HYD-173

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NO. 173

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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HYDRAULIC LABORATORY REPORT NO. 173

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HYDRAULIC MODEL STUDIES FOR SPILLWAY ALTERATIONS AT ELEPHANT BUTTE DAM RIO GRANDE PROJECT, NEW MEXICO-TEXAS

By

F. C. LOWE

- - -

Denver, Colorado
June 5, 1945

FOREWORD

Hydraulic model studies in connection with the spillway alterations at Elephant Butte Dam were made in the hydraulic laboratory of the Bureau of Reclamation, at Denver, Colorado. The studies were begun by J. A. Lindsay, Assistant Engineer, in September, 1941, and completed by R. C. Edge, Junior Engineer, about June, 1942. All tests were made under the immediate supervision of J. W. Ball, Engineer.

Contents

Foreword

1. Introduction and summary of results.
2. The Elephant Butte Dam - Condition in 1939.
3. The spillway.
4. Inadequacy of the existing spillway design.
5. The 1:40 hydraulic model of the spillway.
6. The procedure of the tests.
7. Model studies on the existing spillway (1941).
8. Pressures on west spillway wall.
9. Temporary walls to protect against anticipated floods in 1942.
10. Discharge of prototype spillway in 1942 and comparison with model tests.
11. Model studies for permanent spillway alterations - Baffles in transition section.
12. Tests with dentates.
13. Tests with training walls.
14. Tests with channel cover and overhanging baffles on channel walls-the final design.
15. Additional tests on channel.
16. Revisions to cylinder-gate outlets.
17. Discharge of spillway into river channel.
18. Rating curves for existing and final designs.
19. Abstract of correspondence.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
June 5, 1945

Laboratory Report No. 173
Hydraulic Laboratory
Compiled by: F. C. Lowe

Reviewed by: J. E. Warnock

Subject: Hydraulic model studies for spillway alterations at Elephant Butte Dam - Rio Grande Project, New Mexico-Texas.

1. Introduction and summary of results. This report is concerned primarily with model studies to improve the hydraulic design of the spillway at Elephant Butte Dam. In addition, several dissertations concerning the prototype have been interposed to present a more complete picture, or background, of the entire program concerning the spillway alterations.

Subsequent to the completion of the dam in 1916, the hydraulic design of the spillway was questioned by several engineers. When water discharged through this spillway for the first time in August 1941, it was realized by all concerned that it was inadequate to handle floods which occurred in the Rio Grande River. Accordingly, a program for spillway alterations was proposed, the alterations to be based upon designs evolved from studies on a 1:40 hydraulic model.

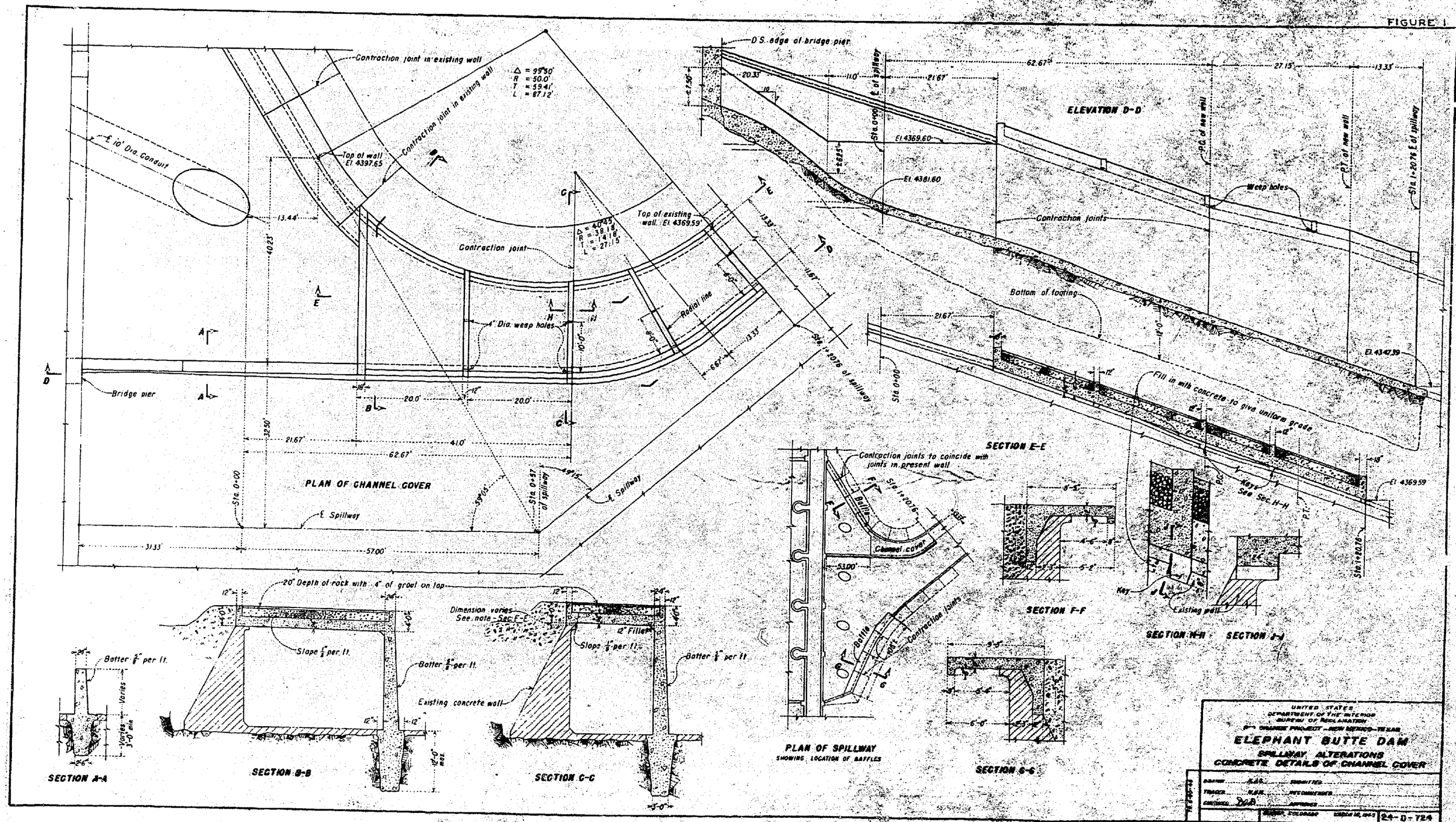
In model tests of the existing design, water piled against the walls of the spillway channel or chute, forming standing waves. These waves topped the channel walls at discharges greater than 8,000 second-feet, limiting the safe spillway capacity to this quantity because bedrock upon which the spillway was built contained much shale, and would

easily erode. A maximum flood of 35,000 second-feet would cause very serious damage, if not failure of the spillway.

Timber walls, to extend the height of the channel walls for temporary protection until permanent alterations could be completed, were first studied on the model. Such walls were actually erected in the prototype in the spring of 1942 when it became apparent that the spillway would be needed to bypass floods. On June 5, 1942, the spillway discharged 7,000 second-feet. It was then observed that the timber walls were properly located to deflect the standing waves, and that the waves would overtop the channel walls at a discharge of approximately 8,000 second-feet, as indicated by the model studies. Observations of the prototype also suggested that air would mix with the water to have the same effect as increasing the height of the waves against the channel wall, thus the spillway capacity in the prototype may be somewhat less than that indicated by the model.

Model studies for permanent spillway alterations included tests using baffles, dentates, training walls, and channel covers to force the flow to change its direction, to enter the spillway chute in a uniform manner and not to pile against the walls. Baffles and dentates were not satisfactory. Training walls could be used but structural difficulties would be encountered. A single training wall with a channel cover over a portion of the spillway, and overhanging sections or baffles on the channel walls immediately downstream from the crest formed the arrangement selected for the final design (figure 1). This design was adequate for discharges to 35,000 second-feet.

FIGURE 1


PLAN OF CHANNEL COVER
ELEVATION D-D
SECTION E-E
SECTION F-F
SECTION G-G
SECTION H-H
SECTION J-J
SECTION A-A
SECTION B-B
SECTION C-C
PLAN OF SPILLWAY
SHOWING LOCATION OF BAFFLES
Contraction joint in existing wall
Contraction joint
Top of wall El. 4397.65
Top of existing wall El. 4369.59
℄ 10' Dia. Conduit
Bridge pier
D.S. edge of bridge pier
Radial line
4" Dia. weep holes
℄ Spillway
Sta. 0+00
Sta. 1+20.76 of spillway
Sta. 1+20.76 ℄ of spillway
Bottom of footing
Weep holes
Fill in with concrete to give uniform grade
Keys See Sec. H-H
Existing wall
Key
Contraction joints to coincide with joints in present wall
Baffle
Channel cover
20" Depth of rock with 4" of grout on top
Dimension varies See note - Sec. F-F
12" Filler
Slope 1/8" per ft.
Batter 1/8" per ft.
Existing concrete wall
Varies 3'-0" min
Varies
12'-0" max
UNITED STATES
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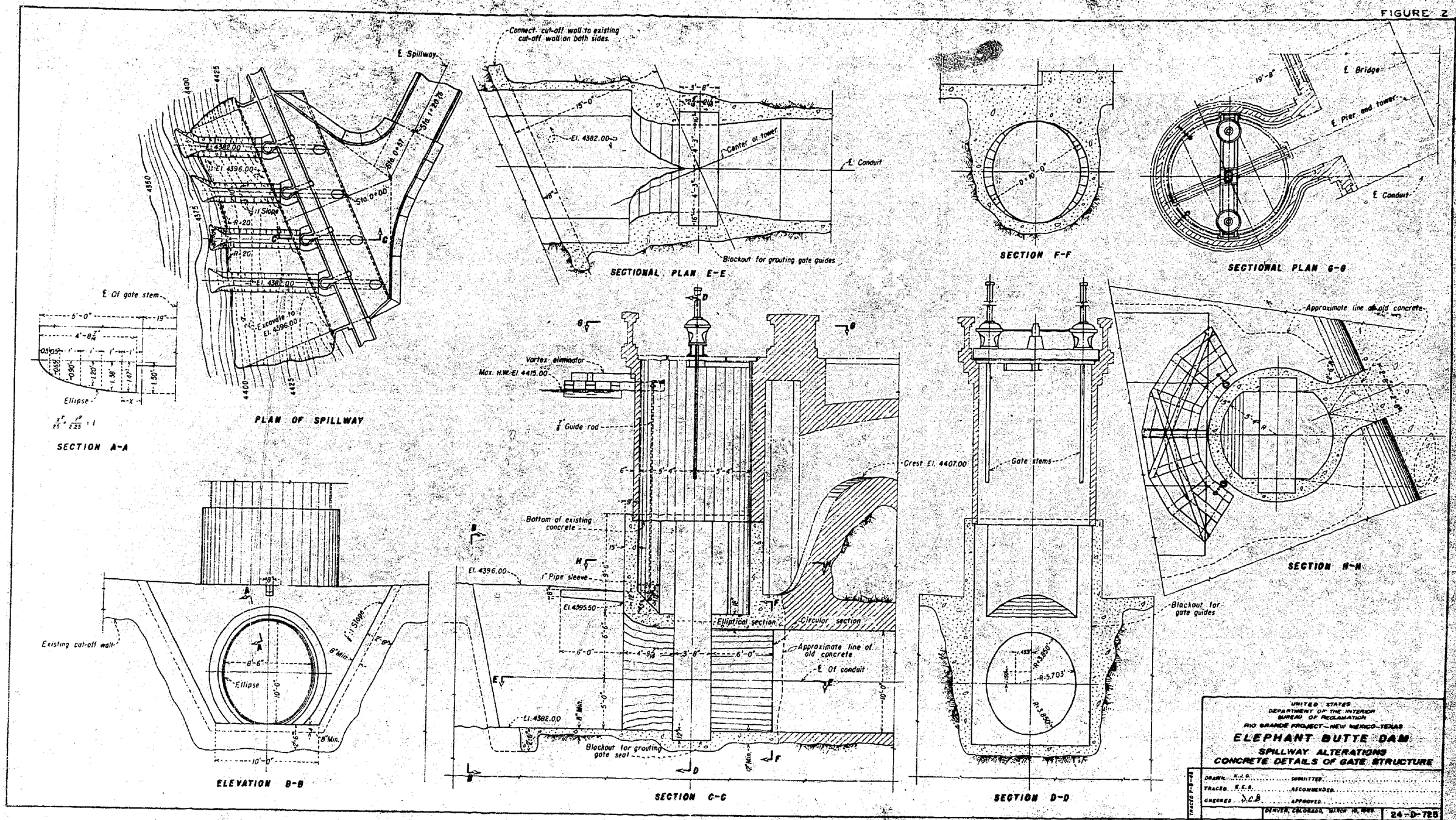
RIO GRANDE PROJECT - NEW MEXICO - TEXAS
ELEPHANT BUTTE DAM
SPILLWAY ALTERATIONS
CONCRETE DETAILS OF CHANNEL COVER
24-D-724

Upon completion of the studies of the spillway channel, revisions to the four outlets under the spillway crest were studied by the model (figure 2), and the flow from the spillway chute into the river bed, or tailrace, was observed. The relation of discharge to reservoir elevation was determined, to furnish rating curves to estimate prototype discharge, for the existing and final designs.

2. The Elephant Butte Dam - Condition in 1939. The Elephant Butte Dam is located on the Rio Grande River at Elephant Butte, New Mexico, about 120 miles northwest of El Paso, Texas (figure 3). This concrete gravity-type dam is 1,674 feet long, with the spillway crest at elevation 4,407, 191 feet above the normal tailwater in the river below. However, the maximum height of the structure itself, above the bedrock, is 306 feet. Upon its completion in 1916, the reservoir, having a capacity of 2,638,000 acre-feet, was used for flood control and for storing water to irrigate the surrounding region. In 1941, the powerhouse was completed so the dam now serves three purposes-- flood control, irrigation storage, and power development.

Naturally, through more than twenty-five years of service the dam has suffered a certain amount of deterioration. In a letter to the Chief Engineer, dated January 3, 1940, R. S. Lieurance and R. F. Blanks describe the condition of the dam and its appurtenant works as they found it on an inspection trip during the week of December 10, 1939, and in this letter made recommendations for repairs. With the exception of the spillway, no unusual repairs were considered necessary. It was recommended that portions of the downstream face of the dam be resurfaced; all drains be opened to carry away leakage; the lighting circuits

FIGURE 2


PLAN OF SPILLWAY
SECTION A-A
ELEVATION B-B
SECTIONAL PLAN E-E
SECTION C-C
SECTION D-D
SECTION F-F
SECTIONAL PLAN G-G
SECTION H-H
Connect cut-off wall to existing cut-off wall on both sides.
Blackout for grouting gate guides
Vortex eliminator
Max. H.W. El. 4415.00
Crest El. 4407.00
Gate stems
Bottom of existing concrete
Elliptical section
Circular section
Approximate line of old concrete
Blackout for grouting gate seal
Existing cut-off wall
Blackout for gate guides
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ELEPHANT BUTTE DAM
SPILLWAY ALTERATIONS
CONCRETE DETAILS OF GATE STRUCTURE
24-D-725

FIGURE 3

THE ELEPHANT BUTTE DAM

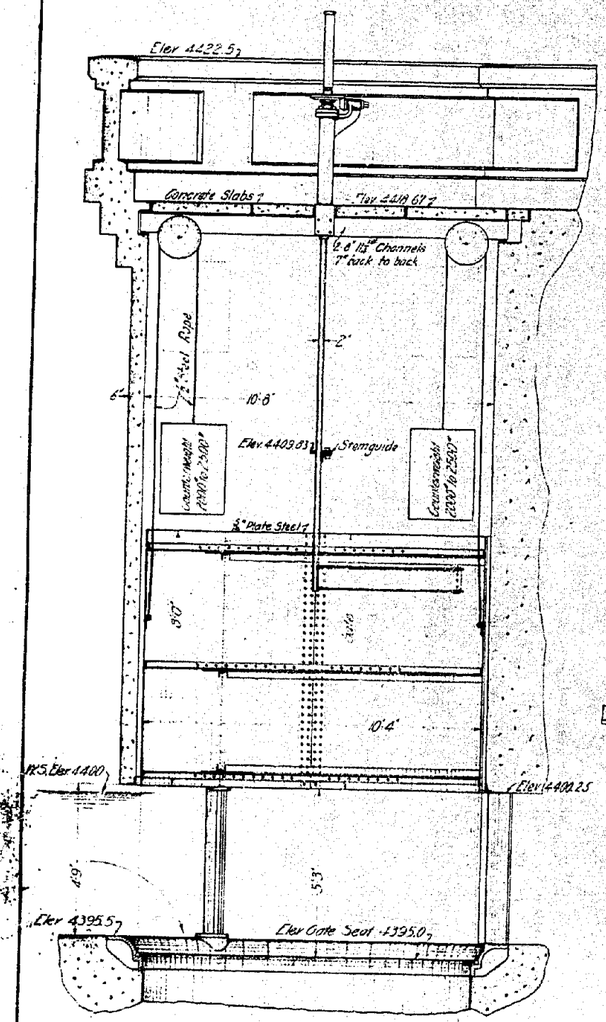
be rewired; channel improvements be continued; and repairs be made to the parapets and the roadway on top of the dam.

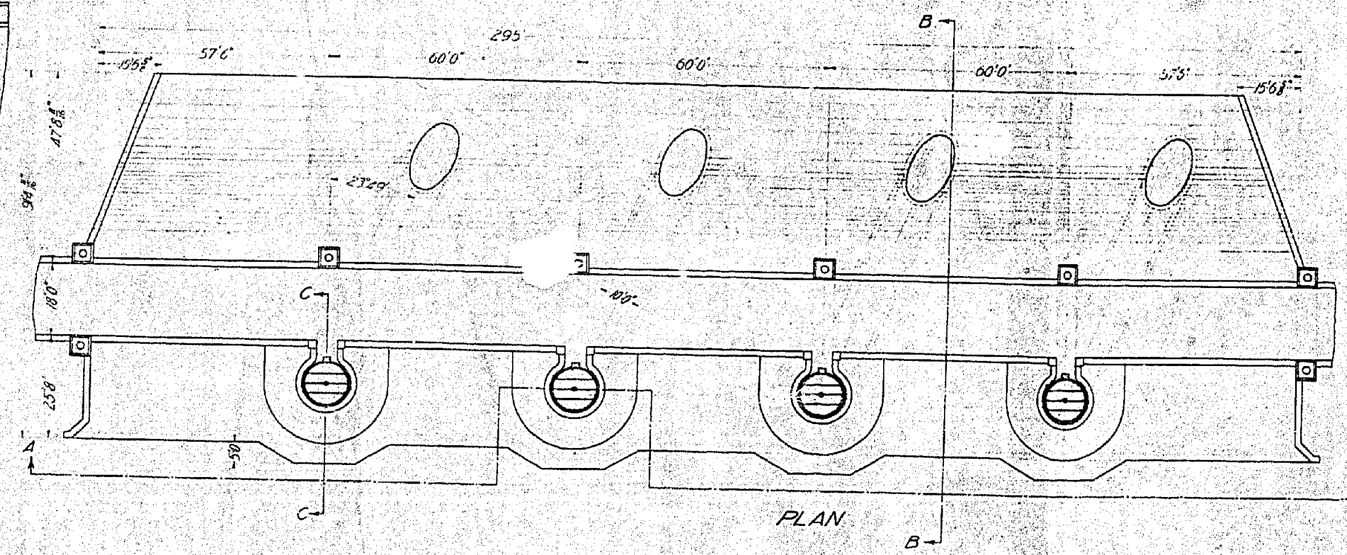
Some damage to the spillway was observed. Compression failures were noted on the spandrel extensions which form the roadway above the spillway, and cracks were observed on the ogee section downstream from the crest. More important, however, the hydraulic design of the spillway was questioned seriously, and it was doubted that the spillway could safely carry the quantity of water for which it was designed. It was recommended -

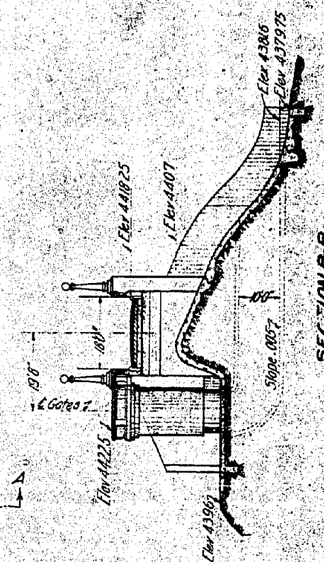
> "that detail flood-control and spillway capacity studies be made in the light of present-day conditions and all available information. Depending upon the results of such study, hydraulic model tests to determine the spillway operating conditions and required remodeling should be made."

