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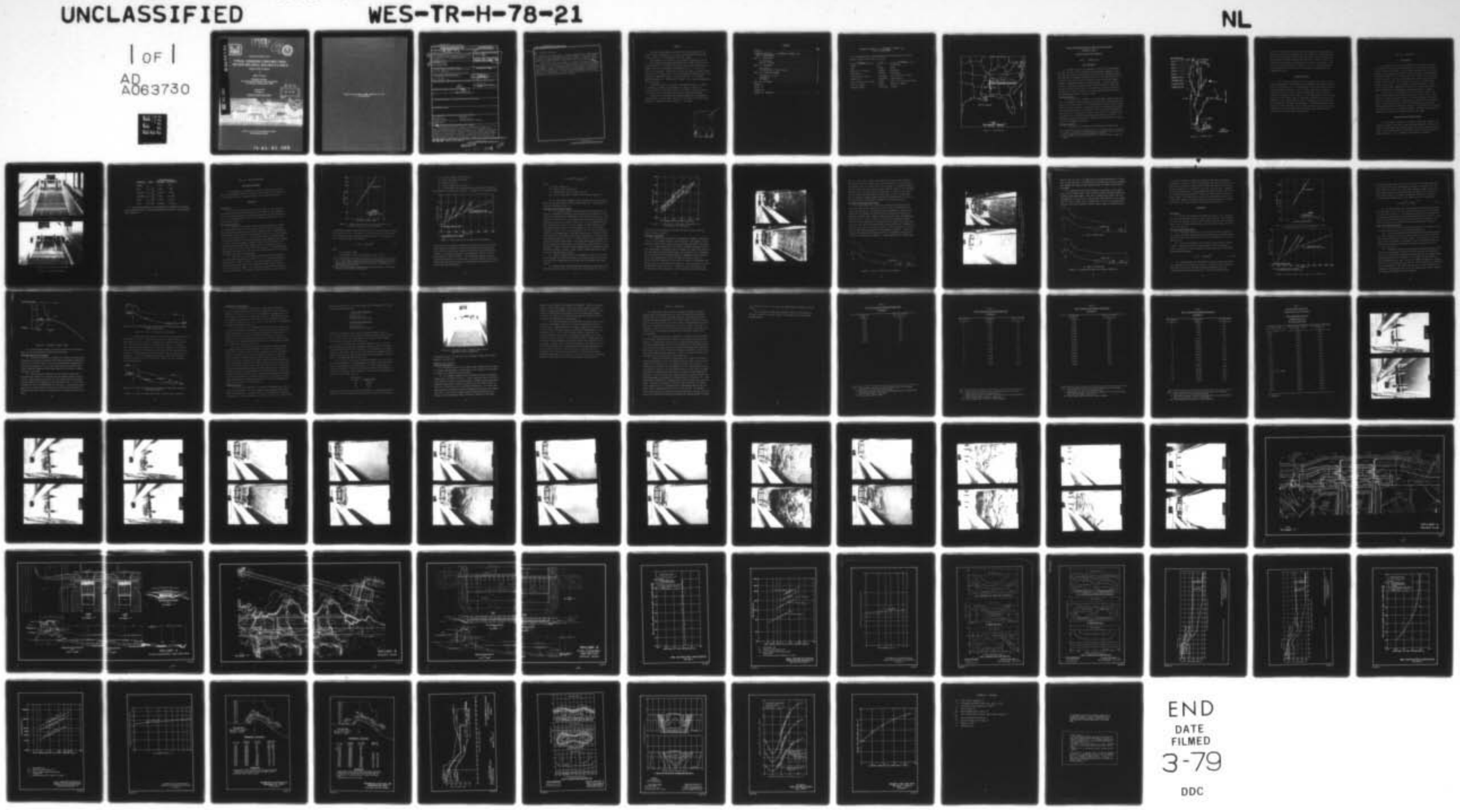

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TECHNICAL REPORT H-78-21

TYPICAL TENNESSEE-TOMBIGBEE CANAL SECTION SPILLWAYS, SPILLWAYS A AND B

Hydraulic Model Investigation

by

Bobby P. Fletcher

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Final Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Model investigations were conducted to determine the adequacy of the designs of two gravity spillways (Spillways A and B) to be located on the Tennessee-Tombigbee Waterway. The investigations were primarily concerned with evaluation of the tendency for surging of flow on the spillway tainter gates, defining the discharge characteristics of the structures, and ensuring adequate stilling basin performance. The models indicated that basic features of the original design structures were unsatisfactory; however, modifications that improved hydraulic performance were developed. *There was no tendency (Continued)* over

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20. ABSTRACT (Continued).

for surging on the tainter gates. Discharge characteristics of both spillways for controlled and uncontrolled flows were determined. Divider walls were located in the stilling basins downstream of the piers to eliminate unsatisfactory flow conditions that occurred during single gate operations.

Additional features investigated in the model of Spillway B included measurement of crest pressures. No adverse pressures were observed. Addition of a 45-degree slope to the face of Spillway B did not affect its hydraulic performance. The model of Spillway B also indicated that the stilling basin apron could be raised 9 ft without impairing the performance of the structure. The size of riprap needed in the exit channel downstream of Spillway B was determined. The magnitudes of dynamic forces to be expected on the stilling basin divider walls of Spillway B were estimated.

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PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers, U. S. Army, on 21 February 1975, at the request of the U. S. Army Engineer District, Mobile.

The studies were conducted in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) during the period February 1975 to November 1976 under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Hydraulic Structures Division, and under the general supervision of N. R. Oswalt, Chief of the Spillways and Channels Branch. The engineer in immediate charge of the model was Mr. B. P. Fletcher, assisted by Messrs. B. Perkins and R. Bryant. This report was prepared by Mr. Fletcher.

During the course of the model investigation, Messrs. J. Ward, M. Thompson, J. Mabry, H. Whittington, W. Odom, R. Gustin, and LT R. Borneman of the Mobile District visited WES to discuss results of the tests and to correlate these results with design studies.

Directors of WES during the testing program and the preparation and publication of this report were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
kips (force)	4.448222	kilonewtons
cubic feet per second	0.02831685	cubic metres per second
square feet	0.09290304	square metres
feet per second per second	0.3048	metres per second per second
feet per minute	0.3048	metres per minute
degrees (angle)	0.01745329	radians

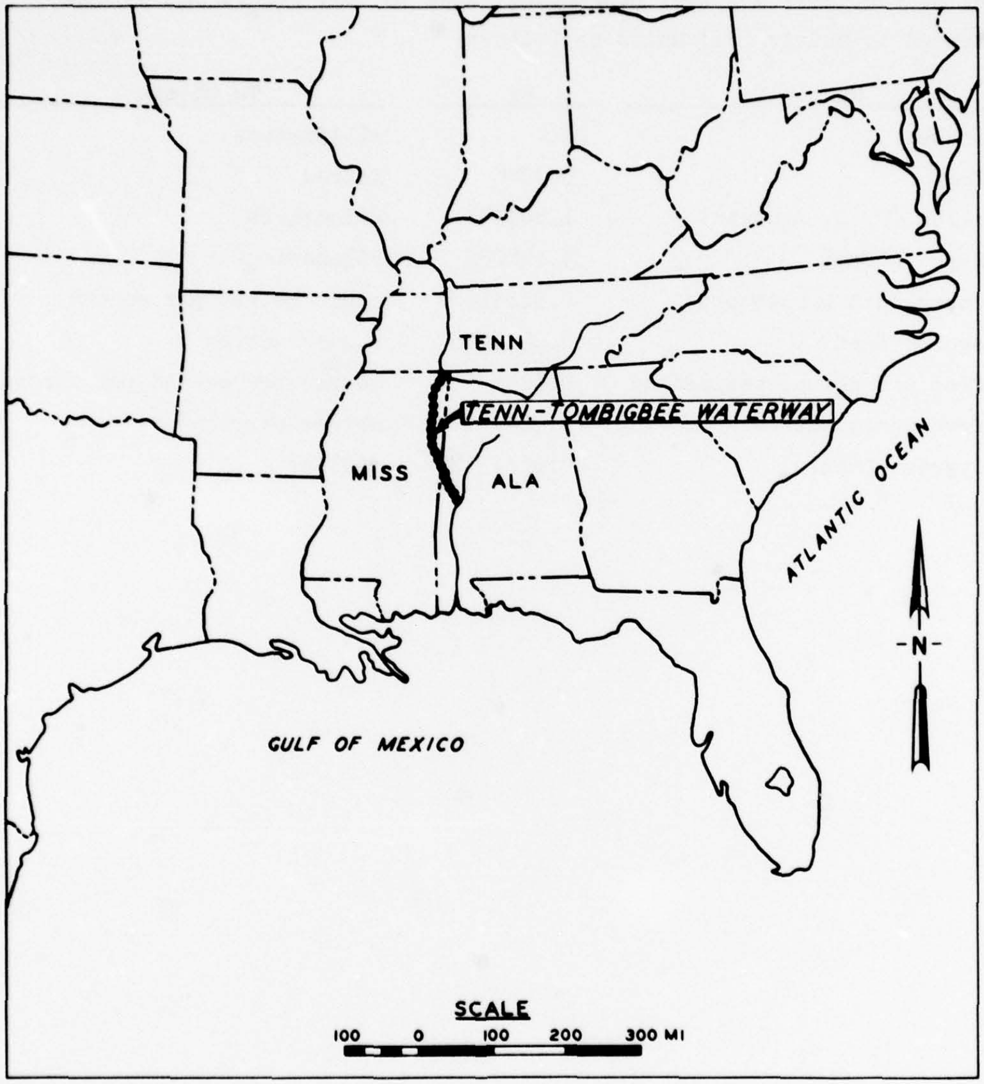

Figure 1. Vicinity map

TYPICAL TENNESSEE-TOMBIGBEE CANAL SECTION SPILLWAYS

SPILLWAYS A AND B

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototypes

1. Spillways A and B are components of the Tennessee-Tombigbee Waterway that will extend navigation from Demopolis, Alabama, on the existing Black Warrior and Tombigbee Waterway 217 miles* above Mobile, upstream via the Tombigbee River to mile 215 on the sailing line of the Tennessee River in the existing Pickwick Reservoir near the common boundary of Alabama, Tennessee, and Mississippi. The project would provide a continuous navigation route from the Tennessee, upper Mississippi, and Ohio River Valleys to tidewater at the port of Mobile, Alabama, on the Gulf of Mexico. A vicinity map and a general plan of the waterway are shown in Figures 1 and 2.

Spillway A project

2. The principal structures for the Spillway A project will consist of a navigation lock located in the canal and a gated spillway adjacent to the lock (Plate 1). The spillway will have an overall length of 134 ft and will consist of four gate bays, two abutments, and three 6-ft-wide piers (Plate 2). Flow over the crest will be controlled by tainter gates 8 ft high and 26 ft wide. The crest of the spillway will be located at el 213.0**; the stilling basin apron, at el 180.5. An abutment wall will be provided on each side of the spillway for transition to the embankment sections.

Spillway B project

3. The principal structure for the Spillway B project will

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

** All elevations (el) cited herein are in feet referred to mean sea level.

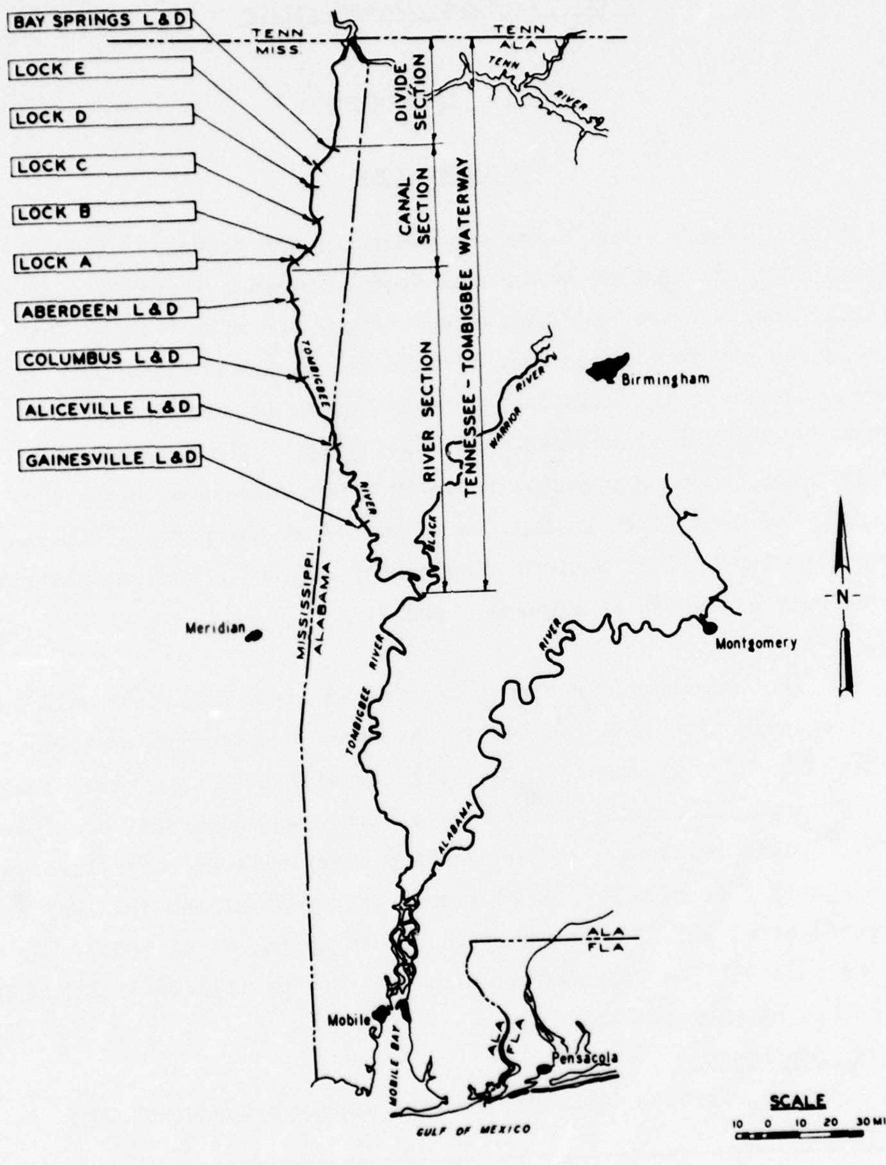


Figure 2. General plan

consist of a navigation lock located in the canal and a gated spillway located in the levee upstream of the lock (Plate 3). The spillway will have an overall length of 591 ft and will consist of eleven gate bays, two abutments, and ten 8-ft-wide piers (Plate 4). Flow over the spillway will be controlled by 15-ft-high by 45-ft-wide tainter gates. The crest of the spillway will be located at el 231.0. An abutment wall will be provided on each side of the spillway for transition to the embankment sections.

Purpose of Study

4. The original purpose of the section model test was to investigate Spillway A for the possibility of surging on the spillway tainter gates and performance of the stilling basin for the wide range of anticipated tailwater conditions. As the study progressed, the sponsor requested additional tests to evaluate single-gate operation and the hydraulic performance of Spillway B. The primary purpose of the section model tests of Spillway B was to investigate hydraulic characteristics similar to those investigated in tests of Spillway A and, in addition, to determine the spillway crest pressures, the minimum allowable stilling basin invert elevation, and the size and extent of riprap protection required for the exit channel and to estimate the hydraulic forces acting on the stilling basin divider walls.

PART II: THE MODELS

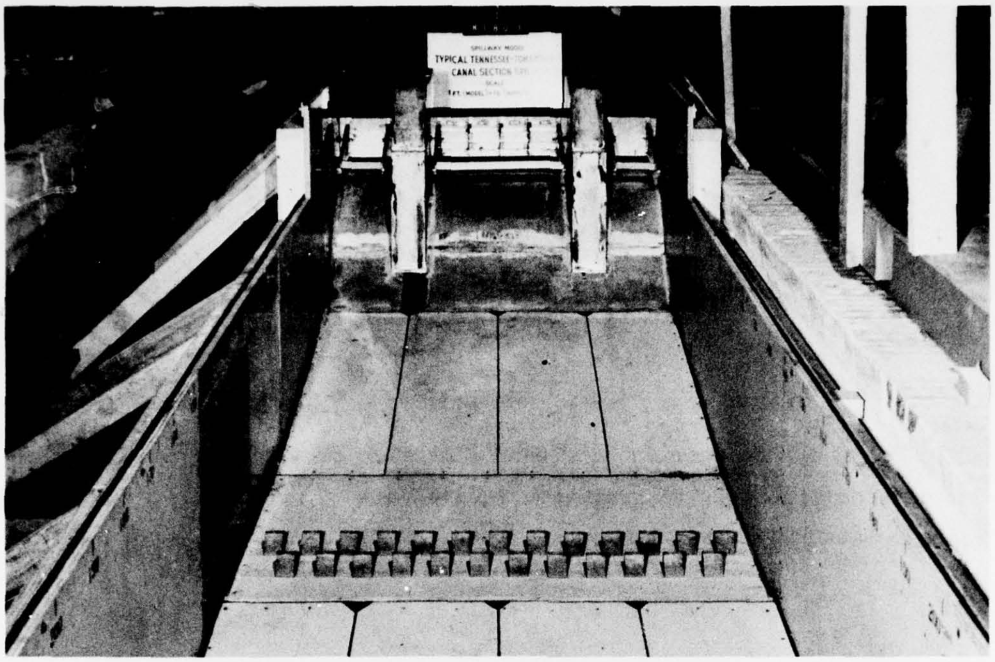
Description

5. Spillways A and B section models were constructed tc linear scale ratios of 1:15 and 1:25, respectively. Each section model reproduced sufficient lengths of the spillway, approach, and exit channel required to investigate the hydraulic characteristics of the proposed structures (Figure 3). The approach and exit channels were constructed of marine plywood. The weirs, gate piers, and tainter gates were fabricated of sheet metal. The stilling basin aprons, training walls, baffle piers, and end sills were made of waterproofed wood. A 4-ft-section of the flume sidewall was constructed of transparent plastic to permit observation of the hydraulic jumps and subsurface currents.

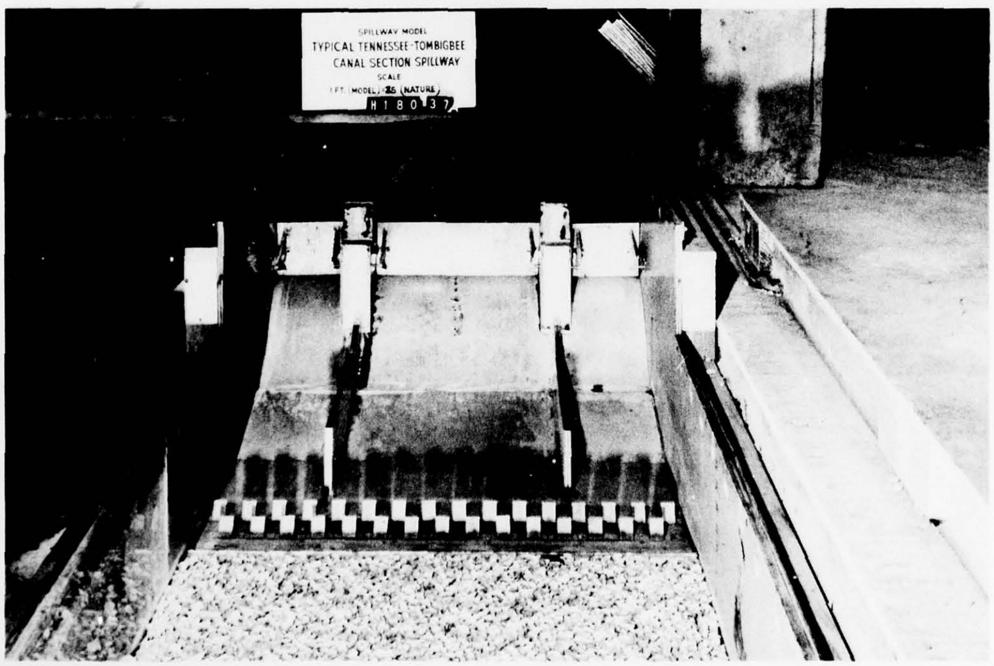
6. Water used in the operation of the models was supplied by pumps, and discharges were measured by means of venturi meters. Steel rails set to grade along the sides of the flume provided a reference plane for measuring devices. Water-surface elevations were measured by means of point gages and velocities were measured with a pitot tube. Current patterns were determined by means of dye injected into the water and confetti sprinkled on the water surface. Tailwater elevations were regulated by a gate at the downstream end of the flume.

Interpretation of Model Results

7. The accepted equations of hydraulic similitude, based on the Froudian criteria, were used to express the mathematical relations between the dimensional and hydraulic quantities of the models and prototypes. The general relations expressed in terms of the model scales or length ratios, L_r, are presented in the tabulation on page 10.



a. 1:15-scale section model of Spillway A



b. 1:25-scale section model of Spillway B

Figure 3. The section models

Dimension	Ratio	Scale Relations	
		Spillway A	Spillway B
Length	L_r	1:15	1:25
Area	$A_r = L_r^2$	1:225	1:625
Velocity	$V_r = L_r^{1/2}$	1:3.87	1:5.00
Discharge	$Q_r = L_r^{5/2}$	1:871	1:3,125
Time	$T_r = L_r^{1/2}$	1:3.87	1:5.00
Force	$F_r = L_r^3$	1:3,375	1:15,625

8. Model measurements of each dimension or variable can be transferred quantitatively to prototype equivalents by means of the preceding scale relations.

PART III: TESTS AND RESULTS

Presentation of Data

9. No attempt has been made to present the model tests and results in chronological order; instead, as each element of the structures is considered, all tests conducted thereon are described in detail.

Spillway A

Description

10. Details of Spillway A are shown in Plate 2. The 1:15-scale section model reproduced a 60-ft width of the structure that included 120 ft of approach channel, one 26-ft-wide gate bay, two 6-ft-wide piers, 11 ft of each adjacent gate bay, the stilling basin, and 120 ft of the exit channel (Figure 3).

Weir and crest piers

11. Details of the original weir design are presented in Plate 2. To simplify presentation of test results, the flow rates in the model were converted to the form of discharge through one bay by multiplying the measured flow by a ratio of net bay width (26 ft) to net crest length of the section model (48 ft). Since the weir crests are high relative to expected tailwaters, free-flow conditions will generally exist through the canal section spillways. Further, either free controlled- or free uncontrolled-flow regimes will normally exist depending on whether or not the gates are used to control spillway releases. For simplification throughout the remainder of the text, the flow regimes will be described as either controlled or uncontrolled.

12. Basic data for uncontrolled and controlled flows obtained from the model are presented in Tables 1 and 2. An uncontrolled-flow rating curve is shown in Figure 4. The model indicated a pier contraction coefficient (Plate 5) less than that shown in HDC 111-5 for the type 3 pier nose shape. The relatively low value of the pier contraction coefficient is attributed to the fact that the piers extend a

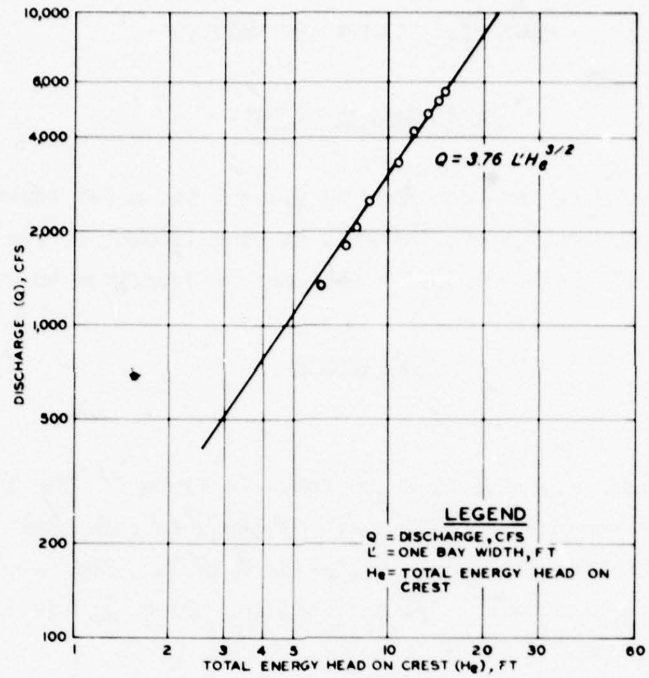


Figure 4. Head-discharge relation for uncontrolled flow through single gate bay of Spillway A

considerable distance upstream which reduces the flow contraction around the nose of the piers. The value of the pier contraction coefficient was determined by substituting measured quantities of discharge and total energy head into the equation,*

$$Q = C(L' - K_p N H_e) H_e^{3/2} \qquad (1)$$

where

Q = discharge, cfs**

C = discharge coefficient (HDC 122-1, $P/H_d = 0.33$)

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* U. S. Army Corps of Engineers, "Hydraulic Design Criteria," Chart 111-5, 1 Apr 1953, prepared for Office, Chief of Engineers, by U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., issued serially since 1952.

