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HYDRAULICS LABORATORY

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RED RIVER WATERWAY, LOCK AND DAM NO. 4

Report 4
STILLING BASIN AND RIPRAP REQUIREMENTS

Spillway Hydraulic Model Study

by

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13. ABSTRACT *(Maximum 200 words)*

Lock and Dam No. 4 is proposed for construction in a cutoff canal on the Red River approximately 71 miles below Shreveport, LA. The principal structures consist of a lock with an adjacent gated spillway and overflow weir. The lock, which will be 84 ft wide with 685 ft of usable length, will be located on the left bank line looking downstream and will have a maximum lift of 25 ft. The gated spillway will contain four tainter gates, 60 ft wide by 36 ft high, with a sill elevation of 86.0 ft (elevations (el) are in feet referred to the National Geodetic Vertical Datum), and an overflow weir with three 100-ft-wide hinged gates. The crest of the hinge-gated weir will be at el 115.0, and the top of the hinged gate in its fully raised (closed) position will be at el 122.0.

Tests were conducted in a 1:40-scale model of Lock and Dam No. 4 to develop a satisfactory energy dissipator and a stable riprap protection plan.

The original crest was lowered to el 85, a fifth tainter gate was added,
(Continued)

14. SUBJECT TERMS
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and the three 100-ft-wide hinge-gated crests were replaced by a single 100-ft-wide baffled chute. Tests were conducted to compare the two designs, and data obtained with both designs are presented in this report. Water-surface profiles were measured for the full range of expected operating conditions.

The recommended stilling basin provides adequate energy dissipation for normal flow and for a single gate fully open and half open operating with minimum tailwater. The recommended riprap protection plan in the upstream and downstream areas adjacent to the structure remained stable for these conditions.

PREFACE

The model investigation reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), on 1 March 1986 at the request of the US Army Engineer District, Vicksburg (LMK).

The study was conducted during the period March 1986 to May 1990 in the Hydraulics Laboratory (HL) of the US Army Engineer Waterways Experiment Station (WES), under the direction of Messrs. F. A. Herrmann, Jr., Chief, HL; and R. A. Sager, Assistant Chief, HL; and under the general supervision of Messrs. G. A. Pickering, Chief, Hydraulic Structures Division (HSD), HL; and N. R. Oswalt, Chief, Spillways and Channels Branch (SCB), HSD. The project engineer for the model study was Mr. J. R. Leech, and model tests were conducted by Mr. E. Jefferson and Mr. J. R. Rucker, all of SCB. This report was prepared by Mr. Leech with assistance from Mr. J. R. Rucker and edited by Mrs. Marsha Gay, Information Technology Laboratory, WES.

During the course of the investigation, Messrs. L. Cook, J. Farrell, and H. Reed, US Army Engineer Division, Lower Mississippi Valley; and Messrs. P. Combs, R. Robertson, T. Smith, B. Author, and S. Barry, LMK, visited WES to discuss the program and results of model tests, observe the model in operation, and correlate these results with design studies.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

	Page
PREFACE	1
CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT	3
PART I: INTRODUCTION	5
Prototype	5
Purpose and Scope of Model Study	6
PART II: MODEL	8
Description	8
Appurtenances	8
Scale Relations	9
PART III: TESTS AND RESULTS	10
Original Spillway Design	10
Separation Between the Lock and Spillway (Four-Bay Structure, Crest El 86)	10
Separation Between the Lock and Spillway (Four-Bay Structure, Crest El 85)	13
Five-Bay Structure with One Hinge-Gated Section	17
PART IV: CONCLUSIONS AND RECOMMENDATIONS	21
TABLES 1-3	
PHOTOS 1-13	
PLATES 1-25	

LIST OF FIGURES

No.		Page
1	Vicinity map	4
2	1:40-scale model of original design looking downstream	8
3	Original design	11
4	69-ft separation between spillway and lock	12
5	Riprap protection plan	15
6	Modified five-bay structure with one hinge gate	18
7	Overall view of downstream channel looking upstream	19

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	0.02831685	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

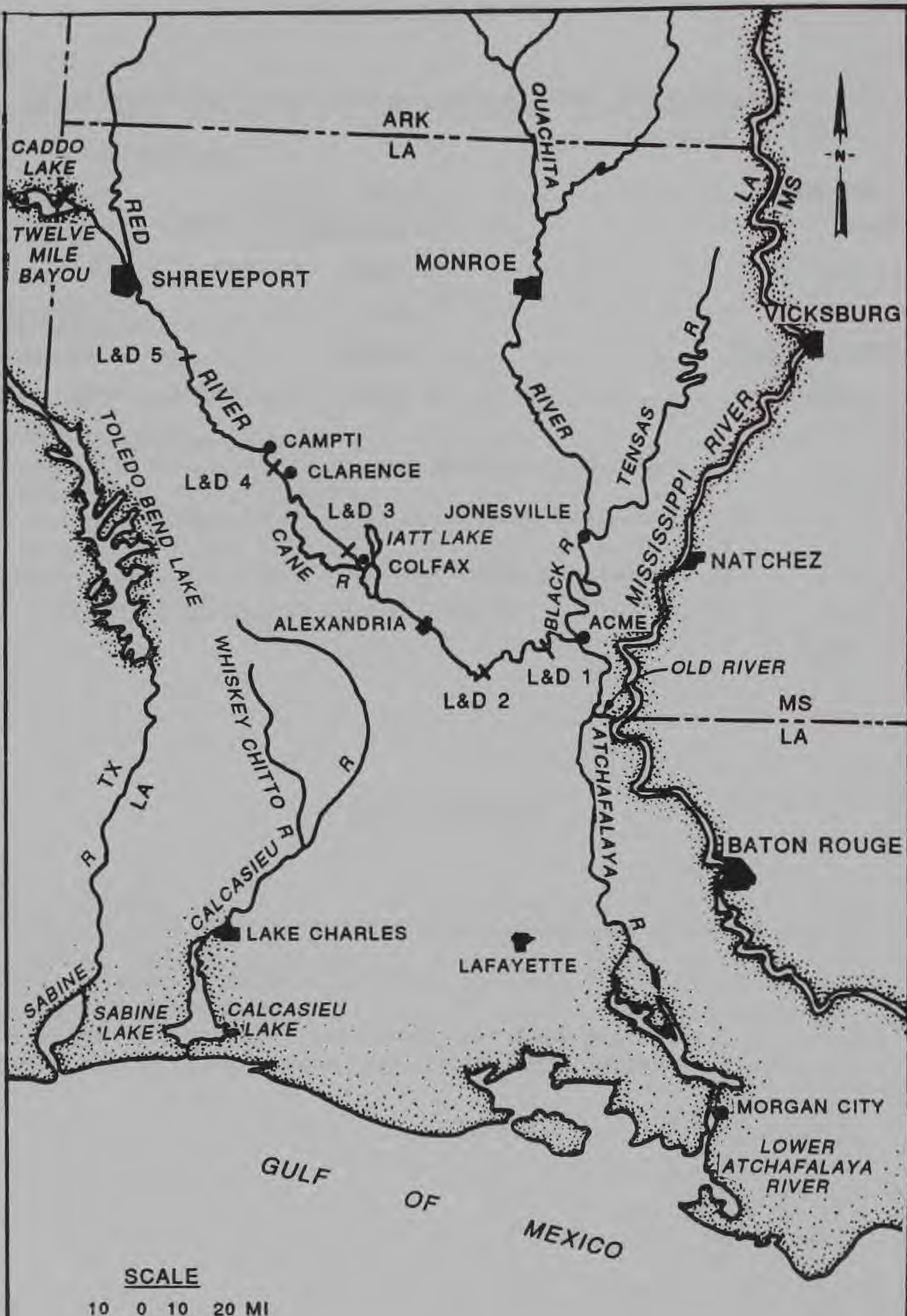

Figure 1. Vicinity map

RED RIVER WATERWAY, LOCK AND DAM NO. 4

STILLING BASIN AND RIPRAP REQUIREMENTS

Spillway Hydraulic Model Study

Part I: INTRODUCTION

Prototype

1. As presently authorized, the Red River multipurpose project provides for the improvement of the Red River and its tributaries in Louisiana, Arkansas, Texas, and Oklahoma through coordinated developments for navigation, bank stabilization, flood control, recreation, fish and wildlife, and water quality control. The project consists of four distinct reaches: (a) Mississippi River to Shreveport, LA, (b) Shreveport, LA, to Daingerfield, TX, by Twelve Mile Bayou, (c) Shreveport, LA, to Index, AR, and (d) Index, AR, to Dennison Dam, TX. Only the reach from the Mississippi River to Shreveport (Figure 1) is pertinent to this report. Within this reach, the plan provides for establishing a navigable channel, approximately 227 miles* long and 9 ft deep with minimum width of 200 ft, from the vicinity of Old River by means of a system of five locks and dams that connects with the Mississippi River through the Old River Lock and Dam (Figure 1).

2. From Dennison Dam, the Red River follows an easterly course along the southern edge of Oklahoma, forming the boundary between that state and Texas, and continues eastward some 47 miles farther to Index, forming the boundary between Texas and Arkansas. Continuing through Arkansas a short distance beyond Index to Fulton, AR, the river then turns abruptly and follows a southerly course for some 77 miles to the Arkansas-Louisiana State line. The remainder of its course lies within the State of Louisiana. At Shreveport, it shifts to a southeasterly direction for some 160 miles to its mouth at the junction with the Atchafalaya River and Old River, 7 miles from the confluence of Old River and the Mississippi River at Red River Landing. Since 1963, flow from the Mississippi River into the Atchafalaya systems has been

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

regulated by control structures near the Mississippi River levee line where an excavated channel carries outflow to the lower Red River. A 75-ft-wide by 1,200-ft-long lock at the mouth of Old River provides for navigation between the Mississippi and the Red-Atchafalaya Rivers via the Old River channel.

3. From Alexandria to its mouth, the Red River traverses the floodplain of the Mississippi River. On the right (south) bank, from the hills above Alexandria to high ground at Moncla, LA, a levee that is part of the Lower Mississippi River Levee System protects the alluvial lands south of the Red River and west of the Atchafalaya Floodway. From Moncla to Lake Long, a local levee provides partial protection from headwater overflows. The banks rise 35 to 40 ft above low water and in general are 700 to 800 ft apart. The slope of the water surface below Alexandria is dependent upon the stage in the Red River backwater area as affected by operation of Old River Control Structure.

4. Public Law 90-483, 90th Congress, approved 13 August 1968, authorized the construction of the "Red River Waterway, Louisiana, Texas, Arkansas, and Oklahoma Project," in accordance with the recommendations of the Chief of Engineers as contained in House Document No. 304, 90th Congress, 2nd Session. The Appropriations Act of 1971, approved 7 October 1970, as Public Law 91-439, provides the authority to initiate preconstruction planning from the Mississippi River to Shreveport reach of the project.

5. Lock and Dam No. 4 is proposed for construction in a cutoff canal approximately 206 miles above the Mississippi River and about 65 channel miles above Lock and Dam No. 3. The principal structure (Plate 1) will consist of a lock with an adjacent gated spillway and overflow weir. The lock will be 84 ft wide with 685 ft of usable length. The gated spillway will contain four tainter gates, 60 ft wide by 36 ft high, with a sill elevation of 86.0* and an overflow weir with three 100-ft-wide hinged gates. A profile of the spillway crest is shown in Plate 2. The crest of the hinge-gated weir (Plate 3) is at el 115.0, and the top of the hinged gate in its fully raised (closed) position is at el 122.0.

Purpose and Scope of Model Study

6. Hydraulic model tests were conducted to assist in the determination

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

of satisfactory hydraulic performance of the gated spillway structure and stilling basin and development of design recommendations and to develop an acceptable scour protection plan for areas just upstream and downstream of the structure. The investigation included making structural modifications as needed and determining the effects on the hydraulic performance of the model structure.

PART II: MODEL

Description

7. The 1:40-scale model (Figure 2) reproduced the total width of lock, spillway, overflow weir, and a length of about 2,700 ft of the Red River channel extending 900 ft upstream of the center line of the dam and 1,800 ft downstream. The spillway, tainter gates, overflow weir, stilling basin, and lock walls were fabricated of sheet metal. The riprap protection was simulated with crushed limestone.

Figure 2. 1:40-scale model of original design looking downstream

Appurtenances

8. Discharges were measured with an orifice plate and elbow meters calibrated with a pitot rod, and water-surface elevations were measured with point gages. Velocities were measured using an electromagnetic velocity meter calibrated in a calibration flume. Steel rails set to grade along the sides

of the flume provided a reference plane for measuring devices. Tailwater elevations were regulated by a flap gate at the downstream end of the flume.

Scale Relations

9. The accepted equations of hydraulic similitude, based upon the Froudian criteria, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations expressed in terms of the model scale or length ratio L_r are presented as follows:

Characteristic	Dimension*	Scale Relations Model: Prototype
Length	L_r	1:40
Area	$A = L_r^2$	1:1,600
Velocity	$T_r = L_r^{1/2}$	1:6.3246
Discharge	$Q_r = L_r^{5/2}$	1:10,119.29
Time	$T_r = L_r^{1/2}$	1:6.3246

* Dimensions are in terms of length.

PART III: TESTS AND RESULTS

Original Spillway Design

10. The spillway was adjacent to the lock wall in the original design, as shown in Plate 1 and Figure 3. Model tests were conducted to determine the percentage of flow passing through each gate bay with the spillway adjacent to the lock chamber and with the spillway and lock separated by 69 ft of nonoverflow dam, as shown in Figure 4. The 69-ft separation provided a design restraint to allow riprap to be placed on a slope against the downstream lock wall as a counterweight. Figure 4b shows the riprap sloping from the top of the lock wall to the channel invert. This series of tests was conducted to determine the effects on the hydraulics due to the modification. Flow percentages through each bay, presented in Table 1, show a more uniform flow distribution with the spillway separated from the lock chamber. Flow passing through gate 1 (gates are numbered 1-4 left to right looking downstream) with the spillway adjacent to the lock was reduced due to a larger separation of flow at the spillway pier by flow through the ported guard wall. Based on these results, a 69-ft separation between the spillway and lock chamber improved the percentage of flow through each bay. The downstream flow conditions remained unchanged and no additional tests were conducted with the original design.

11. Riprap protection for the original channel alignment is presented in Plate 4. Detailed velocities were not taken to evaluate the stability with the original design due to the recommended structure modification.

