UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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HYDRAULIC LABORATORY REPORT NO. 115

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HYDRAULIC MODEL STUDIES OF THE ALTUS DAM SPILLWAYS ALTUS PROJECT, OKLAHOMA

By
J. A. Lindsey

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Denver, Colorado
October 13, 1943

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
October 13, 1945

Laboratory Report No. 115
Hydraulic Laboratory
Compiled by: J. A. Lindsey

Reviewed by: J. E. Warnock

Subject: Hydraulic model studies of the Altus Dam spillways - Altus Project.

INTRODUCTION

1. The prototype. The Altus Dam will be built on the North Fork of the Red River twenty miles north of Altus, Oklahoma (figure 1). The primary functions of the structure will be to store water for: (1) irrigation purposes; (2) flood control; and (3) to guarantee an adequate water supply for the city of Altus. The dam will be a curved gravity-type structure constructed of concrete faced with granite masonry, with a maximum height of 100 feet, and a total length of 1,160 feet (figure 2). The two spillways located in the central portion of the structure are; an uncontrolled spillway with a crest 110 feet long at elevation 1559.00; and a controlled spillway with a net crest 180 feet long at elevation 1547.00, regulated by nine radial gates, each 15 feet high and 20 feet long. The maximum discharge capacity, with both spillways in operation, is 60,000 second-feet. This capacity, together with storage in the reservoir, is deemed adequate to handle a peak inflow of 100,000 second-feet. Outlet works for releasing irrigation water will be located in the left abutment. Two 36-inch I.D. river outlets will be provided for river diversion during construction and for the removal of the dead storage from the reservoir if necessary.

2. Purpose of model studies. The hydraulic characteristics of the structure and the recommended apron for the controlled spillway were obtained after numerous studies on models constructed to a linear scale ratio of 1 to 60 and 1 to 24. The discharge conditions for both spillways were obtained by testing the 1 to 60 scale model of the central portion of the structure (figures 3 and 4). A sectional model of the controlled

spillway was constructed to a scale ratio of 1 to 24 to assist in the design of the controlled spillway apron by enabling a more detailed study to be made of the scouring action of the water after it left the spillway (figure 5).

3. Summary of the investigation. Hydraulic model studies of the Altus Dam spillways were initiated to determine the most satisfactory profiles from a hydraulic standpoint. The original design profile of of the uncontrolled spillway was found to be satisfactory after the slope of the rock excavation at the end of the apron was changed from 3 to 1 to 6 to 1.

The original design of the controlled spillway profile was found to be unsatisfactory and various bucket shapes were found to be more or less unsuitable as it was necessary to traject the jet approximately 50 feet into the air to obtain satisfactory energy dissipation in the river (figures 6, 7, 8, 9, and 10). The controlled spillway profile was then revised by substituting a short apron with a downward slope of 4 to 1 for the bucket shapes (figures 6F and 11A). This design was found to be fairly satisfactory when the center training wall was extended downstream 30 feet and the right training wall 60 feet. A 3.75-foot horizontal lip at the end of the apron was tried, but as no improvement was noted, it was abandoned in favor of the straight sloping apron (figures 6F and 11B). It was then found by adjusting the tailwater elevation that the hydraulic jump could be improved by lowering the apron 2 feet (figure 6G).

Information on the scouring action of the jet after it left the apron was desired and inasmuch as a satisfactory answer could not be obtained on the 1 to 60 scale model, a 1 to 24 scale sectional model of the controlled spillway was constructed (figures 5 and 12). Tests indicated that the sloping apron should be lengthened 12 feet and that some type of sill would help to prevent undue scouring (figure 13). Three types of triangular sills were tested, one with a slope of 10 to 1 downward; one horizontal; and another with a slope of 10 to 1 upward. The only sill which markedly reduced the scour was that with a 10 to 1 upward slope. A Rehbock-type sill, three feet high, with teeth spaced four feet apart, was tested and found to be very satisfactory (figure 14A).

A modified Rehbock sill was too small to adequately dissipate the energy of the jet (figure 14B). Considerations of the cost involved, however, resulted in the adoption of the three-foot wide 10 to 1 upward-sloping triangular sill as it would prevent excessive scour and would be much cheaper to construct than a Rehbock sill. The rock excavation at the toe of the controlled spillway should not be backfilled as it aided in energy dissipation and helped to prevent cavitation (figure 14C and D).

THE INVESTIGATION

4. Description of models. The 1 to 60 model was built of sheet metal, concrete, and wood. The spillway portions were constructed by soldering sheet-metal sections together to form a cellular structure (figure 4A). The ribs of this structure were geometrically similar to a cross-section of the prototype. Each cell was then partially filled with sand, which in turn was covered with a one-inch thick layer of concrete mixed in the proportion of one part moulding plaster to three parts portland cement. This layer of concrete was then screeded to the proper spillway shapes with the aid of the metal ribs and metal templates (figure 4B). The wooden piers were held in position by metal clips soldered to the ribs and to the metal upstream face of the dam. The piezometers were embedded in Cerrobend metal to eliminate the possibility of material spalling off around the openings and thus nullifying the accuracy of the readings (figure 3). The topography consisted of sand covered by a two-inch layer of sawdust-cement, built to represent the prototype by embedding wooden guides at critical points in the surface.

A 1 to 24 scale model of a portion of the controlled spillway subsequently was constructed to enable a detailed study of the scouring action of the water after it left the spillway (figure 5). The model was built by covering a wooden framework with 26-gage galvanized iron. It was placed in a glass-walled flume with sand used to represent the river bottom. For the final studies, the sand was covered with a layer of concrete to stabilize the river bed.

5. Model operation. The models were tested at prototype discharges of 6,000 to 60,000 second-feet. The model discharge was obtained by adjusting the valves in the supply line until the correct reading was

obtained on the laboratory Venturi meter gages. On the 1 to 60 model the water surface elevation in the forebay was adjusted to represent the prototype reservoir elevations by opening or closing the gates on the controlled spillway. On the 1 to 24 model this elevation was not controlled. The tailwater elevation was regulated on both models by raising or lowering a hinged gate at the downstream end of the model box.

6. <u>The original design.</u> The original design of the structure was tested on the 1 to 60 scale model and the uncontrolled spillway profile was found to be satisfactory, however, it was found that the flow could be made to merge more gradually with that in the main channel by changing the slope of the rock excavation at the end of the apron from 3 to 1 to 6 to 1.

The jet issuing from the controlled spillway tended to skim over the surface of the water in the downstream river channel, thus creating severe back currents or eddies on both the right and left side of the river (figure 7A). These eddies were considerably reduced by placing a rock jetty at elevation 1490.00 on the right bank of the river channel perpendicular to the radius of the dam and 210 feet downstream from the axis. This jetty washed out, however, at maximum discharge and the flow again became unsatisfactory. Revision of the controlled spillway design was deemed necessary (figure 7B).

Pressure tests were made on both spillways for discharges of 6,000 to 60,000 second-feet (figures 16 and 17). The pressures obtained were above atmospheric for the most part and the small negative pressures at maximum discharge were not considered sufficient to damage the structure, particularly since such flows are not expected to last for more than a few hours.

In the initial tests the gates of the controlled spillway were opened one at a time as the discharge increased, starting with the right end gate. This method of operation was found to be very undesirable as the high-velocity jet from the right side of the controlled spillway drove into the left bank of the river downstream before there was an appreciable reduction in velocity (figure 8A). The velocity head of this jet was sufficient to lower the tailwater elevation adjacent to the uncontrolled spillway apron sufficient to cause the hydraulic jump to sweep off the apron. When all of the gates were opened uniformly, the jet from the left gates tended to move the center of the high velocity flow to the middle of the channel, allowing eddy currents to flow back towards the uncontrolled spillway apron thus maintaining a tailwater depth sufficient to prevent the jump from sweeping off the apron (figure 8B).

7. Tests leading to recommended design. In the first revision of the original design, the downstream portion of the controlled spillway bucket was made to conform to a 25-foot radius and ended at a point where the tangent line makes an angle of 45 degrees with the horizontal (figure 6B). Tests on this design indicated the need for additional revision as the horizontal velocity of the jet was still great enough to produce undesirable return eddies near both banks of the river especially at the higher discharges (figure 9A).

The bucket was then revised by extending the downstream portion on a 20-foot radius to the point where a tangent line formed an angle of 60 degrees with the horizontal (figure 6C). Tests on this design showed that the angle that the jet left the lip of the bucket was still too flat. The jet struck the water at an angle of between 45 to 60 degrees, and consequently the horizontal velocity component continued to produce the undesirable return eddies previously obtained (figure 9B).

The bucket was then extended upward on a 17.5-foot radius to a point where the tangent line formed an angle of 80 degrees with the horizontal (figure 6D). The jet of water was forced almost vertically upward, consequently no appreciable horizontal component was present when it struck the water surface downstream (figure 10A). No return eddies were apparent, and the flow was distributed evenly across the channel. However, at the higher discharges a very turbulent roller formed above the bucket and the jet leaped more than 50 feet (prototype) above the tailwater surface.

A solution was sought by changing the downstream portion of the bucket to an 18.75-foot radius, extended to the point where a tangent line made an angle of 70 degrees with the horizontal (figure 6E). This design was fairly satisfactory as no return eddies were present, the jet was not excessively turbulent, and the velocity distribution in the channel downstream was excellent (figure 10B). Regardless of these features, it was decided to abandon the bucket type of design for the controlled spillway as: (1) the bucket would be expensive to construct; (2) the stream of water had to be thrown to such a height to eliminate the horizontal velocity it would strike the water at an excessively high vertical velocity; and (3) the mist and spray about the structure would be undesirable.

The next design eliminated the bucket altogether and substituted a short apron with a downward slope of 4 to 1 (figures 6F, design 6, and 11A). This design was a marked improvement over previous ones, but required the extension of the right and center training walls. Experimentation with various wall lengths demonstrated that the center training wall should be extended 30 feet beyond the end of the uncontrolled spillway apron, and the right training wall be extended 60 feet an an angle of 30 degrees to the right from a point 100 feet from the axis of the dam.

When sand was placed in the depression of the channel downstream it was removed by the scouring action of the jet. A 3.75-foot horizontal lip was added at the end of the apron to create a ground roller or return current which it was anticipated would deposit material downstream from the apron (figures 6F, design 7, and 11B). As it failed to do this effectively, and as the jump tended to sweep off the apron, the design was abandoned in favor of the plain sloping apron.

Tests on this apron design showed that the jump could be improved by lowering the apron and by extending the right training wall more nearly parallel to the upstream portion of the wall. When the model was tested, after making these revisions, the flow conditions appeared to be satisfactory although some eddy currents were still present. These were practically eliminated when rock-jetties extending 200 feet long were placed on both banks of the river downstream from the right and left training walls (figure 15).

8. <u>The 1 to 24 scale model tests.</u> Inasmuch as the 1 to 60 scale model did not permit observation of the scouring action of the jet issuing from the controlled spillway, it was decided to construct a 1 to 24 sectional model in a flume with a glass side panel (figure 12).