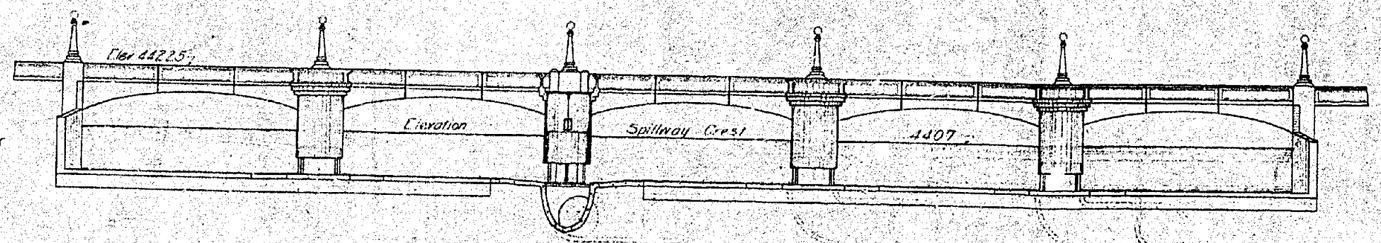
3. The Spillway. The spillway is located at the west or right end of the dam with its crest parallel to the axis of the dam (figure 3). The crest, at elevation 4,407, is 295 feet long, and 11.2 feet below the roadway over the top of the dam. This spillway may be described as consisting of three sections: (1) the crest section, (2) a transition channel, and (3) a chute. The crest section consists of a shelf upstream from the crest, at elevation 4396.0, and the spillway apron downstream to elevation 4381.6 (figure 4). This section includes four 10-foot diameter cylinder-gate outlets which pass underneath the crest and discharge upon the apron. These cylinder-gate outlets increase the spillway capacity and permit the spillway to discharge when the water surface in the reservoir is between elevations 4396.0 and 4407.0. The transition channel begins on the

FIGURE 4









SECTIONAL ELEVATION A-A

DEPARTMENT OF THE INTERIOR
UNITED STATES RECLAMATION SERVICE
RIO GRANDE PROJECT-NEW MEXICO-TEXAS
ELEPHANT BUTTE DAM
SPILLWAY & CYLINDER GATES

Drawn C.A.M. Recommended
Checked F.J.L. Approved

20400 | Denver, Colorado, April 20, 1933 | 24E-6

spillway apron at elevation 4381.6, station 0+00, and joins the chute at elevation 4347.50, station 1+20.76 (figure 5). The chute, 50 feet wide, extends to station 7+15, at elevation 4205.0. The total drop from the crest, elevation 4407.0 to the mouth of the chute, elevation 4205.0 is 202 feet.

With the water surface at elevation 4411.0, four feet above the crest, the spillway will discharge approximately 16,000 second-feet, 8,000 second-feet over the crest and 8,000 second-feet through the cylinder-gate outlets. As the water surface rises above elevation 4411.0, the spandrel arches forming the roadway above the crest will restrict the flow somewhat. However, before the water could rise so high, that there would be danger of overtopping the dam, the spillway discharge would reach 35,000 second-feet, the maximum flood that is anticipated in the Rio Grande River.

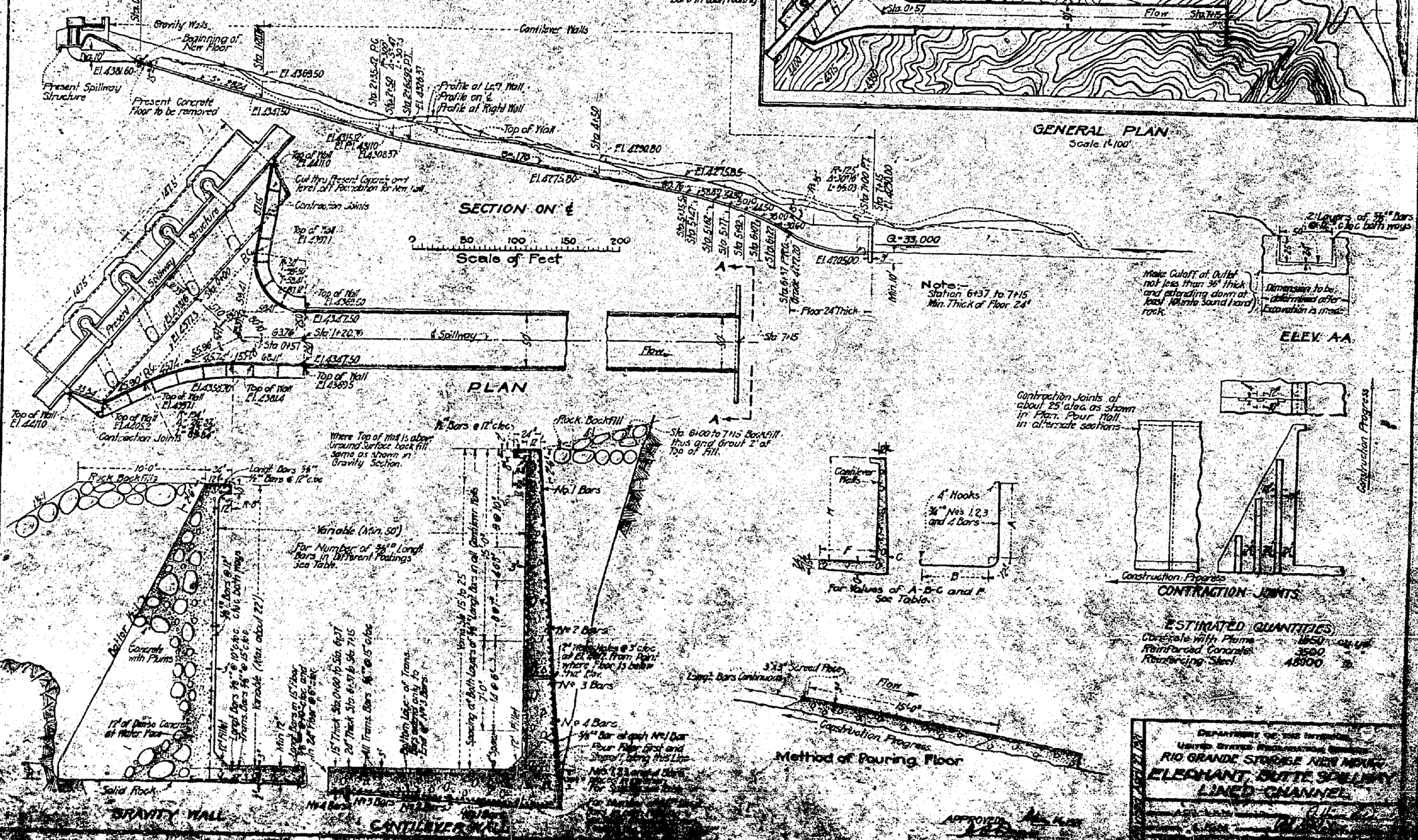
This spillway was not built as one project. The crest section, including the cylinder-gate outlets, as shown in figure 4 was completed in 1916. The construction of the transition channel and chute downstream was delayed for several years, and was not completed until 1922. From the beginning there was uncertainty as to the proper location and alignment of the chute. While it would have been desirable to locate the chute at right angles, or normal, to the axis of the spillway crest the terrain was unfavorable. When the crest section was under construction, before 1916, it was evidently planned to turn the chute about 23 degrees 45 minutes to the right of the normal of the crest, looking downstream. Accordingly, the tunnels of the

FIGURE

MAX H	F	C	SPACING	No 1 BARS A	No 1 BARS B	No 1 BARS LENGTH	No 1 BARS NUMBER	No 2 BARS A	No 2 BARS B	No 2 BARS LENGTH	No 2 BARS NUMBER	No 3 BARS A	No 3 BARS B	No 3 BARS LENGTH	No 3 BARS NUMBER	No 4 BARS A	No 4 BARS B	No 4 BARS LENGTH	No 4 BARS NUMBER
15'	8'-0"	18'	7½"	8'-5"	22'-0"	18'-7"	100	7'-8"	3'-6"	14'-0"	100	5'-3"	5'-9"	17'-0"	100	4'-2"	8'-4"	10'-0"	31
16'	8'-6"	19'	6¾"	8'-6" to 6'-9"	21'-0"	18'-10" to 18'-7"	92	8'-7"	4'-5"	15'-0"	92	5'-3"	5'-9"	17'-0"	92	4'-2"	9'-10"	15'-0"	46
17'	9'-0"	20'	6"	7'-9" to 8'-7"	24'-10"	19'-5" to 19'-3"	72	9'-0"	4'-10"	15'-0"	72	6'-3"	7'-9"	18'-0"	72	4'-2"	11'-8"	15'-0"	36
18'	9'-6"	22'	5¼"	8'-9" to 7'-9"	26'-0"	20'-9" to 20'-7"	61	10'-4"	5'-3"	16'-0"	61	6'-9"	7'-3"	18'-0"	61	4'-8"	12'-6"	15'-0"	30
19'	10'-0"	24'	5"	9'-0" to 8'-6"	31'-1"	21'-6" to 21'-4"	52	11'-4"	5'-9"	16'-0"	52	6'-6"	7'-6"	18'-0"	52	5'-2"	13'-5"	15'-0"	26
20'	10'-6"	25'	4¾"	9'-0" to 9'-0"	31'-5"	22'-9" to 22'-7"	50	11'-0"	5'-0"	16'-0"	50	7'-3"	8'-3"	18'-0"	50	4'-7"	12'-3"	15'-0"	50
21'	11'-0"	27'	4½"	9'-2" to 9'-2"	31'-5"	23'-7" to 23'-7"	55	11'-3"	5'-9"	18'-0"	55	7'-3"	8'-3"	18'-0"	55	4'-7"	12'-3"	18'-0"	55
22'	11'-6"	29'	4"	9'-6" to 9'-6"	31'-7"	24'-7" to 24'-7"	59	12'-6"	6'-6"	20'-0"	59	8'-0"	9'-0"	18'-0"	59	5'-1"	13'-5"	18'-0"	59
23'	12'-0"	30'	3¾"	9'-6" to 9'-6"	3'-0"	25'-6" to 25'-6"	10	3'-0"	6'-0"	20'-0"	10	8'-6"	8'-0"	18'-0"	10	5'-4"	13'-8"	20'-0"	10
24'	12'-6"	32'	3½"	10'-0" to 10'-0"	3'-0"	26'-6" to 26'-6"	11	15'-0"	6'-0"	20'-0"	11	9'-0"	10'-0"	20'-0"	11	5'-6"	14'-0"	21'-0"	11
25'	13'-0"	33'	3¼"	10'-0" to 10'-0"	5'-2"	27'-2" to 27'-2"	40	15'-0"	7'-6"	22'-0"	40	9'-0"	10'-0"	20'-0"	40	5'-6"	15'-0"	21'-6"	40

H	No of BARS
15'	31
16'	46
17'	30
18'	30
19'	26
20'	50
21'	40
22'	55
23'	50
24'	60
25'	75

Number of ⅝" Long. Bars in each footing



cylinder-gate outlets did not go under the crest at right angles to the axis but turned to the right 23 degrees, 45 minutes to discharge directly into the chute, figure 4. When construction of the chute began, it was found that better foundation rock would be available and that a large savings in construction costs would be possible if the chute turned the opposite direction; that is, to the left of the normal of the axis of the crest. Accordingly, the chute was located 40 degrees, 45 minutes, to the left of the normal of the crest and joined to the crest section by the transition channel between stations 0+00 and 1+20.76 (figure 5).

4. Inadequacy of the existing spillway design. This location of the chute means that water flowing over the spillway crest must turn 40 degrees, 45 minutes, to flow into the chute, and that water flowing through the cylinder-gate outlets must eventually turn through an angle of 64 degrees, 34 minutes. Actually, water from the outlet adjacent to the west channel wall, the right wall looking downstream, must turn through an angle of 91 degrees to flow along this adjacent west wall. At the time of the construction of the spillway, before 1922, flow in steep channels was understood only vaguely, or not at all, and model studies to assist in the hydraulic design of such structures were not commonly used. While the chute was designed to carry a flood as large as 35,000 second-feet, insufficient consideration was given to the effects of a change in direction of the flow.

Water flowing down a steep chute in which there is a curve, will pile up or form a standing wave on the outside wall at the curve. This

wave will be reflected to the opposite channel wall further downstream, then reflected back again, and so on to the end of the channel.* In a chute as steep as that at the Elephant Butte spillway the height of such a standing wave could be several times the depth of flow in the channel.

Prior to the inspection of the dam by R. S. Lieurance and R. F. Blanks, December 10, 1939, the spillway had never been used, but, as inferred in their report of January 3, 1940, silting of this dam would eventually reduce the storage to a point where the spillway would be needed. On July 11, 1941, the cylinder-gate outlets discharged for the first time. A maximum flow of 2,742 second-feet occurred on July 17. The operation of the cylinder-gate outlets during the months of July and August is described in a chronological record in a letter from Project Superintendent L. R. Fiock to the Chief Engineer, dated September 4, 1941. Photographs in that report, two of which are shown on figure 6, show water flowing through the tunnels, striking the adjacent west wall of the chute to form waves which are almost as high as the channel walls. The waves tended to reflect on the east wall of the chute further downstream, although their height was greatly diminished. In the letter of September 4, Fiock emphasizes in paragraphs 6 to 9, inclusive, that the existing channel is completely inadequate to handle large floods, and that

* For additional information on this type of flow see the report by A. T. Ippin and R. T. Knapp "A Study of High Velocity Flow in Curved Sections of Open Channels" prepared at the California Institute of Technology for the Los Angeles Flood Control District, March 29, 1936.

A. ALL FOUR SPILLWAY CYLINDER GATES OPEN FULL. DISCHARGE 2.093 c.f.s.

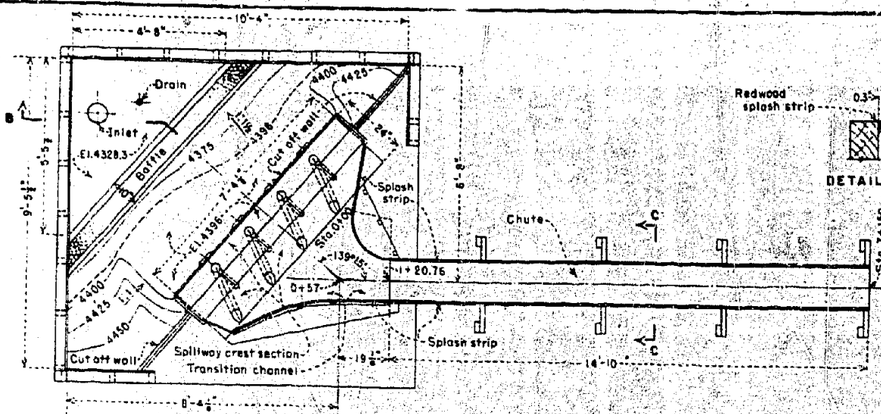
B. SPILLWAY CHANNEL, ALL FOUR CYLINDER GATES OPEN FULL, DISCHARGE 2,093 c.f.s.

ELEPHANT BUTTE DAM SPILLWAY
DISCHARGE IN SPILLWAY AUGUST 1, 1941

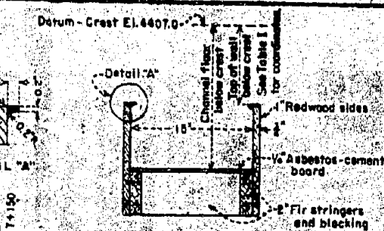
model studies should be made to show the action of the spillway at large discharges and to determine necessary alterations to make it safe.

5. The 1:40 hydraulic model of the spillway. A model of the spillway was built on a scale of 1:40, which included a small portion of topography upstream from the spillway as well as the spillway crest section, transition channel, and chute, figure 7. It was also contemplated that discharge from the chute into the river bed might be studied but the model was not extended beyond the mouth of the chute, station 7+15.00, until the major problem, which concerned flow down the transition channel and in the chute, had been solved (section 17).

