UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

# HYDRAULIC MODEL STUDIES ON THE SPILLWAY FOR THE ANGOSTURA DAM

## ANGOSTURA UNIT - MISSOURI BASIN PROJECT

Hydraulic Laboratory Report No. 192

ENGINEERING AND GEOLOGICAL
CONTROL AND RESEARCH DIVISION

BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO

JANUARY 7, 1946

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
January 7, 1946

Laboratory Report No. 192
Hydraulic Laboratory
Compiled by: R. C. Besel
Reviewed by: J. N. Bradley

Subject: Hydraulic model studies of the spillway for Angostura Dam--Angostura Project--Missouri River Basin--South Dakota.

Summary: A hydraulic model investigation was requested to check the adequacy of the proposed spillway for Angostura Dam for releasing water during floods. The main portion of the investigation was centered on the energy dissipation as the tailwater depth was not sufficient for the proposed type bucket or a conventional stilling pool.

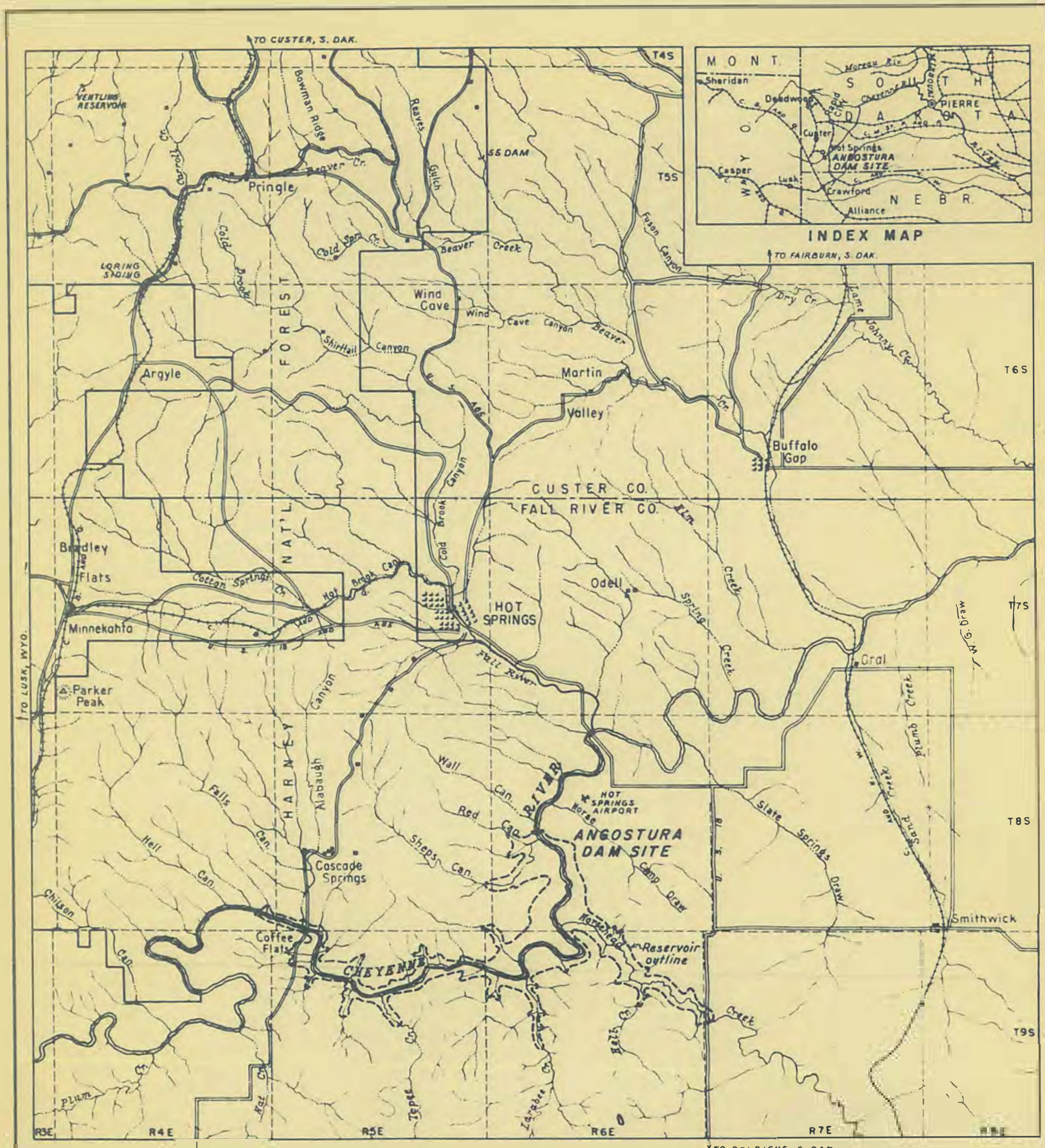
The original design consisted of a 100-foot radius solid bucket. Prevailing conditions made it necessary to develop a new type bucket for this particular dam. A slotted-type energy dissipator with a 40-foot radius produced the desired results, and a saving of approximately $500,000 was realized over a sloping apron design which would have been necessary were it not for the development of the new device.

The experimentation was carried on with two models: One a 1:42 scale sectional model for the detailed studies of the bucket proper, and the other a 1:72 scale model of the complete spillway. The latter model was used to study side effects and to observe the action of the bucket as a whole. The final design of the downstream wing-walls were determined in the 1:72 scale model.

The Prototype. The Angostura Dam will be an earth-fill structure, located on the Cheyenne River in Fall River and Custer Counties, near Hot Springs in the southwestern corner of South Dakota (Figure 1). The principal hydraulic feature involved in its construction is an overfall concrete spillway with a special design of bucket serving as an energy dissipator (Figures 2 and 3).

The concrete spillway and bucket will serve to convey flood waters safely past the dam. The designed capacity of the spillway is 277,000

FIGURE 1




VICINITY MAP

SCALE OF MILES

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ANGOSTURA UNIT — SOUTH DAKOTA

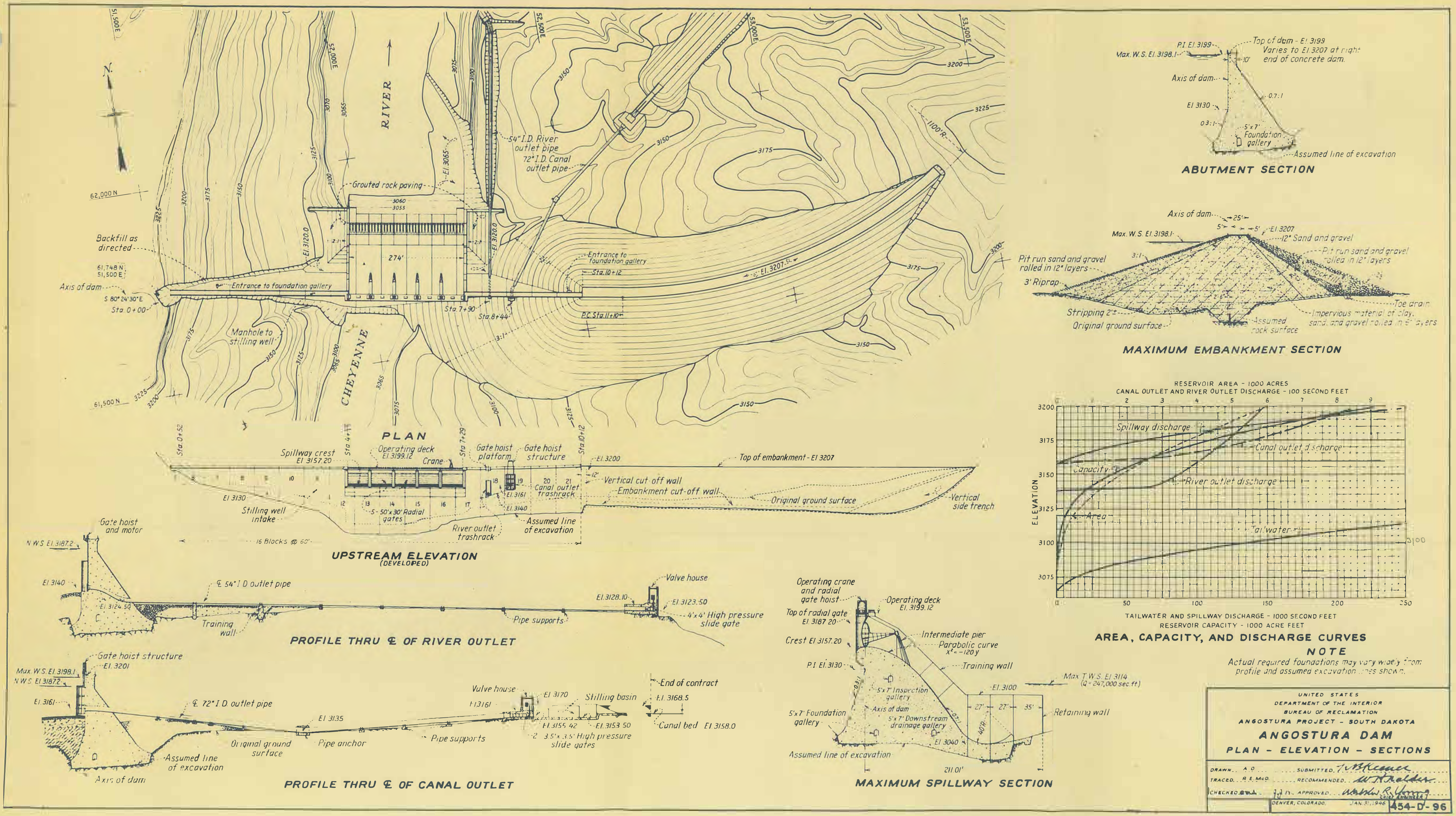
**ANGOSTURA DAM**

**LOCATION MAP**

DRAWN A.T.L. SUBMITTED [signature]
TRACED C.E.M. RECOMMENDED [signature]
CHECKED R.H.W. APPROVED Walker R. Young CHIEF ENGINEER