** For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix A).

L' = net weir length for one bay, ft

K_p = pier contraction coefficient

N = number of piers

H_e = total energy head on crest, ft

13. Uncontrolled- and controlled-flow rating curves for various gate openings are presented in Figure 5. Results of the controlled-flow

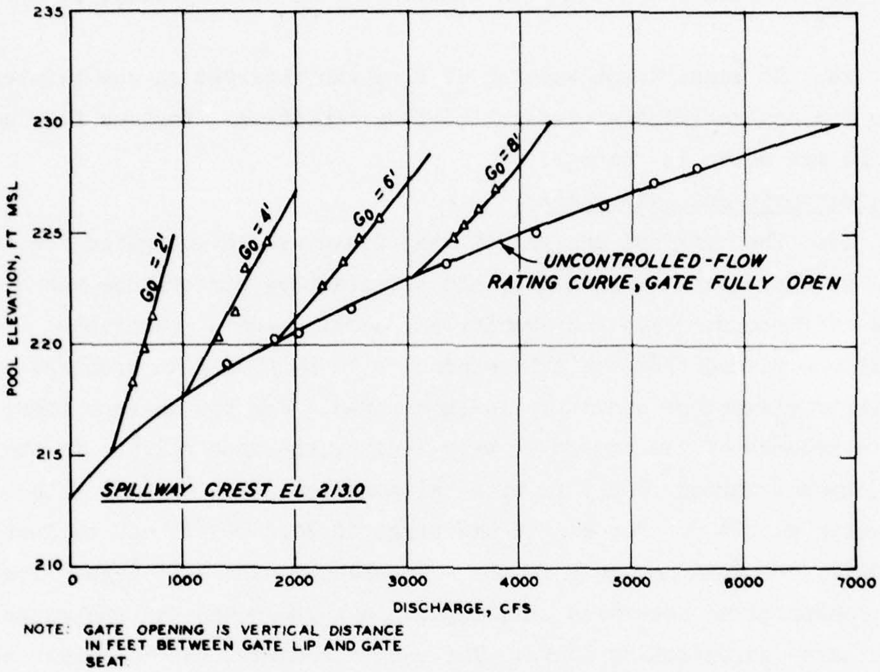


Figure 5. Rating curves for one gate bay of Spillway A

tests were used to develop a generalized equation for the controlled-flow discharge coefficient by plotting discharge versus head on the center line of various gate openings (Plate 6) and then plotting the constants or intercepts for each of the equations in Plate 6 versus gate opening as shown in Plate 7. The following equation relating discharge and head on the center line of the gate opening for any gate opening was developed to describe controlled-flow characteristics of a single gate bay of Spillway A:

$$Q = 0.64 G_o^{0.063} A_o (2gH_{G_o})^{1/2} \qquad (2)$$

where

G_o = gate opening, ft

A_o = area of gate opening, ft^2

g = acceleration due to gravity, ft/sec^2

H_{G_o} = total energy head on center line of gate opening, ft

14. No significant surging of flow was observed on the tainter gates for any anticipated controlled-flow condition. Various flow conditions are shown in Photo 1.

Stilling basin and exit channel

15. The original design stilling basin was investigated for the range of anticipated discharges, and satisfactory performance was observed for uncontrolled and symmetrical multiple-gate operations. Flow conditions viewed from the exit channel with various gate openings and tailwater elevations are shown in Photos 2-6. For the maximum flow, a unit discharge of 212 cfs/ft of weir length, the wave heights in the exit channel varied from 5 ft with tailwater el 206.0 to 8 ft with tailwater el 204.0. For a unit discharge of 30.3 cfs/ft and tailwater el 192.0, the maximum waves in the exit channel were 3 ft high. Tests were conducted to determine stilling basin performance for the range of anticipated uncontrolled flows. For each discharge, the tailwater elevation was lowered sufficiently to determine the minimum tailwater elevation required for maintaining a good hydraulic jump within the stilling basin. Figure 6 indicates these minimum values of tailwater as well as those for which a forced or impact jump is maintained and/or swept out of the stilling basin (spray).

16. Isovels obtained with unit discharges of 103 and 212 cfs/ft of weir length at positions upstream of the baffle piers, over the end sill, and 50 ft downstream from the end sill are presented in Plates 8 and 9.

17. Water-surface profiles observed along the center line of the gate bay, along the side of the crest pier, and through the stilling

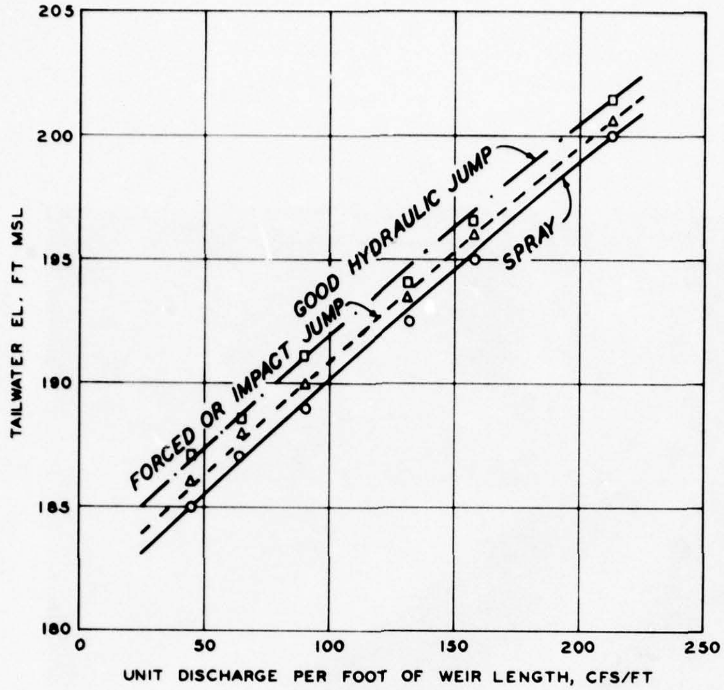


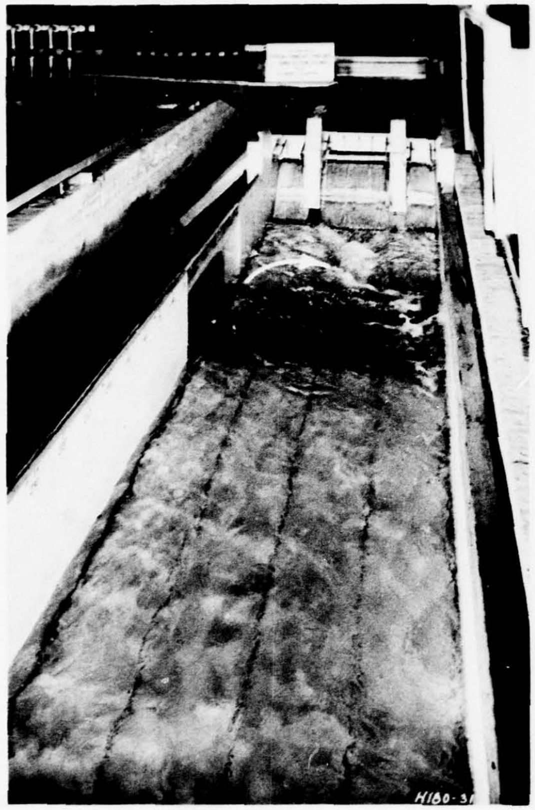
Figure 6. Stilling basin performance characteristics, uncontrolled flow, Spillway A

basin with unit discharges of 103 and 212 cfs/ft of weir crest are shown in Plates 10 and 11.

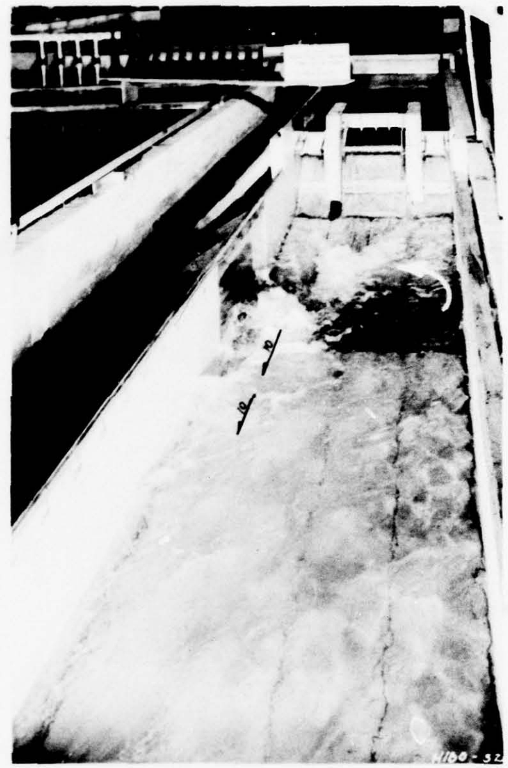
Single gate operation

18. Tests were conducted to investigate the hydraulic characteristics of the structure with one gate fully open. The purpose of temporarily opening only one gate is to pass debris through the structure.

19. A pool elevation of 220.0 and a tailwater elevation of 190.0 were established in the model prior to opening the center gate (Photo 7). The center gate was fully opened from a closed position at a simulated rate of 7 fpm, and the resulting hydraulic conditions that occurred at a 2-ft gate opening and a fully open gate are shown in Figure 7. Bottom velocities measured over the end sill and 50 ft downstream from the end sill are also indicated in Figure 7. Waves measured 50 ft downstream from the end sill were 2 ft high for a 2-ft gate opening and 5 ft high for a fully open gate. As flow entered the stilling basin,



a. Center gate opened 2 ft



b. Center gate fully open

Figure 7. Spillway A, original design, single gate operation; pool el 220.0, tailwater el 190.0

the jet of water was confined by lateral flow from the sides (Figure 7) and remained near the surface as it passed through the stilling basin. The limited width of section model did not permit an accurate evaluation of flow patterns in the horizontal plane and full width of the prototype. However, it is considered that the occurrence of eddies in the section model indicate the likelihood of severe eddies in the prototype that may be capable of moving riprap and debris upstream and into the basin. This could cause severe abrasive damage to the stilling basin.

Recommended stilling basin design

20. Model tests were conducted to develop modifications that would eliminate the possibility of eddies in the stilling basin with single gate operation. Satisfactory flow performance in the stilling basin and exit channel was obtained for all anticipated flows by installing a divider wall (Figure 8) along the center line and downstream from each pier. A pool elevation of 220.0 and a tailwater elevation of 190.0 were established in the model prior to opening the center gate. The center gate was fully opened from a closed position at a simulated rate of 7 fpm, and the resulting conditions that occurred at a 2-ft gate opening and a fully open gate are illustrated in Figure 9. Bottom velocities measured over the end sill and 50 ft downstream from the end sill are also indicated in Figure 9. Waves measured 50 ft downstream

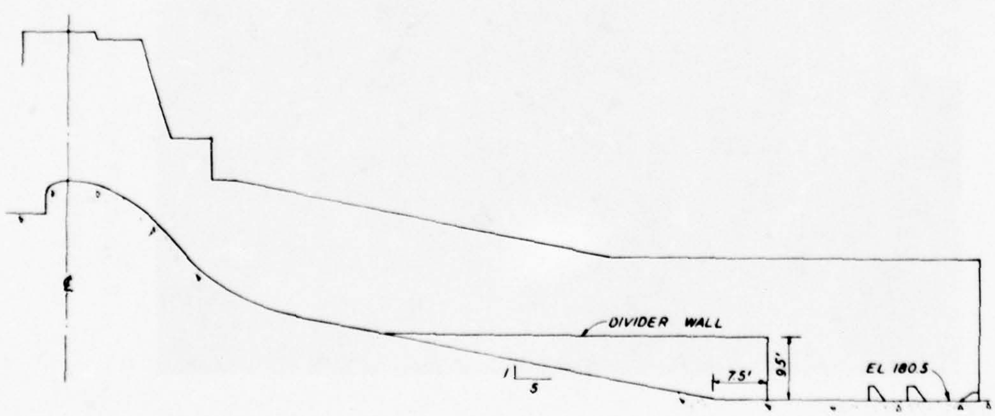
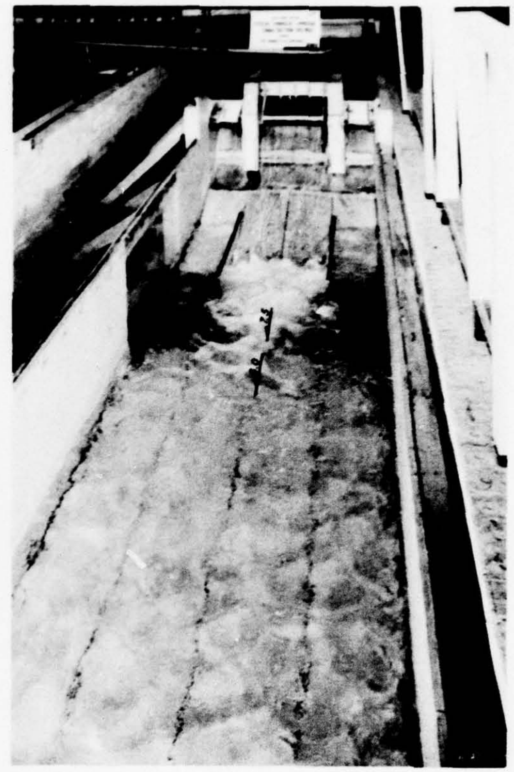


Figure 8. Type 1 divider wall, Spillway A

a. Center gate opened 2 ft

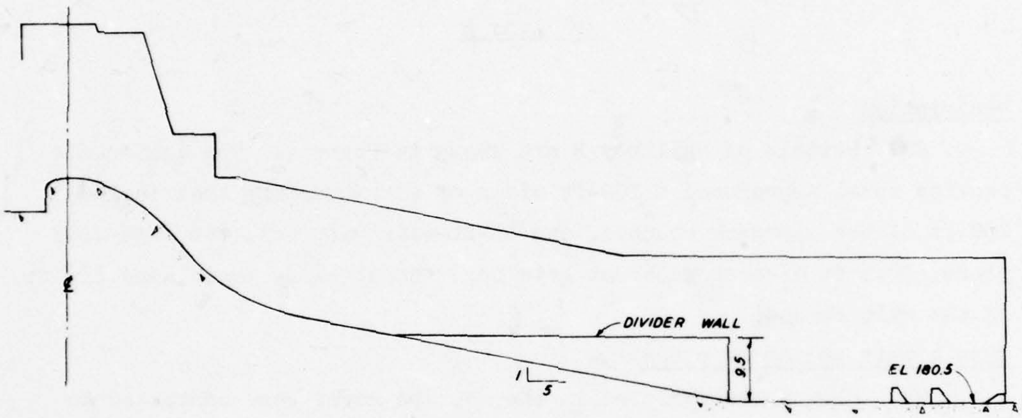


b. Center gate fully open

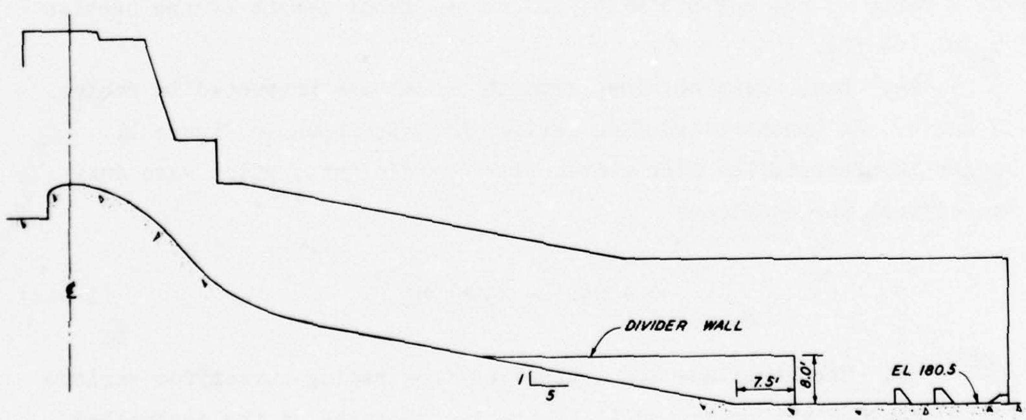
Figure 9. Spillway A, type 1 divider wall, single gate operation; pool el 220.0; tailwater el 190.0

from the end sill were 1 ft high with a 2-ft gate opening and 3 ft high with a fully open gate. Satisfactory flow performance was also observed with symmetrical multiple-gate operation and the range of anticipated discharges.

21. Additional tests were conducted to determine if the dimensions of the divider walls could be reduced without adversely affecting stilling basin performance. The type 2 divider wall (Figure 10a) was terminated at the toe of the IV-on-5H chute slope and was 7.5 ft shorter than the type 1 divider wall. Elimination of 7.5 ft of the downstream portion of the walls permitted lateral flows around the downstream ends



a. Type 2 divider wall



b. Type 3 divider wall

Figure 10. Alternate divider wall designs, Spillway A

of the divider walls to confine the water jet and impaired hydraulic performance. The type 3 divider wall (Figure 10b) was terminated 7.5 ft downstream from the toe of the IV-on-5H chute slope and its top elevation was lowered 1.5 ft relative to the type 1 divider wall. Lowering of the top elevation by 1.5 ft permitted excessive flow over the top of the divider walls which tended to reduce the effectiveness of the hydraulic jump. The results of the model tests indicated that the type 1 divider wall (Figure 8) provided the most effective means for eliminating eddies in the stilling basin with single gate operation.

Spillway B

Description

22. Details of Spillway B are shown in Plate 4. The 1:25-scale section model reproduced a 100-ft width of the structure that included 250 ft of the approach channel, one 45-ft-wide gate bay, two 8-ft-wide piers, 19.5 ft of each adjacent gate bay, the stilling basin, and 250 ft of the exit channel.

Type 1 weir and crest piers

23. Flow rates measured in the section model were converted to the form of discharge through one bay by multiplying the measured flow by a ratio of net bay width (45 ft) to net crest length of the section model (84 ft).

24. Basic data obtained from the model are presented in Tables 3 and 4. An uncontrolled-flow rating curve is shown in Figure 11. Plate 12 presents the pier contraction coefficients, which were determined from the equation:

$$Q = C(L' - K_p N H_e) H_e^{3/2} \qquad \text{(1 bis)}$$

25. Uncontrolled- and controlled-flow rating curves for various gate openings are presented in Figure 12. Results of the controlled-flow tests were used to develop a generalized equation for the controlled-flow discharge coefficient. This was accomplished by

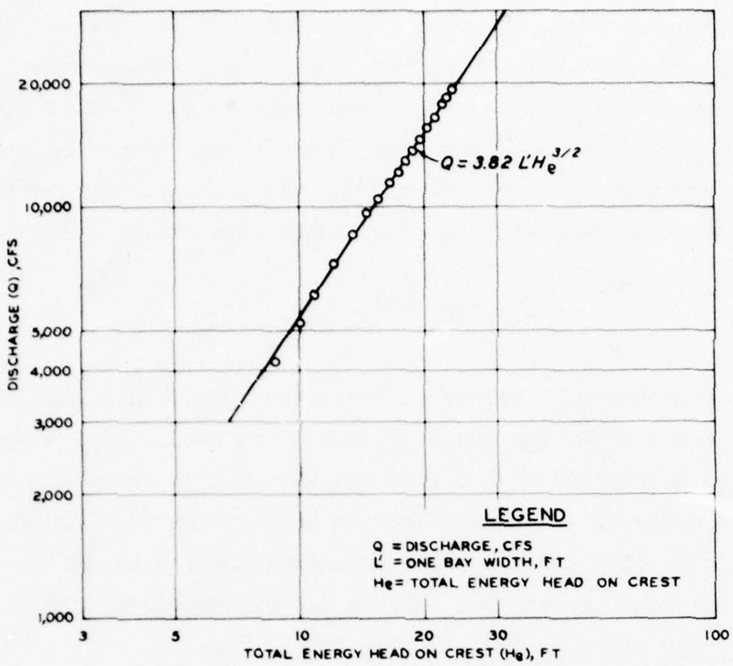


Figure 11. Head-discharge relation for uncontrolled flow through single gate bay of Spillway B

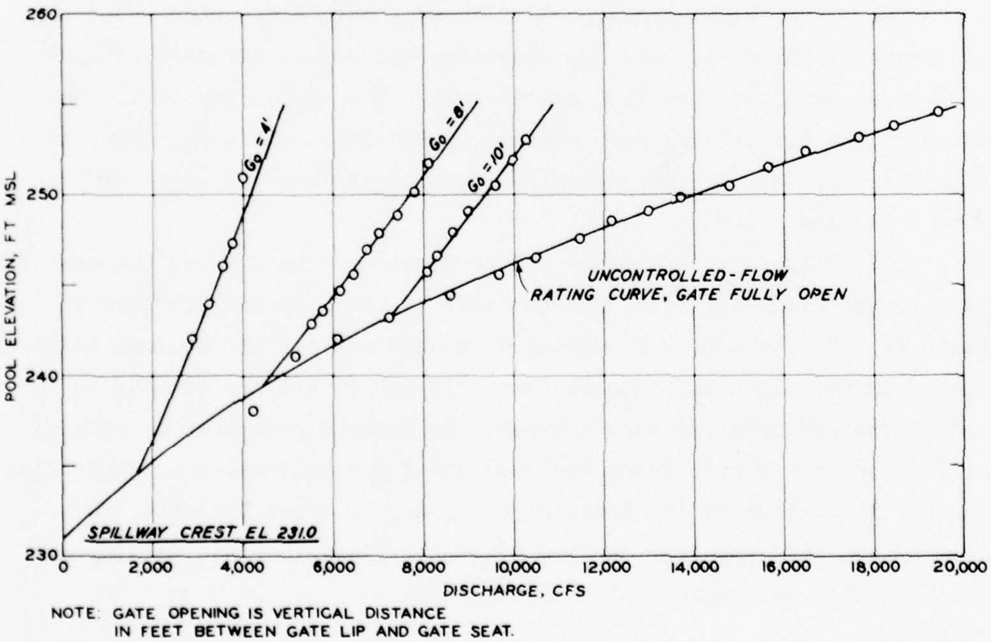


Figure 12. Rating curves for one gate bay of Spillway B

plotting discharge versus head on the center line of various gate openings (Plate 13) and then plotting the constants or intercepts for each of the equations in Plate 13 versus gate opening as shown in Plate 14. The following equation relating discharge and head on the center line of the gate opening for any gate opening was developed to describe controlled-flow characteristics of a single gate bay of Spillway B:

$$Q = 0.60G_o^{0.080}A_o(2gH_{G_o})^{1/2} \qquad \text{(2 bis)}$$

26. Piezometer locations and pressures measured along the longitudinal center line of the center gate bay and the side of an adjacent pier are shown in Plate 15. The pressures presented were obtained for the maximum uncontrolled unit discharge anticipated (413 cfs/ft). Pressures were also observed for various controlled-flow conditions. No adverse pressures were evident for any anticipated flow conditions.

Type 2 weir and crest piers

27. The type 2 crest was developed by adding a 45-degree slope to the upstream face of the type 1 spillway (Figure 13).

28. Tests were conducted with controlled and uncontrolled flows, and results indicated that flow characteristics were almost identical with those obtained with the type 1 crest. The similarity of the results of the two designs is confirmed by HDC 122-4 which indicates no significant difference in discharge coefficient when the ratio of P to H_d is about 0.27.

29. Piezometer locations and pressures measured along the center line of the center gate bay and the side of the pier are provided in Plate 16. The pressures presented were obtained for the maximum anticipated uncontrolled unit discharge of 413 cfs/ft and are similar to those obtained with the type 1 crest. No adverse pressures or surging of flow on the tainter gates was observed for uncontrolled or controlled flows. Evaluation of the tests with the type 2 crest indicated that sloping the spillway face in lieu of the vertical face did not improve the hydraulic performance of the structure.