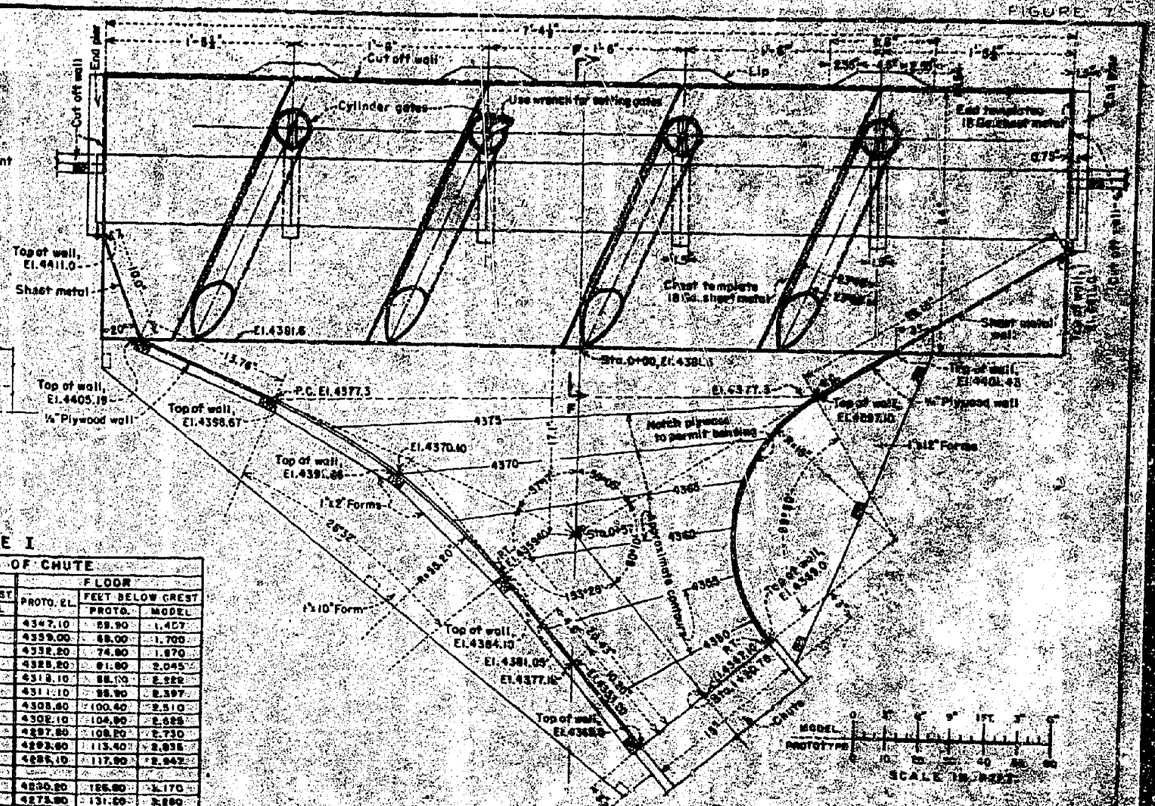
The topography upstream from the spillway was formed with sand and while only approximate, in conjunction with a rock baffle it was sufficient to cause flow to approach the spillway crest properly, (figure 7B). The crest section, which included the spillway above elevation 4381.6, the cylinder-gate outlets, piers and arch roadway, was built as a box in which there were set sheet metal templates with neat cement cast between them. The cylinder-gate outlets of three-inch seamless tubing were cast in place. The cylinder gates were mounted on pin supports and fastened to the piers. The piers and arch roadway were made of redwood held in place on the crest by pins. It was necessary to include the arch roadway in the model because, as aforementioned, the spring line of the bridge arch at elevation 4,411



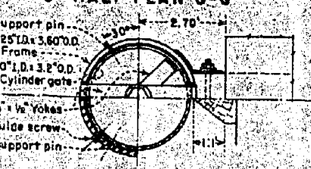
A - PLAN



C - TYPICAL CHUTE SECTION C-C

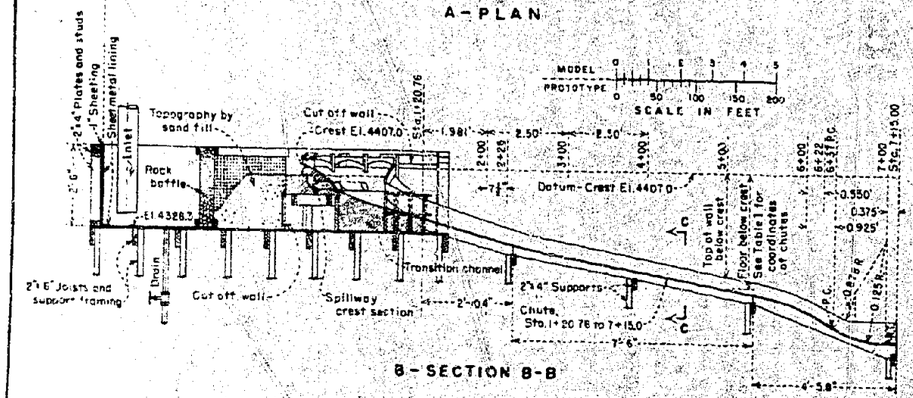


D - PLAN OF SPILLWAY CREST SECTION AND TRANSITION CHANNEL



G - HALF PLAN G-G

H - HALF SECTION H-H

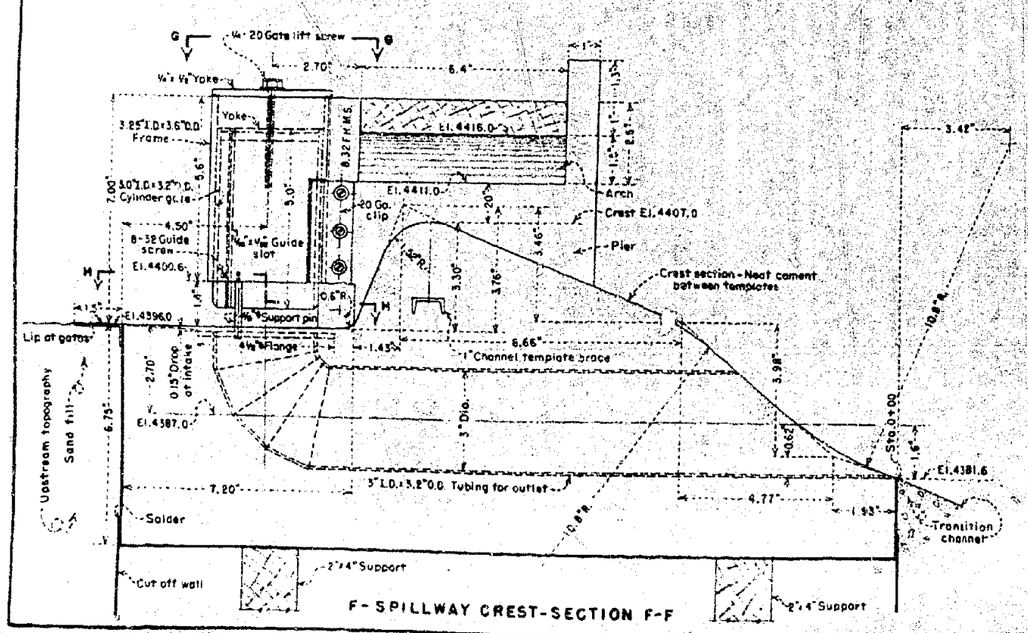


B - SECTION B-B

TABLE I

COORDINATES OF CHUTE

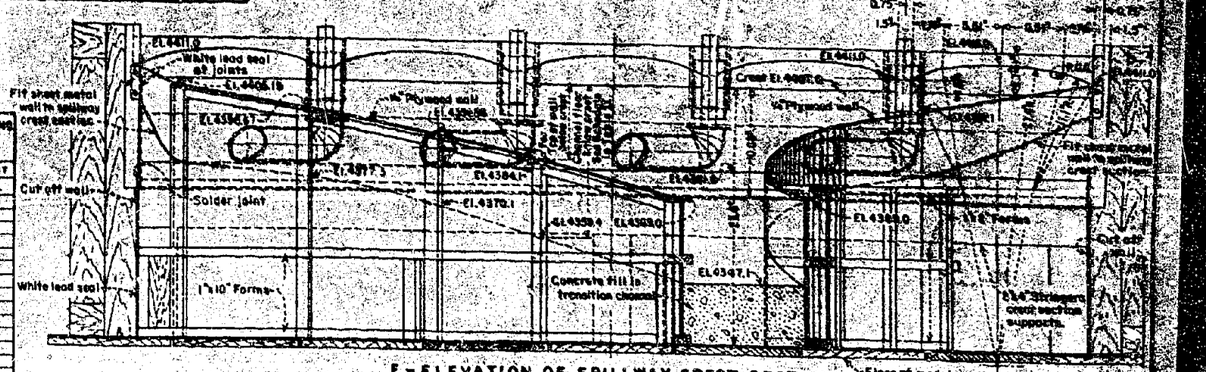
STA.	TOP OF WALL PROTO. EL.	TOP OF WALL FEET BELOW CREST PROTO.	TOP OF WALL FEET BELOW CREST MODEL	FLOOR PROTO. EL.	FLOOR FEET BELOW CREST PROTO.	FLOOR FEET BELOW CREST MODEL
1+20.76	4389.00	38.00	0.950	4347.10	59.90	1.497
+50	4380.01	46.99	1.174	4339.00	68.00	1.700
+75	4358.42	68.58	1.364	4332.80	74.80	1.870
2+00	4344.80	82.20	1.655	4328.80	81.80	2.045
+25	4337.28	89.72	1.743	4319.10	88.10	2.202
+50	4329.58	97.42	1.935	4311.10	96.90	2.397
+75	4324.67	102.33	2.080	4303.80	100.40	2.510
3+00	4319.67	107.33	2.183	4302.10	104.90	2.622
+25	4314.75	112.25	2.306	4297.80	109.20	2.730
+50	4310.06	116.94	2.423	4293.80	113.40	2.835
+75	4305.17	121.83	2.546	4289.10	117.90	2.947
4+00	4300.36	126.64	2.866			
+25	4295.66	131.16	2.778	4280.80	126.80	3.170
+50	4290.94	135.88	2.904	4273.80	131.80	3.280
+75	4286.45	140.35	3.013	4271.80	135.80	3.397
5+00	4282.10	144.90	3.122	4267.10	138.90	3.497
+25	4277.76	149.24	3.231	4262.80	144.20	3.605
+50	4273.70	153.30	3.332	4258.80	148.20	3.712
+75	4266.94	160.06	3.501	4251.70	155.30	3.882
6+00	4258.03	168.97	3.724	4242.70	164.30	4.107
+25				4235.60	171.40	4.410
+37				4233.20	174.80	4.480
7+00	4230.00	177.00	4.425	4205.00	202.00	5.050
7+15	4230.00	177.00	4.425	4203.00	204.00	5.099



F - SPILLWAY CREST-SECTION F-F

TABLE II

LOCATION OF ELEVATION		MODEL VALUES OF ELEVATIONS IN TRANSITION CHANNEL DATUM = CREST EL. 4411.0 ELEVATION	FEET BELOW CREST PROTO.	FEET BELOW CREST MODEL
TOP OF WALLS	LEFT WALL	4401.43	5.57	0.139
		4397.10	8.90	0.247
	RIGHT	4369.00	38.00	0.380
		4406.19	1.81	0.045
		4398.67	9.33	0.208
		4391.86	15.14	0.378
		4384.10	22.90	0.573
		4361.05	45.95	0.848
		4377.16	29.82	0.746
		4328.00	38.00	0.950
FLOOR OF CHANNEL	LEFT SIDE	4381.80	25.40	0.635
		4377.30	29.70	0.742
	RIGHT	4347.10	59.90	1.497
		4381.90	25.40	0.635
		4377.30	29.70	0.742
		4370.10	36.90	0.922
		4359.40	47.60	1.190
		4343.80	53.80	1.345
		4347.10	59.90	1.497



E - ELEVATION OF SPILLWAY CREST SECTION AND TRANSITION CHANNEL

RIO GRANDE PROJECT - NEW MEXICO-TEXAS

ELEPHANT BUTTE DAM

SPILLWAY ALTERATIONS

DETAILS OF 1:40 HYDRAULIC MODEL OF SPILLWAY

was only four feet above the crest and discharges greater than 16,000 second-feet would be affected by the arches.

The transition channel, beginning at the downstream edge of the spillway crest section, at elevation 4381.6 or station 0+00, was built by forming plywood sides secured by one-inch lumber forms or templates. Neat cement was then poured between these sides to form the floor of the channel.

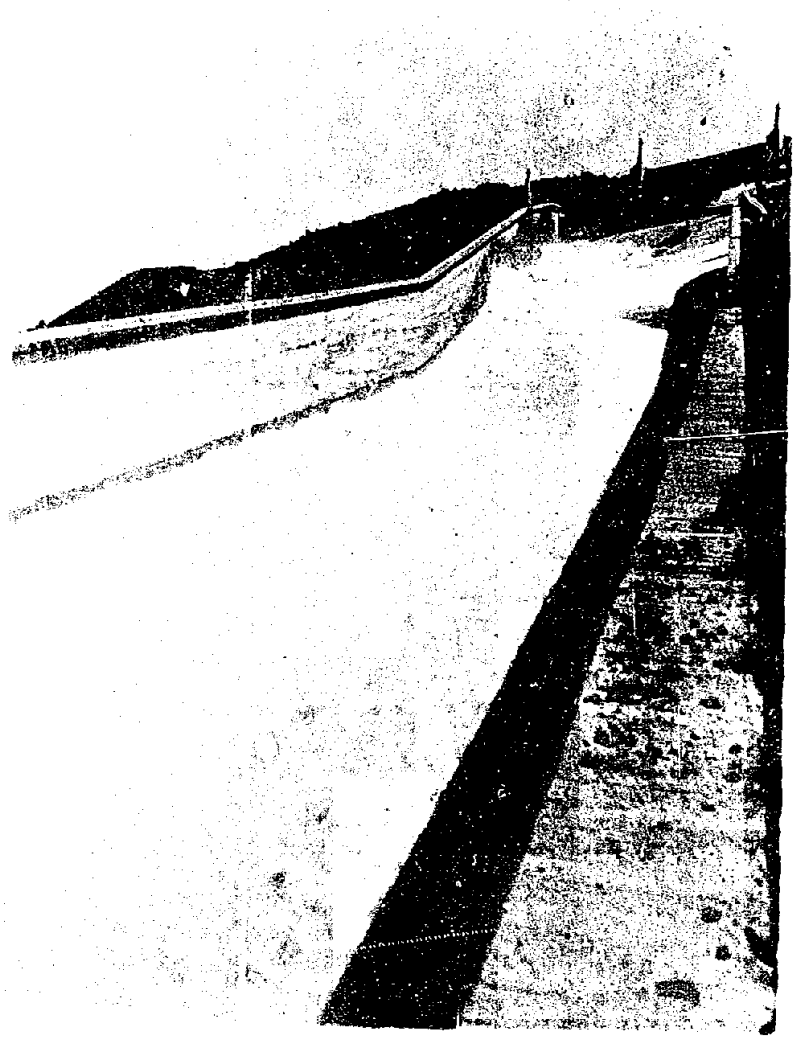
The chute, beginning at station 1+20.76 and extending to station 7+15.00 was built with treated redwood sides and with the bottom of asbestos-cement board. A special survey was made in the field to ascertain the elevations of the floor of the chute and transition channel so the model could be built accurately as possible.

6. The procedure of the tests. In testing the model the principal objective was to observe the manner and extent to which the water piled against the channel walls of the transition section and chute. Photographs were adequate to record most observations and only a few physical measurements were required, which were discharge, water surface elevation in the reservoir, and, in some tests, pressures. Each model arrangement was studied at discharges of 2,000, 4,000, 8,000, 12,000 second-feet, and so on until the capacity of the spillway was exceeded or the desired capacity of 35,000 second-feet was reached. Discharge was measured by the laboratory venturi meters. The water surface of the reservoir was measured by a hook gage, such records being made only during calibration tests on the model (section 18). Pressures were measured by piezometric connections located as the requirements demanded, (section 9 and 14).

Slope adjustments to correct for roughness in the model were not attempted because the nature of the correction was uncertain as far as the particular type of study was concerned. By the very nature of the problem the tests were mostly qualitative studies in which the effects of slope corrections would be immaterial.

7. Model studies on the existing spillway (1941). The existing spillway design, as of 1941, was studied with the model at discharges from 2,000 to 20,000 second-feet. At a discharge of 2,000 second-feet through the cylinder-gate outlets - comparable with the prototype flows which occurred in 1941 - there was sufficient resemblance to the prototype to assure that the model studies would be reliable (figure 8). Water from the cylinder-gate outlets striking the west wall of the transition channel (the left wall looking upstream in figure 8) piled up to form standing waves along this wall. Entering the chute the water spread, but tended to form, or reflect, a standing wave on the east wall near station 2+46. This general pattern remained the same as discharge increased although the height of the waves on the west wall increased, the wave on the east wall near station 2+46 became pronounced, and another wave formed on the west wall further downstream, near station 4+90.

At a discharge of 8,000 second-feet, water began to splash over the west wall near station 1+20.76 where the transition channel joins the chute (figure 9A). As the discharge increased the spill over the channel wall became greater, occurring also where the other waves



A. THE PROTOTYPE, DISCHARGING ABOUT 2,000 c.f.s. THROUGH CYLINDER-GATE OUTLETS. AUGUST, 1941.

B. THE 1:40 MODEL, DISCHARGING 2,000 c.f.s. (in prototype) THROUGH CYLINDER-GATE OUTLETS. AUGUST, 1941.

ELEPHANT BUTTE DAM SPILLWAY
COMPARISION OF FLOW IN MODEL AND PROTOTYPE

FIGURE 8

A. DISCHARGE 6,000 c.f.s., CYLINDER-GATES OPEN.

B. DISCHARGE 20,000 c.f.s., CYLINDER GATES OPEN.

1:40 MODEL OF ELEPHANT BUTTE DAM SPILLWAY

FIGURE 9

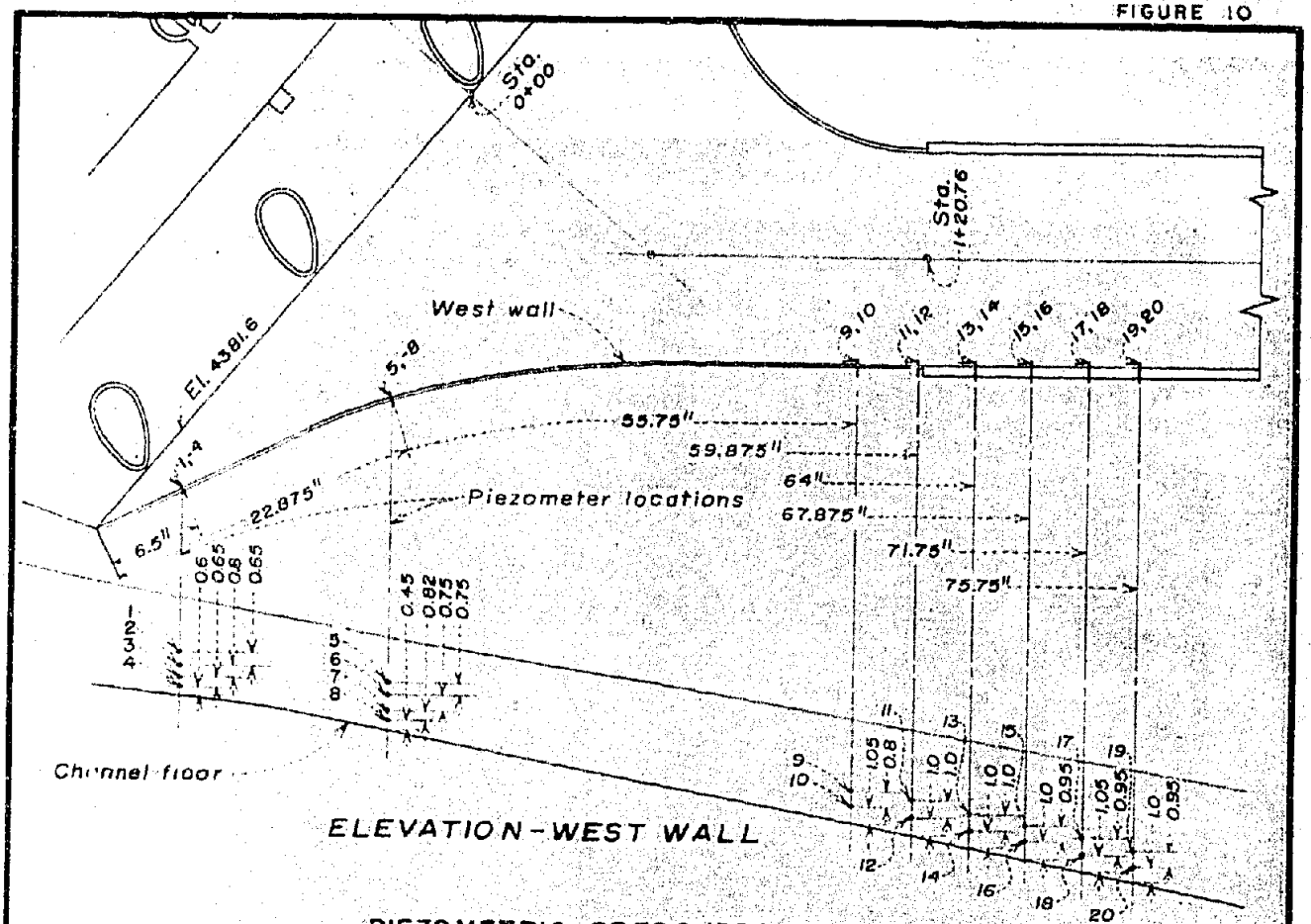
were located. At a discharge of 20,000 second-feet, water spilled over the west wall in front of the exit of the left cylinder-gate outlet, over the west wall near station 1+20.76, over the east wall near station 2+46, and over the west wall near station 4+90 (figure 9B). Increasing the discharge beyond 20,000 second-feet rapidly increased the quantity spilled.