DENVER, COLORADO. JAN. 31, 1946 454-D-92

FIGURE 2


PLAN
CHEYENNE
RIVER
N.
54" I.D. River outlet pipe
72" I.D. Canal outlet pipe
Grouted rock paving
Backfill as directed
Axis of dam
S 80°24'30"E
Sta. 0+00
Entrance to foundation gallery
Manhole to stilling well
274'
Sta. 7+90
Sta. 8+44
Sta. 10+12
P.C. Sta. 11+10
El. 3207
1100' R.
UPSTREAM ELEVATION
(DEVELOPED)
Spillway crest El. 3157.20
Operating deck El. 3199.12
Crane
Gate hoist platform
Gate hoist structure
Top of embankment - El. 3207
Vertical cut-off wall
Embankment cut-off wall
Original ground surface
Vertical side trench
Stilling well intake
5 - 50'x30' Radial gates
River outlet trashrack
Canal outlet trashrack
Assumed line of excavation
16 Blocks @ 60'
PROFILE THRU ℄ OF RIVER OUTLET
Gate hoist and motor
N.W.S. El. 3187.2
℄ 54" I.D. outlet pipe
Training wall
Pipe supports
Valve house
El. 3128.10
El. 3123.50
4'x4' High pressure slide gate
PROFILE THRU ℄ OF CANAL OUTLET
Gate hoist structure
Max. W.S. El. 3198.1
N.W.S. El. 3187.2
El. 3201
El. 3161
℄ 72" I.D. outlet pipe
El. 3135
Original ground surface
Pipe anchor
Pipe supports
Assumed line of excavation
Axis of dam
Valve house
El. 3170
Stilling basin
El. 3155.42
El. 3153.50
2 - 3.5'x3.5' High pressure slide gates
End of contract
El. 3168.5
Canal bed El. 3158.0
MAXIMUM SPILLWAY SECTION
Operating crane and radial gate hoist
Operating deck El. 3199.12
Top of radial gate El. 3187.20
Crest El. 3157.20
Intermediate pier
Parabolic curve $x^2 = -120y$
Training wall
P.I. El. 3130
5'x7' Inspection gallery
Axis of dam
5'x7' Foundation gallery
5'x7' Downstream drainage gallery
El. 3040
Max. T.W.S. El. 3114 (Q = 247,000 sec. ft.)
El. 3100
Retaining wall
Assumed line of excavation
211.01'
ABUTMENT SECTION
P.I. El. 3199
Max. W.S. El. 3198.1
Top of dam - El. 3199 Varies to El. 3207 at right end of concrete dam.
Axis of dam
El. 3130
0.7:1
0.3:1
5'x7' Foundation gallery
Assumed line of excavation
MAXIMUM EMBANKMENT SECTION
Axis of dam
Max. W.S. El. 3198.1
El. 3207
12" Sand and gravel
Pit run sand and gravel rolled in 12" layers
3' Riprap
Rockfill
Stripping 2'±
Original ground surface
Assumed rock surface
Toe drain
Impervious material of clay, sand, and gravel rolled in 6" layers
AREA, CAPACITY, AND DISCHARGE CURVES
RESERVOIR AREA - 1000 ACRES
CANAL OUTLET AND RIVER OUTLET DISCHARGE - 100 SECOND FEET
Spillway discharge
Canal outlet discharge
Capacity
River outlet discharge
Area
Tailwater
ELEVATION
TAILWATER AND SPILLWAY DISCHARGE - 1000 SECOND FEET
RESERVOIR CAPACITY - 1000 ACRE FEET
NOTE
Actual required foundations may vary widely from profile and assumed excavation lines shown.
UNITED STATES
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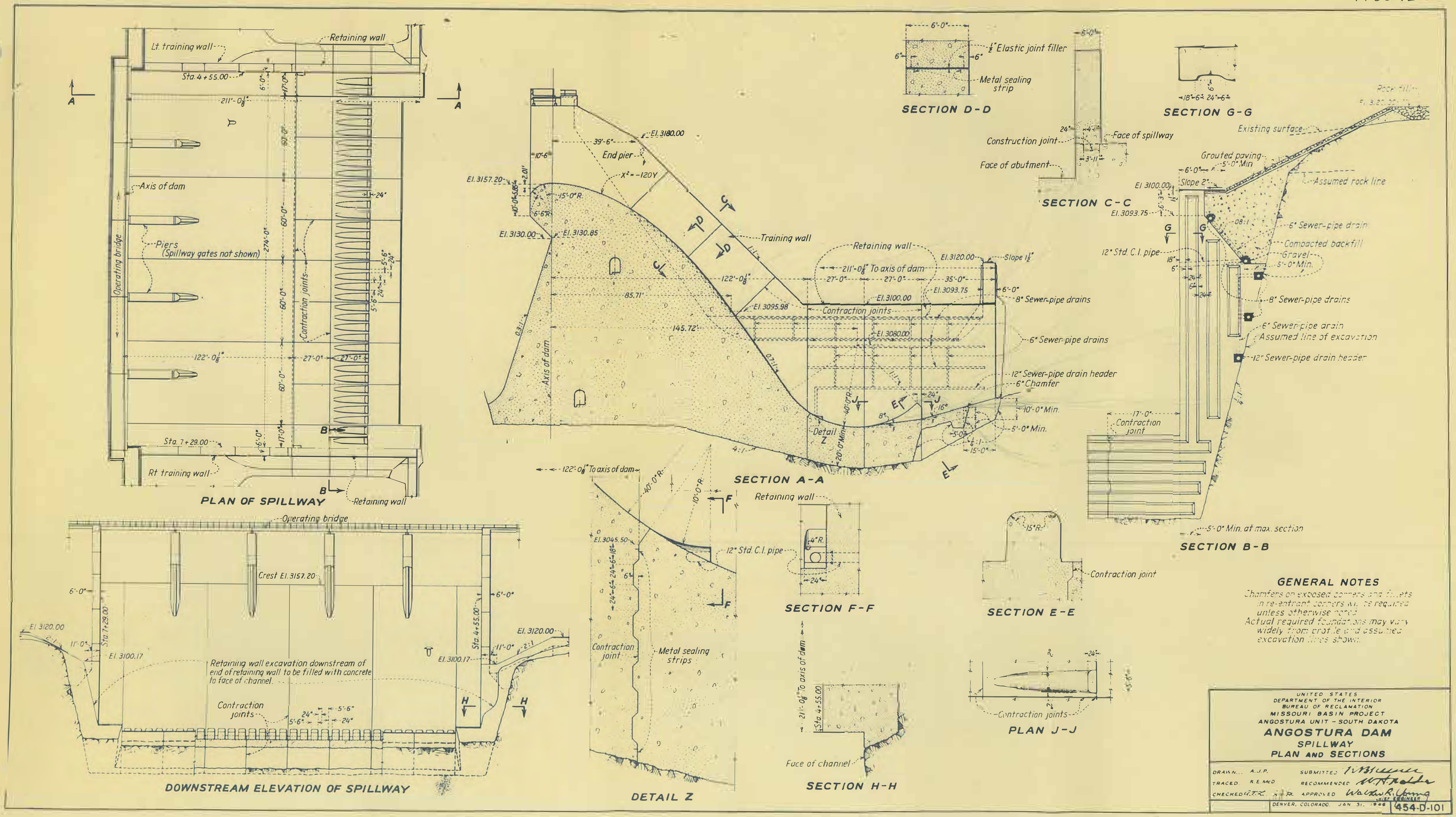
BUREAU OF RECLAMATION
ANGOSTURA PROJECT - SOUTH DAKOTA
ANGOSTURA DAM
PLAN - ELEVATION - SECTIONS
DENVER, COLORADO
JAN. 31, 1946
454-D-96


PLAN OF SPILLWAY
Lt. training wall
Retaining wall
Sta. 4+55.00
211'-0⅛"
Axis of dam
Piers
(Spillway gates not shown)
Operating bridge
Contraction joints
122'-0⅛"
27'-0"
274'-0"
60'-0"
Sta. 7+29.00
Rt training wall
SECTION A-A
El. 3180.00
39'-6"
End pier
$X^2 = -120Y$
El. 3157.20
15'-0" R.
El. 3130.00
El. 3130.85
Training wall
Retaining wall
211'-0⅛" To axis of dam
122'-0⅛"
35'-0"
El. 3120.00
Slope 1½"
El. 3100.00
El. 3093.75
El. 3095.98
El. 3080.00
85.71'
145.72'
Axis of dam
8" Sewer-pipe drains
6" Sewer-pipe drains
12" Sewer-pipe drain header
6" Chamfer
10'-0" Min.
5'-0" Min.
Detail Z
SECTION D-D
½" Elastic joint filler
Metal sealing strip
SECTION C-C
Construction joint
Face of spillway
Face of abutment
SECTION G-G
Rock fill
Existing surface
Grouted paving
Assumed rock line
El. 3100.00
El. 3093.75
12" Std. C.I. pipe
6" Sewer-pipe drain
Compacted backfill
Gravel
8" Sewer-pipe drains
Assumed line of excavation
12" Sewer-pipe drain header
Contraction joint
5'-0" Min. at max. section
SECTION B-B
DOWNSTREAM ELEVATION OF SPILLWAY
Operating bridge
Crest El. 3157.20
El. 3120.00
El. 3100.17
Retaining wall excavation downstream of end of retaining wall to be filled with concrete to face of channel.
Contraction joints
DETAIL Z
122'-0⅛" To axis of dam
40'-0" R.
10'-0" R.
El. 3045.50
Contraction joint
Metal sealing strips
SECTION F-F
Retaining wall
12" Std. C.I. pipe
SECTION H-H
211'-0⅛" To axis of dam
Sta. 4+55.00
Face of channel
SECTION E-E
15" R.
Contraction joint
PLAN J-J
Contraction joints
GENERAL NOTES
Chamfers on exposed corners and fillets in re-entrant corners will be required unless otherwise noted.
Actual required foundations may vary widely from profile and assumed excavation lines shown.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
ANGOSTURA UNIT - SOUTH DAKOTA
ANGOSTURA DAM
SPILLWAY
PLAN AND SECTIONS
DRAWN A.J.P.
TRACED R.E.McD
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO, JAN. 31, 1946
454-D-101

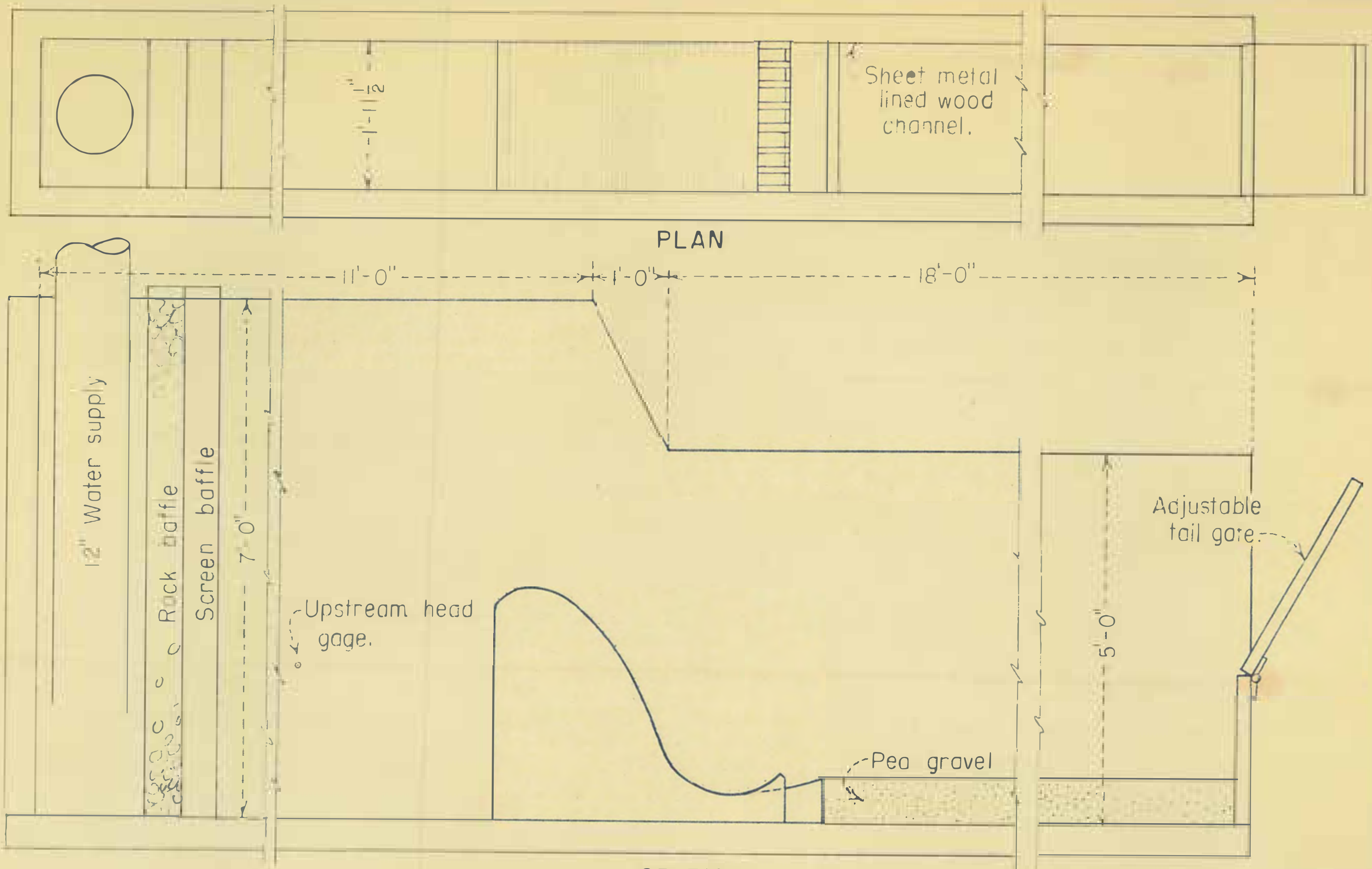
second-feet. Other means for releasing water downstream will be through the river outlet works, controlled by a 4- by 4-foot high pressure slide gate and through a canal headworks which will be controlled by two 3.5- by 3.5-foot high-pressure slide gates.

The drainage basin above the reservoir covers an area of 9,100 square miles located in eastern Wyoming, northwestern Nebraska, and southwestern South Dakota. The rate of runoff is highly variable, ranging from negligible amounts in the dry season to the largest recorded flow of 114,000 second-feet. The average annual percipitation over the area is 19.12 inches.

The plan of development includes the construction of a reservoir, an earth-fill dam with gravity concrete spillway, powerplant, outlet conduit, canal headworks, and laterals. The reservoir will have a capacity of 316,000 acre-feet of which 100,000 acre-feet will constitute dead storage below the irrigation level. The powerplant, which will have two 1,500-kilowatt units, will be located about four miles downstream from the dam. The headworks to the main irrigation canal will be located in the reservoir about 100 feet above the riverbed. The main canal will have a length of 25 miles.

The Models. Two models were used in the hydraulic studies for Angostura Dam. One, a sectional model, was placed in a long flume, and the other consisted of the complete spillway and downstream river channel. The sectional model was on a scale ratio of 1:42. It was of wood construction, lined with sheet metal (Figure 4). The overflow shape was formed of sheet metal permanently soldered to the metal side walls of the flume. The bucket was installed in a manner such that it could be readily replaced by other shapes and sizes. A large glass window was installed in one side of the flume to observe flow conditions over the spillway and the action in the bucket. Pea gravel was placed in the downstream portion of the flume to show the action of loose material in the riverbed and to indicate the scour pattern to be expected in the prototype.