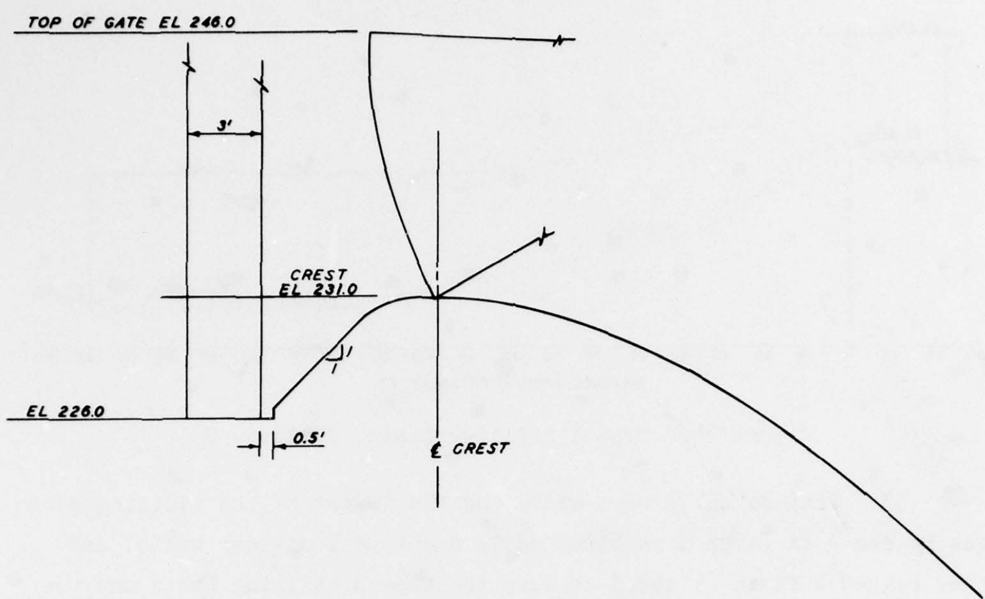


Figure 13. Spillway B, type 2 crest

30. No significant surging of flow was observed on the tainter gates for any controlled-flow condition investigated.

Stilling basin and exit channel

31. Tests were conducted to evaluate the original stilling basin design and to develop an alternate design that would permit raising the invert of the stilling basin as much as possible without impairing the hydraulic performance of the stilling basin during anticipated conditions, including temporary single gate operation for release of debris through the structure.

32. Flow conditions observed with the original design type 1 stilling basin (Figure 14) indicated that the apron elevation could be raised. Single gate operation with the following conditions produced the most adverse flow conditions in the stilling basin: pool el 245.0, tailwater el 215.0, discharge 8800 cfs (one bay). A strong eddy developed in the stilling basin as the jet from the single bay entered the tailwater, and this tended to concentrate the jet along the side of the model.

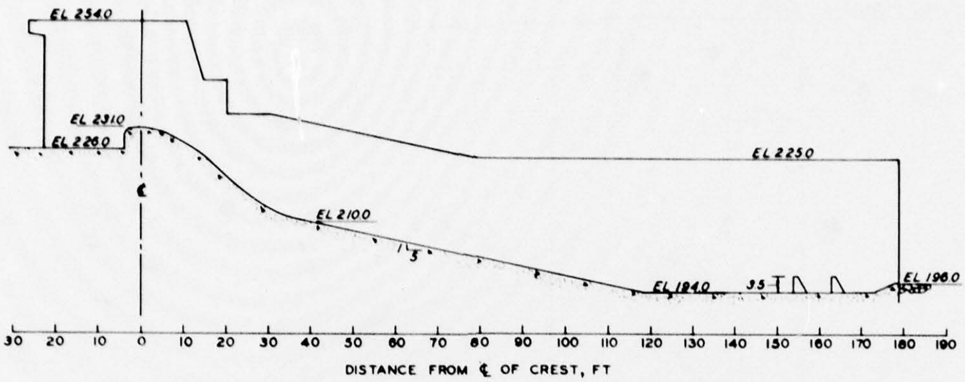


Figure 14. Type 1 stilling basin, Spillway B

33. Divider walls were added and the invert of the stilling basin was raised 2 ft (type 2 stilling basin and type 1 divider walls) and then raised 4 ft to el 198.0 to form the type 3 stilling basin and the type 2 divider walls (Figure 15). Raising the invert 4 ft permits a 20-ft reduction in the length of the chute and sidewalls. The divider walls were effective in eliminating the eddies, and the hydraulic performance of the stilling basin was satisfactory for all anticipated flow conditions. Tests were conducted with various lengths and heights of divider walls and the type 2 divider wall (Figure 15) was considered the most appropriate.

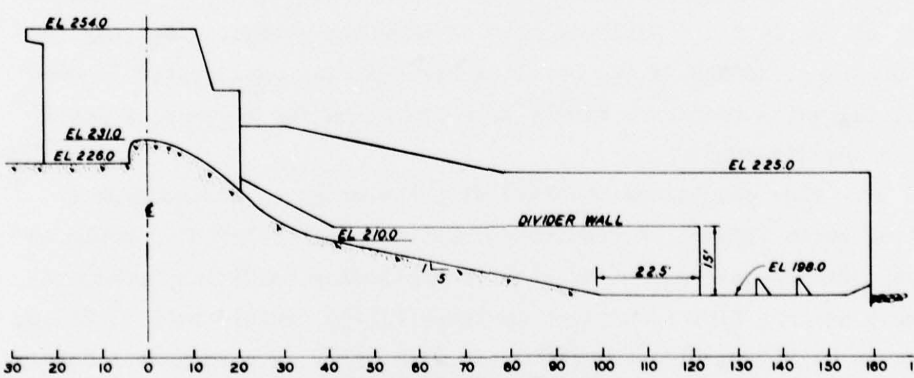


Figure 15. Type 3 stilling basin, type 2 divider wall, Spillway B

Recommended stilling basin

34. Representatives from the U. S. Army Engineer District, Mobile, modified the design of the exit channel by raising the channel invert 5 ft from el 215.0 to 220.0. This provided an additional 5 ft of tailwater elevation for single gate operation. Subsequently, tests were conducted to determine if the invert of the stilling basin could be raised an additional 5 ft to el 203.0 to form the type 4 (recommended) stilling basin shown in Plate 17.

35. Satisfactory flow performance was observed for various controlled and uncontrolled discharges. Water-surface profiles along the pier and the center line of the center gate bay are shown in Plate 17. Table 5 indicates the value of the basic data points. Velocities measured 1 ft upstream from the upstream row of baffles, over the end sill, and 50 ft downstream from the end sill with the maximum discharge are presented as isovels in Plate 18.

36. Tests were also conducted to investigate single hydraulic performance with the following hydraulic conditions anticipated for single gate operation: pool el 245.0, tailwater el 220.0, discharge 8800 cfs (one bay). The type 2 divider walls (Plate 17) induced a stable hydraulic jump and prevented adverse eddies in the stilling basin. The model indicated that further reduction in length or height of the divider walls would permit adverse lateral currents around the ends of the walls and excessive return flow over the tops of the walls. Tests also indicated that raising the apron above el 203.0 would significantly reduce the effectiveness of the stilling basin. Velocities measured over the end sill and 50 ft downstream from the end sill with single gate operation are presented in Plate 19. The type 4 stilling basin and the type 2 divider walls (Plate 17) are the recommended designs for the Spillway B stilling basin.

Riprap protection

37. Tests were conducted to determine the minimum stone size required for protection of the exit channel invert downstream from the type 4 stilling basin. In each of the tests conducted for a duration equivalent to 3 hours prototype, the stone was subjected to various flow

conditions including the following maximum unit discharges with single and multiple-gate operation:

Single Gate Operation
Pool el 245.0
Tailwater el 220.0
Unit discharge 196 cfs/ft

Multiple-Gate Operation
Pool el 253.8
Tailwater el 236.0
Unit discharge 413 cfs/ft

Initially, a blanket of stone having an average diameter (d_{50}) of 22 in. (type 1 riprap) was installed downstream from the end sill with the top at el 206.0. No displacement of stone was observed during either single or multiple gate operations.

38. Type 2 riprap with an average diameter of 11 in. failed during single gate operation throughout a length of about 75 ft downstream from the end sill when subjected to the maximum unit discharge condition. The type 2 riprap also failed during the maximum unit discharge conditions with multiple gate operations throughout a length of about 50 ft downstream from the end sill.

39. The type 3 riprap with an average diameter of 16 in. (Figure 16) was subjected to the maximum unit discharges anticipated with single and multiple-gate openings (Photo 7), and no displacement of stone was observed. It was considered that the following gradation of riprap with an average stone diameter of 16 in. would be adequate for protection of the exit channel.

Rock Diameter in.	Percent Finer
30	85-100
25	50-85
16	15-50
7	0-15

Normally, such protection should be provided for a minimum distance of about 10 times the theoretical sequent depth required for maintaining

Figure 16. Spillway B, type 3 riprap, type 4 stilling basin, type 2 divider wall

a hydraulic jump or, in this case, for a length of about 260 ft downstream of the end sill.

Hydraulic forces acting on the divider walls

40. During the course of the model study, computations were made to estimate the magnitudes of the dynamic forces exerted by the hydraulic jump on the Spillway B divider walls.

41. The computed dynamic forces and moment arms are presented, respectively, in Plates 20 and 21. It was considered that the divider walls would be subjected to maximum dynamic loadings during single gate operation (required for release of debris) when the water surface on each side of the walls was at a maximum differential. The curves were developed from preliminary results of generalized spillway tests (Work Unit 31177 of the Locks and Dams Research Program) sponsored by the Office, Chief of Engineers (OCE), that were conducted to determine

dynamic forces acting on stilling basin sidewalls. This is an ongoing research effort, and results to date are based on studies conducted without stilling basin baffle blocks and an end sill. Therefore, the results presented have been adjusted, based on engineering judgment, to include the effect of the baffle blocks and the end sill that are included in the Spillway B stilling basin.

42. The forces and moment arms presented in Plates 20 and 21 are generated by hydraulic forces due to flow and turbulence within the stilling basin. Any additional forces due to hydrostatic pressure on the back side of the walls should be included in determining the total resultant forces. If the total resultant force is expected to be acting toward the basin, then the minimum instantaneous force curve should be used for design. If the resultant force is acting away from the basin, then the maximum instantaneous force curve should be used for design. Usually, due to the static loading on the back side of the walls and the profile of a hydraulic jump, the minimum instantaneous force should be considered for design of the upstream monoliths (resultant force would be acting toward the stilling basin) and the maximum instantaneous force should be used for design of the downstream monoliths (resultant force would be acting away from the basin).

PART IV: DISCUSSION

43. Spillways A and B are both low-head spillways designed to operate under free uncontrolled- and free controlled-flow conditions. Although the piers on both spillways extended a considerable distance upstream from the upstream face of the tainter gates, there was no tendency for surging of flow on the gates during controlled-flow operation. There was no excessive contraction at the noses or along the sides of the piers. Flow over the weir crests was satisfactory. Discharge characteristics for controlled and uncontrolled flows were obtained for both spillways.

44. Single gate operation required for release of debris through the structures permitted severe eddies in the stilling basins and exit channels. Divider walls located in the stilling basins along the center line and downstream from each pier were effective in eliminating the unsatisfactory flow conditions that occurred during single gate operation. The divider walls did not affect the hydraulic performance of the structures during multiple-gate operation. Flows in both exit channels were satisfactory for all anticipated flow conditions.

45. Additional features investigated in the model of Spillway B included measurement of crest pressures along the sides of the pier and center line of the gate bay. No adverse pressures were observed. A 45-degree slope added to the upstream face of the spillway did not alter the discharge capacity, the flow characteristics, or the crest pressures. Although the original design Spillway B stilling basin performed satisfactorily, it was found that cost savings could be effected without sacrificing hydraulic performance by raising the apron elevation 9 ft. This modification required less excavation and shorter divider walls and sidewalls. The model of Spillway B indicated that riprap with an average stone diameter of 16 in. extending 260 ft downstream from the end sill would provide adequate protection of the exit channel. The dynamic forces acting on the divider walls during single gate operation of Spillway B were computed by equations developed from ongoing general spillway

tests (Work Unit 31177 of the Locks and Dams Research Program) sponsored by OCE.

46. Although the additional hydraulic features investigated in Spillway B cannot be directly related to Spillway A, they do provide design guidance.

Table 1

Basic Uncontrolled Spillway Rating Data

Spillway A

Discharge* cfs	Head on Crest** ft
2,500	6.1
3,370	7.4
3,820	8.0
4,615	8.7
6,100	10.7
7,700	12.1
8,800	13.3
9,600	14.3
10,200	15.0

Note: Section model consists of one 26-ft-wide bay, two 6-ft-wide piers, and 11 ft of each adjacent bay.

* Discharges indicate the flow rates measured in the section model with all model gates fully open.

** Total energy head on crest.

Table 2

Basic Controlled Spillway Rating Data

Spillway A

Gate Opening ft	Discharge* cfs	Head on Gate** ft
2	1,070	4.4
2	1,250	5.8
2	1,400	7.1
4	2,450	5.1
4	2,750	6.4
4	3,050	8.2
4	3,250	9.4
6	4,130	6.2
6	4,450	7.3
6	4,750	8.4
6	5,100	9.3
8	6,380	7.8
8	6,500	8.3
8	6,700	9.0
8	7,100	10.0

Note: Section model consists of one 26-ft-wide bay, two 6-ft-wide piers, and 11 ft of each adjacent bay.

* Discharges indicate the flow rates measured in the section model with all model gates opened as indicated.

** Total energy head on center of gate opening.

Table 3

Basic Uncontrolled Spillway Rating Data

Spillway B

Discharge* cfs	Head on Crest** ft
7,800	8.8
9,600	10.1
11,200	10.9
13,600	12.3
15,900	13.5
17,900	14.6
19,500	15.6
21,200	16.6
22,500	17.5
24,000	18.1
25,300	18.9
27,400	19.5
29,000	20.5
30,500	21.3
32,600	22.2
34,200	22.7
36,000	23.6

Note: Section model consists of one 45-ft-wide bay, two 8-ft-wide piers, and 19.5 ft of each adjacent bay.

* Discharges indicate the flow rates measured in the section model with all model gates fully open.

** Total energy head on center of gate opening.

Table 4

Basic Controlled Spillway Rating Data

Spillway B

Gate Opening ft	Discharge* cfs	Head on Gate** ft
4	5,450	9.0
4	6,000	11.2
4	6,450	13.1
4	6,900	14.3
4	7,400	16.2
8	10,200	7.8
8	10,700	8.5
8	11,400	9.7
8	11,900	10.6
8	12,500	11.8
8	13,000	12.7
8	13,700	13.9
8	14,400	15.2
8	15,000	16.6
10	14,800	9.7
10	15,400	10.7
10	16,000	11.8
10	16,600	13.0
10	17,700	14.5
10	18,500	15.8
10	19,100	17.0

Note: Section model consists of one 45-ft-wide bay, two 8-ft-wide piers, and 19.5 ft of each adjacent bay.

* Discharges indicate the flow rates measured in the section model with all model gates opened as indicated.

** Total energy head on center of gate opening.

Table 5

Water-Surface Elevations

Center Gate Bay of Spillway B

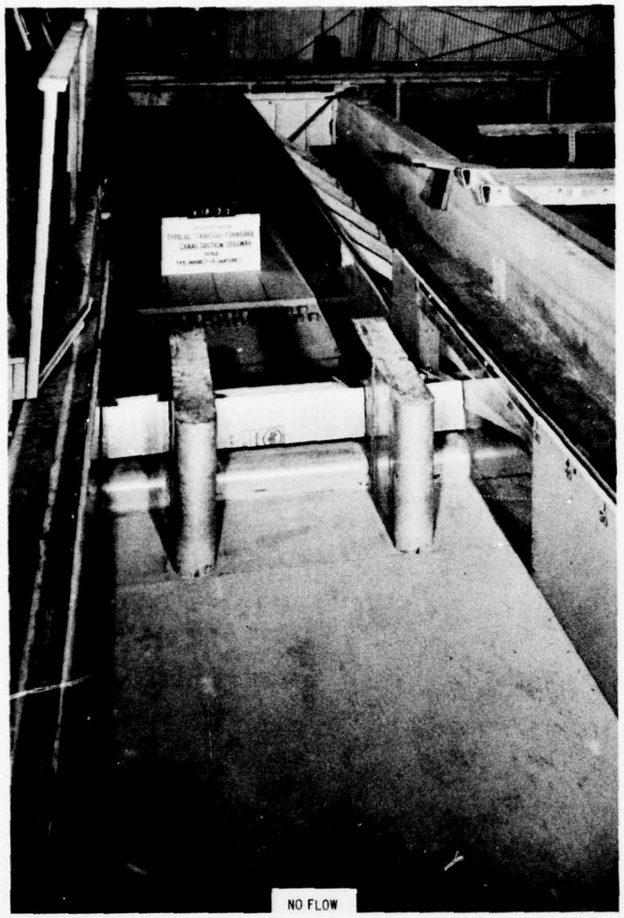
Unit Discharge 413 cfs/ft

Tailwater El 231.0

All Gates Fully Open

Distance from Weir Crest Center Line ft	Water-Surface Elevation Center Line of Bay ft	Water-Surface Elevation Along Pier ft
-20.8*	250.2	251.6
-16.7	249.8	249.5
-12.5	249.4	246.7
-8.3	248.6	245.4
-4.2	247.8	245.2
-0.0	246.9	244.4
4.2	244.9	243.6
8.3	242.7	242.1
12.5	240.0	240.2
16.7	236.9	237.5
20.8	232.9	234.2
25.0	229.5	231.3
29.2	225.2	226.1
33.3	222.0	222.1
41.7 (toe of jump)	218.0	217.4
45.8	218.0	218.0
50.0	218.5	218.5
58.3	219.7	219.7
70.8	221.7	221.7
79.1	223.9	223.9
83.3	225.1	225.1
105.0	231.0	231.0

* Upstream.



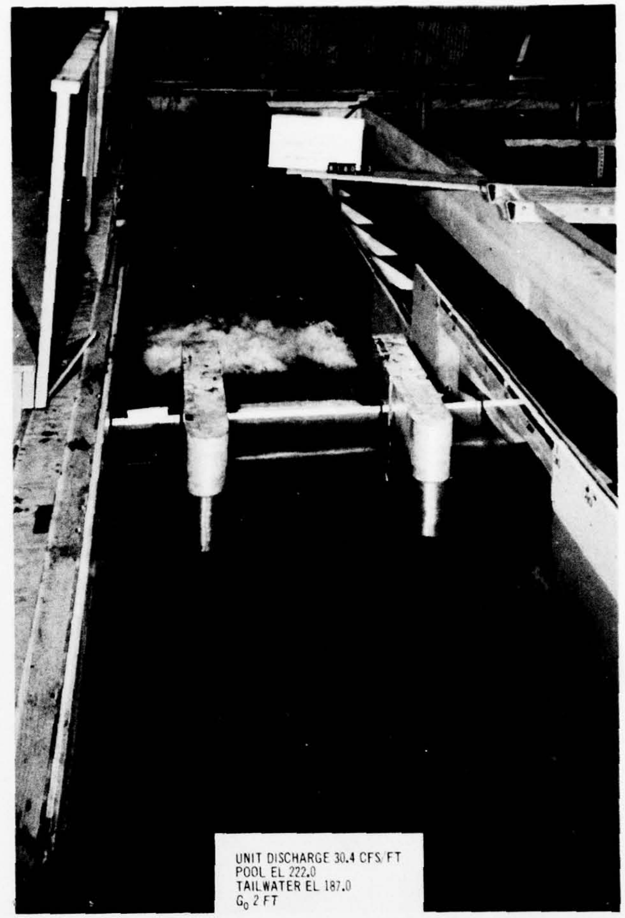
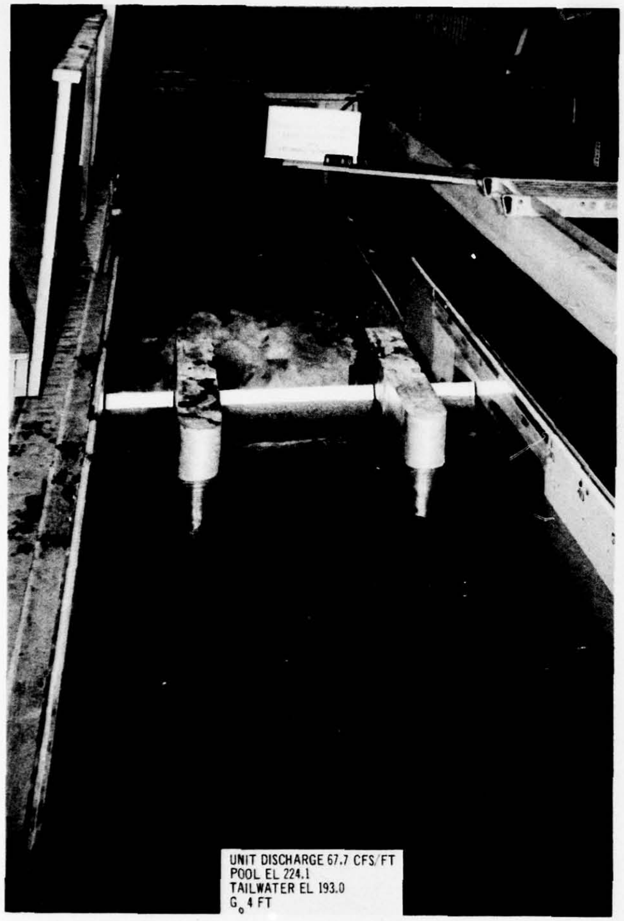


Photo 1. Flow conditions, Spillway A (sheet 1 of 3)



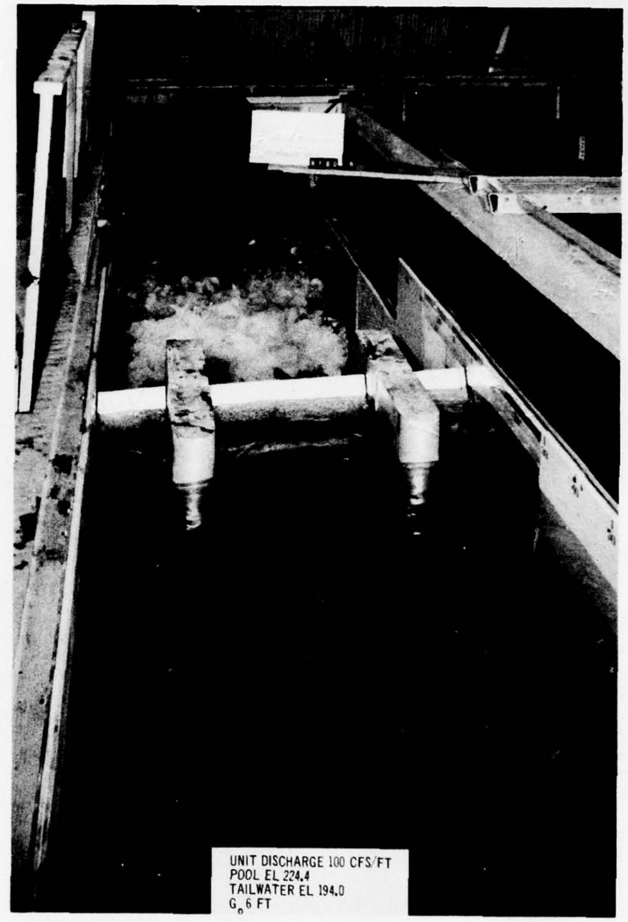
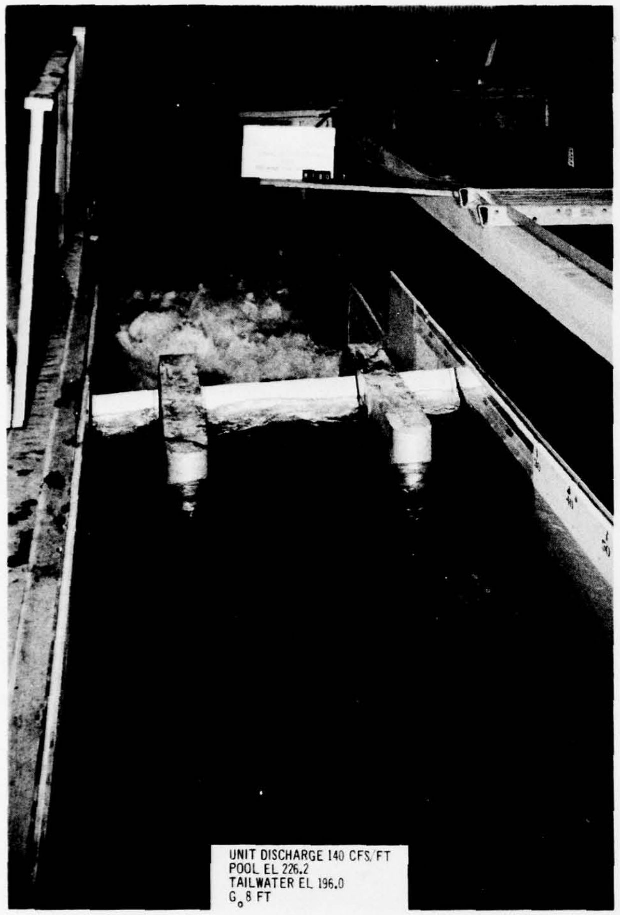


