US Army Corps
of Engineers

HYDRAULICS
LABORATORY

TECHNICAL REPORT HL-86-4

BURLINGTON SPILLWAY AND OUTLET WORKS SOURIS RIVER, NORTH DAKOTA

Hydraulic Model Investigation

by

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June 1986

Final Report

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US Army Engineer District, St. Paul
St. Paul, Minnesota 55101-1479

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report HL-86-4	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) BURLINGTON SPILLWAY AND OUTLET WORKS, SOURIS RIVER, NORTH DAKOTA; Hydraulic Model Investigation		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Jerry V. Markussen Noel R. Oswalt		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Engineer Waterways Experiment Station Hydraulics Laboratory PO Box 631, Vicksburg, Mississippi 39180-0631		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Engineer District, St. Paul 1135 USPO & Custom House St. Paul, Minnesota 55101-1479		12. REPORT DATE June 1986 13. NUMBER OF PAGES 55
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Hydraulic models (LC)
Outlet works (WES)
Spillways (LC)

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

Two separate physical hydraulic model investigations concerning the proposed Burlington flood-control project are reported herein. The first investigation used a 1:80-scale general model of the spillway and outlet works with stilling basins and common embankment to verify the adequacy of design and to develop necessary modifications. The second study used a 1:25-scale outlet works model to allow detailed evaluation and modification of various outlet works components. Significant modifications were made to both the spillway and

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. ABSTRACT (Continued).

outlet works during these investigations to improve approach flows, improve spillway efficiency, and eliminate a vortex during combined spillway and outlet works operation.

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PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers (OCE), US Army, on 30 October 1978 at the request of the US Army Engineer District, St. Paul (NCS). The studies were conducted by personnel of the Hydraulics Laboratory, US Army Engineer Waterways Experiment Station (WES), during the period June 1979 to July 1981. All studies were conducted under the direction of Messrs. H. B. Simmons and F. A. Herrmann, Jr., former and present Chiefs of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Hydraulic Structures Division. The tests were conducted by Messrs. J. V. Markussen, R. Bryant, Jr., R. Davidson, and J. Rucker, under the supervision of Mr. N. R. Oswalt, Chief of the Spillways and Channels Branch. This report was prepared by Mr. Markussen and edited by Mrs. Beth F. Burris, Publications and Graphic Arts Division.

Messrs. T. Munsey of OCE, J. F. Ordonez of North Central Division, and H. Johnson, E. Eaton, and J. Murphy of NCS visited WES during the study to discuss test results and to correlate these results with concurrent design work.

Director of WES was COL Allen F. Grum, USA. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
inches	2.5	centimetres
miles (US statute)	1.609347	kilometres
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

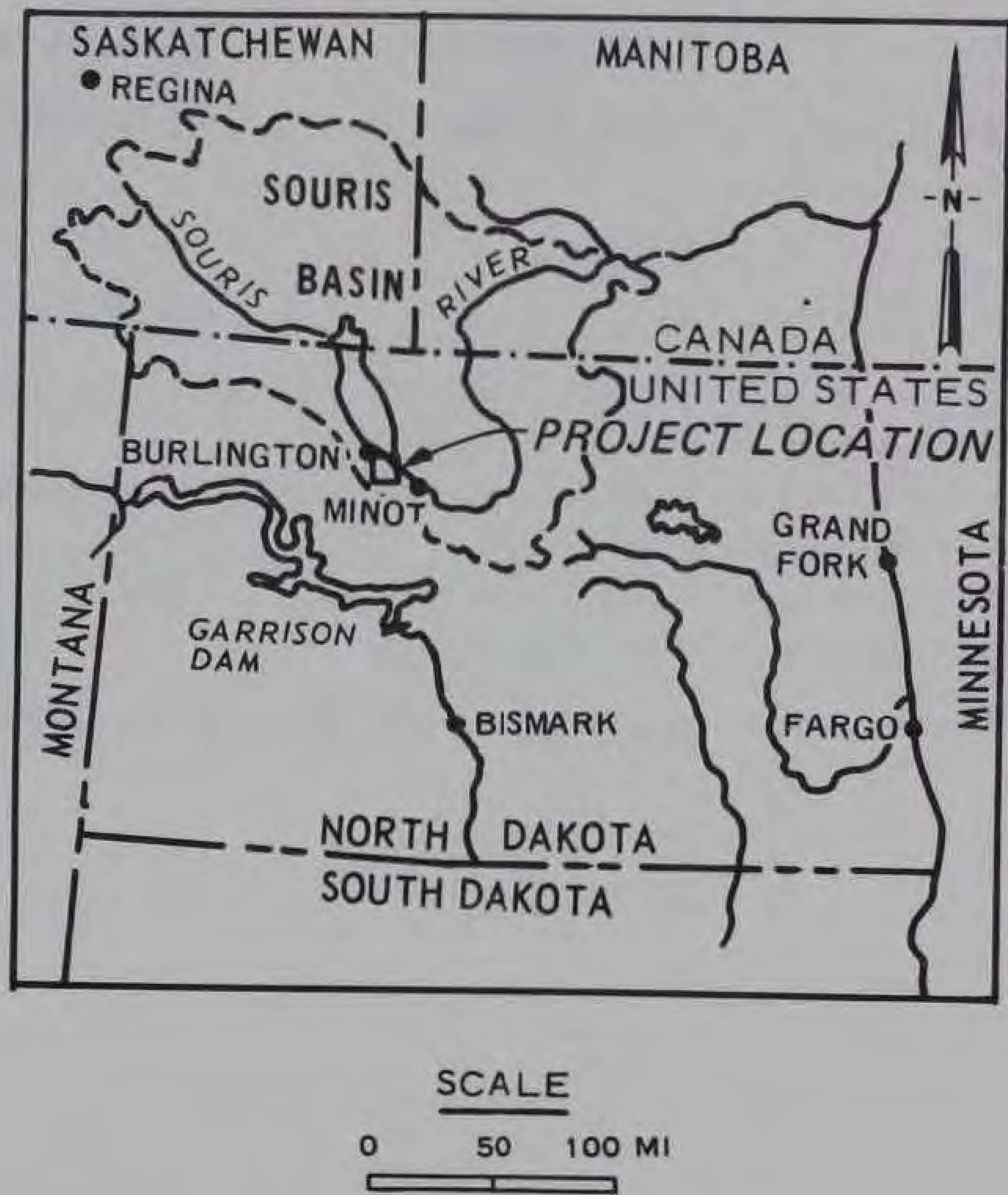

Figure 1. Vicinity map

BURLINGTON SPILLWAY AND OUTLET WORKS

SOURIS RIVER, NORTH DAKOTA

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The Burlington flood-control project will be located on the Souris River approximately 2 river miles* downstream from the city of Burlington and 6 river miles upstream of Minot (Figure 1). The project will consist of an overflow spillway, outlet works, and earthen embankment. The top of the embankment will be approximately 70 ft above the valley floor at el 1630,** with the spillway and outlet works located near the left bank when looking downstream (Plate 1). The ogee spillway will consist of three 43-ft-wide by 21-ft-high tainter gates supported by two 8-ft-wide piers totaling a gross width of 145 ft. The spillway is designed to pass approximately 78 percent of the probable maximum flood (PMF) of 60,300 cfs at the design head of 25 ft (pool el 1625) and to operate only in the free-flow regime.

2. Typical reservoir releases will be regulated by the gated outlet works structure located approximately 150 ft riverward of the overflow spillway. The outlet works structure consists of a low-flow water quality withdrawal facility and high-capacity flood-control facility. Both facilities are designed to be operated independently but share the same service gates and conduits for transporting the flow downstream. The water quality withdrawal facility has a design discharge of 700 cfs, whereas the flood-control facility was designed to pass approximately 3,480 cfs (22 percent of the PMF or 17,400 cfs) for the design head on the center of the gate of 62.5 ft (pool el 1625). The water quality withdrawal facility is located in the upstream face of the intake tower and is designed to release flow from the reservoir between el 1592 to 1620 by varying the elevation of the 8-ft-square

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* A table of factors for converting non-SI units of measurement to SI (metric) units is provided on page 3.

** All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

multilevel intakes or apertures. Flow entering a given aperture is passed downstream through independent wet wells, service gates, and conduits. The three independent conduits are 15 ft high by 11.25 ft wide by 300 ft long.

3. During water quality releases, the emergency gate is closed thereby blocking the flood-control facility, whereas during flood-control releases the emergency gate is open, closing off the water quality withdrawal facility. Regardless of the mode of operation, all flows are controlled by the service gate.

Purpose for the Model Study

4. The model study was considered necessary to verify the adequacy of and develop desirable modifications to the spillway, outlet works, and embankments. The study was conducted to evaluate the performance of the spillway and outlet works and attached stilling basins, determine a satisfactory approach and exit design, and develop an adequate design of riprap protection. Flow patterns near the embankment resulting from normal operations of the spillway and outlet works were also determined.

PART II: THE MODEL AND TEST PROCEDURES

Description

5. Two models were used to conduct the study. The 1:80-scale model reproduced a 4,000-ft-long by 1,600-ft-wide area comprising 1,600 ft of the approach and 2,400 ft of the exit area. The 1:25-scale model of the outlet works reproduced a 1,600-ft-long by 500-ft-wide area comprising 600 ft of the approach and 1,000 ft of the exit area. The model limits are identified in Plate 1. The spillways were constructed of sheet metal and marine board, and the outlet works and conduit were constructed of transparent plastic. The stilling basins, baffle blocks, and end sills were constructed of marine board. The embankment and approach and exit areas were molded to sheet-metal templates with cement mortar and given a brushed finish. The exit channel and toe of the embankment in the 1:80-scale model were molded of sand in order to study the potential for scour. Views of the approach and exit areas to the models are shown in Photos 1-4.

Model Appurtenances

6. Water used in the operation of the models was supplied by pumps, and the discharges were measured by venturi meters. Steel rails set to grade provided reference planes for measuring devices. Water-surface elevations were obtained by means of point gages. Velocities were measured with a pitot tube and by stopwatch for timing the movement of flotage and dye over measured distances. Current patterns were determined by observing the movement of dye injected into the water and confetti sprinkled on the water surface. Piezometers were installed throughout the intake structure and conduit to measure pressures.

7. Riprap was reproduced in the model using crushed limestone with a specific weight of 165 pcf. The limestone was sieved into sizes ranging from 0.19 in. (No. 4 sieve) to 1 in. and mixed to represent the various prototype gradations. The riprap was tested in the model on nylon cloth used to represent a filter blanket.

Design Considerations

8. In the design of the models, geometric similitude was preserved between model and prototype by means of undistorted scale ratio. The accepted equations of hydraulic similitude, based on the Froudian relations, were used to express the mathematical relation between the dimensional and hydraulic quantities of the model and the prototype.

9. A valid study of flow conditions in the outlet works required an accurate simulation of the prototype hydraulic grade line in the model. If water is the fluid in the prototype, it is not possible to satisfy the similitude requirements of both the Reynolds and Froude criteria. Since hydraulic similitude between the model and prototype is based on Froudian relations, the Reynolds number of the design flow in the model will be lower than that of the prototype. This will result in a larger resistance coefficient in the model than that expected in the prototype. The excess losses in the model would normally be compensated for by constructing a shorter length of model conduit. Usually reproducing about 60 percent of the full conduit length is appropriate when accounting for these frictional differences. Unfortunately, shortening the outlet works conduit in this model would change the stilling basin location and prevent accurate simulation of the downstream flow patterns during combined releases of the spillway and outlet works. Instead, the full length of conduit was reproduced and a supplemental slope was added to the conduit to account for the frictional difference between the prototype and model. The head loss, h_f (in ft), of both the model and the prototype were computed using the Darcy-Weisbach equation

$$h_f = f \frac{L}{D} \frac{V^2}{2g}$$

where

- f = resistance factor obtained from the Moody diagram, dimensionless
- L = conduit length, ft
- D = equivalent diameter equal to four times the hydraulic radius of the noncircular conduit, ft
- V = velocity, fps

The prototype head loss was computed for smooth pipe and for an effective roughness, k_s , of 0.003 (rough assumption from HDC Sheet 224-1*) to provide a lower and upper bound of head loss between which the actual head loss of the prototype conduit can be expected.

Scale Relations

10. General relations for transfer of the model data to prototype equivalents are presented in the following tabulation:

Dimension	Ratio	Scale Relation	
Length	L_r	1:25	1:80
Time	$T_r = L_r^{1/2}$	1:5	1:8.94
Velocity	$V_r = L_r^{1/2}$	1:5	1:8.94
Discharge	$Q_r = L_r^{5/2}$	1:3,125	1:57,243.34
Pressure	$P_r = L_r$	1:25	1:80
Roughness (Manning's n)	$N_r = L_r^{1/6}$	1:1.71	1:2.08

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

Test Procedure

12. Tests pertinent to the general approach and exit flow conditions to spillway and outlet works were conducted in the 1:80-scale model. This model also provided a qualitative method of determining the extent of riprap protection required to stabilize the exit channel. The resulting design established in the 1:80-scale model was then checked, and where necessary, modified in the 1:25-scale model. Tests pertinent to the operation of the outlet works, performance of the stilling basins, and sizing of the riprap protection were conducted in the 1:25-scale model.

* US Army, Corps of Engineers, "Hydraulic Design Criteria," prepared for Office, Chief of Engineers, by US Army Engineer Waterways Experiment Station, Vicksburg, Miss., issued serially since 1952.

Presentation of Data

13. The data are provided through a series of figures, photographs, and plates. An explanation of the test procedure and discussion of results are provided in the text. Recommended modifications to the original design are provided herein.

PART III: TESTS AND RESULTS

Approach Design

14. Tests were conducted in the 1:80-scale model to optimize the approach to the spillway and outlet works for the PMF condition. The original approach, shown in Plates 1 and 2, was comprised of straight walls angled approximately 45 deg from the spillway center line and parallel to the conduit center line for the outlet works. Flow lines in the reservoir were satisfactory except in the immediate area of the spillway and outlet works. The straight approach walls were inefficient in transitioning the flow from the reservoir into the structures. As indicated in Photos 5 and 6, spillway gates 1 and 3 experienced a reduced capacity due to the poor transitioning of the approach walls. Furthermore, flow splitting around the outlet works tower caused high velocities along the upstream face of the embankment and incited the formation of a vortex at the entrance of the outlet works.

15. Numerous approach wall designs were tested in the model. Ultimately, the approach wall design shown in Plate 3 performed most satisfactorily. Flow conditions with this design are shown in Photos 7 and 8. Equal distribution of flow across the spillway was obtained with the installation of the elliptical approach walls. These walls were designed so that they would not be overtopped during the design flow. Flow velocities along the embankment were greatly minimized, and installation of the upper wing wall along the riverward face of the outlet works tower essentially eliminated the occurrence of a vortex during combined spillway and outlet works operation. The efficiency of the flood-control facility for the outlet works was also improved by replacing the original design approach walls (Photo 3) with circular quadrant walls (Plate 3, Photo 13). As with the spillway, the performance of the outer gates for the outlet works was greatly improved with the recommended quadrant walls. The recommended approach design to the spillway and outlet works is shown in Plate 3.

Exit Design

16. The exit channel was molded of sand so that the natural scouring tendencies of the exiting flow could be recorded. Prolonged operation at the

PMF condition indicated that the original channel alignment would remain stable and perform satisfactorily in transitioning the outflow to the main channel.

17. Due to the angle of the outflow entering the main channel, a slow clockwise eddy developed along the downstream face of the embankment. Though velocities were measured to be less than 2 fps, tests indicated that flow along the toe of the embankment could be essentially eliminated by not excavating the natural berm located adjacent to the proposed outlet works stilling basin. This berm is shown in Photo 9, and when compared with Photo 7, does indicate the effectiveness of leaving the berm in situ. No model sand scour was indicated at the toe of the embankment.

18. It is recommended that the back-fill areas (el 1584.5) adjacent to outlet works stilling basin be raised to el 1589, or enclosed with walls at el 1589 so that these areas will remain dry. Eddies were prevalent in these areas when overtopping occurred (Photo 7).

Riprap Requirements

19. Based on velocities and riprap failure tests measured in the models, a recommended design of upstream protection was developed. The original and recommended designs of protection are shown in Plates 2 and 3, respectively. The recommended design provides a heavier riprap and larger area of protection than that provided in the original design.

20. Tests of the original design of downstream protection indicated the tendency for deep scour and resulting failure of the riprap due to undercutting. Prolonged operation at the PMF condition indicated scour holes approximately 30 ft deep that moved progressively upstream with time (Photos 10 and 11). Though qualitative, the model does indicate the areas with high scour potential. It can be expected that the depth and extent of scour in the prototype will be much more severe than that indicated in the model. The models indicated the need for heavier riprap to be carried farther downstream than in the original design. The original and recommended designs of protection are shown in Plates 4 and 5, respectively.

21. The recommended thickness and gradations of riprap that were tested in the models are provided below:

21-in. thickness	W_{100}	= 98 lb
	W_{50}	= 42 lb
	W_{15}	= 12 lb
28-in. thickness	W_{100}	= 330 lb
	W_{50}	= 98 lb
	W_{15}	= 42 lb
45-in. thickness	W_{100}	= 780 lb
	W_{50}	= 330 lb
	W_{15}	= 98 lb
54-in. thickness	W_{100}	= 2,640 lb
	W_{70}	= 780 lb
	W_{50}	= 540 lb
	W_{15}	= 330 lb

Spillway

22. Details of the spillway are provided in Plate 6. The spillway consists of three 43-ft-wide by 21-ft-high tainter gates supported by two 8-ft-wide piers totaling a gross width of 145 ft. The crest is at el 1600 and has the design capacity of 60,300 cfs for the design head of 25 ft. The upstream quadrant of the crest is shaped by the elliptical equation

$$\frac{x^2}{5.825^2} + \frac{y^2}{3.425^2} = 1$$

and the downstream portion is shaped by the parabolic equation

$$y = 0.031x^{1.85}$$

The spillway is designed to always operate in the free-flow regime.

23. A plot of the head on the spillway crest versus discharge for both the controlled and uncontrolled flow regimes is provided as Plate 7. The calibration data were collected with uniform gate operation and with the outlet works closed. The pool elevation was measured approximately 500 ft upstream of the dam center line where the velocity head was negligible. The

equation of the curve for uncontrolled flow was determined by least squares analysis of the data and computed to be

$$Q = 3.3LH^{1.54}$$

where

Q = total spillway discharge, cfs

L = net length of crest, ft

H = total head on the crest, ft

The measured capacity of the spillway in the model was 60,525 cfs for the design head of 25 ft. The measured spillway capacity is 225 cfs higher than predicted which is less than 1/2 of 1 percent of the computed capacity.

24. Water-surface profiles were measured along the center line of the spillway for discharges of 17,000, 32,200, 46,700, and 60,500 cfs. The profiles, shown in Plate 8, indicate that the tainter gate trunnions will remain above the water surface for the expected range of discharge conditions.

25. Operation of the spillway at gate openings greater than approximately six-tenths the head on the crest resulted in surges of 3 to 4 ft on the gates that persisted until the gates lost control. Modifications to the pier length and crest geometry did little to reduce the surging. Surging appeared to be a function of the rapid control shift between flow regimes inherent at larger gate openings. In this case, the flow control was shifting between the controlled and uncontrolled flow regimes. Even though surging is undesirable and should be avoided, the phenomenon should not jeopardize the integrity of the structure unless the gate or trunnion anchorage or stilling basin performance is affected. Surging may be eliminated by opening the gates to permit uncontrolled flow.

Outlet Works

26. An extensive hydraulic analysis of the flood-control and water quality withdrawal facilities was conducted in the 1:25-scale model of the outlet works. Views of the outlet works tower prior to and after installation in the model are provided as Photos 12 and 13, respectively. Design details of the outlet works are shown in Plate 9.

Flood-control facility

27. The efficiency of the flood-control facility was improved by replacing the original approach walls with the circular quadrant walls shown in Photo 13 and Plate 3. This modification was discussed previously in paragraph 15.

28. The discharge rating curves for the flood-control facility were developed in accordance with the expected aggraded and degraded tailwater elevations provided by the sponsor as Plate 10. The discharge curves were determined in the model for uniform full and partial gate openings, and are provided as Plates 11 and 12 for the degraded and aggraded tailwater conditions, respectively. Flow regimes in the conduit were found to be a function of the gate opening, the tailwater, or some combination of the two. The four flow regimes can be identified as free or submerged gate control, and as conduit or tailwater control. A description of the four flow regimes is shown in Plate 13.

29. The discharge capacity of the flood-control facility was approximately 25,800 cfs for the PMF head of 62.5 ft on the center of the gate, assuming smooth pipe and accounting for friction as described in paragraph 9. Assuming a less efficient coefficient, $k_s = 0.003$, will reduce the capacity to approximately 24,800 cfs. The capacity of the prototype conduit can be expected to fall within this range of discharges (Plates 11 and 12, paragraph 9).

