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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES FOR THE DESIGN OF THE ANGOSTURA CANAL OUTLET WORKS

MISSOURI BASIN PROJECT - SOUTH DAKOTA

Hydraulic Laboratory Report Hyd.-235

ENGINEERING AND GEOLOGICAL
CONTROL AND RESEARCH DIVISION

BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO

NOVEMBER 7, 1947

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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
Date: November 7, 1947

Laboratory Report No. 235
Hydraulic Laboratory
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Ben R. Blackwell
Reviewed by: A. J. Peterka

Subject: Hydraulic model studies for the design of the Angostura Canal outlet works--Missouri Basin Project, South Dakota.

SUMMARY

This report describes model studies on a 1 to 12 scale model of the Angostura Canal outlet works. The model studies indicated that improved operation could be obtained by modifying the layout of the stilling-basin and the canal. The original design is shown in Figure 1 and the recommended design in Figure 2. Improved operation was obtained as a result of the following changes and additions.

1. The width of the stilling-basin was increased from 9.67 feet to 14.00 feet
2. The horizontal floor and vertical step were replaced with a sloping floor
3. Four undercut teeth 8 feet high and 1.675 feet wide, Figure 3, were placed in the stilling-basin
4. The top of the center pier in the stilling-basin was lowered 3 feet to elevation 3165
5. The vertical wing-walls connecting the stilling-basin to the canal were replaced with a smooth transition
6. A minimum length of 40 feet of dumped riprap in the canal immediately below the transition is recommended

These changes improved stilling-basin operation and materially reduced wave heights in the canal.

DESCRIPTION OF THE PROJECT

The Angostura Dam, Missouri Basin Project, Angostura Unit, South Dakota, is located on the Cheyenne River, south of Hot Springs, South Dakota, Figure 4. The dam, Figure 5, will consist of a concrete gravity-type overflow spillway and left abutment sections. The right abutment section will be of earth-fill construction. The overall length of the dam will be 1,900 feet; 1,000 feet of concrete and 900 feet of earth fill.

Both the river and the canal outlet works originate in the short concrete section to the right of the spillway. Over 500 feet of 72-inch pipe carries the water from the reservoir to the canal headworks. A 7.8-foot wheel slide gate at the face of the dam permits inspection and repair of the pipeline.

The canal discharge is controlled by two 3.5-foot square high-pressure slide gates located in the canal headworks structure. The difference in elevation between the maximum reservoir watersurface and the center line of the control gates is 42.7 feet. The main canal will be about 25 miles long with a maximum capacity of 840 second-feet. The normal flow is expected to be 490 second-feet. Plans of the canal outlet works are shown in Figure 6.

DESCRIPTION OF THE MODEL

A 1 to 12 hydraulic model of the Angostura Canal outlet works was constructed in the Hydraulic Laboratory in the Denver Federal Center. The 500 feet of 72-inch pipe from the reservoir to the canal headworks was not reproduced in the model. In its place, to obtain steady and uniform flow through the two slide gates, a head box was placed 1 foot upstream from the gates, Figure 1. The two slide gates were constructed of 1/4-inch brass plate. A vertical screw with a crank operated the gates. The stilling-basin, center pier, and teeth were constructed of wood with the exception of one undercut tooth containing 25 piezometer connections. This tooth was constructed of sheet metal. The piezometer openings were 1/16-inch in diameter. The transitions were constructed of concrete while the canal materials were rock, scaled down from the expected prototype size of dumped riprap, and sand.

Model layout and details for the original design are shown in Figure 1 and for the recommended design in Figure 2.

Canal watersurface elevations for various discharges were obtained from a curve furnished by the Design Division and are shown in Figure 8.

Normal flow in the canal is expected to be 490 second-feet. Normal operating conditions call for both gates to open uniformly. The Design Division computed the maximum discharge on the assumption that both slide gates might be fully opened with the reservoir at maximum elevation. Under this extreme condition the discharge would be 840 second-feet.

THE INVESTIGATION

Original Design

The original design of the Angostura Canal outlet works is shown in Figure 1 (model) and Figure 6 (prototype). In model operation the watersurface in the stilling-pool was very rough. Undesirable surges frequently overtopped the stilling-basin walls, Figure 7. The rough watersurface in the stilling-pool caused 3- to 5-foot waves in the canal. The vertical wing-walls that directed the flow from the stilling-basin to the canal, Figure 1, caused eddies to form with objectionable wave action in the canal.

Stilling-basin Studies

General

To produce smoother flow conditions in the canal, various widths and floor elevations of the stilling-basin were tried. The effects on flow conditions of different numbers and sizes of teeth were studied as well as the effect of changes in the length and height of the center wall.

Width of the Stilling-basin

Two widths of stilling-basins, 9.67 and 14.00 feet, were studied. Operation with the narrower width basin was unsatisfactory. Neither changes in the stilling-basin floor nor the addition of teeth improved flow conditions. The watersurface in the stilling-basin was very rough with undesirable waves in the canal. Operation was greatly improved when the width was increased to 14.00 feet. The dimension of 14.00 feet was selected because this is the base width of the canal. The improvement obtained through this increase in width was not sufficient to give completely satisfactory operation. The increased width in conjunction with floor changes and the addition of teeth (described elsewhere in this report) did result in satisfactory operation.

Floor of the Stilling-basin

In the original stilling-basin design, the floor was horizontal at elevation 3153.50 with a 4.5-foot vertical step at the end of the basin, Figure 1. This step was of no apparent hydraulic value and was replaced with a 0.045 sloping floor, Figure 2. The sloping floor reduced the necessary excavation and also decreased the stilling-basin wall heights. In itself the sloping floor did not improve flow conditions but satisfactory operation resulted when the sloping floor was used in conjunction with the undercut teeth described in the following section.

Teeth in the Stilling-basin

Tests on teeth in the stilling-basin were made in conjunction with changes in the floor and in the width of the stilling-basin. The use of teeth in the narrow, 9.67 foot, basin was unsuccessful. A satisfactory stilling-basin was evolved using the 14.00-foot wide basin with undercut teeth. The different floor designs had a negligible effect on the operation of the stilling-basin when teeth were used.

Various combinations of small teeth were tested in the model. These teeth ranged from 1.25 to 5.00 feet in height and were submerged during operation. When the teeth were located close to the outlets, the water was deflected upwards and over the teeth resulting in a very rough watersurface in the stilling-basin and undesirable waves in the canal. In moving the teeth downstream to a point where they did not deflect the water upwards they became relatively ineffective as energy dissipators. In no case was there a noticeable improvement in flow conditions.

Since the small teeth proved unsatisfactory, it was believed that properly shaped larger teeth might not deflect the water upwards. These teeth projected above the maximum watersurface. One, two and three teeth were placed below each gate. The single-tooth layout was the least effective of the three. The three-tooth layout was discarded because the thinness of the teeth would result in construction difficulties. A thickness of 1.675 feet for each of the two teeth equally spaced below each gate proved to be most effective and practical. At the maximum discharge of 840 second-feet the teeth provided good stilling-basin operation with reduced wave heights in the canal. Through a series of tests it was found that the tooth height could be reduced to 8.00 feet without being detrimental to flow conditions. At the normal discharge of 490 second-feet flow conditions were unsatisfactory since the teeth, with the lower tailwater, did not offer enough resistance to the flow to dissipate the energy.

In order to obtain better flow conditions at intermediate discharges the teeth were undercut on a 3-foot radius, Figure 3. The best location for the teeth was found to be 24.50 feet from the upstream end of the stilling-basin. Very satisfactory stilling-basin operations with reduced wave heights in the canal were obtained for discharges of 840 and 490 second-feet with both gates open and at 420 and 200 second-feet with one gate open.