Photo 1 (sheet 2 of 3)



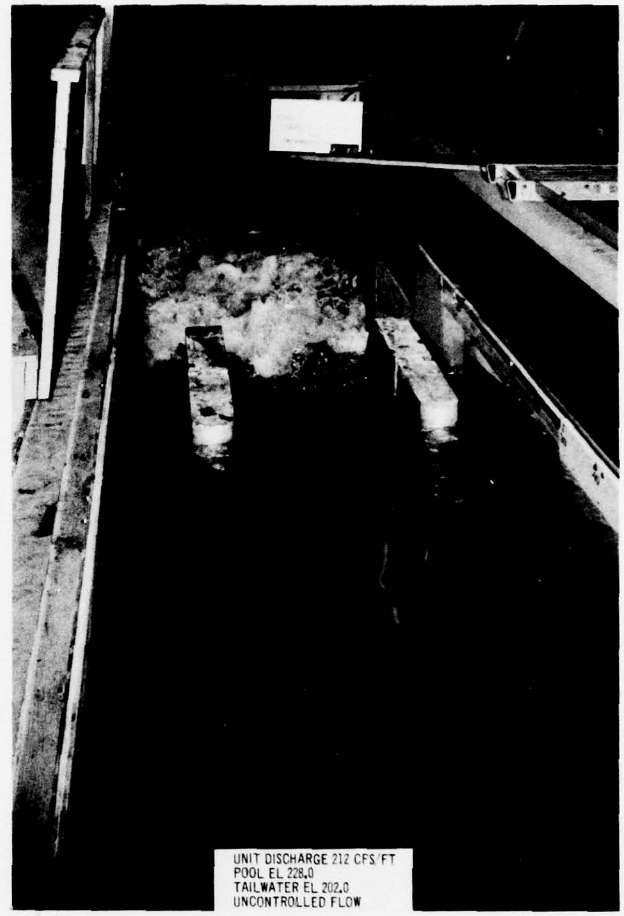
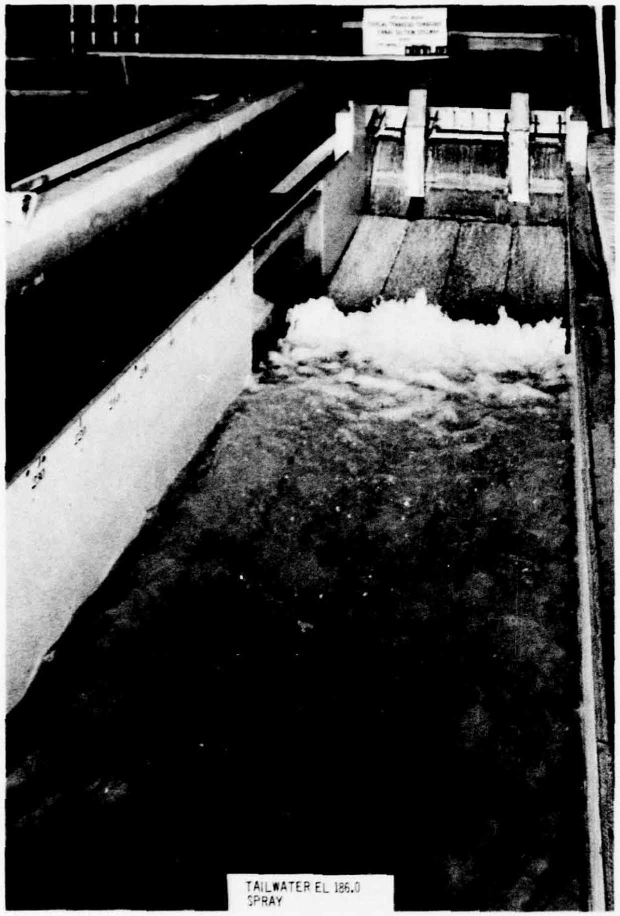


Photo 1 (sheet 3 of 3)



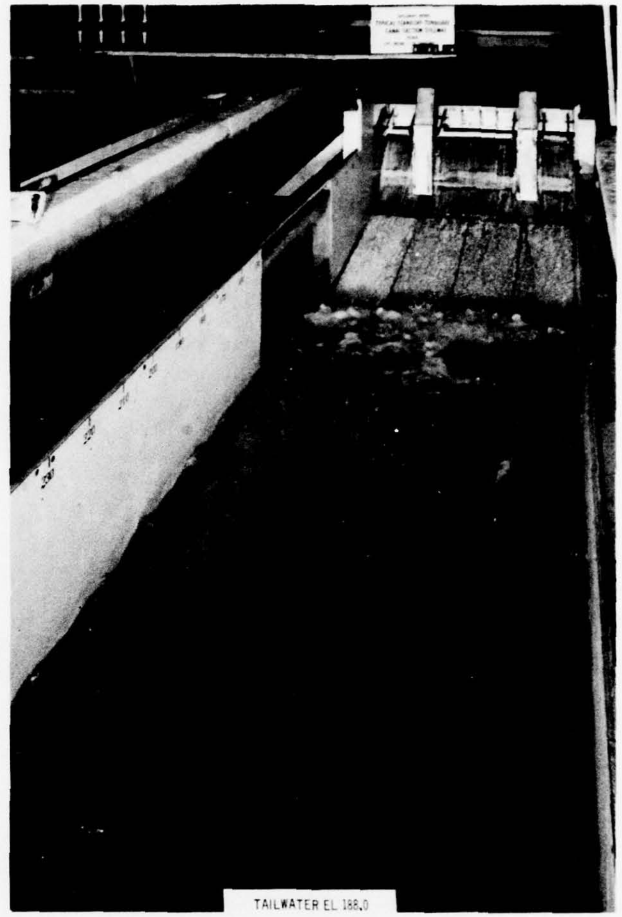
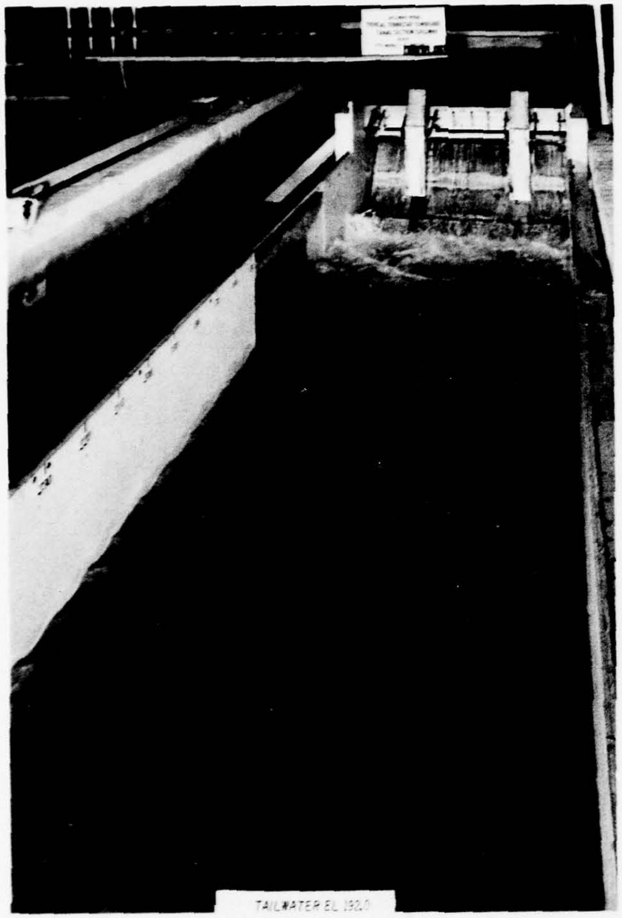


Photo 2. Flow conditions in stilling basin of Spillway A; unit discharge 30.4 cfs/ft, pool el 222.0, gate opening 2.0 ft (sheet 1 of 2)



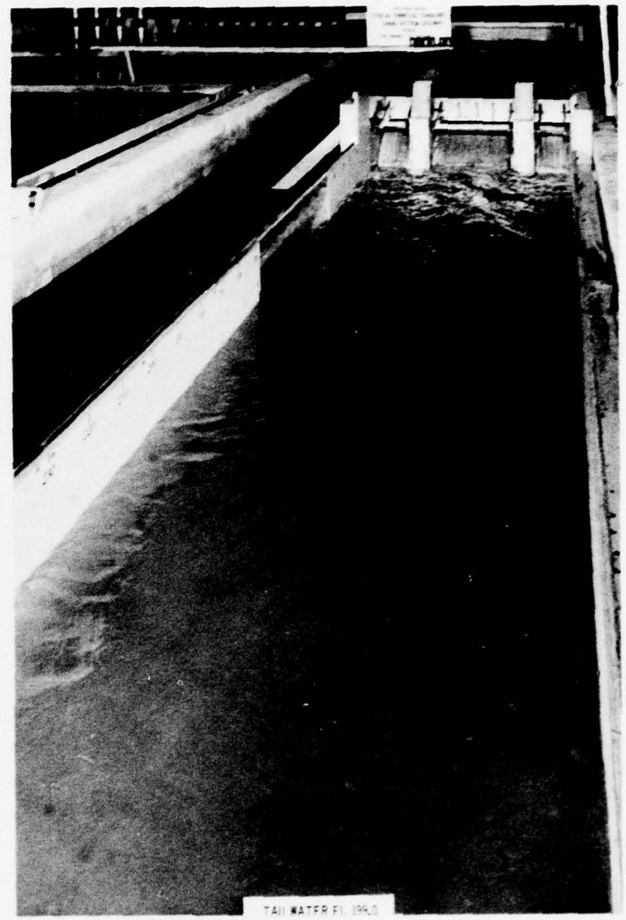


Photo 2 (sheet 2 of 2)

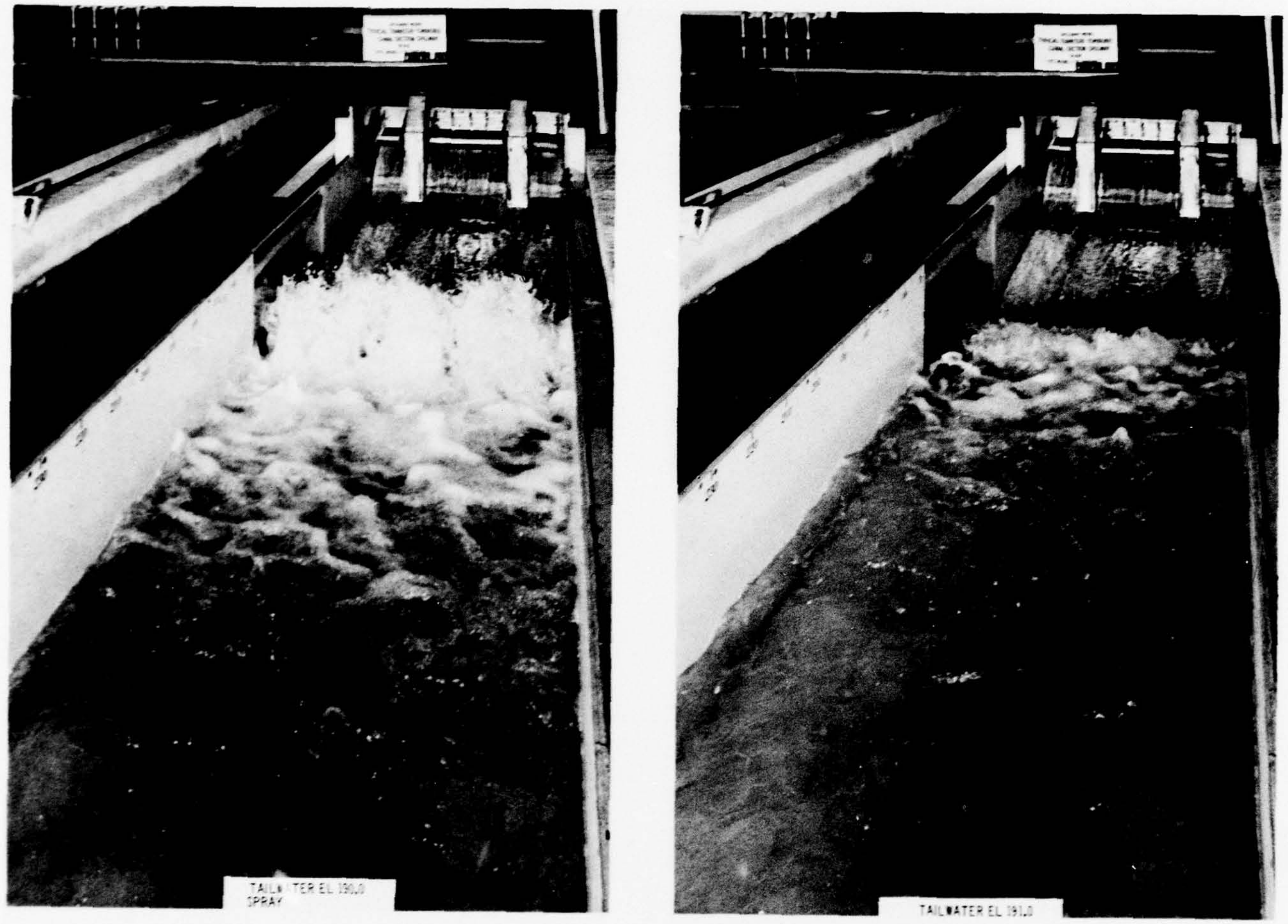
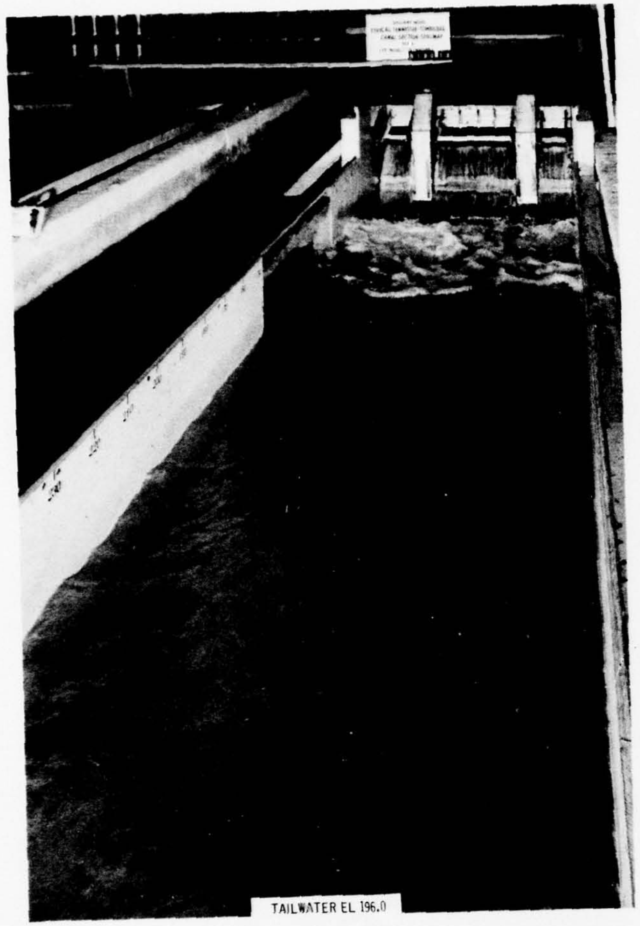


Photo 3. Flow conditions in Spillway A stilling basin; unit discharge 67.7 cfs/ft, pool el 224.1, gate opening 4 ft (sheet 1 of 2)



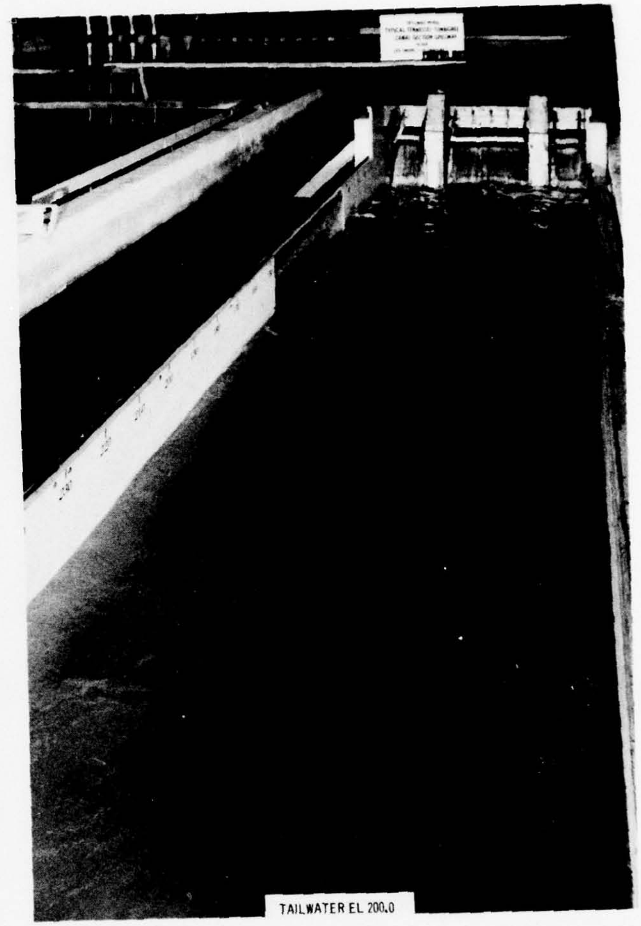
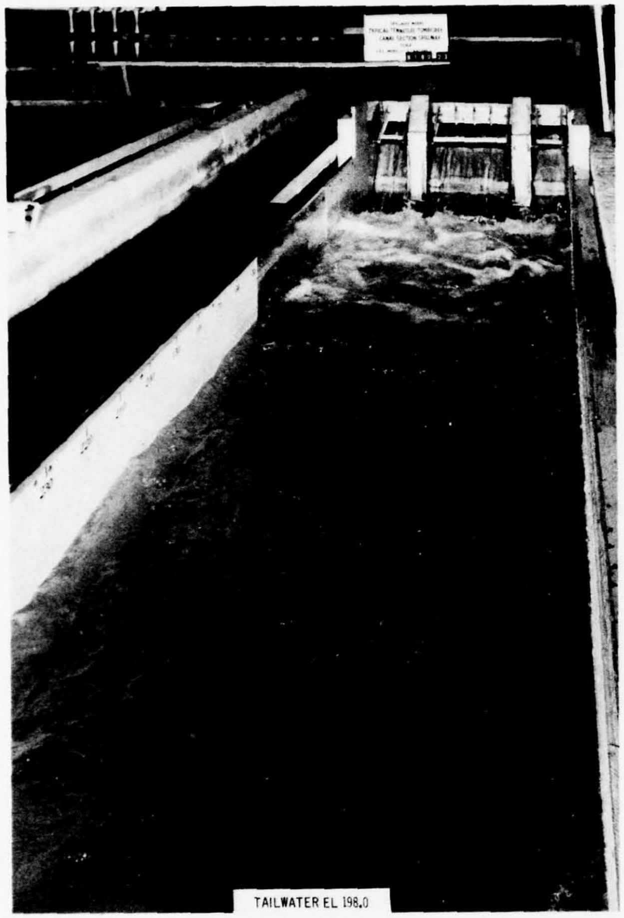


Photo 3 (sheet 2 of 2)



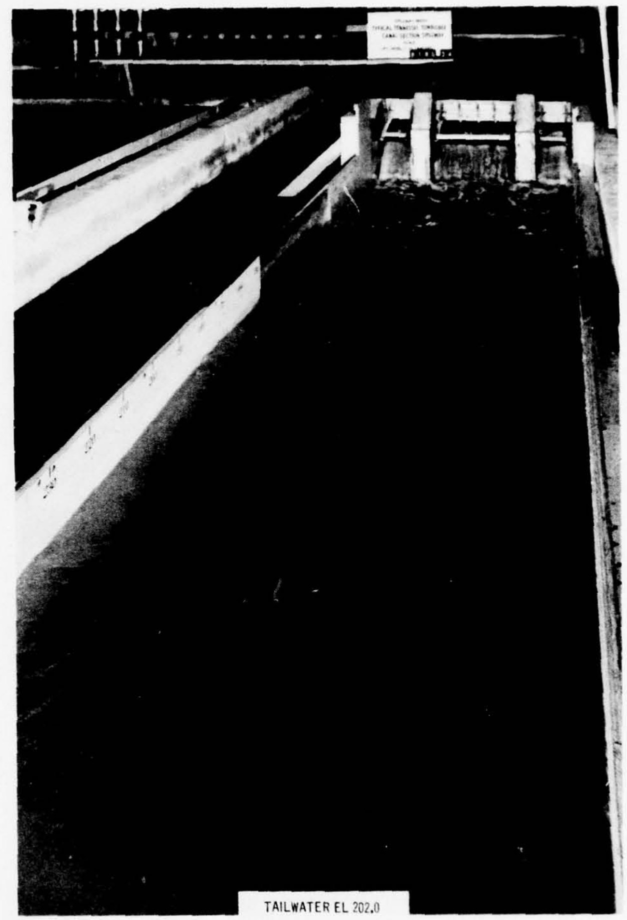


Photo 4 (sheet 2 of 2)