The model for the complete spillway and downstream river channel was constructed using a 1:72 scale ratio. The head and tail boxes were




ANGOSTURA DAM SPILLWAY
HYDRAULIC MODEL STUDIES
SCALE 1:42 SECTIONAL MODEL

FIGURE 4

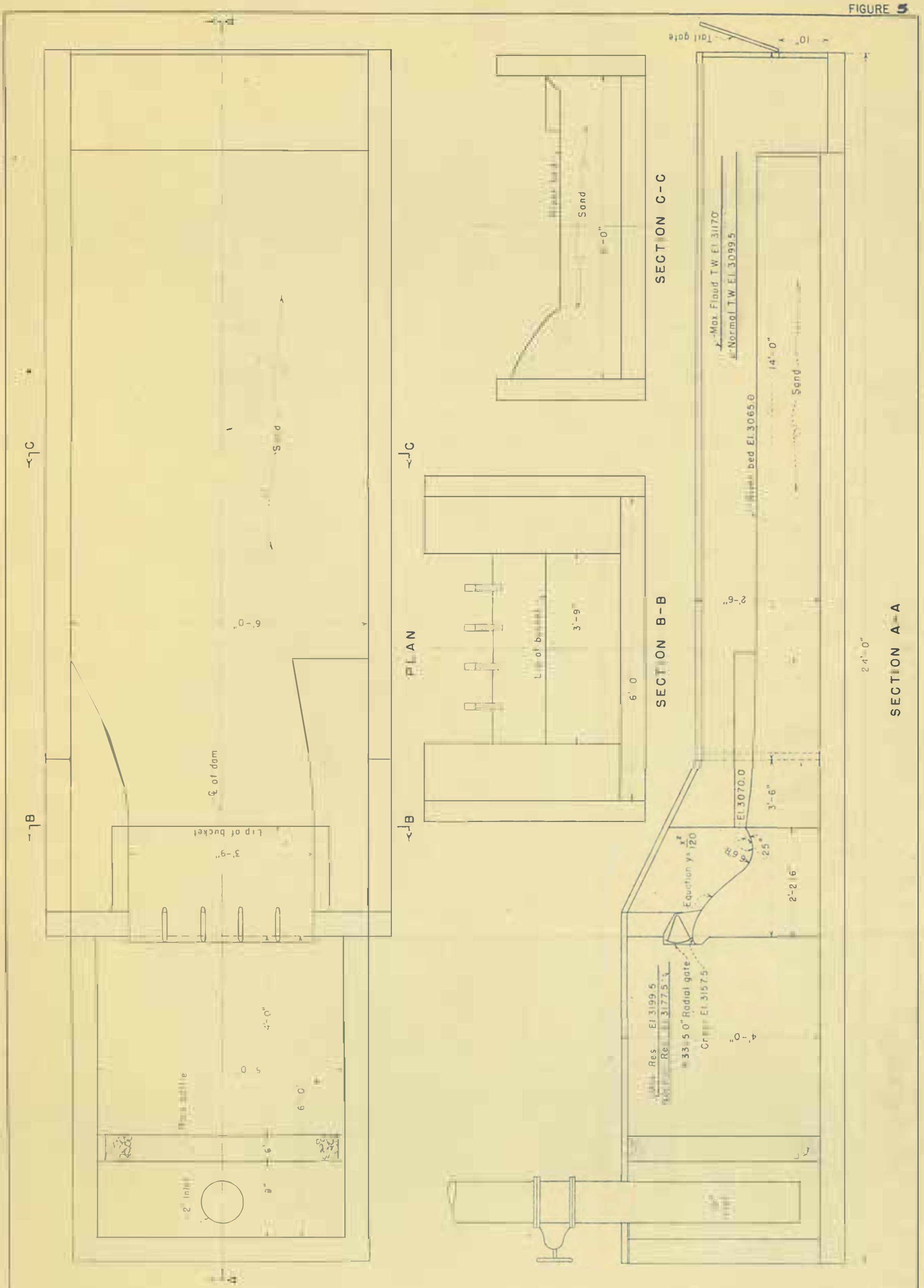
of wood construction lined with sheet metal (Figure 5). The overflow section and bucket were formed of sheet metal and soldered to the lining of the box. The solid portions of the channel walls were constructed of concrete backed with wood and metal lath for false work. The gate piers on the crest were constructed of oiled redwood. The 50- by 30-foot radial gates on the crest were constructed of sheet metal and hinged to the piers. The riverbed and downstream channel were filled with fine sand to observe scour patterns after various flows over the spillway. The tailwater was controlled by a variable-height weir-type gate hinged at the bottom and raised and lowered by cables fastened to a pipe windlass which was located near the downstream end of the tail box.

The flow of water to the model was supplied by a 12-inch pump through a 12-inch inlet pipe. The quantity of water was measured through 8- and 12-inch venturi meters. The water leaving the model over the variable-height weir spilled into the sump under the floor of the laboratory from which it was recirculated.

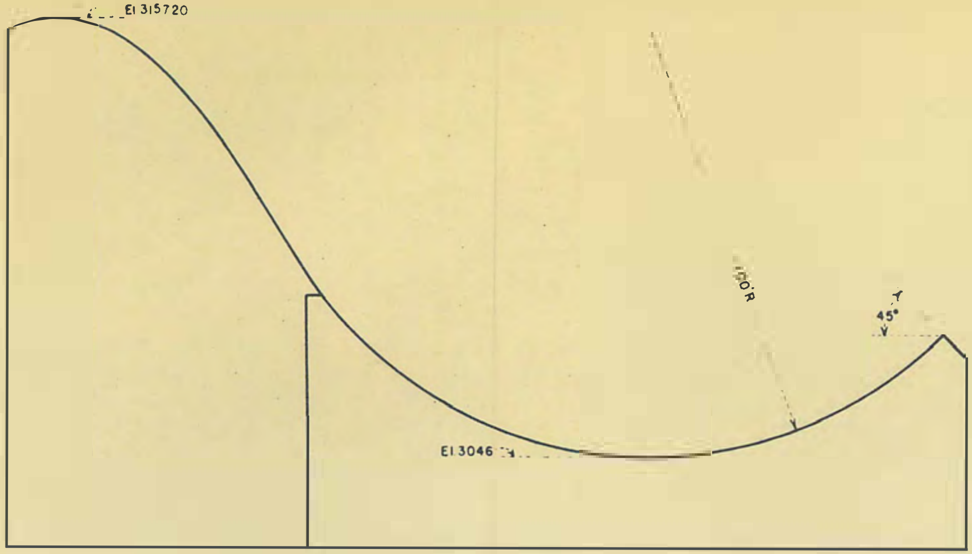
Preliminary Investigations on the 1:42 Scale Models. The preliminary investigation on Angostura Dam Spillway was to determine a suitable as well as an economical stilling basin design. These investigations were carried out in the 1:42 scale sectional model. The original dissipating device consisted of a solid bucket with a 100-foot radius as shown in Design 1, Figure 6. The downstream portion of the lip ended on a 45-degree tangent. This bucket produced undesirable flow conditions, in that the water surface was extremely rough and the scour downstream was excessive (Figure 7A) for the limited tailwater depth available. The action in the bucket was violent, and the ground roller, which continually moved material upstream against the end of the bucket, was strong. The model showed the bucket to be unnecessarily large for the flows anticipated.

Next a solid bucket having a 63-foot radius was installed in the model (Design 2, Figure 6). This bucket produced even more unsatisfactory flow and erosion than the previous design, as can be observed from Figure 7B. The scour was excessive in this case.

FIGURE 5




MISSOURI BASIN PROJECT
ANGOSTURA UNIT - SOUTH DAKOTA
ANGOSTURA DAM SPILLWAY
HYDRAULIC MODEL-ORIGINAL DESIGN
SCALE 1:72
BUCKET DESIGN 5

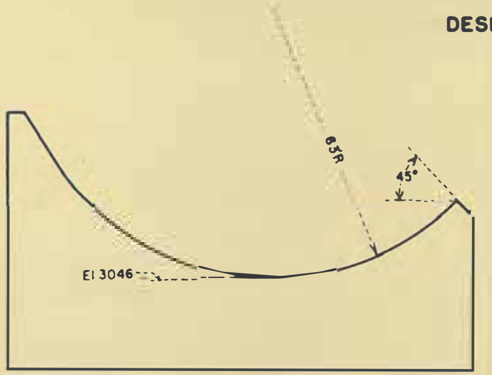



CREST AND 100' RADIUS BUCKET

**DESIGN 1**

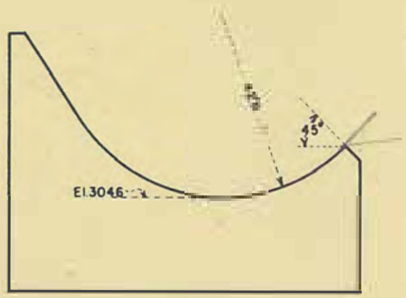

42' RADIUS BUCKET - 15° LIP

**DESIGN 4**




63' RADIUS BUCKET

**DESIGN 2**




42' RADIUS BUCKET

**DESIGN 3**


42' RADIUS BUCKET - 25° LIP

**DESIGN 5**

MISSOURI BASIN PROJECT
ANGOSTURA UNIT - SOUTH DAKOTA

**ANGOSTURA DAM SPILLWAY**

HYDRAULIC MODEL STUDIES - PRELIMINARY

FIGURE 6

A - Flow of 277,000 second-feet.

100 FOOT RADIUS BUCKET WITH DOWNSTREAM
LIP ON 45° TANGENT

B - Flow of 277,000 second-feet

63 FOOT RADIUS BUCKET WITH DOWNSTREAM
LIP ON 45° TANGENT

SECTIONAL MODEL ON 1:42 SCALE

A 42-foot radius solid bucket was used for the third trial (Design 3, Figure 6). This bucket handled the maximum flow as well as the previous designs as far as dissipation of energy was concerned, but the violent movement of the riverbed material was objectionable and erosion downstream was excessive (Figure 8A). Alteration of the downstream lip of the bucket appeared a probable solution for decreasing the erosion and improving flow conditions.

A 42-foot radius solid bucket with the downstream lip tangent to a 15-degree angle, referred to the horizontal and bottom of bucket raised, was next tried in an effort to reduce the erosion of the river channel (Design 4, Figure 6). In this case, the invert of the bucket was raised to elevation 3,070. The result was a trajectory jet on the surface as shown in Figure 8B. Erosion was excessive and the water surface was extremely rough. This bucket demonstrated no particularly desirable features.

The next bucket had a 42-foot radius with the downstream lip tangent to a 25-degree angle, and invert at elevation 3,070 (Design 5, Figure 6). The operation was somewhat improved with this installation for the dissipation of the energy appeared satisfactory and the erosion of the river channel was decreased principally because the former violent ground roller was diminished. The next step was to install this bucket in the 1:72 scale model and study the action of the bucket in connection with the spillway as a whole.

Development of a Bucket with Slots. Experience along the line of the roller bucket has been limited in the past to a few installations of which the Grand Coulee Dam Spillway is one. At Grand Coulee Dam considerable difficulty has been experienced with erosion of the concrete in the bucket because of large boulders and rock rolling around in it, especially for unsymmetrical flow conditions. It was undesirable to make another similar installation until this objectionable feature was corrected.

It was thought that some inexpensive and effective means could be provided to keep the loose rock away from the lip of the bucket. The first idea along this line was to install tubes in the lip of the

A - Flow of 277,000 second-feet 42 foot radius bucket.

42 FOOT RADIUS BUCKETS WITH DOWNSTREAM
LIP ON 45° TANGENT

B - Flow of 277,000 second-feet.