These preliminary tests were made with square edges on the undercut portion of the teeth. Experience has shown that square edges of this type are difficult to construct and maintain in the prototype. Further, the sharp edges often result in subatmospheric pressures on the structure during operation. To avoid these difficulties, the square edges were rounded. Twenty-five piezometers, Figure 3, were installed in one of the teeth to check the effectiveness of the rounded corners in preventing low pressures. At the maximum discharge of 840 second-feet, both gates open, subatmospheric pressures of 2.5 feet of water prototype were observed at piezometers 7 and 10. All other piezometers showed greater than atmospheric pressures. With 420 second-feet discharging through one gate, subatmospheric pressures between 0.7 and 2.4 feet of water prototype were observed on piezometers 2, 7, and 10. At normal discharge of 490 second-feet with both gates open, all pressures were above atmospheric. The piezometer pressures are shown in Table 1 in tabular form. The observed pressures could probably be increased by further rounding the edges on the undercut portion of the teeth but this would also reduce their efficiency as energy dissipators. Considering the infrequency of operation with full gate openings and the small magnitude of the subatmospheric pressures, the above tooth design, Figure 3, is recommended.

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TABLE 1

PRESSURES IN FEET OF WATER ON RECOMMENDED TEETH*

Piezometer Number	3 Gates 840 SF	2 Gates 490 SF	1 Gate 420 SF
1	9.1	4.6	5.3
2	0.7	2.5	-0.7**
3	2.3	3.0	0.4
4	3.4	3.7	1.2
5	7.1	4.0	2.2
6	10.0	6.8	9.8
7	-2.5**	2.8	-2.4**
8	4.9	4.8	3.2
9	***	9.0	***
10	-2.5**	2.9	-1.7**
11	3.2	4.3	1.0
12	3.8	5.1	1.9
13	2.9	6.0	4.2
14	6.4	6.1	4.6
15	***	9.8	***
16	1.5	5.2	2.3
17	8.2	7.4	6.6
18	***	9.4	***
19	8.2	8.2	7.2
20	7.6	7.9	6.1
21	7.2	7.9	6.1
22	7.9	8.4	6.6
23	9.00	8.6	7.3
24	9.7	8.8	7.8
25	9.7	8.8	7.8

* Pressure in feet of water prototype at the piezometer.
** Minus(-) indicates that the pressure is subatmospheric.
*** Pressure is greater than 10.0 feet of water prototype.

Piezometer locations are shown in Figure 3.

Center Pier in the Stilling-basin

The original design of the center pier in the stilling-basin is shown in Figure 1. The top is at elevation 3168. Model tests showed that the top elevation of the pier could be lowered 3 feet to elevation 3165 with very minor changes in flow conditions. With this lower elevation and with the maximum discharge of 840 second-feet, the watersurface in the stilling-basin was 0.5 feet above the top of the pier. At lower discharges the watersurface was always below the top of the pier. Any reduction in the length of the pier increased the wave heights in the canal. The recommended pier is the same length as the original, with the top lowered 3 feet to elevation 3165, Figure 2.

Transition Studies

In the original design, Figures 1 and 6, vertical wing-walls, 25 feet long, conducted the flow from the stilling-basin to the canal causing eddies and objectionable waves to form in the canal. The wing-walls were replaced with a 25-foot long, gradually-changing transition, Figure 2. This transition carried the water from the stilling-basin to the canal with a minimum of disturbance. A second transition, 50 feet long and following the general lines of the first transition, did not improve flow conditions. Therefore, the 25-foot long, gradually-changing transition is recommended.

Canal Studies

In the original canal design the riprap extended beyond the transition for 40 feet, Figures 1 and 6. The riprap section in the original model was paved with concrete with the remainder of the canal of sand. The smooth surface of the concrete paving exaggerated the wave action along the banks of the canal. To more nearly represent conditions that would obtain in the prototype the concrete paving was replaced in the model with rock, scaled down from the expected prototype size of dumped riprap. The rough surface of the dumped riprap tended to absorb the waves and reduced the wave heights in the canal. The model studies indicated the need for a minimum length of 40 feet of dumped riprap in the canal below the transition.

Recommended Design

The recommended design of the Angostura Canal outlet works includes the 14.00-foot width of stilling-basin with the sloping floor, four undercut teeth and the revised center pier. The revised transition and 40 feet of dumped riprap in the canal are included. This recommended design is shown in Figures 2 and 9B. Details of the undercut teeth are shown in Figure 3. Energy dissipation in the stilling-basin was satisfactory for all discharges with both one and two gates open. In no case did waves or surges overtop the stilling-basin walls. The transition conducted the flow smoothly from the stilling-basin into the canal. The dumped riprap below the transition protected the canal against scour and because of its rough surface helped to reduce wave heights along the canal banks farther downstream.

The stilling-basin center wall is at elevation 3165.0, the side walls are at elevation 3170.0, while the top of the canal banks are at elevation 3168.5. Figure 10 shows model operation at the maximum discharge of 840 second-feet with both gates open. The canal watersurface is at elevation 3167.8. The downstream end of the center wall is submerged but the side walls of the stilling-basin are not overtopped. Figure 11 shows model operation at the normal discharge of 490 second-feet with both gates open. The canal watersurface is at elevation 3165.4. Figure 12 shows model operation at a discharge of 420 second-feet through one gate. The canal watersurface is at elevation 3164.8. Figure 9A shows one gate discharging 200 second-feet with the canal watersurface at elevation 3162.8.

Table 2 shows wave heights for the recommended design as measured at four locations on the centerline of the canal for discharges of 840 and 490 second-feet with both gates open and for 420 second-feet with one gate open.