Separation Between the Lock and Spillway (Four-Bay Structure, Crest El 86)

Water-surface elevations

12. After the section of nonoverflow dam was added between the lock and spillway, water-surface elevations were measured with various discharges. These data are shown in Table 2. Discharges and tailwater elevations for these tests were given by the US Army Engineer District, Vicksburg.*

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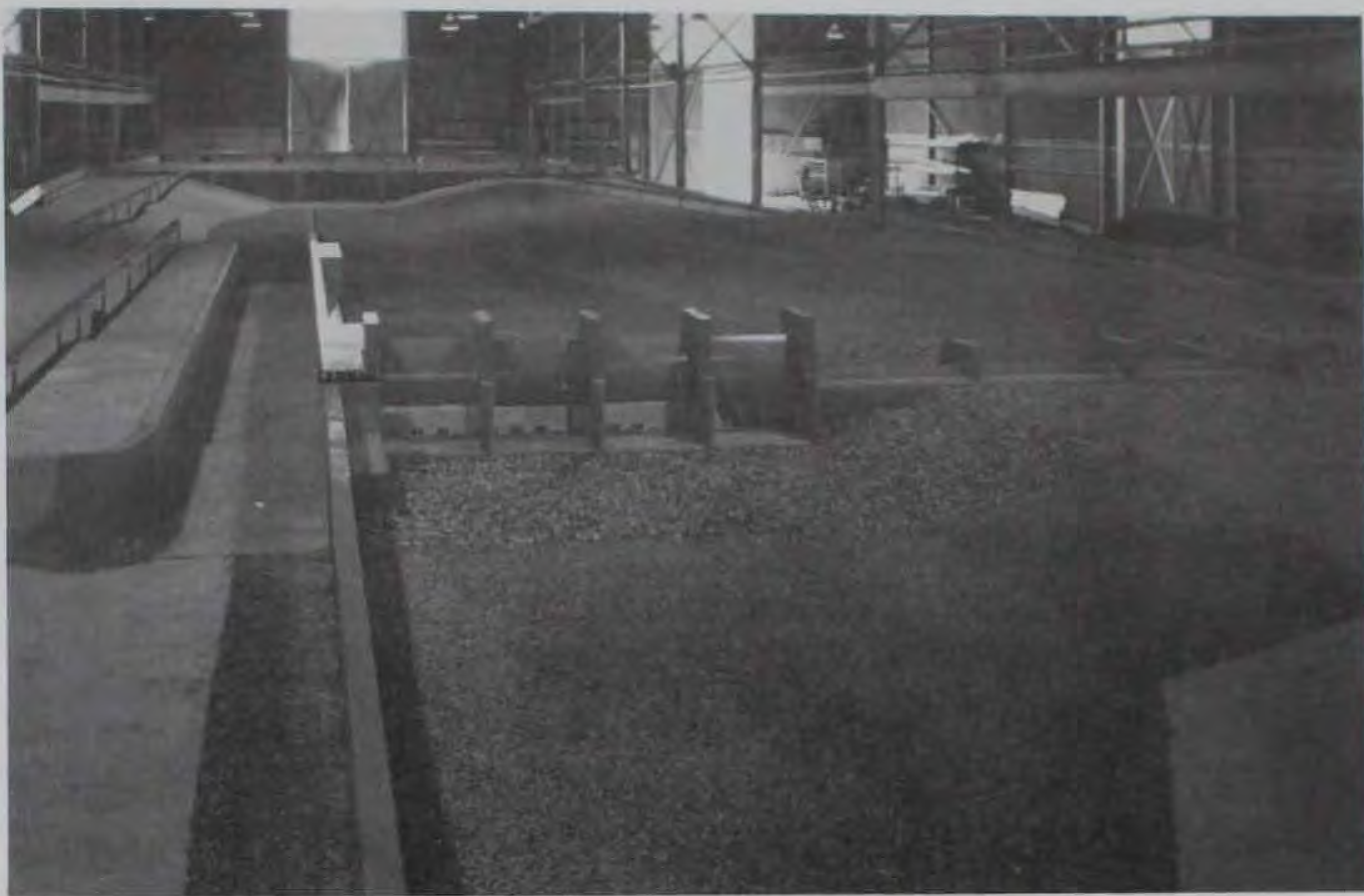
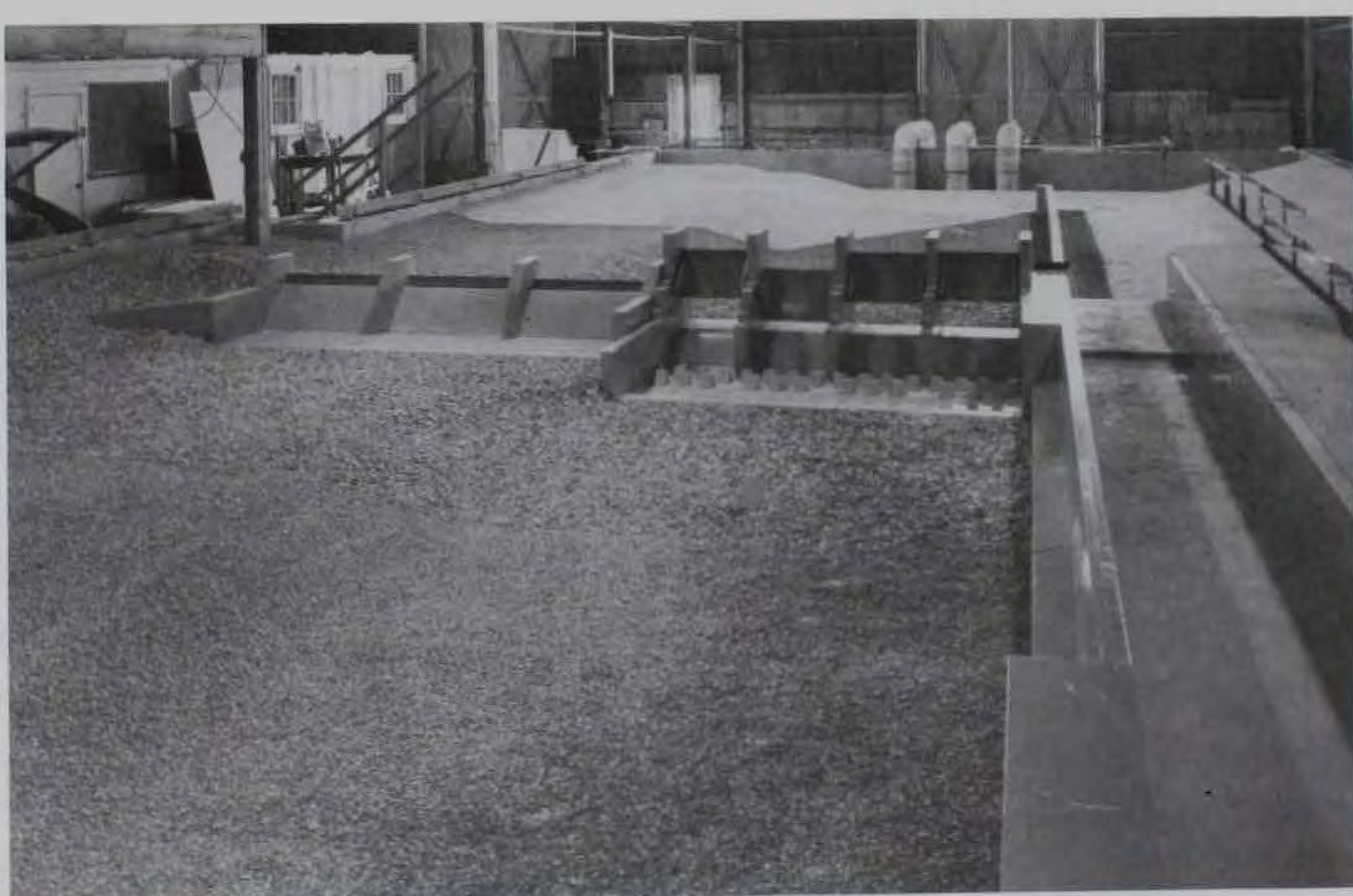
* US Army Engineer District, Vicksburg. 1985 (Nov). "Red River Waterway, Louisiana, Texas, Arkansas, and Oklahoma, Mississippi River to Shreveport, Louisiana: Design Memorandum No. 29 (Revised), Hydrology and Hydraulic Design, Lock and Dam No. 4," US Army Engineer District, St. Louis, St. Louis, MO.

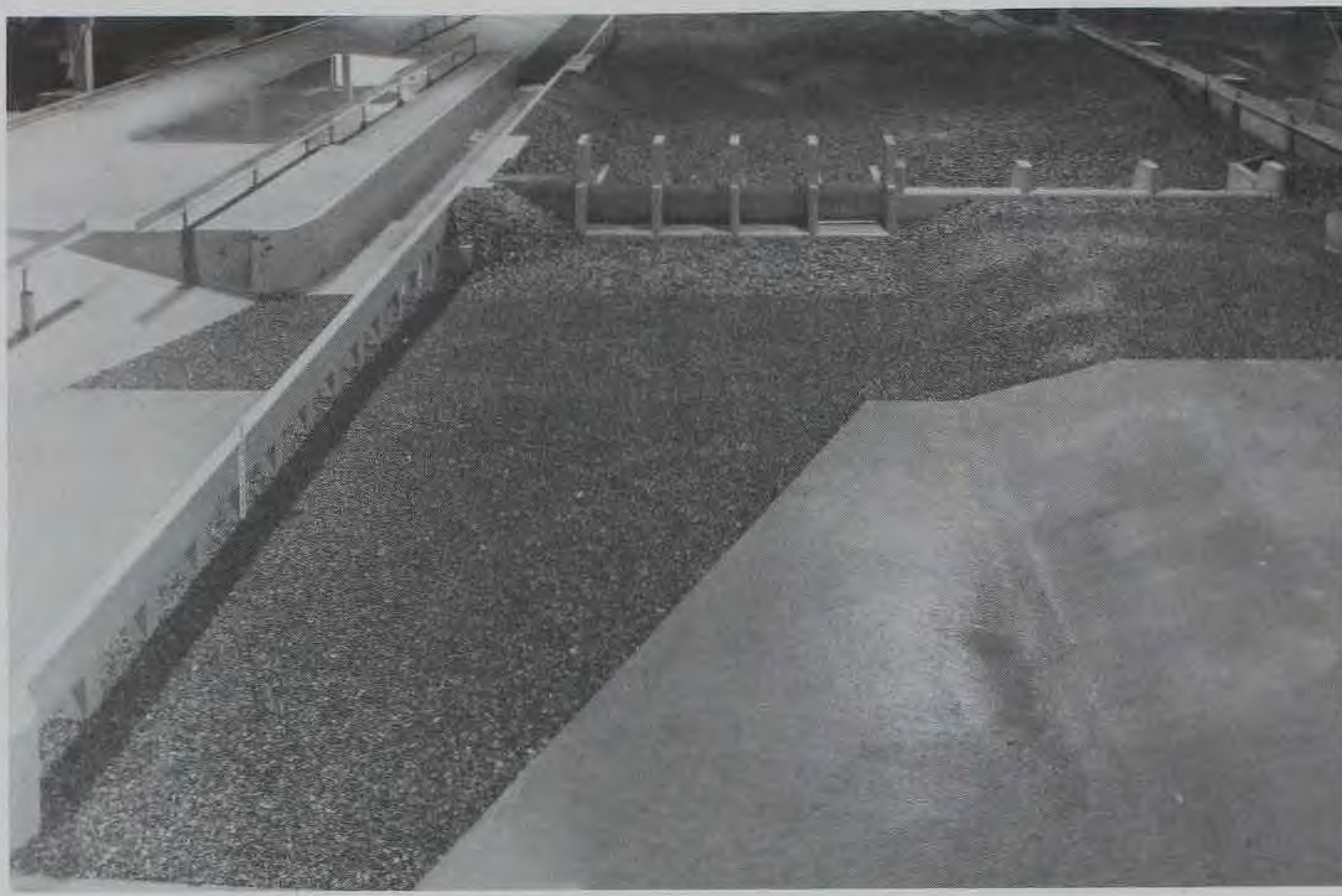


a. Looking downstream



b. Looking upstream

Figure 3. Original design



a. Looking downstream

b. Looking upstream

Figure 4. 69-ft separation between spillway and lock

Discharges were set, and the tailwater elevations were measured 1,600 ft downstream of the center line of the structure with all gates fully opened. Plate 5 presents a graph of water-surface elevations versus distance from the center line of the structure. Curves on this plot are left dashed for a distance of 200 ft upstream and 400 ft downstream indicating the zone of approach drawdown and stilling action.

Hinge-gated stilling basin

13. The length of stilling basin downstream from the hinge-gated spillway was reduced 15 ft and the height of the end sill was increased from 1 to 2.5 ft. This modification provided satisfactory hydraulic performance for all anticipated flow conditions. Observation of the model hinge gate operating with one or two gates open shows an eddy in the stilling basin (Photo 1) that could be hazardous to fishing boats, even with low discharges. Photo 1 shows a drawdown behind the pier with one hinge gate open, a pool elevation of 122, and tailwater elevation of 95.

Separation Between the Lock and Spillway (Four-Bay Structure, Crest El 85)

Stilling basin

14. Additional modifications were implemented in the model at the request of the sponsor. Modifications to the tainter-gated spillway involved lowering the spillway crest from el 86 to 85 with the stilling basin remaining at el 62. This modification created the same head on the structure as the proposed Red River Lock and Dam No. 5. Energy dissipation in the stilling basin was observed and performance was satisfactory for all anticipated flows. Following recommended procedures,* the baffle piers were detached from both training walls (Plates 6 and 7) due to pressure fluctuations and eddies that could cause scour damage behind each baffle, as observed by the author during prototype dewatering operations at several Corps projects, such as the Old River Low-Sill Control Structure. Section B-B in Plate 7 shows the model modification of the baffle piers. The left training wall, Section C-C in Plate 7, was effectively reduced to a 9-ft height with the riprap sloping 1V

* Headquarters, US Army Corps of Engineers. 1990 (16 Jan). "Hydraulic Design of Spillways," EM 1110-2-1603, US Government Printing Office, Washington, DC.

on 2H, as shown in the same section. Satisfactory performance was observed for all anticipated flow conditions with the reduced training wall.

Water-surface elevations

15. Water-surface profiles were reevaluated with the crest at el 85. The measured elevations are shown in Table 2. Plate 8 presents the results. Discharges and tailwaters were set the same as with crest el 86. The water surfaces were slightly lower than with the crest at el 86.