The sloping-apron design placed in the model showed some scouring at low flows and a great deal at the higher flows (figure 12). The scour could be prevented by lengthening the apron to the point where the jump was completed, but this would be very expensive to construct. A more economical solution was found by lengthening the apron only 12 feet and adding a sill. Three types of triangular sills were tried: one with the top surface sloping downward at 10 to 1; one with it horizontal; and another with it sloping upward at 10 to 1 (figure 13B). The downward-sloping and horizontal sills produced very little improvement of the flow conditions, but the 10 to 1 upward-sloping sill materially reduced the scour and caused the jump to move further upstream on the apron.

Two sizes of the Rehbock sill were also tested. The first, three feet high, with teeth four feet wide spaced four feet apart, formed a good ground roller and minimized the scour; the second, two feet high, with teeth three feet wide spaced three feet apart was too small to adequately dissipate the energy of the jet and consequently there was considerable scour at the higher discharges (figures 13A and 14). The first Rehbock sill effectively protected the toe of the dam, but would be quite expensive to construct, so it was decided to use the triangular sill with the 10 to 1 upward slope. The latter would not provide quite as much protection, but since there will be no discharge over the spillways during the dry season, damage that might occur to the structure during an exceptional flood could be repaired.

The sand which represented the river bottom was placed with concrete in the final test enabling observation of the jump action when the river bed was stablized as would be the case on the prototype which has a solid granite river channel (figure 14C). The jump was more satisfactory than it had been with the sand bottom. This would indicate that the scour tests were probably conservative since the granite river bed would serve as an extension to the concrete apron, producing better jump conditions than the sand bed used in the previous tests. A test was made with concrete backfilled into the footing excavation at the toe of the apron (figure 14C). Bubbles of air collected at this point indicating that negative pressures were present. When the V-shaped excavation was not backfilled, a small roller formed in the notch which seemed to eliminate the negative pressures (figure 14D). A comparison of the two showed that the energy of the jet was dissipated more effectively when the excavation was not backfilled.

9. The recommended design. In the recommended design, the uncontrolled spillway shape was the same as in the original design. The rock excavation at the end of the apron was changed, however, from a slope of 3 to 1 to a slope of 6 to 1 to more evenly distribute the flow in the river (figure 15).

The controlled spillway was changed considerably from the original design. The crest and the 0.6 to 1 slope remained the same, but the 25-foot radius curve began two feet lower at elevation 1481.46 and continued to elevation 1470.08. Beginning at that point, the apron extended downward on a 4 to 1 slope to elevation 1461.31, then upward on a 10 to 1 slope to the end of the apron at elevation 1461.31. The rock excavation for the footings at the toe of the dam was not backfilled with concrete as the V-shaped cut aided in dissipating the energy of the jet.

The center training wall was extended 30 feet beyond the end of the uncontrolled spillway apron and the right training wall was extended 50 feet at an angle of ten degrees to the right from a point 100 feet from the axis of the dam, then extended 33 feet at an angle of 22 degrees to the right from the end of the 50-foot extension (figure 2). Rock jetties were placed on both banks for a distance of 200 feet downstream from the training walls to eliminate return eddies.

ANALYSIS OF RESULTS

10. Conclusions. Hydraulic model studies of the Altus Dam spillways showed that it is extremely difficult to design a bucket which will traject

the flow into a pool downstream without creating undesirable flow conditions. It was found that in order to eliminate the horizontal velocity of the jet, it was necessary to project it upward at an angle of 70 degrees from the horizontal. Consequently, the jet rose to over half the height of the dam and struck the water surface downstream with a high vertical velocity. Such a design would prove unacceptable on the prototype as severe erosion would occur. The spray and mist created would also be quite objectionable. It would have been possible to evolve a satisfactory bucket design if it had been economically feasible to excavate a large amount of rock from the river bed to construct a roller bucket, but this was not considered as the cost would have been prohibitive.

The sloping-apron type of design has proven its worth on many structures and the design selected should give good service as the depression in the river channel forms a natural stilling pool which will effectively dissipate the energy and spread the flow evenly across the river. If the structure should become undermined in the future, this could probably be remedied by adding the three-foot high Rehbock sill with teeth four feet wide spaced four feet apart (figure 13A).

11. Recommendations. On the basis of the hydraulic model studies of the Altus Dam spillways, it is recommended:

(1) That the original design profile of the uncontrolled spillway be used and that the rock excavation at the end of the apron be at a 6 to 1 slope.

(2) That the original design of the crest and 0.6 to 1 sloping protion of the controlled spillway be retained.

(3) That the 0.6 to 1 slope be continued to elevation 1481.46 where a circular curve with 25-foot radius would connect it with a 4 to 1 slope from elevation 1470.08 to elevation 1461.01. The pool floor should then slope upward on a slope of 10 to 1 to elevation 1461.31 at the end of the apron.

(4) That all of the controlled spillway gates be opened uniformly and not individually (figure 8).

(5) That the center training wall be extended 30 feet beyond the end of the uncontrolled spillway apron.

(6) That the right training wall be extended 50 feet at an angle of 10 degrees to the right from a point 100 feet from the axis of the dam, then extended 33 feet at an angle of 22 degrees to the right from the end of the 50-foot extension.

(7) That rock jetties be placed on the right and left banks to extend at least 200 feet downstream from both the right and left training walls.

(8) That no material be backfilled into the rock excavation at the end of the controlled spillway apron.

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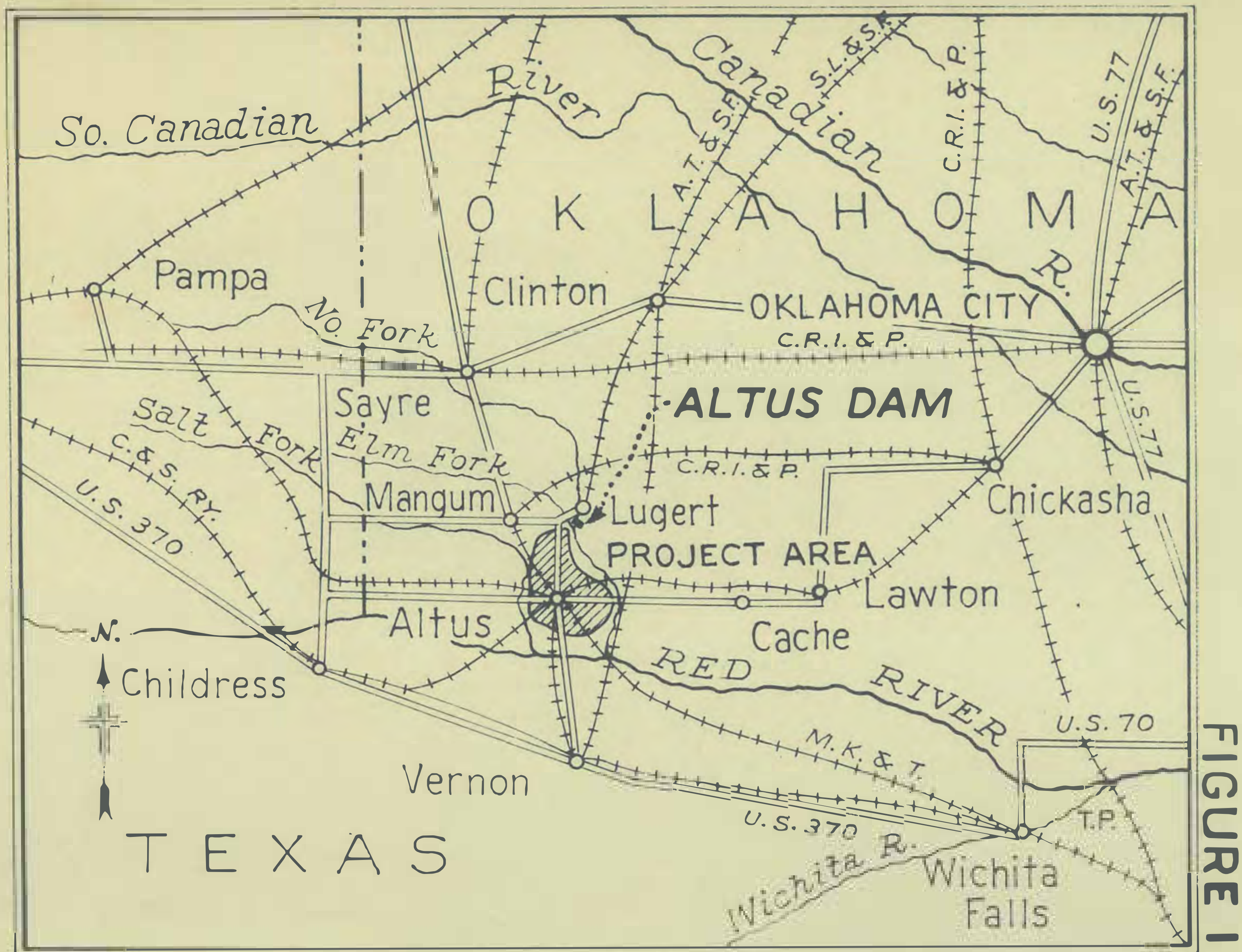
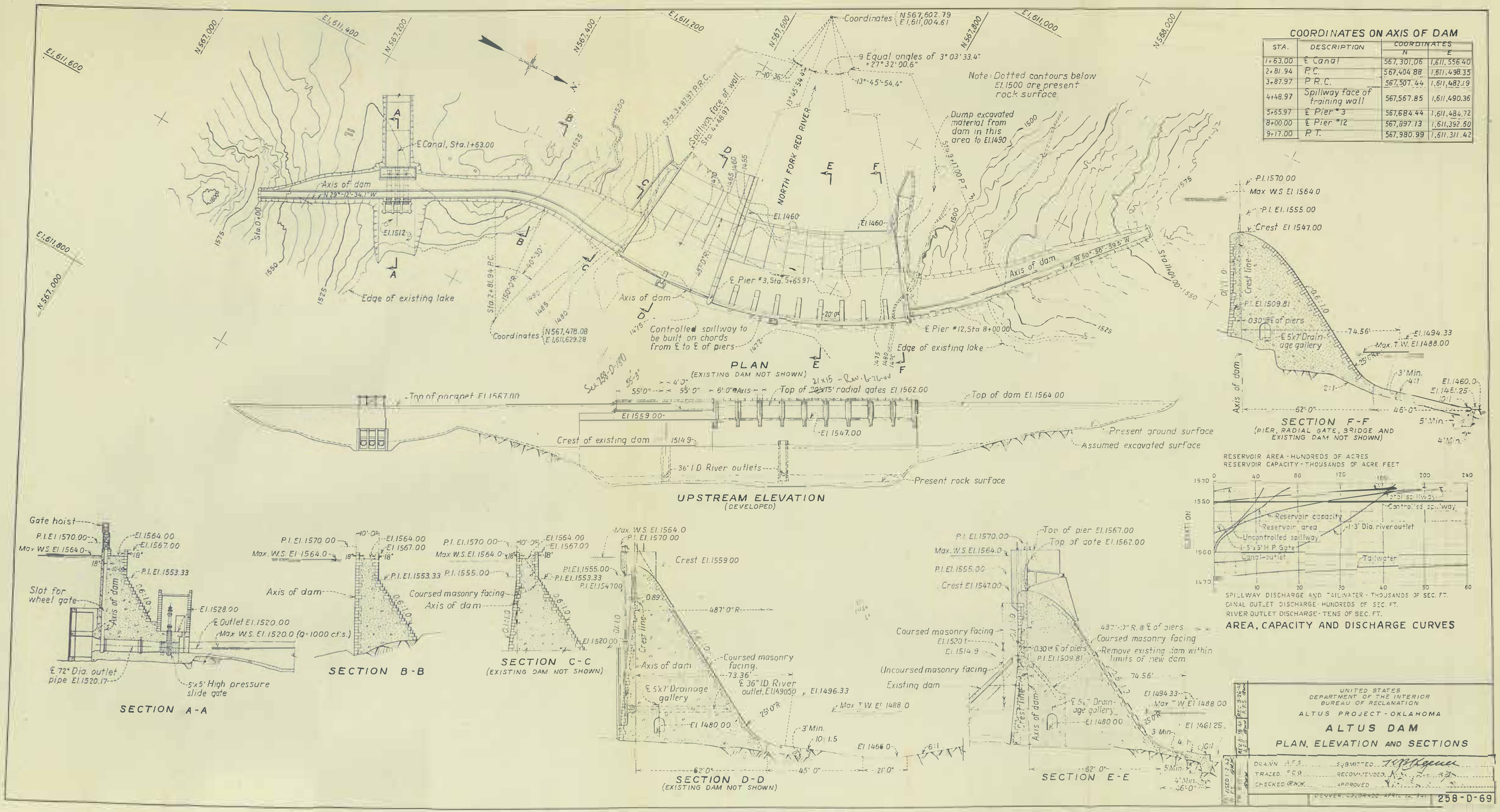
J. A. Lindsey.