42 FOOT RADIUS BUCKET WITH DOWNSTREAM LIP
ON 15° TANGENT

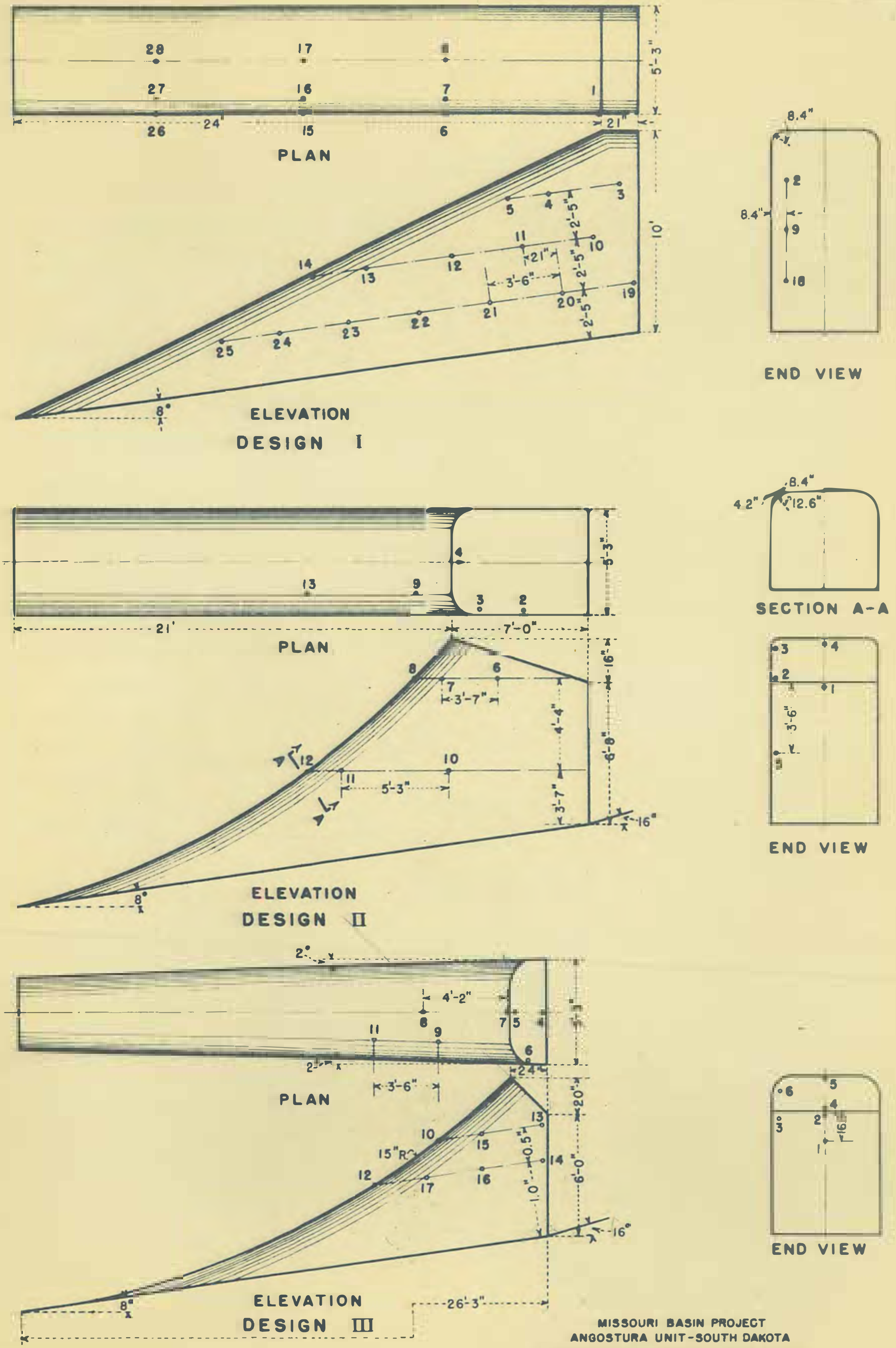
SECTIONAL MODEL ON 1:42 SCALE

bucket through which, it was contemplated, jets of water would flow sweeping the loose material away from the downstream edge of the bucket. This was tried and the results were satisfactory at low discharges, but at the higher flows, the ground roller piled the loose rock over the jet openings virtually closing them. Larger tubes seemed necessary if this scheme was to work satisfactorily.

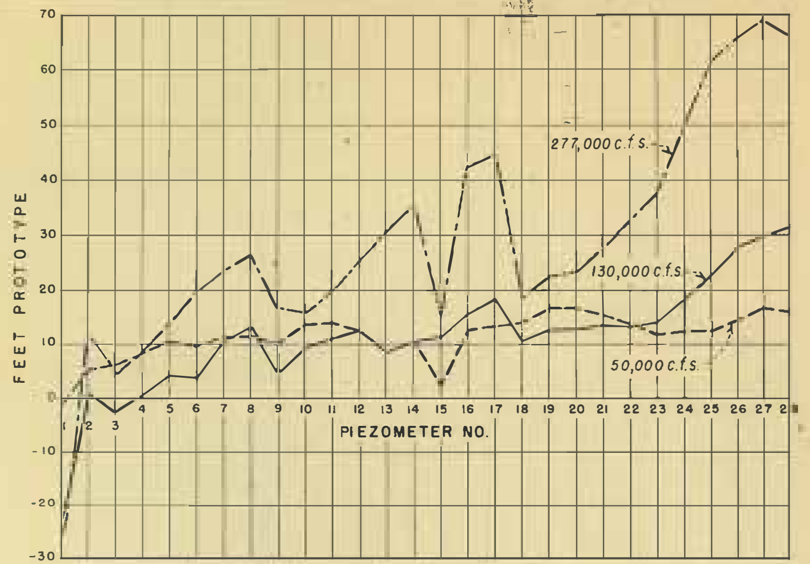
It was suggested that slots be placed in the bucket instead of tubes through the lip. The first design (Design 1, Figure 9), was encouraging, except for the fact that the gravel crawled up the downstream face of the teeth producing an abrasive action. The action downstream from the slots, however, was entirely satisfactory. An apron was then installed downstream from the teeth to spread the jets issuing through the slots in an effort to keep the gravel away from the bucket. Pressures were observed on the teeth at critical points in the bucket to detect subatmospheric conditons. In general, the pressures proved satisfactory although several areas of negative pressure existed. These were registered by piezometers 1 and 3, Design I, Figures 9 and 10.

The radius of the bucket was next continued throughout the length of the teeth, Design II, Figure 9. The floor of the slots between the teeth was a plane on an angle of 8 degrees with the horizontal, starting at the point of tangency with the bucket radius. The apron downstream was also a plane but on an angle of 16 degrees with the horizontal. The curved teeth proved more satisfactory than those in Design 1, as the energy was dissipated more readily and a smoother water surface resulted downstream. The pressures on the teeth were negative for piezometers 1, 2, 3, 4, 6, 7, and 8, Design II, Figure 10, the majority of which were on the downstream face. The rounding of the edges of the teeth was determined by the use of radii ranging from 0.1 inch- to 0.3-inch radius on the model. The larger radius (about 15 inches prototype) was the most desirable for the pressures on the teeth were higher.

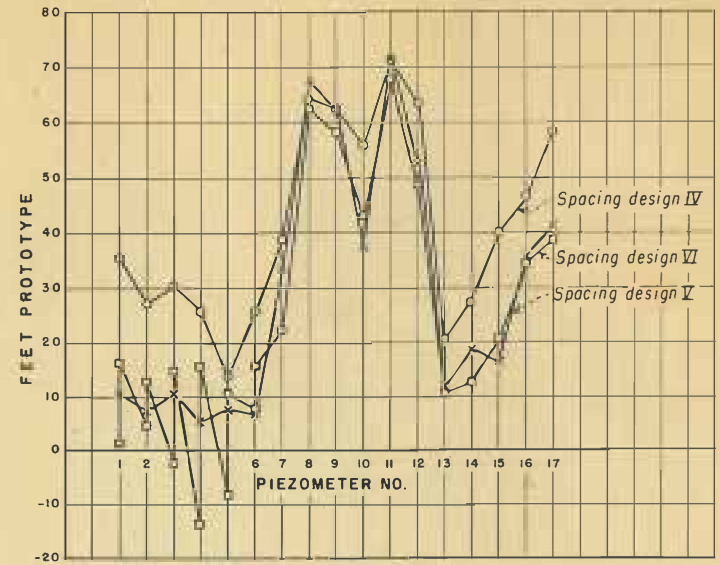
The downstream portions of the teeth were shaped differently for the next design in an attempt to improve pressure conditions. The third design was similar to the previous one except that the teeth were shortened, the sloping ends were on a 45-degree angle, and the sides were



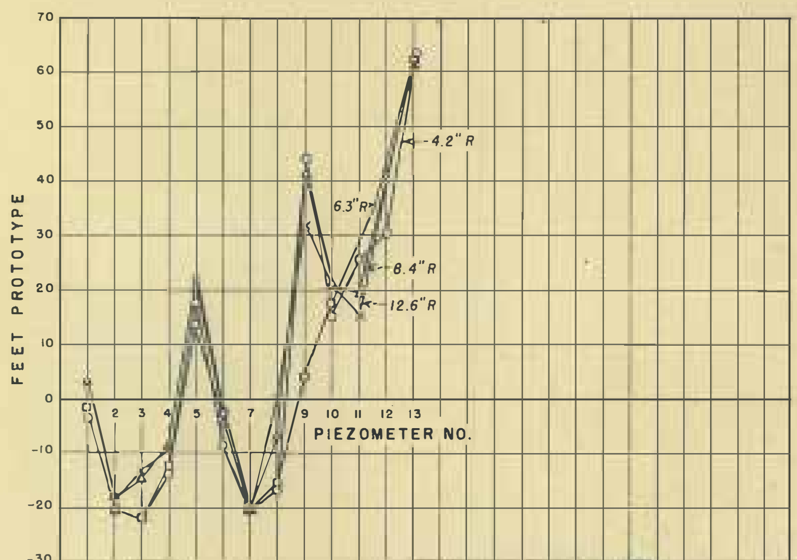

MISSOURI BASIN PROJECT
ANGOSTURA UNIT-SOUTH DAKOTA
ANGOSTURA DAM SPILLWAY
SHAPE OF TEETH AND LOCATION OF PIEZOMETERS




DESIGN I




DESIGN III
277,000 C.F.S.




DESIGN II
277,000 C.F.S.

MISSOURI BASIN PROJECT
ANGOSTURA UNIT – SOUTH DAKOTA

**ANGOSTURA DAM SPILLWAY**

PRESSURES ON BUCKET TEETH

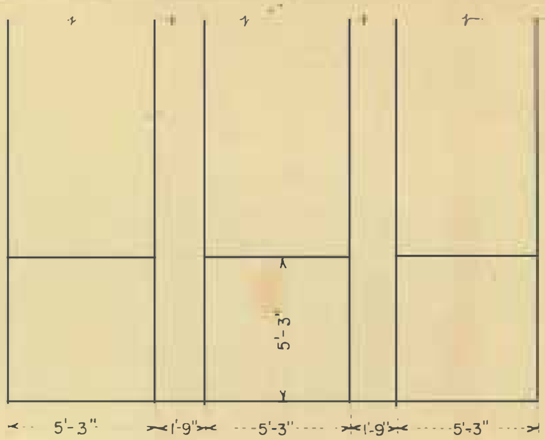
FIGURE 10

tapered 2 degrees in plan to increase the pressures in the slots (Design III, Figure 9). This design was quite satisfactory in all respects as the dissipation was excellent and the negative pressures were few and above the critical range in which cavitation would occur. Negative pressures were present at piezometers 3, 4, and 5 (Design III, Figure 10). The next step was to determine the most desirable spacing of these teeth.

Spacing of the Teeth. The spacing of the teeth was an important factor in the design of the bucket. It was desired not to let any more water through the slots than would be required to keep the downstream apron free of gravel. Spacings tried on the model for the Designs shown as I or II on Figure 9, were: (1) teeth three times the width of the slot, (2) teeth twice as wide as the slot, and (3) teeth the same width as the slot (Designs I, II, & III, Figure 11). Photographs of the model operating at a maximum discharge are shown for the tooth spacing in the same order on Figure 12.

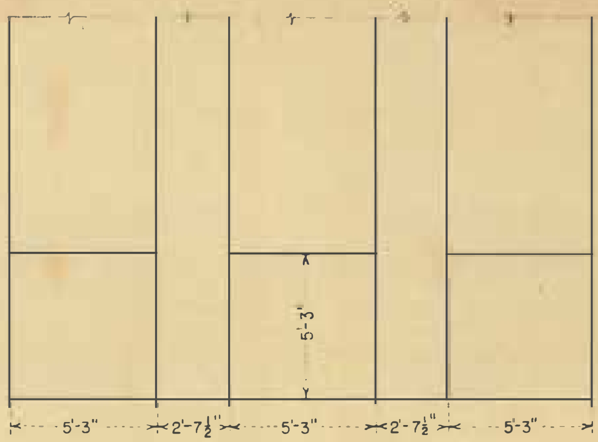
When it became desirable to increase the pressures on the inside faces of the teeth as in Design III, Figure 9, it was again necessary to experiment with the spacing. The 1-foot, 2.7-inch spaces between the teeth, Design IV, Figure 11, were rather small, for rocks and debris could easily be caught between the teeth. The 2-foot, 7½-inch spacing was then tried (Design V, Figure 11), but this spacing was too great and the pressures on the teeth dropped considerably. An intermediate value of 2 feet proved the more satisfactory spacing, shown as Design VI, Figure 11. With the latter spacing, the pressures were reasonably high and operation was satisfactory. Dissipation was principally a spreading action rather than roller action and in no case did bed material come in contact with the teeth.