Riprap protection

16. The riprap protection plan (Figure 5) was evaluated for stability during both normal and extreme flow conditions using several riprap gradations to establish failure points in zones of high turbulence. Riprap gradations were provided by the Vicksburg District* and developed for a unit weight for riprap of 155 lb/cu ft. The 81-in.-thick riprap blanket downstream of the end sill of the tainter-gated section was stable during various control flows with all four tainter gates operating (Photo 2), with uncontrolled flows up to 227,000 cfs (Photos 3 and 4), and with one gate fully open (Photo 5) and one gate half open (Photo 6) with pool el 122 and tailwater el 95. The riprap thickness was then reduced to the next available stone size of 54 in. and tested with one gate fully open. Photo 7 shows the failure that occurred immediately downstream of the end sill for a distance of about 100 ft. Failure also occurred with one gate half open. Therefore, the 81-in. blanket thickness was recommended for this area. Downstream of the hinged gates, the blanket thickness was reduced to 54 in. and remained stable for all anticipated flow conditions. The extent of the 81-in.-thick blanket upstream of the tainter-gated section was shortened to 75 ft, and the blanket was stable for all flows. Immediately upstream of the hinge-gated section, the riprap was reduced to a 36-in. thickness and remained stable during all anticipated flow conditions. The last four ports of the upstream guard wall were also protected with 81-in.-thick riprap. The recommended riprap protection plan is shown in Plate 9.

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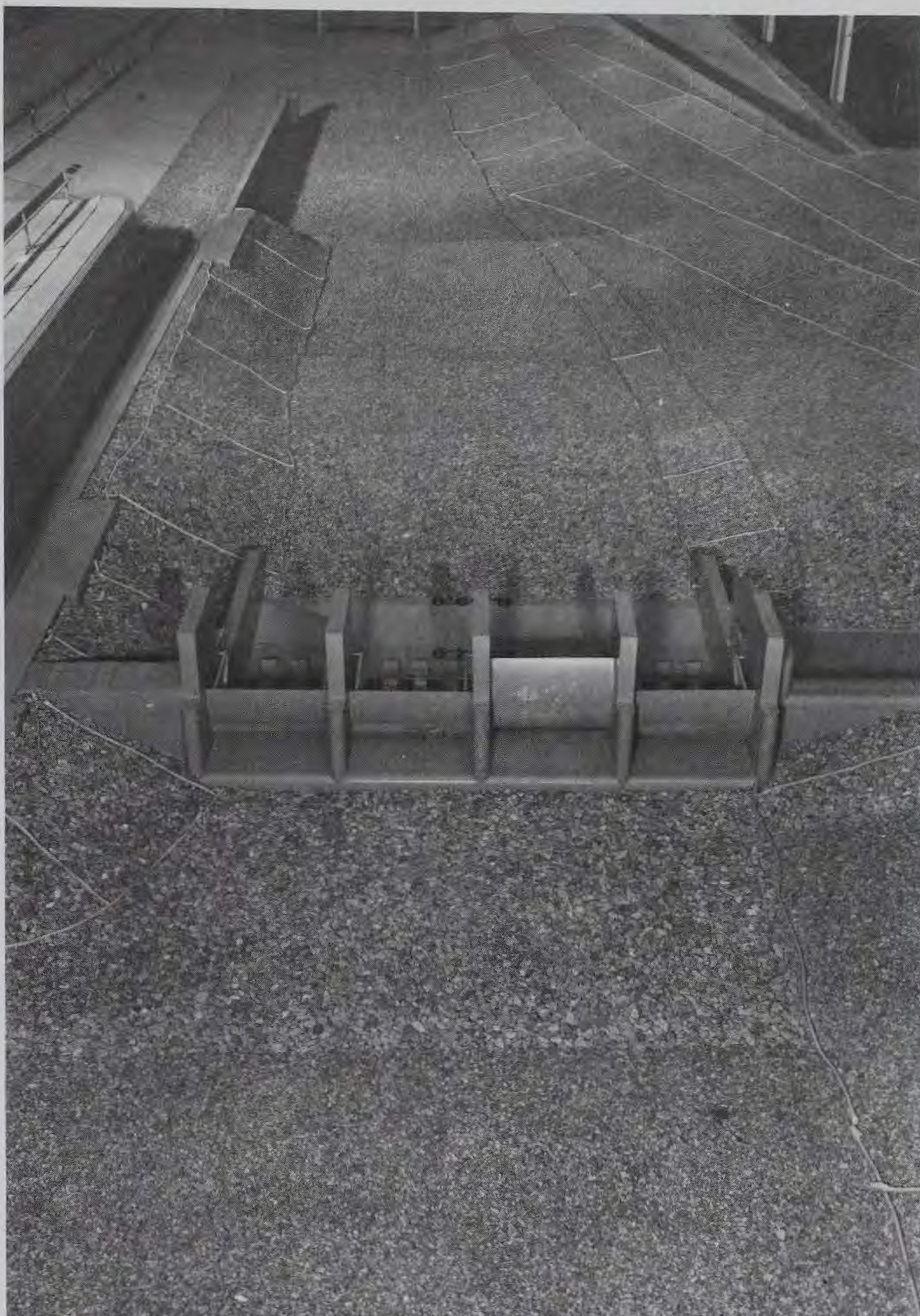
* US Army Engineer District, Vicksburg. 1986 (Mar). "Red River Waterway, Louisiana, Texas, Arkansas, and Oklahoma, Mississippi River to Shreveport, Louisiana: Design Memorandum No. 29 (Revised), Hydrology and Hydraulic Design, Lock and Dam No. 4," US Army Engineer District, St. Louis, St. Louis, MO.



a. Looking downstream

Figure 5. Riprap protection plan (Continued)

b. Looking upstream

Figure 5. (Concluded)

Velocities

17. Plates 10 and 11 show velocities measured 4 ft above the invert of the channel for controlled and uncontrolled flows of 35,000 and 160,000 cfs, respectively. These velocities were measured along the interface of each different blanket thickness. Additional velocities were obtained at middepth 40 ft upstream of the upstream guard wall (Plate 12) for three different uncontrolled flow conditions. Velocities were also taken at Section A-A of Plate 11 for two uncontrolled flow conditions. These velocities, shown in Plates 13 and 14, were measured in intervals of 4 ft off the bottom of the channel.

Five-Bay Structure with One Hinge-Gated Section

69-ft separation between the lock and spillway

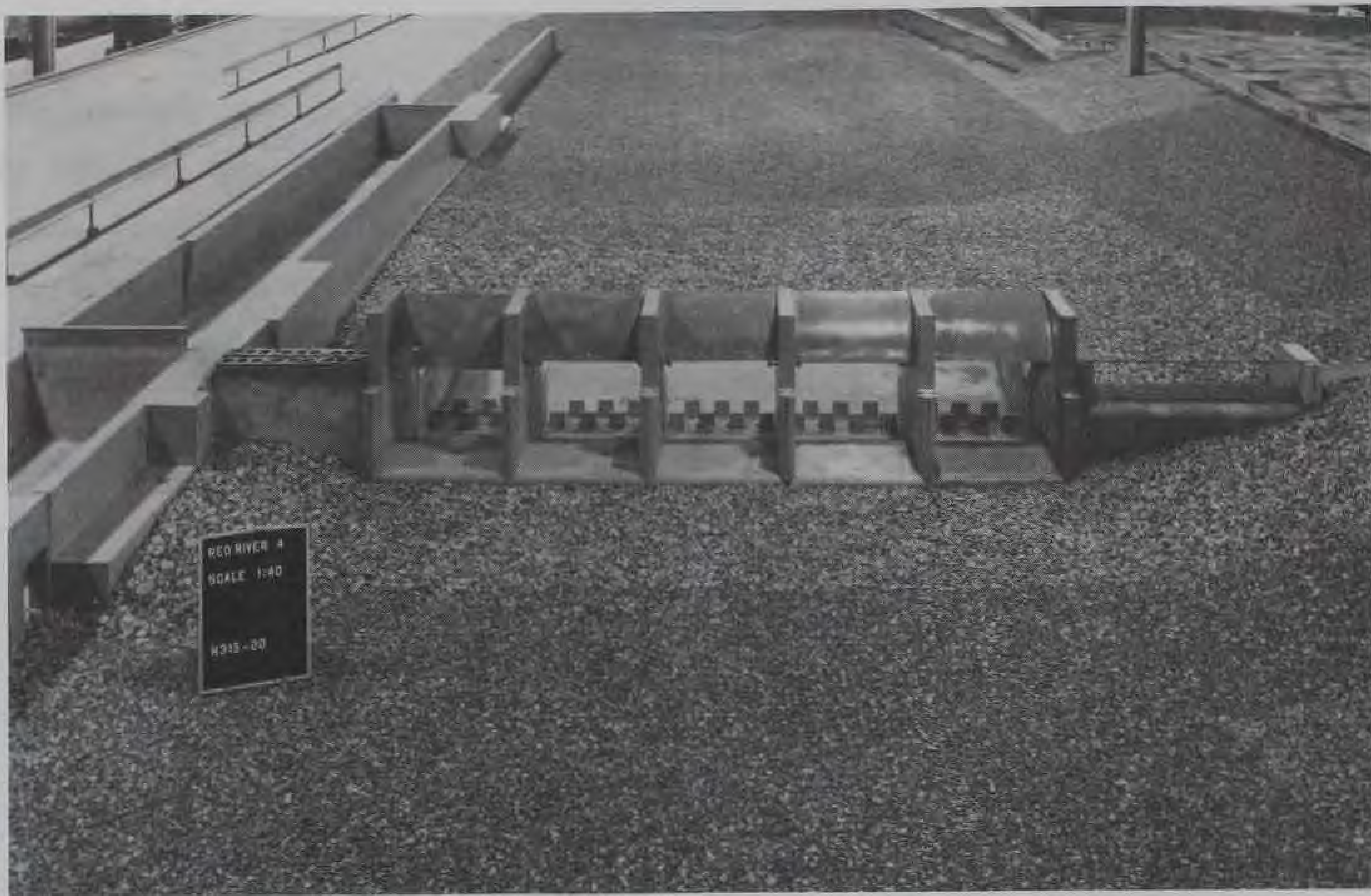
18. A fifth spillway bay was added to duplicate the proposed structure of Red River Lock and Dam No. 5. Tests were conducted to determine the effects of adding a fifth spillway bay and reducing the original three-bay hinge-crest section to one bay with a baffled chute. A plan view of the proposed modification is shown in Plate 15. Figure 6a shows the modified structure looking downstream. A close-up view looking upstream (Figure 6b) reveals the baffling on the downstream quadrant of the hinge-gated section. Six rows of 4-ft-high baffle piers were placed on the slope of the downstream quadrant of the hinge-gated section (Plate 16). Each row of baffles was spaced 8 ft apart along the 1V on 2H chute slope, and the stilling basin was removed allowing the downstream riprap to tie into the baffled chute. Figure 7 is an overall view of the downstream channel.

Water-surface elevations

19. Water-surface elevations were measured in the model using the same tailwater rating curve as in previous tests and are presented in Table 3. Tailwater elevations were set 1,600 ft downstream from the center line of the structure. Plate 17 shows the water-surface profiles. Water-surface elevations were slightly lower due to a larger cross-sectional area.

Flow conditions

20. Photographs were obtained to document surface flow patterns for various flow conditions. Photo 8 shows flow patterns looking downstream with only the hinge gate operating with a pool elevation of 120.0 and a tailwater



a. Looking downstream

b. Looking upstream

Figure 6. Modified five-bay structure with one hinge gate

Figure 7. Overall view of downstream channel looking upstream

elevation of 95.0. Photo 9 is the same flow condition with a view looking upstream. The flow over the baffled chute began to spray along the fourth row of baffle piers, as shown in Photo 9. Photo 10 is a view looking downstream with pool el 120, tailwater el 95, all tainter gates open 1 ft, and the hinge gate closed. The flow was fairly uniform over the entire channel width. Photo 11 is a view looking upstream with the same flow conditions. There again the flow was uniform across the channel with the exception of the stagnant area just downstream of the hinge gate. Photo 12 shows a view looking downstream with all gates fully open, pool el 123.6, tailwater el 119.6, and uncontrolled flow of 134,000 cfs. The flow concentrated along the right side of the channel. Photo 13 is a view looking upstream of the same flow condition. The flow is slightly concentrated uniformly to the left side of the photo. The eddy on the left side of the photograph had no adverse effects on the riprap protection.

Velocities

21. Surface velocities were obtained for the approach flow conditions

along a cross section at the upstream end of the lock guard wall. A typical flow pattern is shown in Plate 18 for a discharge of 134,000 cfs, pool el 123.6, and tailwater el of 119.6. Notice the flow lines concentrated toward the right half of the structure indicating a higher percentage of flow being passed through these bays. Observation of the velocities taken for surface conditions indicates lower velocities along the guard wall. Plates 19 and 20 present velocity measurements made at middepth and 4 ft above the bottom, respectively.

22. The velocities presented in Plates 21, 22, and 23 were measured along the interface of the riprap and represent surface, middepth, and bottom velocities for a 160,000-cfs flow condition. The maximum velocity measured over the end sill, 12.3 ft/sec, occurred at the surface for this flow condition.

23. At this point in the testing, the width of the channel bottom was increased to 200 ft from the lock guard wall to the toe of the berm at el 100. Velocities taken in Section A-A of Plate 20 are presented in Plates 24 and 25 for discharges of 80,000 and 134,000 cfs, respectively. The velocities were higher on the left side of the channel than on the right (looking upstream), just the opposite of velocities measured before the fifth bay was added at the same location (Plates 13 and 14).

Riprap protection

24. The recommended riprap protection plan for the five-bay structure is shown in Plate 15. The riprap remained stable for all flow conditions shown in Table 3 and with one gate fully open, pool el 120, and tailwater el 95. Also, the riprap protection remained stable upstream and downstream from the baffled chute for all flow conditions tested.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

25. Tests with the original design and with the spillway separated from the lock with a section of nonoverflow dam determined that a more uniform flow distribution passed through the structure with the spillway and lock separated by 69 ft. Based on these results, the recommended design was to add a 69-ft separation between the spillway and lock.

26. The height of the left training wall was reduced by 29 ft to 9 ft to eliminate the excessive portion of the free-standing wall. This reduction of the wall would reduce construction cost. The reduced wall height did not alter the hydraulic performance.

27. Energy dissipation in the spillway stilling basin was observed, and performance was satisfactory for all anticipated flows. It is recommended that the baffle piers be detached from both training walls due to pressure fluctuations and eddies that could cause scour damage behind each baffle, as observed in the prototype dewatering operation of the Old River Low-Sill Control Structure.