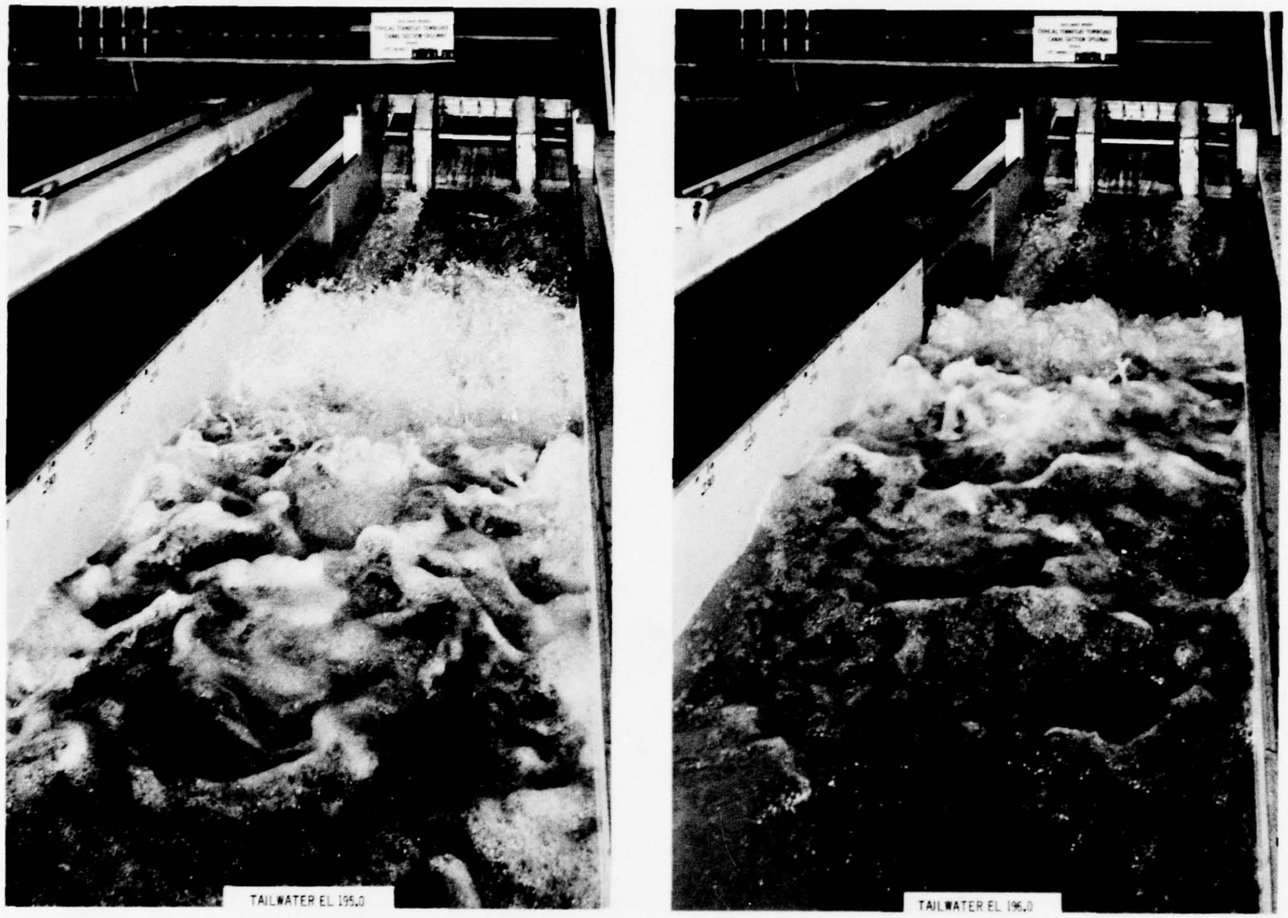
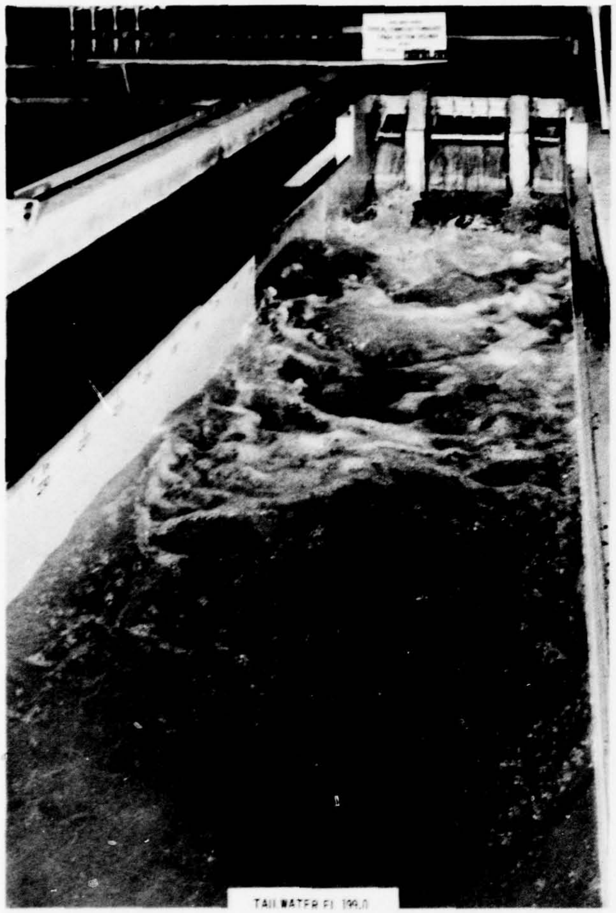


Photo 5. Flow conditions in Spillway A stilling basin; unit discharge 140 cfs/ft, pool el 226.2, gate opening 8 ft (sheet 1 of 2)



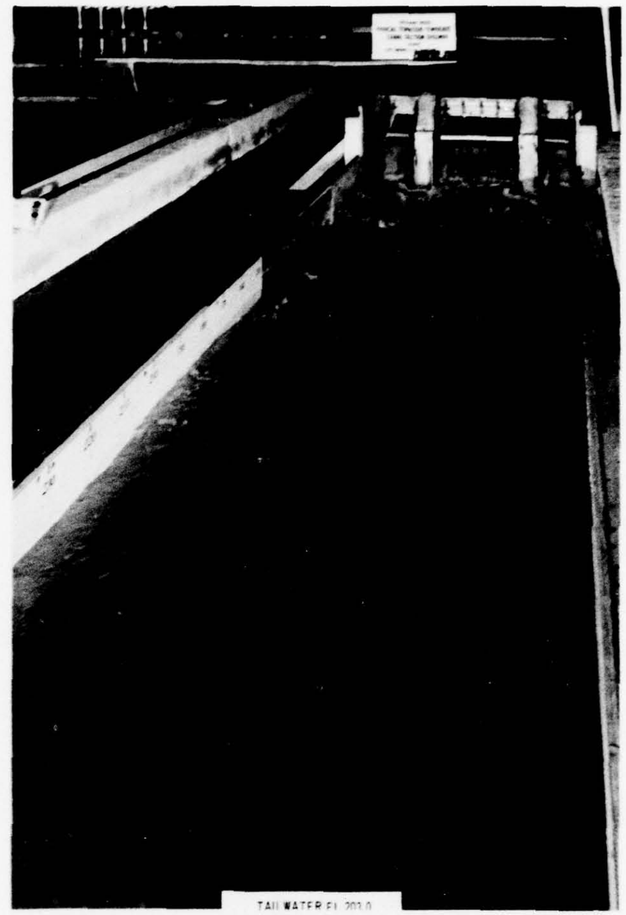


Photo 5 (sheet 2 of 2)

Photo 6. Flow conditions in Spillway A stilling basin; unit discharge 212 cfs/ft, pool el 228.0, uncontrolled flow (sheet 1 of 2)

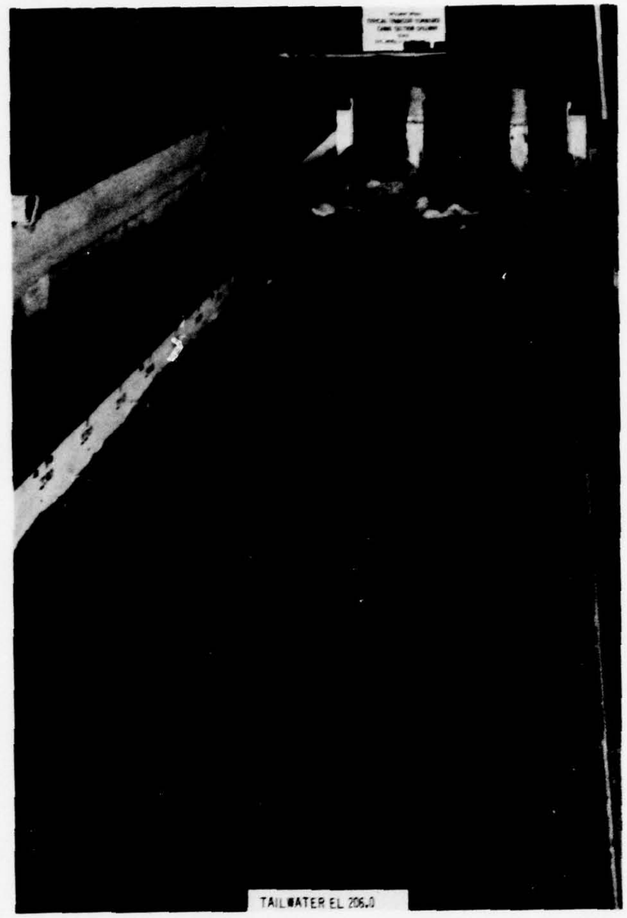


Photo 6 (sheet 2 of 2)

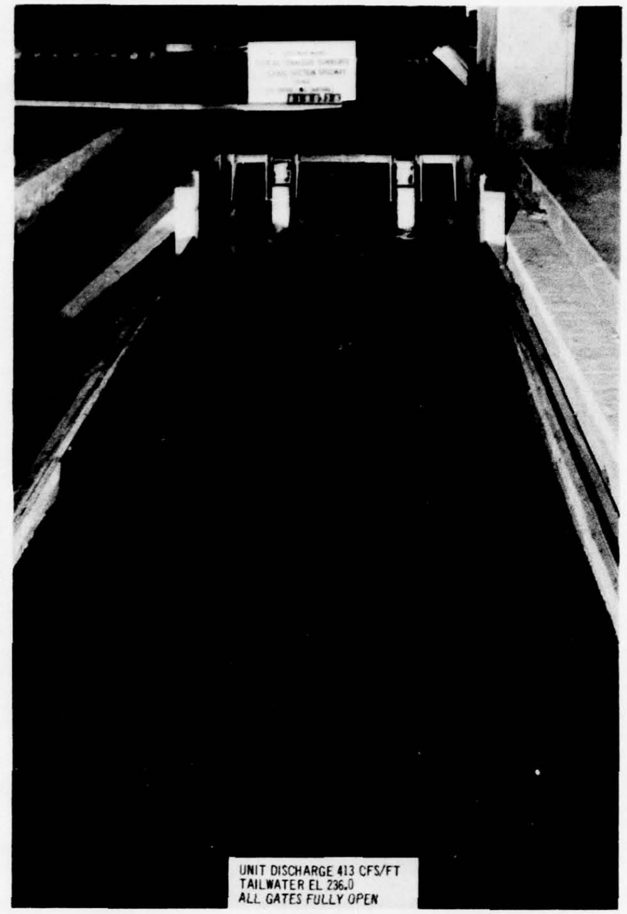
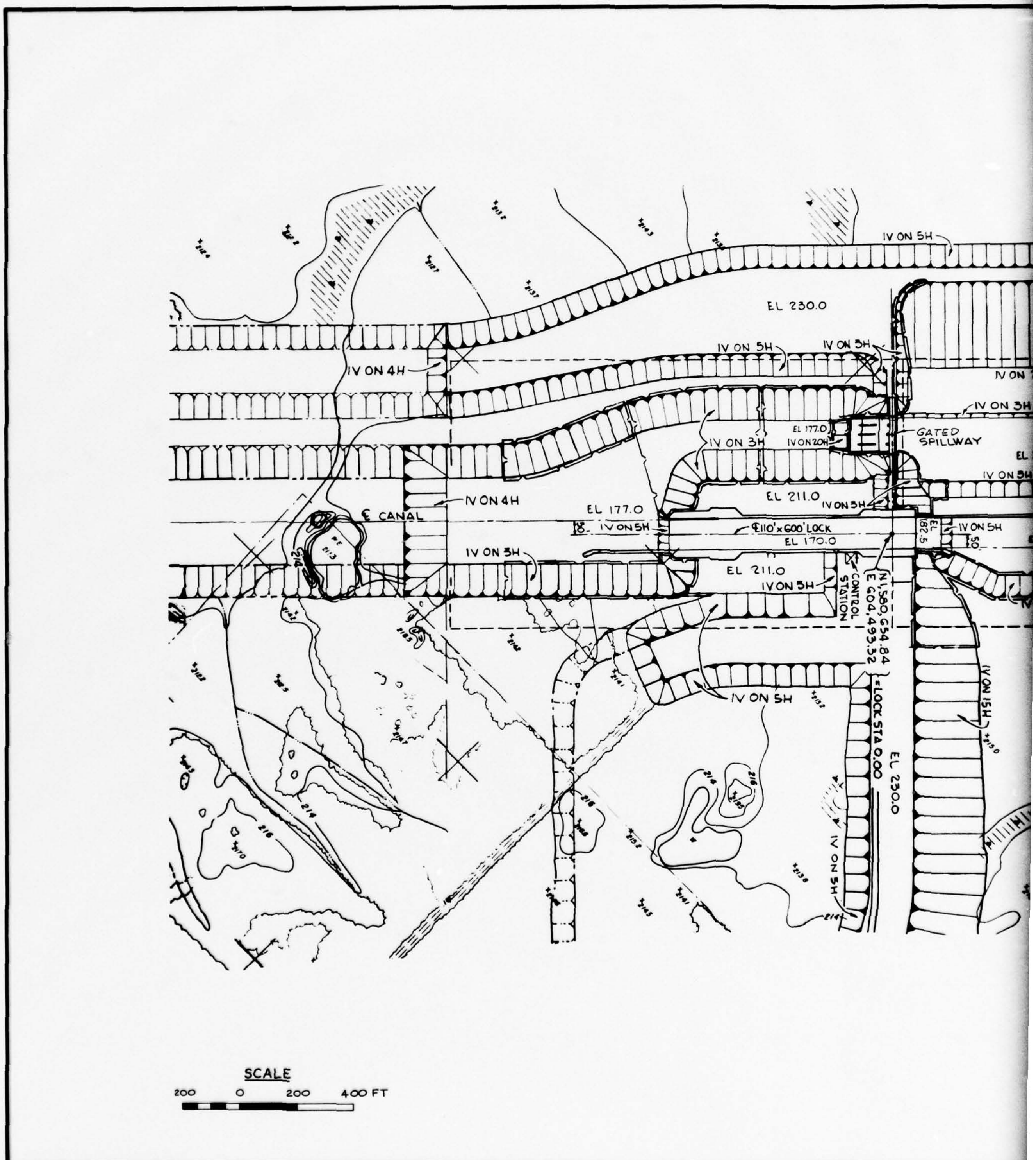
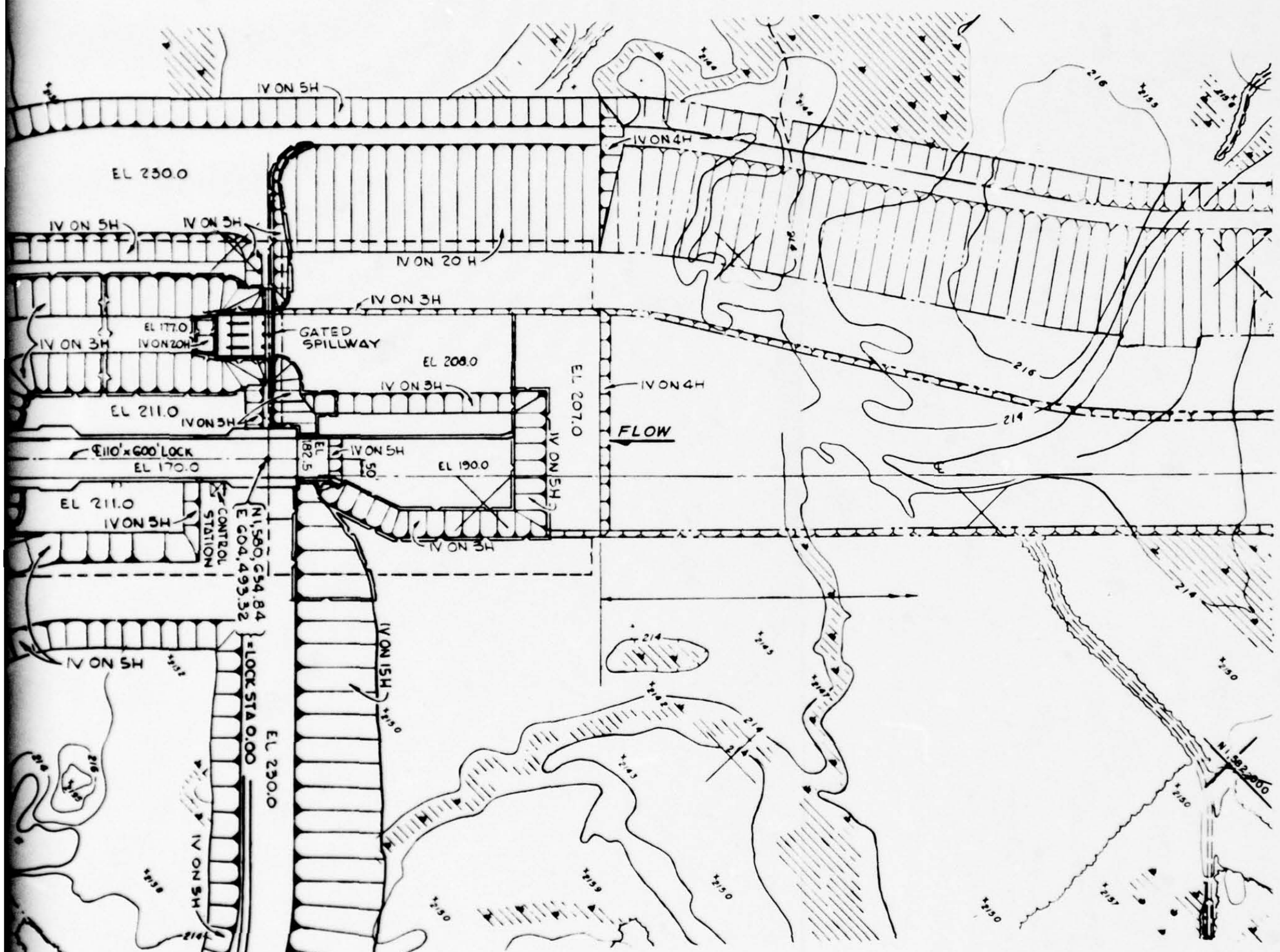


Photo 7. Spillway B, type 4 stilling basin, type 2 divider walls

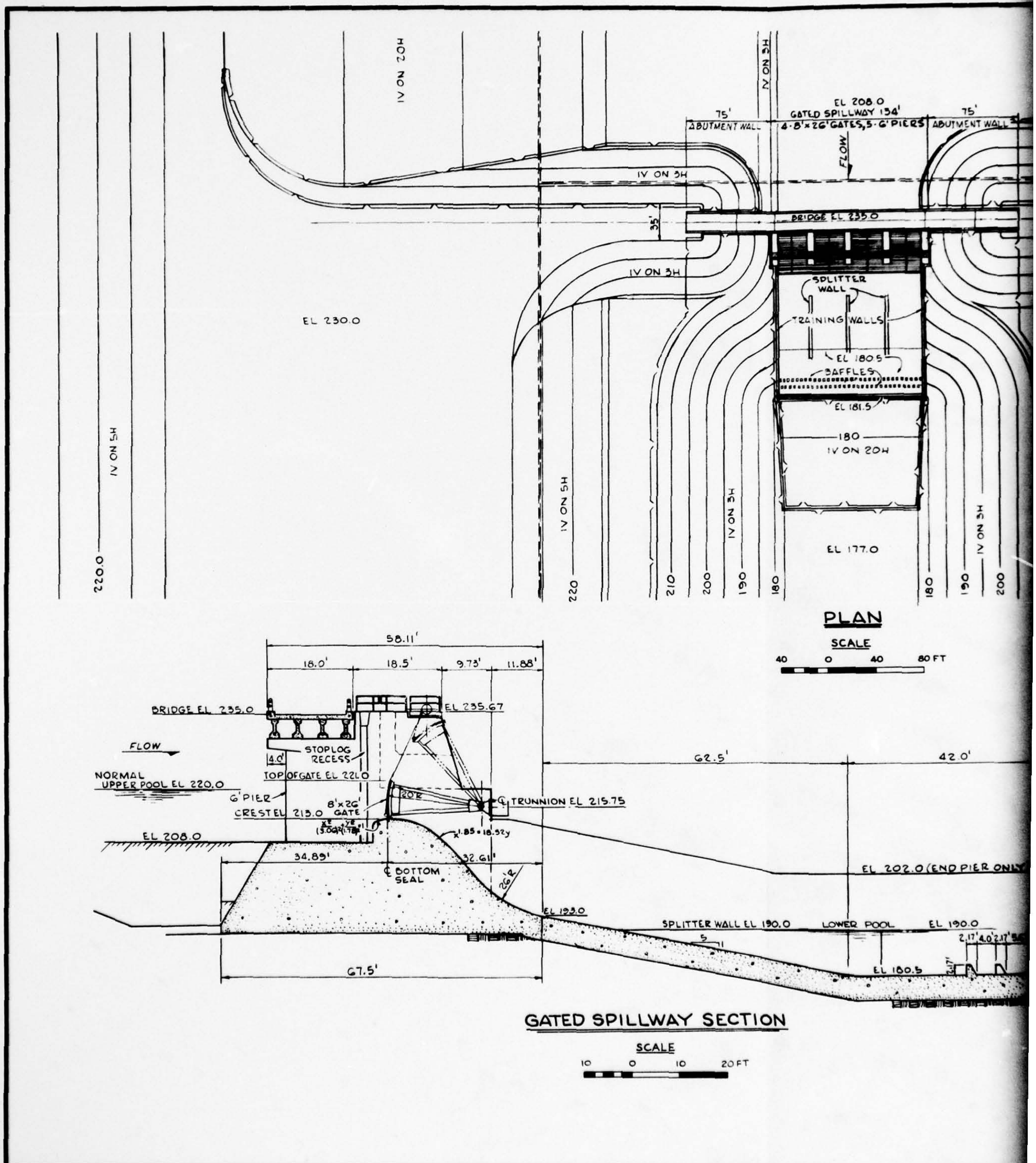


IV ON 5H
EL 230.0
IV ON 4H
IV ON 5H
IV ON 5H
IV ON 3H
EL 177.0
IV ON 20H
GATED SPILLWAY
IV ON 3H
IV ON 3H
IV ON 4H
℄ CANAL
EL 177.0
EL 211.0
IV ON 5H
IV ON 5H
℄ 110' x 600' LOCK
EL 170.0
EL 182.5
IV ON 5H
IV ON 5H
EL 211.0
IV ON 5H
CONTROL STATION
N 1,580,654.84
E 604,493.32
℄ LOCK STA 0.00
IV ON 5H
IV ON 15H
EL 230.0
IV ON 5H
SCALE
200 0 200 400 FT

