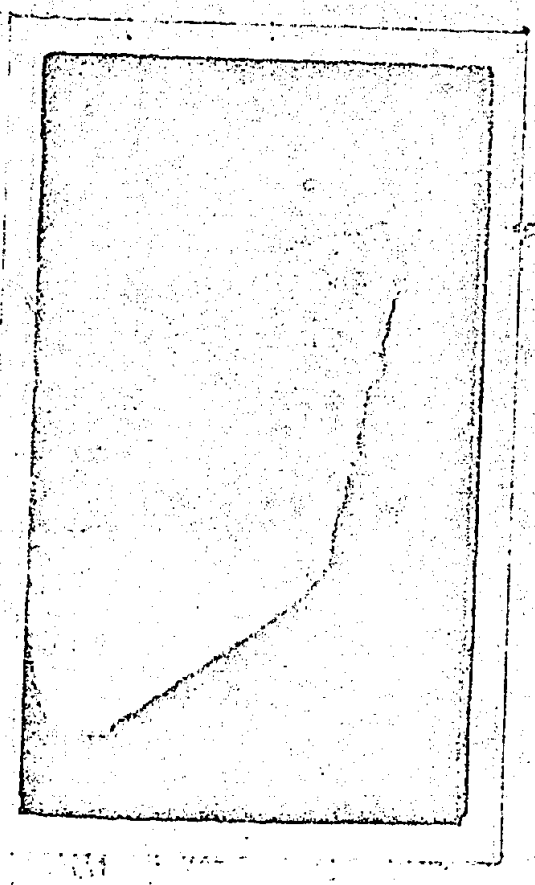
Set up
Dentated Baffles
on floor



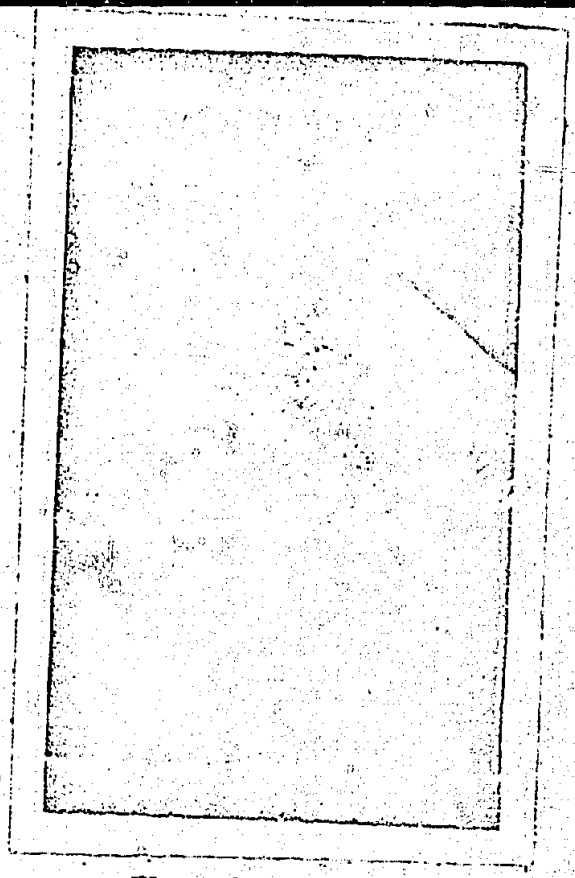
Flow 150,000 c.f.s.
Dentated Baffles on
on floor.



Flow 150,000 c.f.s.
Dentated Baffles on



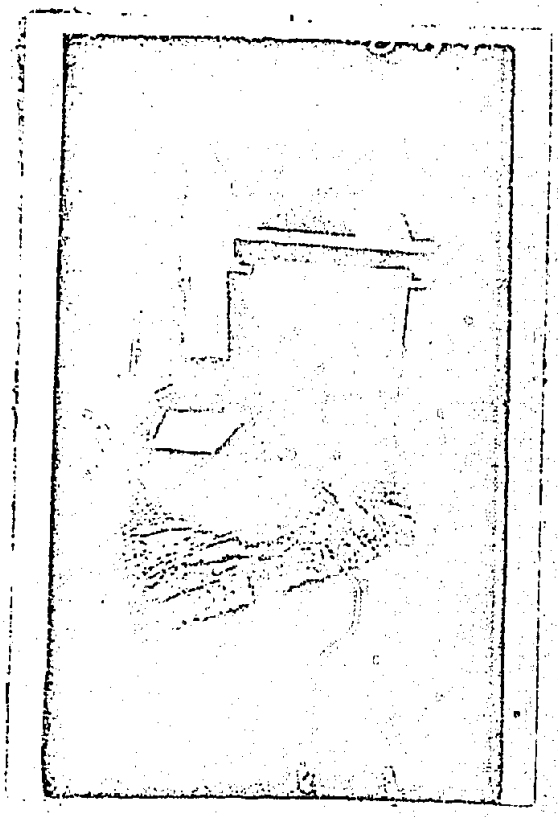
Flow 150,000 c.f.s.
No Baffles.