However, no attempts were made to measure the rate of flow over the walls although it was guessed that there would be as much as 100 second-feet at a discharge of 20,000 second-feet. Regardless of the quantity, this spill over the walls could not be tolerated because the backfill and foundation rock contained shale which would quickly erode. It follows that the capacity of the existing design was, therefore, only 8,000 second-feet.

8. Pressures on west spillway wall. Studies on the existing design included pressure measurements on the west wall of the transition channel and chute for discharges of 8,000, 12,000 and 16,000 second-feet with the cylinder gates both opened and closed. The location of piezometric connections and a table containing measurements are shown on figure 10. As anticipated, there was a pressure increase where water piled against the wall. No unusual pressure conditions, such as negative pressures, could be observed. It was concluded that no additional pressure measurements would be necessary until the final design was obtained.

9. Temporary walls to protect against anticipated floods in 1942. A spillway capacity of 8,000 second-feet was completely inadequate,

FIGURE 10



ELEVATION-WEST WALL

PIEZOMETRIC PRESSURES ON WALL

DISCHARGE IN C.F.S.	8000		12,000		16,000	
POSITION OF GATES	OPEN	CLOSED	OPEN	CLOSED	OPEN	CLOSED
PIEZOMETER NO.						
1	2.4	2.0	4.8	4.8	3.2	2.0
2	10.0	4.0	16.0	8.0	12.8	10.0
3	1.2	4.8	16.0	12.8	10.0	16.0
4	10.0	6.4	16.4	14.0	12.0	16.0
5	8.0	3.6	10.0	4.0	6.8	6.0
6	8.0	4.0	12.8	8.0	6.0	10.0
7	8.0	7.6	16.0	12.0	8.8	10.0
8	8.8	6.4	18.4	15.6	9.2	19.2
9	2.0	0	10.0	14.0	6.0	18.0
10	8.8	8.0	12.4	18.0	8.0	20.0
11	8.0	2.0	11.2	14.0	7.6	15.0
12	9.2	6.0	13.6	16.8	6.0	19.2
13	7.2	2.0	8.8	10.0	7.6	12.8
14	8.8	4.0	12.0	12.0	4.0	16.0
15	6.4	8.8	10.0	10.0	5.2	12.0
16	6.0	4.0	12.0	11.2	2.0	12.0
17	6.8	7.2	8.8	10.0	4.8	12.0
18	8.0	4.8	12.4	12.0	3.6	14.0
19	4.0	4.0	8.0	8.8	6.0	10.0
20	8.8	8.0	12.0	12.0	6.4	14.8

RIO GRANDE PROJECT—NEW MEXICO—TEXAS

ELEPHANT BUTTE DAM

SPILLWAY ALTERATIONS BY HYDRAULIC MODEL—1:40 SCALE

PRESSURES ON WEST WALL OF EXISTING DESIGN

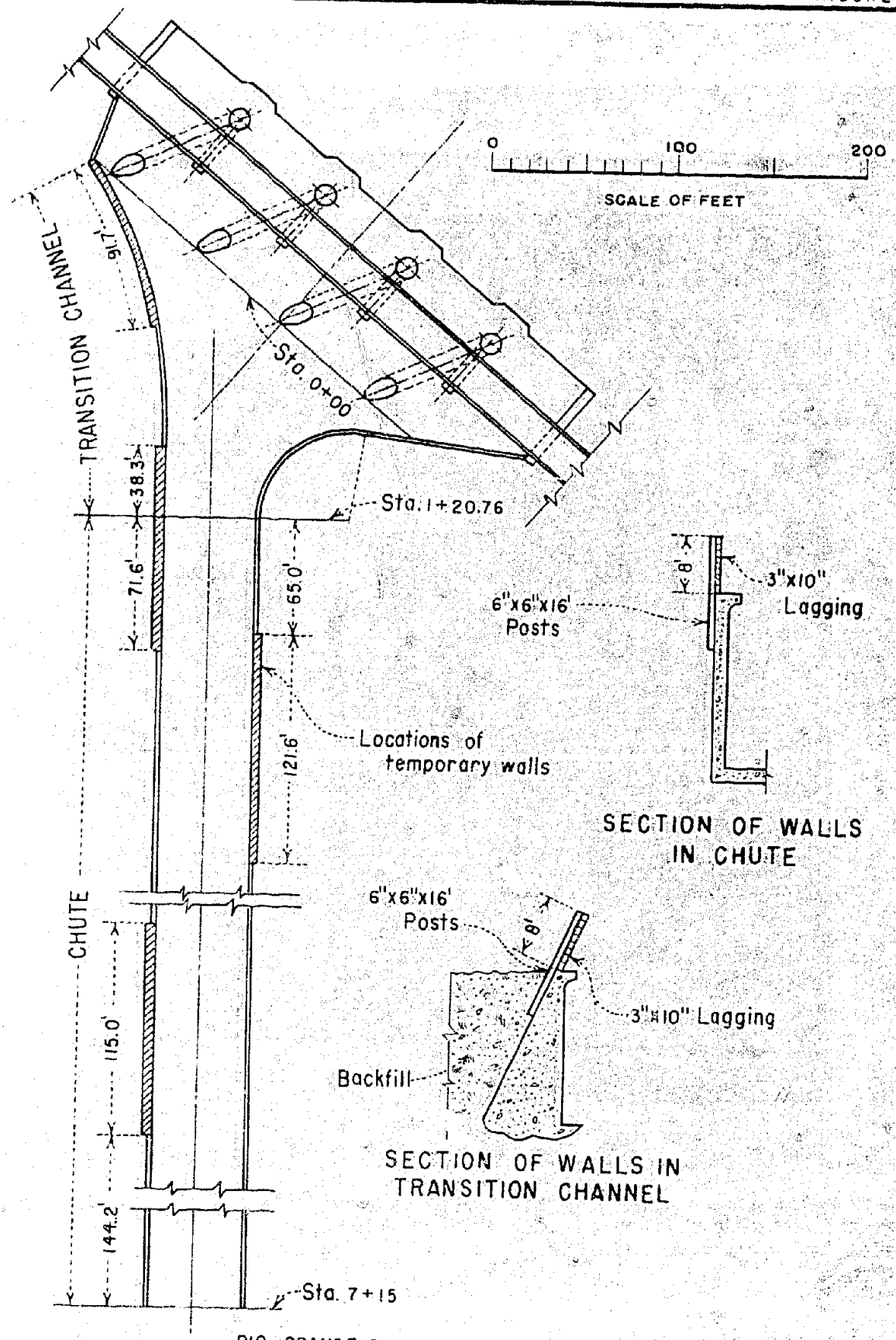
and from the model tests it was hoped that a method could be devised whereby the spillway could be altered to accommodate a maximum flood of 35,000 second-feet. However, at the time the tests were planned (November 1941) there was an unusually large quantity of water stored in the Elephant Butte Reservoir, and should large floods occur in the spring of 1942 it was almost certain that the spillway would again overflow. Therefore, the first model tests were used to develop a temporary and relatively inexpensive method for making the spillway safe.

Timber bulkheads or walls placed on top of the channel walls were suggested as a temporary protective works since they could be installed on short notice. These walls were eight feet high, built with 3- by 10-inch lagging fastened to 6- by 6-inch posts. The posts, 16 feet long, were to be fastened on the outside of the walls of the transition channel and chute (figure 11 and 12A).

The walls were installed in the model to scale, figure 12A, and a series of runs were made at discharges up to 35,000 second-feet. It was found that the 8-foot walls would be satisfactory for discharges up to 28,000 second-feet (figure 12B). This maximum discharge could be increased by increasing the height of the temporary walls, but this was not considered necessary for temporary protection.

It would be possible to use such a scheme for permanent spillway alterations by increasing the height of the existing channel walls. However, such a plan would not be practical because the additional weights of the extended walls, in concrete, would be

FIGURE 11



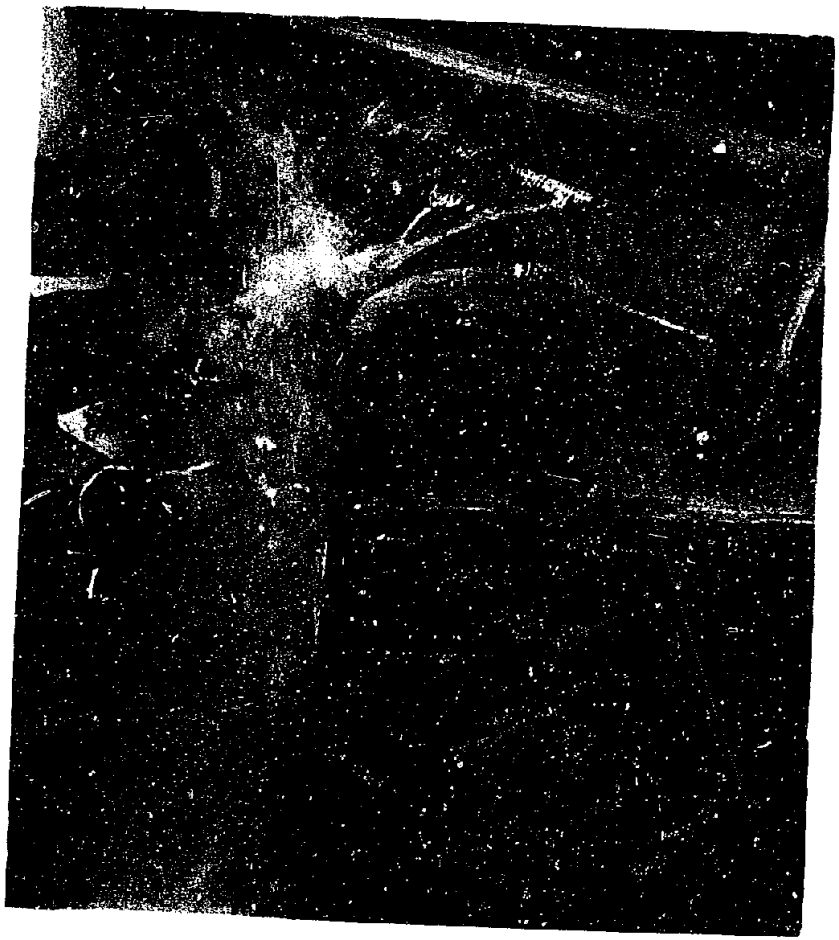
RIO GRANDE PROJECT-NEW MEXICO-TEXAS

ELEPHANT BUTTE DAM

SPILLWAY ALTERATIONS BY HYDRAULIC MODEL-1:40 SCALE

TEMPORARY WALLS TO PROTECT SPILLWAY AGAINST FLOODS

A. LOCATION OF WALLS



B. DISCHARGE 28,000 c.f.s., CYLINDER GATES OPEN.

1:40 MODEL OF ELEPHANT BUTTE DAM SPILLWAY
TEMPORARY WALLS TO PROTECT AGAINST ANTICIPATED FLOODS IN 1942

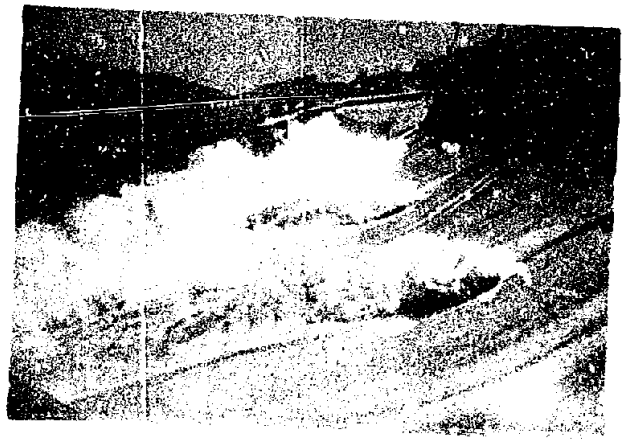
FIGURE 12

so great that the foundations would have to be enlarged. Moreover, the final result would appear so haphazard and unsightly that it would invite much adverse criticism.

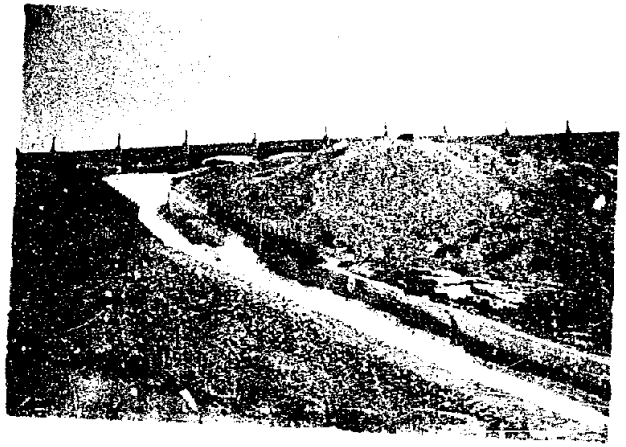
10. Discharge of prototype spillway in 1942 and comparison with model tests. As anticipated, the reservoir having remained nearly full throughout the season of 1941 filled again early in 1942. On April 23, the spillway was discharging 2,500 second-feet, and a much larger flow appeared inevitable. In a telegram dated April 24, the Chief Engineer directed Superintendent Fiock to begin construction of the protective timber walls (figure 11).

Inspection of the spillway was made June 5, by D. C. McConnaughy, senior engineer from the Denver office, in the company of Mr. Fiock, Mr. Caylor, and other members of the project staff. On that day the water surface stood at elevation 4408.18, 1.18 feet above the spillway crest. By fully opening the cylinder gates a spillway discharge, estimated to be 7,000 second-feet, was obtained. In a "Memorandum for Mr. Keener," dated June 16, 1942, which described this inspection trip Mr. McConnaughy states:

"3. The action of the water followed that in the model very closely, and temporary protective works, consisting of timber walls, which may be seen in the photographs (figure 13), were evidently at the correct locations. These locations were predicted from the model; it had been expected that the protective work would not be necessary for discharges smaller than about 8,000 second-feet, and this seemed to be the case. Although the timber was wet by spray to such an extent that

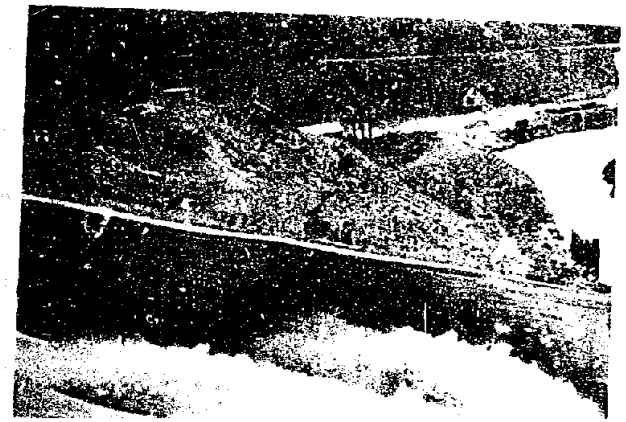


A. STANDING WAVES ON WEST WALL OF TRANSITION SECTION BELOW CYLINDER-GATE OUTLETS.



B. REFLECTED WAVE ON EAST WALL OF CHUTE NEAR STATION 2+46.00.

C. STANDING WAVE ON WEST WALL NEAR STATION 1+20.76.



D. EAST WALL OF TRANSITION SECTION BELOW CYLINDER-GATE OUTLETS.

ELEPHANT BUTTE DAM SPILLWAY
THE PROTOTYPE, DISCHARGING APPROXIMATELY 7000 c.f.s., JUNE 5, 1942

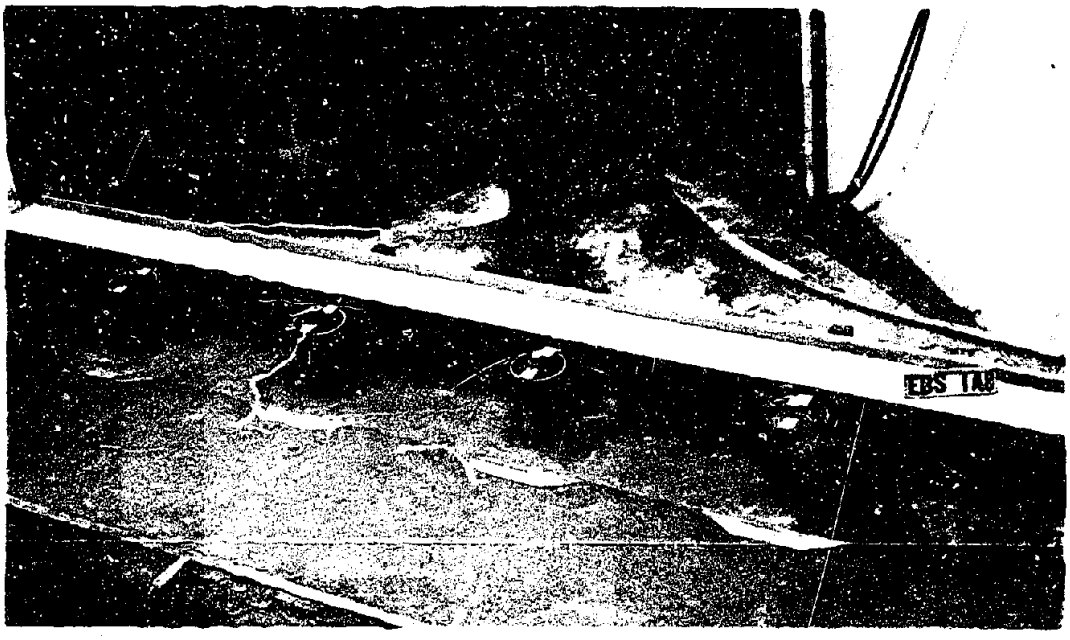
FIGURE 13

swelling had caused some of the lagging to bulge outward, there was no considerable volume of water against the timber at the maximum attainable discharge of 7,000 second-feet.--
---"

The photographs of Mr. McConaughy's report furnish an opportunity for a model-prototype comparison. The similar views of figure 14 indicate that waves in the prototype, at a discharge of 7,000 second-feet, are as high as corresponding waves in the model at the larger discharge of 8,000 second-feet. The cause for this difference is apparent for considerable air is mixed with the water in the prototype whereas the water surface in the model is comparatively smooth. In other words, the model cannot duplicate the prototype as far as effects concerning surface tension and entrainment of air are concerned. Therefore, in the prototype the waves will be higher for similar discharges, and the model results should be modified in some manner to account for this phenomenon. Unfortunately, there is not sufficient knowledge on the subject at the present to apply proper corrections to the model so this factor must be neglected. At the same time it should be realized that the capacity of the prototype may be somewhat less than that indicated by the model.