TABLE 2

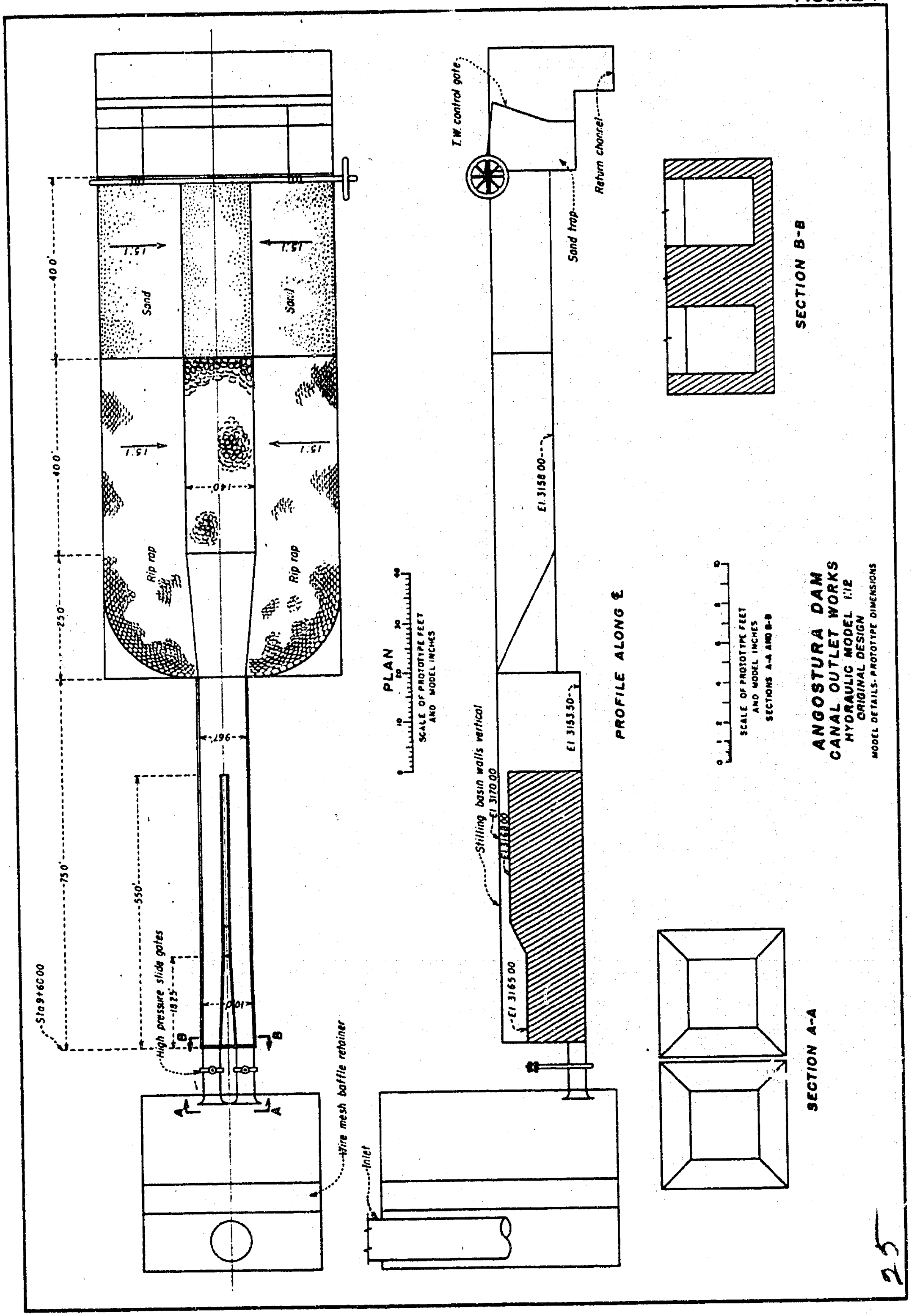
WAVE HEIGHTS IN PROTOTYPE FEET

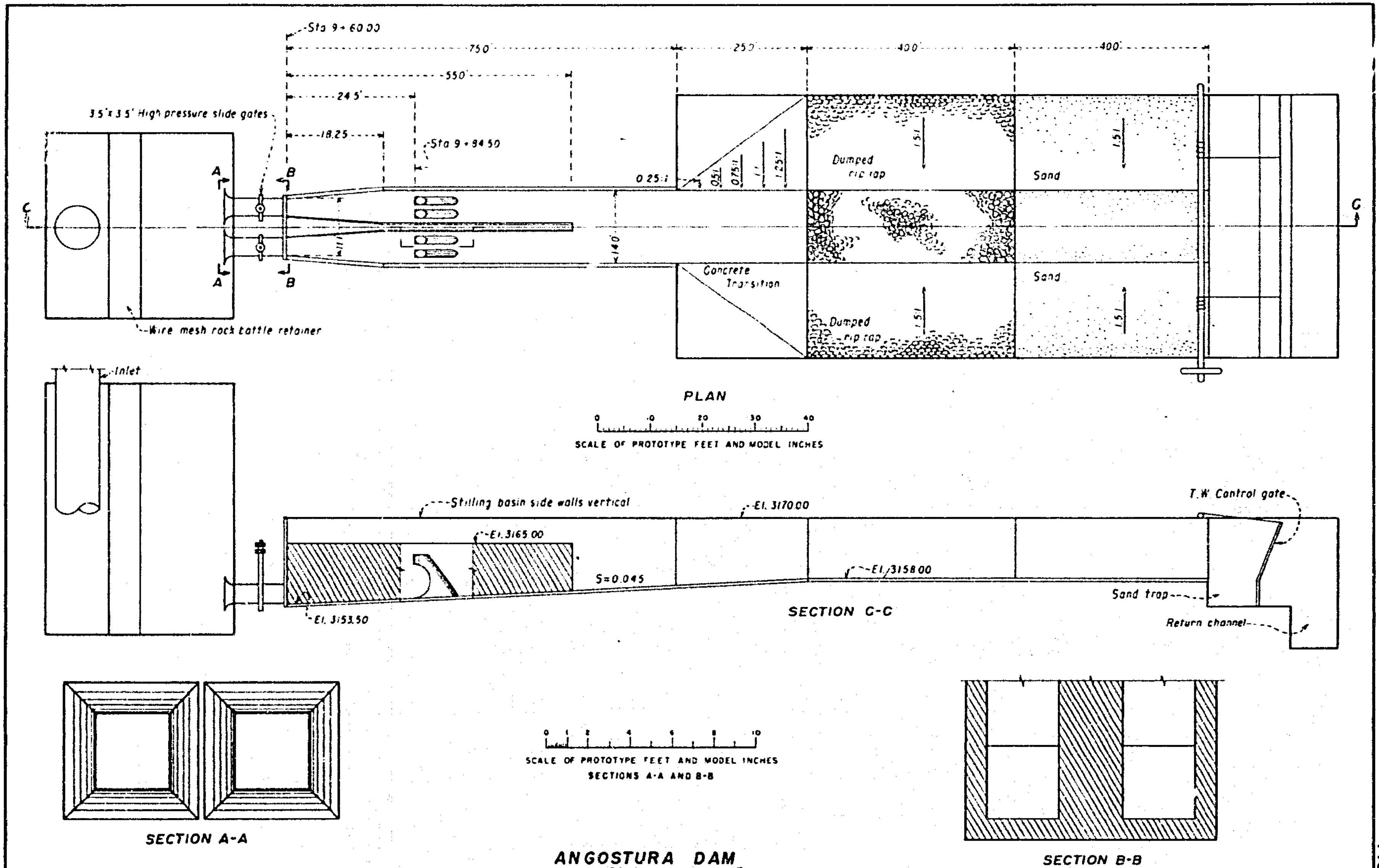
Discharge	840 SF	490 SF	420 SF
Number of gates open	2	2	1
Station 1	1.00 feet	0.40 feet	1.00 feet
Station 2	0.50 feet	0.20 feet	0.62 feet
Station 3	0.25 feet	0.12 feet	0.25 feet
Station 4	0.19 feet	0.06 feet	0.12 feet

Location of Stations - On canal centerline

Station 1 - end of stilling-basin - 0 feet
Station 2 - end of transition - 25 feet
Station 3 - end of dumped riprap - 65 feet
Station 4 - end of model - 105 feet