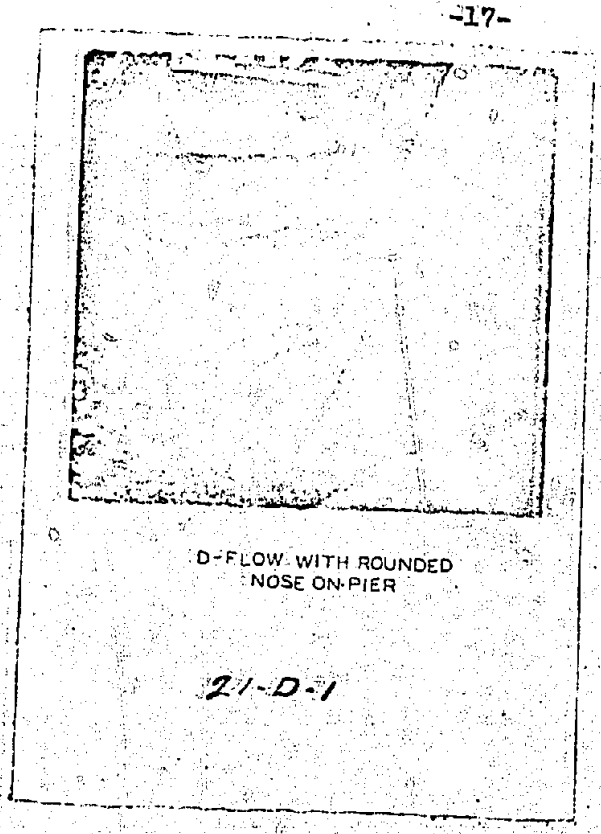
Flow 200,000 c.f.s.
Dentated baffles along floor.

Gate Pier Extension.

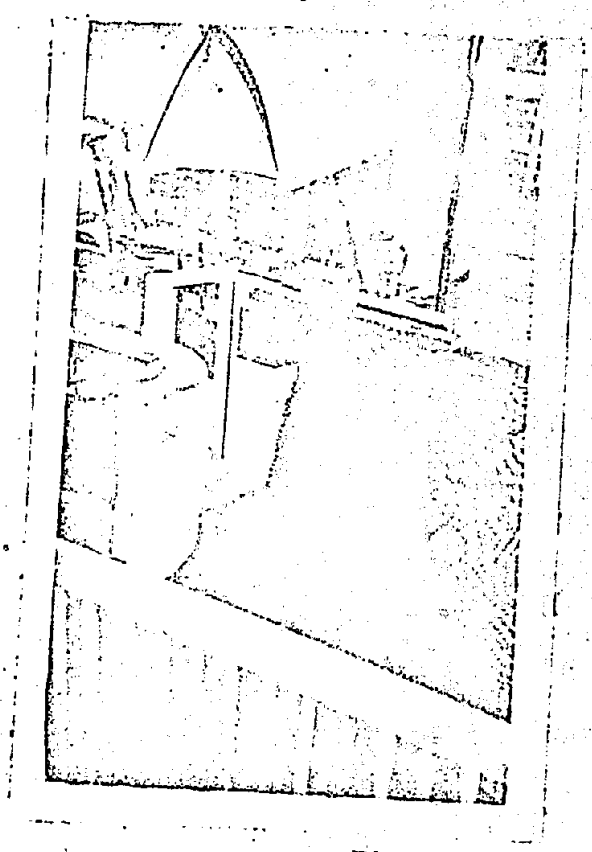
At the Stoney Gate entrance there is quite a swirl and eddy loss around the outside pier due to the gate draw down, see Photo, 8-A-1 on the following page. This was not alleviated by rounding the nose, see photo 21-D-1, but was overcome by extending the curve of the pier upstream. In the photograph on the following page the extension was taken to the entrance of the intake excavation, where the difficulty is entirely overcome. It is thought that this might be shortened considerably with good results, but of course, the further upstream the extension is made the more the flow is improved.