28. Satisfactory riprap plans were developed for the upstream and downstream areas adjacent to the structure for normal flows and the single gate criteria. The hinge gate with baffled chute was keyed in with a riprap blanket, which remained stable reducing the need for a stilling basin. Riprap downstream of the end sill was reduced to a failure point to give some idea of a safety factor for the recommended plan.

29. The five-bay structure performed satisfactorily for all observed flows. The recommended riprap plan, modified to include the fifth bay, remained stable. The water-surface profiles for the modified structure demonstrate a slightly lower water-surface elevation downstream of the structure. Approach flows were more uniform than for the four-bay structure. The five-bay structure will be used in the prototype so that the structures on Red River Locks and Dams No. 4 and 5 will be identical. If care is taken to maintain similarity, these results can be used to guide the design of Red River Lock and Dam No. 5.

Table 1

Percentage of Flow Through Each Bay

Discharge cfs	Tailwater El	Crest El	Percentage of Flow for Gate 1	2	3	4
		Spillway Adjacent to Lock				
50,000	108.1	86	12.1	27.0	30.0	30.9
80,000	112.8	↓	16.6	25.9	29.6	27.6
100,000	115.6		18.0	25.9	28.0	28.1
134,000	119.6		19.1	22.6	29.9	28.4
160,000	122.5		20.1	23.2	28.5	28.2
200,000	126.5		18.4	22.0	30.5	29.1
		Spillway Separated from Lock				
50,000	108.1	86	22.4	25.7	26.7	25.2
80,000	112.8	↓	22.4	26.4	27.2	24.0
100,000	115.6		20.7	26.7	27.7	24.9
135,000	119.6		19.7	26.0	27.6	26.7
160,000	122.5		22.9	24.0	27.5	25.6
200,000	126.5		20.6	25.4	26.8	27.2
100,000	115.6	85	21.8	26.2	27.4	24.6
200,000	126.5	85	20.1	26.0	29.3	23.8

NOTE: All gates were fully opened. Tailwaters were obtained from the tailwater rating curve and set 1,600 ft downstream of dam axis center line.

Table 2

Water-Surface Elevations

Original Design and Lowered Crest

Discharge cfs	Distance Upstream of Dam Axis Center Line, ft 1,000	400	200	Distance Downstream of Dam Axis Center Line, ft 400	800	1,600
			Crest El 86			
20,000	103.6	103.4	103.3	103.1	103.09	103.08
50,000	109.9	109.3	109.2	108.6	108.5	108.04
80,000	115.6	115.3	114.8	114.0	113.8	113.3
100,000	118.1	117.8	117.5	116.2	115.8	114.9
134,000	123.3	122.7	122.3	121.2	120.6	119.0
160,000	126.8	126.2	125.5	124.3	123.5	122.5
200,000	131.2	130.5	129.9	127.4	127.0	126.0
			Crest El 85			
20,000	102.6	102.6	102.5	102.4	102.1	102.0
50,000	109.8	109.7	109.6	109.2	108.6	108.1
80,000	115.1	115.0	115.0	113.9	113.4	113.0
100,000	119.1	119.08	119.0	117.3	117.1	115.6
134,000	123.6	123.4	123.4	121.6	121.0	119.6
160,000	126.7	126.5	126.4	124.3	124.2	122.5
200,000	129.6	129.5	129.4	127.6	127.5	126.5
227,000	132.2	132.0	132.0	129.8	129.4	129.0

NOTE: Tailwater was set 1,600 ft downstream with gate fully opened.

Table 3

Water-Surface Elevations

Five-Bay Structure, Crest El 85

Discharge cfs	Distance Upstream of Dam Axis Center Line, ft			Distance Downstream of Dam Axis Center Line, ft		
	1,000	400	200	400	800	1,600
20,000	102.5	102.4	102.3	102.1	102.1	102.0
50,000	109.4	109.3	109.0	108.4	108.1	108.1
80,000	114.6	114.5	114.2	113.8	113.5	113.0
100,000	117.4	117.2	116.9	116.4	116.1	115.6
134,000	122.6	122.2	121.6	120.2	120.0	119.6
160,000	125.2	124.8	124.4	123.5	123.2	122.5
200,000	130.2	129.9	129.5	128.0	127.8	126.5
227,000	132.8	132.6	132.4	130.4	129.6	129.0

NOTE: Tailwater was set 1,600 ft downstream with gate fully opened.

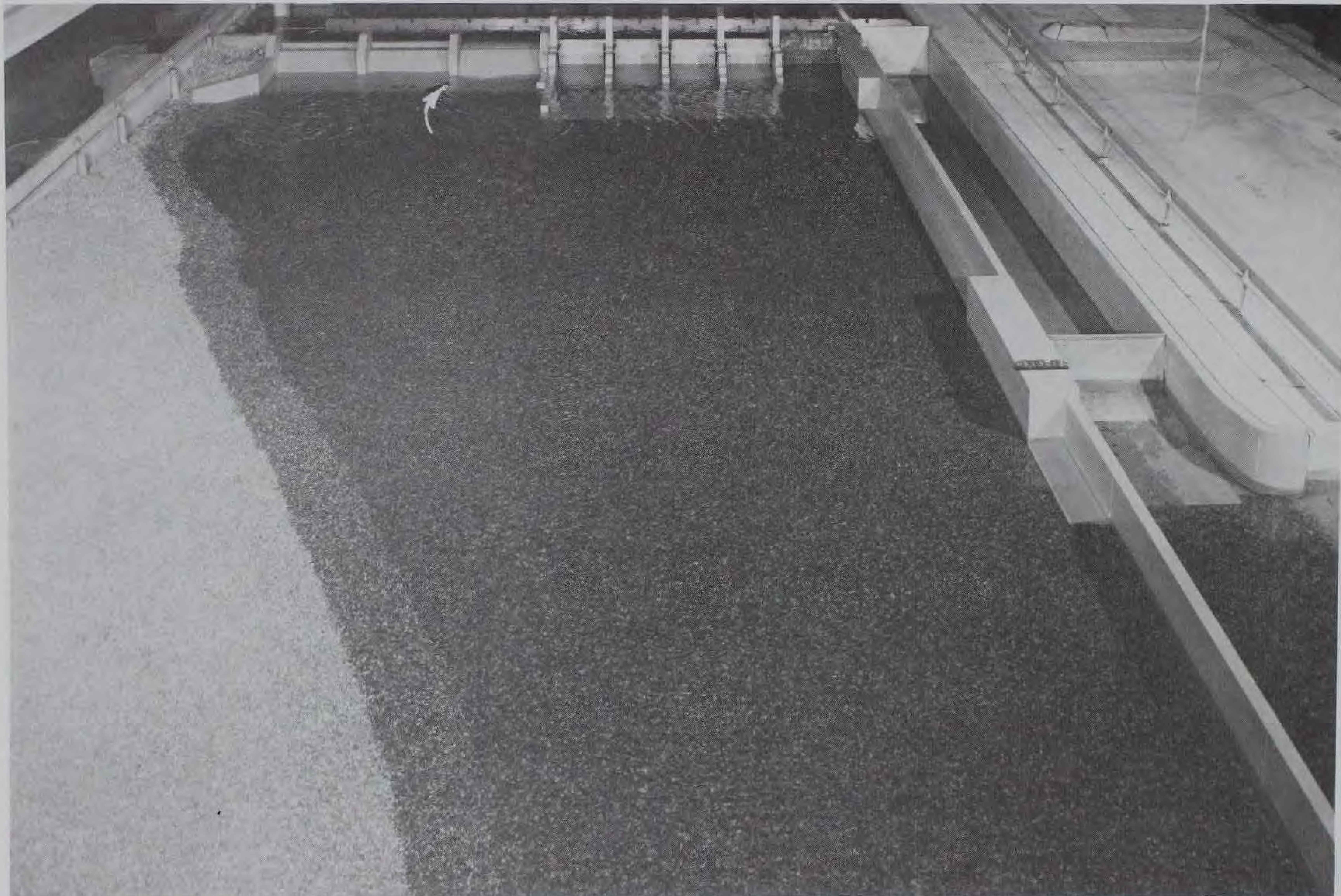


Photo 1. One hinge gate open; pool el 122; tailwater el 95; with the 69-ft separation

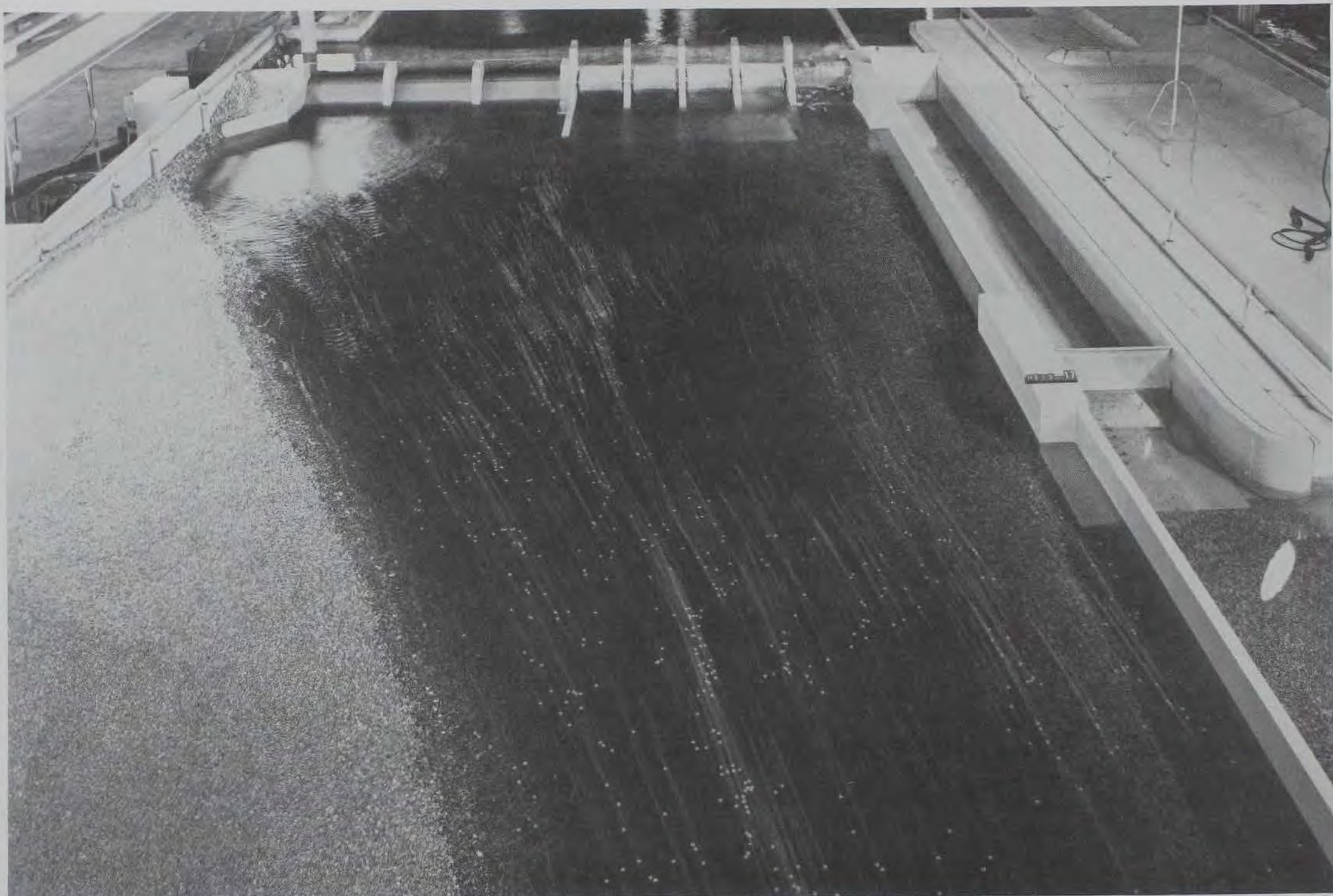


Photo 2. All hinge gates open; all tainter gates open 4 ft; pool el 122, tailwater el 95; discharge 57,300 cfs

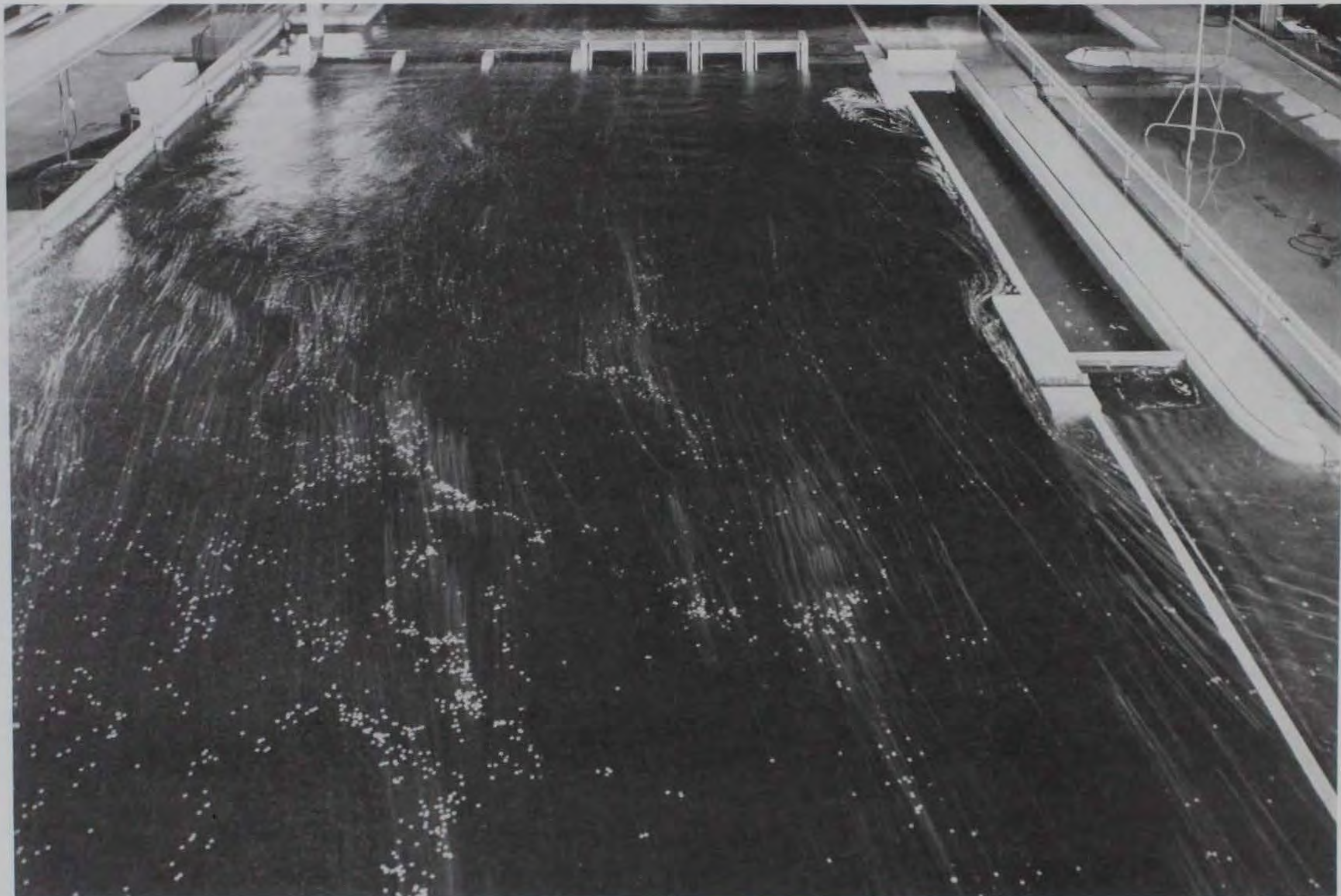


Photo 3. All gates open; pool el 128.3; tailwater el 125.5; discharge 200,000 cfs