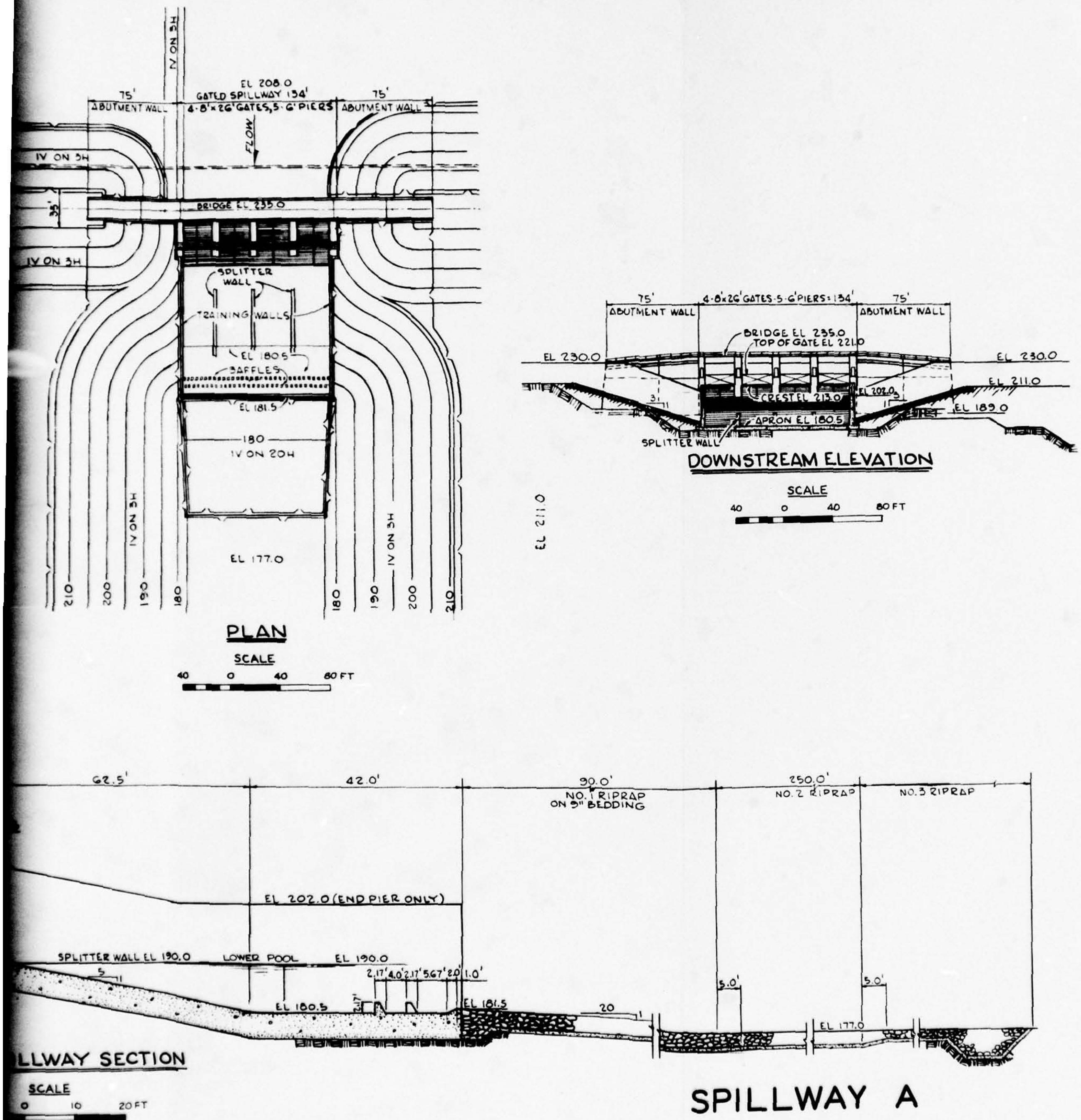


SPILLWAY A
PROJECT PLAN

PLATE 1

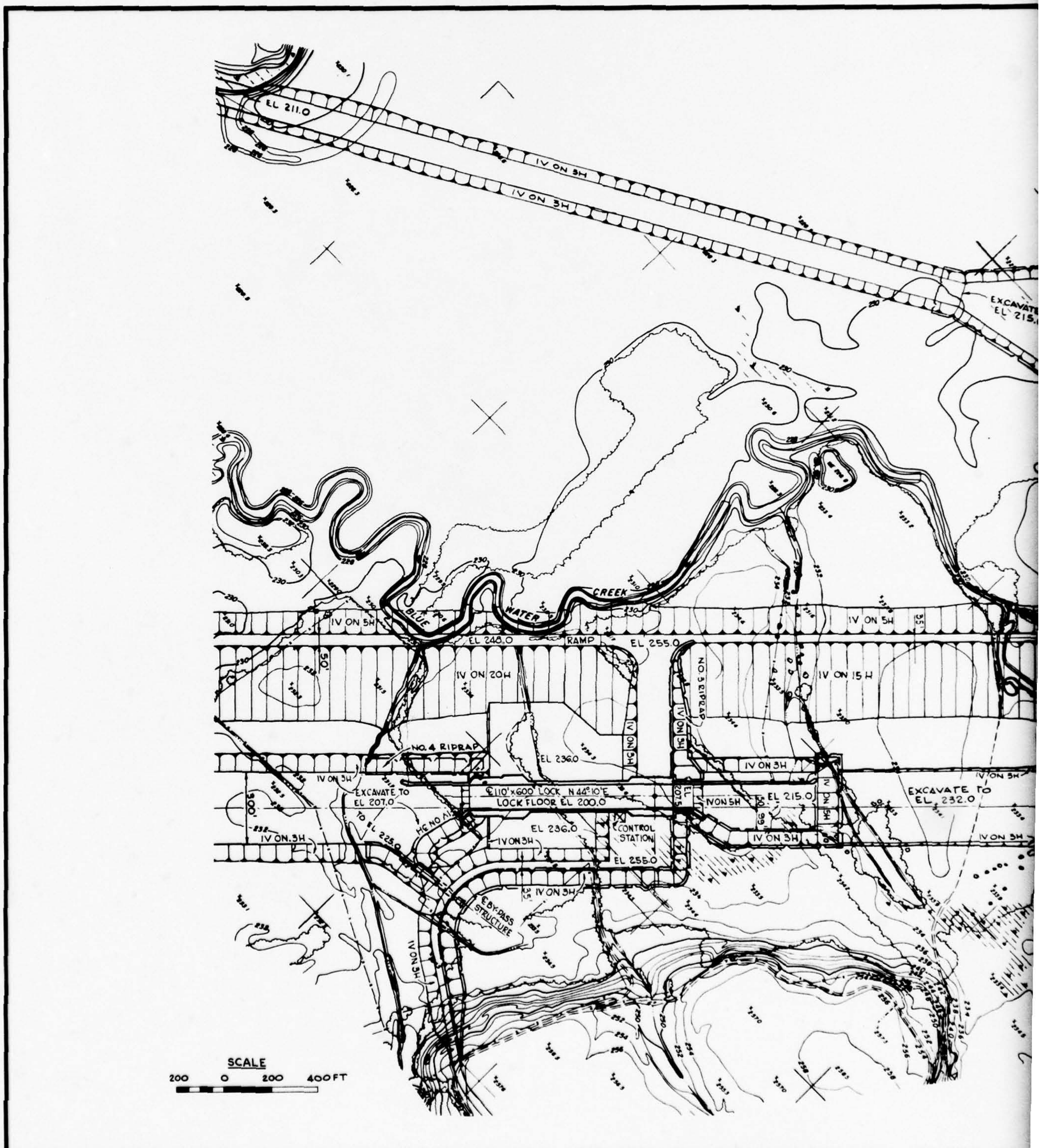


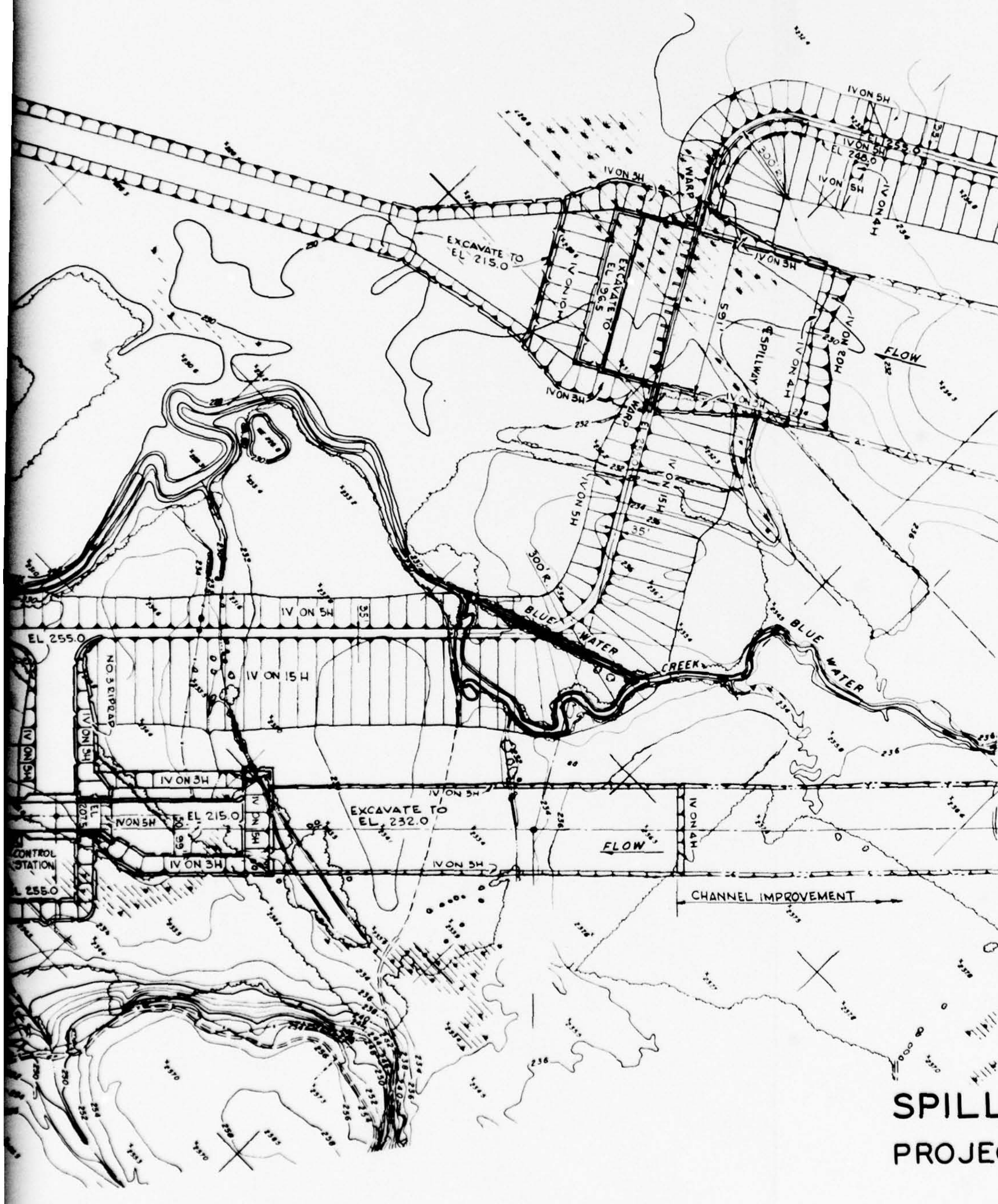
EL 208.0
GATED SPILLWAY 134'
4-8'x26' GATES, 5-6' PIERS
75'
ABUTMENT WALL
FLOW
IV ON 3H
IV ON 5H
IV ON 20H
35'
BRIDGE EL 235.0
SPLITTER WALL
TRAINING WALLS
EL 180.5
BAFFLES
EL 181.5
180
EL 230.0
EL 177.0
220.0
220
210
200
190
180
PLAN
SCALE
40 0 40 80 FT
58.11'
18.0'
18.5'
9.73'
11.88'
BRIDGE EL 235.0
EL 235.67
FLOW
STOPLOG RECESS
4.0'
TOP OF GATE EL 221.0
NORMAL UPPER POOL EL 220.0
6' PIER
8'x26' GATE
20'R
CREST EL 213.0
TRUNNION EL 215.75
EL 208.0
$x^{1.85} = 18.52y$
34.89'
32.61'
BOTTOM SEAL
26'R
EL 193.0
62.5'
42.0'
EL 202.0 (END PIER ONLY)
SPLITTER WALL EL 190.0
LOWER POOL EL 190.0
5
1
EL 180.5
67.5'
GATED SPILLWAY SECTION
SCALE
10 0 10 20 FT



SPILLWAY A

PLAN, ELEVATION, AND SECTION

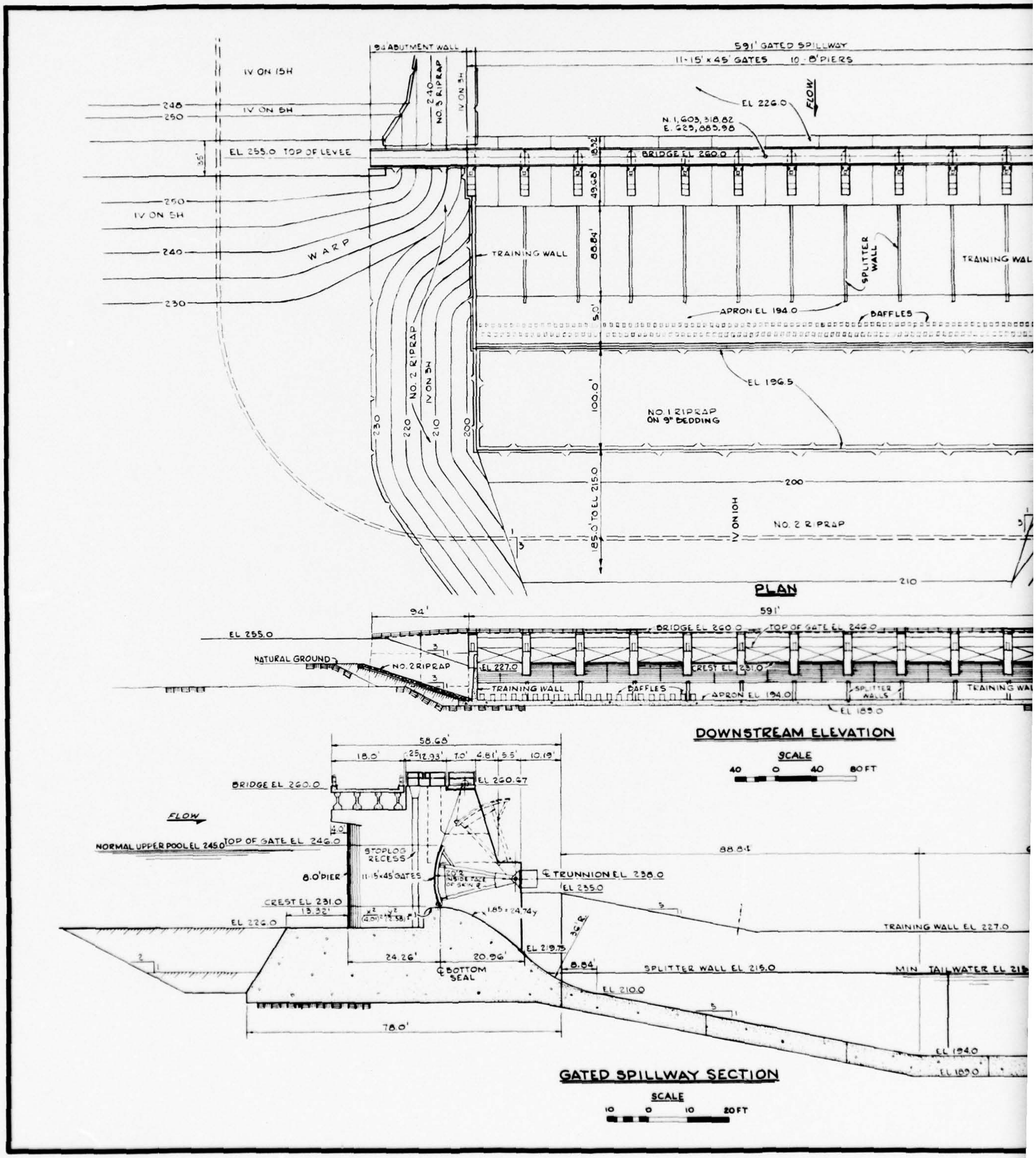

EL 211.0
IV ON 3H
IV ON 3H
EXCAVATE
EL 215.
BLUE
WATER
CREEK
IV ON 5H
EL 248.0
RAMP
EL 255.0
IV ON 20H
NO. 5 RIPRAP
IV ON 15 H
NO. 4 RIPRAP
EL 236.0
IV ON 3H
EXCAVATE TO
EL 207.0
℄ 110'×600' LOCK N 44°10'E
LOCK FLOOR EL 200.0
EL 215.0
EXCAVATE TO
EL 232.0
TO EL 225.0
EL 236.0
IV ON 3H
CONTROL
STATION
EL 255.0
IV ON 3H
℄ BY-PASS
STRUCTURE
IV ON 3H
SCALE
200 0 200 400 FT

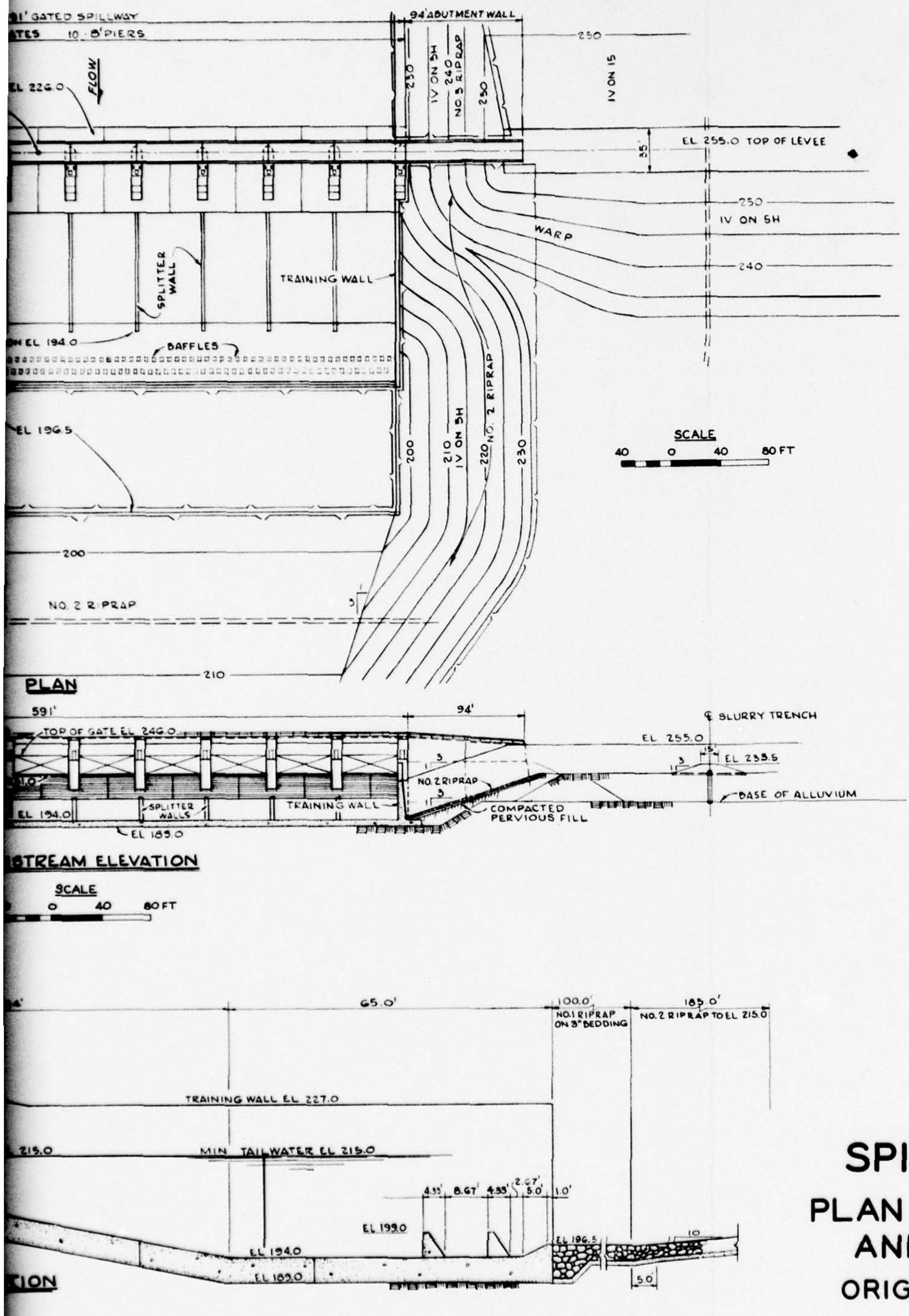


SPILLWAY B

PROJECT PLAN

PLATE 3

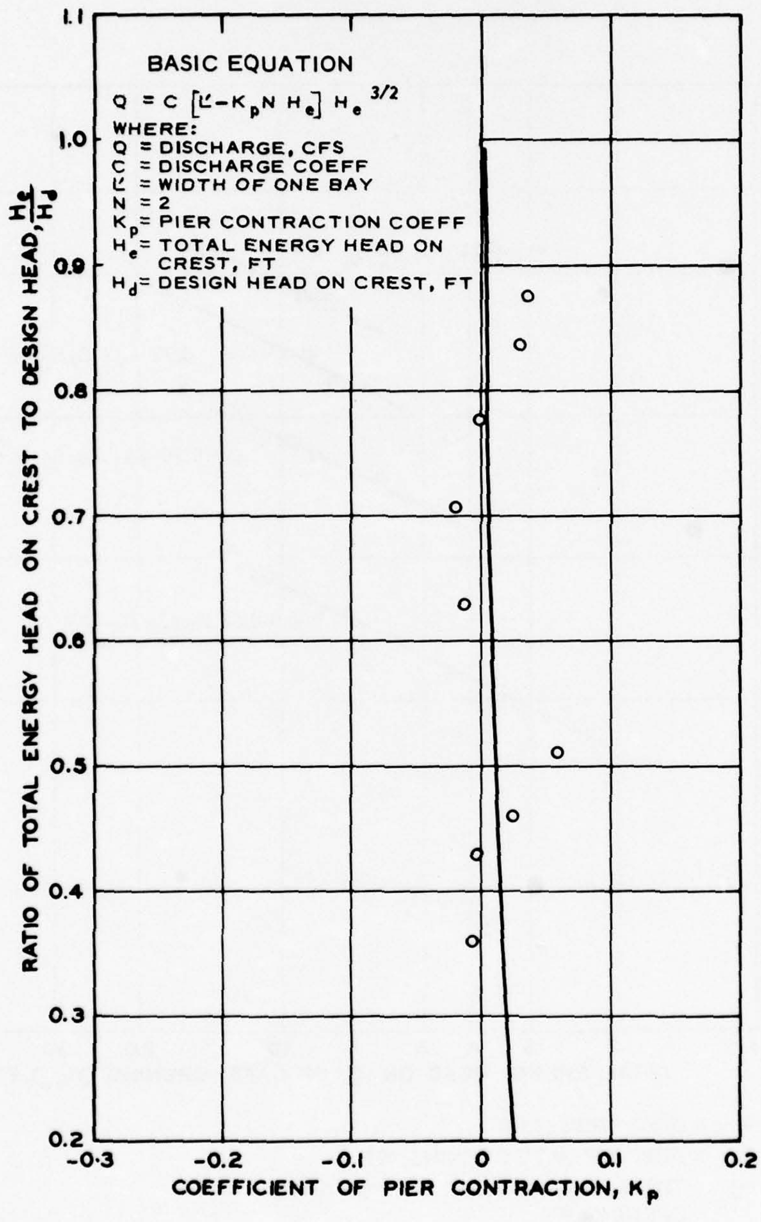

591' GATED SPILLWAY
11-15'x45' GATES 10-8' PIERS
94' ABUTMENT WALL
IV ON 15H
IV ON 5H
NO. 3 RIPRAP
EL 255.0 TOP OF LEVEE
EL 226.0
FLOW
N. 1,603,318.82
E. 625,885.98
BRIDGE EL 260.0
WARP
TRAINING WALL
SPLITTER WALL
APRON EL 194.0
BAFFLES
NO. 2 RIPRAP
IV ON 3H
EL 196.5
NO. 1 RIPRAP ON 9" BEDDING
185.0' TO EL 215.0
IV ON 10H
NO. 2 RIPRAP
PLAN
EL 255.0
NATURAL GROUND
TOP OF GATE EL 246.0
EL 227.0
CREST EL 231.0
SPLITTER WALLS
EL 189.0
DOWNSTREAM ELEVATION
SCALE
40 0 40 80 FT
BRIDGE EL 260.0
EL 260.67
FLOW
NORMAL UPPER POOL EL 245.0
TOP OF GATE EL 246.0
STOPLOG RECESS
8.0' PIER
11-15'x45' GATES
℄ TRUNNION EL 238.0
EL 235.0
CREST EL 231.0
EL 226.0
℄ BOTTOM SEAL
EL 219.75
SPLITTER WALL EL 215.0
TRAINING WALL EL 227.0
MIN TAILWATER EL 21
EL 210.0
EL 194.0
EL 189.0
78.0'
GATED SPILLWAY SECTION
SCALE
10 0 10 20 FT