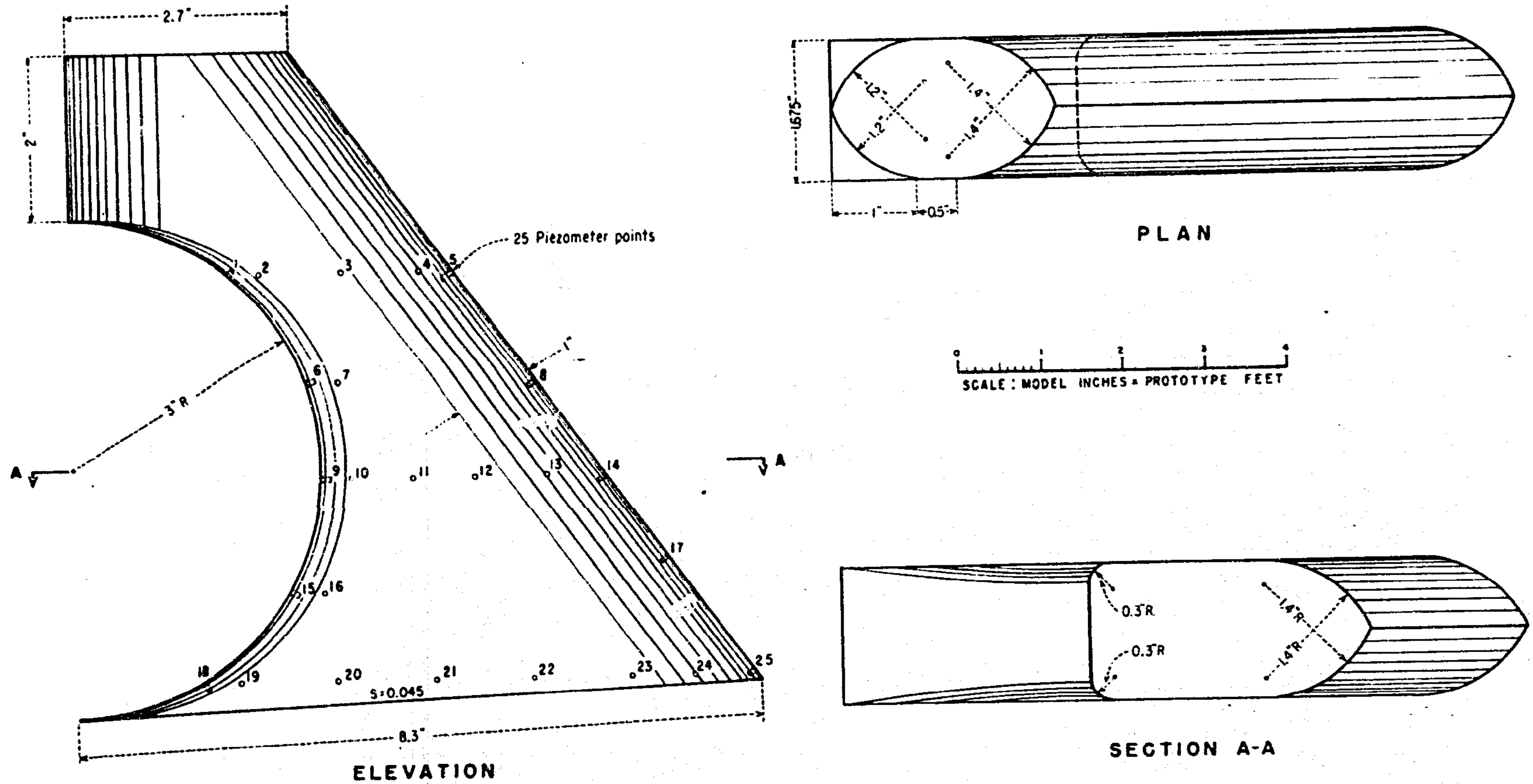
FIGURE 1


ANGOSTURA DAM
CANAL OUTLET WORKS
HYDRAULIC MODEL 1:12
ORIGINAL DESIGN
MODEL DETAILS-PROTOTYPE DIMENSIONS
PLAN
SCALE OF PROTOTYPE FEET AND MODEL INCHES
PROFILE ALONG ℄
SECTION A-A
SECTION B-B
SCALE OF PROTOTYPE FEET AND MODEL INCHES SECTIONS A-A AND B-B
T.W. control gate
Return channel
Sand trap
Sand
Rip rap
1.5:1
400'
250'
750'
550'
140'
96.7'
10.0'
18.25'
Sta 9+60.00
High pressure slide gates
Wire mesh baffle retainer
Inlet
Stilling basin walls vertical
El. 3158.00
El. 3153.50
El. 3170.00
El. 3168.00
El. 3165.00