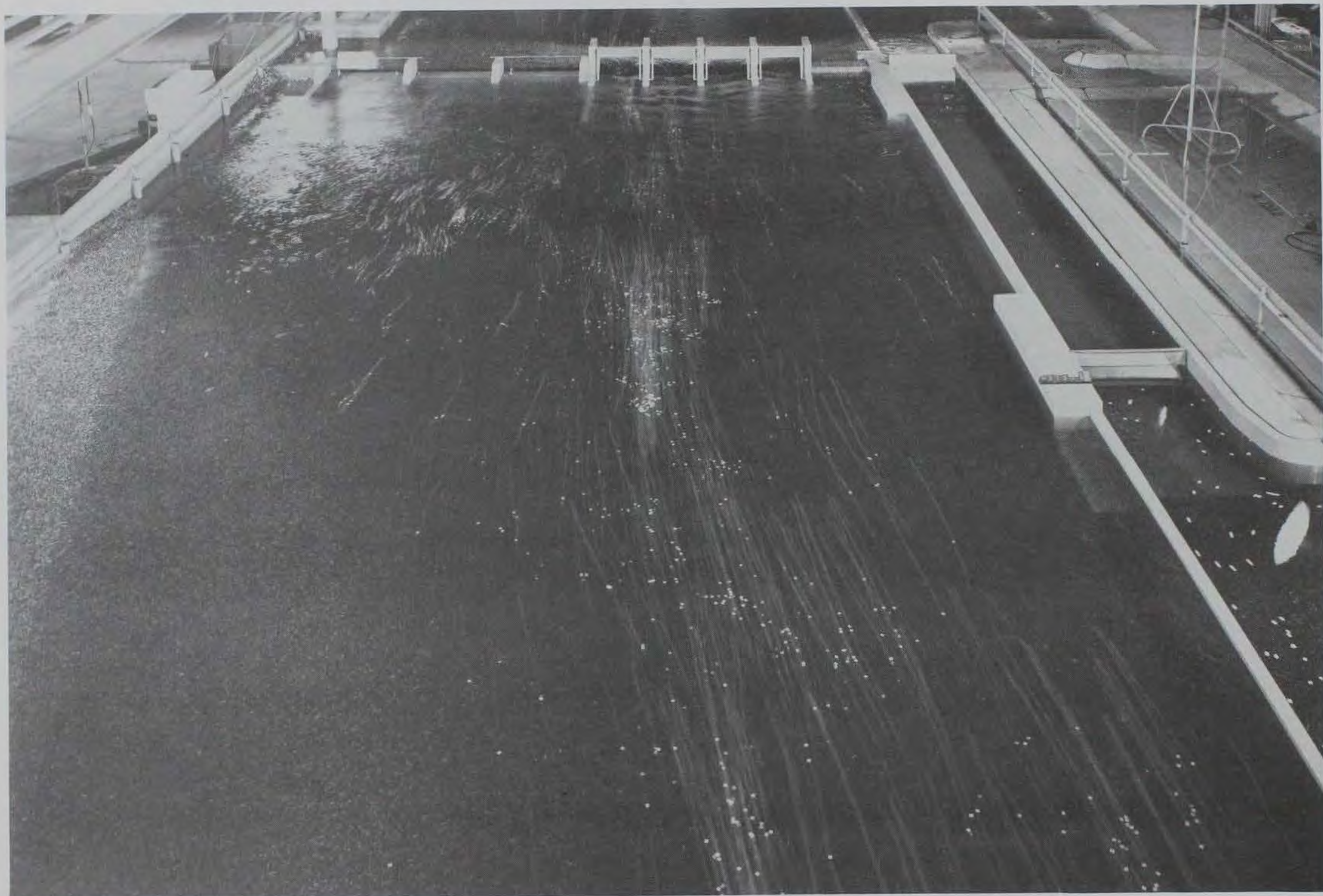


Photo 4. All gates open; pool el 121; tailwater el 115; discharge 100,000 cfs

Photo 5. One tainter gate fully open; pool el 122; tailwater el 95; looking upstream

Photo 6. One tainter gate half open; pool el 122; tailwater el 95; looking upstream

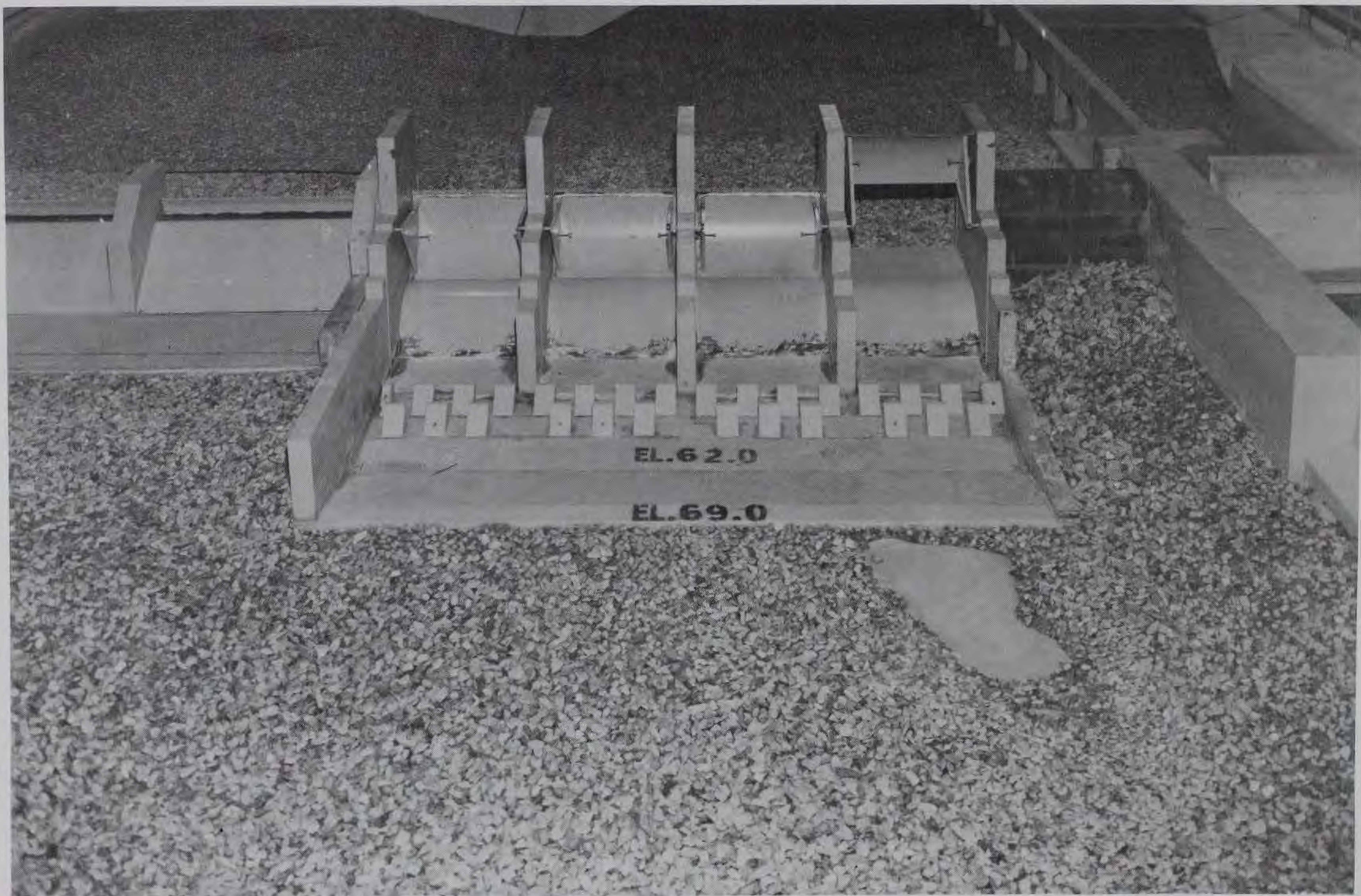


Photo 7. 54-in. riprap blanket failure due to one gate fully open; pool el 122; tailwater el 95; looking upstream