11. <u>Model studies for permanent spillway alterations - Baffles in the transition section.</u> Following tests involving temporary protective walls, the model was used to study plans for permanent spillway alterations. Several schemes were proposed by which the water could be directed into the chute without spilling over the

A. THE PROTOTYPE, DISCHARGING APPROXIMATELY 7,000 c.f.s. JUNE 5, 1942.



B. THE 1:40 MODEL, DISCHARGING 8,000 c.f.s.

ELEPHANT BUTTE DAM SPILLWAY
COMPARISION OF MODEL WITH PROTOTYPE

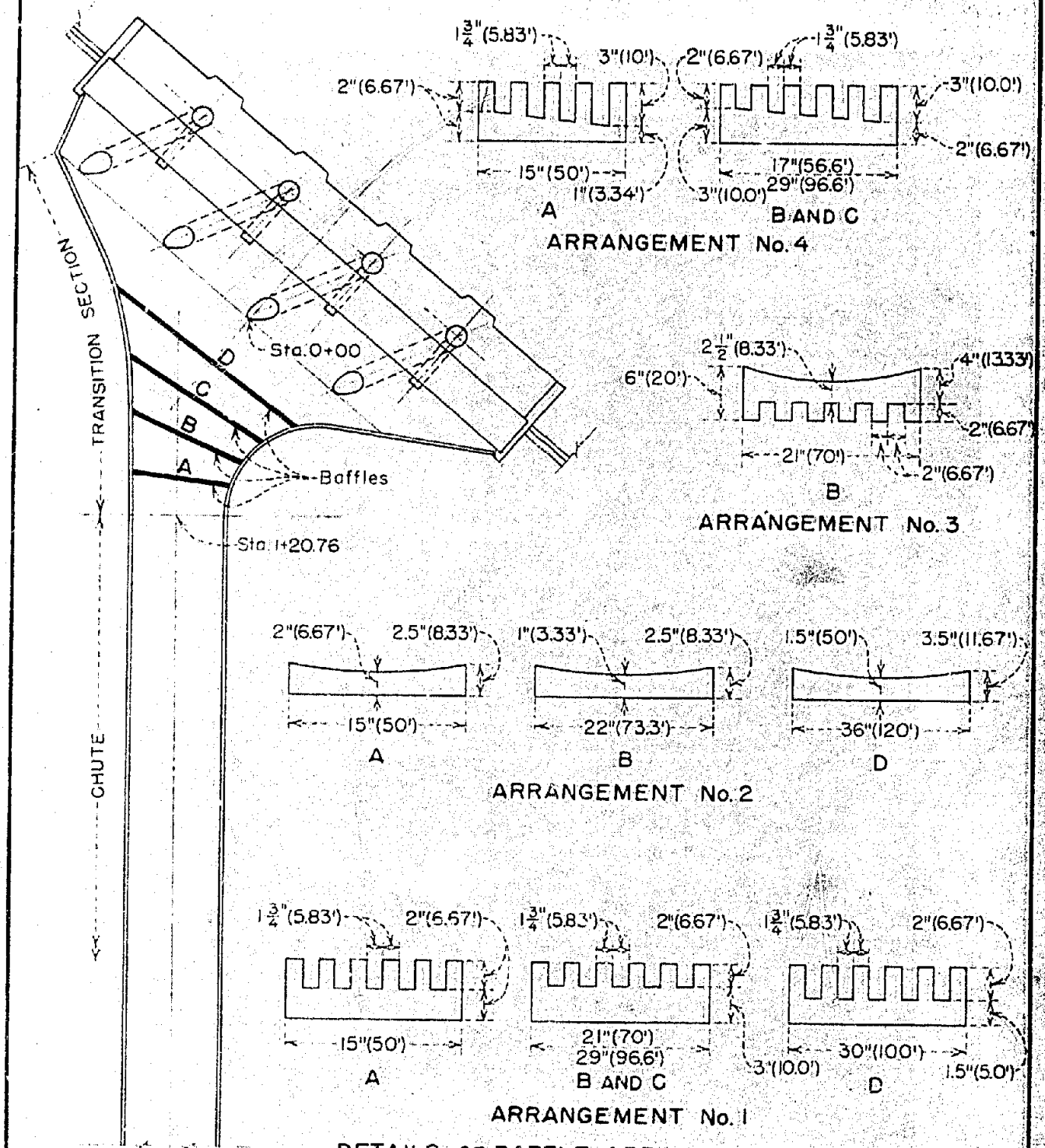
channel walls. These included baffles, dentates, training walls, and channel covers.

It at first appeared desirable to create a series of drop pools with baffles in the transition section, the last pool arranged so water would drop into the chute at a low velocity and in a uniform manner. In all, four different arrangements of baffles were placed across the transition section and tested (figure 15). None of these arrangements reduced the amount of water topping the channel walls for the pools formed by the baffles were completely ineffective at large discharges. Therefore, no further consideration was given to the use of baffles.

12. Tests with dentates. Dentates on the spillway apron and on the floor of the transition channel were suggested as an effective method for dissipating the energy of flow and disturbing the water over the transition channel so as to enter the chute in a more uniform manner. Therefore, wedge-shaped dentates were placed on the spillway apron in horizontal rows 6 feet 8 inches apart, and on the floor of the transition sections in similar horizontal rows but forming a radial pattern. The dentates in each row were spaced eight feet on centers, and staggered with respect to dentates in the adjacent rows. Each dentate was four feet wide, four feet high, three feet four inches thick at the base, and one foot thick at the top.

These dentates were satisfactory for small discharges but appeared to be worse than none at all at large discharges in that they tended to raise the water surface, spilling more water than

FIGURE 15



DETAILS OF BAFFLE ARRANGEMENTS TESTED

NOTE: Dimensions in model, prototype in parenthesis

RIO GRANDE PROJECT – NEW MEXICO – TEXAS

ELEPHANT BUTTE DAM

SPILLWAY ALTERATIONS BY HYDRAULIC MODEL — 1:40 SCALE

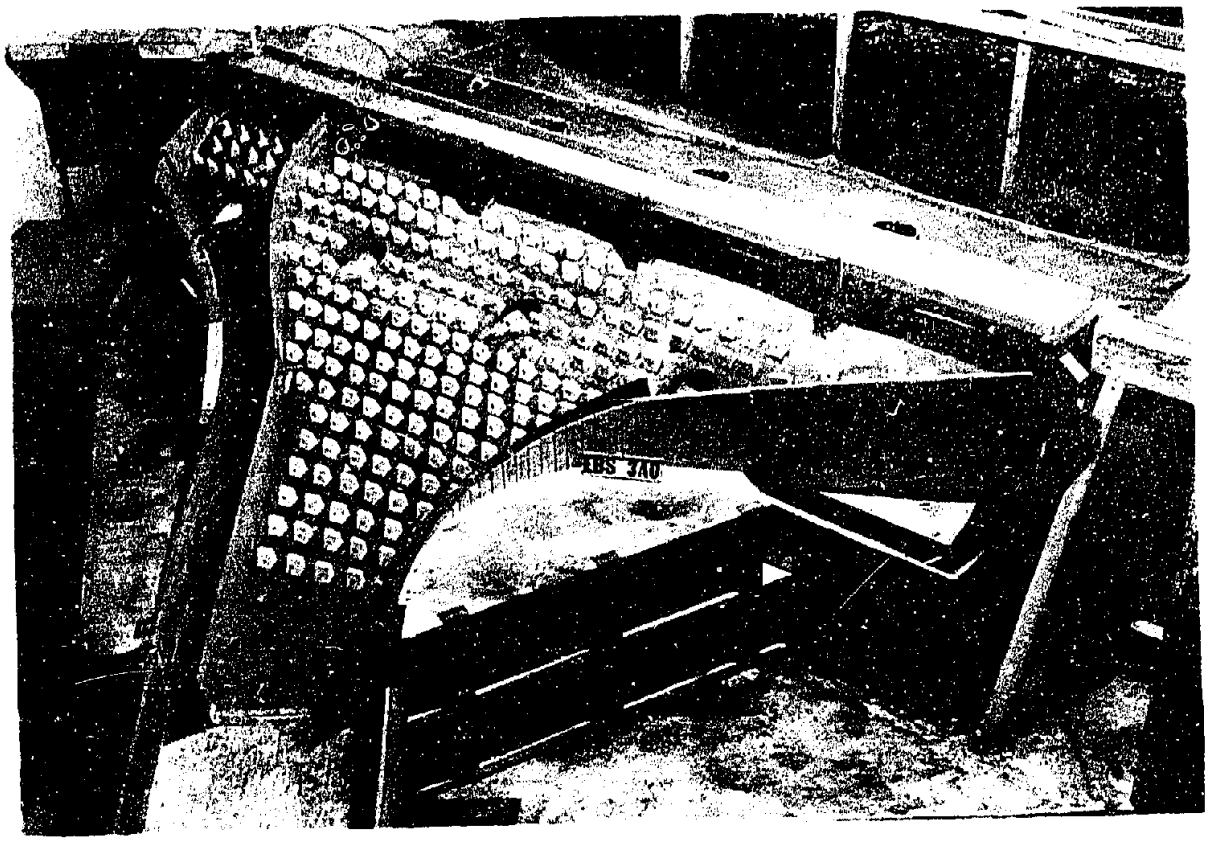
TESTS WITH BAFFLES IN TRANSITION SECTION

over over the channel walls. As in the case of the baffles, changes in the spacing and alignment of the dentates did not improve materially the flow conditions in the spillway, and it was concluded that the use of dentates alone would be unsatisfactory.

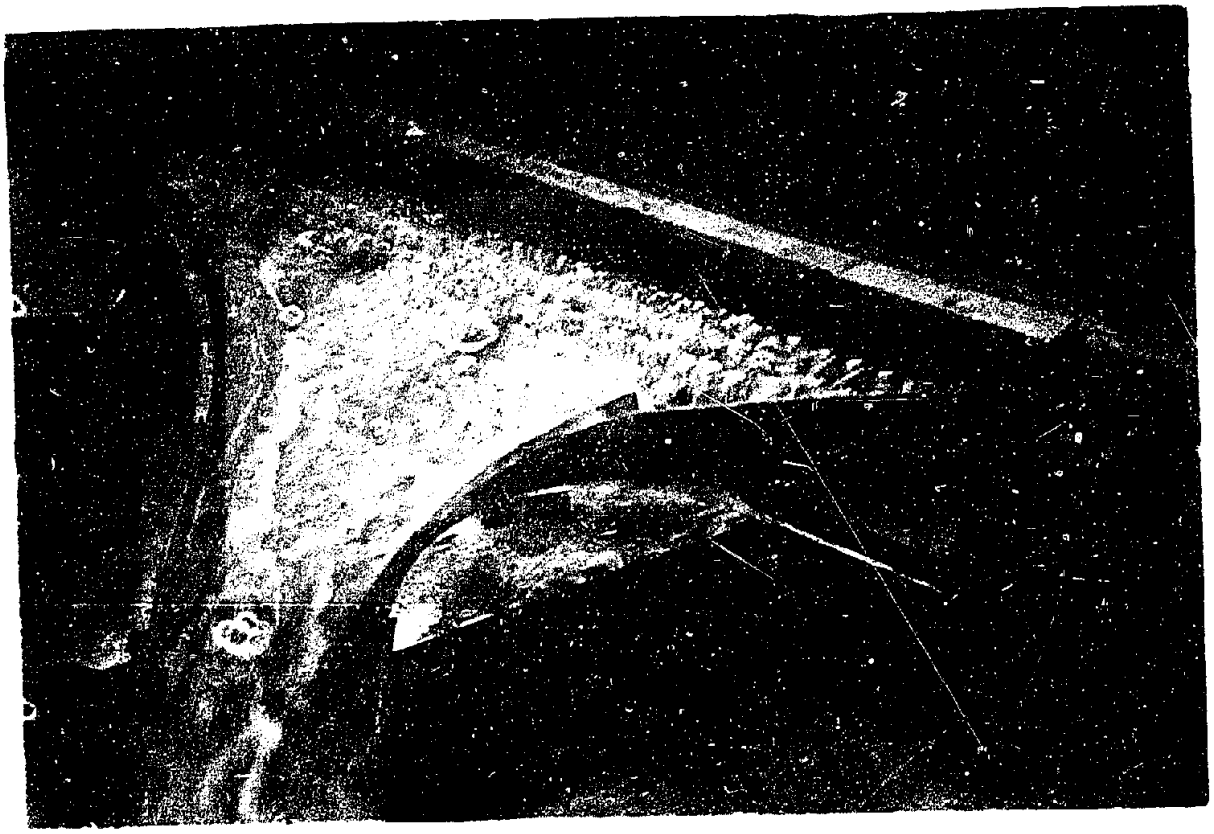
It was suggested that training walls be used in conjunction with the dentates. Two training walls 16 feet 8 inches high were placed as shown in figure 16. The object of the walls was to assist the dentates to divide and spread the flow in the transition section. This arrangement was good for discharges to 20,000 second-feet, but at greater discharges water overtopped the west wall of the transition section (figure 16B). This arrangement worked better with the cylinder gates closed as water flowing over the crest attained a more uniform distribution than water flowing through the tunnels.

A third combination was tried by placing dentates on the spillway apron above the beginning of the transition section, station 0+00, and a series of low training walls in the transition section below (figure 17A). This combination did not work as well as the former arrangement, with high training walls, for water overtopped the channel walls at discharges greater than 16,000 second-feet (figure 17B). However, in contrast with the former arrangement (figure 16) the combination with low training walls (figure 17) operated better with the cylinder gates open.

13. Tests with training walls. It became apparent that schemes for dissipating the energy of flow and spreading the water