ANGOSTURA DAM
CANAL OUTLET WORKS
1:12 SCALE HYDRAULIC MODEL
RECOMMENDED DESIGN
MODEL DETAILS-PROTOTYPE DIMENSIONS

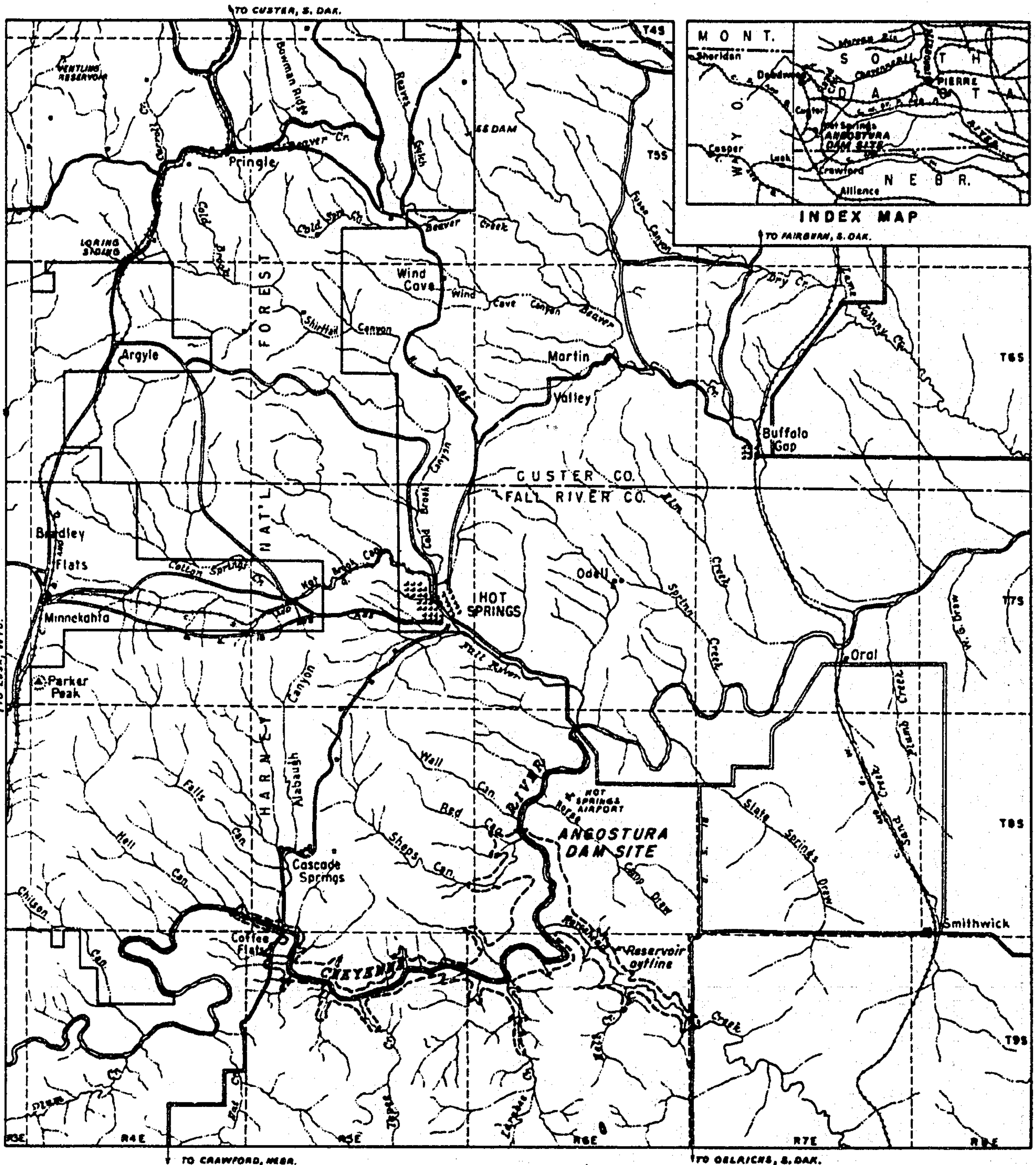
FIGURE 2



ANGOSTURA DAM
CANAL OUTLET WORKS
HYDRALIC MODEL 1:12
DETAILS OF TEETH
DIMENSIONS IN MODEL INCHES = PROTOTYPE FEET

FIGURE 3

FIGURE 4



VICINITY MAP

1 0 5
SCALE OF MILES

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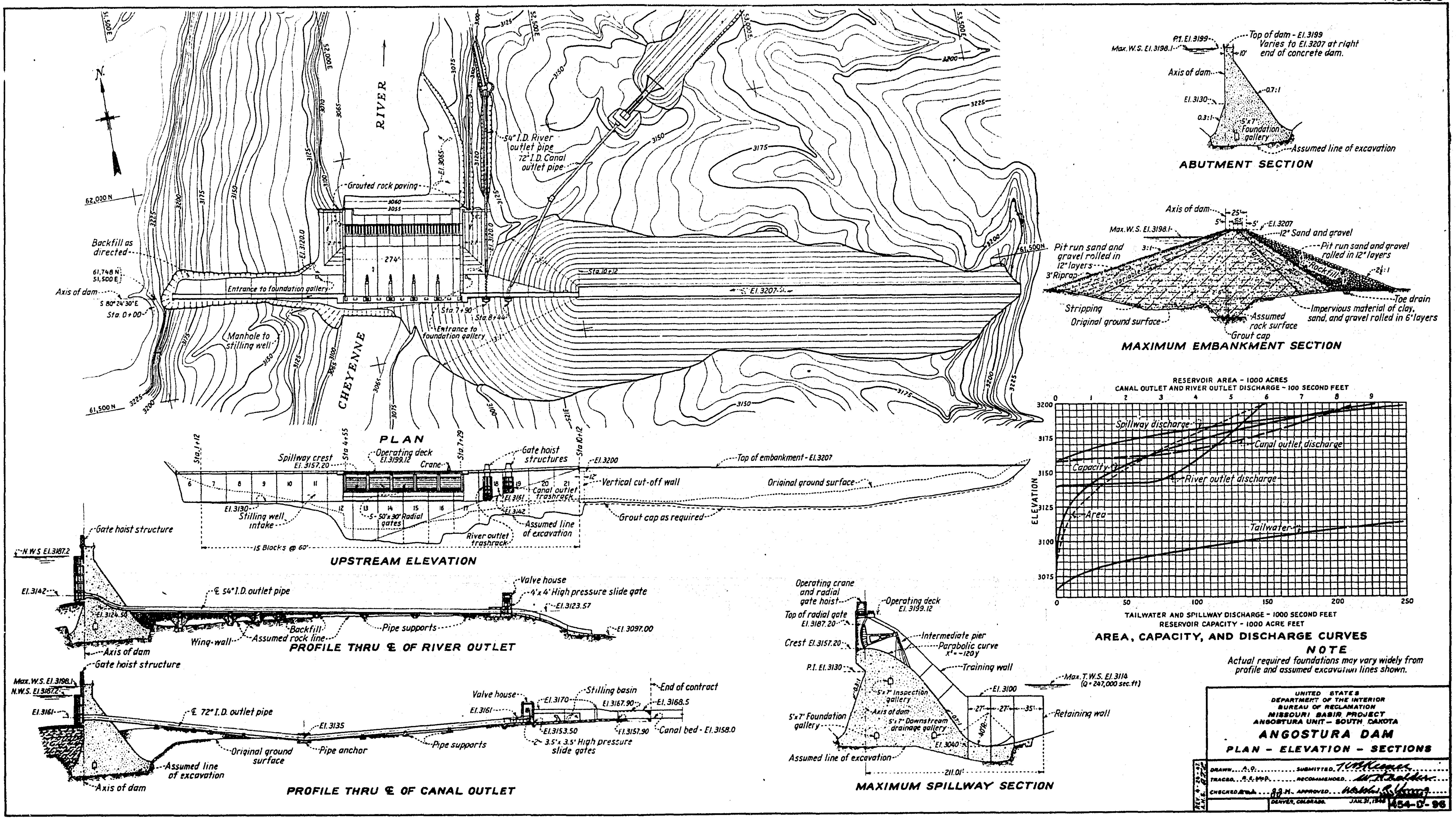
MISSOURI BASIN PROJECT
ANGOSTURA UNIT—SOUTH DAKOTA

ANGOSTURA DAM
LOCATION MAP

DRAWN A.T.L. SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED
CHIEF ENGINEER
DENVER, COLORADO, JAN. 31, 1946 454-D-92