SPILLWAY B

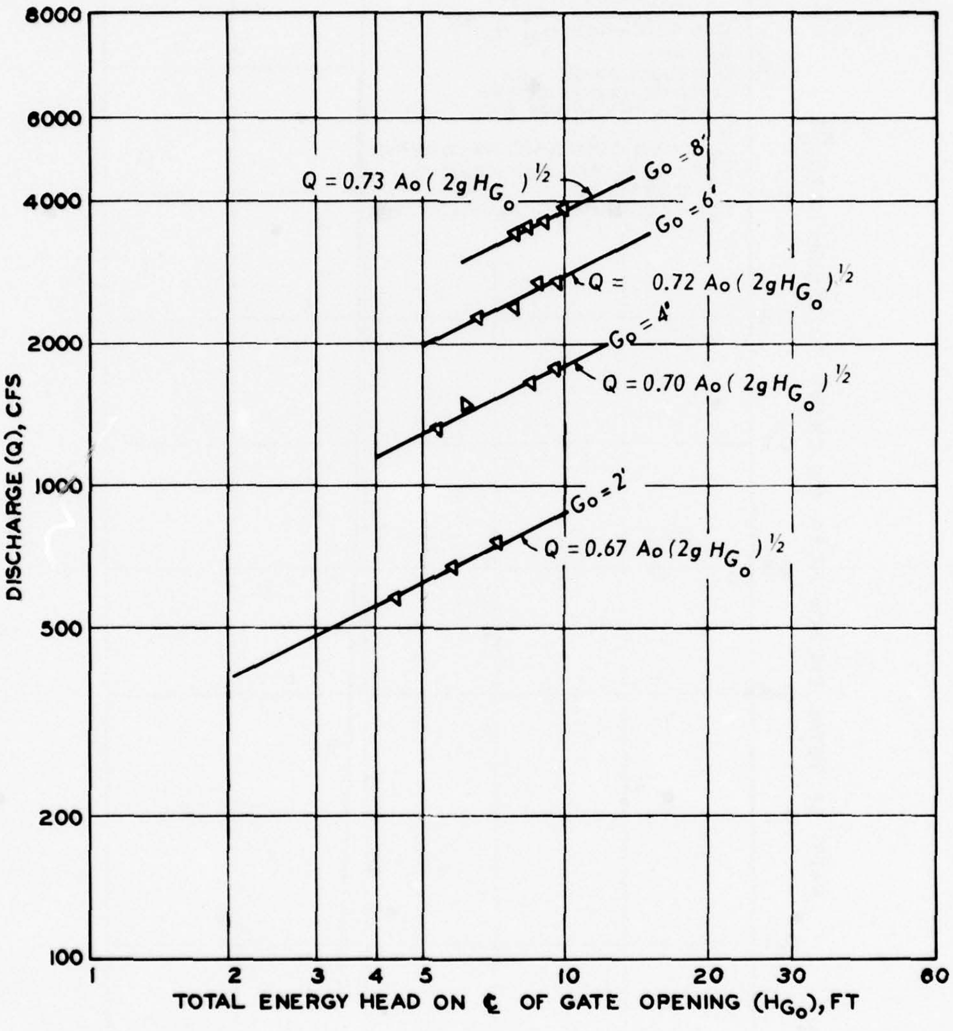
PLAN, ELEVATION, AND SECTION

ORIGINAL DESIGN



PIER CONTRACTION COEFFICIENTS

SPILLWAY A



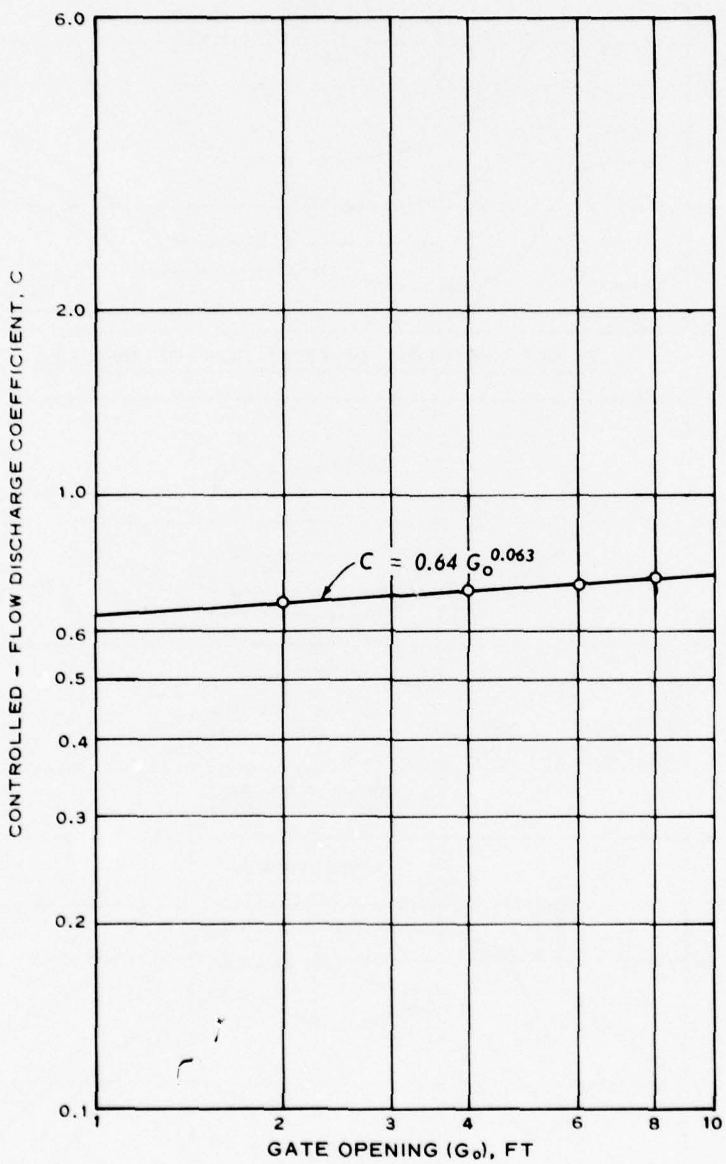
Q = DISCHARGE, CFS

A_o = AREA OF GATE OPENING, FT^2

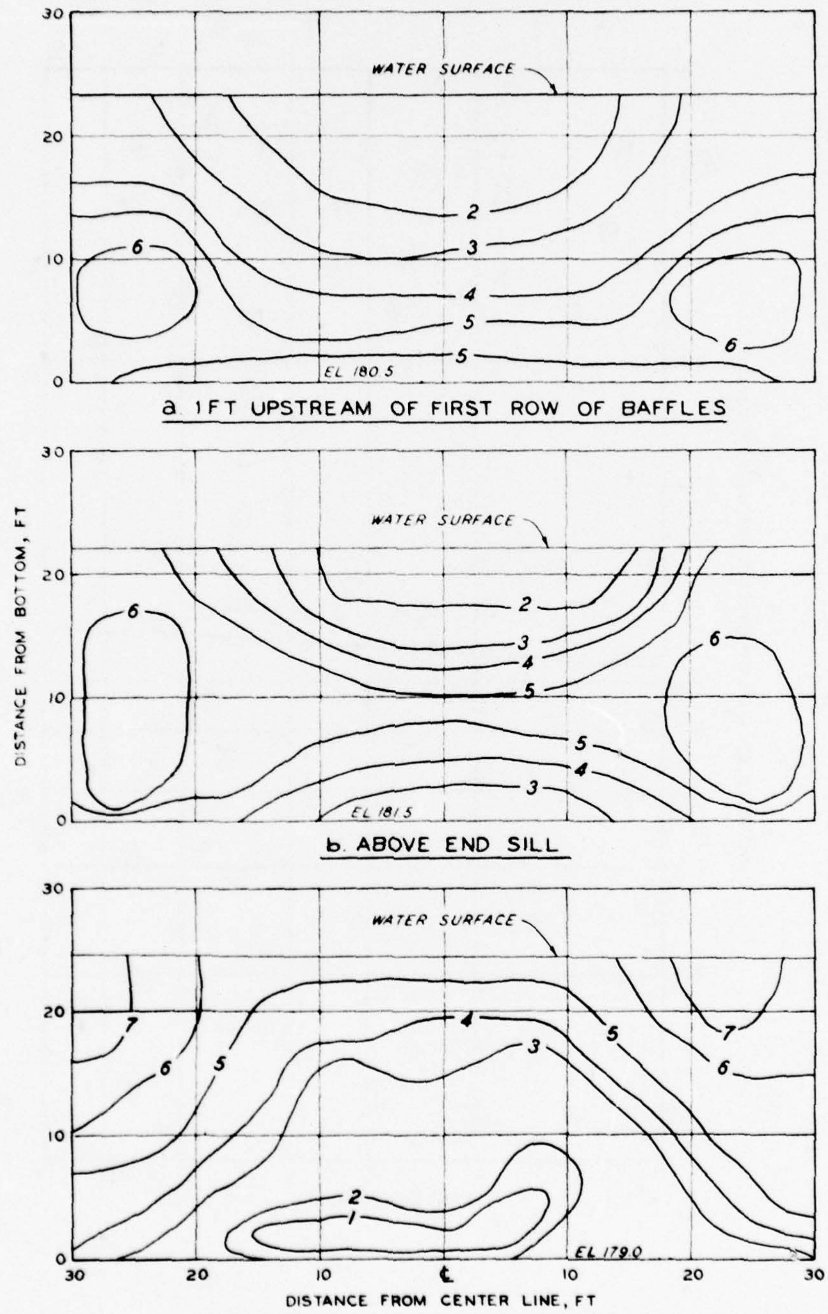
H_{G_o} = TOTAL ENERGY HEAD ON ℄ OF GATE OPENING, FT

g = ACCELERATION DUE TO GRAVITY, FT /SEC^2

HEAD – DISCHARGE RELATIONS FOR CONTROLLED FLOW THROUGH SINGLE GATE BAY OF SPILLWAY A



CONTROLLED-FLOW DISCHARGE
COEFFICIENT VERSUS GATE OPENING
SPILLWAY A

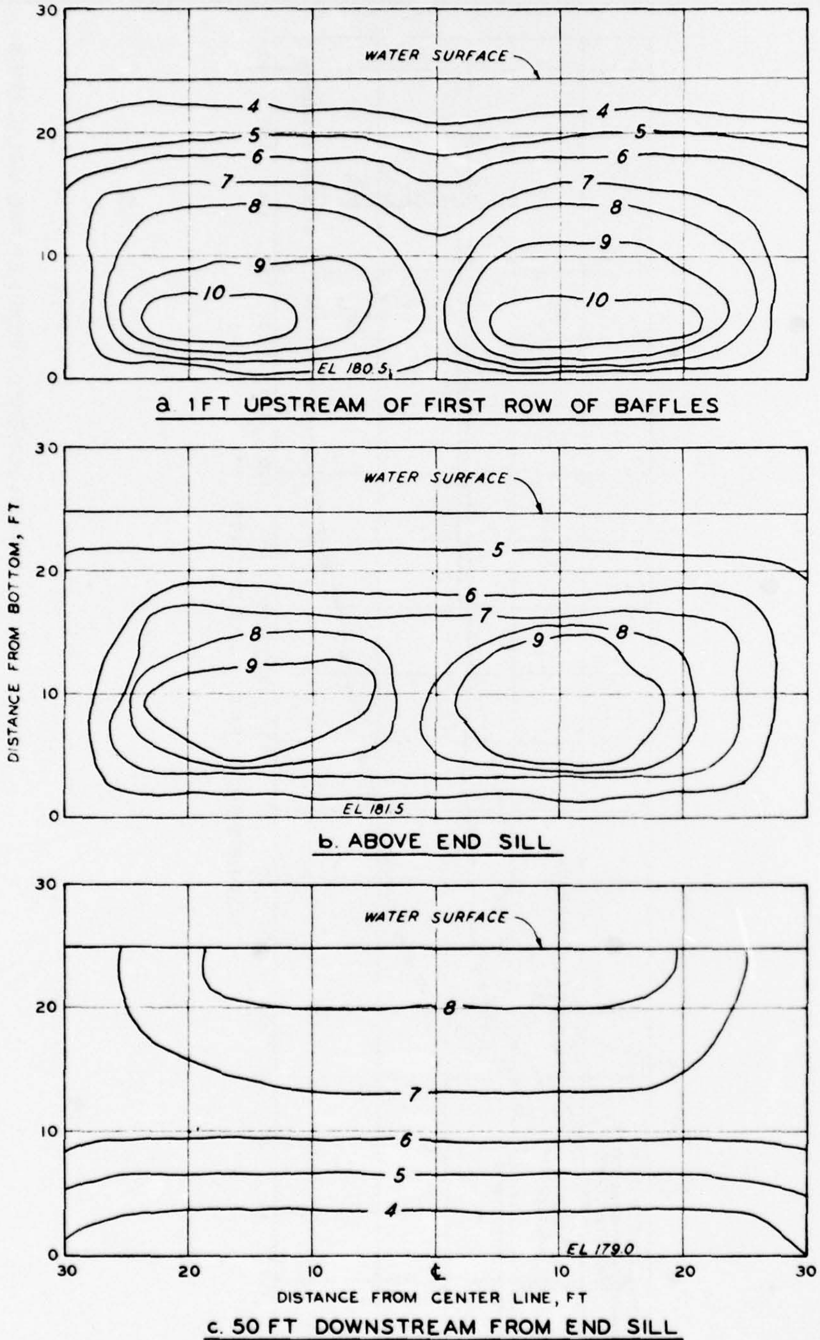


c. 50 FT DOWNSTREAM FROM END SILL

TEST CONDITIONS

G_o 6 FT
TAILWATER EL 203.6

ISOVELS, SPILLWAY A
UNIT DISCHARGE 103 CFS/FT



a. 1 FT UPSTREAM OF FIRST ROW OF BAFFLES

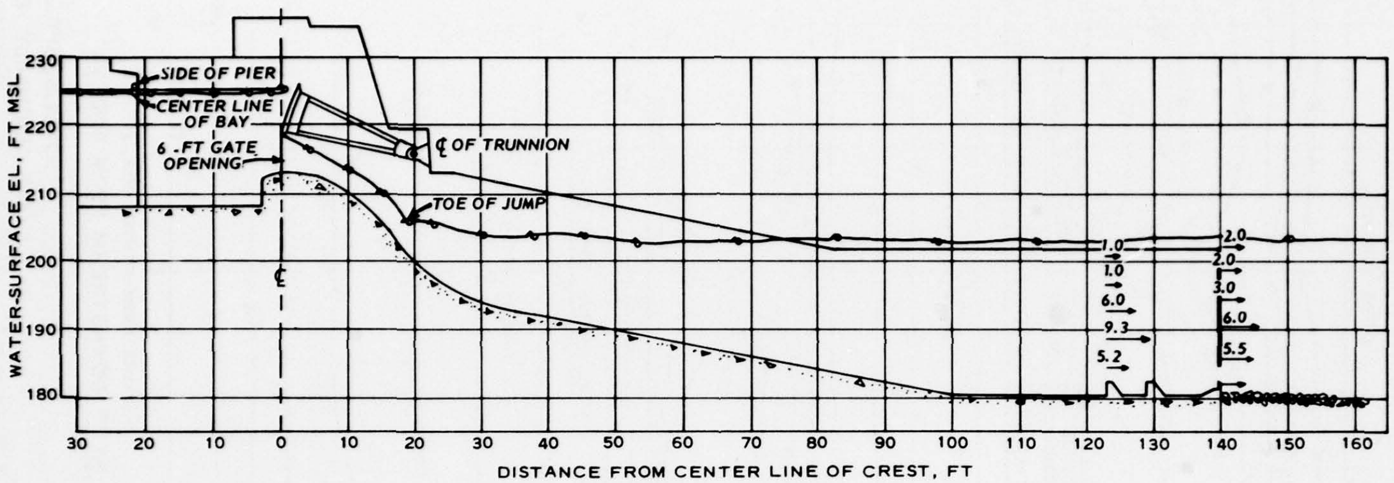
b. ABOVE END SILL

c. 50 FT DOWNSTREAM FROM END SILL

TEST CONDITIONS

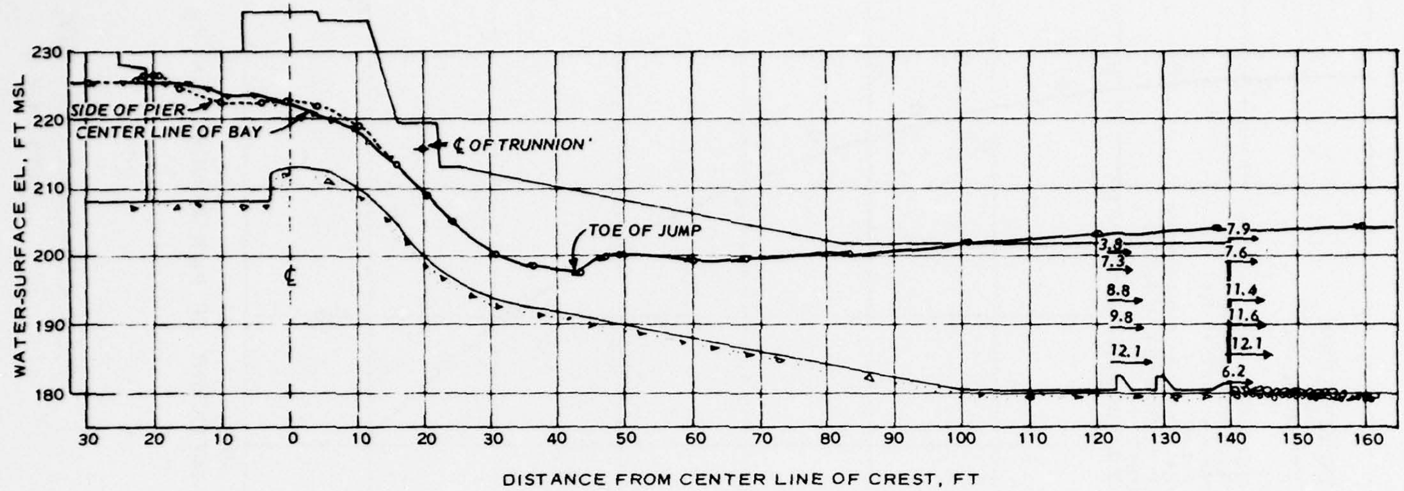
TAILWATER EL 204.7
ALL GATES OPEN

ISOVELS, SPILLWAY A
UNIT DISCHARGE 212 CFS/FT



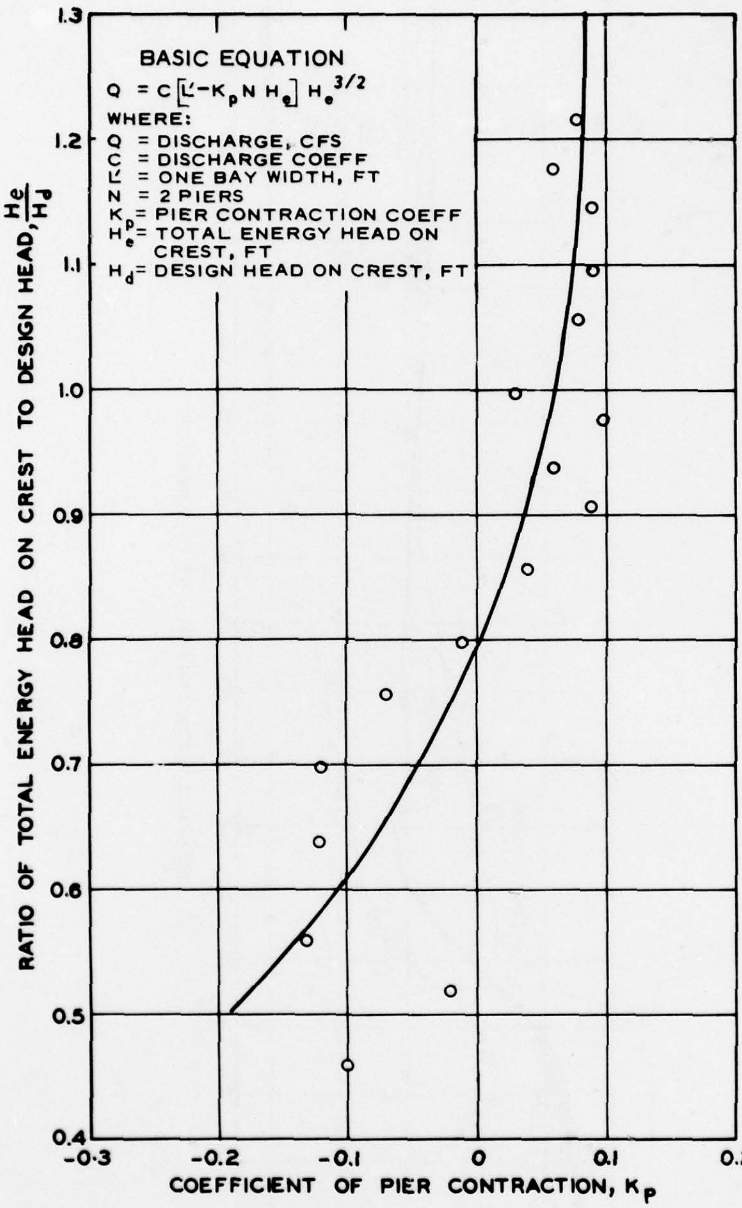
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND

WATER-SURFACE PROFILES AND VELOCITIES
SPILLWAY A, ORIGINAL DESIGN
UNIT DISCHARGE 103 CFS/FT
TAILWATER EL 203.6 FT



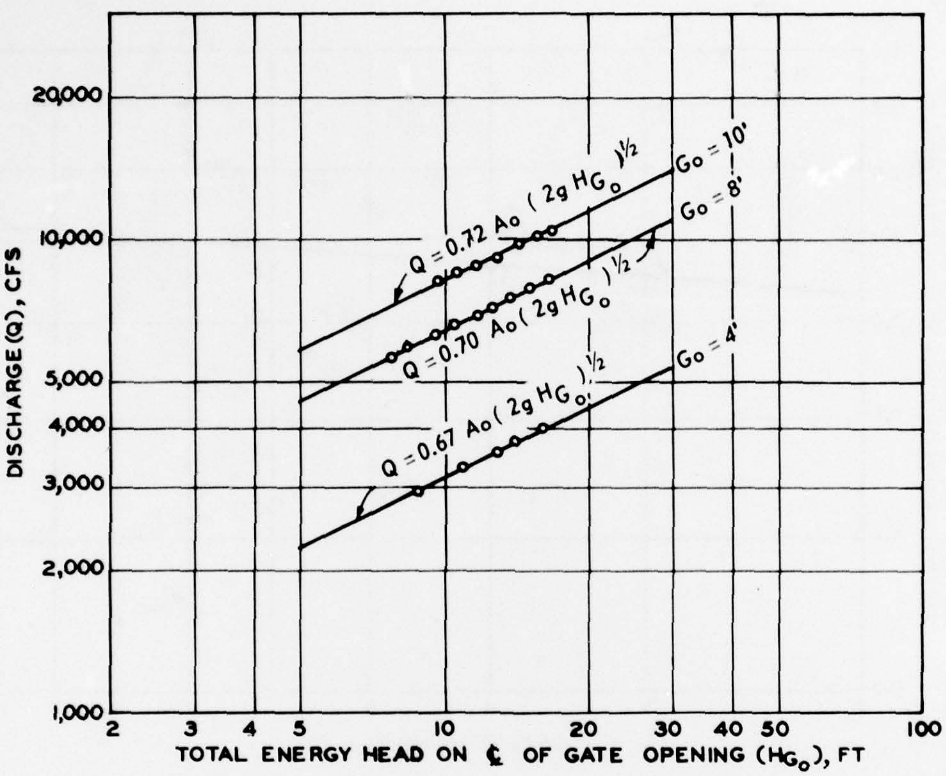
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND

WATER-SURFACE PROFILES AND VELOCITIES
SPILLWAY A, ORIGINAL DESIGN
UNIT DISCHARGE 212 CFS/FT
TAILWATER EL 224.7 FT



PIER CONTRACTION COEFFICIENTS

SPILLWAY B



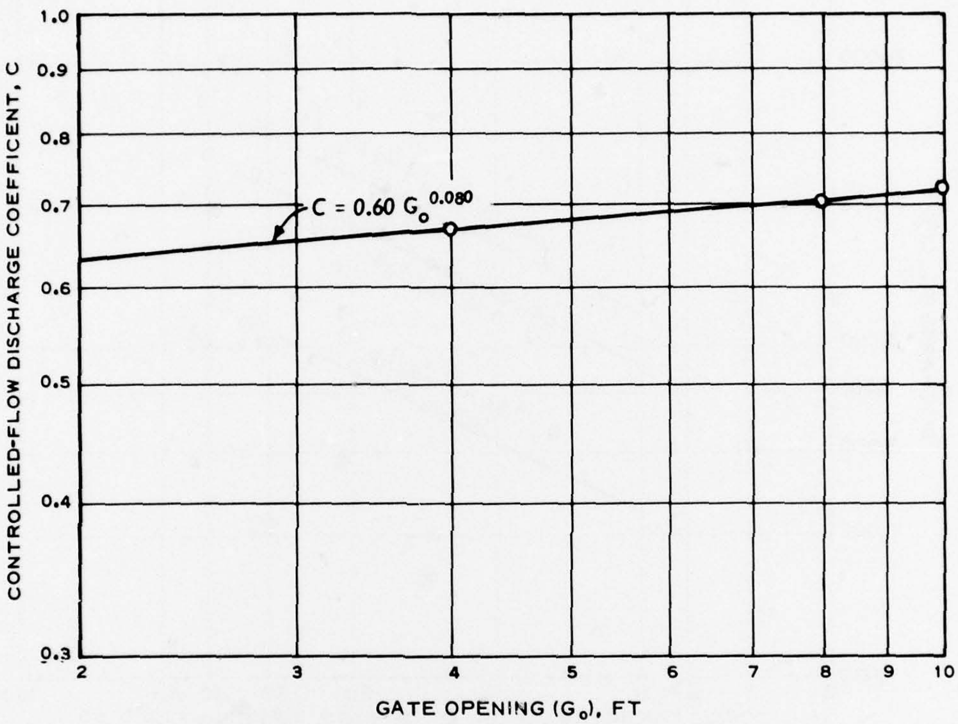
Q = DISCHARGE, CFS

Ao = AREA OF GATE OPENING, FT^2

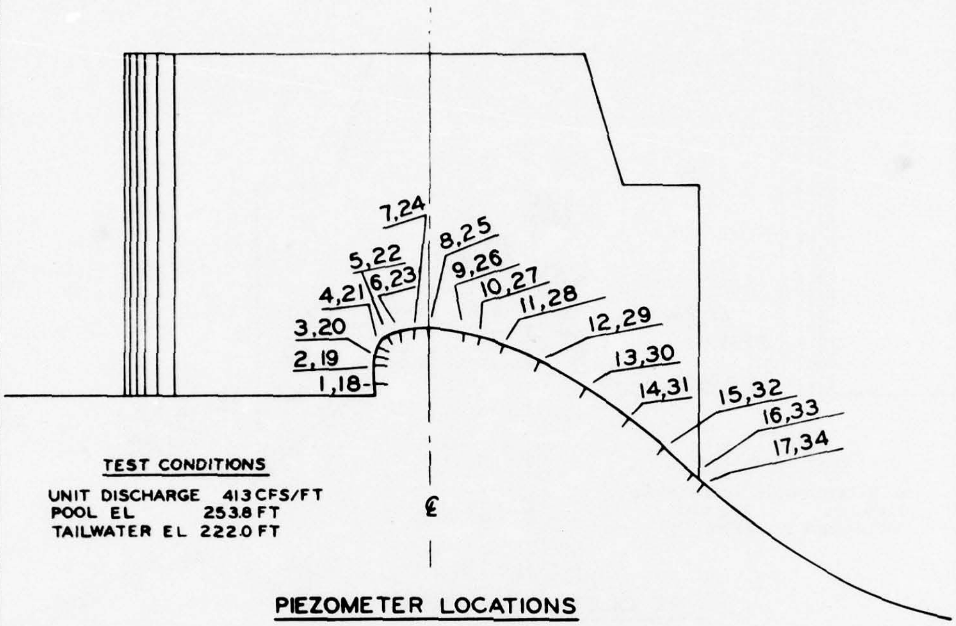
H_{G_o} = TOTAL ENERGY HEAD ON ℄ OF GATE OPENING, FT

g = ACCELERATION DUE TO GRAVITY, FT/SEC^2

HEAD – DISCHARGE RELATIONS FOR CONTROLLED FLOW THROUGH SINGLE GATE BAY OF SPILLWAY B



CONTROLLED-FLOW DISCHARGE
COEFFICIENT VERSUS GATE OPENING
SPILLWAY B



TEST CONDITIONS

UNIT DISCHARGE 413 CFS/FT
POOL EL 253.8 FT
TAILWATER EL 222.0 FT

PIEZOMETER LOCATIONS

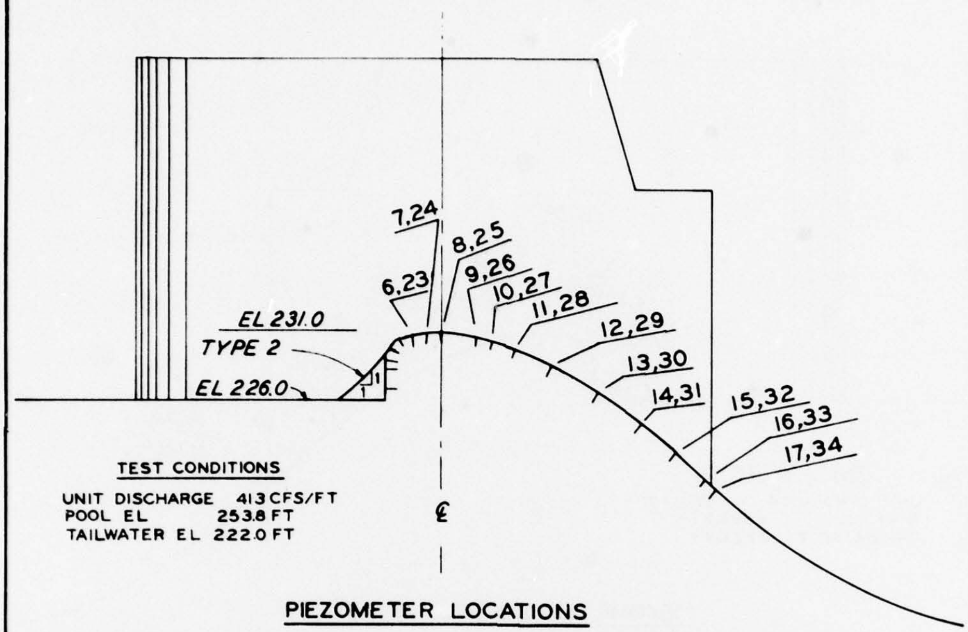
PIEZ NO.*	ELEVATION FT MSL	DIST FROM ℄, FT	PRESSURE** SIDE	PRESSURE** ℄
1,18	227.0	4.01	26.0	26.0
2,19	228.2	4.01	24.3	23.8
3,20	228.7	3.9	22.3	22.3
4,21	229.4	3.5	20.1	17.9
5,22	229.8	3.0	13.7	13.2
6,23	230.3	2.0	5.7	6.7
7,24	230.5	1.0	0.5	1.5
8,25	231.0	0.0	-0.5	0.0
9,26	230.8	2.67	-0.8	-0.8
10,27	230.5	3.89	-1.5	-1.5
11,28	230.0	5.65	-1.0	-1.0
12,29	229.0	8.22	-1.0	0.0
13,30	227.0	11.95	0.0	0.0
14,31	225.0	14.88	0.0	1.0
15,32	223.0	17.38	3.0	4.0
16,33	221.0	19.61	4.0	4.5
17,34	219.8	20.96	5.0	5.0

PRESSURES

* PIEZOMETERS 1-17 ARE LOCATED ON ℄ OF GATE BAY AND PIEZOMETERS 18-34 ARE LOCATED ON A LINE 0.3 FT FROM THE PIER

** PRESSURES ARE IN FEET OF WATER.

PIEZOMETER LOCATIONS AND PRESSURES ON CREST
SPILLWAY B



TEST CONDITIONS

UNIT DISCHARGE 413 CFS/FT
POOL EL 253.8 FT
TAILWATER EL 222.0 FT

PIEZOMETER LOCATIONS

PIEZ NO.*		ELEVATION FT MSL	DIST FROM ℄, FT	PRESSURE † SIDE	PRESSURE † ℄
**	1,18	227.0	4.01		
**	2,19	228.2	4.01		
**	3,20	228.7	3.9		
**	4,21	229.4	3.5		
**	5,22	229.8	3.0		
	6,23	230.3	2.0	3.0	2.0
	7,24	230.5	1.0	-0.8	-2.0
	8,25	231.0	0.0	-0.8	-1.3
	9,26	230.8	2.67	-0.5	-1.3
	10,27	230.5	3.89	-0.8	-0.5
	11,28	230.0	5.65	-0.3	0.0
	12,29	229.0	8.22	0.0	0.0
	13,30	227.0	11.95	1.0	1.0
	14,31	225.0	14.88	1.5	1.5
	15,32	223.0	17.38	4.0	3.6
	16,33	221.0	19.61	4.5	4.2
	17,34	219.8	20.96	5.0	5.0

PRESSURES

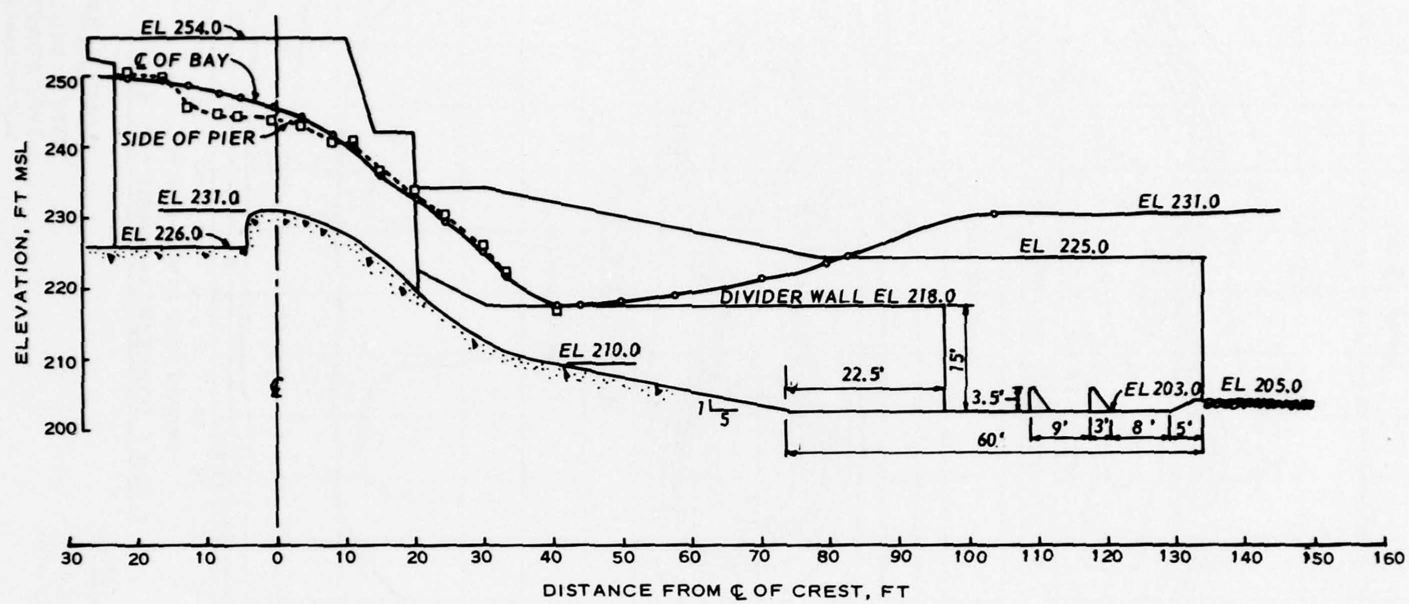
* PIEZOMETERS 1-17 ARE LOCATED ON ℄ OF GATE BAY AND PIEZOMETERS 18-34 ARE LOCATED ON A LINE 0.3 FT FROM THE PIER

** PIEZOMETERS 1-5 WERE ELIMINATED BY SLOPING THE SPILLWAY FACE

† PRESSURES ARE IN FEET OF WATER

PIEZOMETER LOCATIONS AND PRESSURES ON CREST

SPILLWAY B (TYPE 2 CREST)



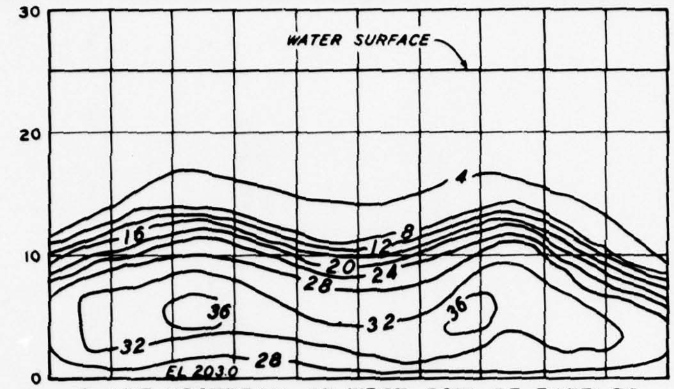
TEST CONDITIONS

UNIT DISCHARGE 413 CFS/FT (CREST)
TAILWATER EL 231.0 FT
ALL GATES FULLY OPEN

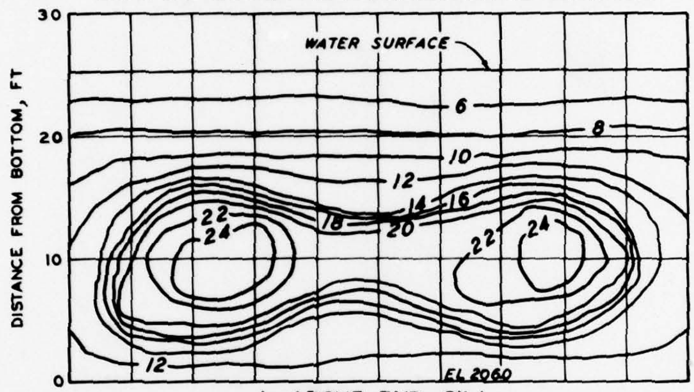
SCALE

10 0 10 20FT

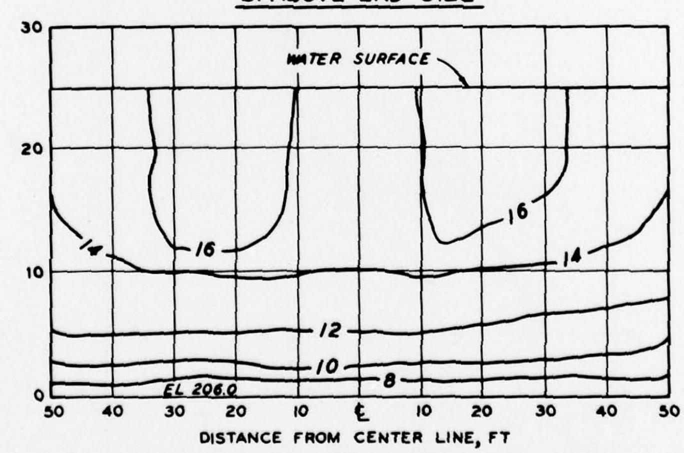
TYPE 4 (RECOMMENDED) STILLING BASIN
TYPE 2 DIVIDER WALLS
SPILLWAY B



a. 1 FT UPSTREAM OF FIRST ROW OF BAFFLES



b. ABOVE END SILL



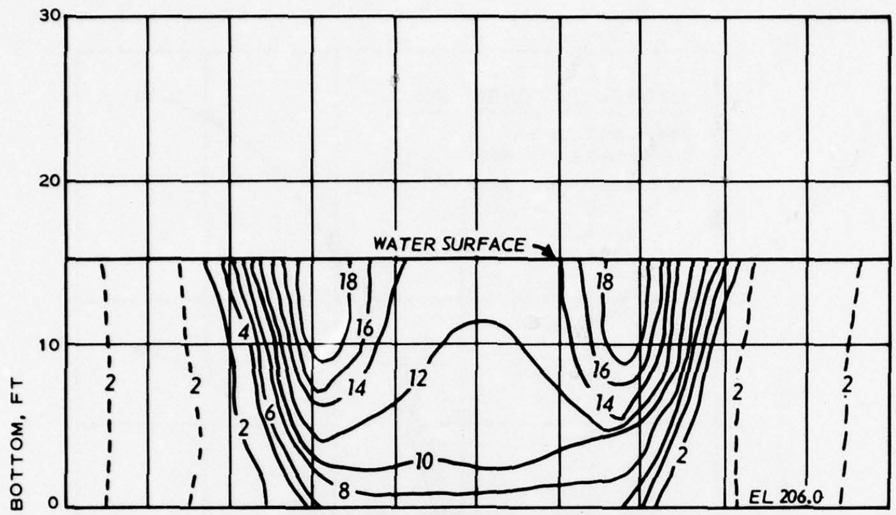
c. 50 FT DOWNSTREAM FROM END SILL

TEST CONDITIONS

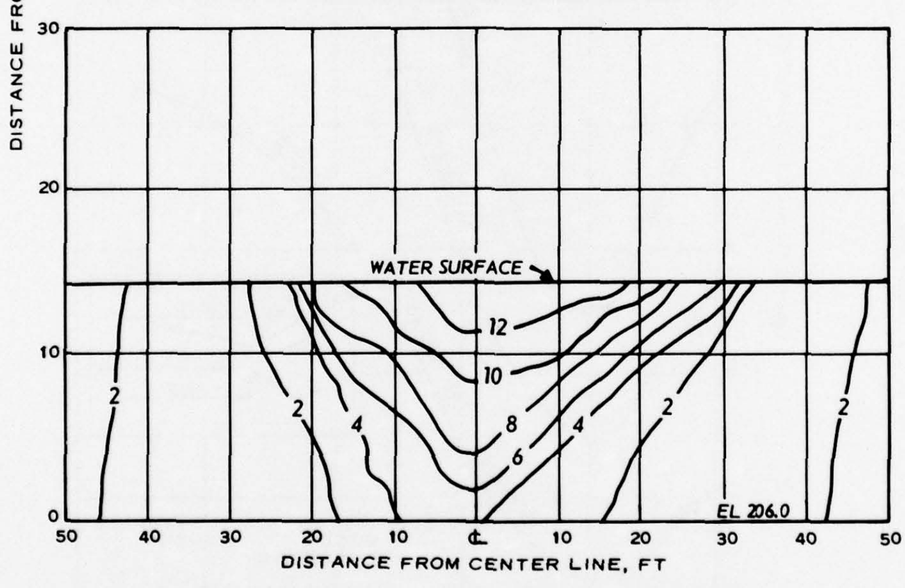
TAILWATER EL 231.0 FT
ALL GATES FULLY OPEN

ISOVELS, SPILLWAY B

TYPE 4 STILLING BASIN
TYPE 2 DIVIDER WALLS
UNIT DISCHARGE 413 CFS/FT



a. SINGLE GATE OPERATION, ABOVE END SILL



b. SINGLE GATE OPERATION, 50 FT DOWNSTREAM FROM END SILL

LEGEND

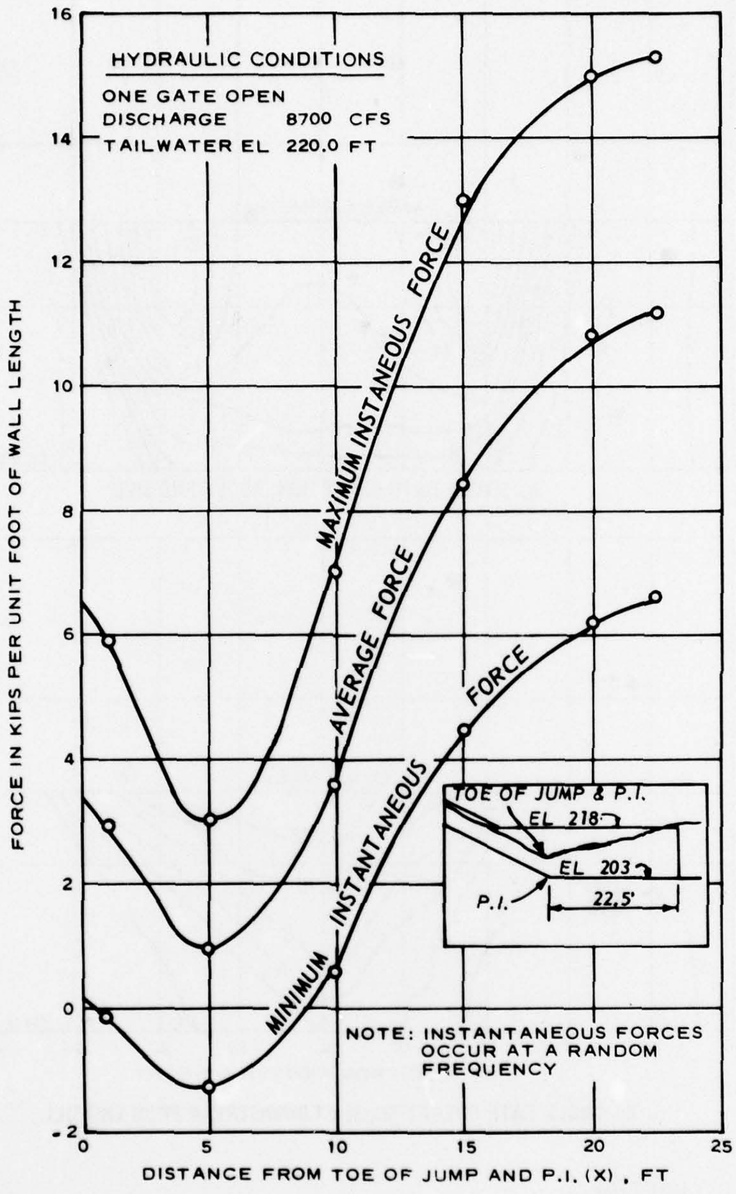
- - - UPSTREAM
—— DOWNSTREAM

TEST CONDITIONS

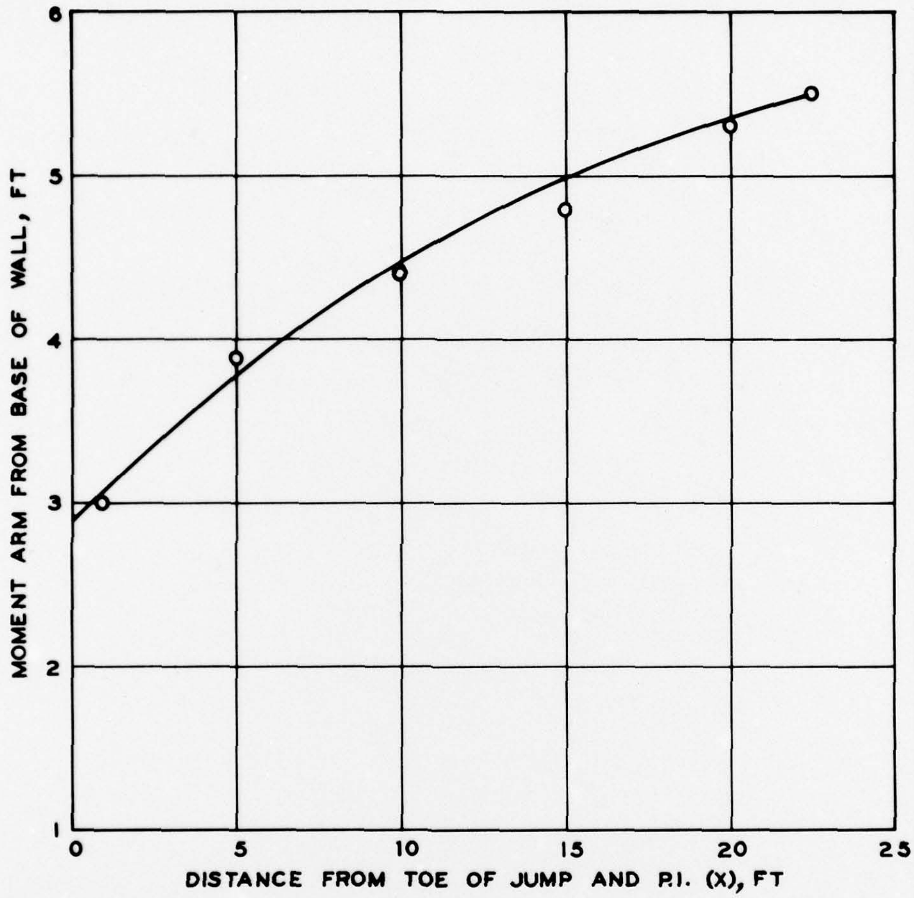
POOL EL 245.0
TAILWATER EL 220.0
CENTER GATE FULLY OPEN

ISOVELS, SPILLWAY B

TYPE 4 STILLING BASIN
TYPE 2 DIVIDER WALLS
UNIT DISCHARGE 196 CFS/FT



SPILLWAY B
FORCE PER FOOT OF DIVIDER
WALL LENGTH



MOMENT ARM PER FOOT OF WALL LENGTH
SPILLWAY B

APPENDIX A: NOTATION

A_o	Area of gate opening, ft^2
C	Discharge coefficient (HDC 122-1, $P/H_d = 0.33$)
g	Acceleration due to gravity, ft/sec^2
G_o	Gate opening, ft
H_e	Total energy head on crest, ft
H_{G_o}	Total energy head on center line of gate opening, ft
K_p	Pier contraction coefficient
L'	Net weir length for one bay, ft
N	Number of piers
Q	Discharge, cfs

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Fletcher, Bobby P

Typical Tennessee-Tombigbee canal section spillways, Spillways A and B; hydraulic model investigation / by Bobby P. Fletcher. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

30, [20] p., 21 leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; H-78-21)

Prepared for U. S. Army Engineer District, Mobile, Mobile, Alabama.

1. Flow control. 2. Hydraulic models. 3. Spillway discharge coefficient. 4. Spillway gates. 5. Spillways. 6. Stilling basins. 7. Tennessee-Tombigbee Waterway. I. United States. Army. Corps of Engineers. Mobile District. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; H-78-21.

TA7.W34 no.H-78-21