Downstream Apron. The slope and length of the downstream apron was another important requirement for satisfactory operation. The apron served to spread the jets flowing through the slots and the stability of the bucket action was dependent on the vertical angle of the apron. Of the three shown on Figure 13A, the 16-degree sloping apron was the most satisfactory. For the 12-degree slope, the jet became unstable intermittently diving and scouring the riverbed downstream. For the



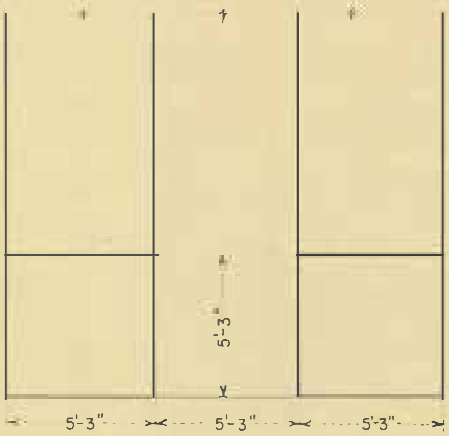

TOOTH SPACING 3 TO 1

DESIGN I



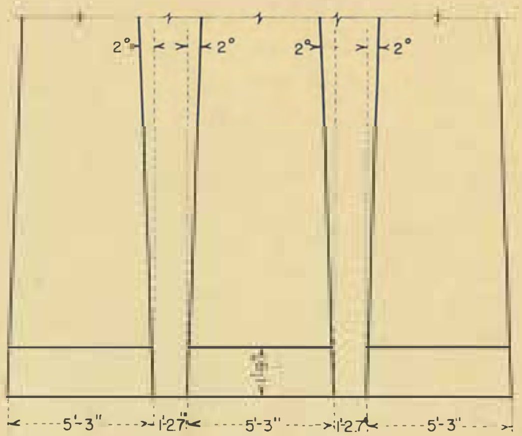

TOOTH SPACING 2 TO 1

DESIGN II



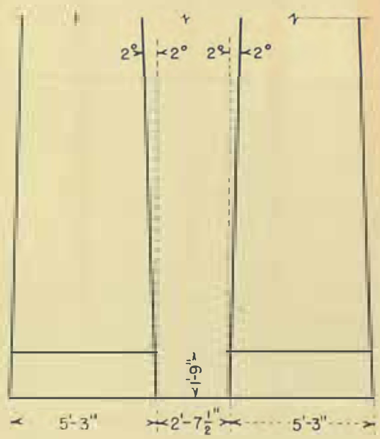

TOOTH SPACING 1 TO 1

DESIGN III



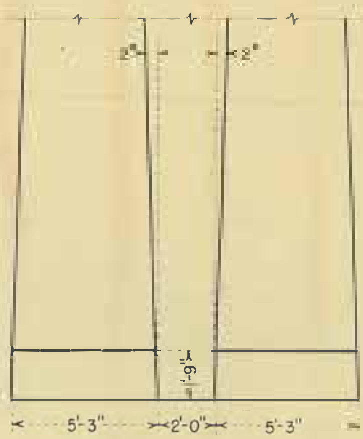

BEVELED TOOTH SPACING

DESIGN IV




BEVELED TOOTH SPACING

DESIGN V




BEVELED TOOTH SPACING

DESIGN VI

FINAL DESIGN

MISSOURI BASIN PROJECT

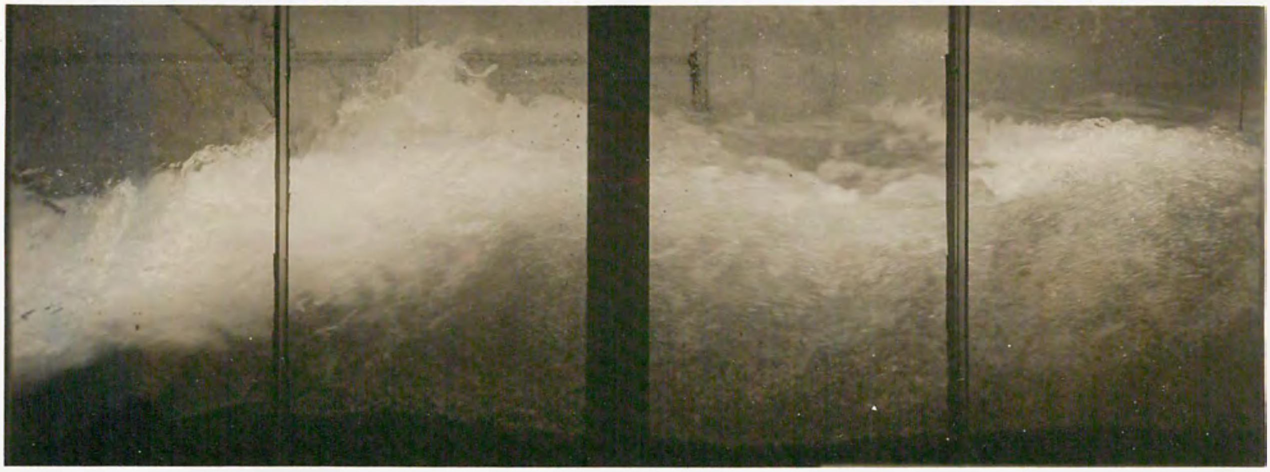
ANGOSTURA UNIT–SOUTH DAKOTA

**ANGOSTURA DAM SPILLWAY**

VARIOUS SPILLWAY BUCKET TOOTH ARRANGEMENTS

A - Flow of 277,000 second-feet.

3 TO 1 TOOTH SPACING



B - Flow of 277,000 second-feet.

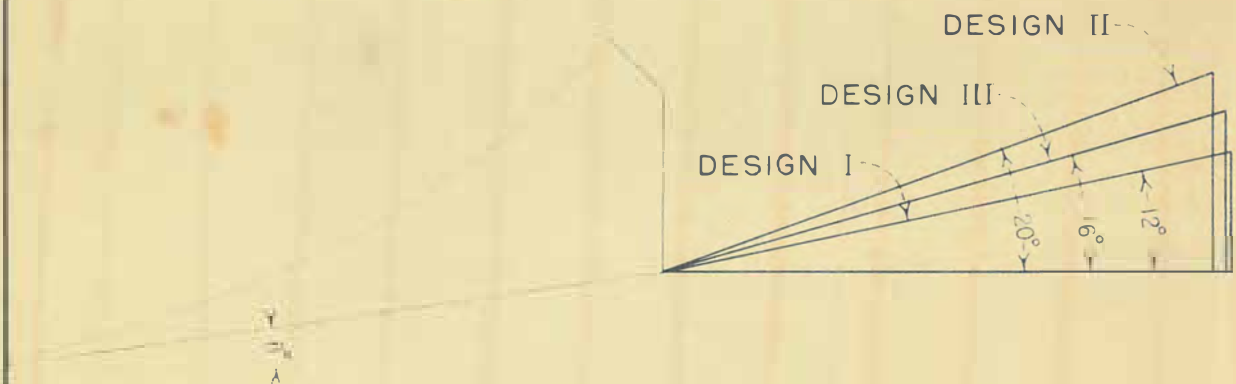
2 TO 1 TOOTH SPACING

C - Flow of 277,000 second-feet.

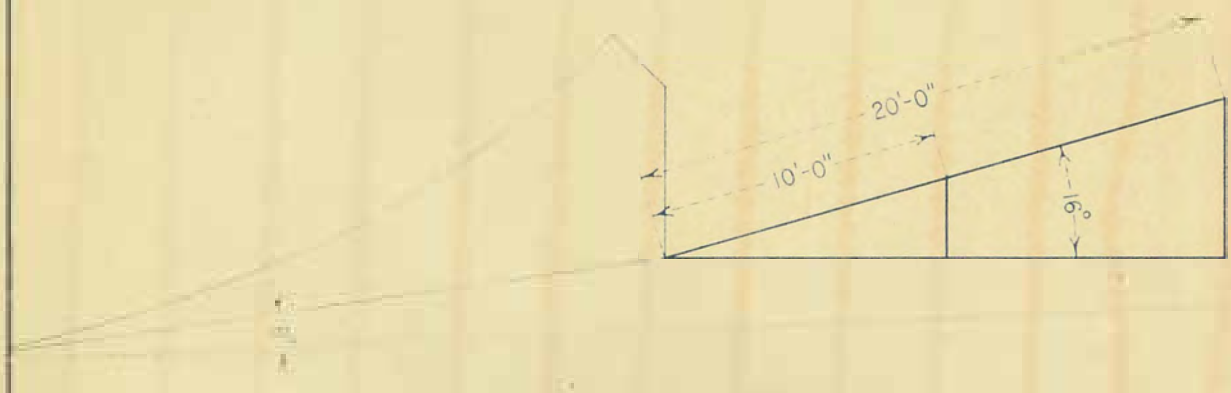
1 TO 1 TOOTH SPACING

SECTIONAL MODEL ON 1:42 SCALE

FIGURE 13




A-DEGREE OF SLOPING APRON
DOWNSTREAM FROM TEETH




B-LENGTH OF SLOPING APRON
DOWNSTREAM FROM TEETH

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ANGOSTURA DAM SPILLWAY

20-degree slope, the spreading of the jet was less effective. Photographs of the three aprons for maximum discharge are shown on Figure 14.

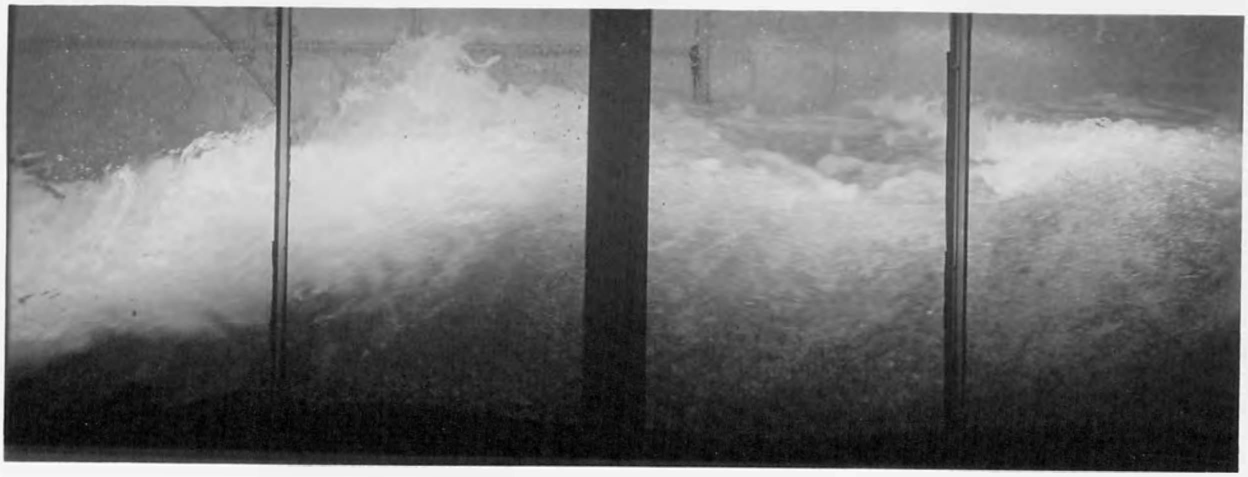
After arriving at the best slope for the apron, it was then necessary to determine the minimum length required for satisfactory operation. Two apron lengths were tried as shown on Figure 13B. The longer of the two was necessary to provide length for the jets to spread, thus producing a more uniform jet leaving the apron. The bucket operated satisfactorily over a wide range of tailwater and discharge conditions. An expanded study as to ranges of flexibility of the different sizes of this type of bucket will be reported on in the future.

Reviewing the development of the new roller type bucket, three factors were involved: (1) the radius of the bucket for a given flow condition; (2) the shaping and spacing of the teeth; and (3) the degree of slope of the apron downstream from the teeth. All of these factors are important in the design of a bucket that will produce the desired dissipation of energy, a smooth water surface, and a minimum amount of erosion of the river channel.

Original Design 1:72 Scale Model. Operation of the 1:72 scale model of Angostura Dam using the solid trajectory bucket indicated objectionable features. This corresponded to the test on the 1:42 scale model for which a plain solid bucket was used with invert placed at elevation 3,070, Design 5, Figure 6. A flow of 277,000 second-feet over the spillway produced a jet action which caused excessive erosion of the riverbed (Figures 15A and B). At the lower discharges sand from the riverbed circulated in and out of the bucket which indicated that considerable erosion of the concrete in the prototype would result from this design. There was also violent motion of the sand at the downstream lip of the bucket which, if permitted to exist for a period of time, would damage the lip of the bucket.