FIGURE 5



PLAN
RIVER
CHEYENNE
N.
62,000 N
61,500 N
52,000 E
52,500 E
53,000 E
51,500 E
Grouted rock paving
54" I.D. River outlet pipe
72" I.D. Canal outlet pipe
Backfill as directed
61,748 N
51,500 E
Axis of dam
S 80°24'30"E
Sta. 0+00
Entrance to foundation gallery
274'
El. 3207
Sta. 10+12
Sta. 7+90
Sta. 8+44
Entrance to foundation gallery
Manhole to stilling well
3:1
ABUTMENT SECTION
P.I. El. 3199
Top of dam - El. 3199 Varies to El. 3207 at right end of concrete dam.
Max. W.S. El. 3198.1
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
25'
El. 3207
Max. W.S. El. 3198.1
12" Sand and gravel
Pit run sand and gravel rolled in 12" layers
Pit run sand and gravel rolled in 12" layers
3' Riprap
Variable
Rockfill
Toe drain
Stripping
Original ground surface
Assumed rock surface
Grout cap
Impervious material of clay, sand, and gravel rolled in 6" layers
UPSTREAM ELEVATION
Sta. 1+12
Sta. 4+55
Sta. 7+29
Sta. 10+12
Spillway crest El. 3157.20
Operating deck El. 3199.12
Crane
Gate hoist structures
El. 3200
Top of embankment - El. 3207
Vertical cut-off wall
Original ground surface
Canal outlet trashrack
El. 3130
Stilling well intake
5 - 50'x30' Radial gates
El. 3161
El. 3142
River outlet trashrack
Assumed line of excavation
Grout cap as required
15 Blocks @ 60'
RESERVOIR AREA - 1000 ACRES
CANAL OUTLET AND RIVER OUTLET DISCHARGE - 100 SECOND FEET
ELEVATION
Spillway discharge
Canal outlet discharge
Capacity
River outlet discharge
Area
Tailwater
TAILWATER AND SPILLWAY DISCHARGE - 1000 SECOND FEET
RESERVOIR CAPACITY - 1000 ACRE FEET
AREA, CAPACITY, AND DISCHARGE CURVES
PROFILE THRU ℄ OF RIVER OUTLET
Gate hoist structure
N.W.S. El. 3187.2
El. 3142
℄ 54" I.D. outlet pipe
Valve house
4'x4' High pressure slide gate
El. 3123.57
El. 3124.50
Backfill
Pipe supports
El. 3097.00
Wing-wall
Assumed rock line
Axis of dam
PROFILE THRU ℄ OF CANAL OUTLET
Gate hoist structure
Max. W.S. El. 3198.1
N.W.S. El. 3187.2
El. 3161
℄ 72" I.D. outlet pipe
El. 3135
Valve house
El. 3161
El. 3170
Stilling basin
End of contract
El. 3167.90
El. 3168.5
El. 3153.50
El. 3157.90
Canal bed - El. 3158.0
2 - 3.5'x 3.5' High pressure slide gates
Pipe supports
Pipe anchor
Original ground surface
Assumed line of excavation
Axis of dam
MAXIMUM SPILLWAY SECTION
Operating crane and radial gate hoist
Operating deck El. 3199.12
Top of radial gate El. 3187.20
Intermediate pier
Crest El. 3157.20
Parabolic curve
P.I. El. 3130
Training wall
Max. T.W.S. El. 3114 (Q = 247,000 sec. ft)
El. 3100
5'x7' Inspection gallery
Axis of dam
5'x7' Downstream drainage gallery
5'x7' Foundation gallery
El. 3040
Retaining wall
Assumed line of excavation
211.01'
NOTE
Actual required foundations may vary widely from profile and assumed excavation lines shown.
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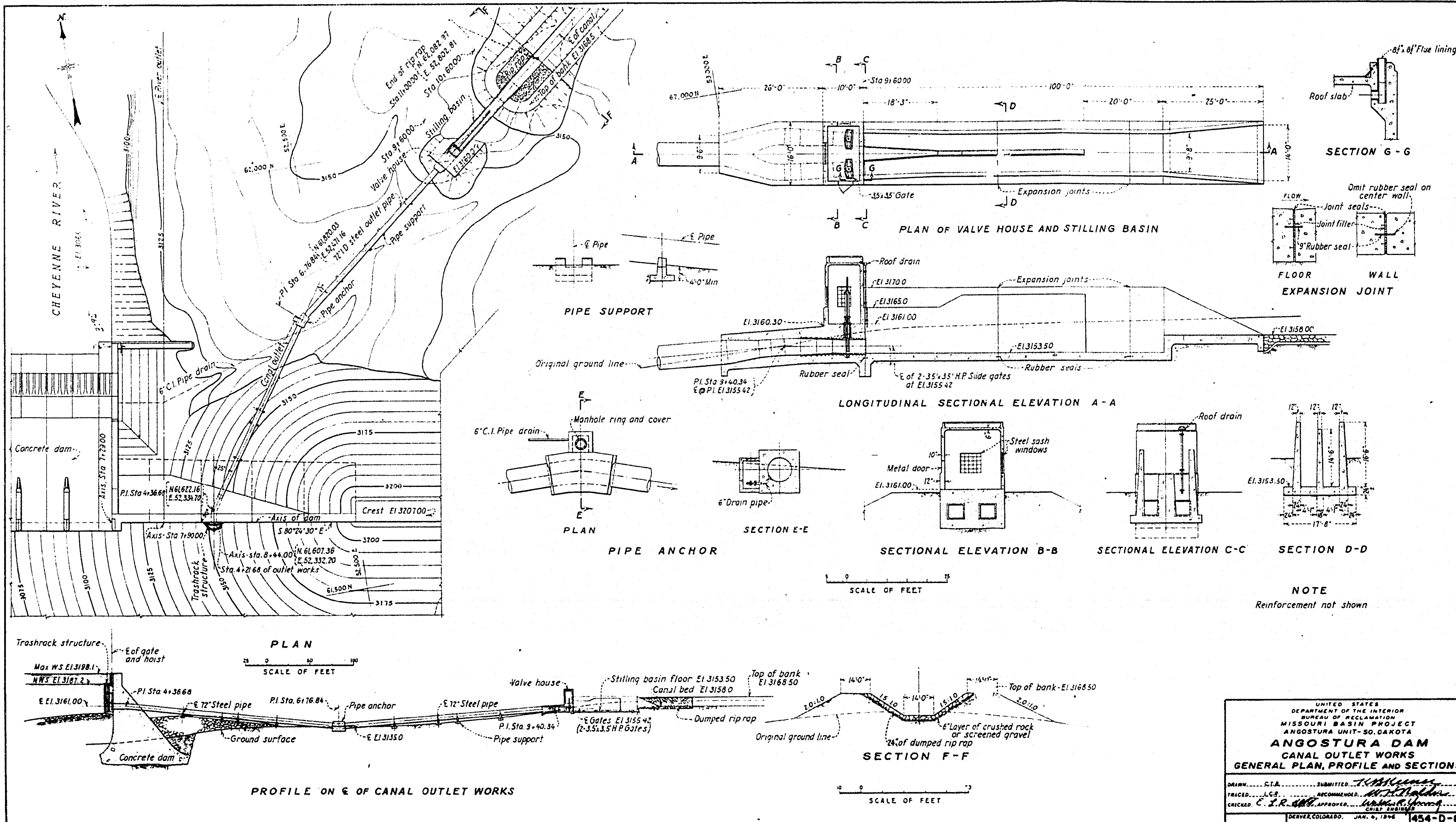
MISSOURI BASIN PROJECT
ANGOSTURA UNIT - SOUTH DAKOTA
ANGOSTURA DAM
PLAN - ELEVATION - SECTIONS
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO
454-D-96



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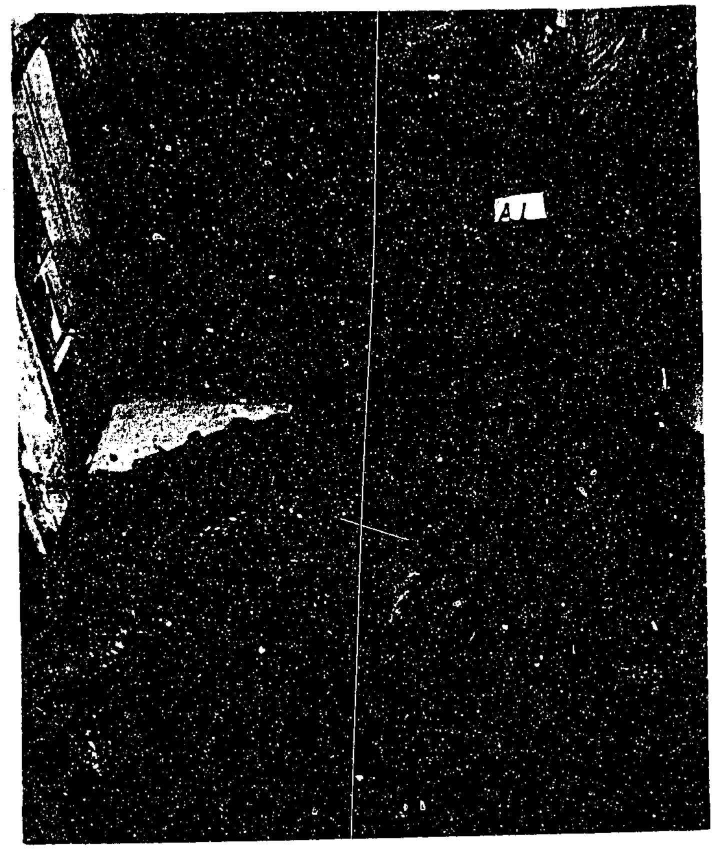
ANGOSTURA UNIT - SO. DAKOTA