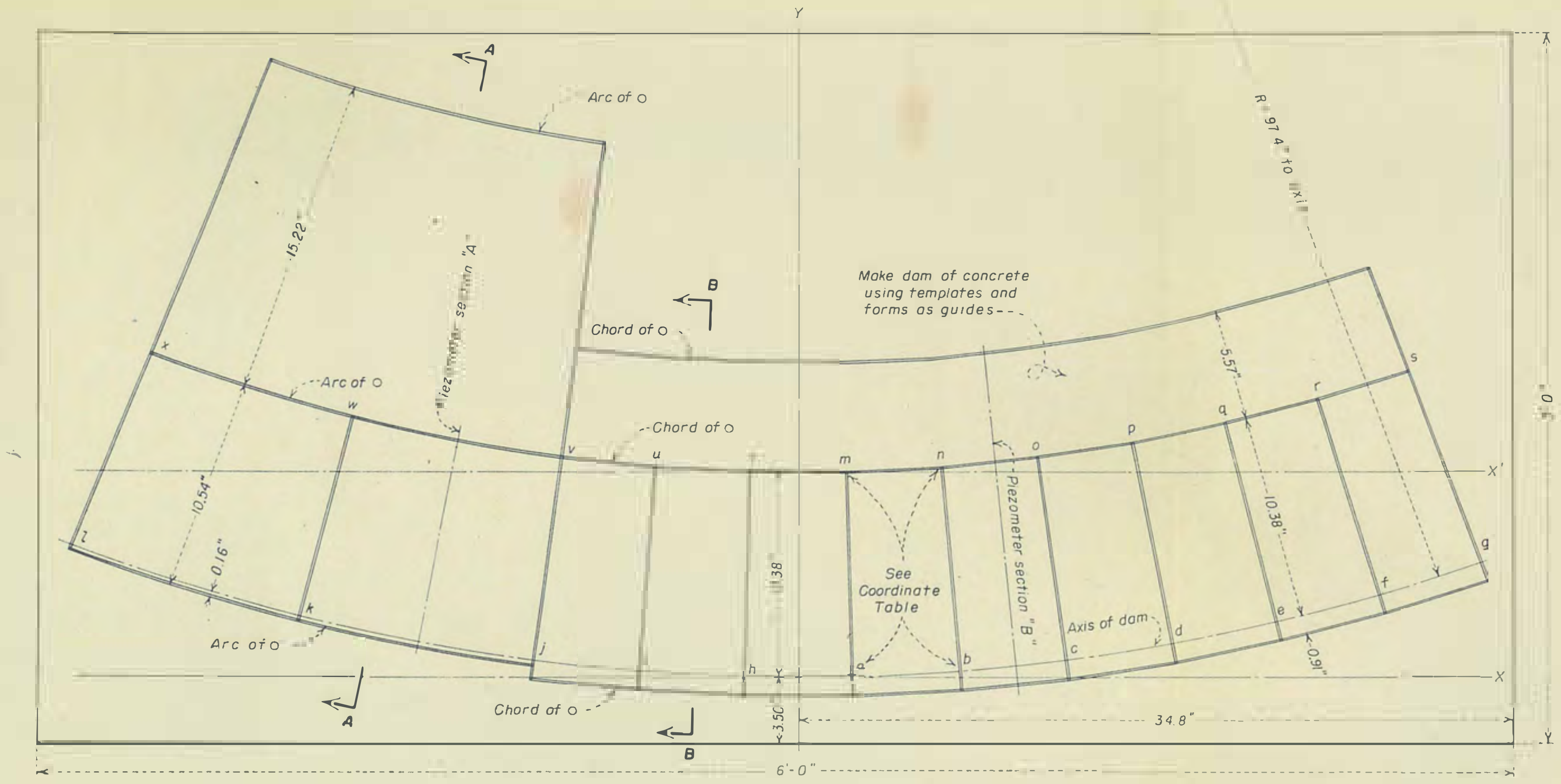


VICINITY MAP

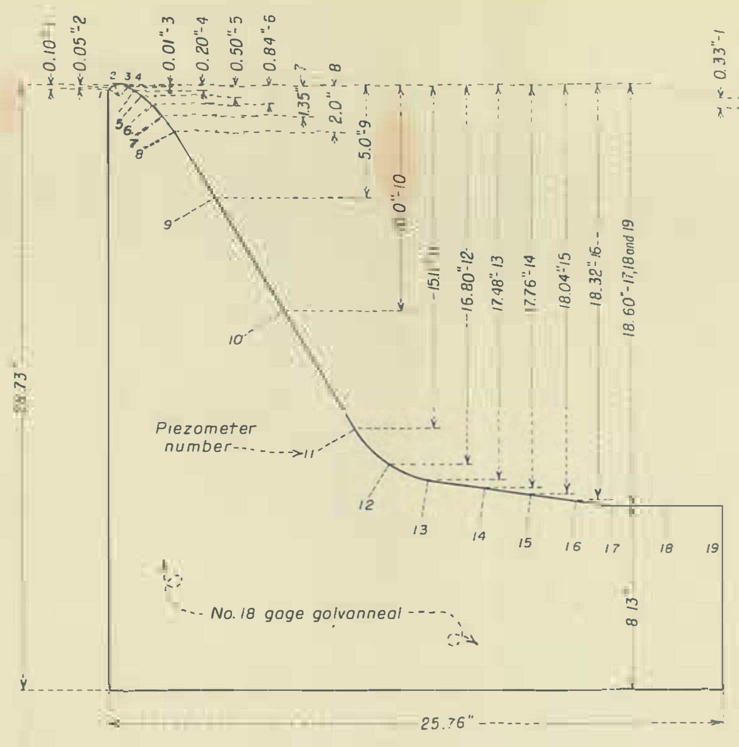


COORDINATES ON AXIS OF DAM

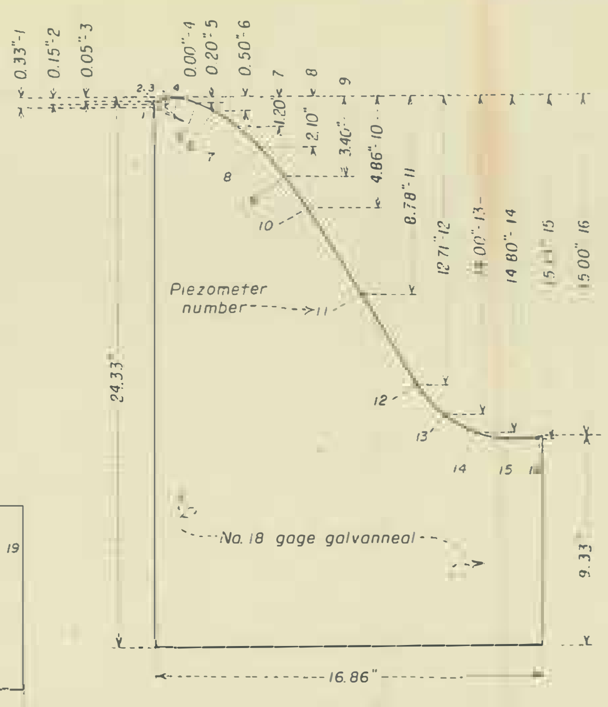
STA.	DESCRIPTION	COORDINATES N	COORDINATES E
1+63.00	℄ Canal	567,301.06	1,611,556.40
2+81.94	P.C.	567,404.88	1,611,498.35
3+87.97	P.R.C.	567,507.44	1,611,482.19
4+48.97	Spillway face of training wall	567,567.85	1,611,490.36
5+65.97	℄ Pier #3	567,684.44	1,611,484.72
8+00.00	℄ Pier #12	567,897.13	1,611,392.50
9+17.00	P.T.	567,980.99	1,611,311.42



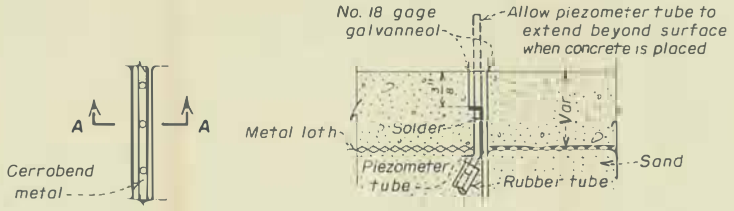
PLAN



PIEZOMETER SECTION "A"

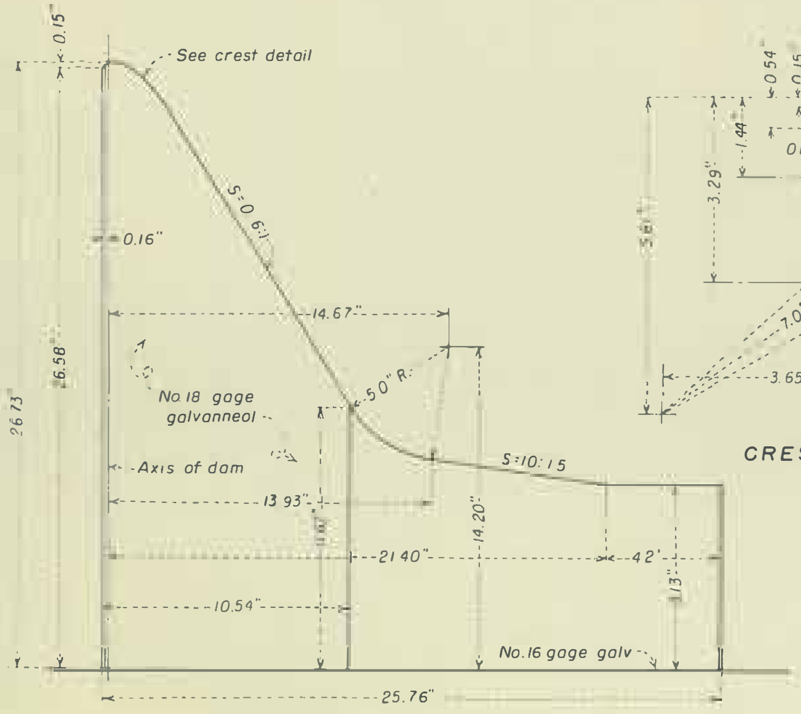


PIEZOMETER SECTION "B"