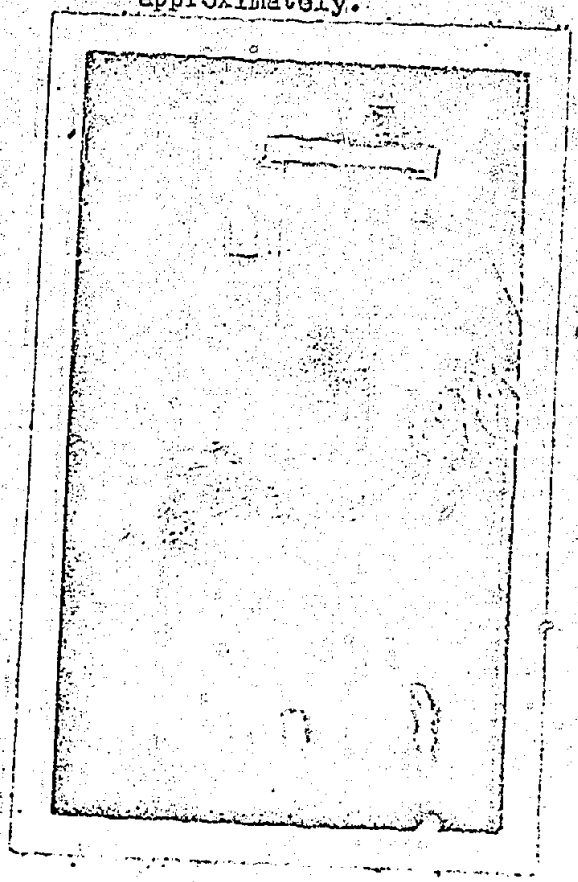
Gate entrance as designed, Flow 155,000 c.f.s. Approximately



Pier nose rounded. Flow 170,000 c.f.s. approximately.