30. Pressures measured along the roof of the flood-control facility and the length of conduit were satisfactory for the range of expected controlled flow operating conditions. The pressure profile obtained in the model is provided in Plate 14.

Water quality withdrawal facility

31. The water quality withdrawal facility is located in the outlet works intake tower as detailed in Plate 15. The flow progresses sequentially through the trashrack (detailed in Figure 2), 8-ft-square aperture, wet well, throat section, and then under the service gate into the conduit (Plate 15). The facility has a design discharge of 700 cfs.

32. The water quality withdrawal facility was found to operate in three flow regimes depending on the gate opening. A description of the regimes is provided in Plate 16. The service gate was found to control for gates opening up to 1.75 ft. At larger gate openings, the flow control

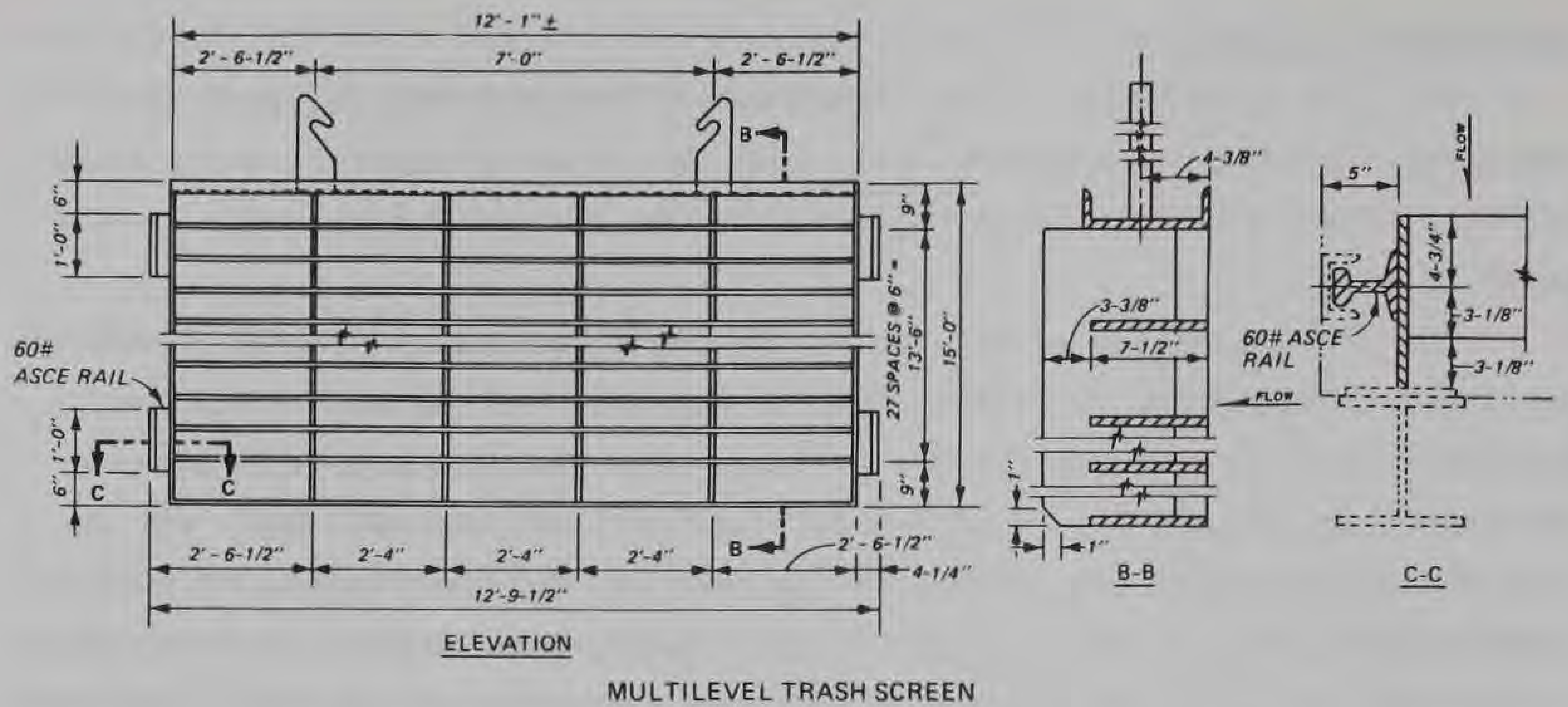


Figure 2. Details of trashrack configuration

shifted to free weir flow at the aperture. Cavitation will likely occur in the throat area with gate openings greater than 4 ft when the throat section becomes primed because of low pressures in this area. Pressure profiles measured in the throat are provided in Plates 17 and 18. The data shown are average pressures, and instantaneous pressures could be several feet more in the negative than those shown.

33. A plot of pool elevation versus gate opening for flow through a single wet well is shown in Plate 19. The data were taken with the design discharge of 700 cfs and with the aperture at the minimum elevation of 1592. The three operating regimes (Plate 16) are identified. The plot in Plate 19 indicates that usable gate control is limited to 1.0 to 1.75 ft since smaller gate openings result in overtopping of the closed spillway gates, while larger gate openings result in a flow control shift to the aperture.

34. As referenced in paragraph 15, the installation of an upper wing wall along the riverward face of the outlet works tower eliminated the vortex that occurred during combined operations of the spillway and outlet works. However, operation of only the outlet works with the maximum discharge and pool elevation of 1620 resulted in a vortex as shown in Photo 14. Tests indicated that the vortex could be eliminated by replacing the solid working platform (Plate 9, Photo 12) with a perforated working platform allowing flow to be drawn uniformly along the face of tower and thereby dispersing the

vortex. The perforated platform used in the model, shown in Photo 13, simulated a prototype grid spacing of 1-in. square. The favorable results provided by this modification are shown in Photo 15.

Stilling Basins

35. The design details of the spillway and outlet works stilling basins are provided as Plates 6 and 9, respectively, and a view of the stilling basins and exit area is provided in Photo 4. The energy dissipation of the stilling basins was satisfactory based on flow observations and velocity measurements. Views of the stilling action produced when operating the spillway and outlet works with the maximum PMF discharge are provided as Photos 16 and 17, respectively. Symmetrical gate operation is preferred in order to minimize both adverse eddy formation and flow concentrations in the stilling basin.

PART IV: DISCUSSION

36. The original design approach walls to the spillway and outlet works were replaced with elliptical and circular quadrant walls in order to improve the efficiency of the outer gates for the spillway and outlet works. An upper wing wall was placed along the riverward face of the outlet works tower in order to eliminate the occurrence of a vortex during combined spillway and outlet works operation. The tops of the elliptical approach walls to the spillway are set above the PMF pool at el 1625.5 to prevent flow from passing between the embankment and outlet works tower.

37. The original exit channel alignment was found to remain stable and perform satisfactorily for the range of expected operating conditions. An eddy along the downstream toe of the embankment was essentially eliminated by leaving in situ, rather than excavating, the natural berm located adjacent to the spillway and outlet works (Photos 6 and 9). The stilling basin sidewalls for the spillway and outlet works were raised to el 1589 so that the adjacent backfill areas (el 1584.5) would remain dry. The upstream and downstream riprap protection was improved by increasing the weight and area of protection.

38. The uncontrolled flow equation for the spillway was determined to be $Q = 3.3LH^{1.54}$, and the discharge capacity was found to be 60,525 cfs for the design head of 25 ft. The tainter gate trunnions remained above the water surface for the range of expected operating conditions. Surging of about 3 to 5 ft on the spillway gates was evident when operating at gate openings greater than six-tenths the head on the crest. No solution to this problem other than raising the gates to permit uncontrolled flow was obtained from the model because the problem only occurred at the extremely high gate openings. The few modifications tried proved unsuccessful and the project was terminated by the sponsor before another solution was developed. Extended periods of operation with noticeable surges should be avoided.

39. The discharge capacity of the flood-control facility for the outlet works was determined to be approximately 25,300 cfs for the design head on the center of the gate of 62.5 ft. Four flow regimes were identified for the flood-control facility and found to be a function of the gate opening and/or tailwater. Pressures measured along the roof geometry were found to be satisfactory for the range of expected operating conditions.

40. The water quality withdrawal facility was found to have three operating regimes depending on the gate opening. With flow though a single wet well, the range of usable gate control was found to be limited to 1.0 to 1.75 ft. The greater range of flow control was provided when operating with the aperture at the minimum elevation of 1592. Pressures low enough to cause cavitation were measured in the throat section of the wet well with gate openings greater than 4 ft. The occurrence of a vortex during operation of only the outlet works was eliminated by replacing the solid working platform with a perforated working platform.

41. The stilling basins for the spillway and outlet works performed satisfactorily for the range of expected operating conditions. Symmetrical gate operation is preferred in order to minimize adverse eddy formation and flow concentrations in the stilling basins.

42. Although several improvements were made to the original design during this model study, further improvements were not accomplished due to the termination of the project.

Photo 1. Original approach design, 1:80 scale

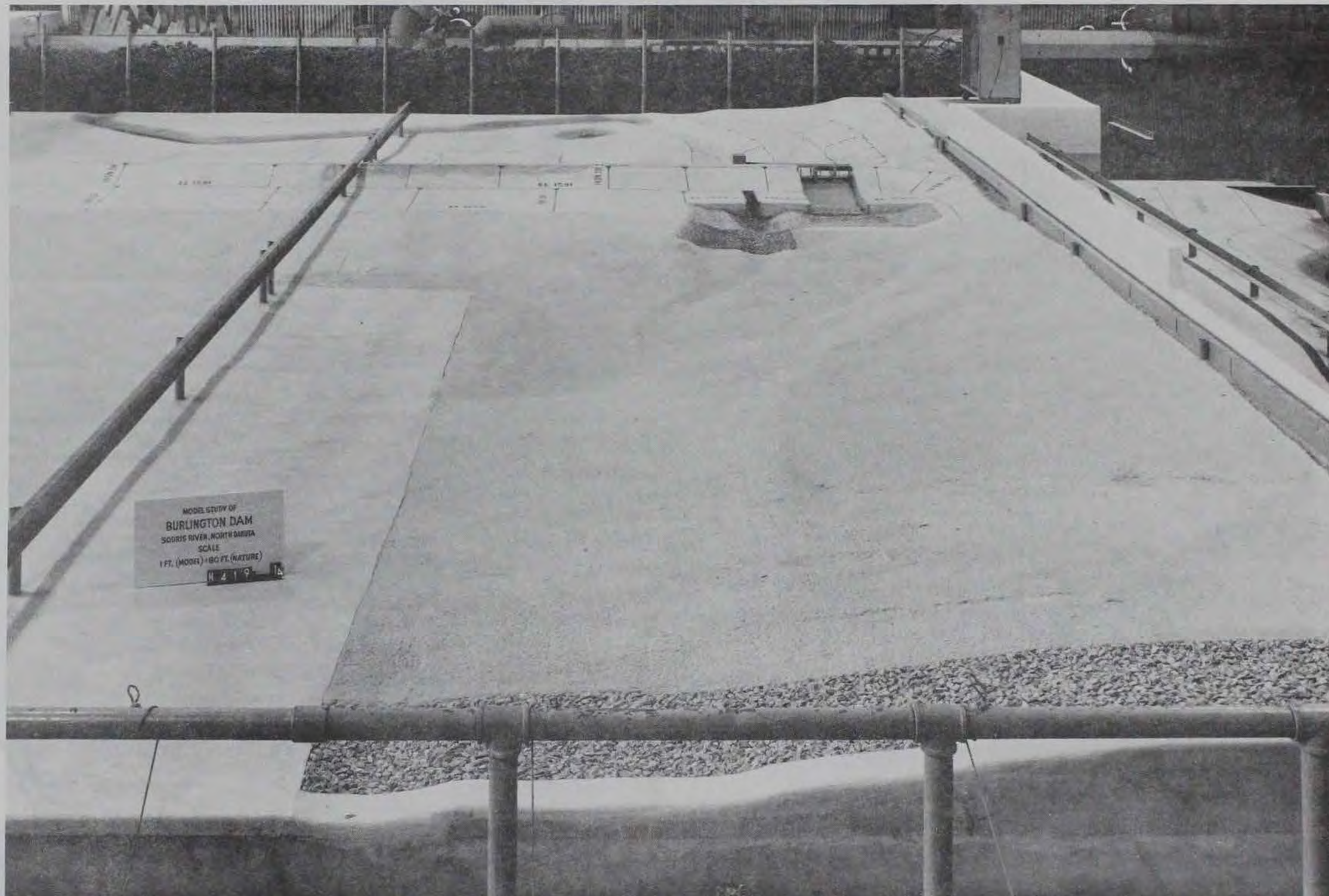


Photo 2. Original exit design, 1:80 scale

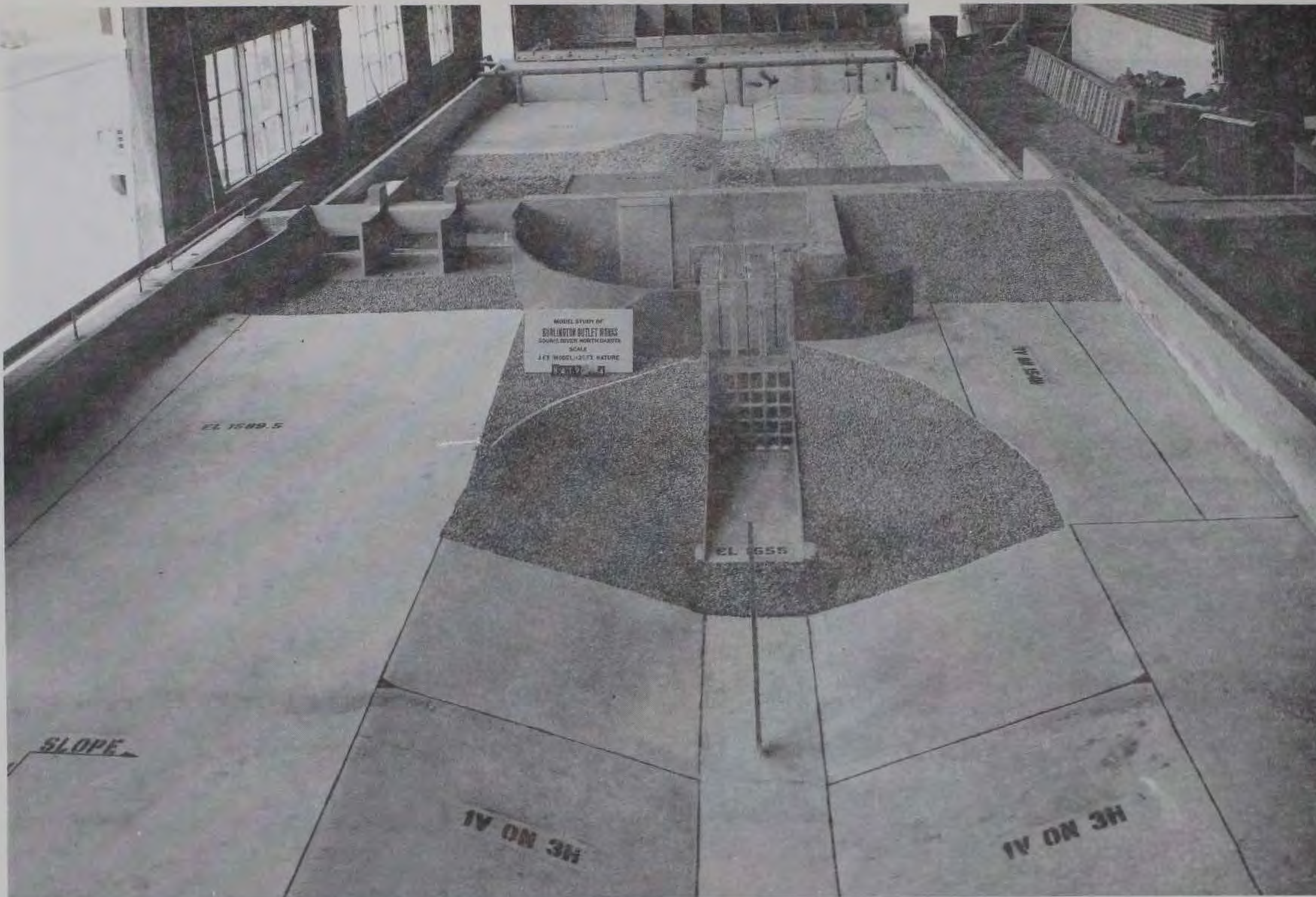


Photo 3. Original approach design with recommended spillway approach walls and upper wingwall added, 1:25 scale