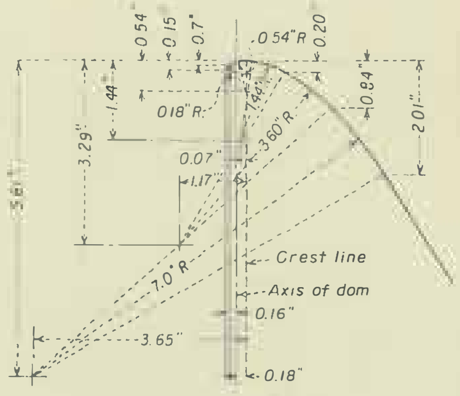


PIEZOMETER LOCATION AND DETAILS

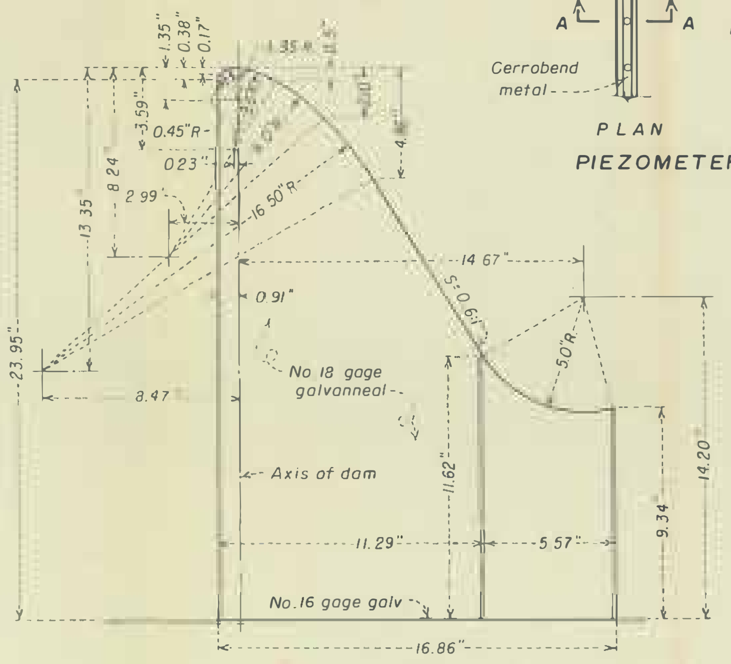
COORDINATES OF POINTS					
POINT	X	Y	POINT	X'	Y'
a	2.60"	0.0	m	2.32"	0.0"
b	7.79	0.28	n	6.96	0.25
c	12.96	0.83	o	11.59	0.74
d	18.10	1.66	p	16.17	1.48
e	23.18	2.76	q	20.70	2.47
f	28.19	4.14	r	25.19	3.70
g	33.13	5.77	s	29.60	5.16
h	-2.60	0.0	t	-2.32	0.0
i	-7.79	0.28	u	-6.96	0.25
j	-12.96	0.83	v	-11.59	0.74
k	-24.44	3.08	w	-21.83	2.75
l	-35.56	6.69	x	-31.78	5.98



SECTION A-A



CREST DETAIL



SECTION B-B

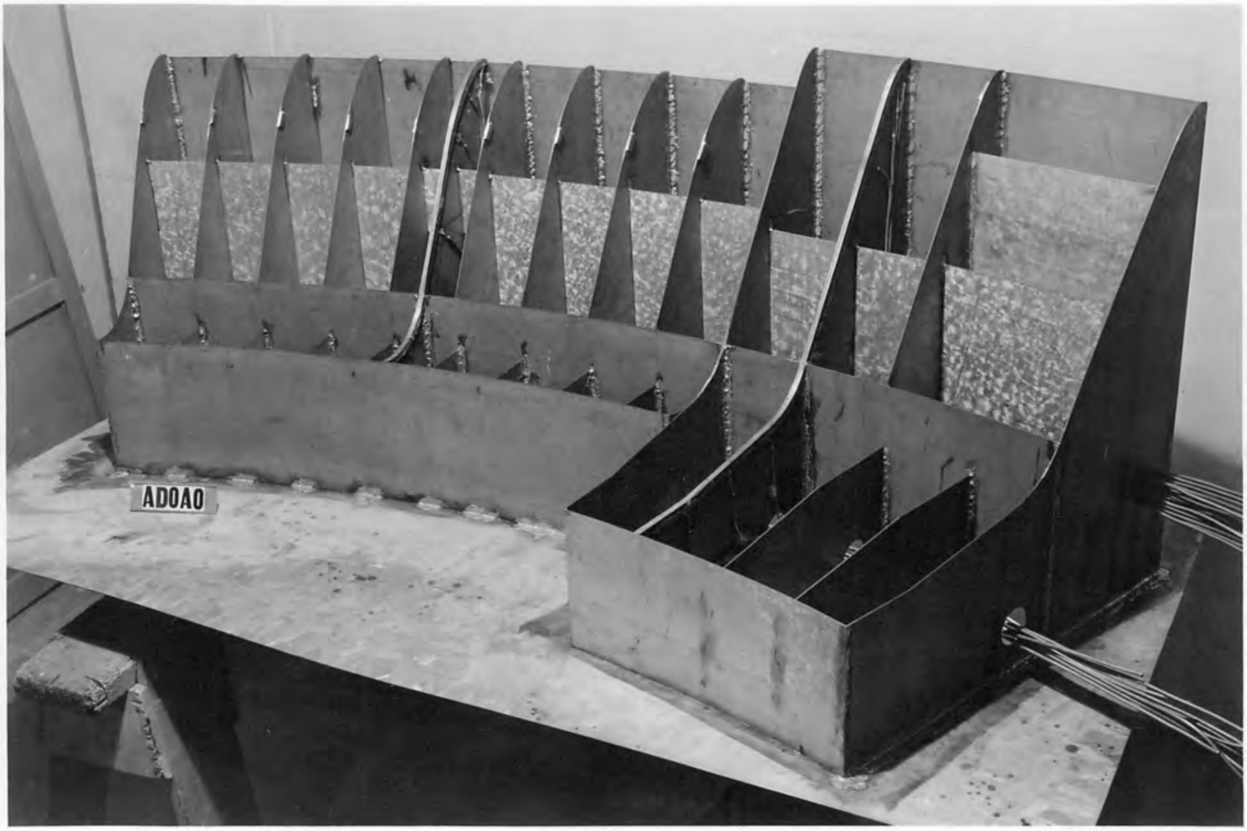
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
ALTUS PROJECT - OKLAHOMA

ALTUS DAM

HYDRAULIC MODEL STUDIES - 1:60 SCALE

MODEL DETAILS

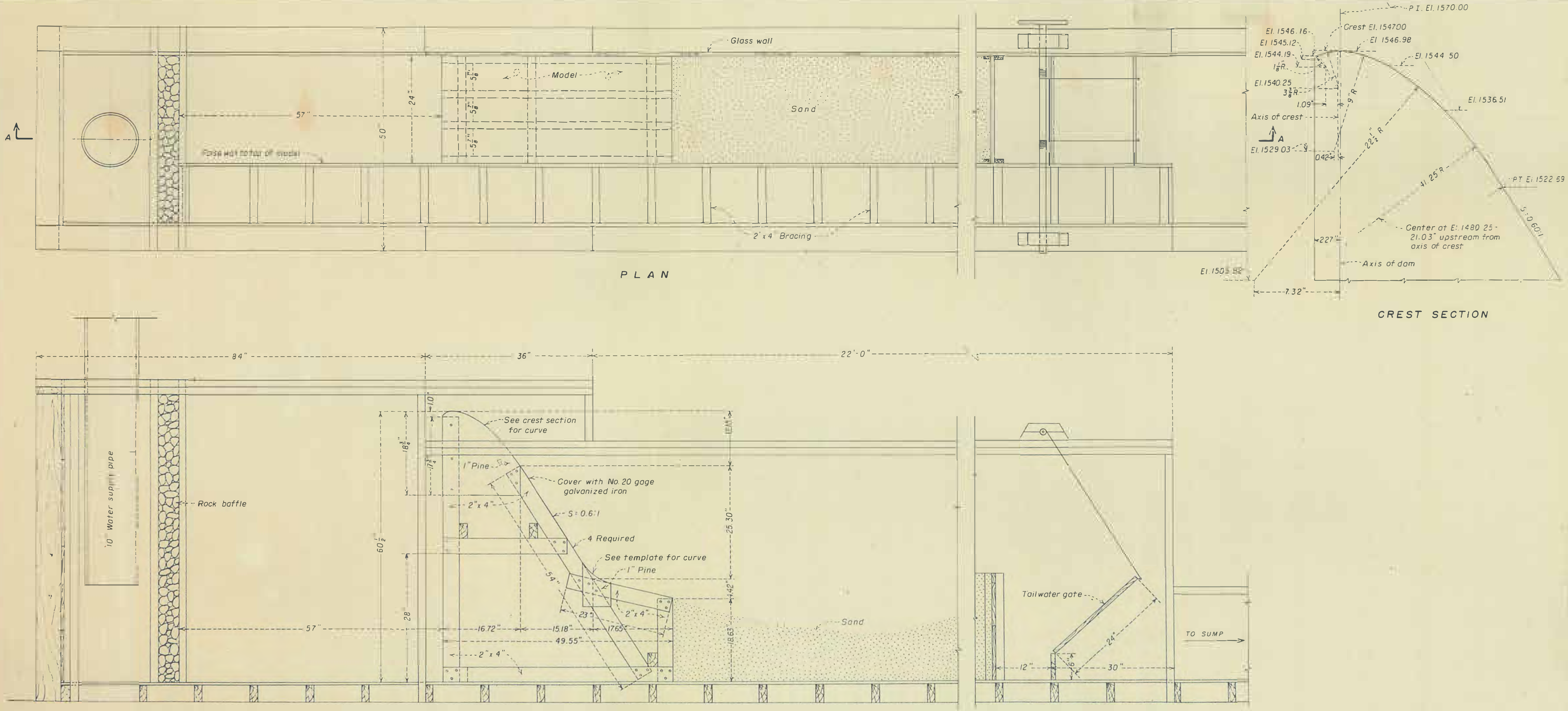
DRAWN		SUBMITTED	
TRACED		RECOMMENDED	
CHECKED		APPROVED	
	DENVER, COLORADO		258-D-134



A CONSTRUCTION DETAILS.

B VIEW FROM RIGHT BANK DOWNSTREAM.