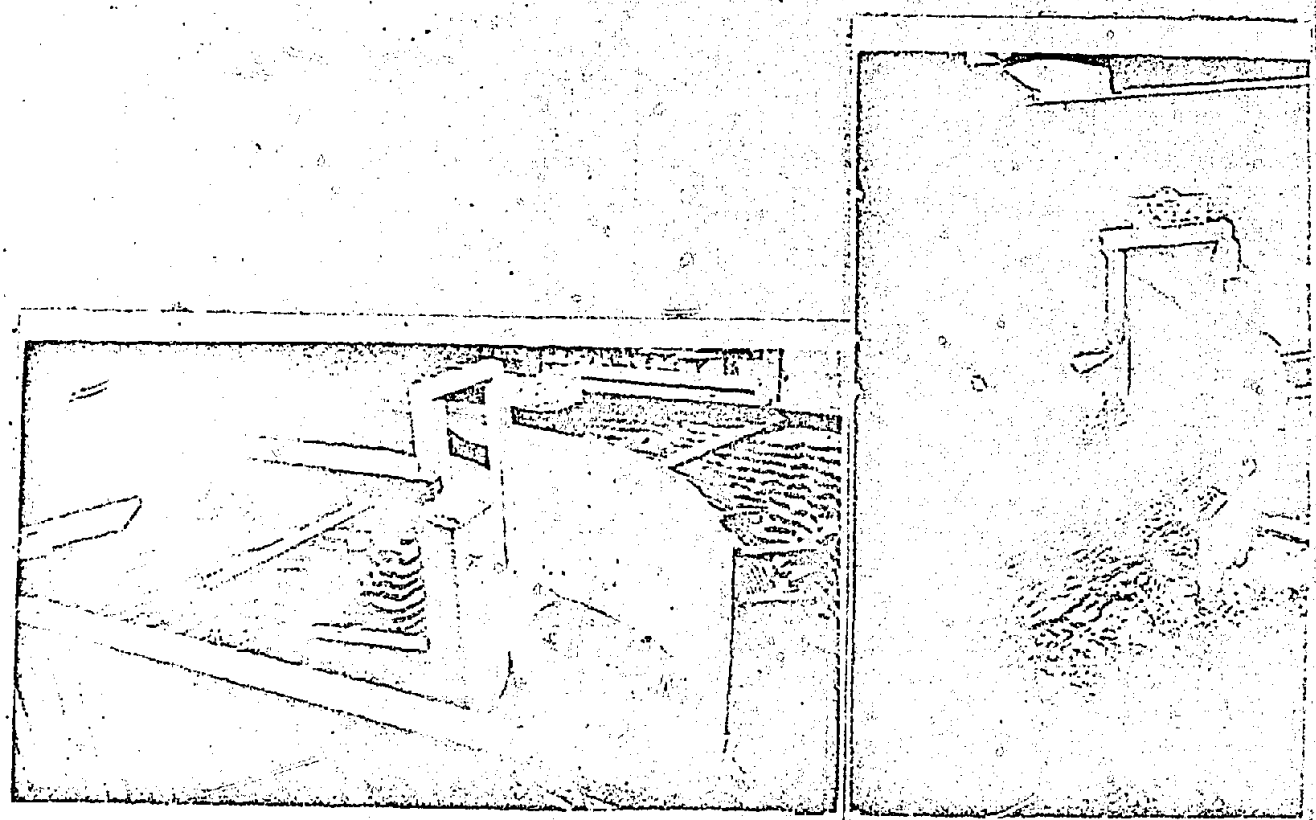
Set Up



Pier nose extended upstream. Flow 200,000 c.f.s.

Gate Intake Excavation.

It seemed that the excavation for the Stoney Gate Intake was too large as there was dead water along the right bank. Four different settings were tried, gradually drawing the right side wall in, and it was found that the velocity of the beginning could be doubled, without any detriment, but with improvement in the flow lines. With the extension on the left pier, as illustrated below, the flow into the gate was balanced and smooth.



False wall in Gate Excavation - Left Pier Extension.

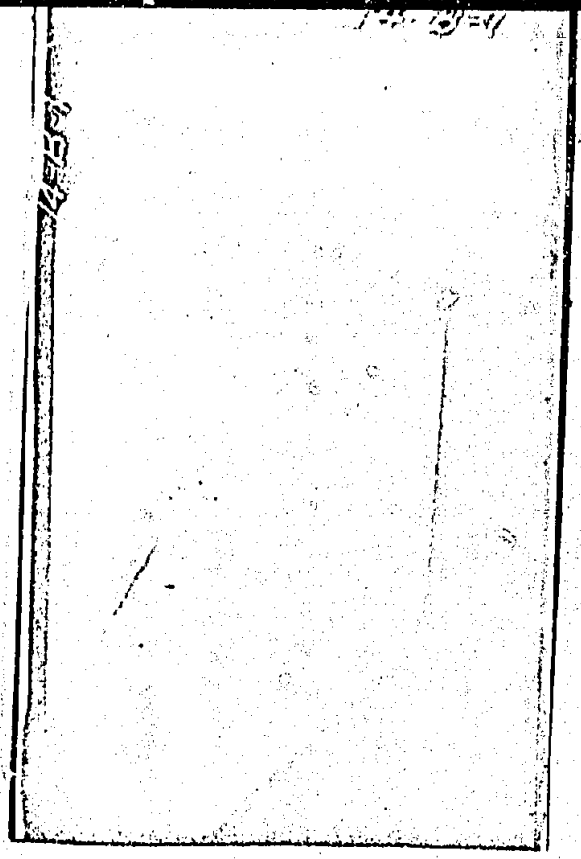
Set up. Flow 200,000 c.f.s.