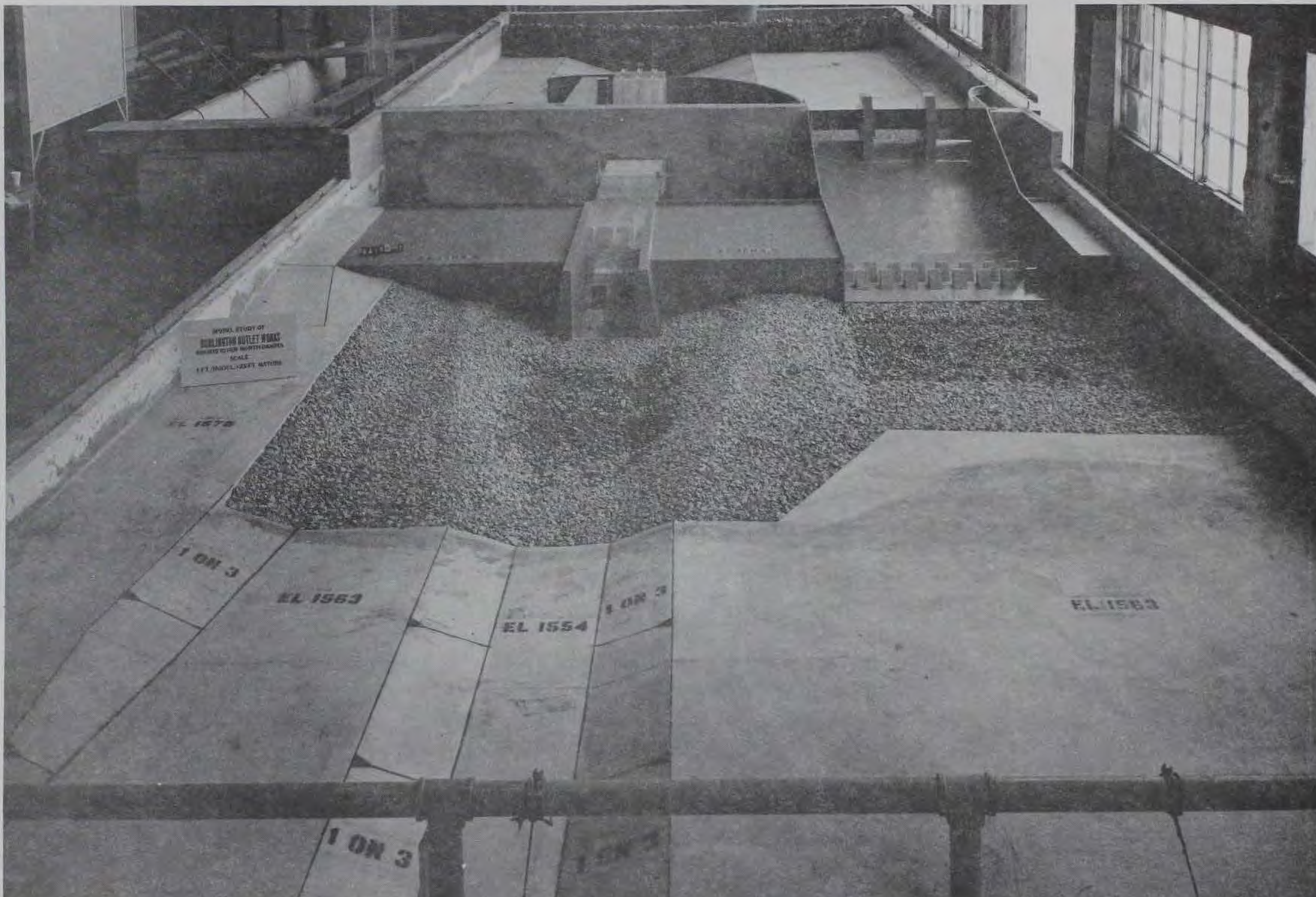


Photo 4. Original exit design, 1:25 scale

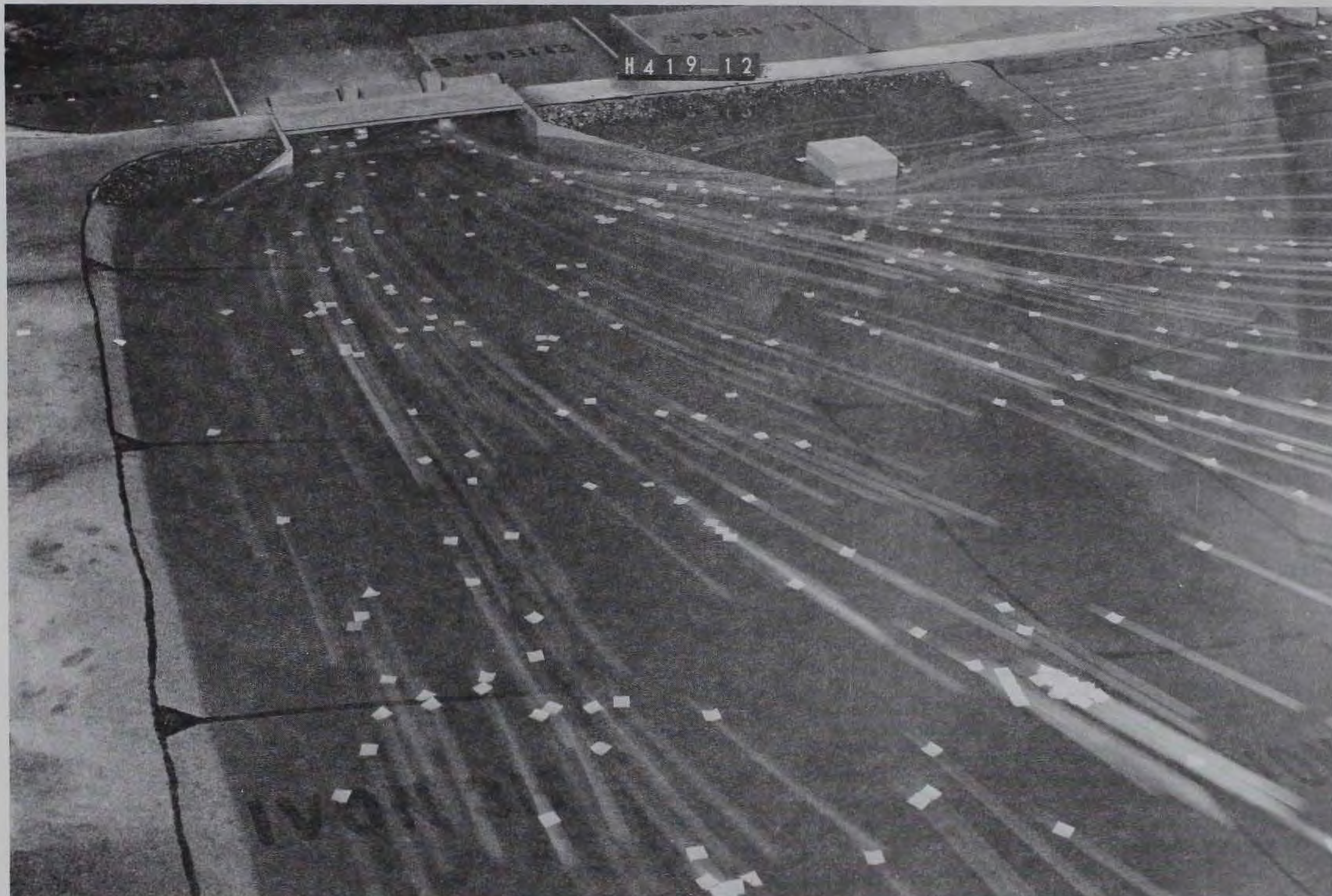


Photo 5. Original approach design for the PMF discharge, 1:30 scale

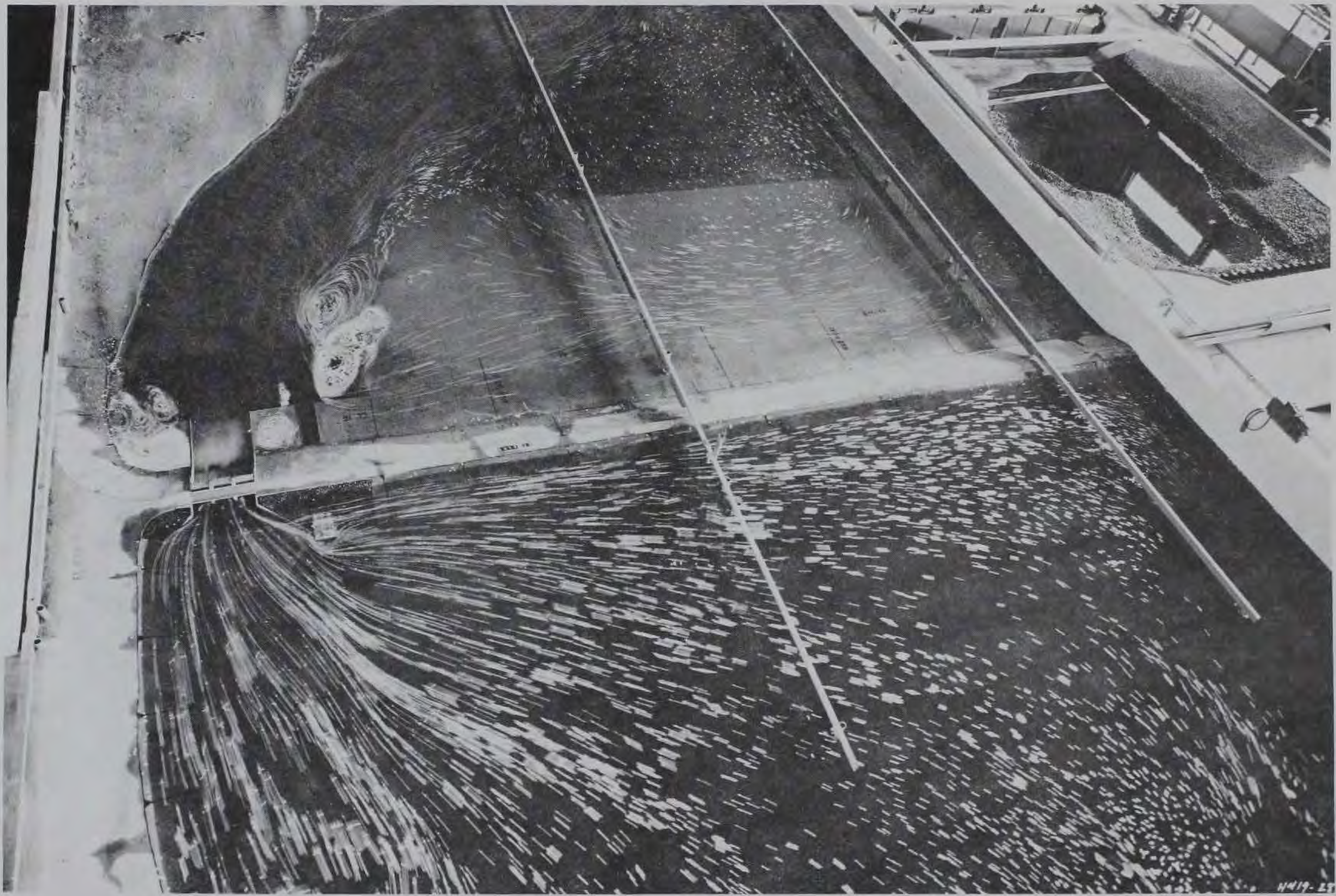


Photo 6. Original approach design for the PMF discharge, 1:30 scale

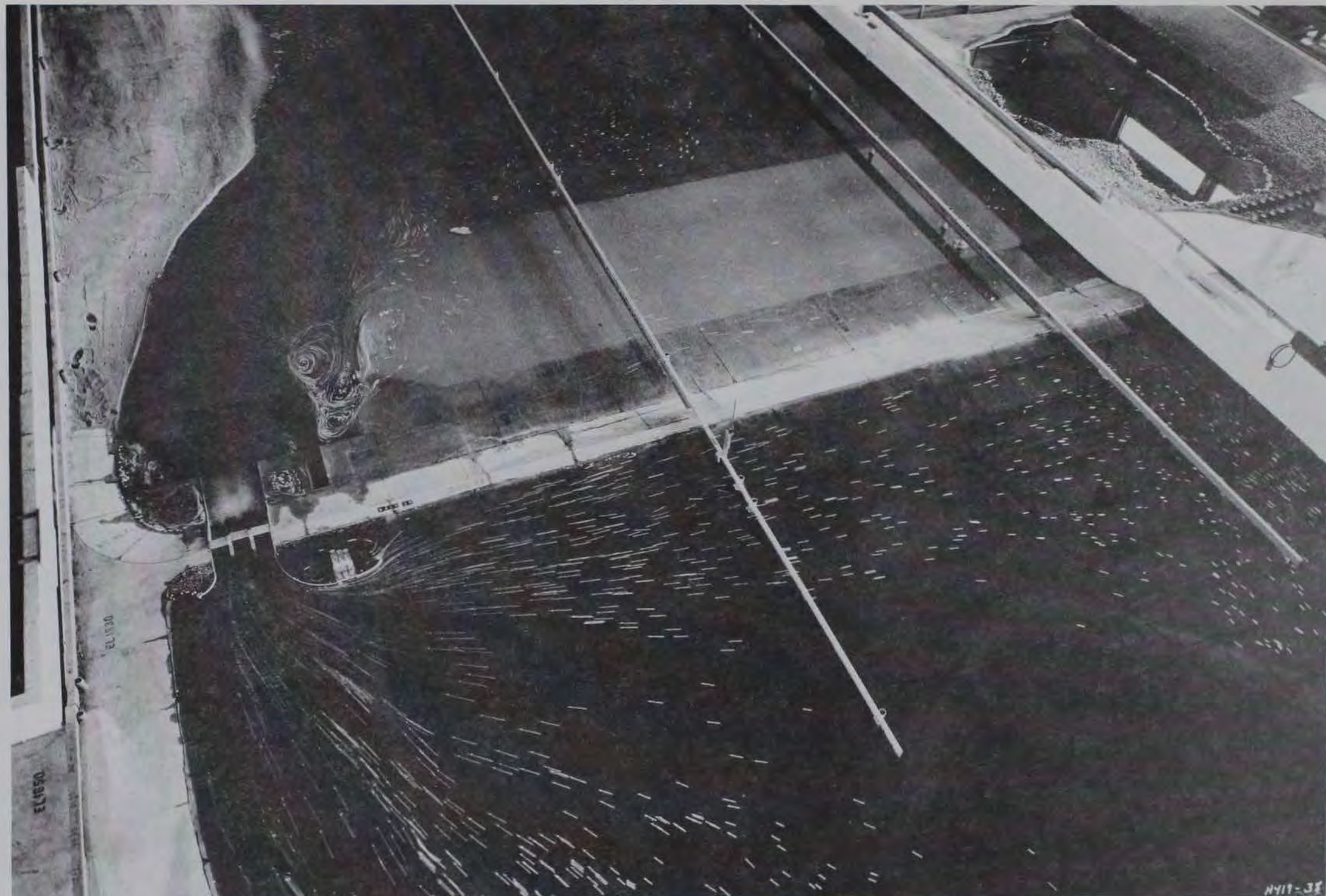


Photo 7. Recommended approach design for the PMF discharge, 1:80 scale

Photo 8. Recommended approach design for the PMF discharge, 1:25 scale

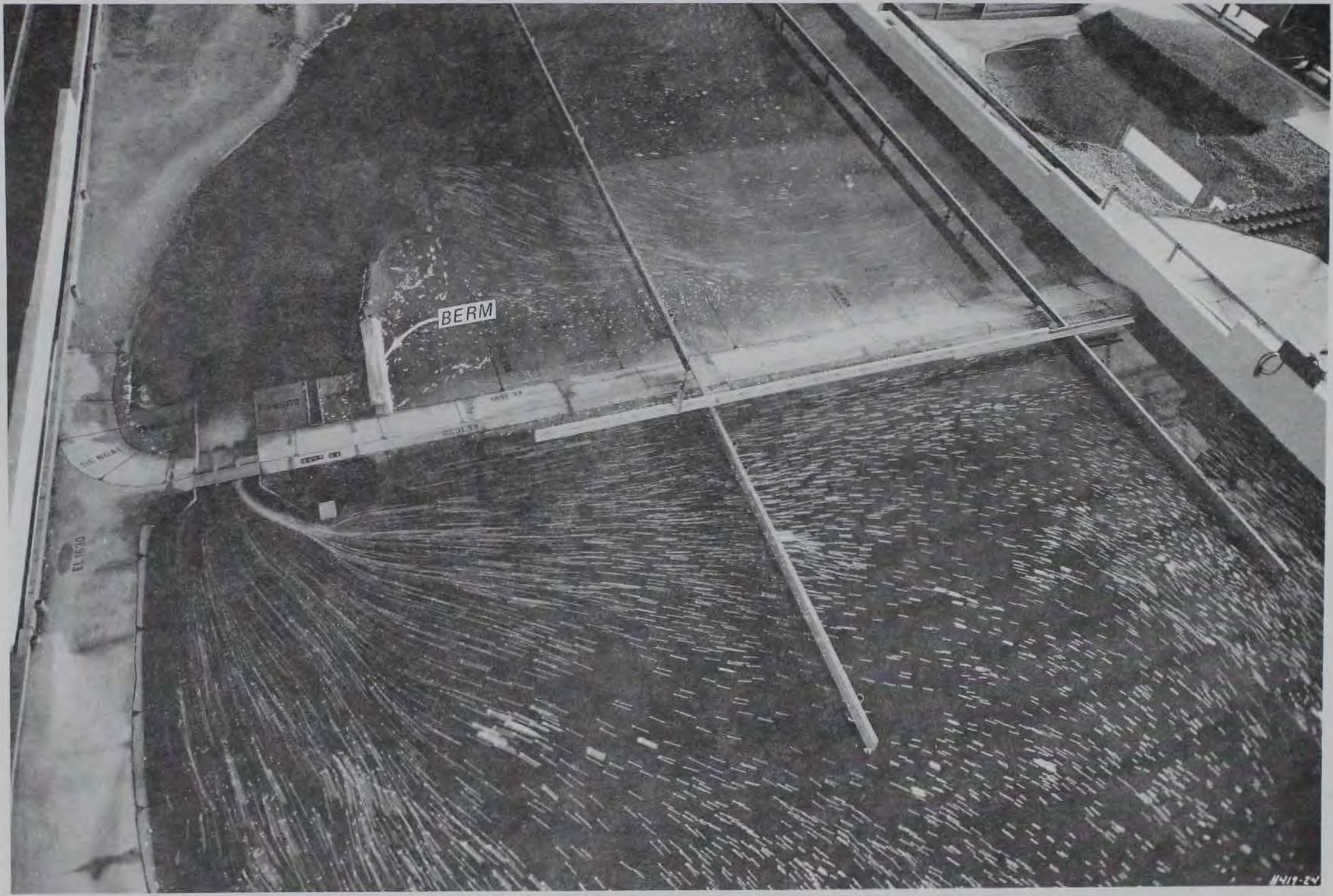


Photo 9. Simulation of berm located adjacent to outlet works

Photo 10. Scour downstream of outlet works stilling basin for the PMF discharge (1:80 scale) after 96 hr

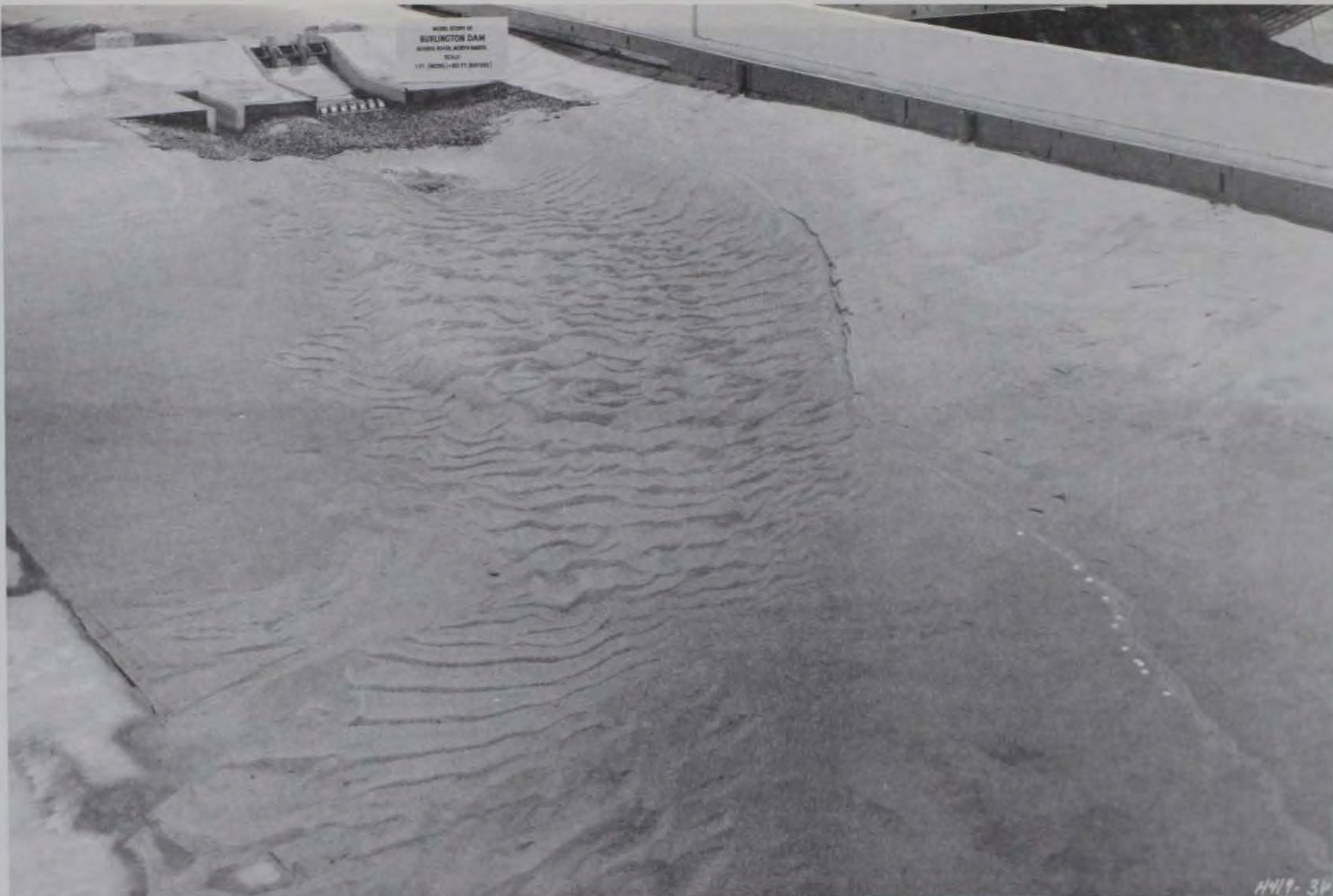


Photo 11. Scour downstream of spillway stilling basin
for the PMF discharge (1:80 scale) after 96 hr