ALTUS DAM MODEL - ORIGINAL DESIGN DETAILS - 1 TO 60 SCALE



PLAN

CREST SECTION

SECTION A-A

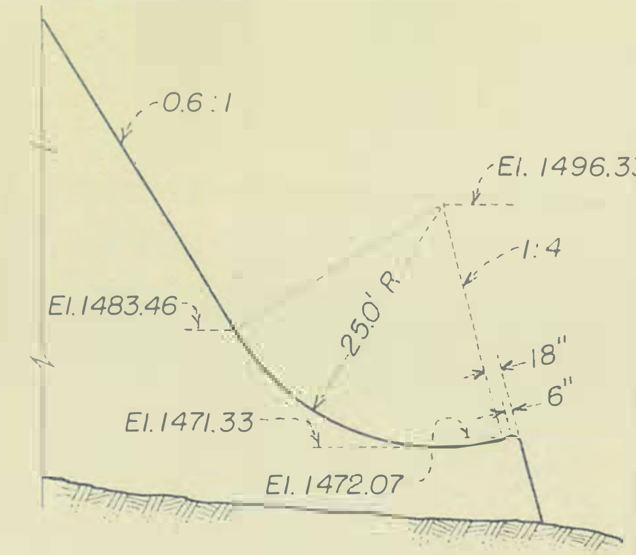
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
ALTUS PROJECT - OKLAHOMA

ALTUS DAM

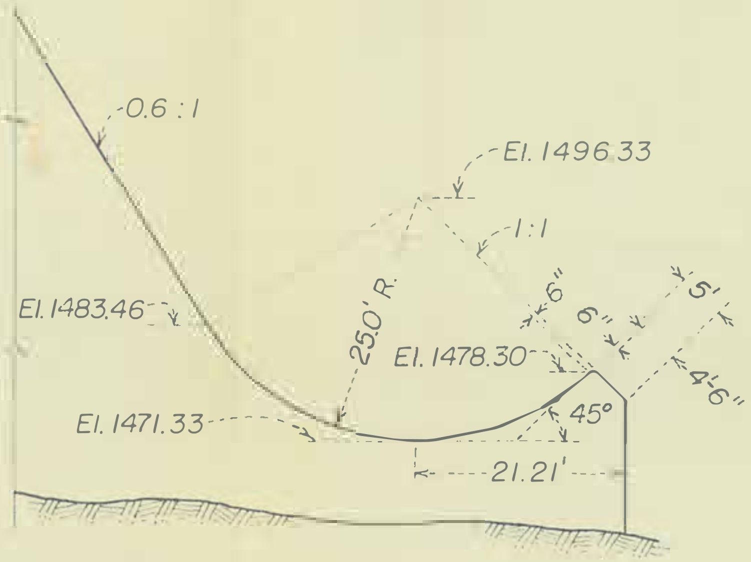
HYDRAULIC MODEL STUDIES - 1:24 SCALE

DETAILS OF SECTIONAL MODEL

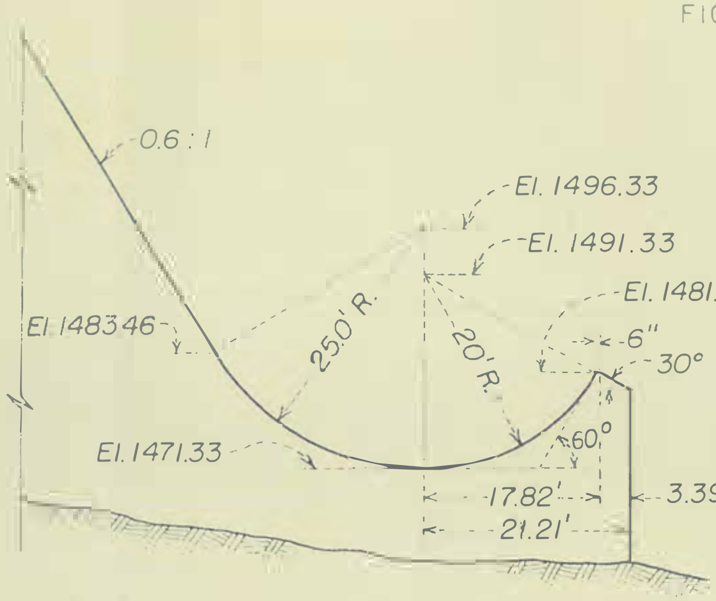
DRAWN	J.A.L.	SUBMITTED	
TRACED		RECOMMENDED	
CHECKED		APPROVED	
	DENVER, COLORADO - JUNE 16, 1942		258-D-135



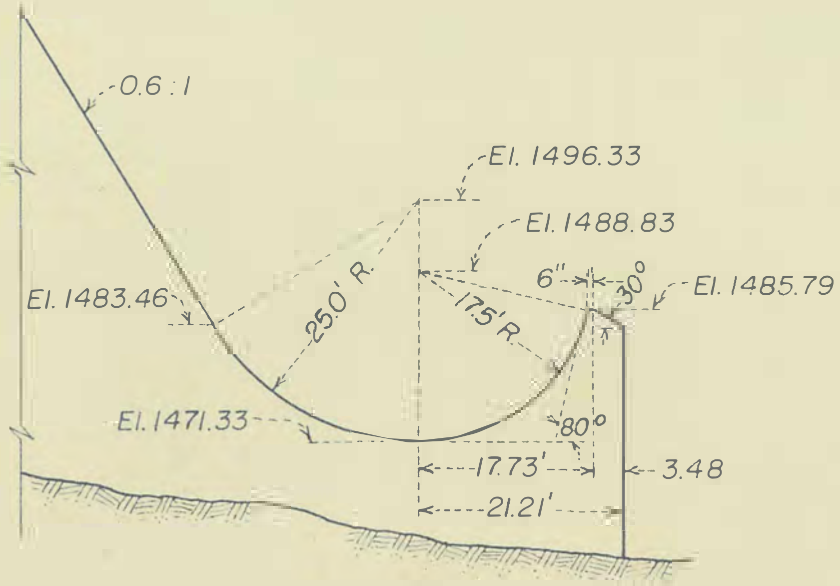
A. DESIGN 1 (ORIGINAL DESIGN)