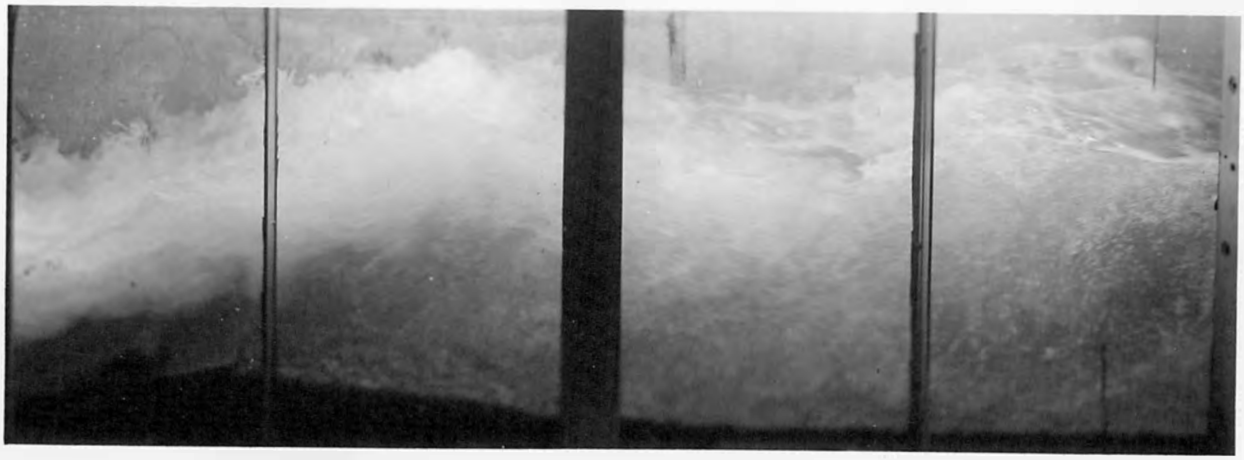
Final Investigation on the 1:72 Scale Model. The new bucket design was now installed in the 1:72 complete model of Angostura Dam Spillway to study side effects which were absent in the sectional model. The bucket design with the sloping apron and the straight teeth (Design I, Figure 9) was first tried in the 1:72 scale model. A photograph of this model is shown on Figure 16. The operation was

FIGURE 14



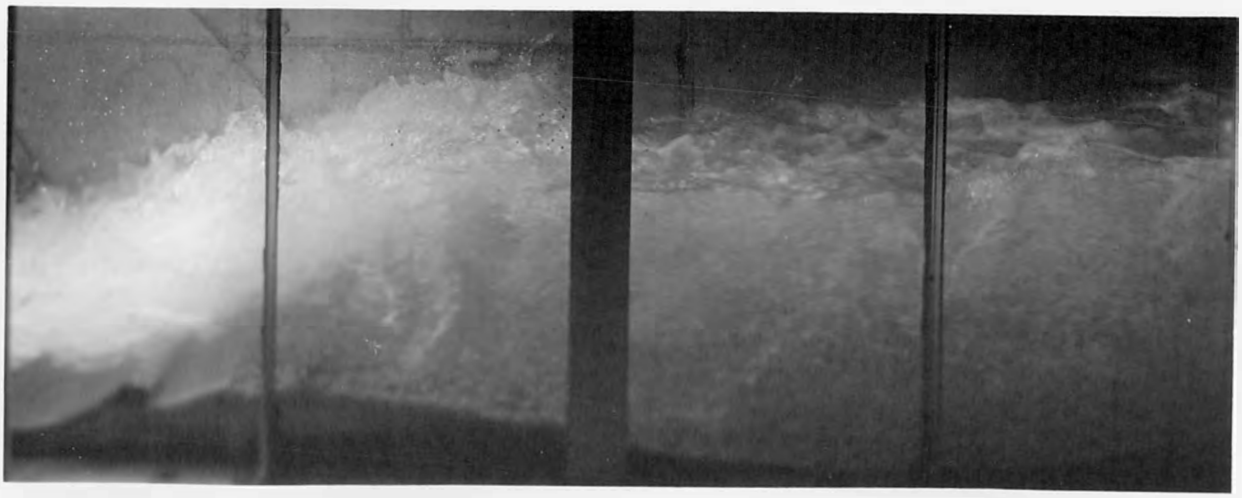
A - Flow of 277,000 second-feet.

DOWNSTREAM APRON ON 16° ANGLE



B - Flow of 277,000 second-feet.

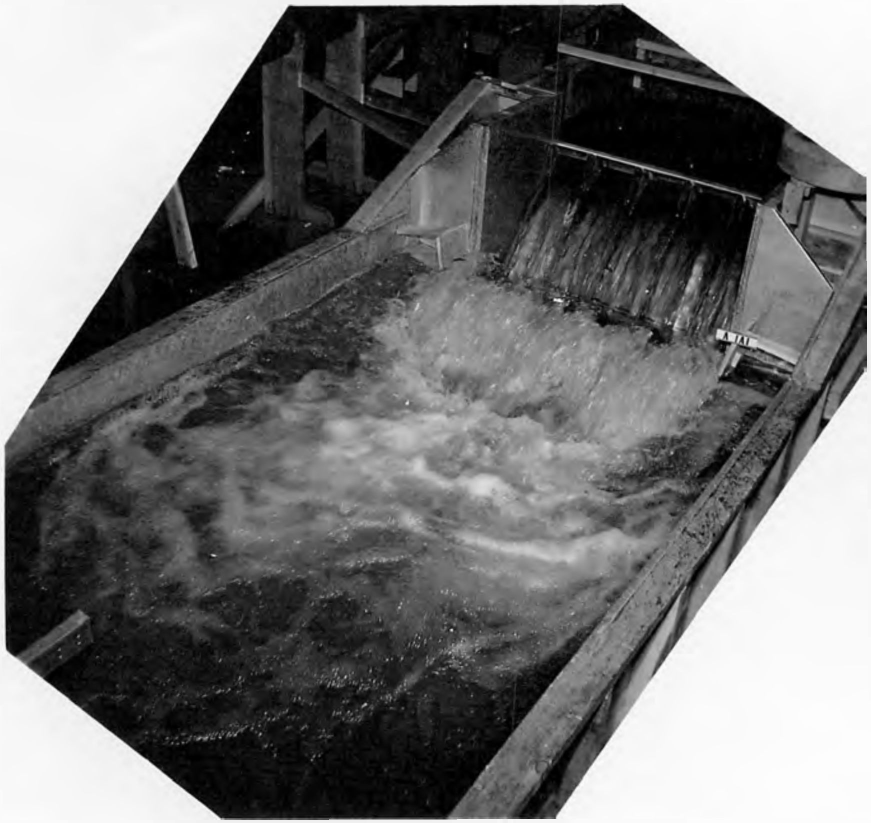
DOWNSTREAM APRON ON 12° ANGLE



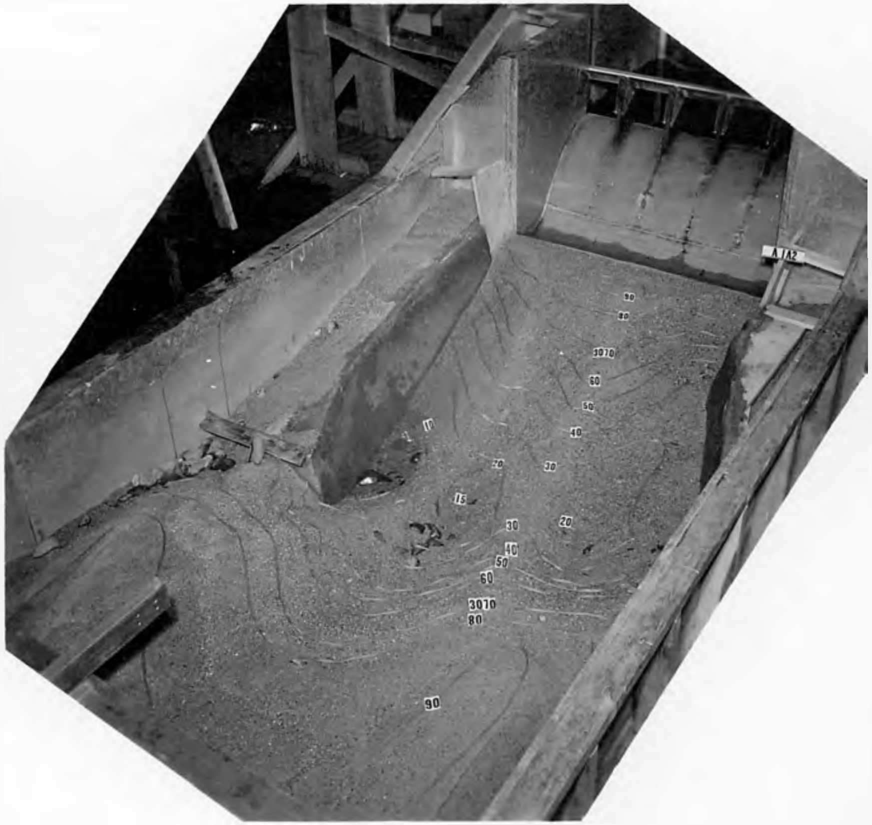
C - Flow of 277,000 second-feet.

DOWNSTREAM APRON ON 20° ANGLE

SECTIONAL MODEL ON 1:42 SCALE



A - Flow of 277,000 second-feet over spillway

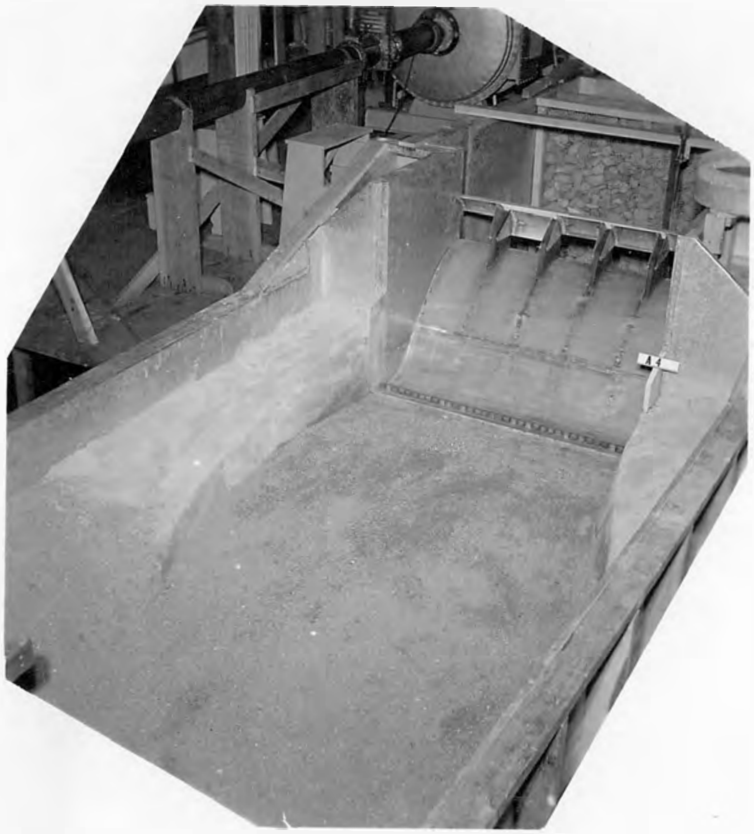


B - Erosion of river channel after flow of 277,000 second-feet.

ANGOSTURA DAM SPILLWAY MODEL (scale 1:72)

ORIGINAL DESIGN

FIGURE 15



A - Model dam and river channel

ANGOSTURA DAM SPILLWAY MODEL (scale 1:72)

REVISED DESIGN I

satisfactory in that the erosion was a minimum and the resulting water surface was quite smooth. The teeth were then replaced by the curved teeth with tapered sides (Design III, Figure 9) as the latter proved the better in the 1:42 sectional model. These teeth were also an improvement in the 1:72 model, for erosion was decreased over the former design and a smoother water surface resulted. Figure 17A shows the model in operation for a maximum discharge and Figure 17B shows the resulting scour after a 20-minute run (model). This arrangement was considered the final design for the bucket proper.

Downstream Wing-walls. It was desired to have wing-walls adjacent to the bucket which would be economical to construct and at the same time produce no undesirable end effects. The first design, Design I, Figures 17 and 18, resulted in satisfactory operation but the amount of concrete needed to construct the walls was excessive.