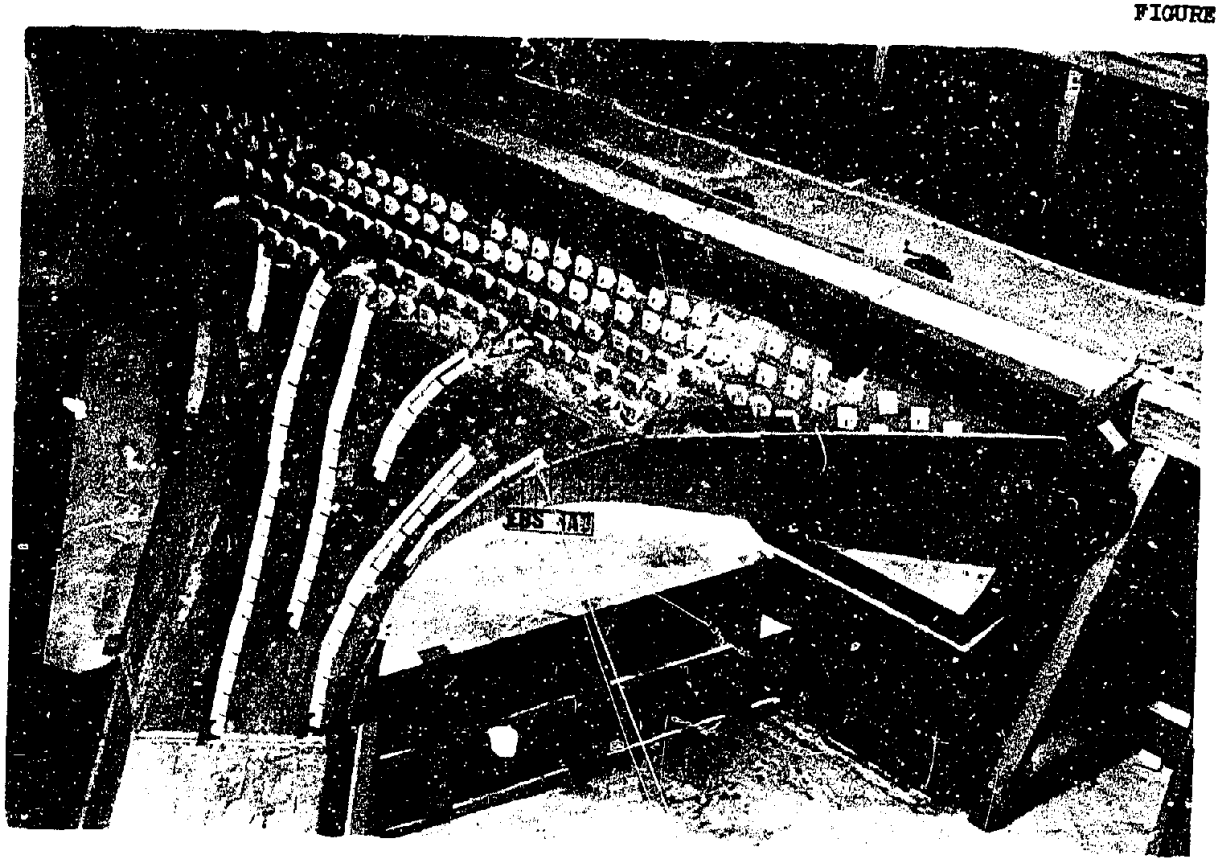


A. ARRANGEMENT OF DENTATES AND LOCATION OF TRAINING WALLS.

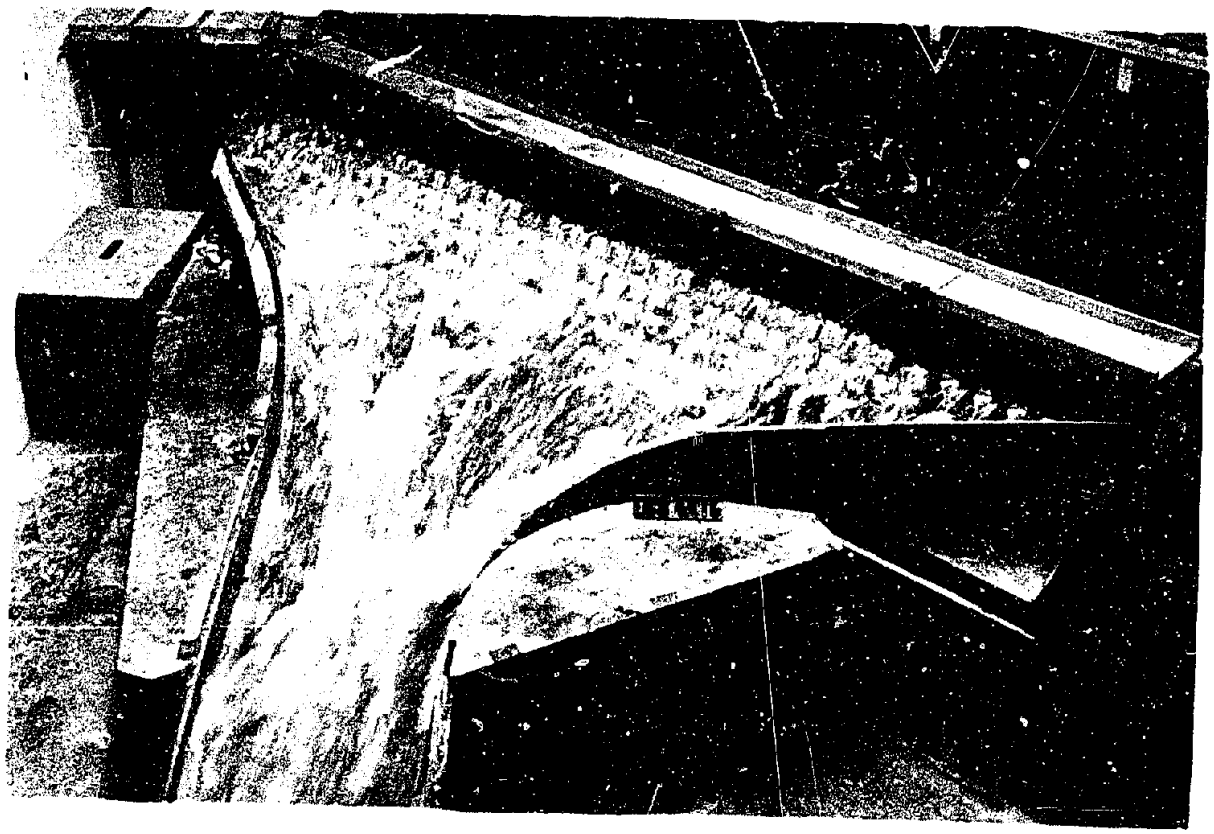


B. DISCHARGE 20,000 c.f.s., CYLINDER GATES OPEN.

1:40 MODEL OF ELEPHANT BUTTE DAM SPILLWAY
CONTROL OF SPILLWAY FLOW BY DENTATES AND TWO HIGH TRAINING WALLS



A. ARRANGEMENT OF DENTATES AND LOW TRAINING WALLS.



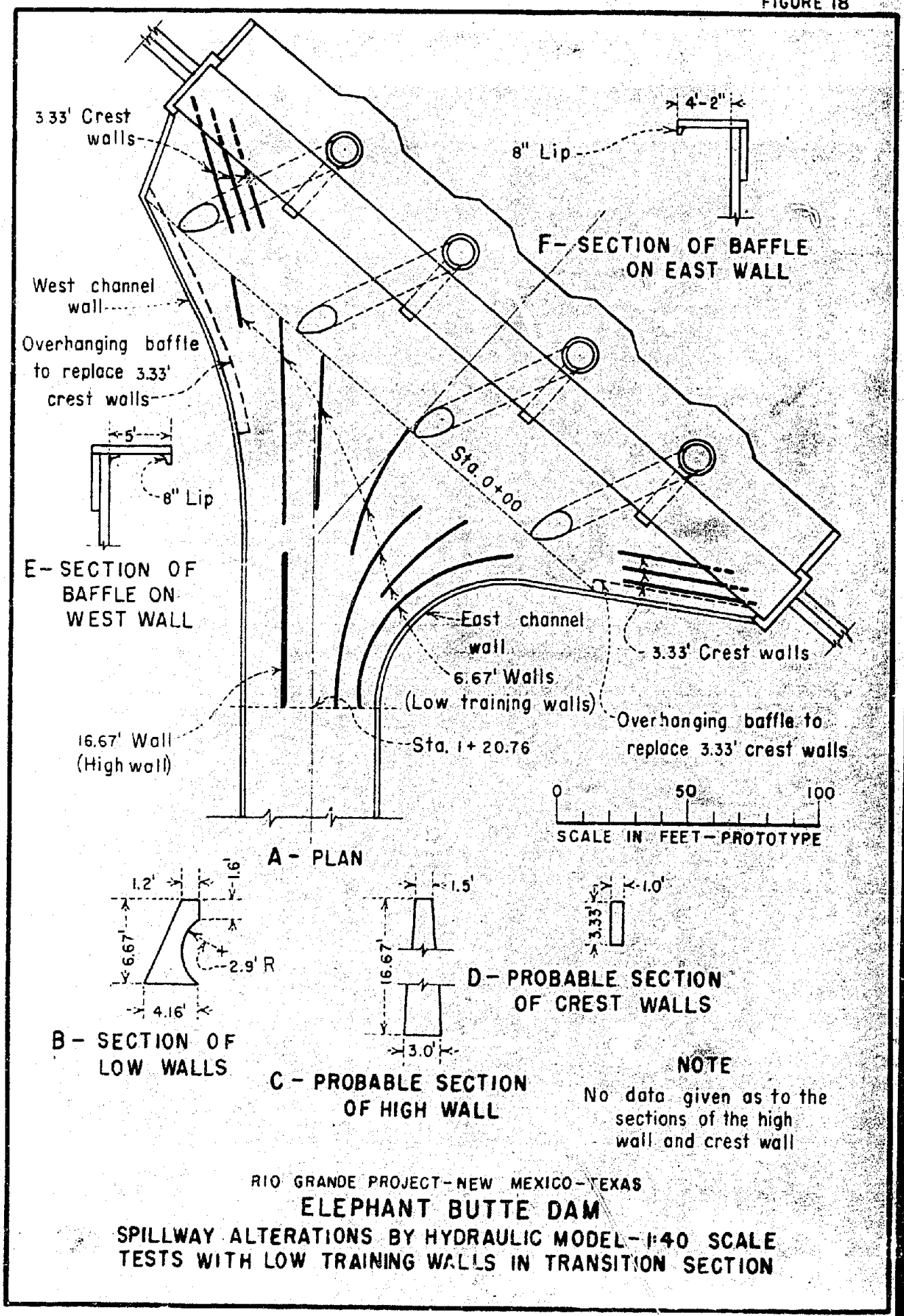
B. DISCHARGE 16,000 c.f.s., CYLINDER GATES OPEN.

1:40 MODEL OF ELEPHANT BUTTE DAM SPILLWAY
CONTROL OF SPILLWAY FLOW BY DENTATES AND LOW TRAINING WALLS

over the transition section would not work on the Elephant Butte spillway, and that the water would have to be guided into the chute in some other manner. Therefore the dentates were removed and a number of tests with training walls were made. The 6.67-foot walls of the previous test were used except that a high wall, 16.67-feet high, replaced a portion of one low wall above station 1+20.76 (figure 18). Also three 3.33-foot walls were set at each end of the spillway immediately below the crest to prevent water from overtopping the channel walls of the transition section. This combination operated satisfactorily for discharges up to 25,000 second-feet. The principal difficulty was that the low walls at each end of the crest reduced the discharge over the crest. Accordingly, these crest walls were replaced by overhanging sections or baffles on the channel walls immediately downstream from the crest (figure 18). The discharge capacity was then increased to 30,000 second-feet, and later to 35,000 second-feet when eight-inch lips were placed on the outer edge of the overhanging baffles to turn the water downwards.

This was the first arrangement to accomplish the desired results but it was not satisfactory from the standpoint of appearance and the low training walls would cause much spray. Accordingly, high training walls were next considered (figure 19). The object was to replace several low walls with a single high wall. In addition the overhanging baffles on the channel walls were removed. A number of combinations of walls were tried from which a combination of two walls was selected for further tests, walls E

FIGURE 18

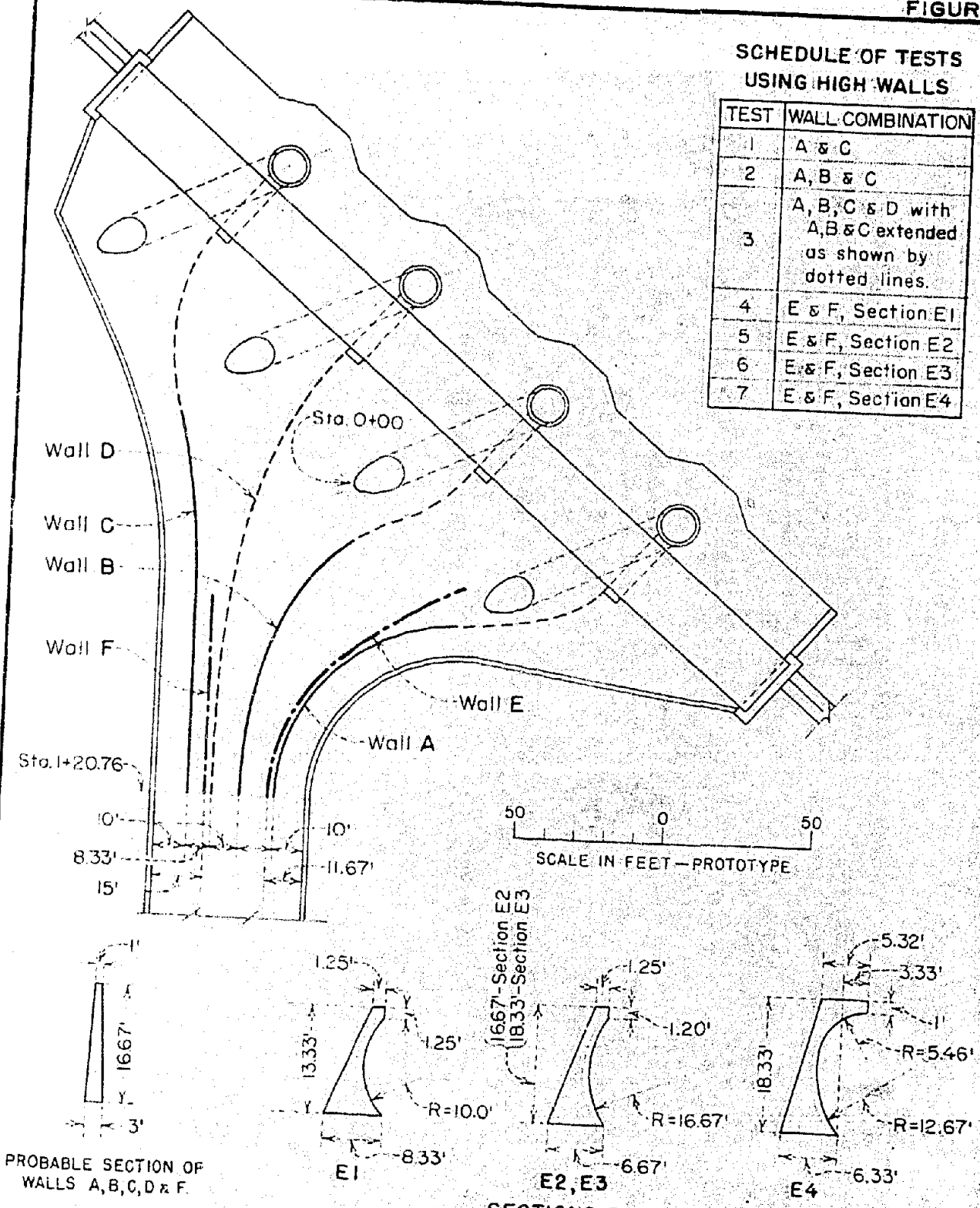


RIO GRANDE PROJECT-NEW MEXICO-TEXAS

ELEPHANT BUTTE DAM

SPILLWAY ALTERATIONS BY HYDRAULIC MODEL-1:40 SCALE TESTS WITH LOW TRAINING WALLS IN TRANSITION SECTION

FIGURE 19



SCHEDULE OF TESTS USING HIGH WALLS

TEST	WALL COMBINATION
1	A & C
2	A, B & C
3	A, B, C & D with A, B & C extended as shown by dotted lines.
4	E & F, Section E1
5	E & F, Section E2
6	E & F, Section E3
7	E & F, Section E4

SECTIONS FOR WALL E

NOTE: Section of walls A, B, C, D and F not given but wall similar to probable section shown. All dimensions in prototype.

RIO GRANDE PROJECT—NEW MEXICO-TEXAS

ELEPHANT BUTTE DAM

SPILLWAY ALTERATIONS BY HYDRAULIC MODEL—1:40 SCALE

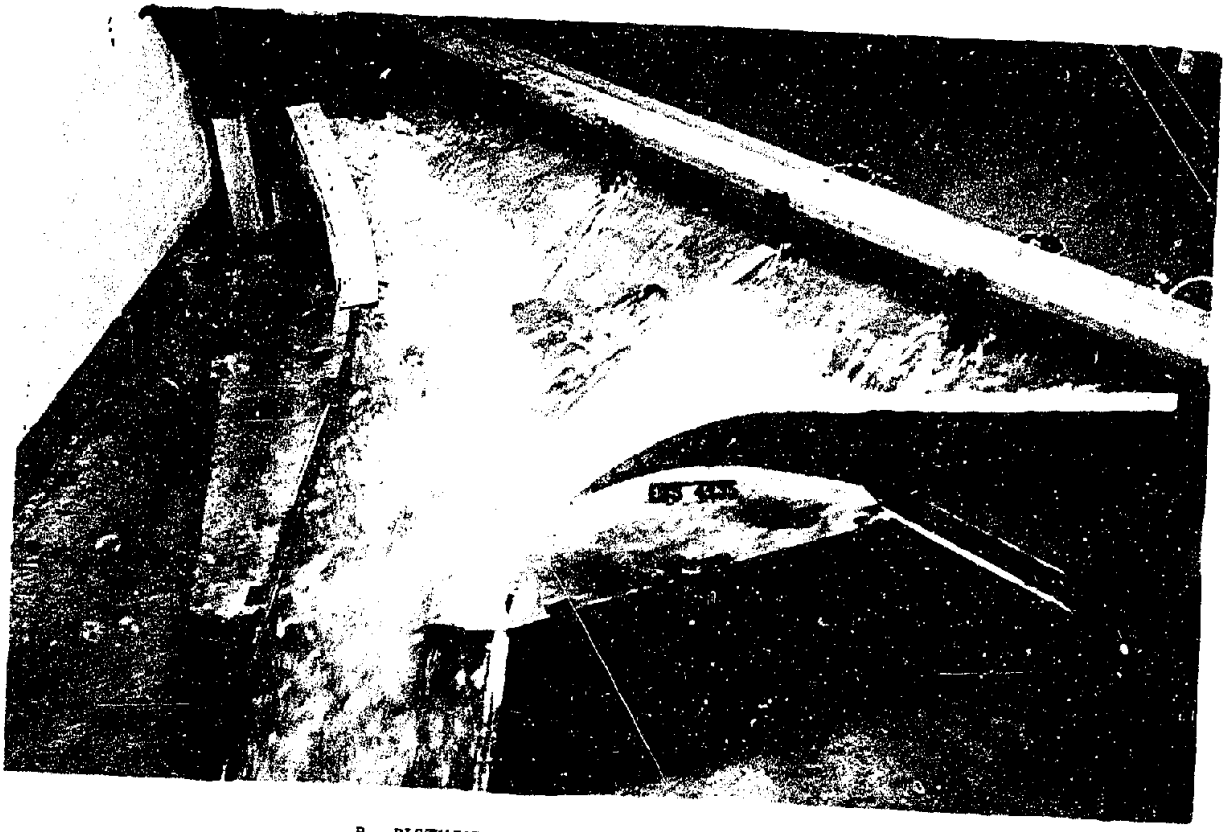
TESTS WITH HIGH TRAINING WALLS

and F. The section of wall E was made convex to form a roller to turn the water towards the east channel wall. Four different sections of this type of wall were tried, all working fairly well, holding water in the channel for flows up to 20,000 second-feet. However, when the overhanging baffles on the channel walls were replaced to prevent water from splashing over the transition channel, the discharge capacity was increased to 30,000 second-feet.

14. Tests with channel cover and overhanging baffles on channel walls - the final design. Training walls were better than any previous scheme tried, nevertheless they would not be satisfactory because a large amount of spray would be thrown into the air, and the pressure of water against the walls would cause a cantilever action requiring a heavy foundation. To avoid these undesirable features a channel cover over a portion of the transition section was suggested, for the cover would retain much spray, and the cantilever action on the training walls would be eliminated. The arrangement shown on figure 20A was first tried. The east portion of the transition section was covered, between station 0+00 and the chute entrance, sta. 1+20.76. The overhanging baffles on the channel walls were also included since they were found to be necessary in previous tests.

Water flowing down the transition section and into the chute did so in a uniform manner, the undesirable standing waves being eliminated. The design was adequate for the maximum discharge of 35,000 second-feet, and was therefore considered as an approach to the final design (figure 20B). Pressure measurements were made

A. THE MODEL WITH CHANNEL COVER AND OVERHANGING BAFFLES ON CHANNEL WALLS.



B. DISCHARGE 35,000 c.f.s., CYLINDER GATES OPEN.

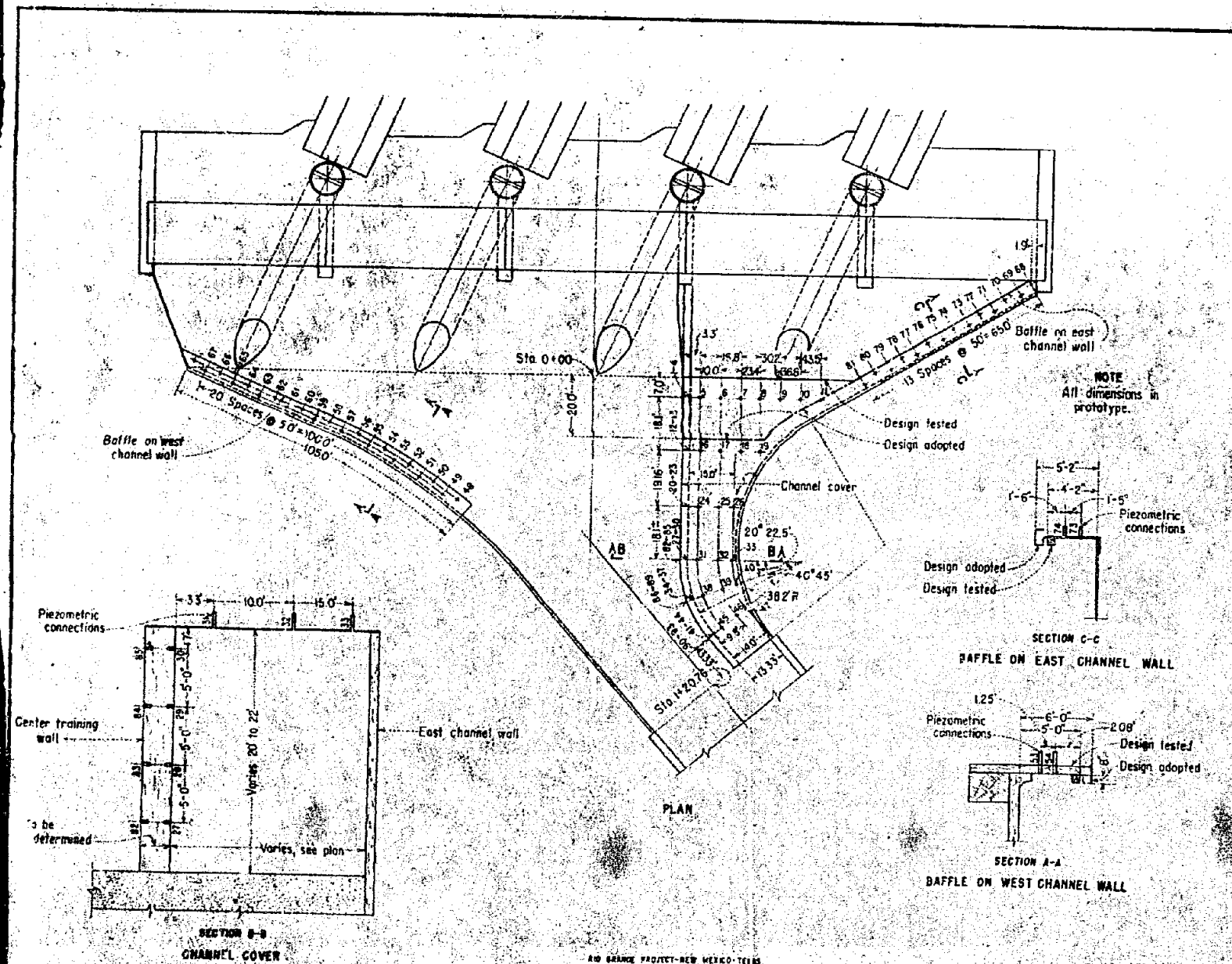
1:40 MODEL OF ELEPHANT BUTTE DAM SPILLWAY
CONTROL OF SPILLWAY FLOW BY CHANNEL COVER
AND OVERHANGING BAFFLES ON CHANNEL WALLS

were made on both sides of the training wall, on the underside of the channel cover, and on the underside of the overhanging baffles to determine loading conditions for the structural design (figure 21).