ANGOSTURA DAM
CANAL OUTLET WORKS
GENERAL PLAN, PROFILE AND SECTIONS

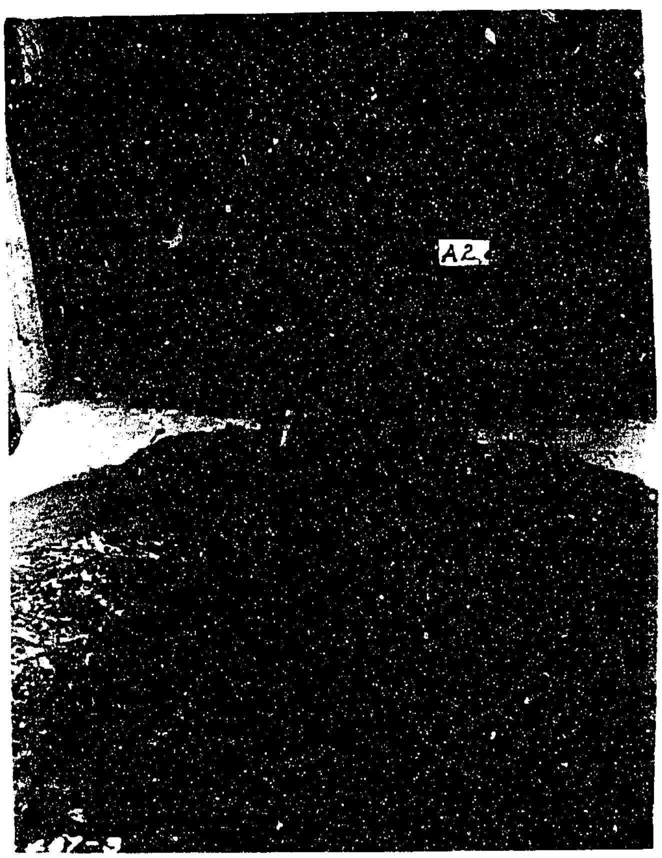
DRAWN C.T.B. SUBMITTED
TRACED L.C.B. RECOMMENDED
CHECKED APPROVED CHIEF ENGINEER
DENVER, COLORADO, JAN. 4, 1946
454-D-88

HYD 235

FIGURE 7



A. Low Surge
840 Second-feet
Both Gates Open



B. High Surge
840 Second-feet
Both Gates Open

ANGOSTURA OUTLET WORKS
1:12 SCALE MODEL
ORIGINAL DESIGN

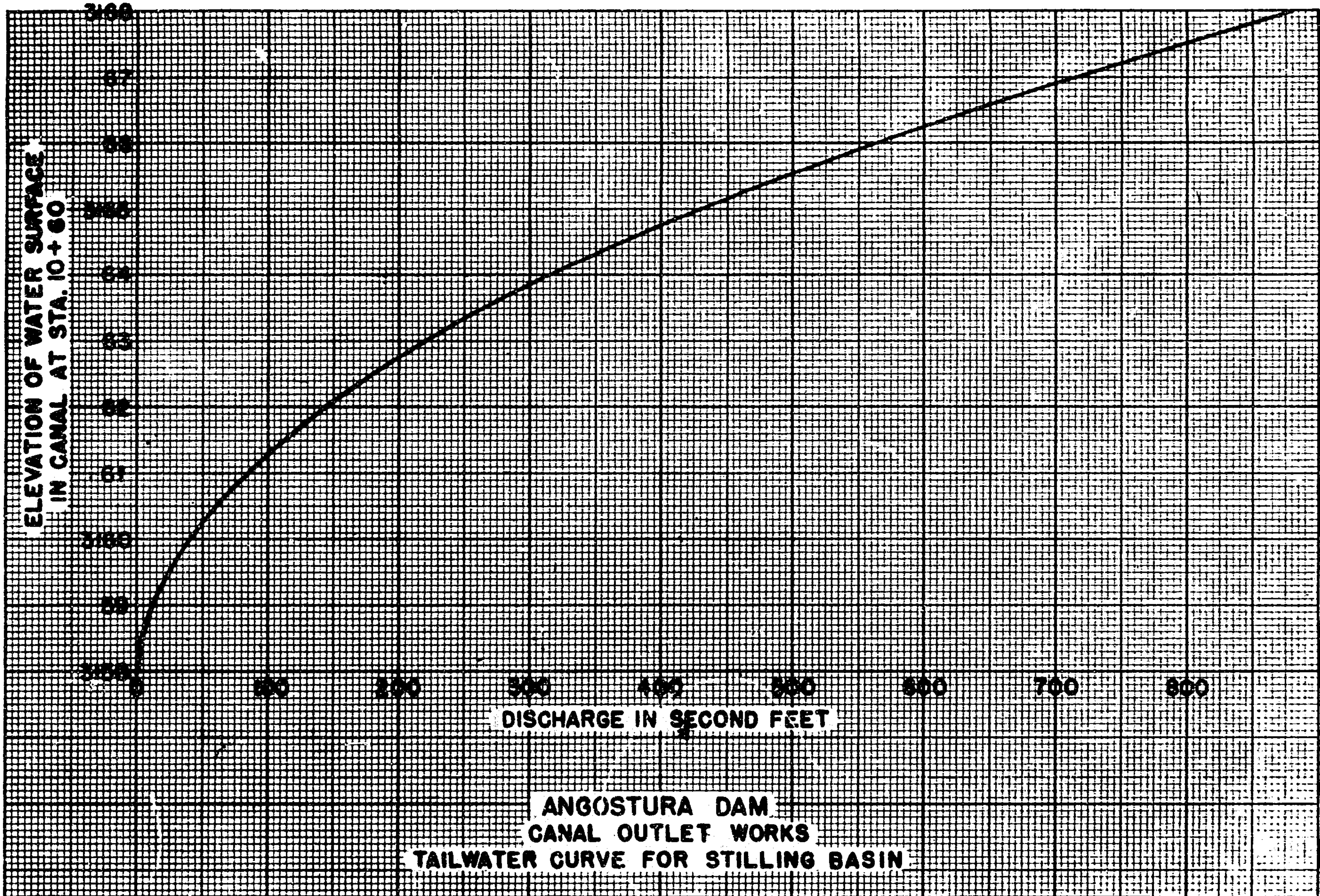
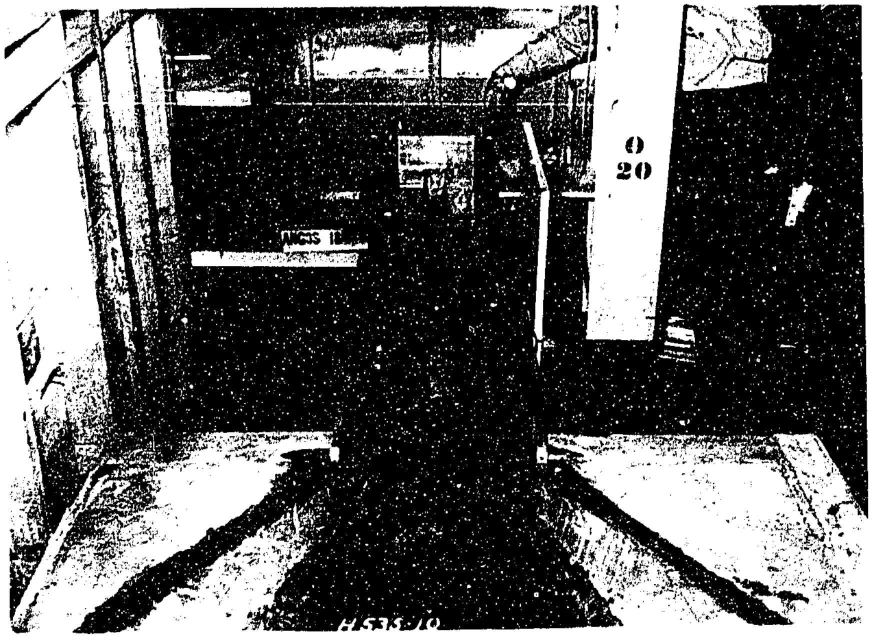

ELEVATION OF WATER SURFACE
IN CANAL AT STA. 10+60
3160
61
62
63
64
0
100
200
300
400
500
600
700
800
DISCHARGE IN SECOND FEET
ANGOSTURA DAM
CANAL OUTLET WORKS
TAILWATER CURVE FOR STILLING BASIN