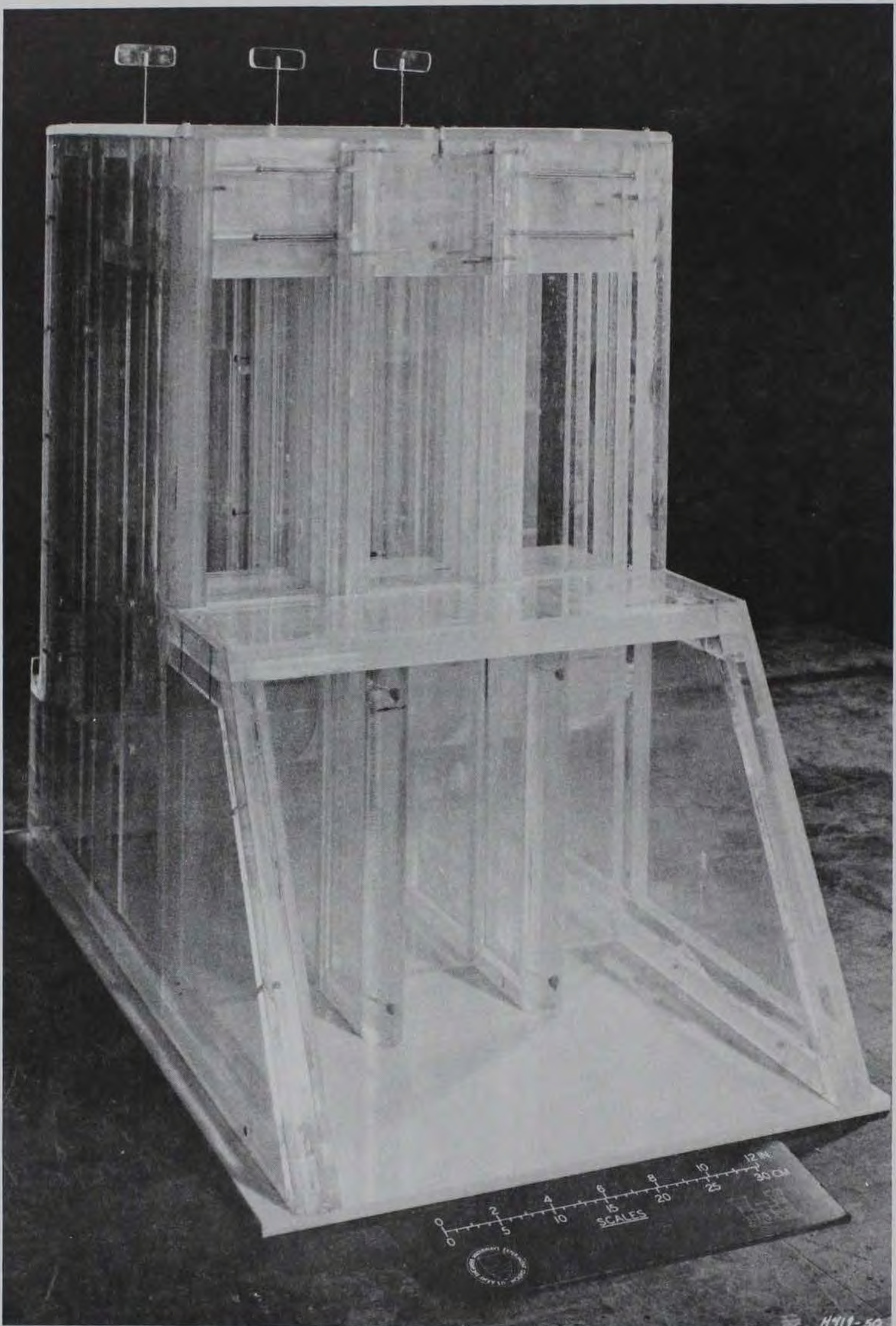


Photo 12. Model of outlet works intake tower prior to installation, 1:25 scale

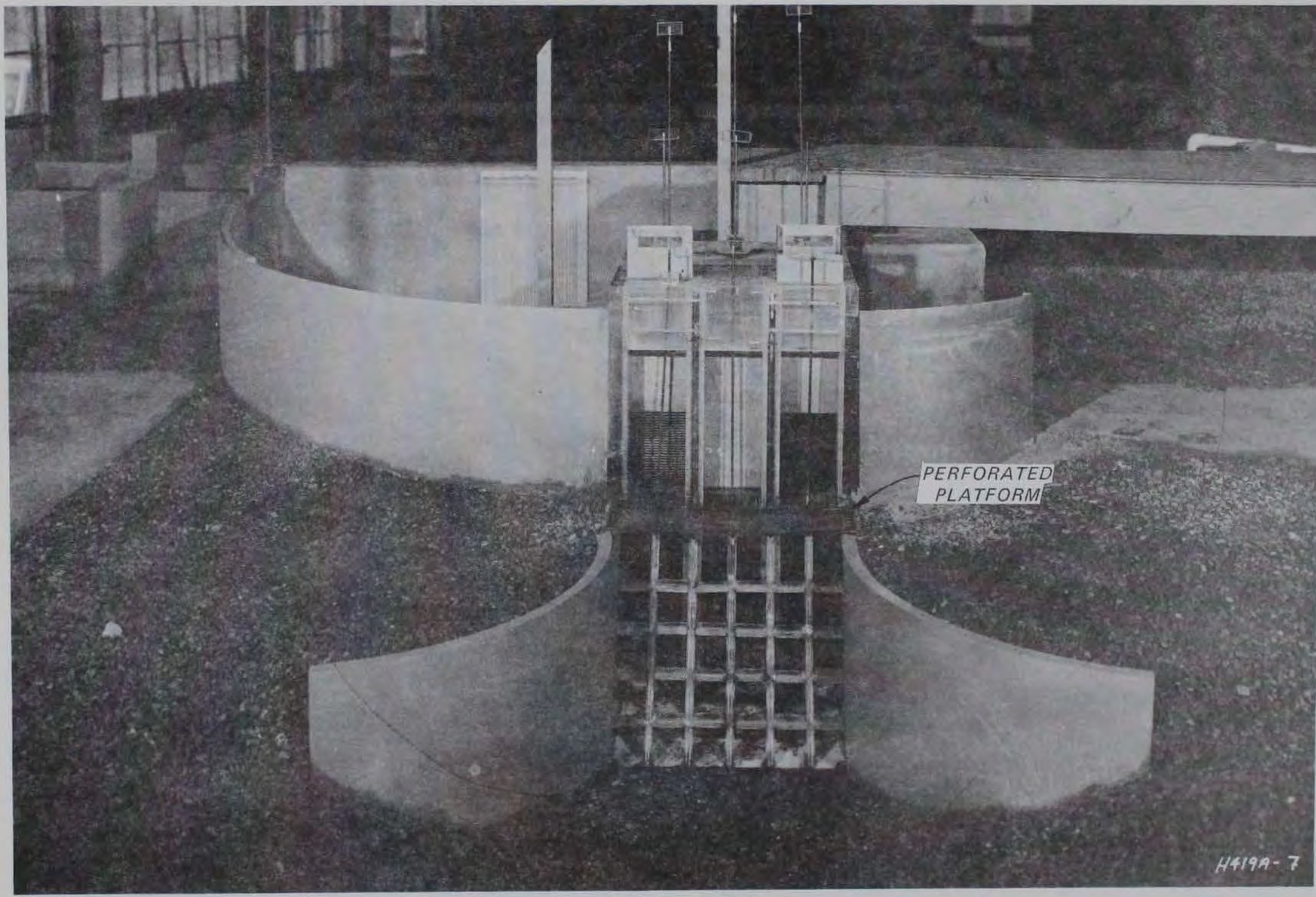


Photo 13. Recommended approach design, 1:25 scale

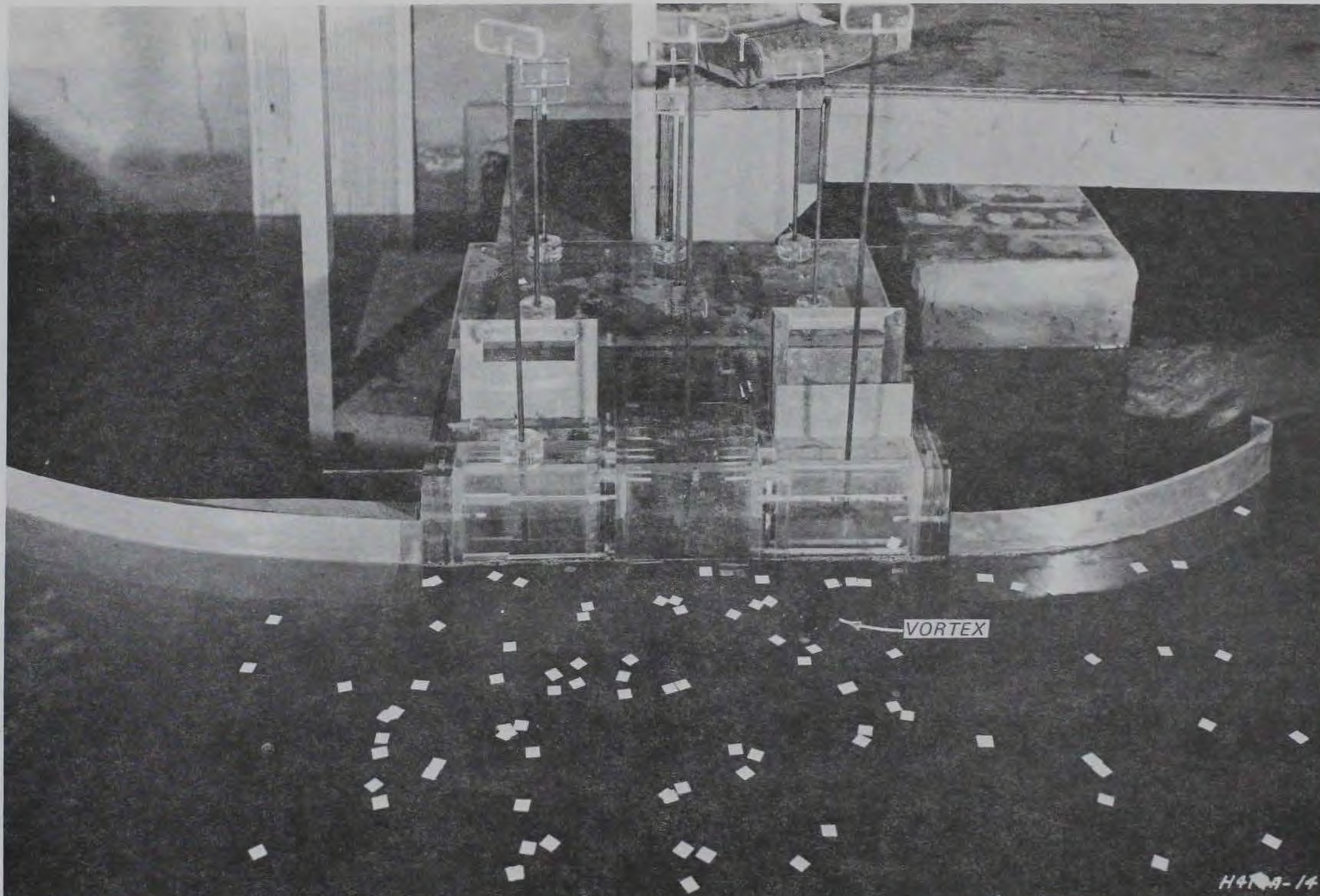


Photo 14. Vortex occurring during operation of the flood control facility with the solid working platform and PMF discharge, 1:25 scale

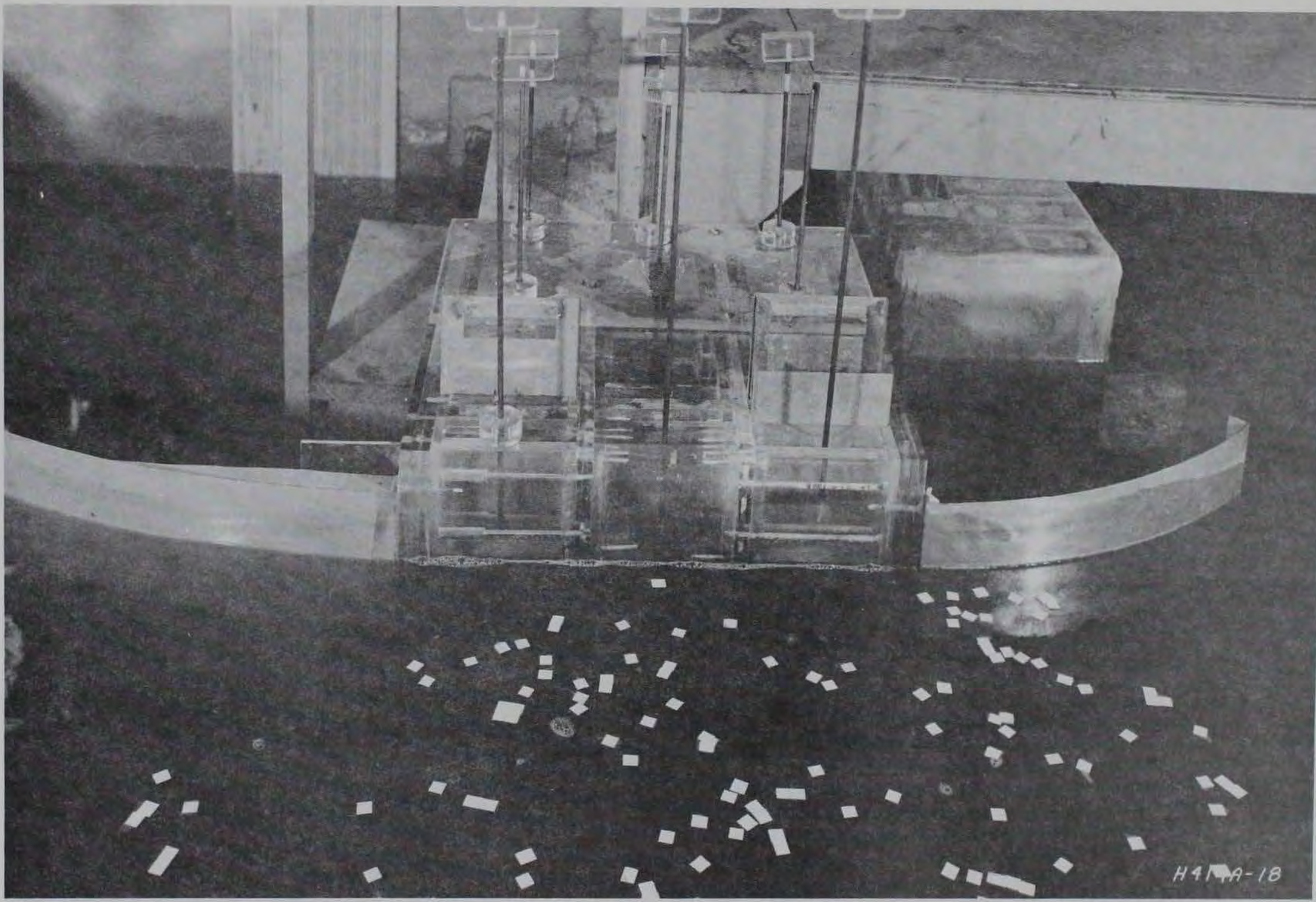


Photo 15. Vortex eliminated by installing recommended perforated working platform, 1:25 scale

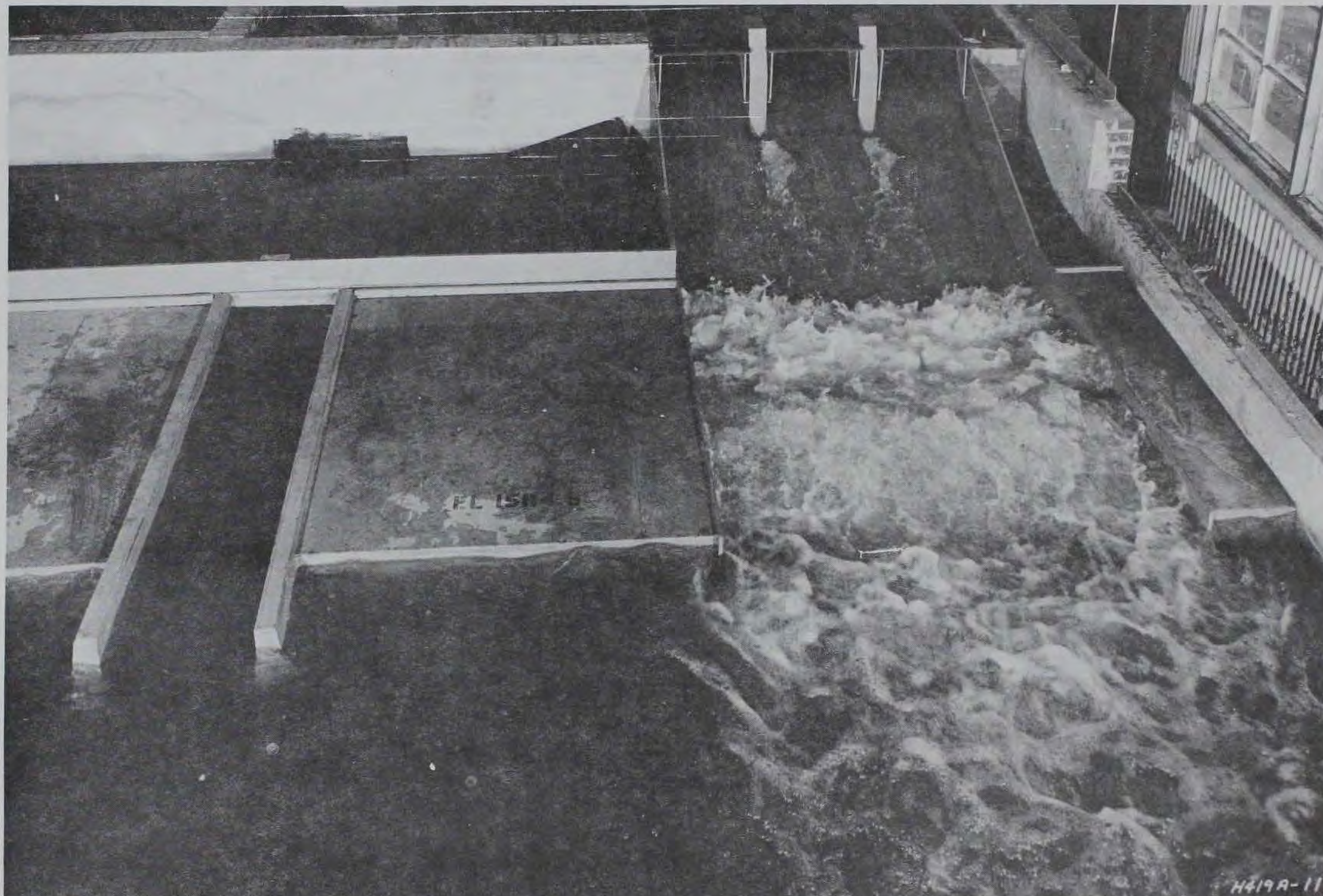


Photo 16. Spillway stilling basin performance for the PMF discharge, 1:25 scale

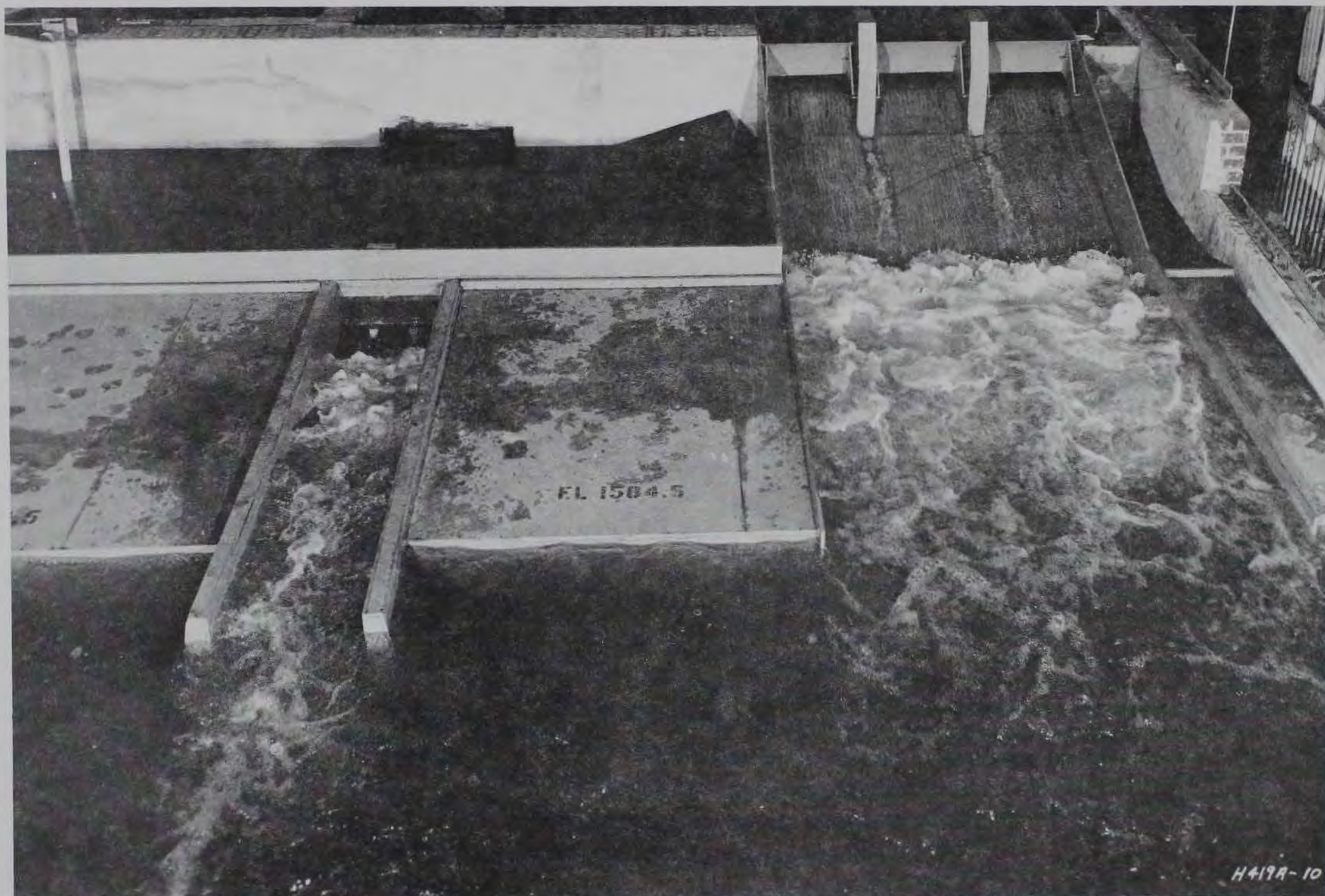
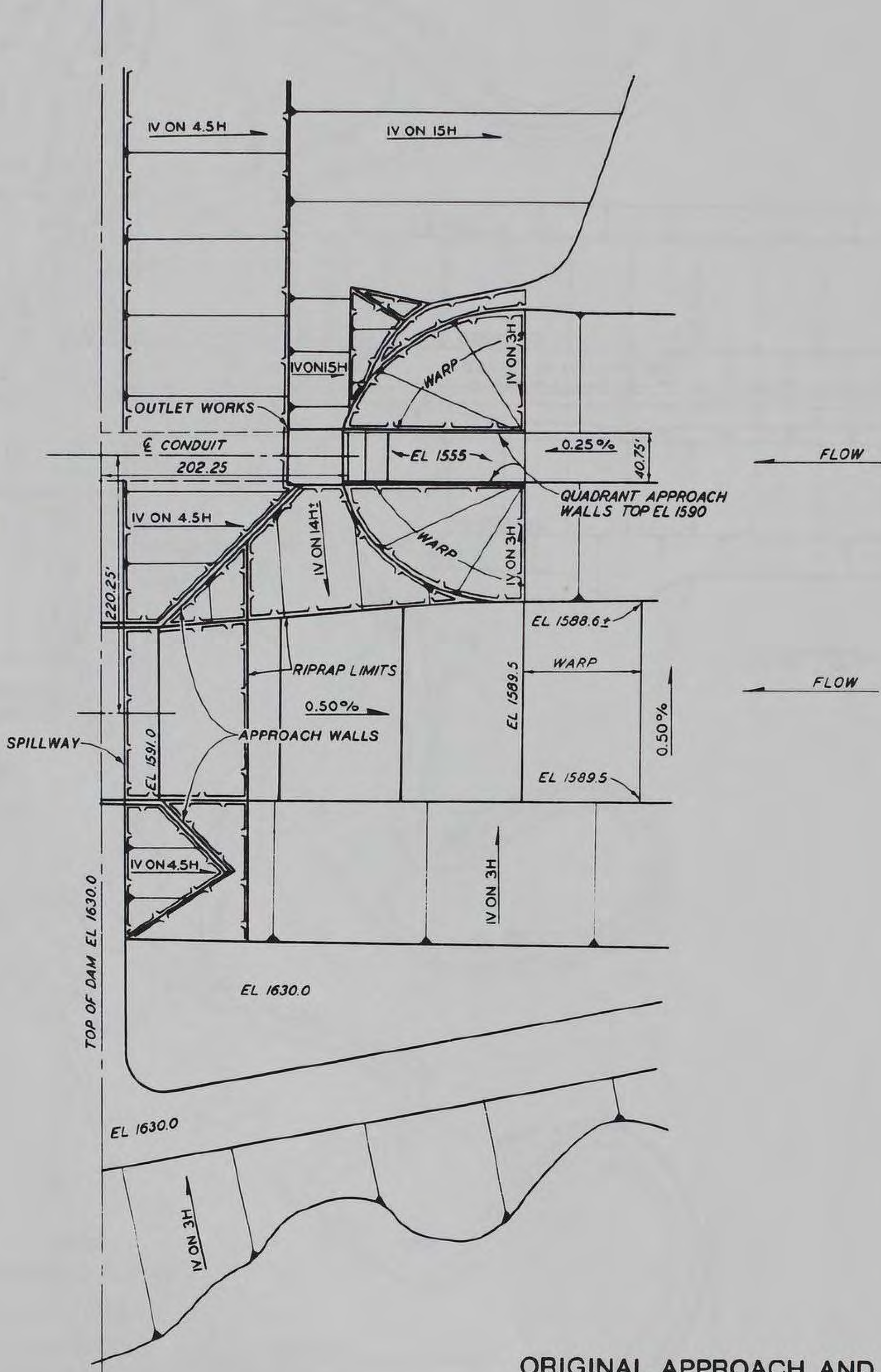