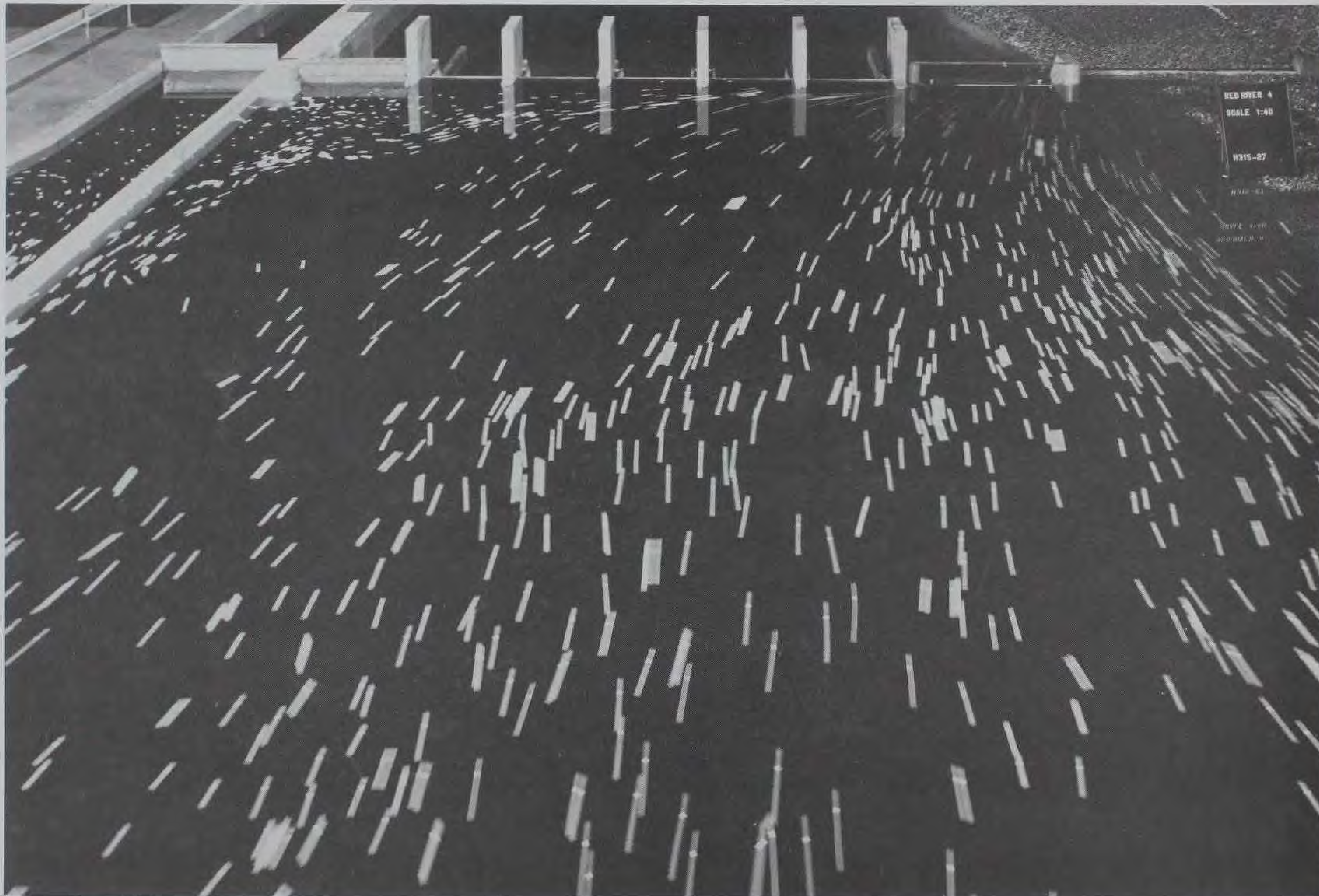


Photo 8. Hinge gate operating; pool el 120; tailwater el 95; looking downstream

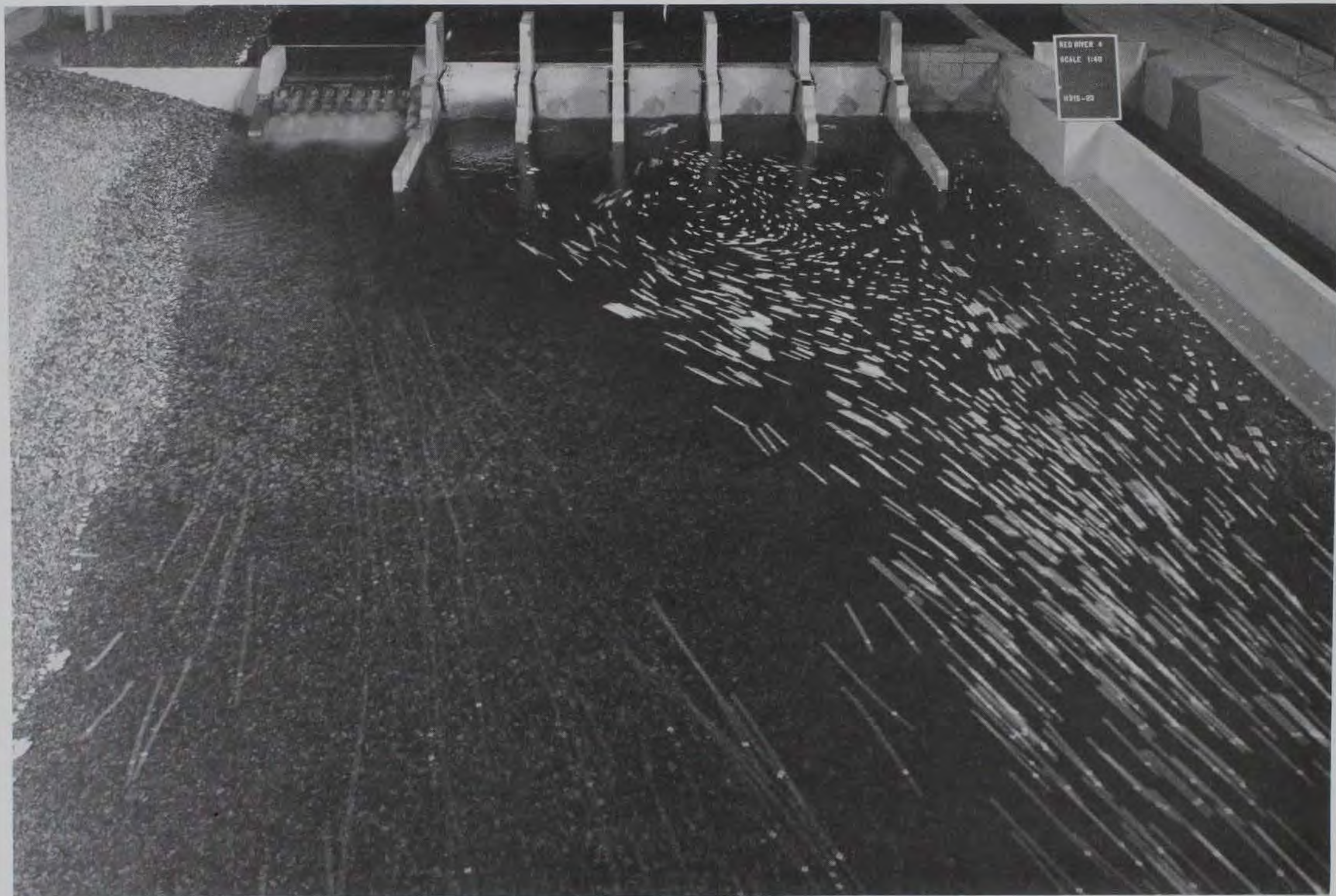


Photo 9. Hinge gate operating; pool el 120; tailwater el 95; looking upstream

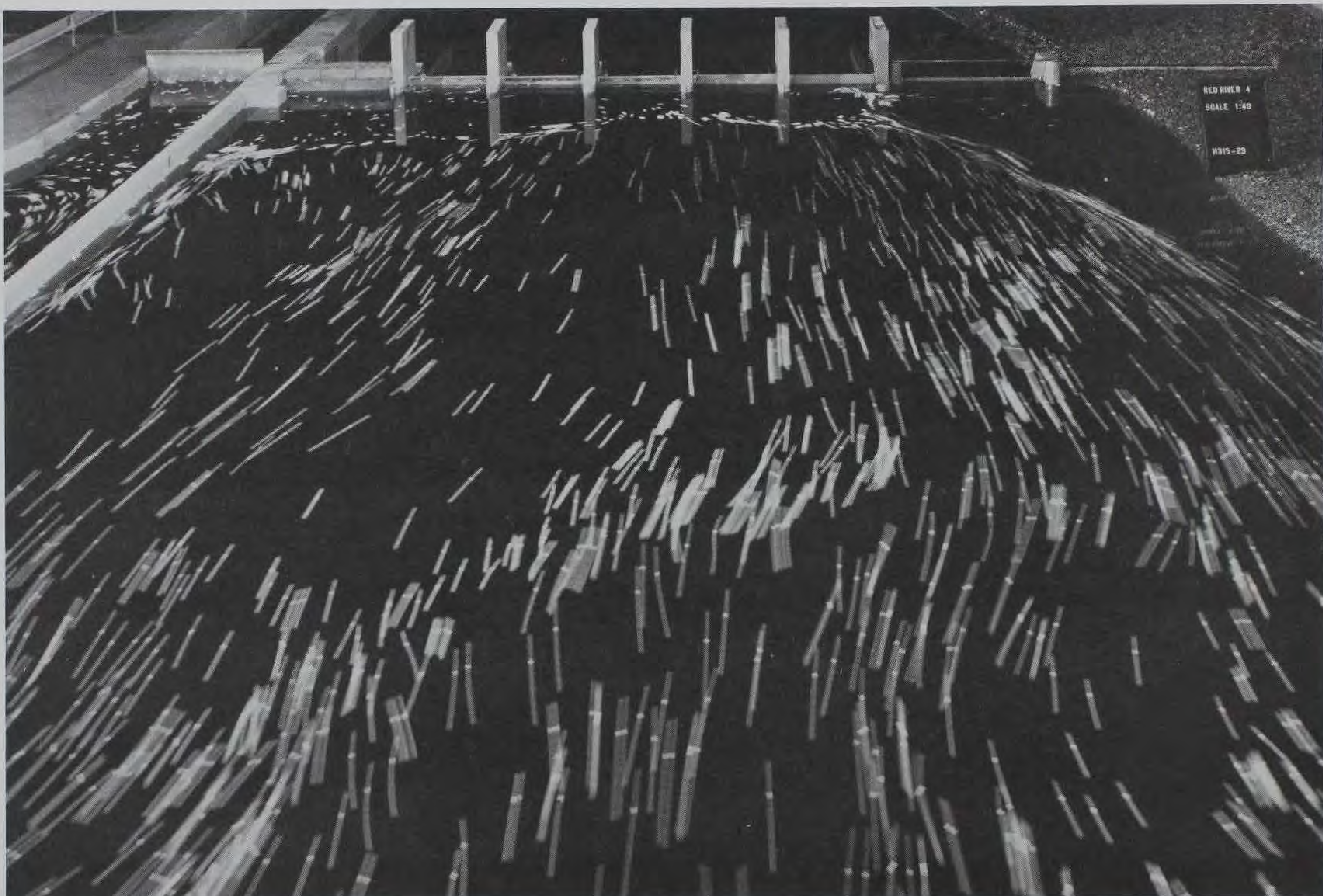


Photo 10. Hinge gate closed; tainter gates open 1 ft; pool el 120; tailwater el 95; looking downstream

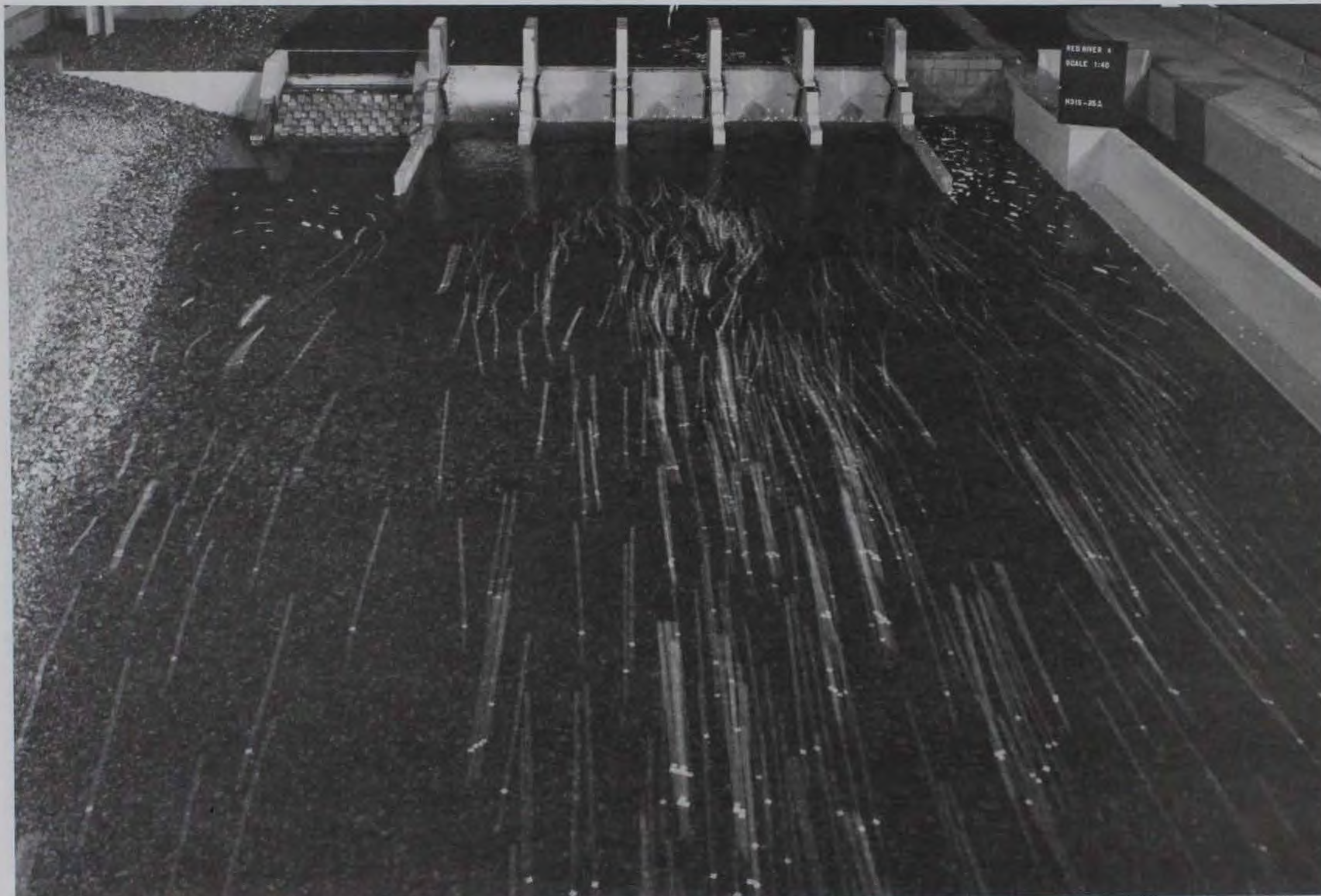


Photo 11. Hinge gate closed; tainter gates open 1 ft; pool el 120; tailwater el 95; looking upstream

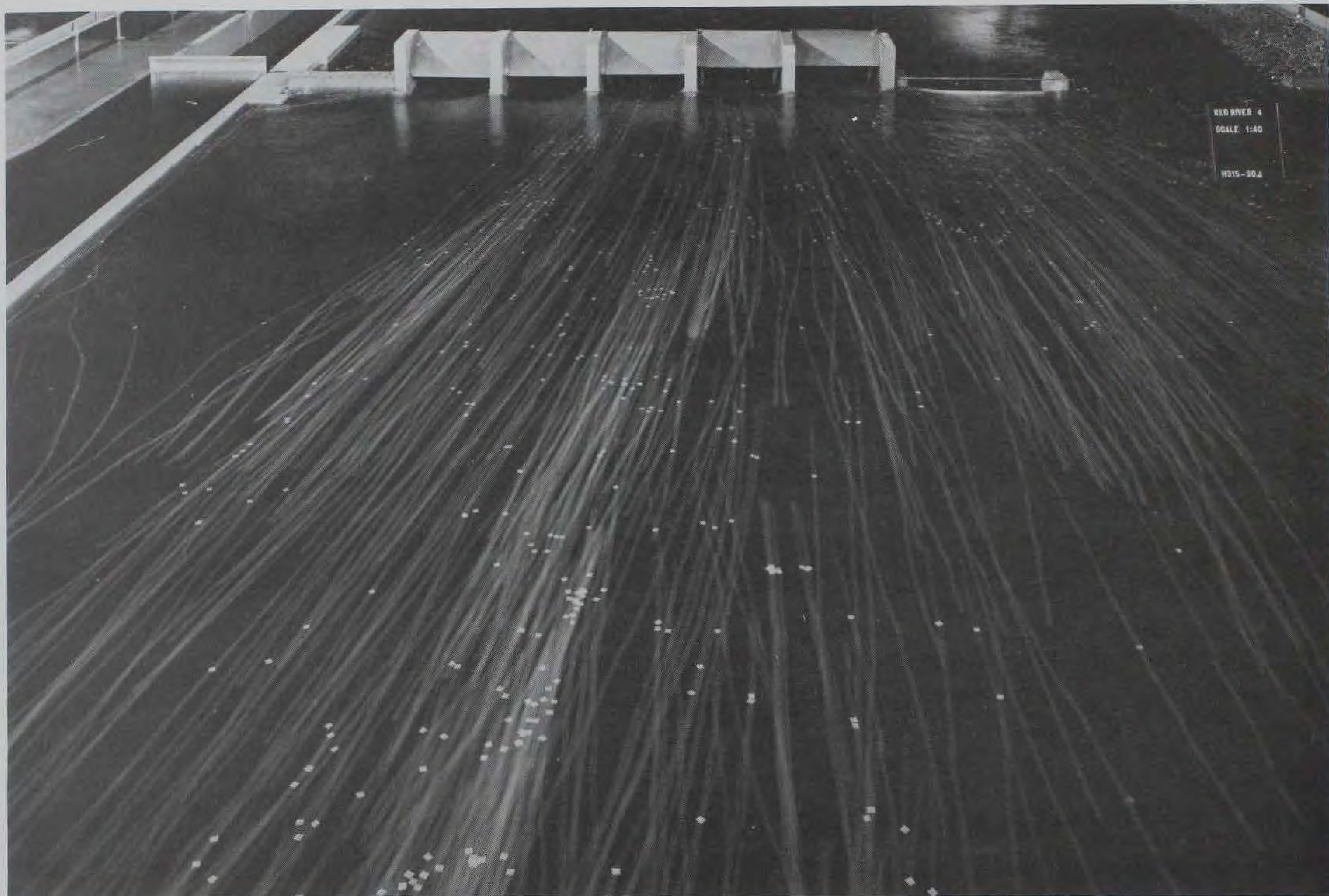


Photo 12. All gates fully open; pool el 123.6; tailwater el 119.6; discharge 134,000 cfs; looking downstream