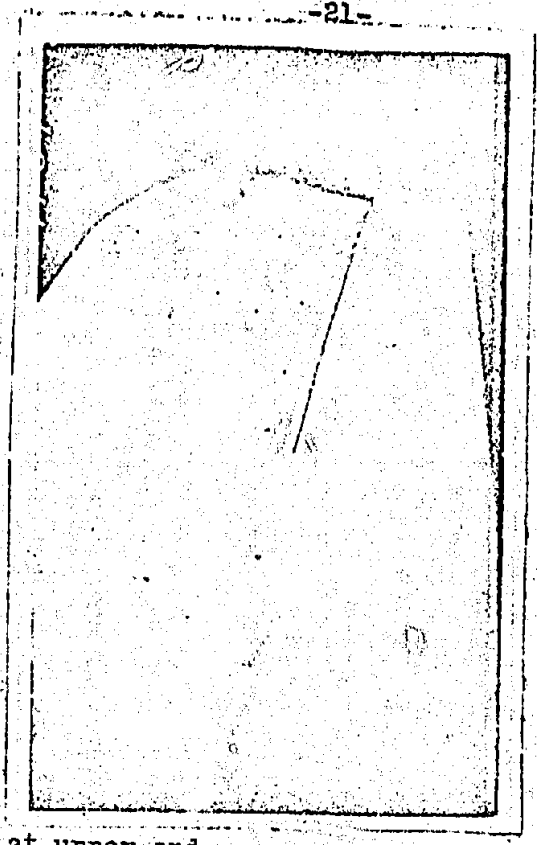
Transition - Gate to Channel.

The difficulty did not seem to lie in turning the water in front of the Gate, where the velocities are comparatively low, but below the Gate in the Side Channel proper. The radius of the transitionseemed too sharp causing the water to pile up on the right wall, thence it was deflected across the channel to the crest side causing irregular flow down the tunnel. See Photograph Number 9-A-1 in preceding section on page 8.

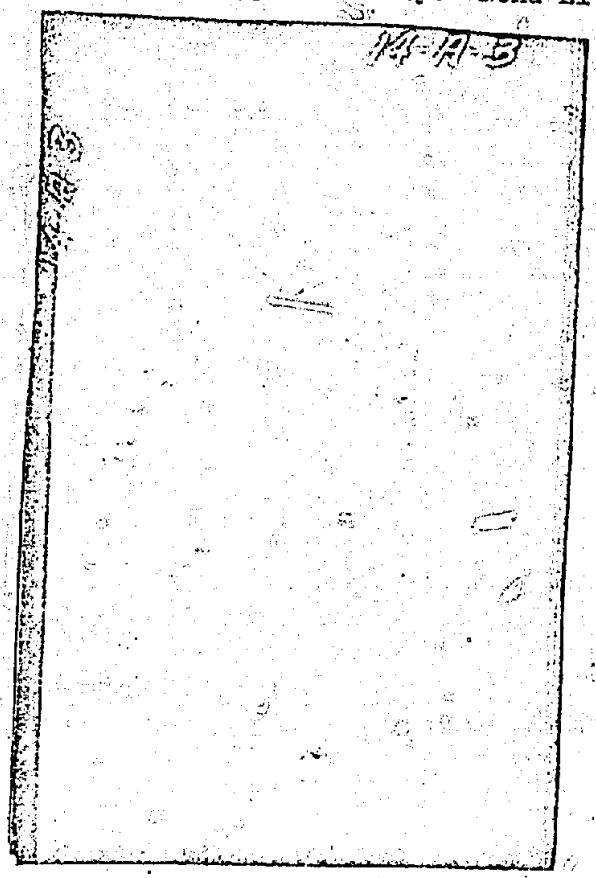
This was improved to some extent by lengthening the transition section, making the radius of the turn flatter, effected by the false wall as illustrated below. Comparison can be made with Photographs 9-A-1 and 9*b*1 in preceding section on page 8.

False transition side in channel.
Flow approximately 170,000 c.f.s.





Floor raised 45 feet at upper end.
Flow 55,000 c.f.s. approximately. Pond El. 1232.



Floor raised 45 feet at upper end.
Flow 200,000 c.f.s.

There were several changes indicated from the tests that could be made to improve the operation, but as the Stoney Gate layout was not favorably considered by the Designing department, investigations were not carried further than as mentioned in the above discussion of the tests.

The main difficulty seemed to lie in attempting to turn the water after it had passed thru the Stoney Gate and attained a high velocity. If the gate was set in the end of a straight channel, and the turn into it made above, in the approach channel, it would seem that the flow conditions could be greatly improved.

Other improvements, as noted, could be made by extending the Gate pier and the end Crest piers upstream, flattening the slope of the channel floor and perhaps using a dentated baffle along it.

Respectfully submitted,

R. R. Randolph Jr.
Asst. Engineer, Madden Dam Designs.