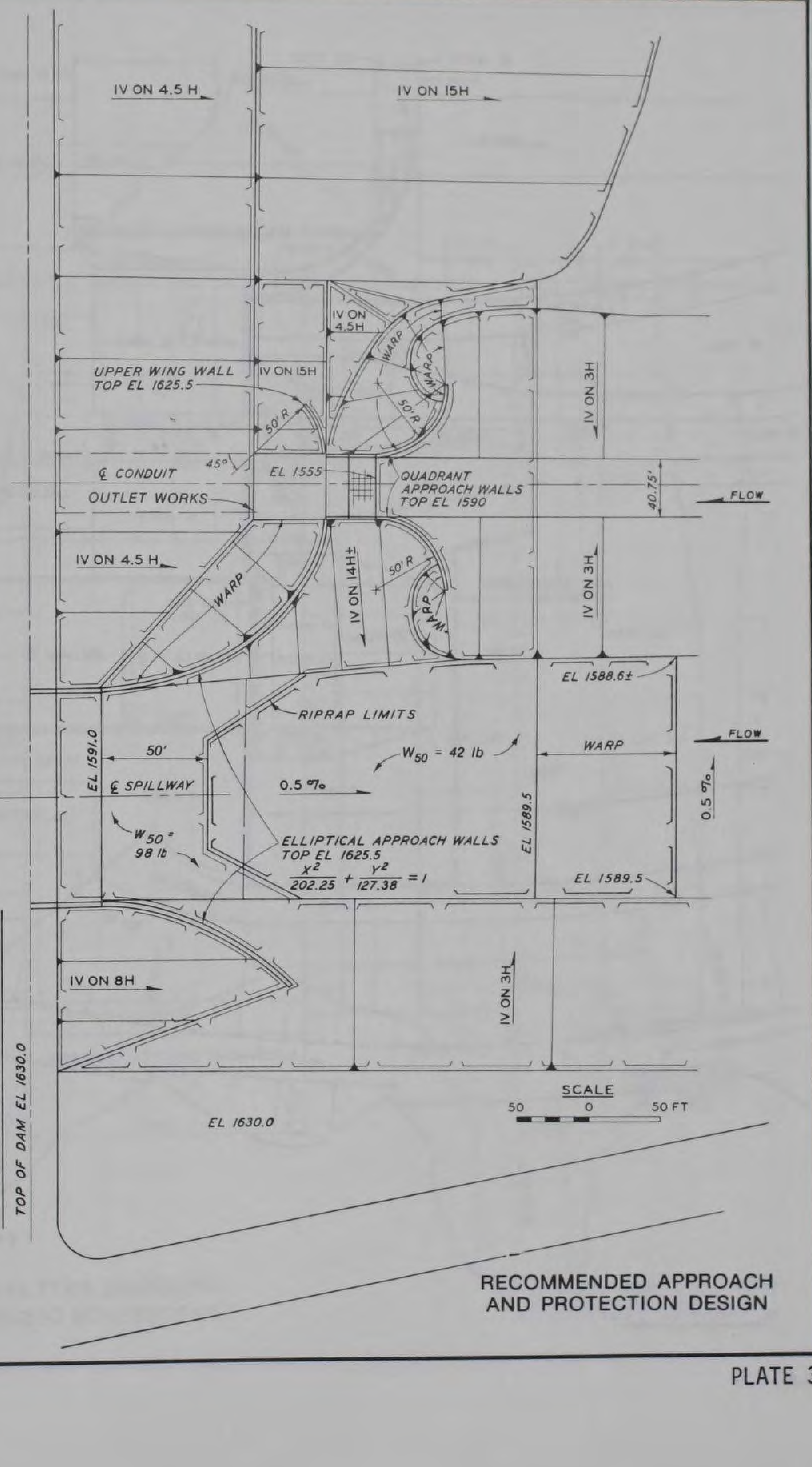
Photo 17. Outlet works stilling basin performance for the PMF discharge and the spillway stilling basin performance with 50 percent of the PMF discharge, 1:25 scale

1:80-SCALE MODEL LIMITS
EL 1576.0
IV ON 15H
EL 1600.0
OUTLET WORKS
TOP OF DAM EL 1630.0
IV ON 4.5H
EL 1591.0
IV ON 3H
EL 1584.5
IV ON 25H
EL 1579.0
R = 1360'
IV ON 3H
1:25 SCALE
MODEL LIMITS
R = 650'
SERVICE
ROAD
EL 1588.5
SLOPE
SLOPE
SLOPE
IV ON 3H
IV ON 3H
SLOPE
SPILLWAY
IV ON 3H
EL 1630.0
COUNTY ROAD EL 1630.0
IV ON 3H
EL 1620.0
IV ON 3H
IV ON 20H
SLOPE
IV ON 4H
1563
1563
1563
1565
1565
1560
1560
1565
1560
1560
1566
1565
1560
1560
1575
1600
1625
1675
1625
1560
1560
SCALE
200 0 200 400 FT
MODEL LIMITS
1:80 SCALE
1:25 SCALE