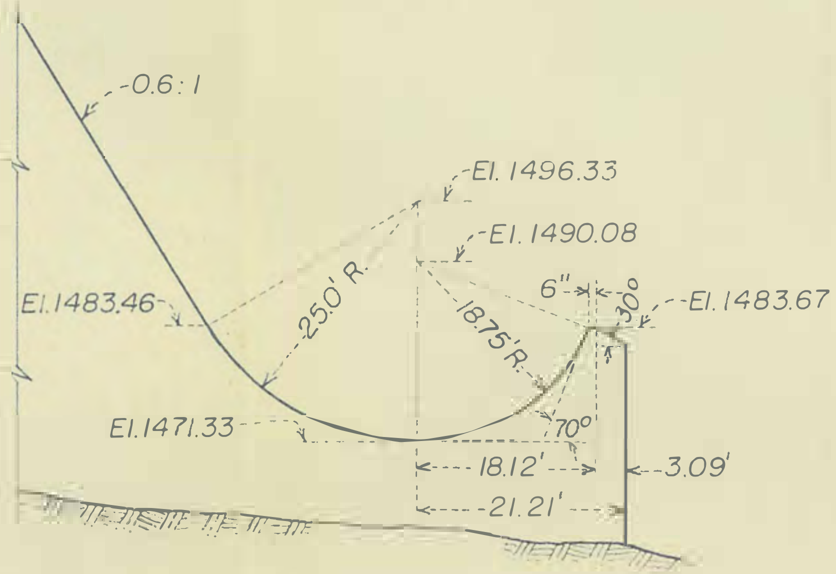
B. DESIGN 2



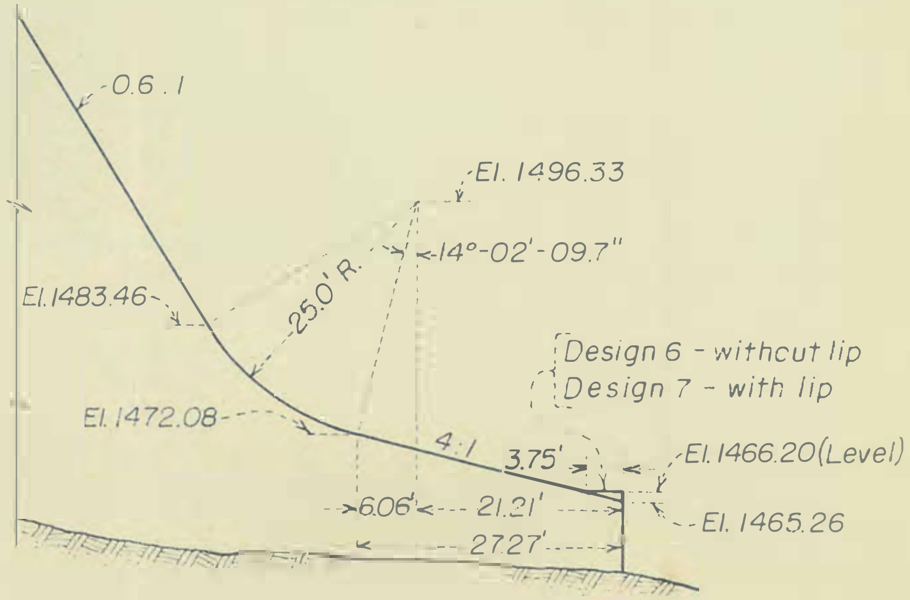
C. DESIGN 3



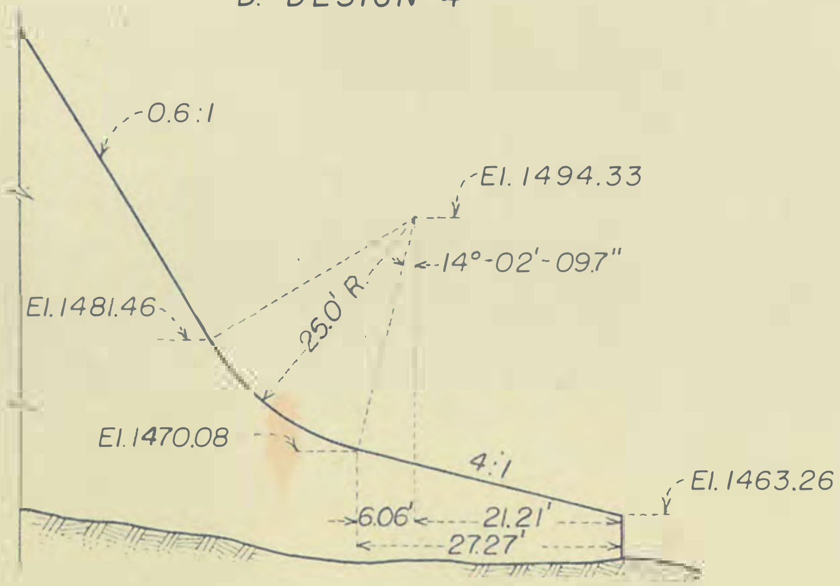
D. DESIGN 4



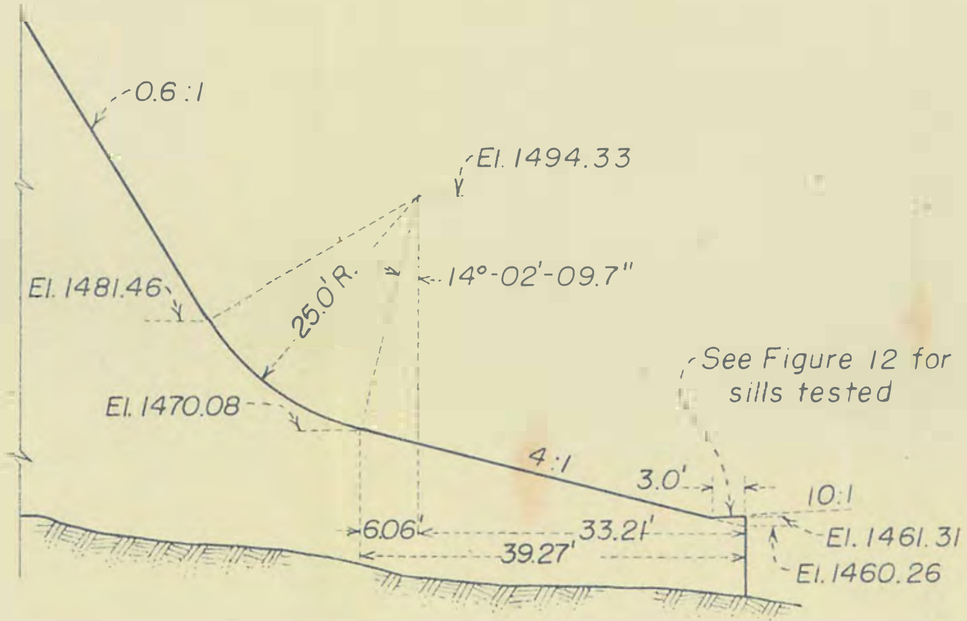
E. DESIGN 5



F. DESIGNS 6 AND 7



G. DESIGN 8



H. DESIGN 9 (RECOMMENDED DESIGN)

ALTUS PROJECT - OKLAHOMA

ALTUS DAM

HYDRAULIC MODEL STUDIES - 1 TO 60 SCALE

BUCKET AND APRON SHAPES

CONTROLLED SPILLWAY

258-D-136

A RESERVOIR ELEVATION 1564.00, DISCHARGES - UNCONTROLLED SPILLWAY 6,000, CONTROLLED SPILLWAY 54.000 SECOND-FEET.

B ROCK JETTY EXTENDED OUT FROM RIGHT BANK, AFTER 3/4 HOUR, 60,000 SECOND-FEET DISCHARGE

ALTUS DAM FLOW CONDITIONS AND SCOURS - ORIGINAL DESIGN SPILLWAYS - 1 TO 60 SCALE

A HYDRAULIC JUMP SWEEPS OFF UNCONTROLLED SPILLWAY APRON WHEN GATES 4 TO 9 ARE OPEN ON CONTROLLED SPILLWAY.

B HYDRAULIC JUMP REMAINS ON UNCONTROLLED SPILLWAY APRON WHEN ALL GATES OF CONTROLLED SPILLWAY ARE OPENED EQUALLY.

ALTUS DAM GATE OPERATION INFLUENCES HYDRAULIC JUMP ON UNCONTROLLED SPILLWAY
ORIGINAL DESIGN - 1 TO 60 SCALE

A CONTROLLED SPILLWAY BUCKET EXTENDED UP AT 25-FOOT RADIUS TO POINT WHERE TANGENT LINE IS 45 DEGREES FROM THE HORIZONTAL.

B CONTROLLED SPILLWAY BUCKET EXTENDED UP AT 20-FOOT RADIUS TO POINT WHERE TENGENT LINE IS 60 DEGREES FROM THE HORIZONTAL.

ALTUS DAM FLOW CONDITIONS - CONTROLLED SPILLWAY DESIGNS 2 AND 3 - 1 TO 60 SCALE

RESERVOIR ELEVATION 1564.00, DISCHARGES - UNCONTROLLED SPILLWAY 6,000,

FIGURE 10

A CONTROLLED SPILLWAY BUCKET EXTENDED UP AT 17 1/2-FOOT RADIUS TO POINT WHERE TANGENT LINE IS 80 DEGREES FROM THE HORIZONTAL.

B CONTROLLED SPILLWAY BUCKET EXTENDED UP AT 18 3/4-FOOT RADIUS TO POINT WHERE TANGENT LINE IS 70 DEGREES FROM THE HORIZONTAL.

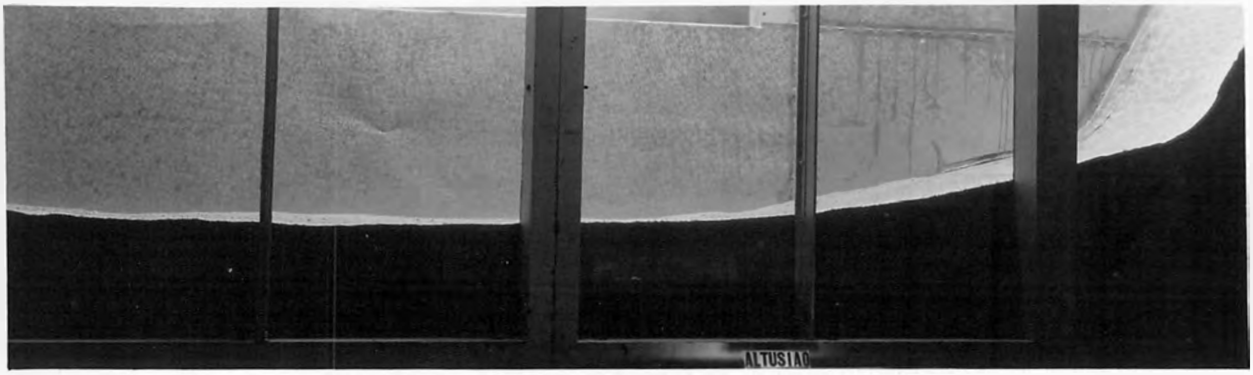
ALTUS DAM FLOW CONDITIONS - CONTROLLED SPILLWAY DESIGNS 4 AND 5 - 1 TO 60 SCALE

RESERVOIR ELEVATION 1564.00, DISCHARGES - UNCONTROLLED SPILLWAY 6,000,

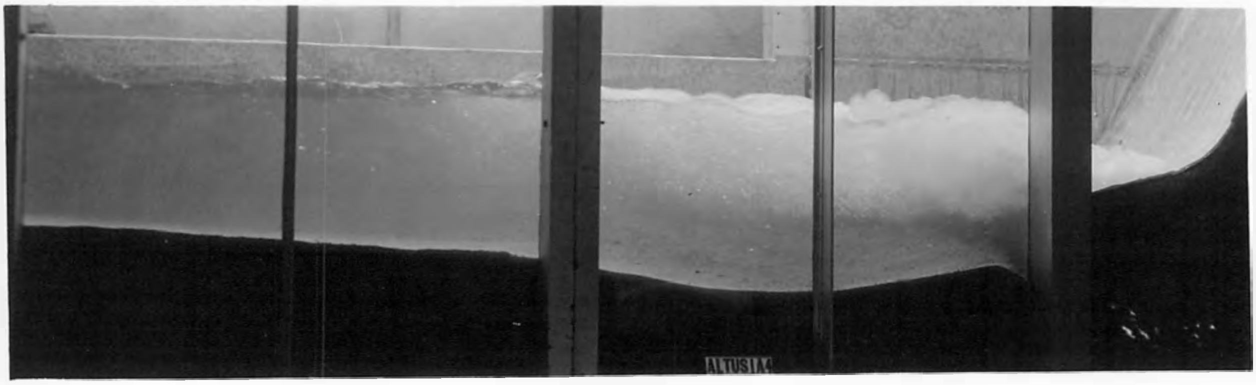
A CONTROLLED SPILLWAY BUCKET REPLACED WITH 4:1 SLOPING APRON TO ELEVATION 1465.26.

B HORIZONTAL LIP 3 FEET 9 INCHES LONG PLACED AT END OF 4:1 SLOPING APRON.

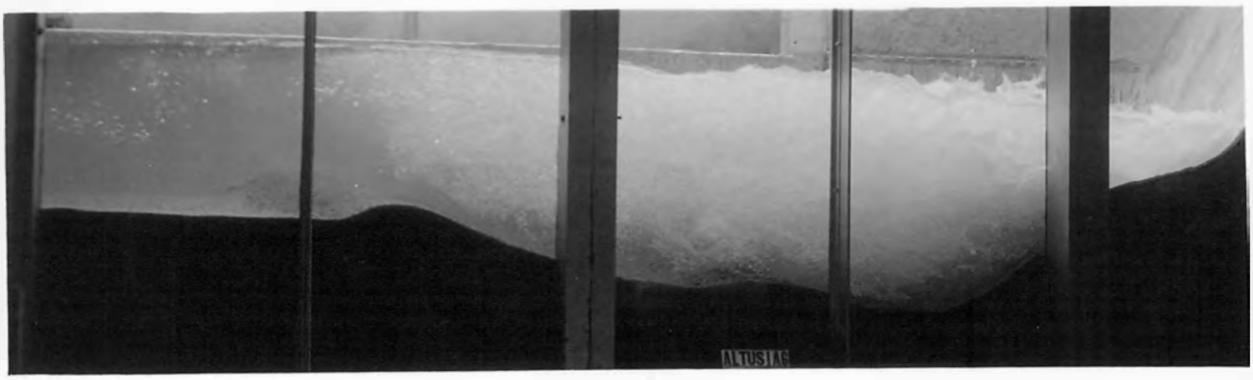
ALTUS DAM FLOW CONDITIONS - CONTROLLED SPILLWAY DESIGNS 6 AND 7 - 1 TO 60 SCALE



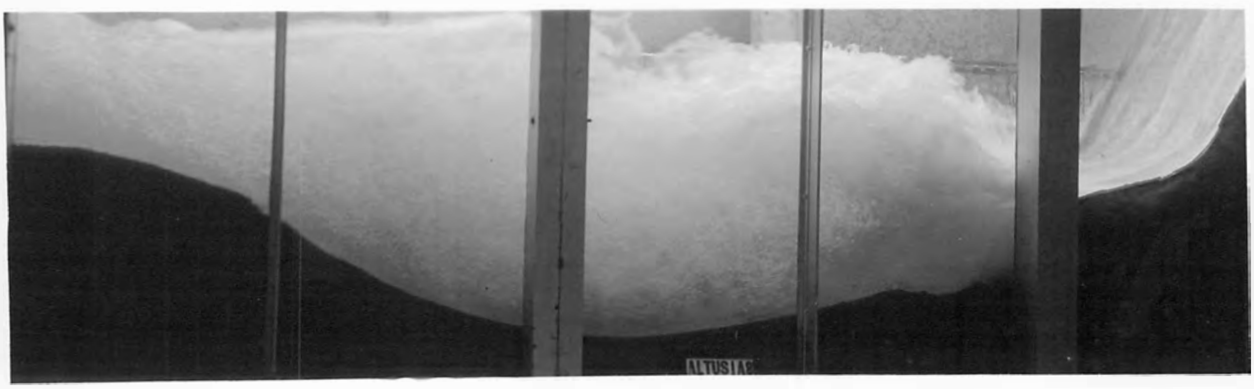
A MODEL BEFORE RUN.