FIGURE 8

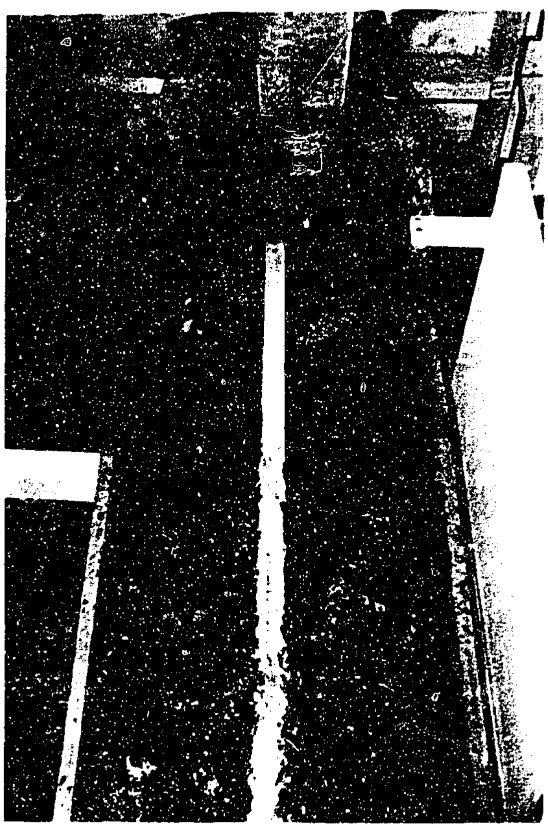


A. One Gate Discharging 200 Second-feet

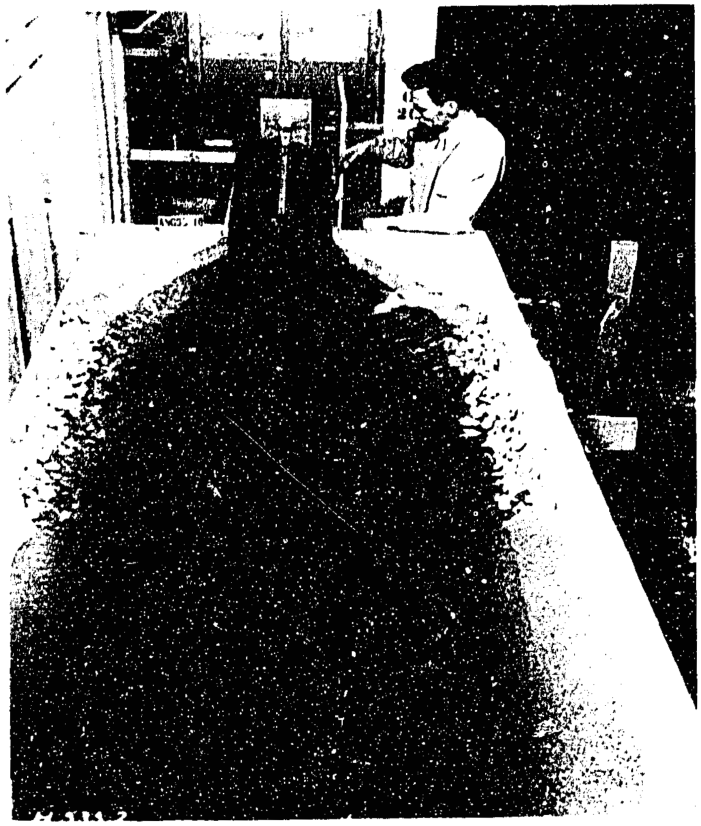
ANGOSTURA OUTLET WORKS
1:12 SCALE MODEL
RECOMMENDED DESIGN

B. Model Ready for Operation

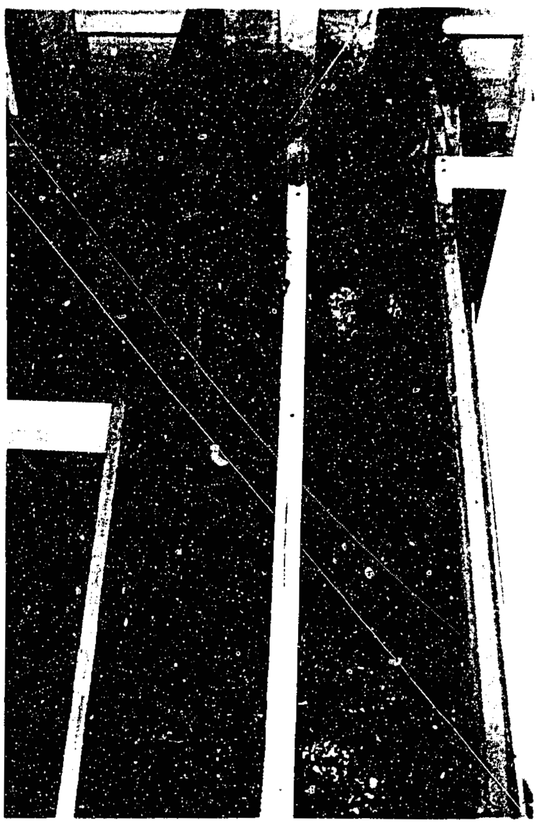
Maximum Discharge
840 Second-feet
Both Gates Open



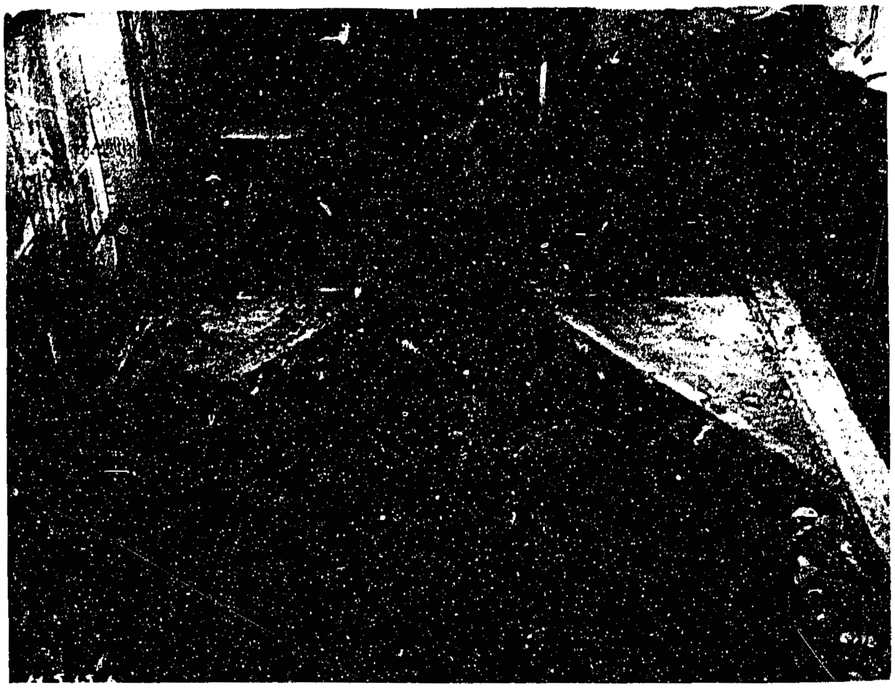
ANGOSTURA OUTLET WORKS
1:12 SCALE MODEL
RECOMMENDED DESIGN



Normal Discharge
490 Second-feet
Both Gates Open



ANGOSTURA OUTLET WORKS
1:12 SCALE MODEL
RECOMMENDED DESIGN



Maximum Discharge
420 Second-feet
One Gate Open

ANGOSTURA OUTLET WORKS
1:12 SCALE MODEL
RECOMMENDED DESIGN