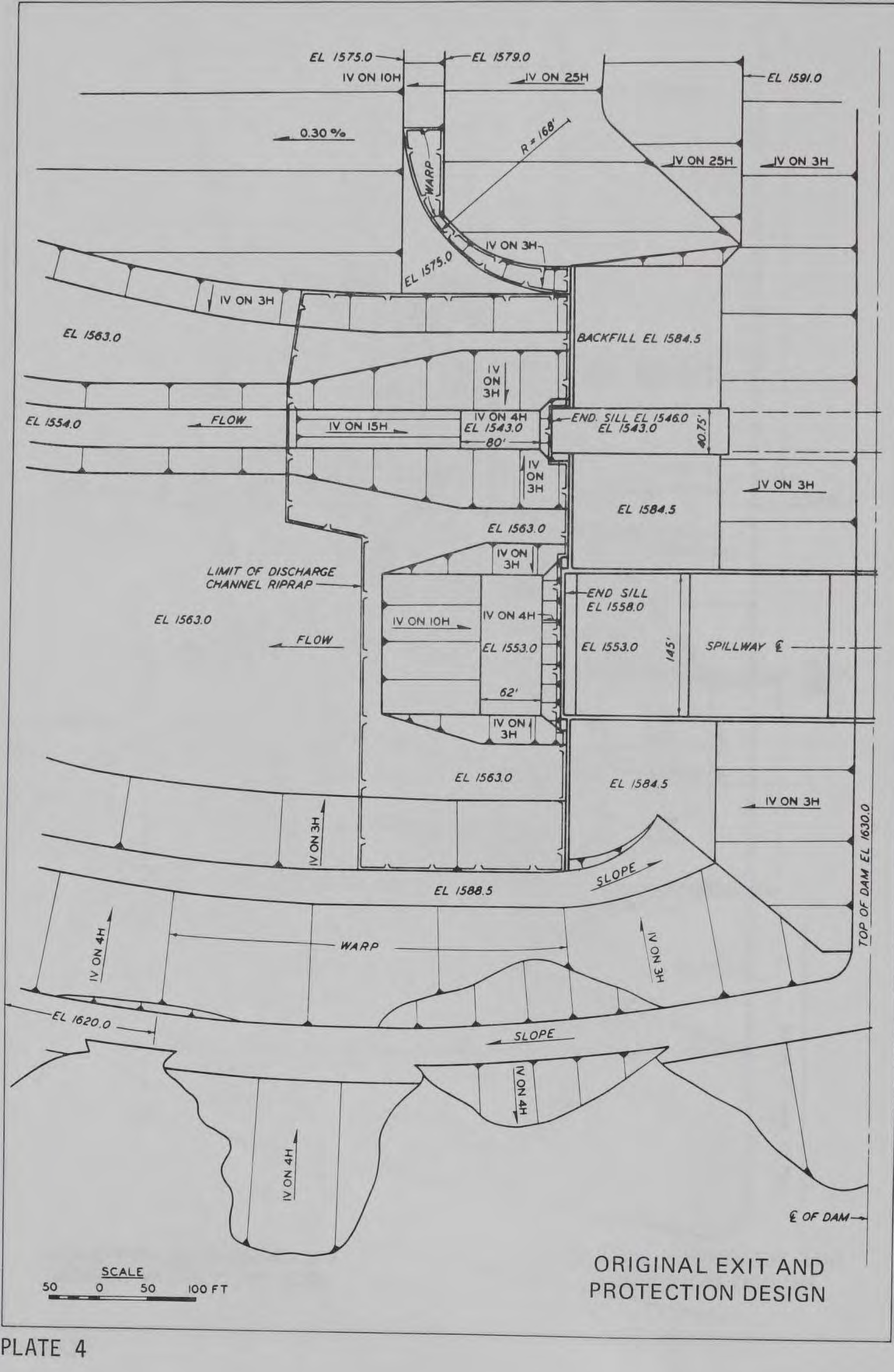
PLATE 1



ORIGINAL APPROACH AND PROTECTION DESIGN

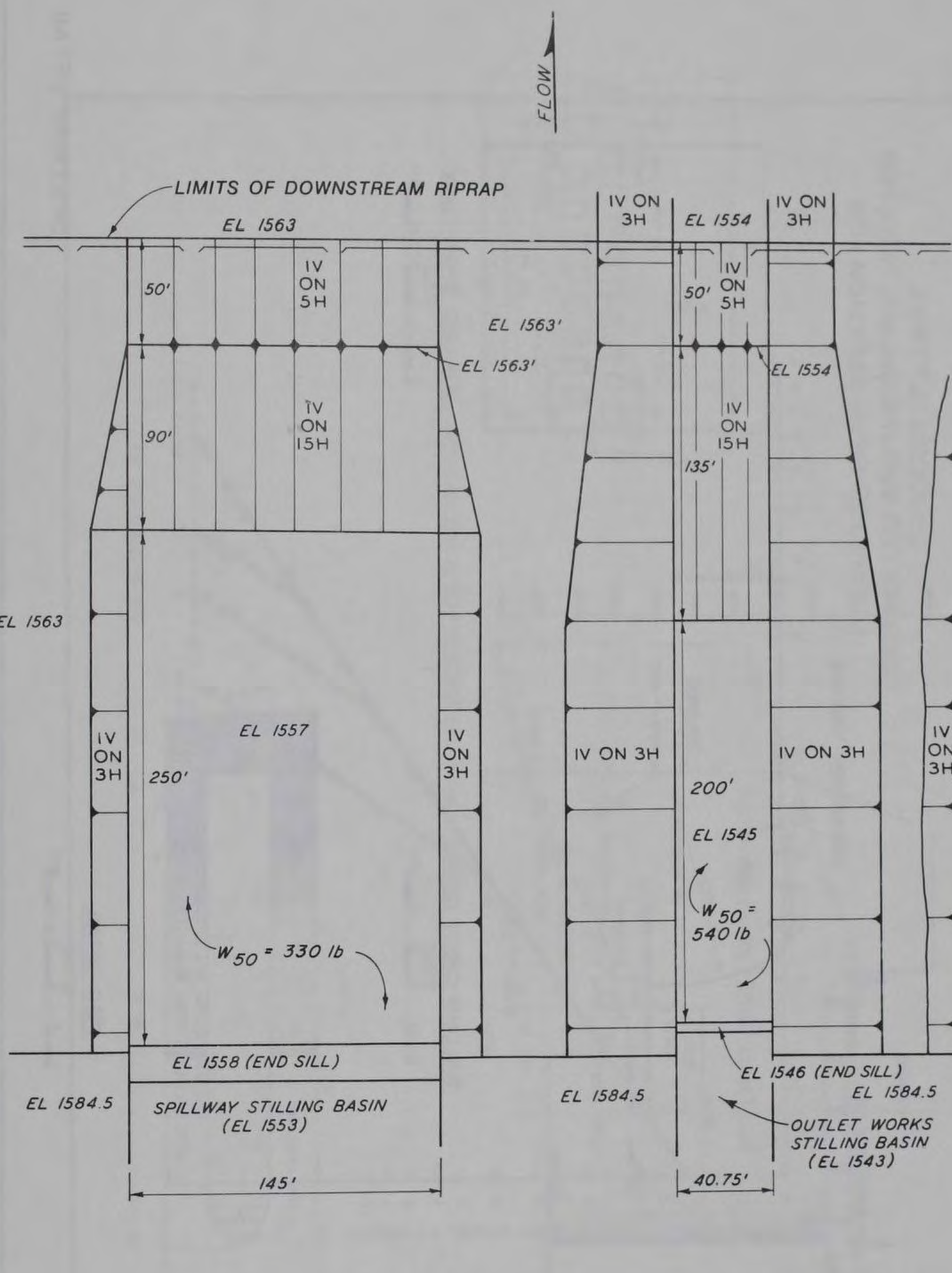


RECOMMENDED APPROACH AND PROTECTION DESIGN



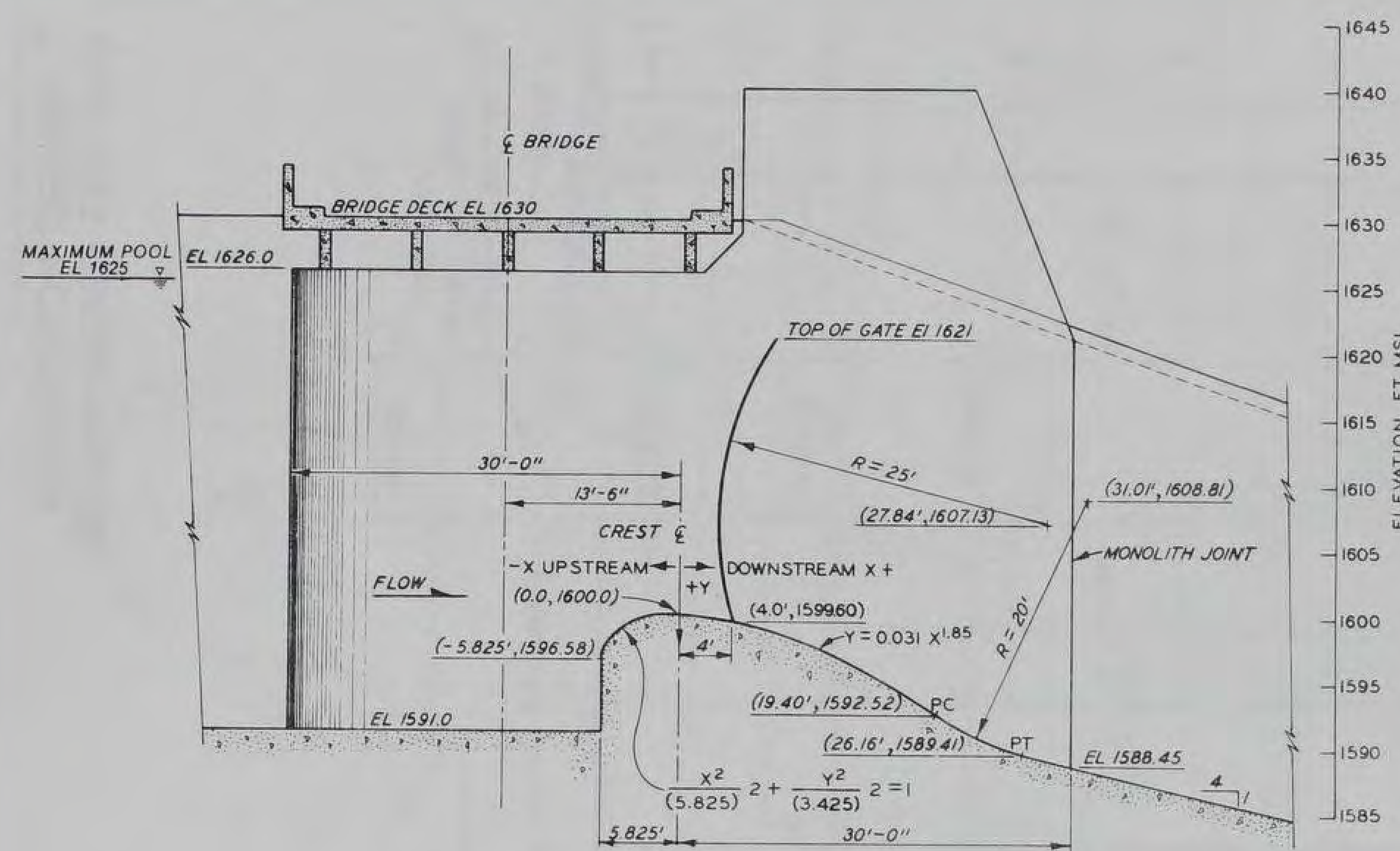
ORIGINAL EXIT AND PROTECTION DESIGN

PLATE 4



RECOMMENDED EXIT AND PROTECTION DESIGN

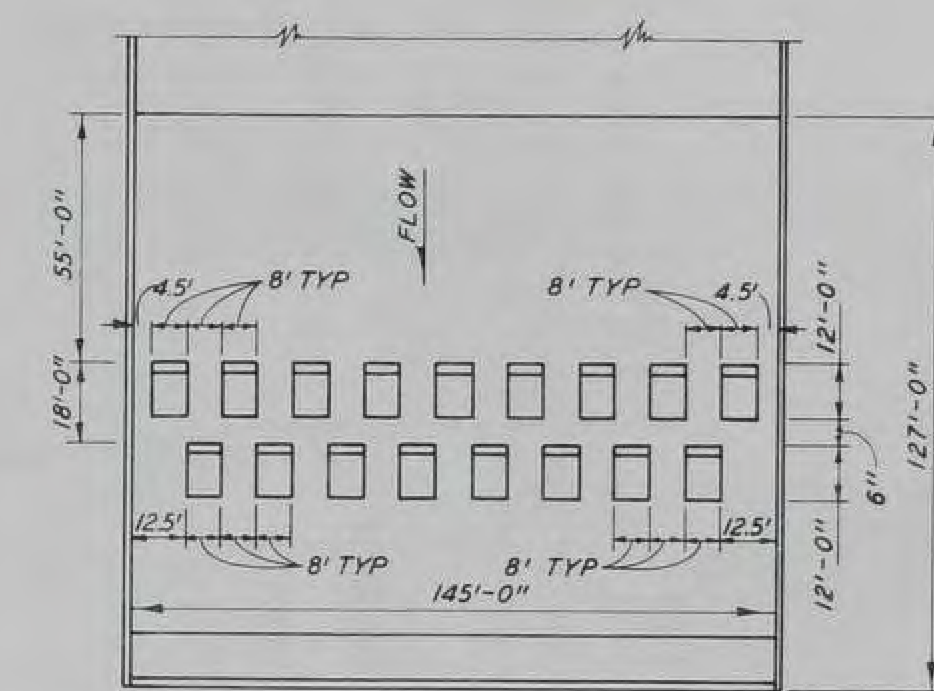
PLATE 6



SPILLWAY CREST DETAIL

SCALE

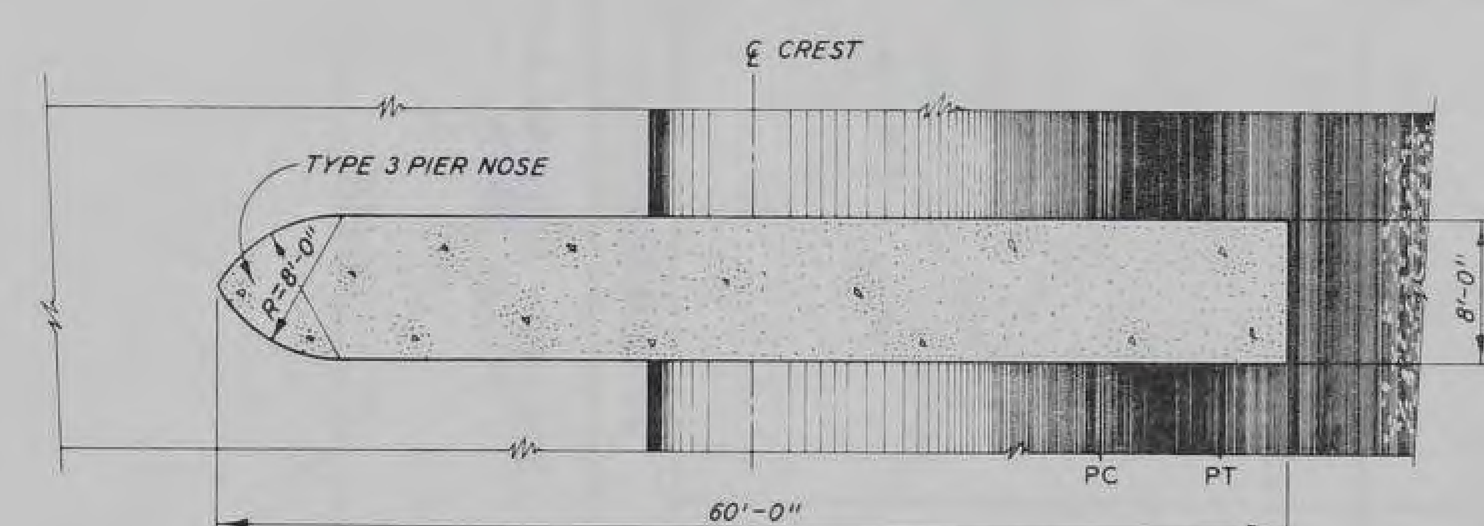
5 0 5 10 15 20 FT



STILLING BASIN PLAN

SCALE

5 0 5 10 15 20 FT

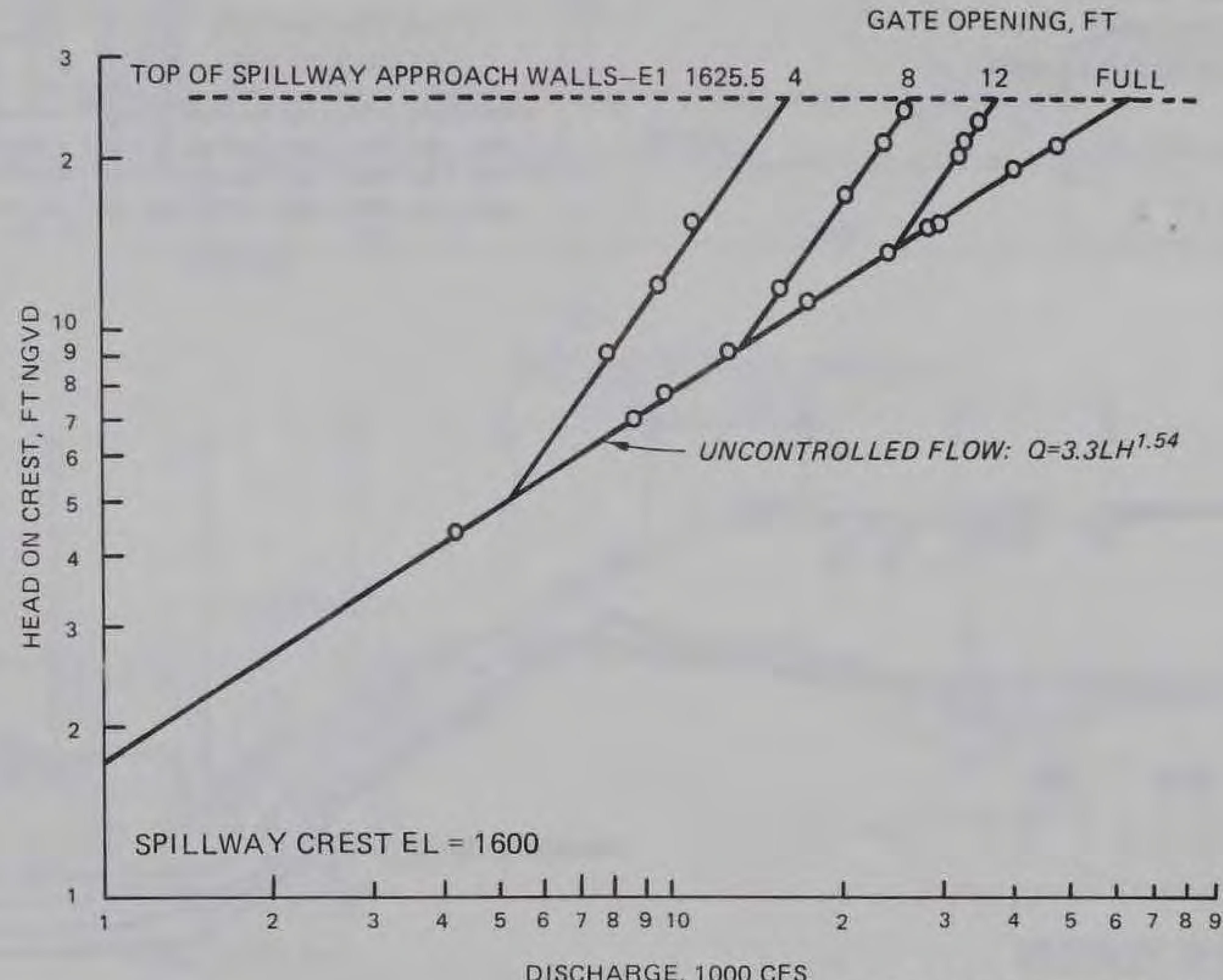


PIER DETAIL

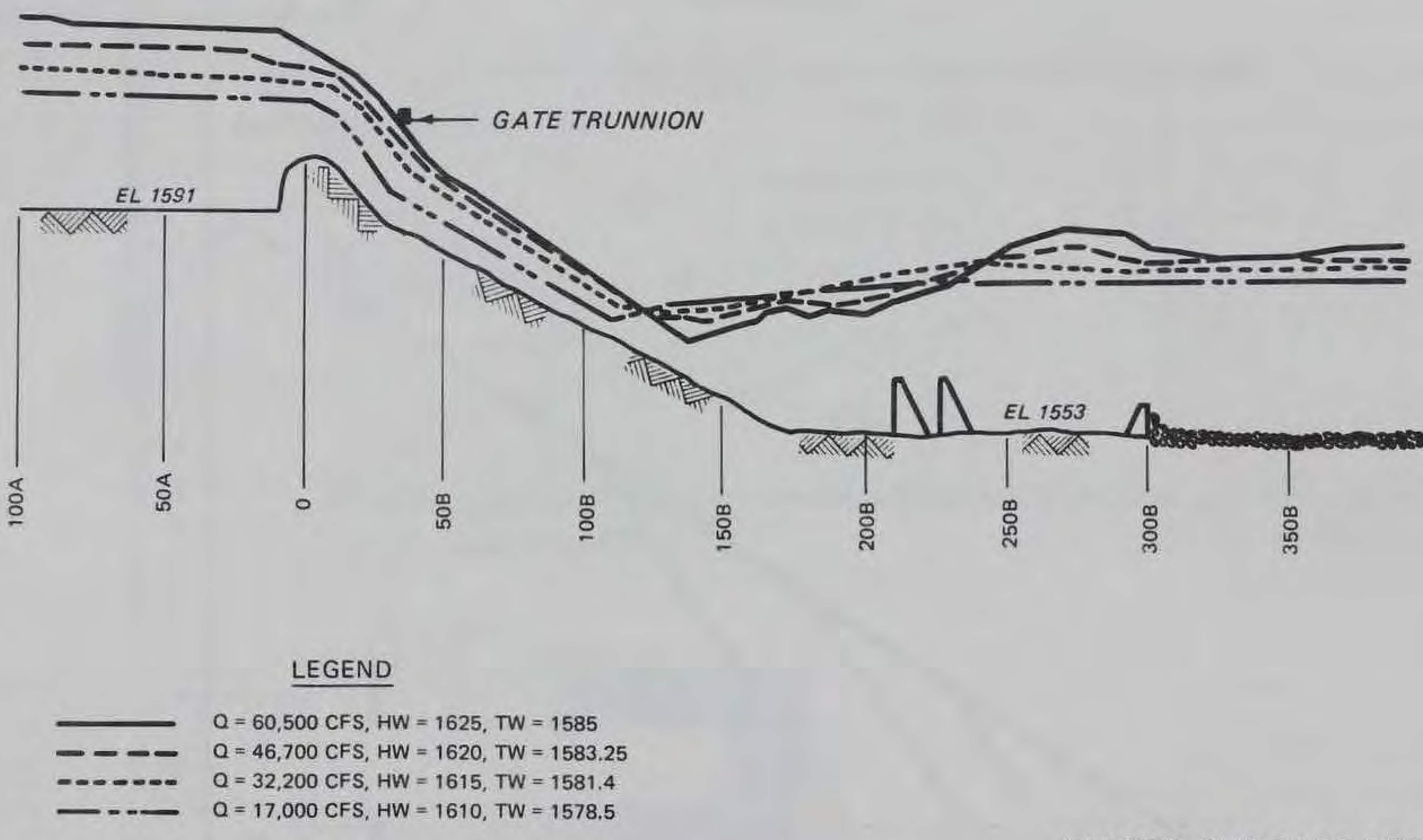
SCALE

5 0 5 10 15 20 FT

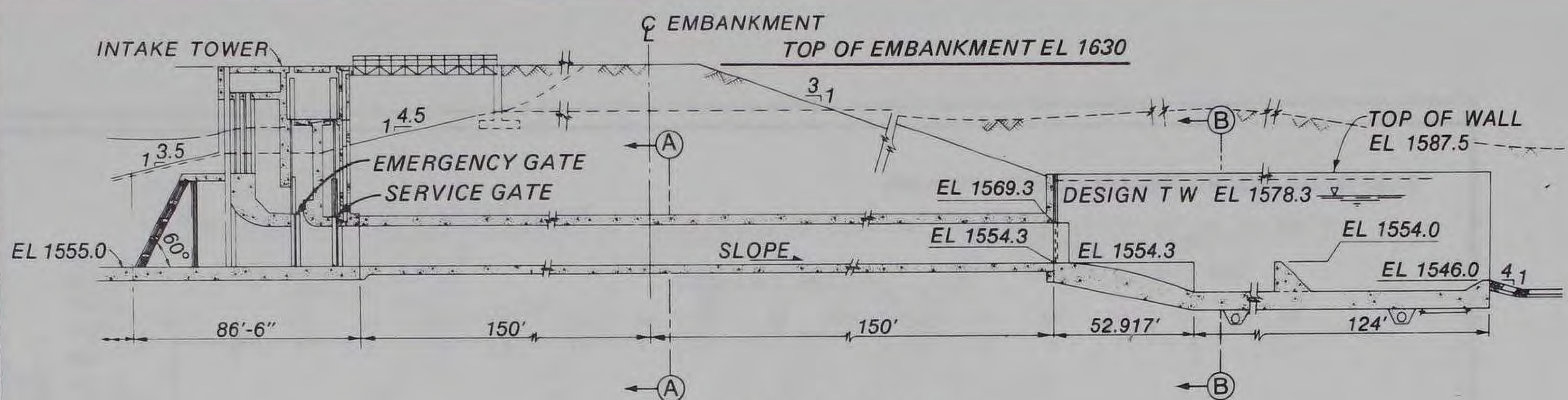
SPILLWAY DETAIL



DISCHARGE-HEAD RELATION FOR CONTROLLED AND UNCONTROLLED FLOW THROUGH SPILLWAY

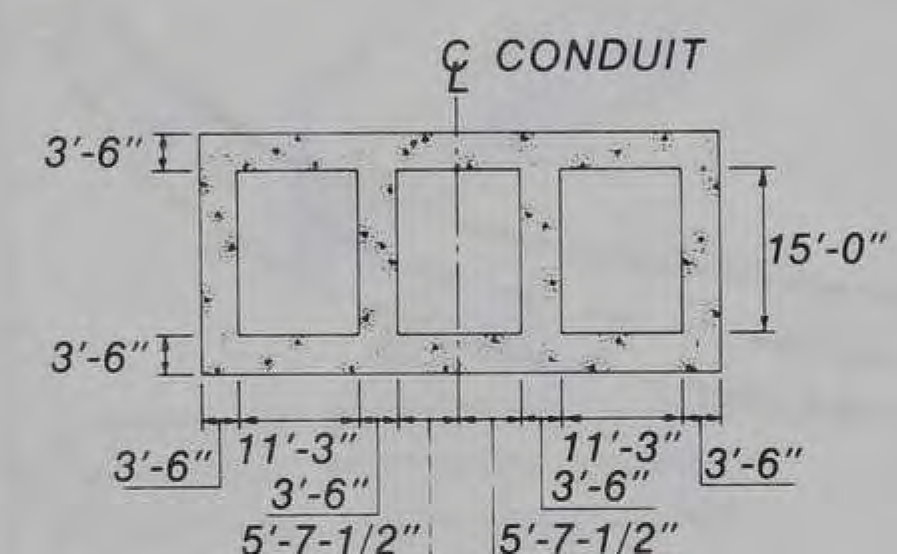


WATER-SURFACE PROFILES
THROUGH SPILLWAY
UNCONTROLLED FLOW



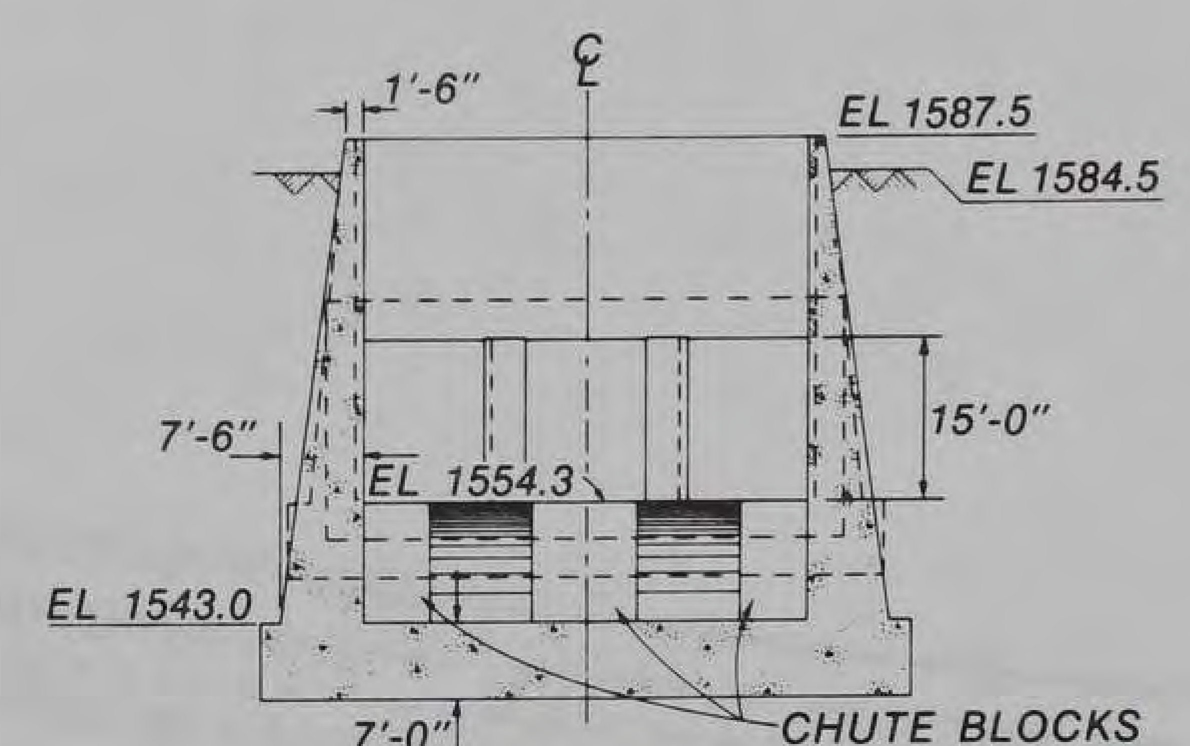