B DISCHARGE 20,000 SECOND-FEET

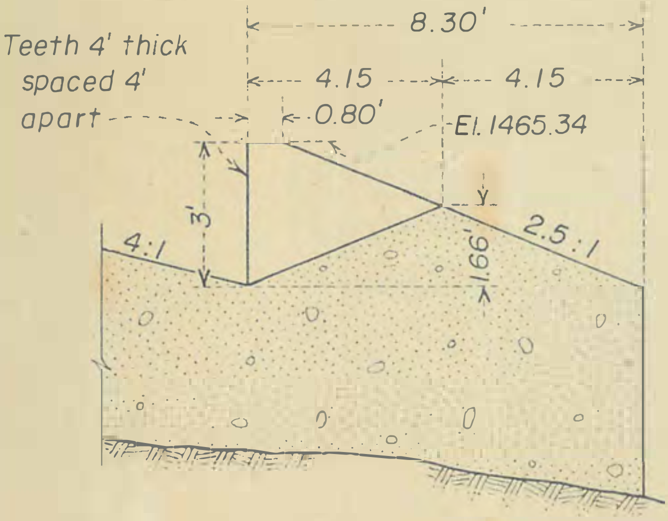


C DISCHARGE 40,000 SECOND-FEET

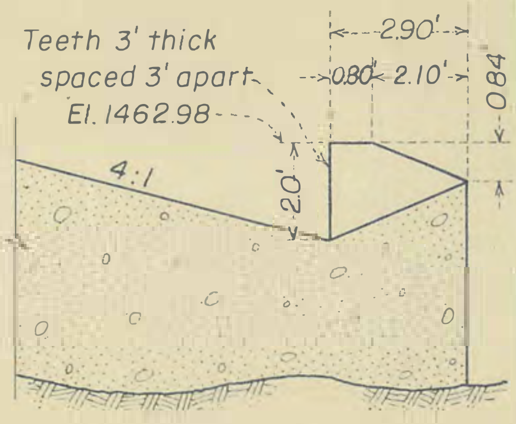


D DISCHARGE 60,000 SECOND-FEET.

ALTUS DAM SECTIONAL MODEL - SCOUR CONDITIONS - CONTROLLED SPILLWAY DESIGN 8
1 TO 24 SCALE

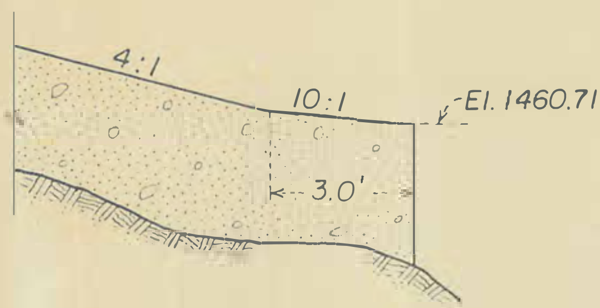


ORTHODOX REHBOCK SILL

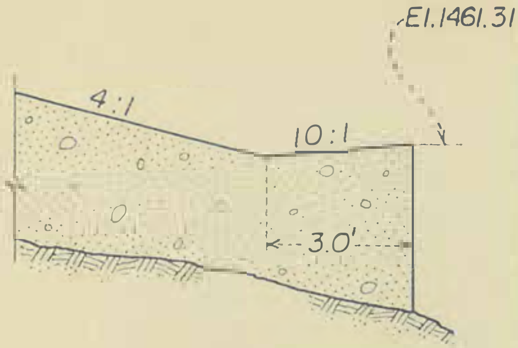


MODIFIED REHBOCK SILL

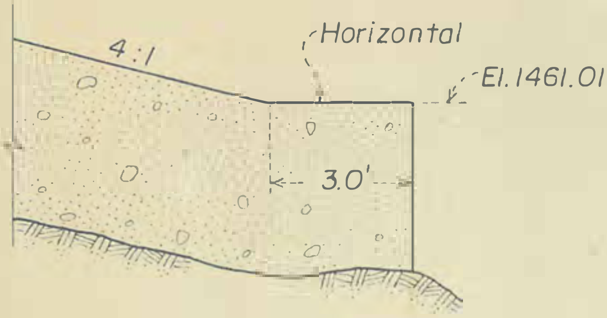
A. REHBOCK SILLS



10:1 DOWNWARD SLOPING SILL



10:1 UPWARD SLOPING SILL
(RECOMMENDED DESIGN)



HORIZONTAL SILL

B. TRIANGULAR SILLS

ALTUS PROJECT - OKLAHOMA

ALTUS DAM

HYDRAULIC MODEL STUDIES - 1 TO 48 SCALE

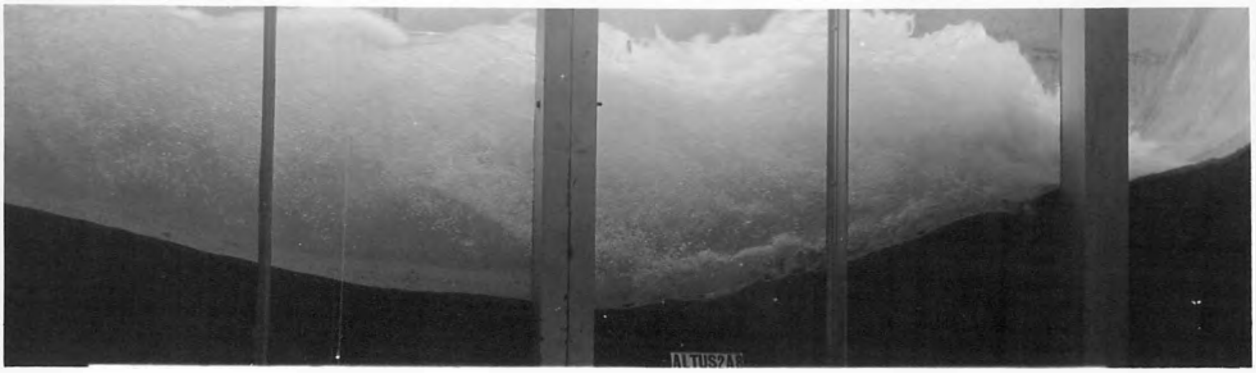
SILLS TESTED ON RECOMMENDED APRON

CONTROLLED SPILLWAY

258-D-137

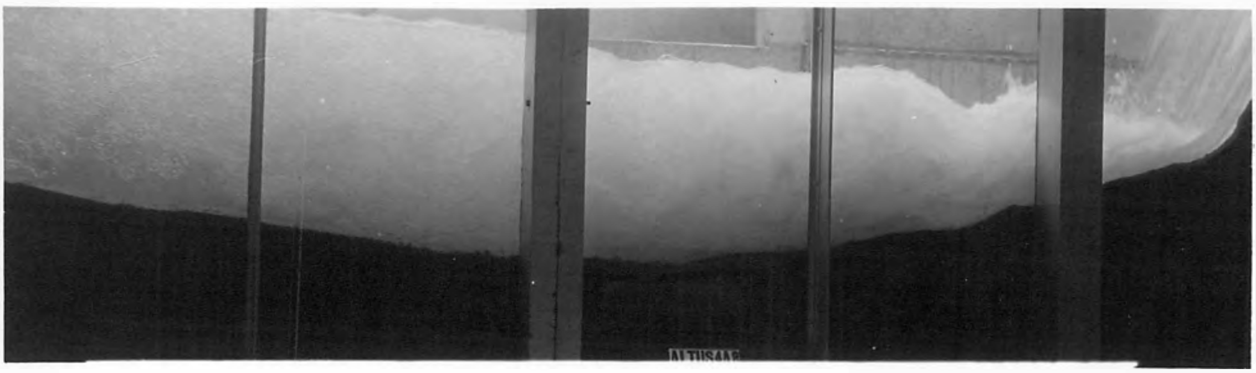
J.A.L. 5-20-42

FIGURE 14

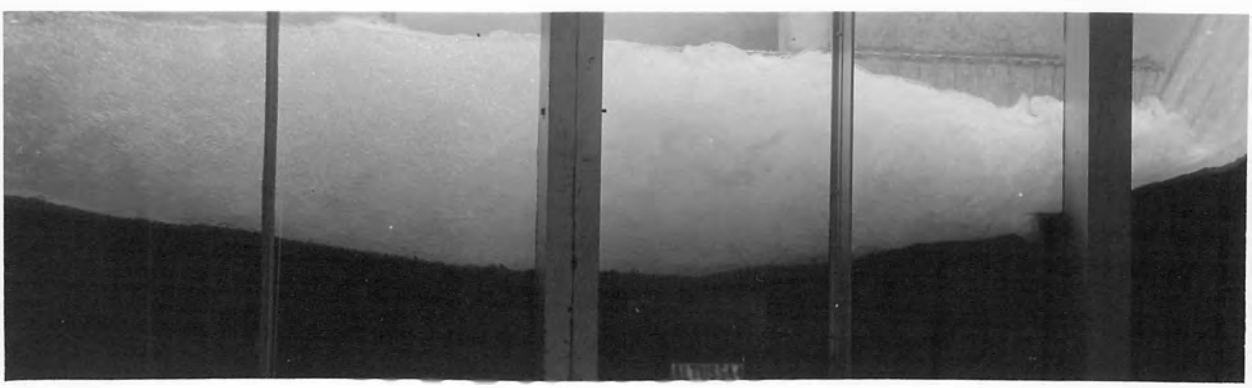


A REHBOCK SILL 3 FEET HIGH, 4 FEET THICK, TEETH SPACED 4 FEET APART.

B MODIFIED REHBOCK SILL 2 FEET HIGH, 3 FEET THICK, TEETH SPACED 3 FEET APART.

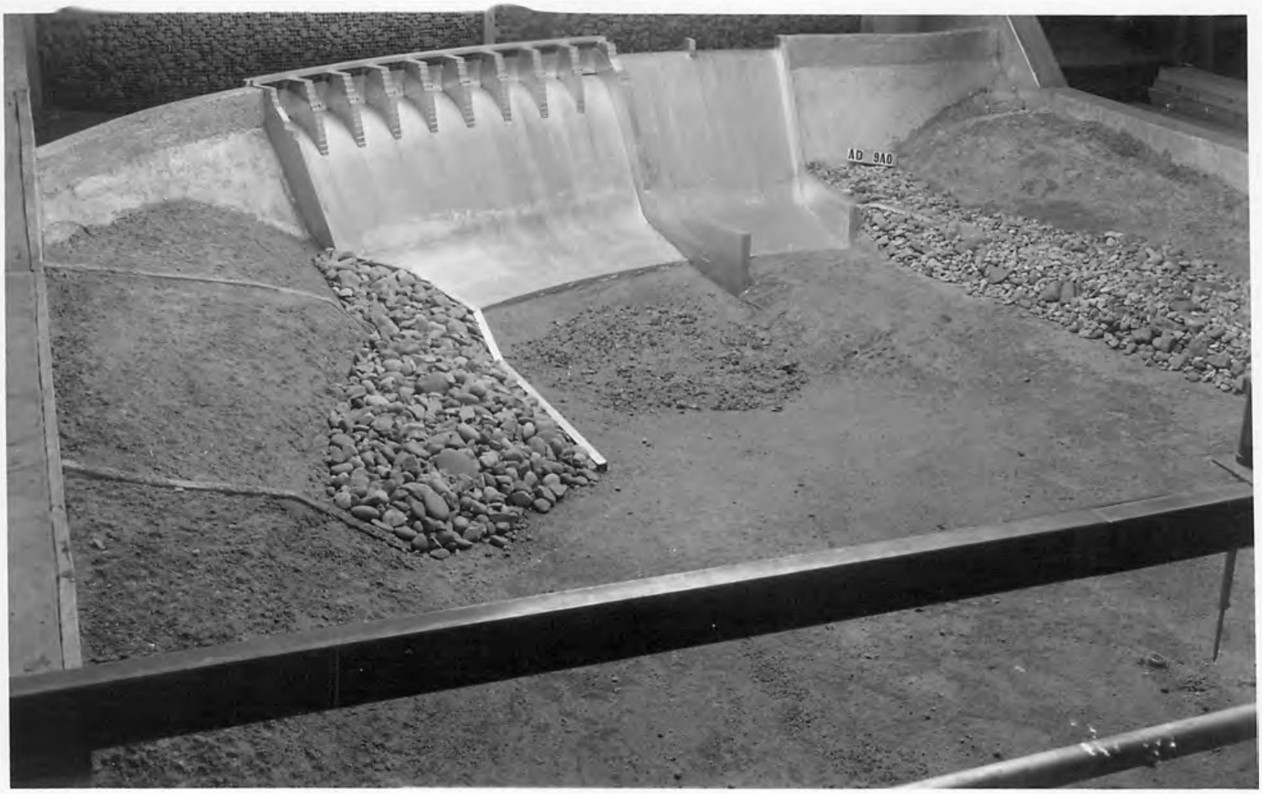


C RECOMMENDED APRON DESIGN WITH CONCRETE BACKFILLED AT END OF APRON.