The final design was evolved by moving the entrance of the covered section downstream to reduce the large span of the cover at its entrance. Conditions were not materially changed by moving the entrance cover 20-feet downstream from the beginning of the transition section at station 0+00 (figures 1 and 22A). At maximum discharge of 35,000 second-feet, all conditions were satisfactory except that waves would splash over the entrance of the channel cover (figure 22B). Such splash was not critical, however, because the channel cover would be of concrete and so arranged that the water splashing over the top would reenter the chute below. Moreover a wall or beam four feet high would reduce the amount of splash on the cover.

15. Additional tests on spillway channel. The channel cover of the final design was not considered a desirable solution of the problem for the arrangement and appearance made it obvious that it was an expedient to force the spillway to function properly. Four additional tests were made, three using training walls and the fourth a channel cover.

The tests with training walls were practically a repetition of previous tests. A single training wall down the transition was good for discharges to 20,000 second-feet (figure 23). The next arrangement consisted of three walls or fins partially



NOTE
All dimensions in prototype.

PIEZOMETRIC PRESSURES ON CENTER WALL, CHANNEL COVER, AND BAFFLES

PIEZ. NO.	LOCAT'N	PRESSURES IN FEET OF WATER PROTOTYPE Q=20,000	Q=25,000	Q=30,000	Q=35,000
1	CENTER WALL INSIDE	2.0	4.0	8.4	10.0
2		.0	2.0	3.2	4.2
3		.5	.0	.0	3.2
4		.0	.0	.0	1.6
5	CHANNEL COVER	.0	.0	.0	.0
6		.0	.0	.0	.0
7		.0	.0	.0	.0
8		.0	.0	.0	.0
9		.0	.0	.0	.0
10		.0	.0	.0	.0
11		.0	.0	.0	.0
12		12.0	12.8	15.8	16.8
13	CENTER WALL INSIDE	6.0	11.2	9.0	7.8
14		1.2	8.0	14.0	14.0
15		.0	.32	8.0	8.0
16	CHANNEL COVER	.5	.0	.20	4.8
17		.0	.0	.04	2.0
18		.0	8.0	.04	.08
19		.0	8.0	.0	2.8
20	CENTER WALL INSIDE	10.0	12.8	14.0	14.0
21		6.8	9.6	11.2	7.4
22		4.0	8.0	8.4	8.4
23		3.2	4.8	4.4	3.6
24	CHANNEL COVER	.0	.08	.20	2.0
25		.0	.20	.20	2.0
26		.0	.04	.0	1.2
27	CENTER WALL INSIDE	14.0	16.8	20.0	22.0
28		10.0	12.0	14.0	15.2
29		4.4	7.6	9.6	8.0
30		2.4	4.4	4.0	3.6
31	CHANNEL COVER	.0	.08	.04	.0
32		.0	.0	.04	.0
33		.0	.0	.04	.0
34	CENTER WALL INSIDE	18.8	20.0	23.2	21.0
35		16.0	16.8	19.2	20.0
36		8.0	10.0	14.0	16.8
37		4.0	5.2	8.8	7.8
38	CHANNEL COVER	.0	.0	.20	.20
39		.0	.0	.0	.0
40		.08	.04	.0	.0
41	CENTER WALL INSIDE	18.0	18.0	18.4	18.8
42		14.4	16.0	16.0	16.7
43		8.0	10.0	12.8	10.0
44		4.2	4.8	7.2	7.8
45	CHANNEL COVER	.0	.08	.0	.0
46		.0	.0	.0	.0
47		.04	.04	.04	.0
48		.04	.0	.04	.0
49	BAFFLE ON WEST CHANNEL WALL				4.0
50					4.0
51					4.0
52					4.0
53					4.0
54					4.0
55					4.0
56					4.0
57					4.0
58					4.0
59					4.0
60					4.0
61					4.0
62					4.0
63					4.0
64					12.0
65					12.0
66					10.0
67					6.0
68					6.0
69					4.0
70	BAFFLE ON EAST CHANNEL WALL				4.0
71					4.0
72					4.0
73					4.0
74					4.0
75					4.0
76					4.0
77					4.0
78					4.0
79					4.0
80					0
81					0
82					0
83					0
84	CENTER WALL OUTSIDE		4.0	8.0	12.0
85			7.0	4.0	8.0
86			0	7.0	4.0
87				0	4.0
88					4.0
89					4.0
90			8.0	8.0	10.0
91			4.0	4.0	4.0
92			2.0	2.0	4.0
93			2.0	4.0	4.0

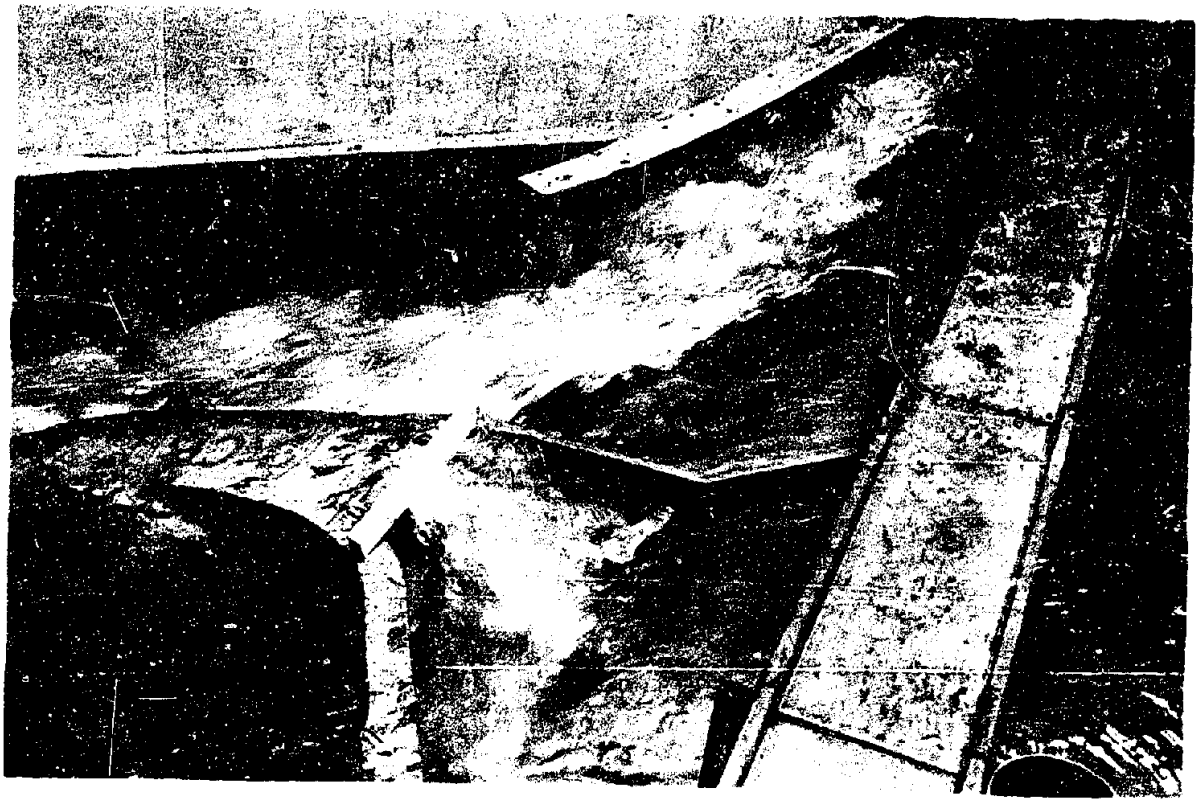
FIGURE 12.1

AID GRANDE PROJECT-NEW MEXICO-TEXAS

ELEPHANT BUTTE DAM

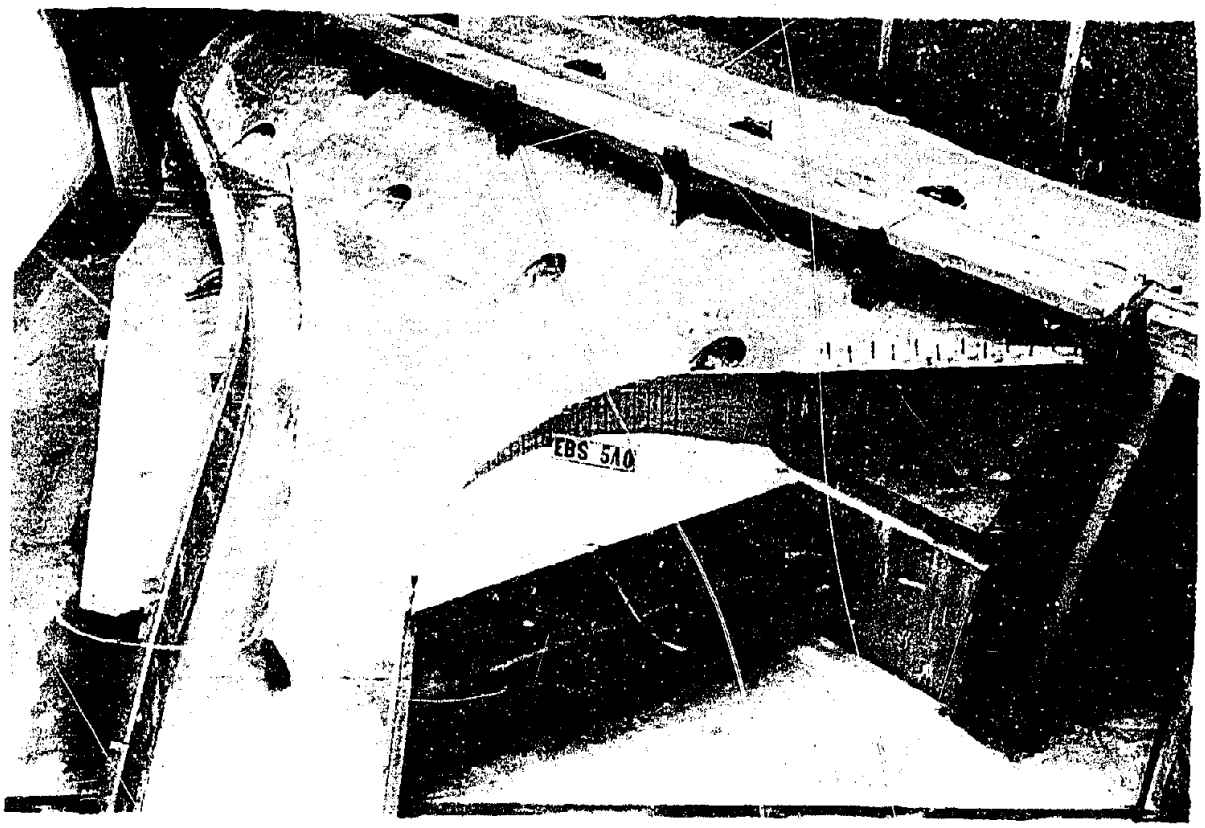
SPILLWAY ALTERATIONS BY HYDRAULIC MODEL 1:40 SCALE
THE FINAL DESIGN—LOCATION OF PIEZOMETERS AND PRESSURE DATA

A. ARRANGEMENT OF CHANNEL COVER AND OVERHANGING BAFFLES IN FINAL DESIGN.

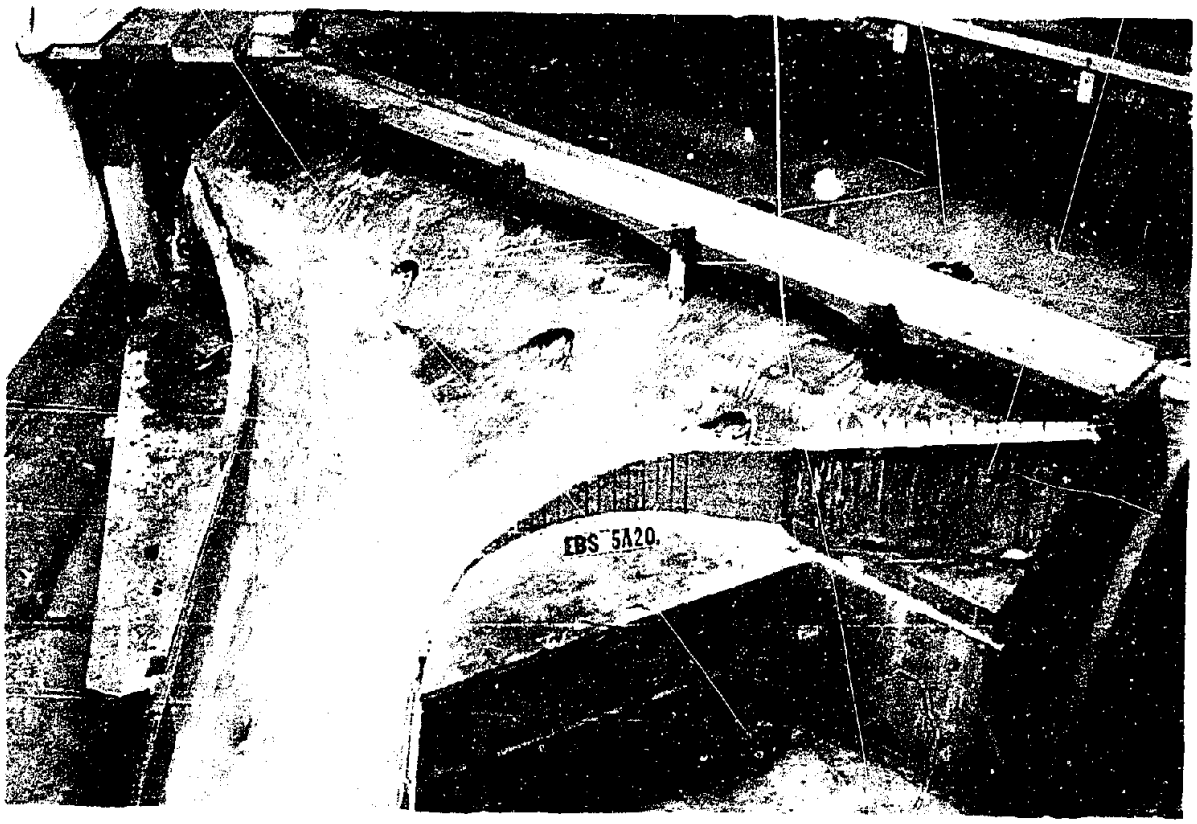


B. DISCHARGE 35,000 c.f.s., OUTLET GATES OPEN. NOTE WAVE TOPPING CHANNEL COVER.

1:40 MODEL OF ELEPHANT BUTTE DAM SPILLWAY
CHANNEL COVER AND OVERHANGING BAFFLES ON CHANNEL WALLS
THE FINAL DESIGN



A. SINGLE TRAINING WALL DOWN TRANSITION SECTION.



B. DISCHARGE 20,000 c.f.s., CYLINDER GATES OPEN.

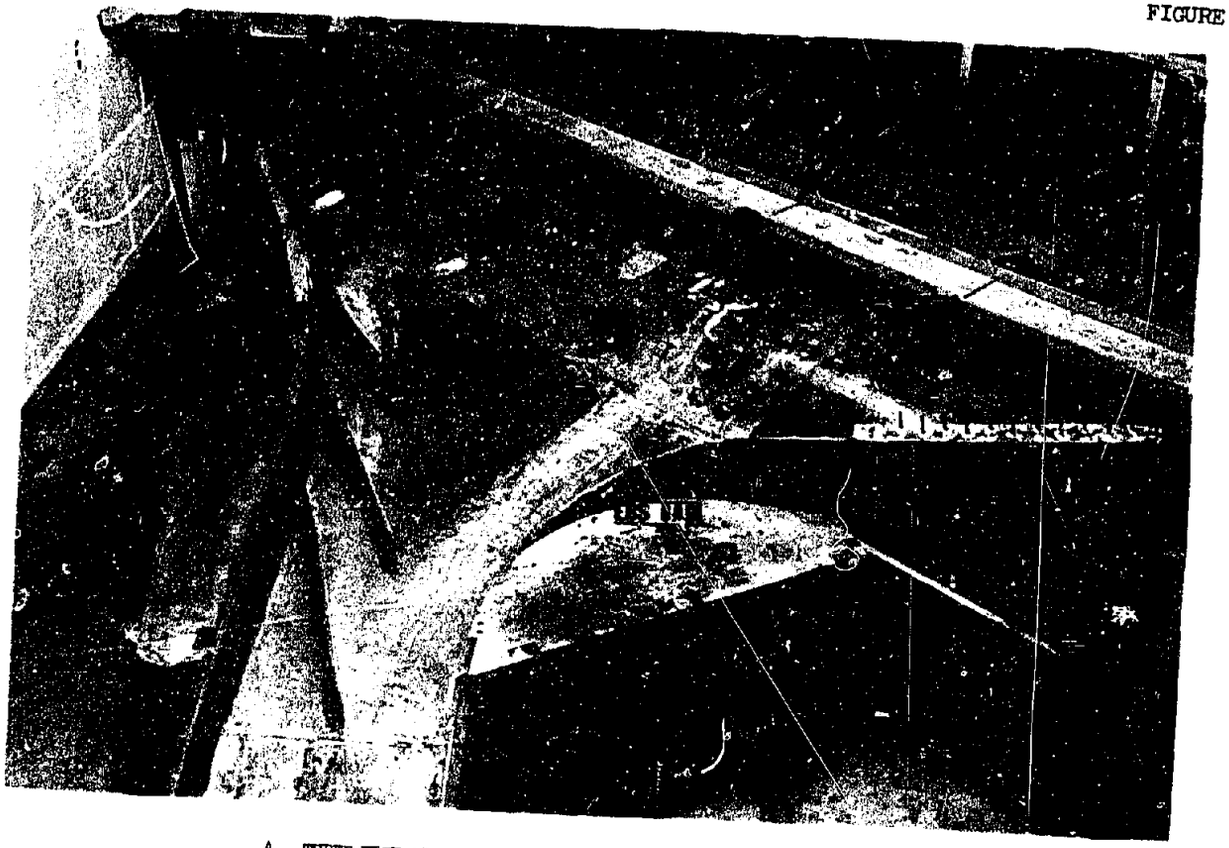
1:40 MODEL OF ELEPHANT BUTTE DAM SPILLWAY
CONTROL OF SPILLWAY BY SINGLE TRAINING WALL

traversing the channel to act as a combination baffle and training wall (figure 24). The three fins were good only for discharges up to 16,000 second-feet for the upstream fin appeared to hold back water and push it over the channel walls (figure 24). When it was removed the discharge capacity was increased to about 20,000 second-feet.

A final test was made by placing a cover over the entire transition section. However, such a scheme was not practical because water piled against the west wall of the chute, forming standing waves in the same manner as if no channel cover existed.