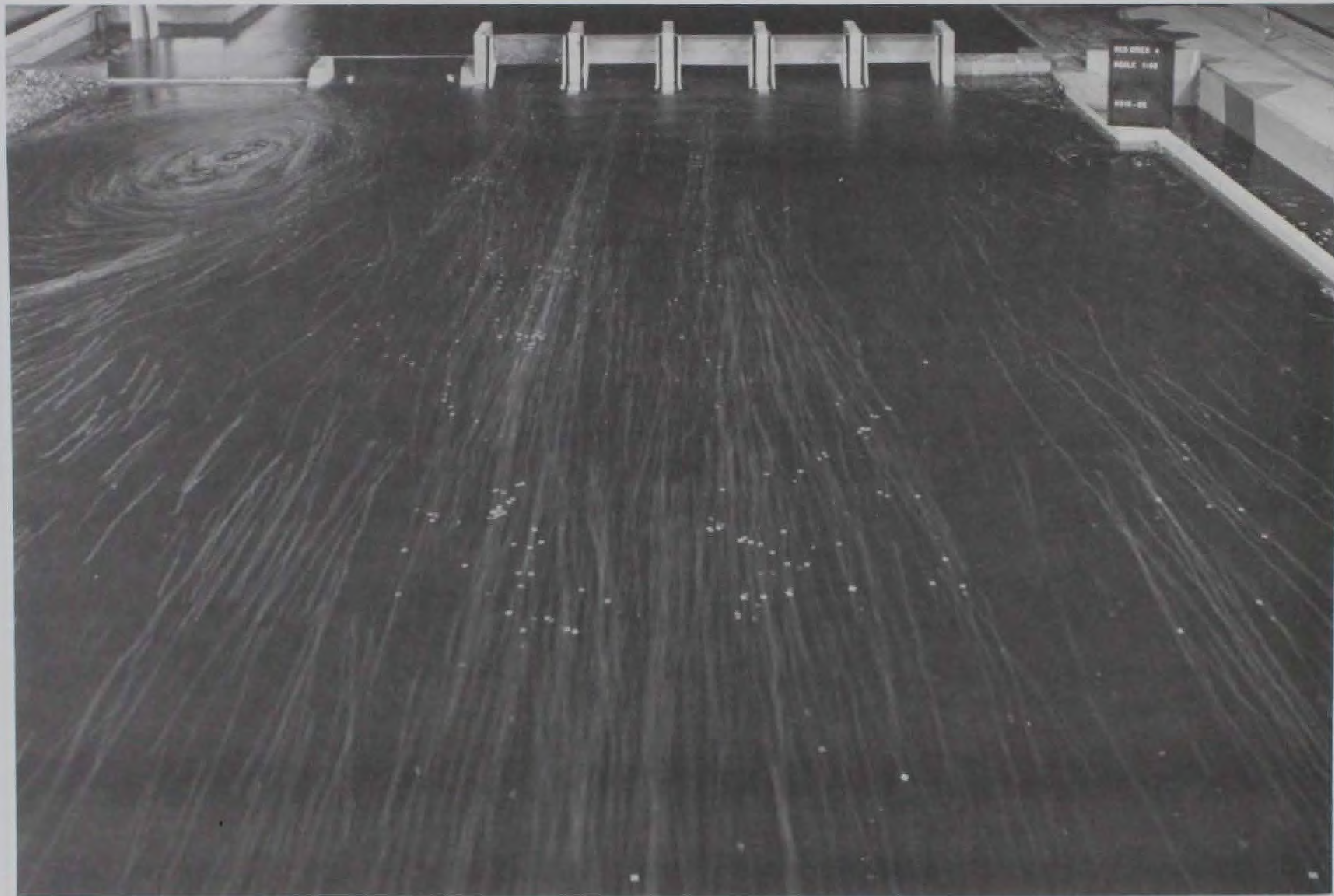
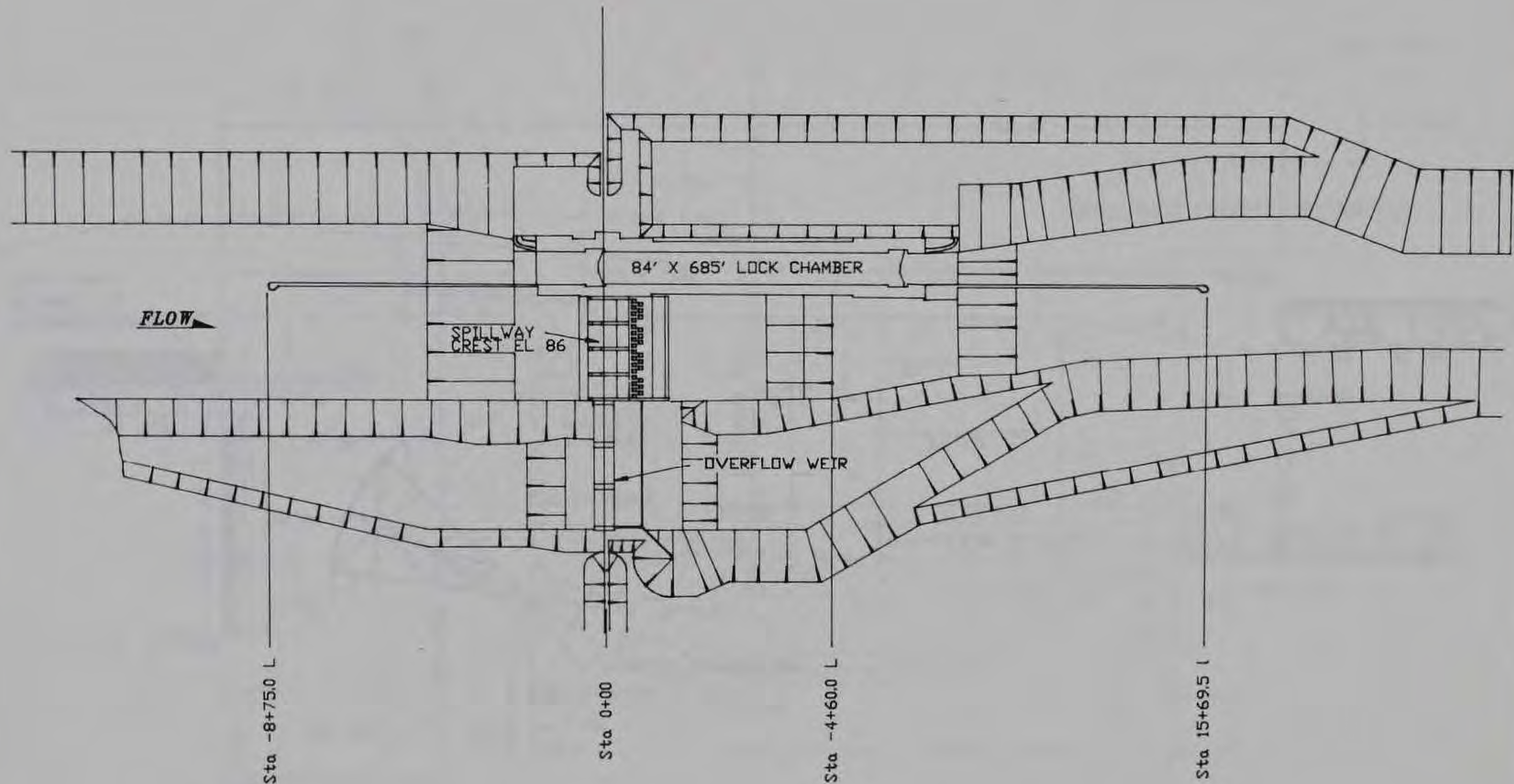
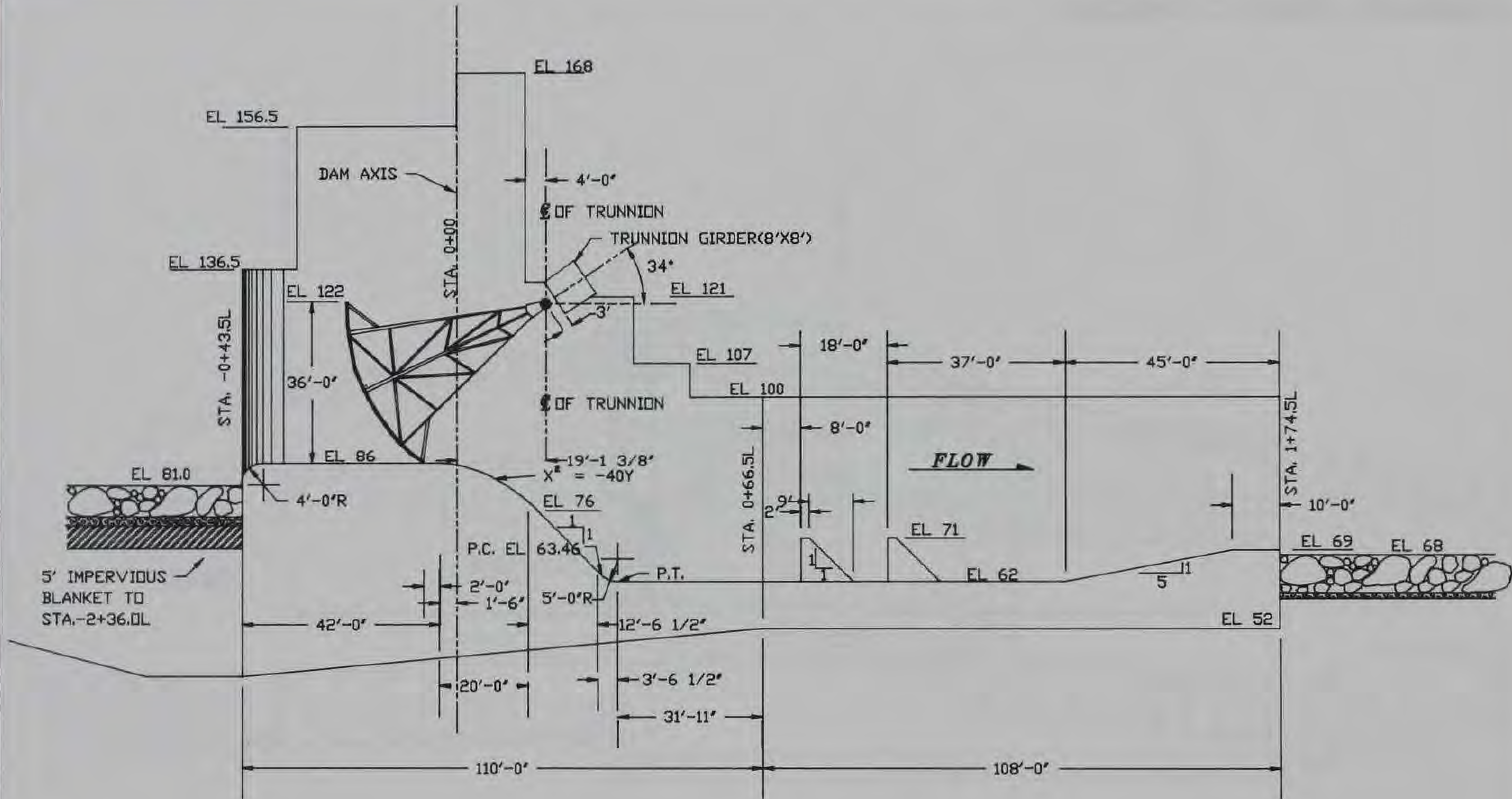


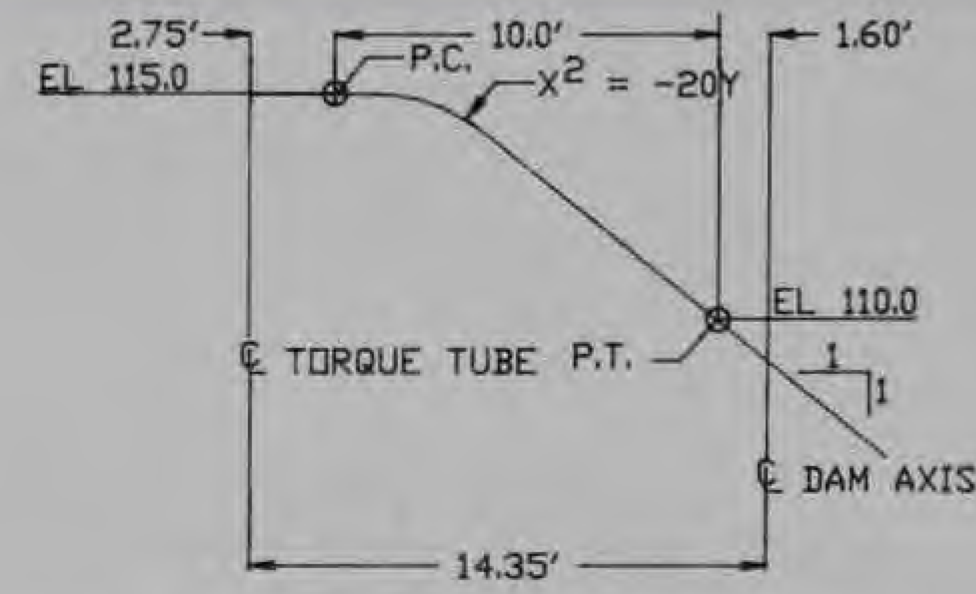
Photo 13. All gates fully open; pool el 123.6; tailwater el 119.6; discharge 134,000 cfs; looking upstream