OUTLET WORKS SECTION

20 0 20 40 FT



SECTION A-A

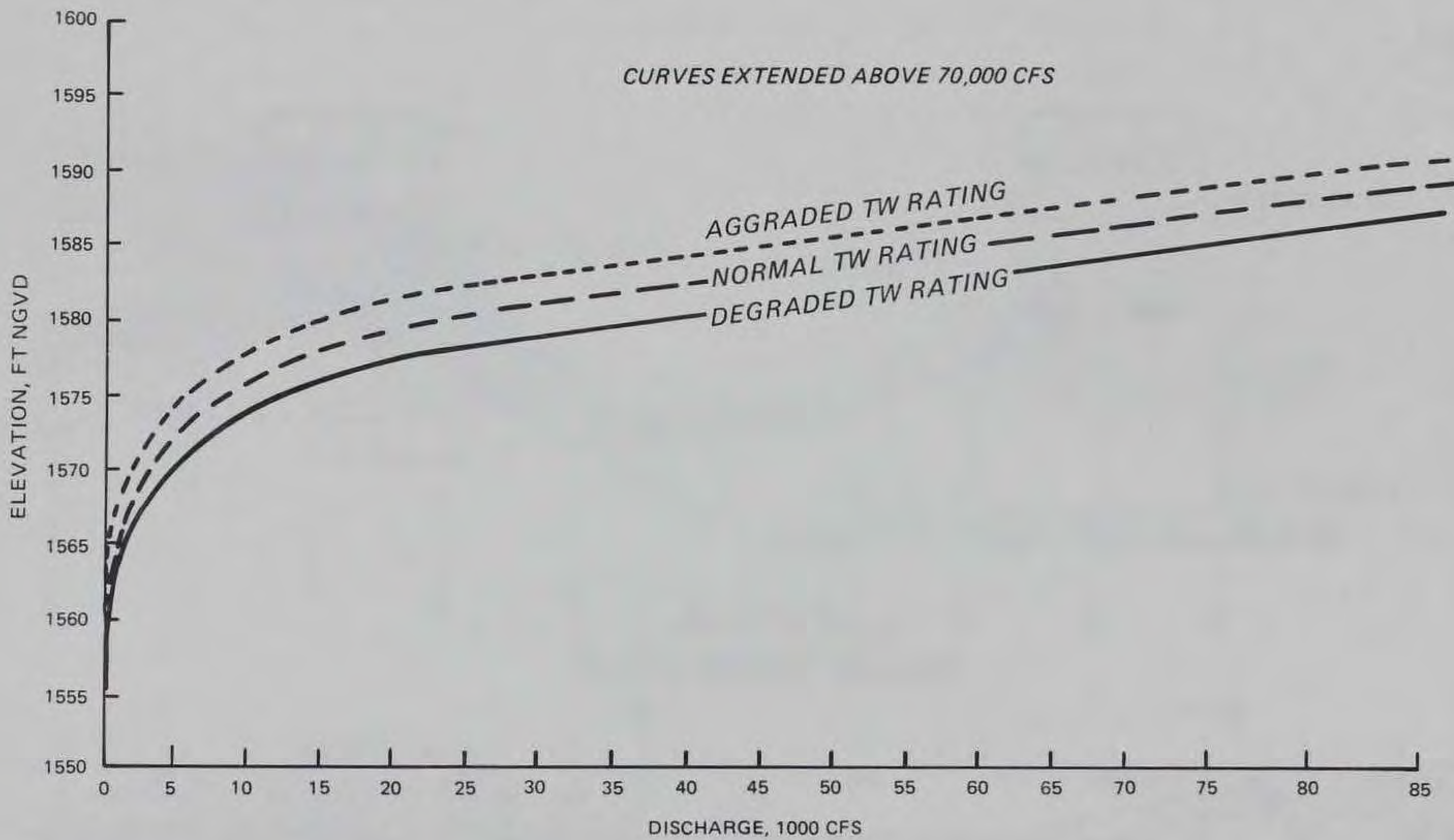
10 0 10 20 FT



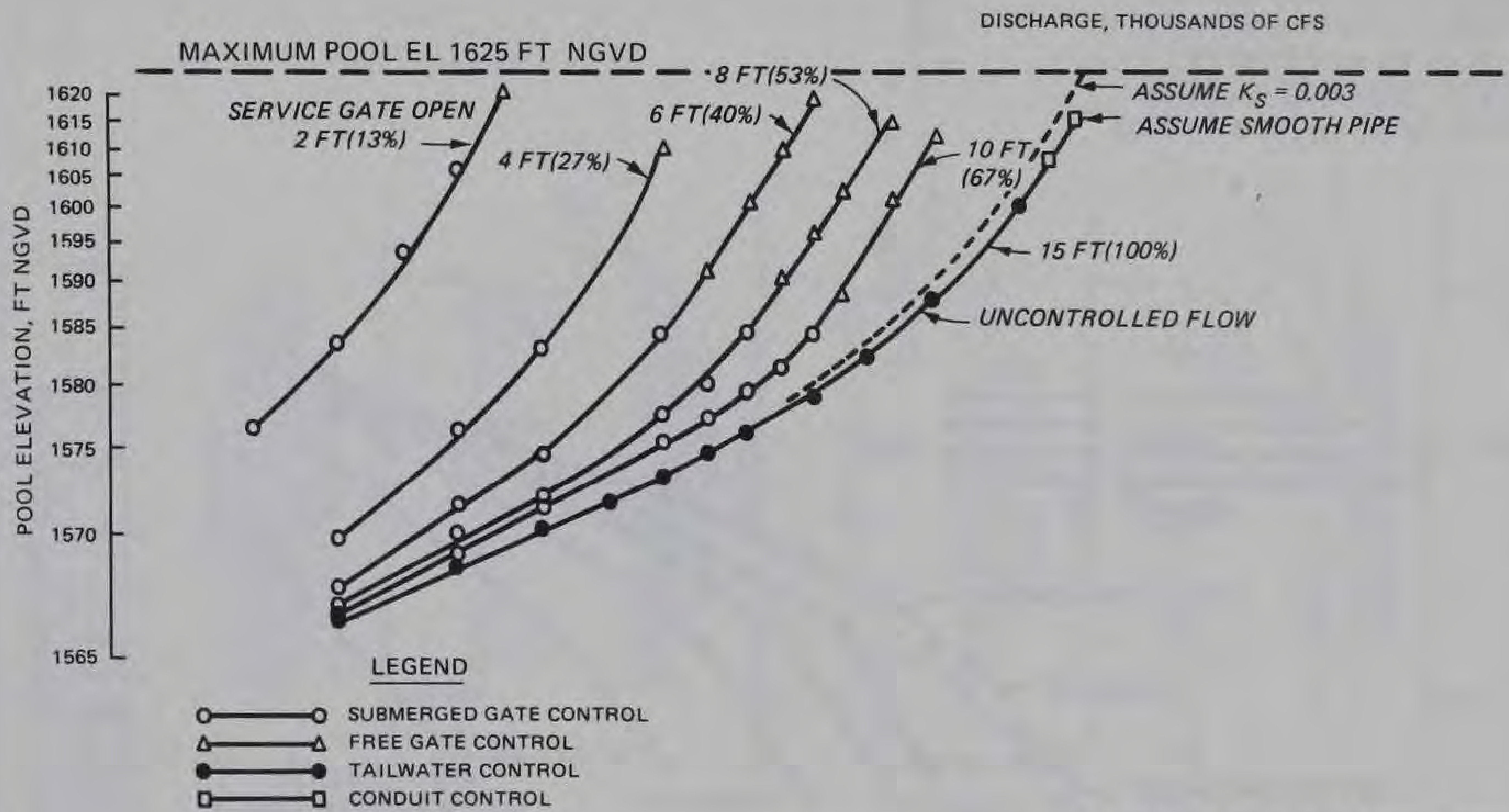
SECTION B-B

10 0 10 20 FT

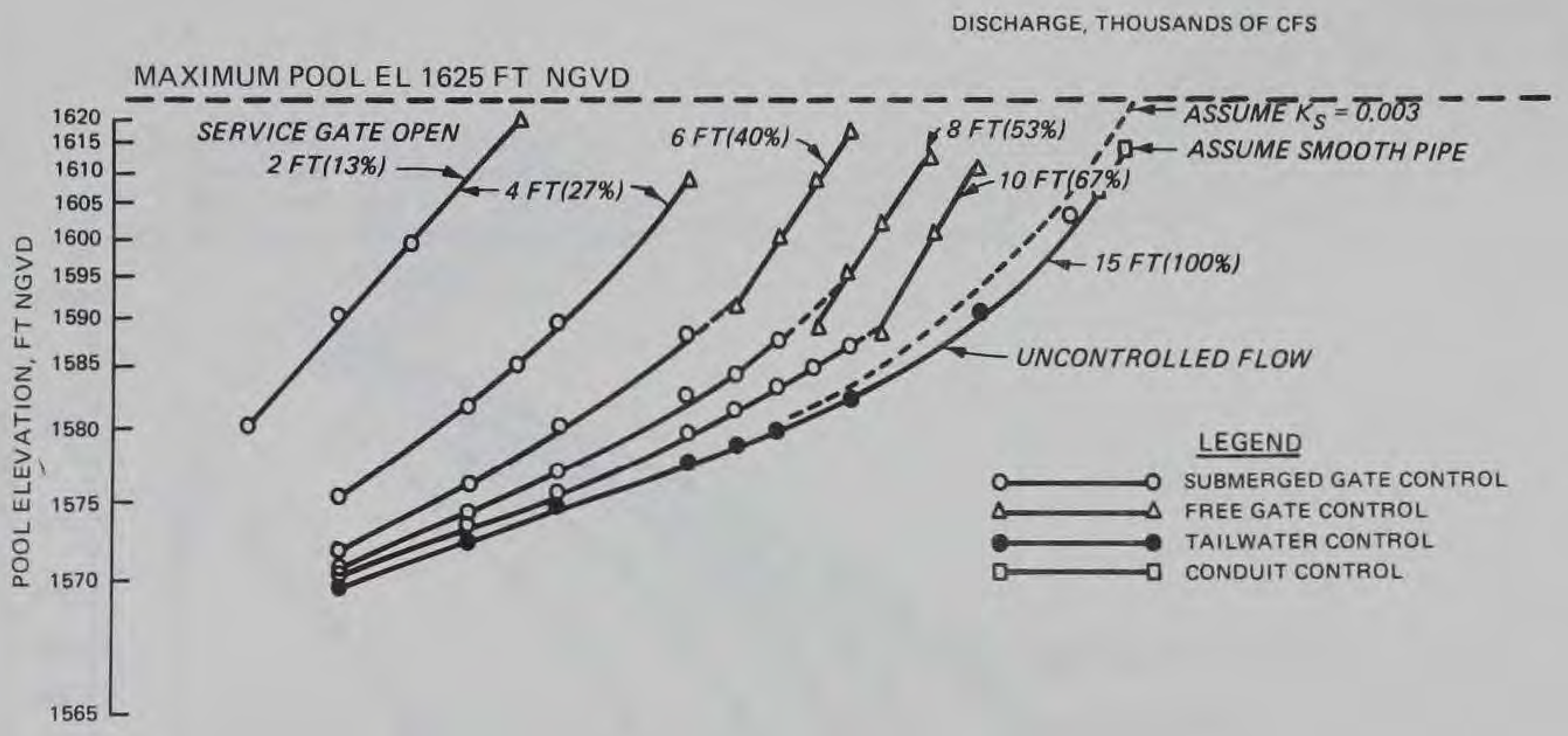
OUTLET WORKS
DETAIL



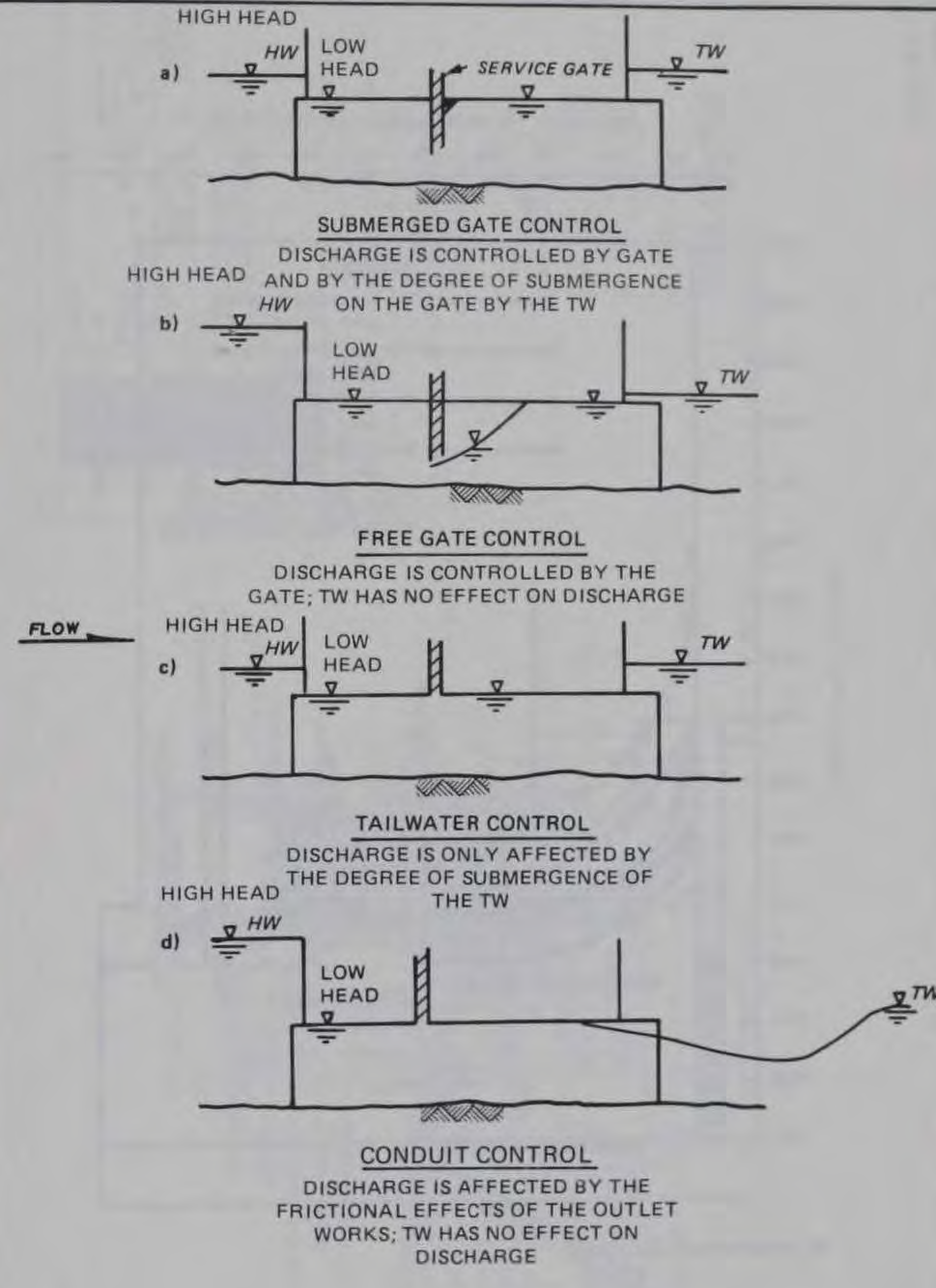
TAILWATER RATING CURVE



DISCHARGE RATING CURVES
FLOOD-CONTROL FLOW
3-GATE OPERATION
FULL AND PARTIAL OPENINGS
DEGRADED TAILWATER



DISCHARGE RATING CURVES
FLOOD-CONTROL FLOW
3-GATE OPERATION
FULL AND PARTIAL OPENINGS
AGGRADED TAILWATER



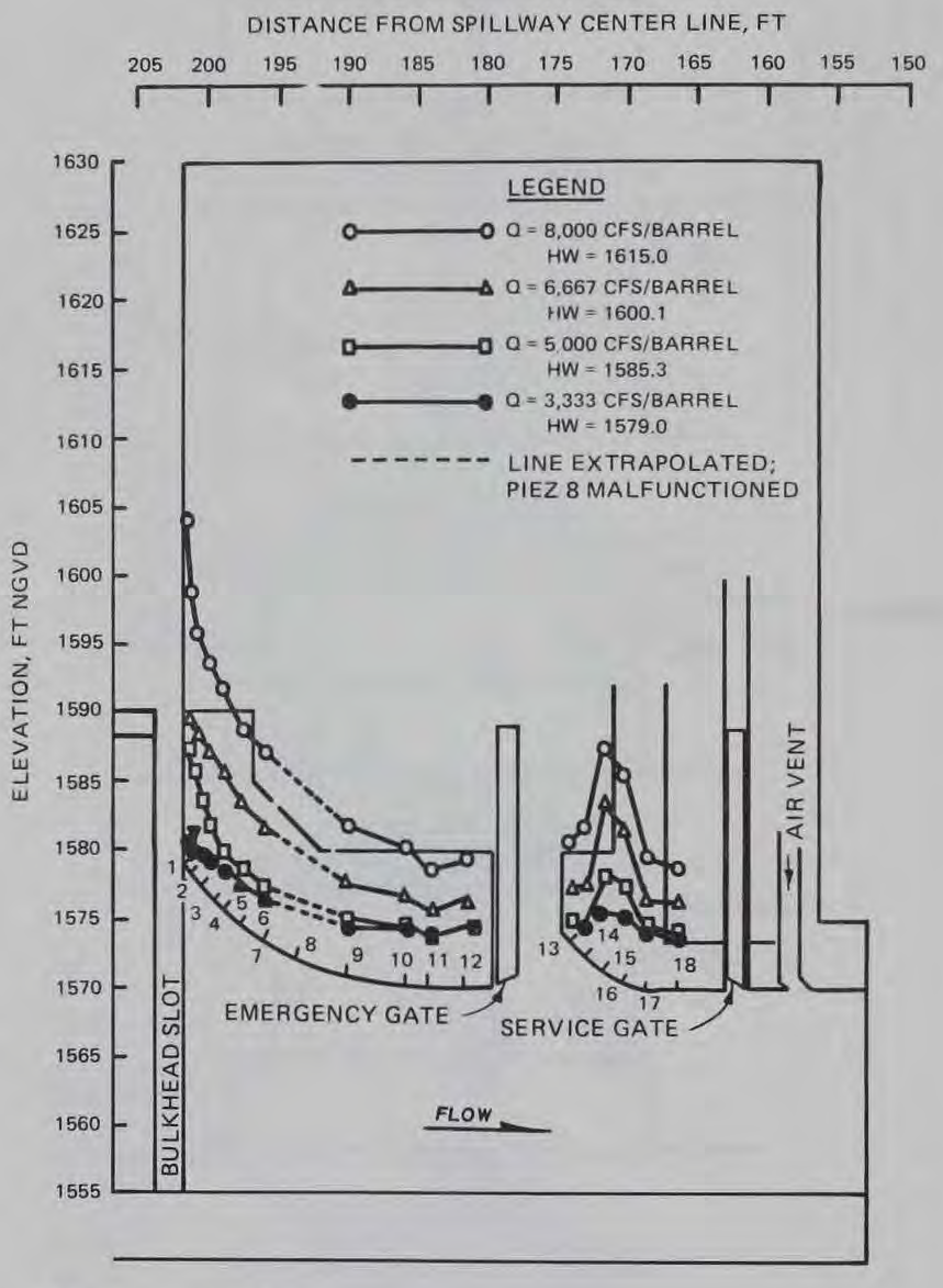
a) SUBMERGED GATE CONTROL
DISCHARGE IS CONTROLLED BY GATE AND BY THE DEGREE OF SUBMERGENCE ON THE GATE BY THE TW

b) FREE GATE CONTROL
DISCHARGE IS CONTROLLED BY THE GATE; TW HAS NO EFFECT ON DISCHARGE

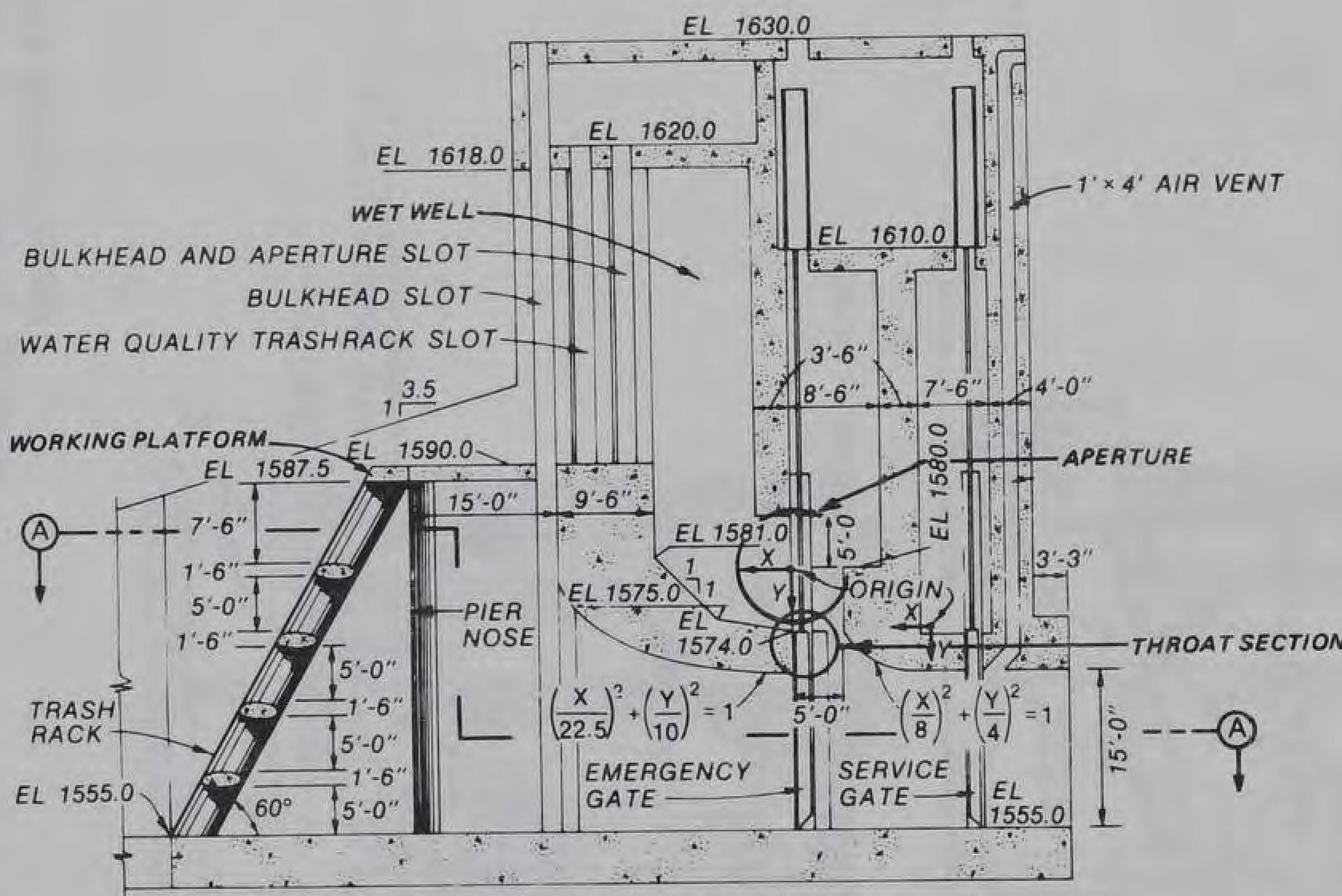
c) TAILWATER CONTROL
DISCHARGE IS ONLY AFFECTED BY THE DEGREE OF SUBMERGENCE OF THE TW