16. Revisions to cylinder gate outlets. Upon completion of studies on the spillway channel, attention was given to revising the cylinder-gate outlets. Trenches were cut into the natural shelf, or bench, upstream from the crest section in line with the ten-foot diameter tunnels under the crest (figures 2 and 25A). The cylinder gates were replaced by rectangular gates, wooden blocks in the model, which fit into the cylinder-gate frames, thus utilizing as much of the existing structure as possible. The purpose of this alteration was to permit water to flow into the trenches and through the tunnels under the crest when the water surface in the reservoir was above elevation 4382.0; whereas in the existing structure the water had to rise above the rock shelf at elevation 4396.0. By such alteration a greater emergency storage could be utilized for flood control.

Model tests indicated that the tunnels would operate satisfactorily, except that a vortex would form at the entrance of each



A. THREE HIGH FINS TO ACT AS COMBINATION BAFFLE AND TRAINING WALL.

B. DISCHARGE 16,000 c.f.s., CYLINDER GATES OPEN.

1:40 MODEL OF ELEPHANT BUTTE DAM SPILLWAY
CONTROL OF SPILLWAY FLOW WITH THREE HIGH FINS

A. THE CHANNELS IN THE SHELF UPSTREAM FROM THE CREST.

B. DISCHARGE THROUGH OUTLETS SHOWING VORTEX IN ONE OUTLET AND FLOAT OVER OTHER OUTLET TO ELIMINATE AIR FILAMENT OF VORTEX.

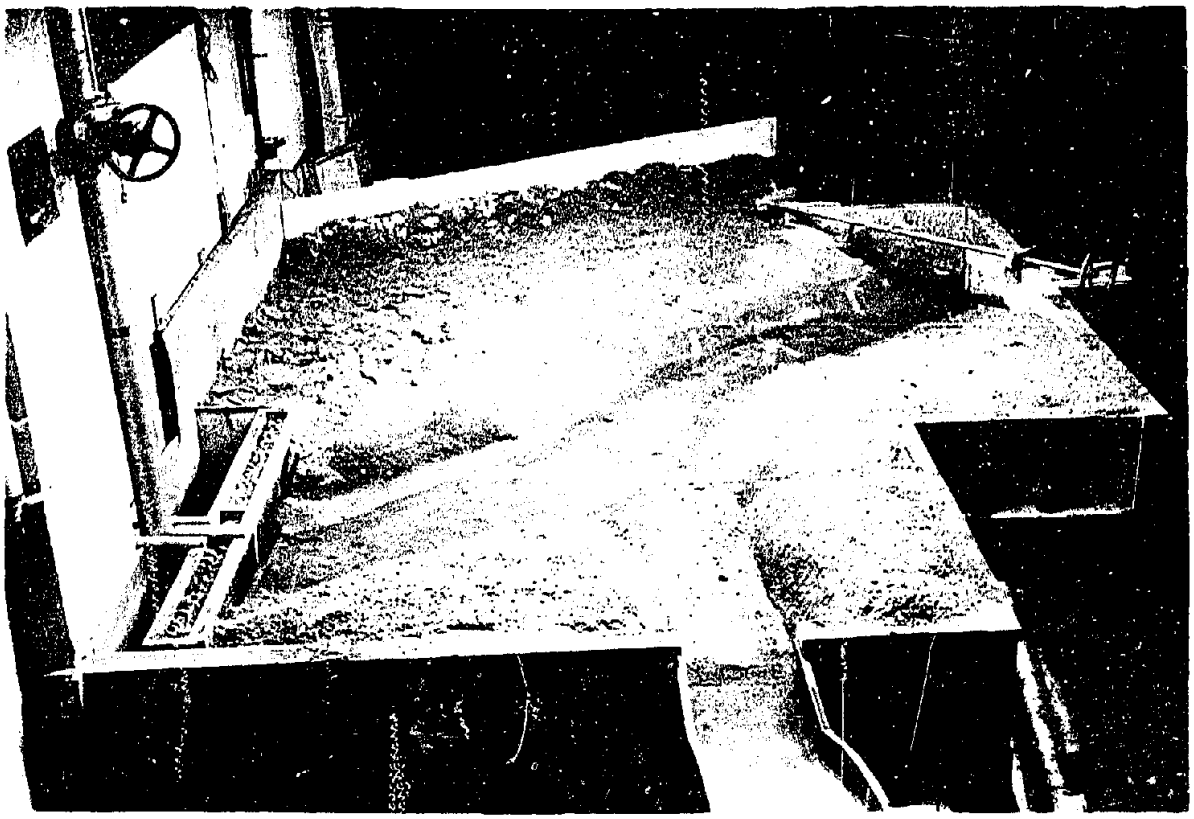
1:40 MODEL OF ELEPHANT BUTTE DAM SPILLWAY
REVISIONS TO CYLINDER GATE OUTLETS

outlet (figure 25B). It was shown that the quantity of water flowing into the outlets would be reduced when an air filament as shown in figure 25B was permitted to form. However, it was found that a float would reduce this vortex action to the extent that the air filament would be eliminated and such a device was adopted in the final design (figure 2).

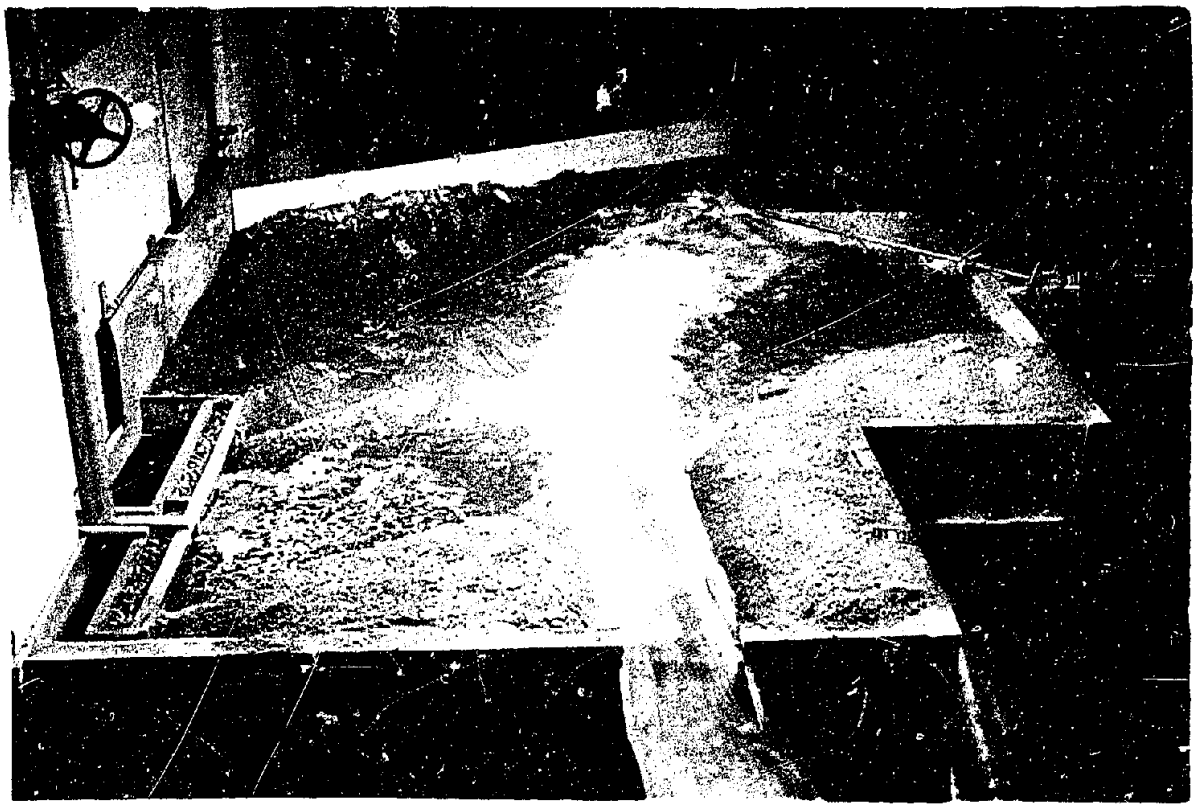
17. Discharge of spillway into river channel. At first the tests were concerned with flow in the transition section and into the chute, and the model as built originally extended only to the mouth of the chute, station 7+15.0 (figure 7). The river bed at this point formed the tailrace to the power plant and some concern was expressed as to the possibility of damage by flow from the chute washing out the opposite banks. Therefore, the model was enlarged to include topography downstream from the chute, the river bed and the adjacent banks at the foot of the dam (figure 26A).

Tests indicated that a hydraulic jump would occur in the mouth of the chute for discharges less than 3,700 second-feet under normal field conditions; that is, with the tailwater near elevation 4216. At larger discharges the jump swept out of the chute and the water entering the tailrace tended to pile upon the opposite bank. This condition was also observed in the prototype at discharges as large as 7,000 second-feet and described in D. C. McConaughy's report of June 16, 1942.

At a discharge greater than 16,000 second-feet the model indicated that the opposite bank would virtually wash away



A. LOOKING DOWNSTREAM WHERE CHUTE JOINS TAILRACE.



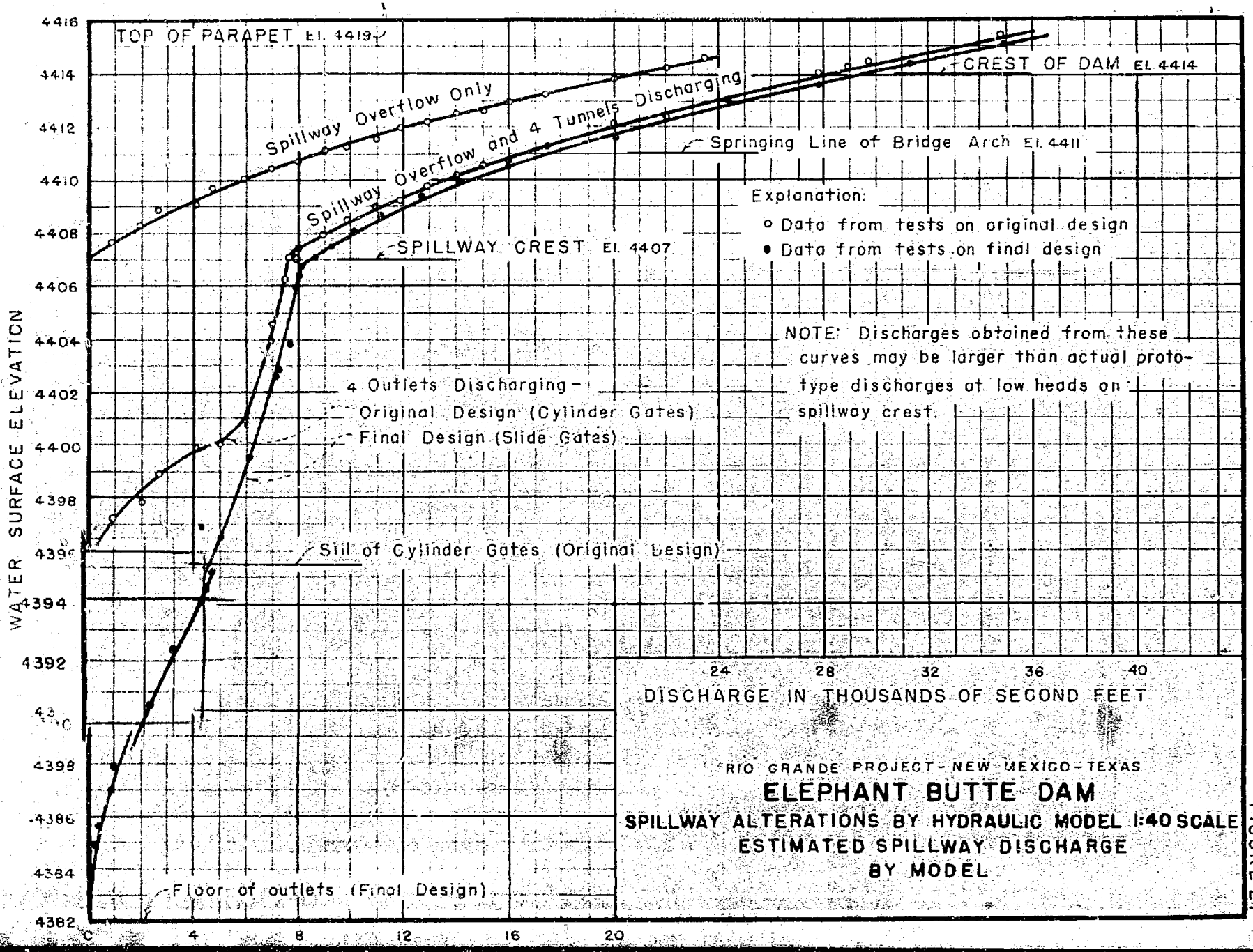
B. DISCHARGE 36,000 c.f.s., SHOWING FLOW FROM CHUTE WASHING AWAY OPPOSITE BANK.

1:40 MODEL OF ELEPHANT BUTTE DAM SPILLWAY
DISCHARGE OF SPILLWAY INTO RIVER CHANNEL

(figure 26b). This condition suggested the need of a stilling pool, but, as Mr. McConnaughy stated in his report, such pools are expensive to build and in view of the infrequent intervals at which large discharges will occur it is more expedient to repair the resulting damage. For this reason no tests were made on a stilling pool or other structures to avoid this sweep-out of the tailrace.

18. Rating curves for the existing and final designs. The relationship of discharge to water surface elevation is shown on figure 27 for both the existing and final designs. These curves include discharge through the four outlets under the crest with their gates wide open at water surface elevations less than 4407, the combined discharge over the crest and through the four outlets above elevation 4407, and the discharge over the crest only. As one might anticipate, the discharge through the outlets was slightly larger in the final design because of the revision to the more efficient entrance described in section 16. The flow over the crest, however, was unchanged.

The discharge over the crest obtained from the model tests may be slightly larger than actual prototype discharges, especially at low heads on the crest. This was evident when the discharge coefficient for the crest was computed (from $Q = K L H^{3/2}$, where Q = discharge, K = the coefficient, L = net length of crest, and H = head on crest) and found to be too large based upon experience with other crests. From the nature of the data it was believed that the gage for measuring head was zeroed about 0.01 foot too high (model) which would account for this higher coefficient. No



RIO GRANDE PROJECT - NEW MEXICO - TEXAS

ELEPHANT BUTTE DAM

SPILLWAY ALTERATIONS BY HYDRAULIC MODEL 1:40 SCALE

ESTIMATED SPILLWAY DISCHARGE BY MODEL

FIGURE 27

data on these coefficients are presented in this report because they would not be of any value, and further, the model had to be dismantled before any checks on the coefficients could be obtained.

In the model of the original design the discharge through the cylinder gates may have been measured in an incorrect manner. As the reservoir water surface rose air pockets formed below the elbows of the outlets so the outlets did not fill. However, there was some question as to whether the outlets would fill in the prototype, for the air pockets could be eliminated by momentarily sealing the outlet exits. This was done in the model. While sealing the air pockets may have not been a true condition and would give a larger discharge through the outlets in the model than in the prototype it was not considered important because the cylinder gates were to be eliminated and the entire outlet design changed. In the new design no air pockets would form.

19. Abstract of correspondence.

December 7, 1939. Memorandum to R. F. Blanks, from J. E. Warnock, requesting information concerning the construction of the spillway at Elephant Butte Dam. To show available information Warnock presents excerpts from letters dated from May 6, 1915, to April 9, 1941, from various engineers who describe the history of the construction of the spillway at Elephant Butte Dam.

January 3, 1940. Letter from R. S. Lieurance and R. F. Blanks to Chief Engineer, describing condition at Elephant Butte Dam as they found it on inspection trip during week of December 10, 1939.

July 10, 1941. Telegram from L. R. Fiock to Chief Engineer stating that reservoir has reached maximum elevation, and will test spillway under limited discharge.

July 15, 1941.	Letter from Superintendent to the Commissioner, transmitting prints and negatives of spillway discharging for first time July 12, and 13. Also, clippings from local newspapers.
Sept. 4, 1941.	Letter from Superintendent to Chief Engineer, enclosing chronological record of the spillway-gate operations, and photographs. In paragraphs 6, 7, 8, and 9 the inadequacy of the present spillway channel is emphasized, and model studies are believed necessary to predict the action of larger discharges.
Sept. 19, 1941.	Letter from Chief Engineer to Superintendent, stating that hydraulic model of spillway was considered necessary, that design was started. Also requesting topography of the river bottom for construction of the model downstream from the spillway.
Sept. 19, 1941.	Letter from Chief Engineer to Superintendent, stating that model construction has begun, testing possible in three or four weeks and asking for interpretation of paragraph 7 of letter of September 4.
Sept. 26, 1941.	Letter from Superintendent to Chief Engineer, in answer to letters of September 19, explaining meaning of paragraph of letters of Setpember 4, and stating that topography of stilling pool is being obtained.
Nov. 25, 1941.	Letter from Superintendent to Chief Engineer, enclosing drawings showing actual elevations of the floor and top of the walls of the spillway explaining differences from original plans. Also conditions of backfill along spillway. Also a drawing of topography of stilling pool.
April 18, 1942	Letter from Chief Engineer to Superintendent, requesting drill holes to determine conditions of spillway in connection with spillway alterations.
April 23, 1942.	Telegram from Chief Engineer to Fiock stating that drilling may be deferred until after flood season.
April 23, 1942.	Letter from Superintendent to Chief Engineer stating that spillway discharging 2,500 second-feet with probability of greater floods, and that drilling not advisable. Also received

April 23, 1942 (continued)	letter of April 21, with Savage and Smith report, and states in connection with lowering spillway gates not practical because existing walls may be submerged for several years.
April 24, 1942.	Telegram from Chief Engineer to Fiock, stating that construction of timber bulkheads on the spillway walls be started immediately.
April 25, 1942.	Letter from Chief Engineer to Superintendent, confirming telegram of April 24, and enclosing sketch of proposed construction.
April 28, 1942.	Letter from Chief Engineer to Superintendent in reply to letter of April 23, stating that drilling may be postponed, but that lowering of spillway gates and permanent changes should be made by next March.
May 23, 1942.	Letter from Chief Engineer to Superintendent, stating that the Denver office was concerned with the spillway capacity for the 1943 flood season, that there were differences of opinion in the Denver office, and that the superintendent's views were wanted.
June 16, 1942.	Memorandum for Mr. Keener by D. C. McConaughy, Inspection of Elephant Butte Spillway and other structures. A report of an inspection trip to observe flow over the spillway up to 7,000 second-feet. Location of timber walls was indicated by the model correct, and that they would not be necessary for discharges less than 8,000 second-feet also correct as water came to the top of the channel walls at 7,000 second-feet discharge. Other works downstream from Elephant Butte Dam observed.
June 23, 1942.	Letter from Superintendent to Chief Engineer, in reply to letter of May 23, and others, enclosing drawings showing the construction and present conditions of the spillway, crest, gates, and temporary repairs, to assist the design department in connection with the spillway revisions. Also, superintendent's view on the 1943 flood season is that it is unlikely that abnormal floods will occur, and that spillway revisions should be delayed until better times.

July 23, 1942. Letter from Chief Engineer to Superintendent, in reply to letter of June 23, stating that it is satisfactory to postpone alterations to the spillway. Also that a diamond drill will be available to explore the rock under the spillway.