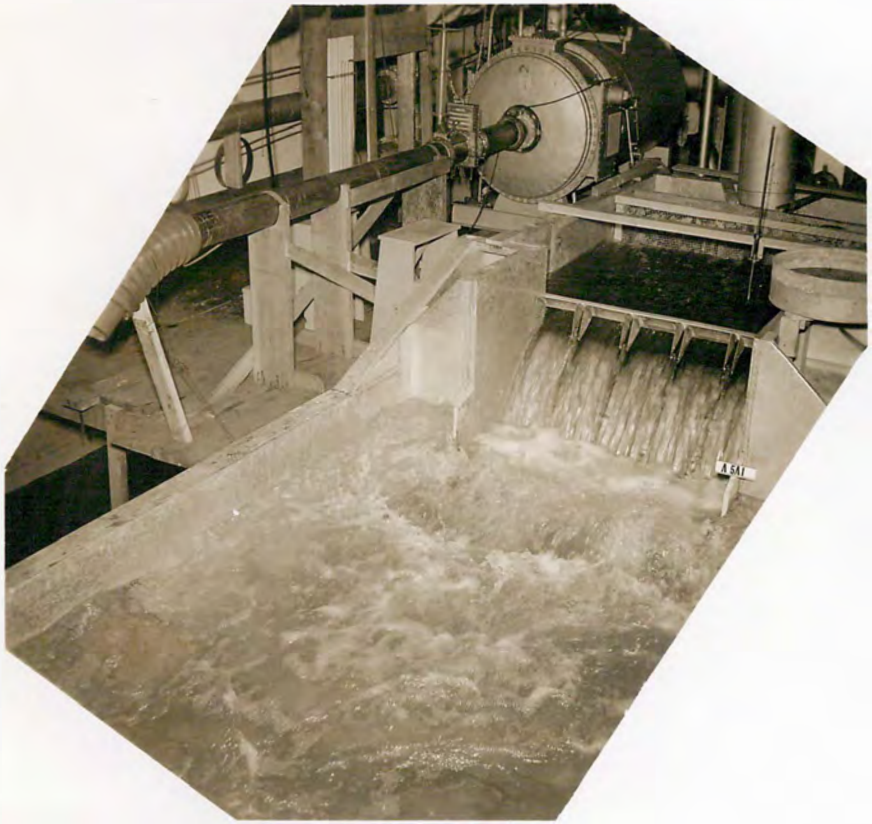
A curved wall on the left side (Design II, Figures 18 and 19A) was the next design tried. This arrangement produced no undesirable flow condition but there was an objection to the cost of constructing a curved wall.

In the next design the curved wall was replaced by a wall on a 45-degree angle (Design III, Figures 18 and 19B). This design was undesirable as an eddy formed at each end of the wall. Water from the river, which was at a higher elevation than that in the bucket, flowed into the bucket along the wing-walls.

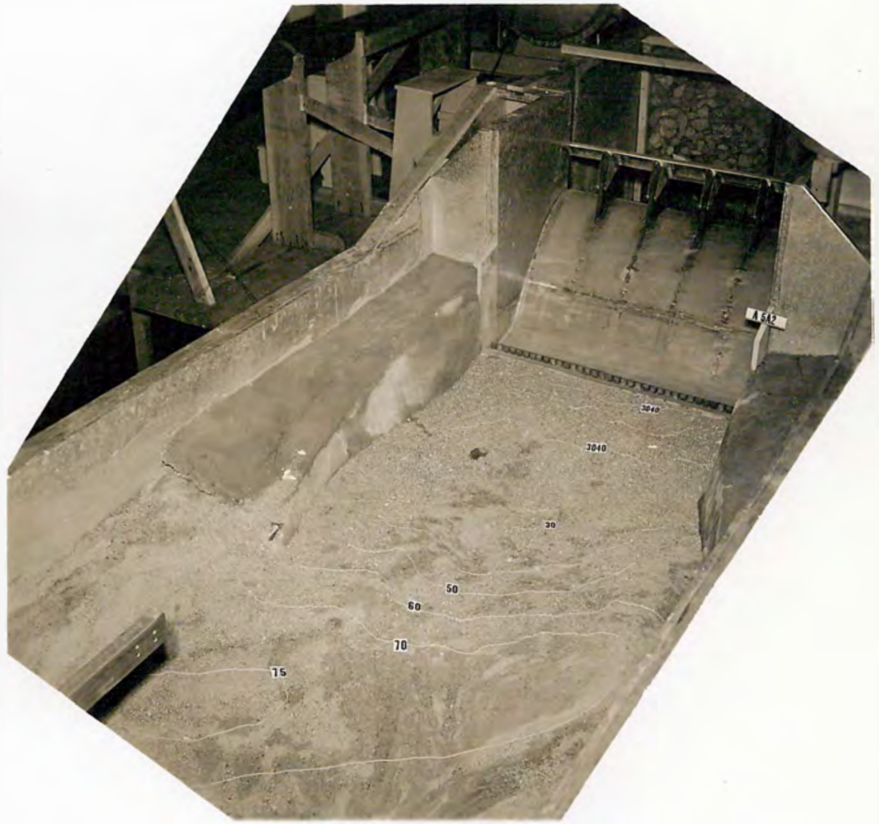
A square-cornered wall (Design IV, Figures 18 and 19C) eliminated the previous objections. The top of this wall was lowered 10 feet to elevation 3100 to save concrete.

Finally a cutoff wall was constructed at a point 15 feet downstream from the end of the bucket and bonded riprap was placed on a 2:1 slope upstream from this wall (Design V, Figure 18). The purpose of the bonded riprap was to reduce the possibility of loose rock falling into the bucket at the higher discharges. This arrangement was considered the final wing-wall design.

The Final Design. Summing up the results of the model studies for Angostura Dam, it is recommended that the final design have incorporated in it a 40-foot radius bucket with teeth, at elevation 3040, and




A - Flow of 277,000 second-feet over spillway.

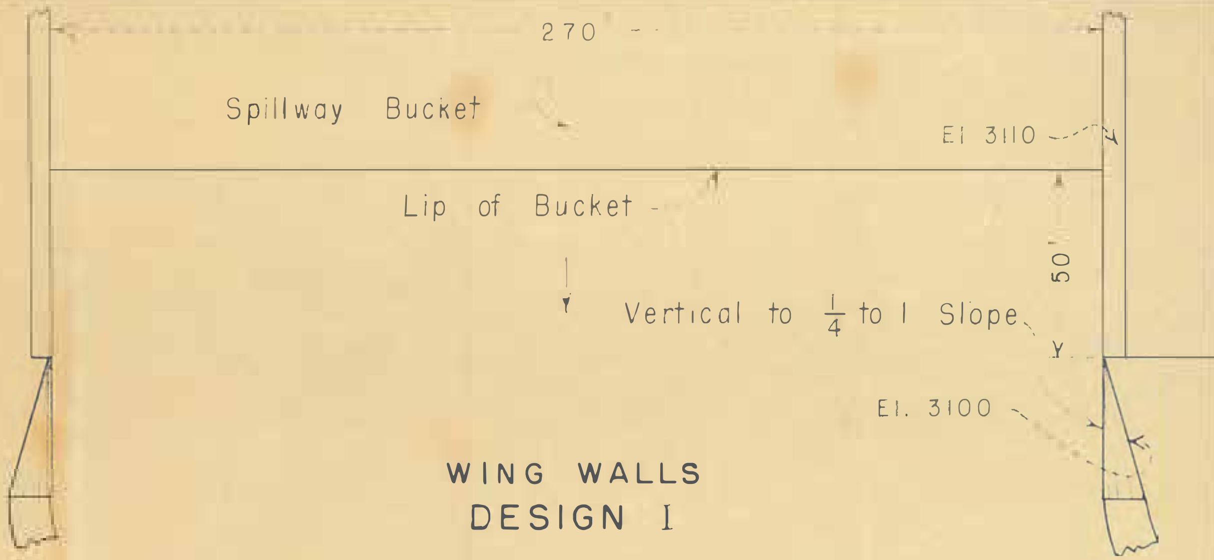



B - Erosion of river channel after flow of 277,000 second-feet. (Duration 20 minutes, model time).

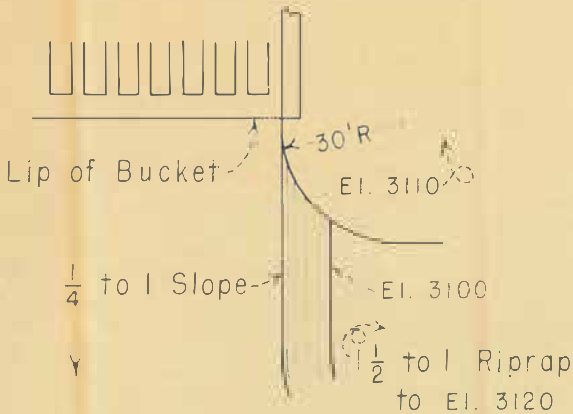
ANGOSTURA DAM SPILLWAY MODEL (scale 1:72)

REVISED DESIGN I

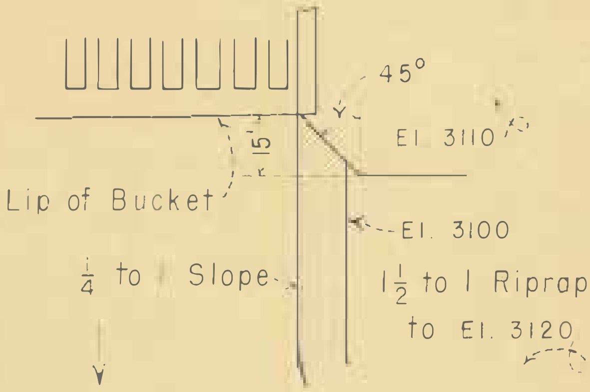
FIGURE 17



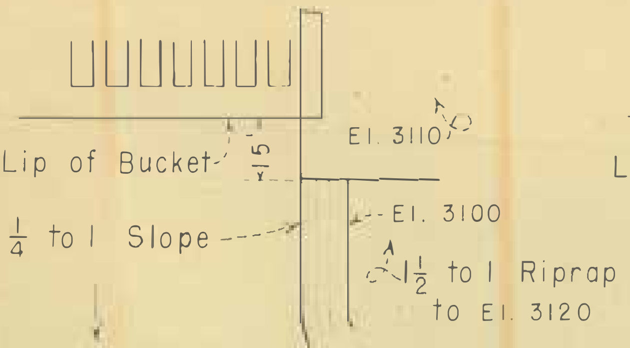

WING WALLS
DESIGN I



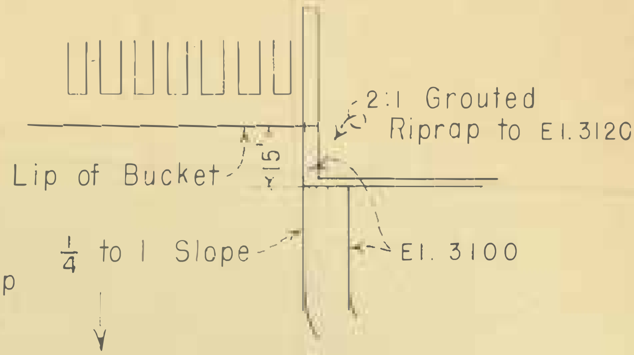

LEFT WING WALL
DESIGN II




LEFT WING WALL
DESIGN III




LEFT WING WALL
DESIGN IV




LEFT WING WALL
DESIGN V
RECOMMENDED DESIGN

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DOWNSTREAM WING WALL DESIGN


A - 30-fcot radius wingwall

B - 45 degree angle wingwall.

C - Square cornered wingwall.

ANGOSTURA DAM DOWNSTREAM WING WAIL DESIGN (1:72 SCALE MODEL)

FIGURE 19

wing-walls according to Design V, Figure 18. The final prototype design of the spillway dissipator is shown on Figures 2 and 3. Photographs of the model constructed according to the final design are shown on Figures 20, 21, and 22. Figure 20A shows the model discharging at the maximum flow of 277,000 second-feet and 20B shows the erosion after a 20-minute run (model). Figure 20C shows the erosion after a flow of $1\frac{1}{2}$ hours of continuous operation at maximum discharge. The difference in the erosion between photographs 20B and 20C is small. Figure 21A shows a flow of 50,000 second-feet and 21B, the erosion after 20 minutes of operation at this discharge. Closeup views of the spillway and bucket are shown in Figure 22. The space between the last tooth and side wall of bucket on each end is necessary to prevent a small eddy from forming in the corner of the bucket.

Profiles of the water surfaces at discharges of 235,000, 130,000, and 50,000 second-feet are shown on Figure 23. The curves were used mainly to determine the height of the spillway walls and the necessary freeboard for the maximum discharge.

Spillway Calibration Curves. The head-discharge curve obtained from the model is plotted on Figure 24. This curve shows that for the maximum reservoir elevation, corresponding to a head of 44 feet over the crest, a discharge of 277,000 second-feet can be passed over the spillway. The coefficient of discharge curve on the same figure shows a coefficient of 3.87 for the maximum designed head. This was obtained from the expression $Q = CLH^{3/2}$ in which L is the net length of crest (excluding the width of the piers) and H is the total head including velocity head of approach.


A - Flow of 277,000 second-feet over spillway.


B - Erosion after flow of 277,000 second-feet for 20 minutes.