D RECOMMENDED DESIGN - NO BACKFILL AT END OF APRON.

ALTUS DAM SECTIONAL MODEL - SCOUR AND FLOW CONDITIONS - DESIGN 9
1 TO 24 SCALE

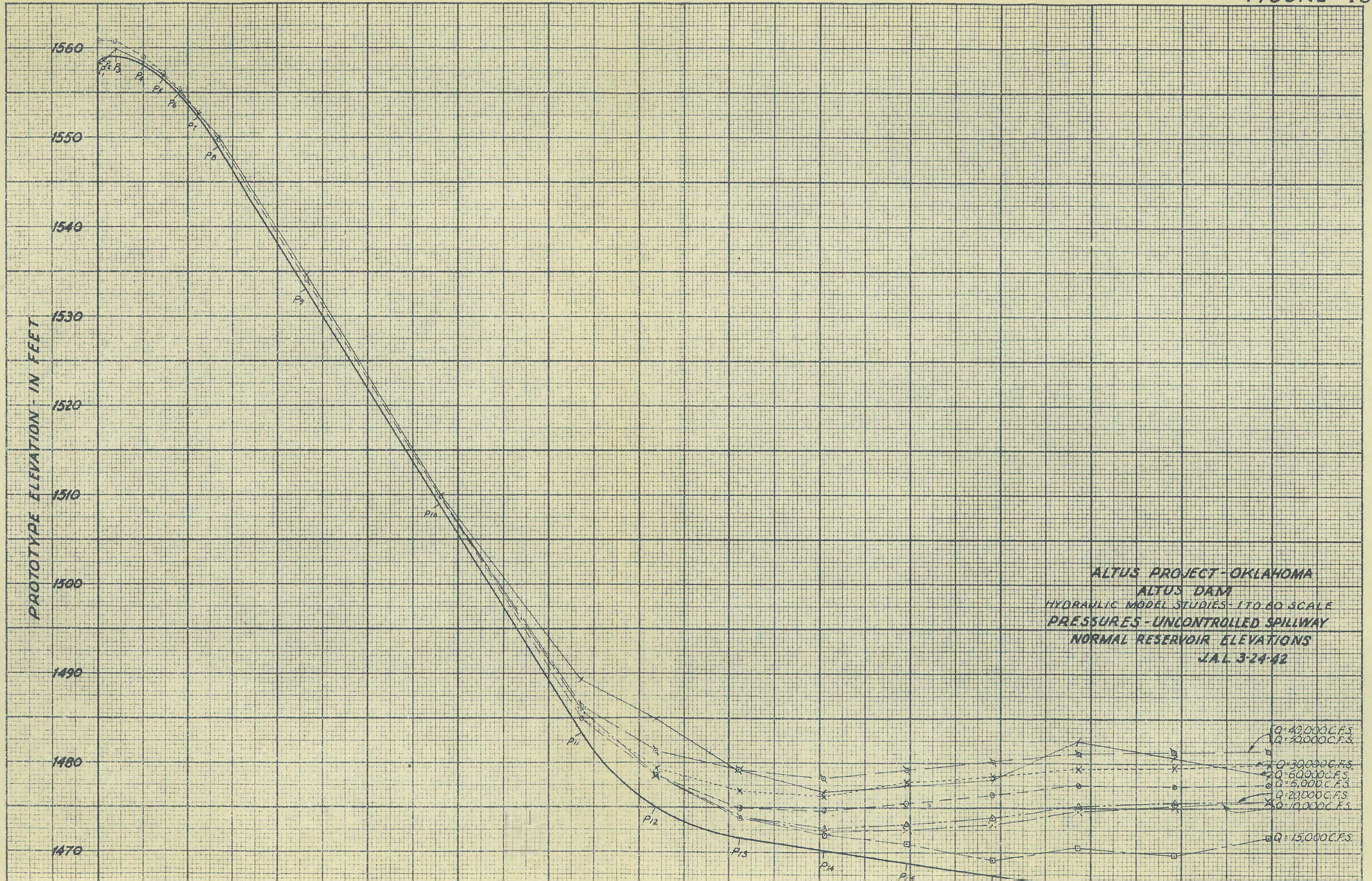


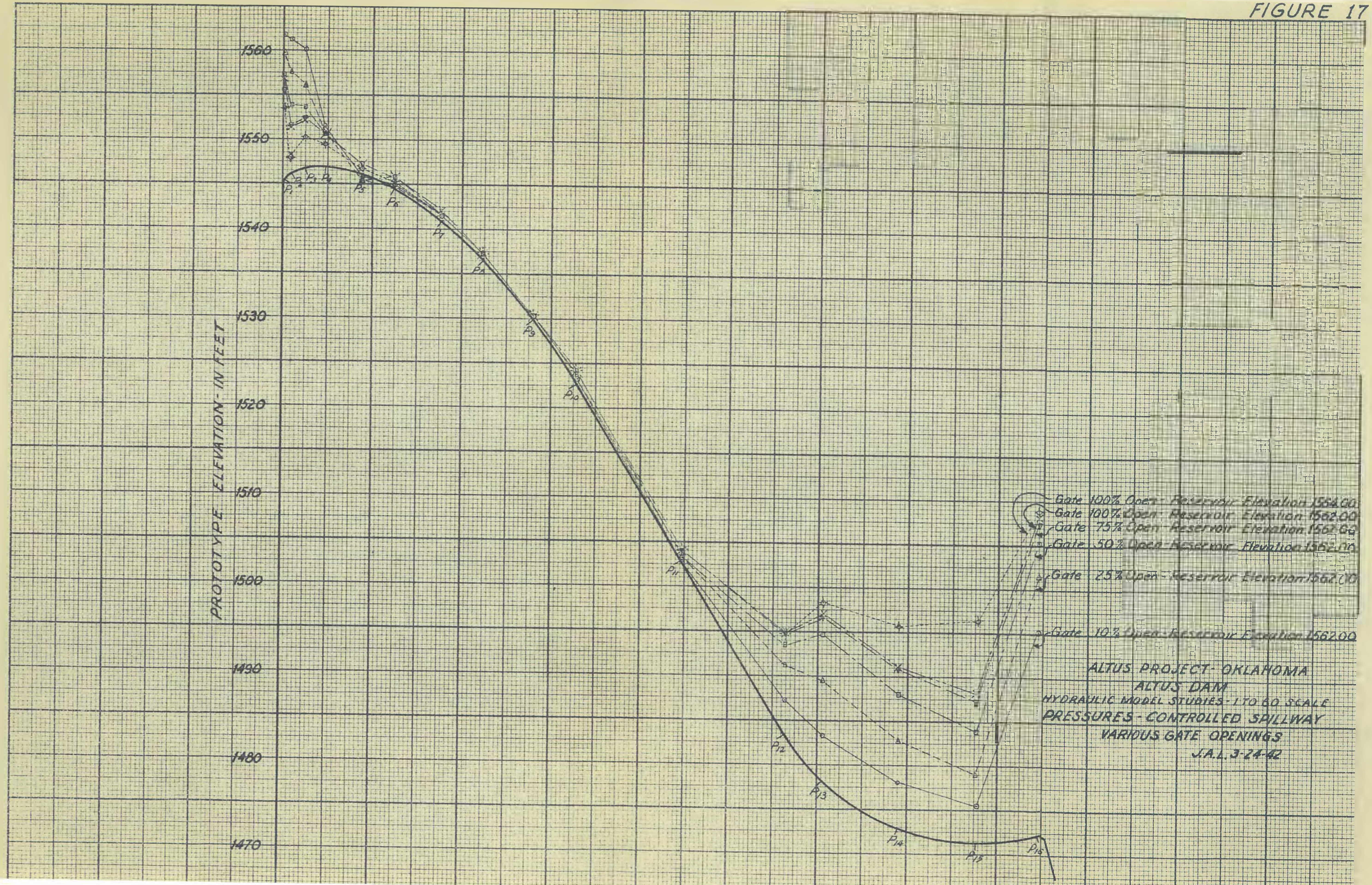
A MODEL ARRANGEMENT.

B FLOW CONDITIONS - RESERVOIR ELEVATION 1564.00, DISCHARGES - UNCONTROLLED SPILLWAY 6,000, CONTROLLED SPILLWAY 54,000 SECOND-FEET.

ALTUS DAM RECOMMENDED DESIGN - 1 TO 60 SCALE

FIGURE 16


1560
1550
1540
1530
1520
1510
1500
1490
1480
1470
PROTOTYPE ELEVATION - IN FEET
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
P12
P13
P14
P15
Q=40,000 C.F.S.
Q=50,000 C.F.S.
Q=30,000 C.F.S.
Q=60,000 C.F.S.
Q=6,000 C.F.S.
Q=20,000 C.F.S.
Q=10,000 C.F.S.
Q=15,000 C.F.S.
ALTUS PROJECT - OKLAHOMA
ALTUS DAM
HYDRAULIC MODEL STUDIES - 1 TO 60 SCALE
PRESSURES - UNCONTROLLED SPILLWAY
NORMAL RESERVOIR ELEVATIONS
J.A.L. 3-24-42


1560
1550
1540
1530
1520
1510
1500
1490
1480
1470
PROTOTYPE ELEVATION - IN FEET
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
P12
P13
P14
P15
P16
Gate 100% Open - Reservoir Elevation 1564.00
Gate 100% Open - Reservoir Elevation 1562.00
Gate 75% Open - Reservoir Elevation 1562.00
Gate 50% Open - Reservoir Elevation 1562.00
Gate 25% Open - Reservoir Elevation 1562.00
Gate 10% Open - Reservoir Elevation 1562.00
ALTUS PROJECT - OKLAHOMA
ALTUS DAM
HYDRAULIC MODEL STUDIES - 1 TO 60 SCALE
PRESSURES - CONTROLLED SPILLWAY
VARIOUS GATE OPENINGS
J.A.L. 3-24-42