d) CONDUIT CONTROL
DISCHARGE IS AFFECTED BY THE FRICTIONAL EFFECTS OF THE OUTLET WORKS; TW HAS NO EFFECT ON DISCHARGE

CONDUIT FLOW REGIMES

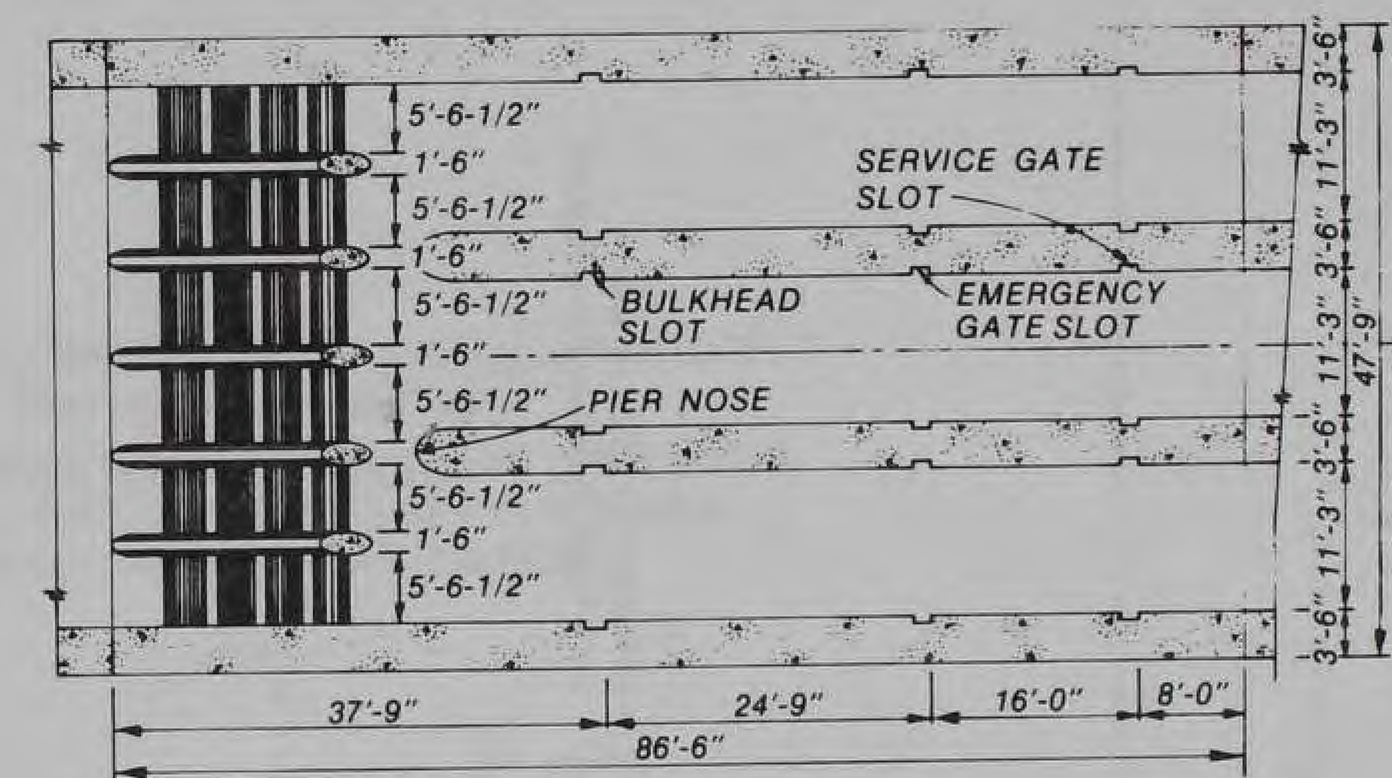


PRESSURE PROFILE FOR
FLOOD FLOW THROUGH A SINGLE CONDUIT
UNCONTROLLED FLOW



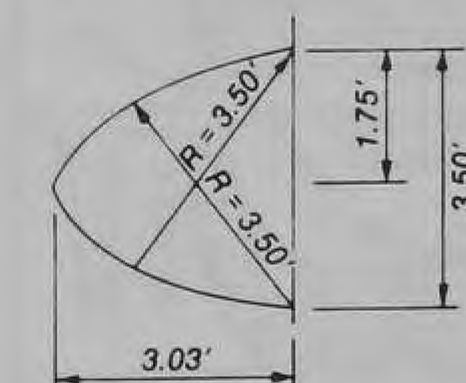
INTAKE TOWER SECTION

10 0 10 20 FT



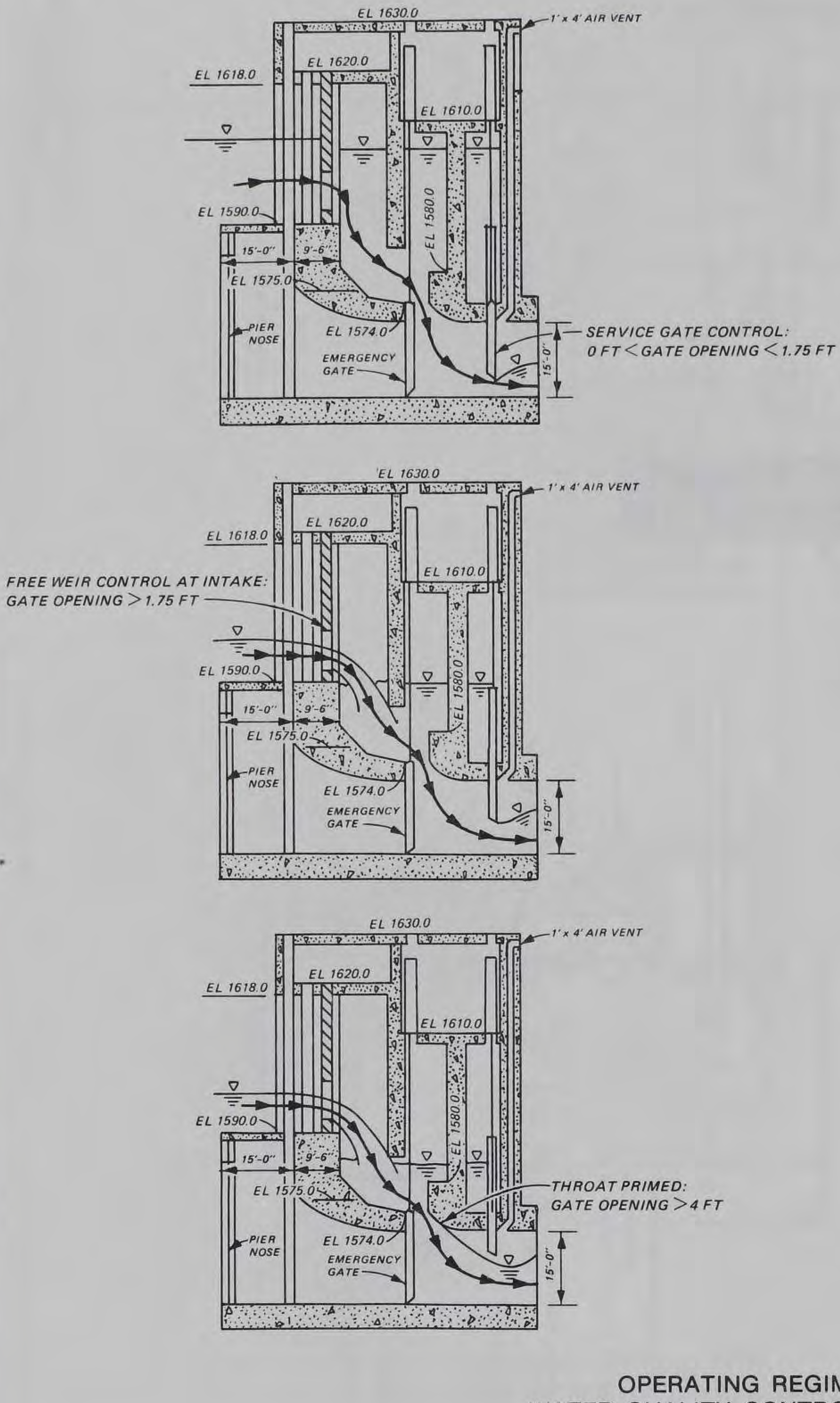
SECTION A-A

10 0 10 20 FT

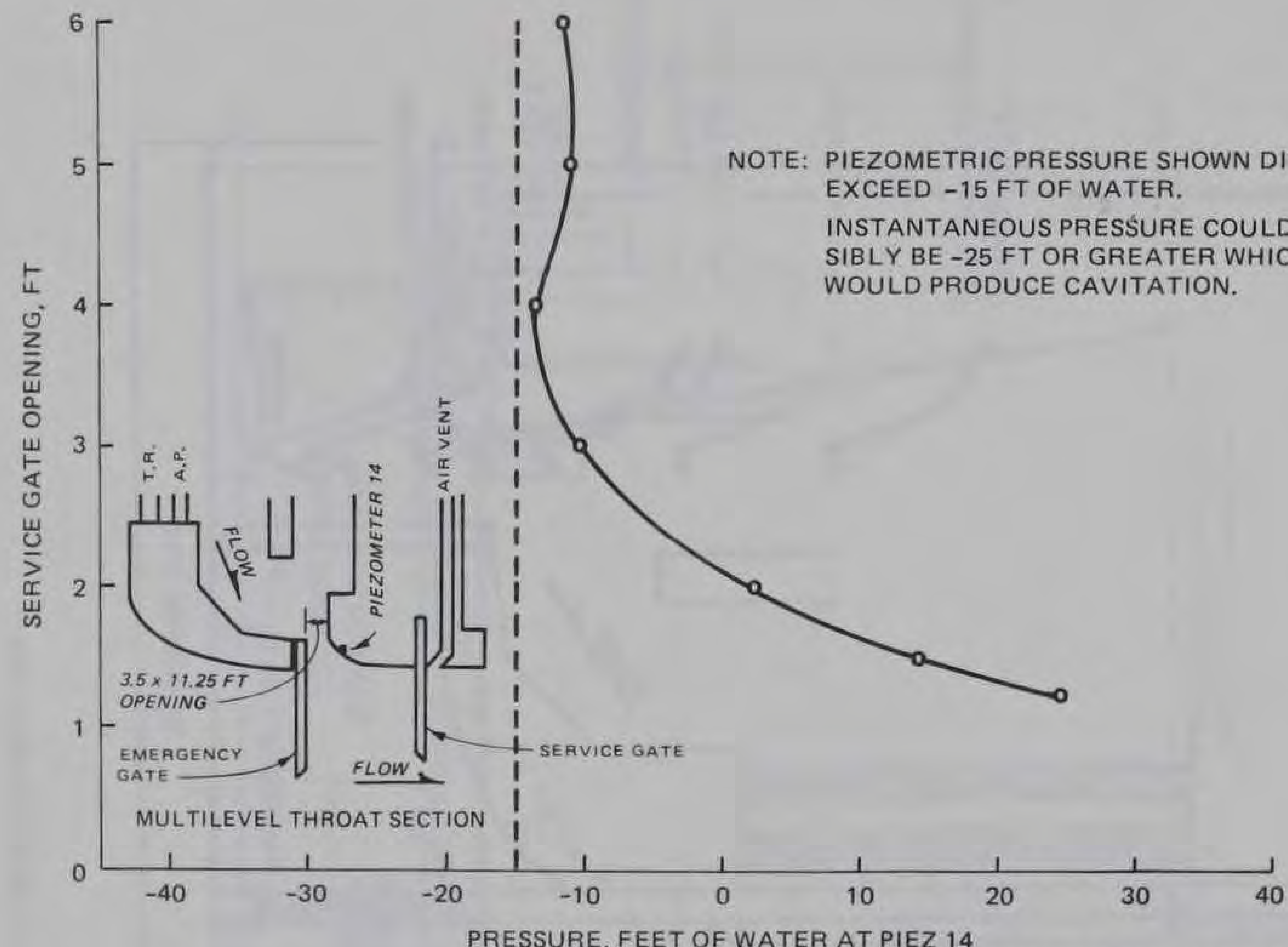


TYPE 3 PIER NOSE

OUTLET WORKS INTAKE TOWER DETAIL



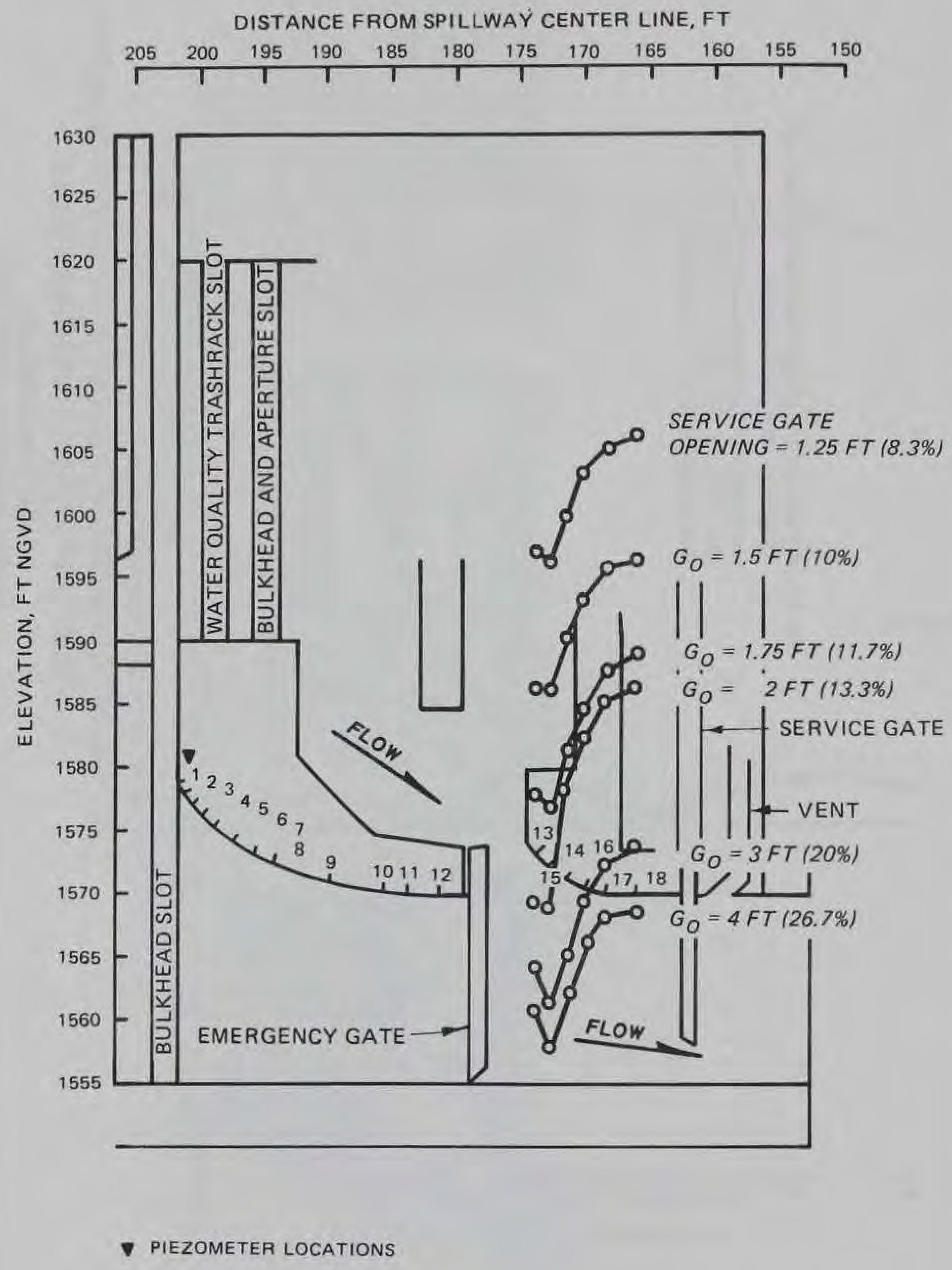
OPERATING REGIMES
WATER QUALITY CONTROL SYSTEM



MINIMUM PRESSURES MEASURED FOR WATER QUALITY FLOW THROUGH A SINGLE WET WELL

DISCHARGE 700 CFS

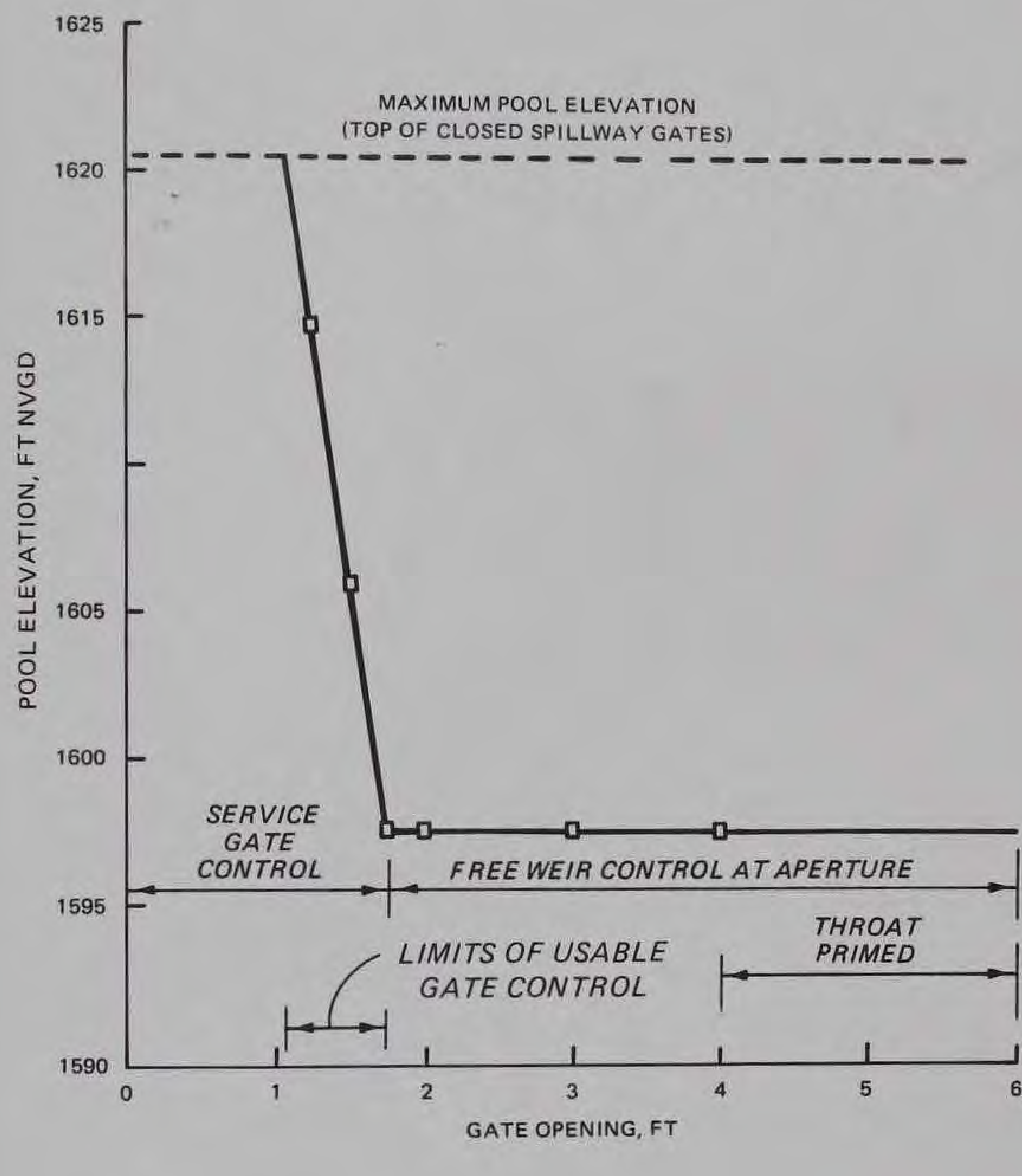
MINIMUM APERTURE EL 1592



PRESSURE PROFILE FOR WATER QUALITY FLOW THROUGH A SINGLE WET WELL

DISCHARGE 700 CFS

MINIMUM APPERTURE EL 1592



POOL EL VERSUS GATE OPENING FOR
WATER QUALITY THROUGH A SINGLE WET WELL
DISCHARGE 700 CFS
MINIMUM APERTURE EL 1592
OPERATING REGIMES IDENTIFIED