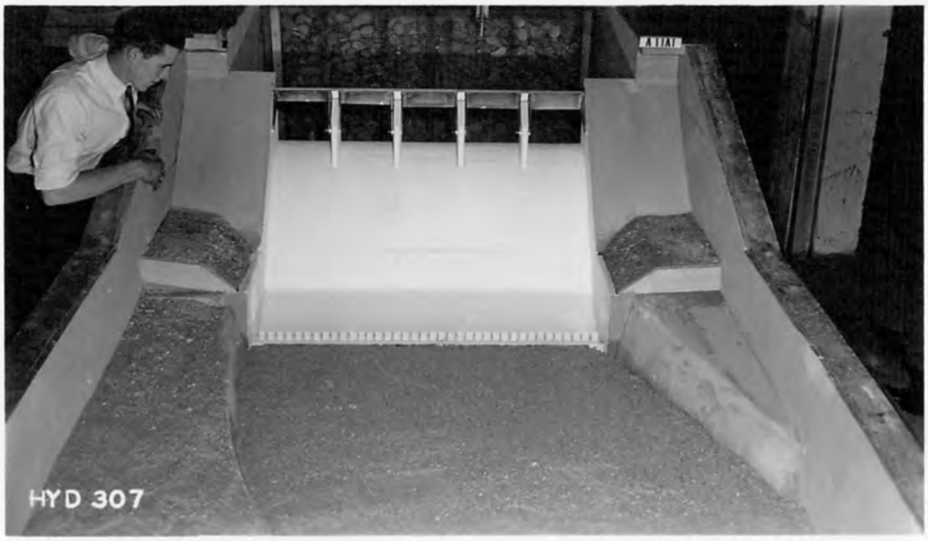
C - Erosion after flow of 277,000 second-feet for 1.5 hours.

ANGOSTURA DAM SPILLWAY MODEL (scale 1:72)
RECOMMENDED DESIGN

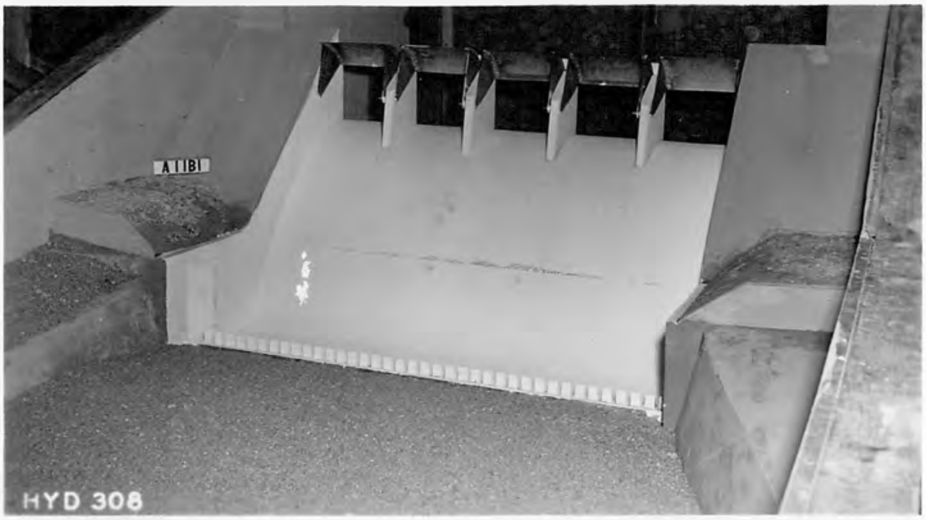

A - Flow of 50,000 second-feet over spillway.


B - Erosion after flow of 50,000 second-feet.

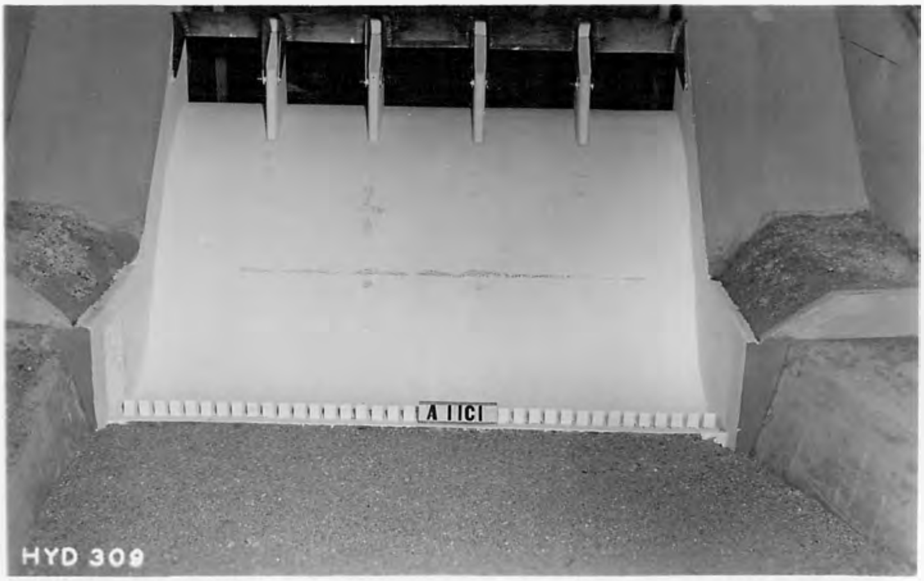
ANGOSTURA DAM SPILLWAY MODEL (scale 1:72)
RECOMMENDED DESIGN




A - Model dam and river channel.

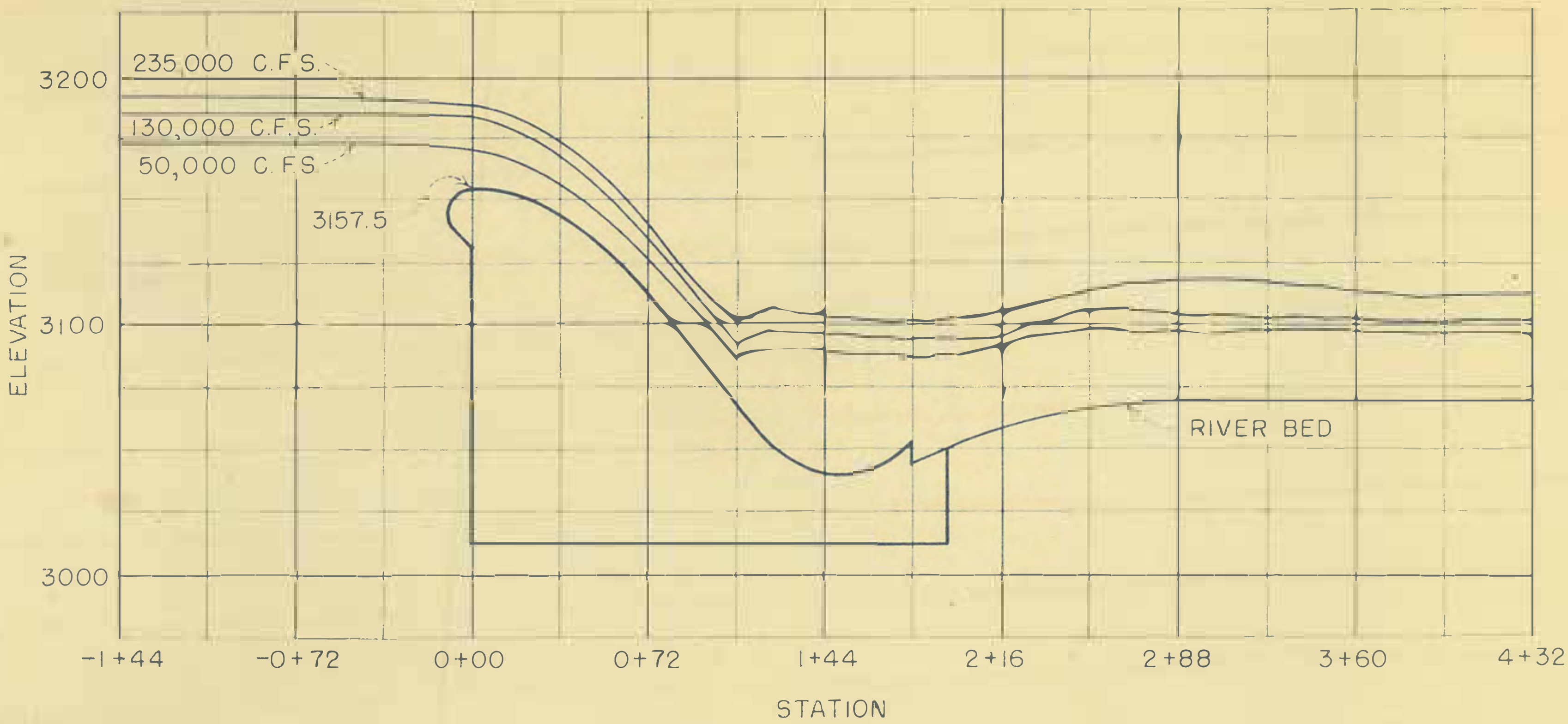



B - Model dam from left bank.




C - Model dam closeup.

ANGOSTURA DAM SPILLWAY MODEL (scale 1:72)
RECOMMENDED DESIGN

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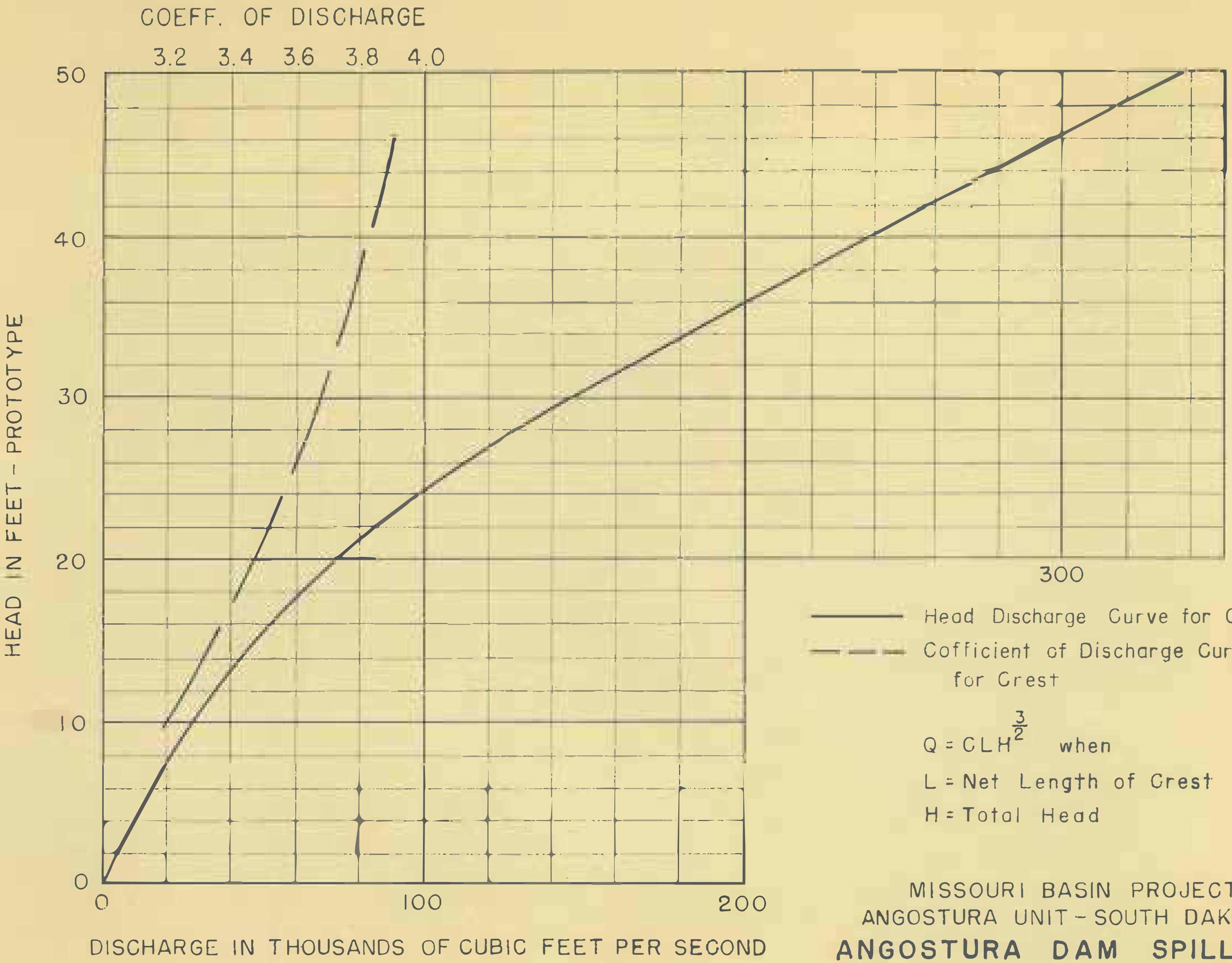
**ANGOSTURA DAM SPILLWAY**
**WATER SURFACE PROFILES**

FIGURE 23




Head Discharge Curve for Crest

Cofficient of Discharge Curve for Crest

$Q = CLH^{\frac{3}{2}}$ when

L = Net Length of Crest

H = Total Head

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**ANGOSTURA DAM SPILLWAY**

FIGURE 24