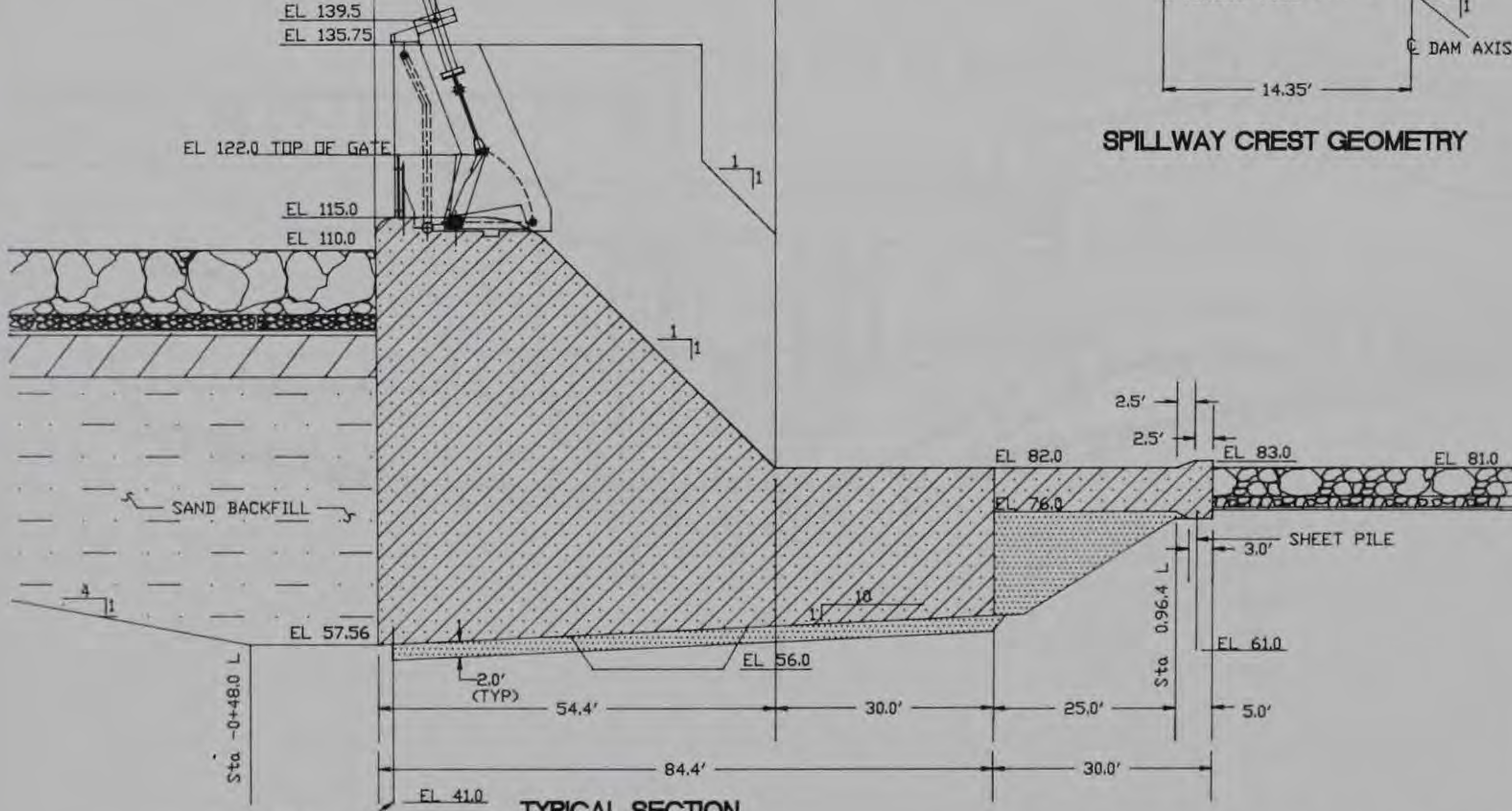
ORIGINAL CHANNEL ALIGNMENT



SPILLWAY
TYPICAL SECTION



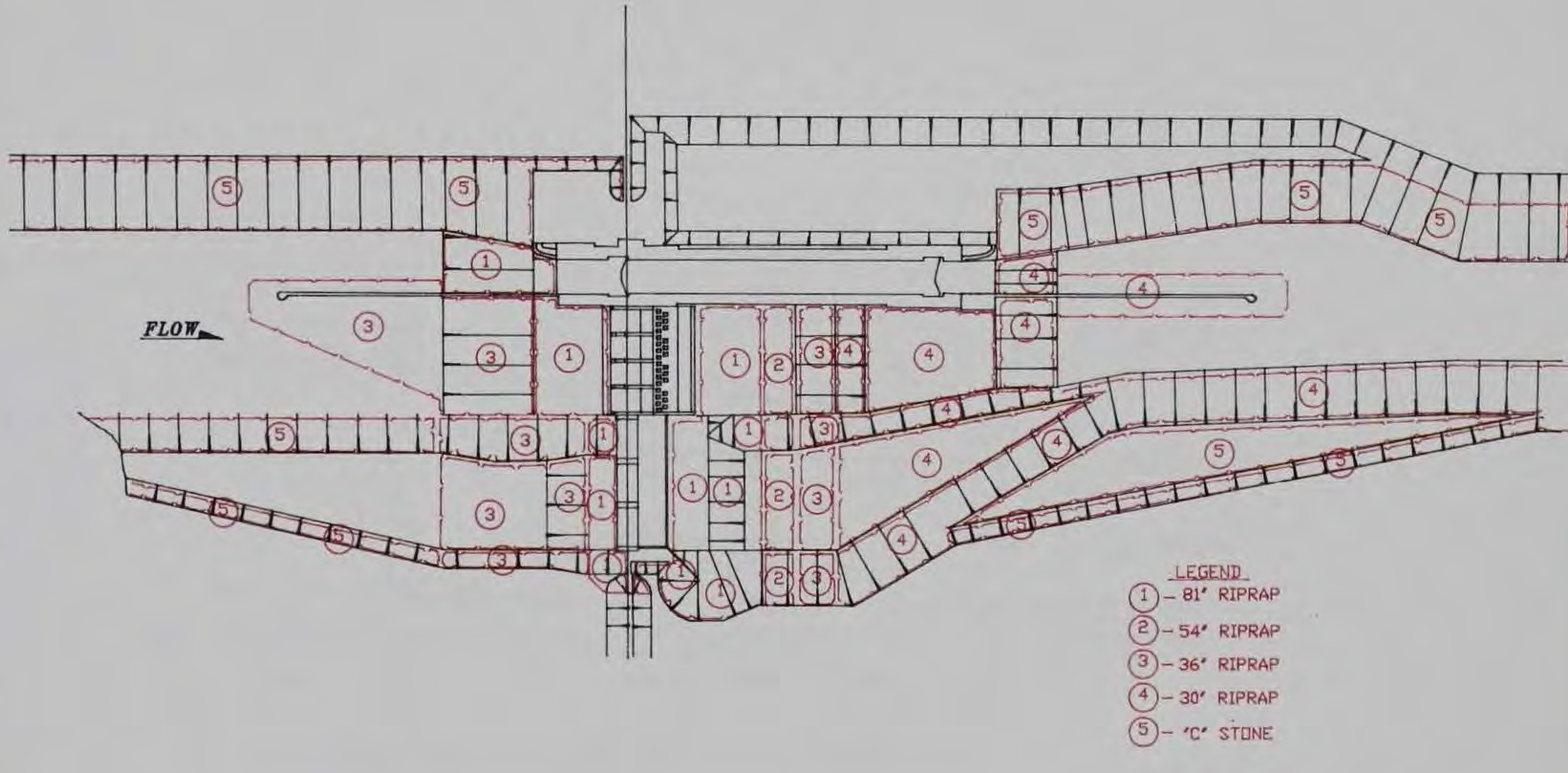
SPILLWAY CREST GEOMETRY



TYPICAL SECTION

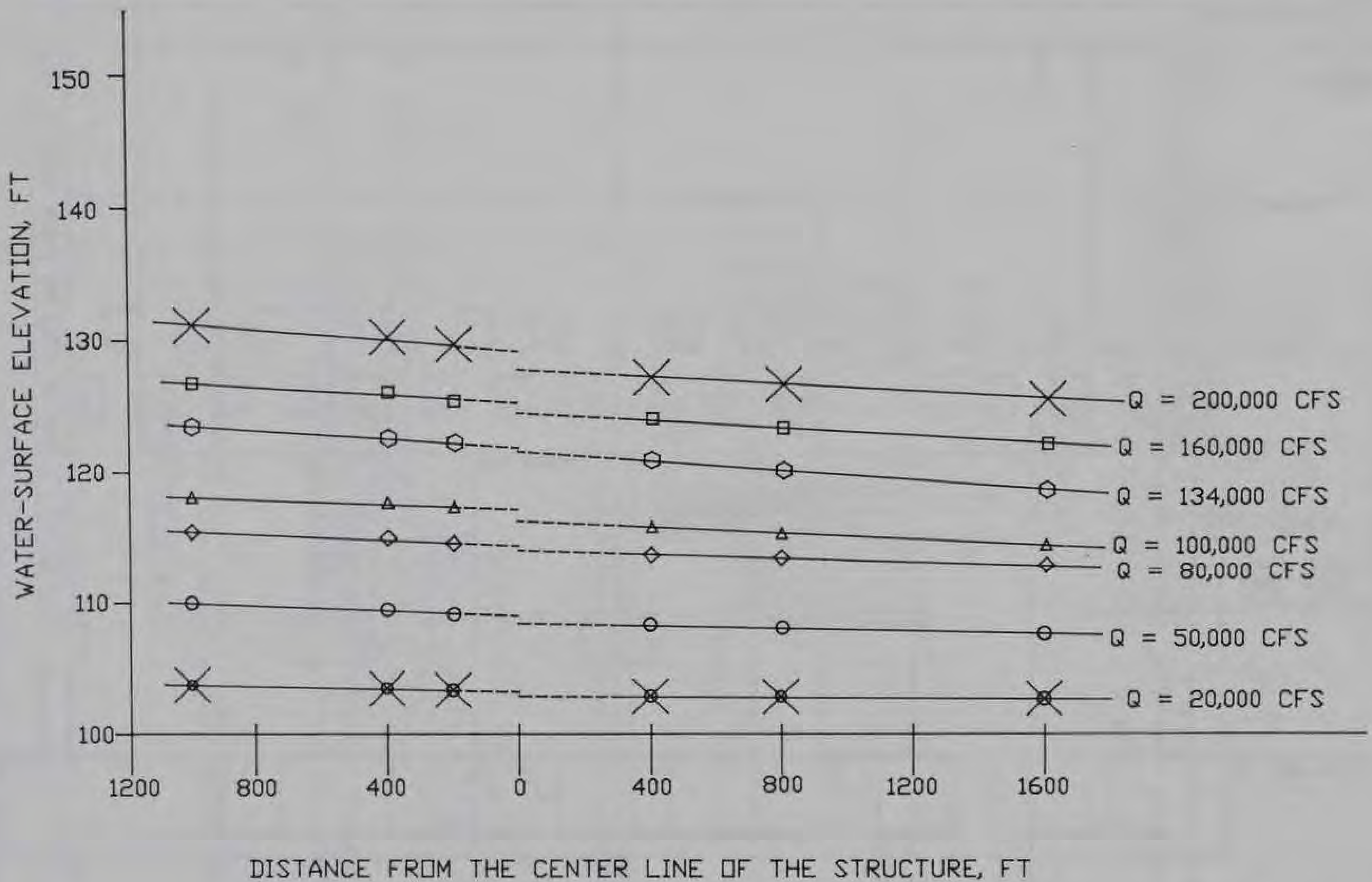
ORIGINAL DESIGN OF HINGE-GATED CREST

PLATE 3



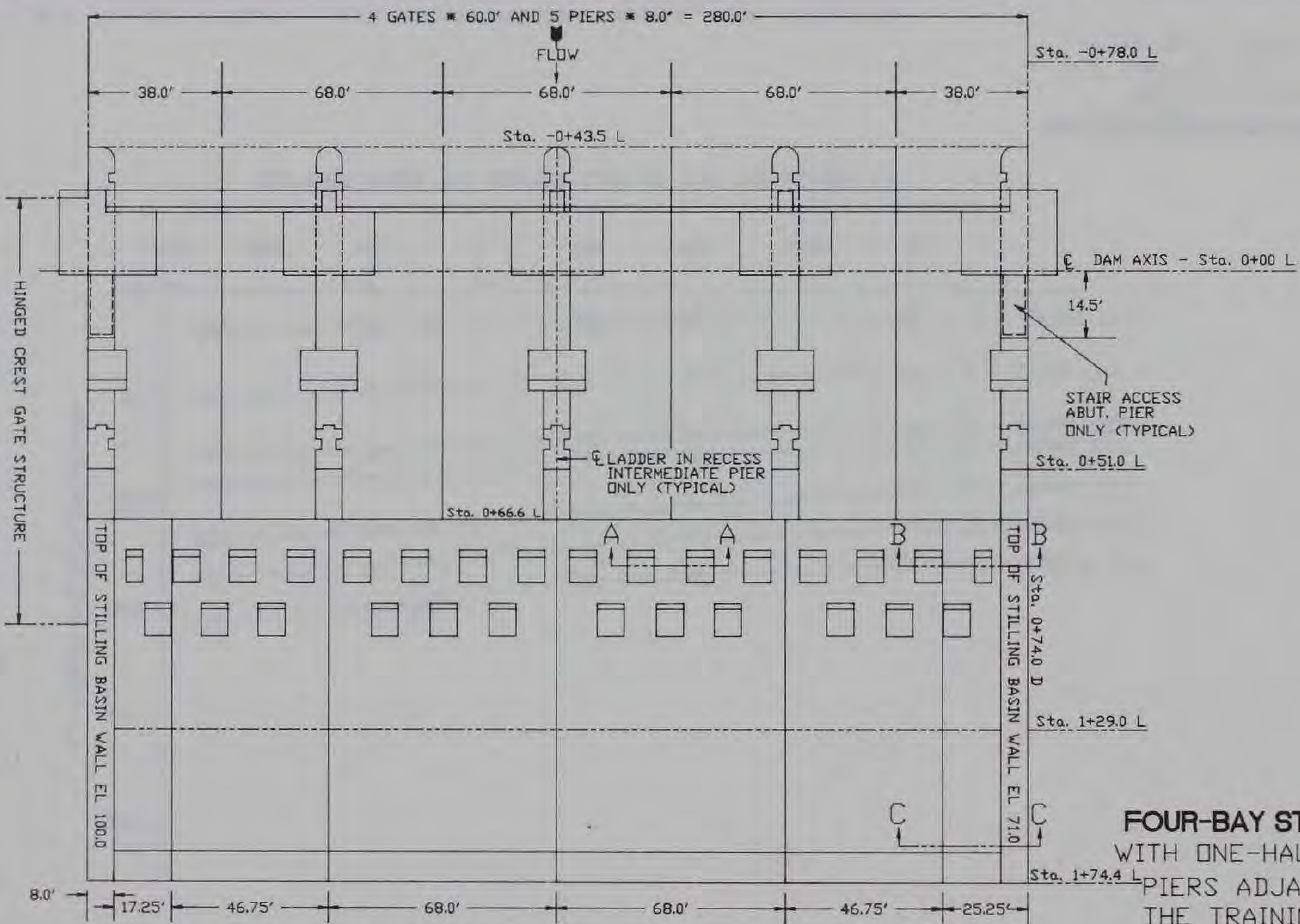
ORIGINAL CHANNEL ALIGNMENT

RIPRAP PROTECTION PLAN



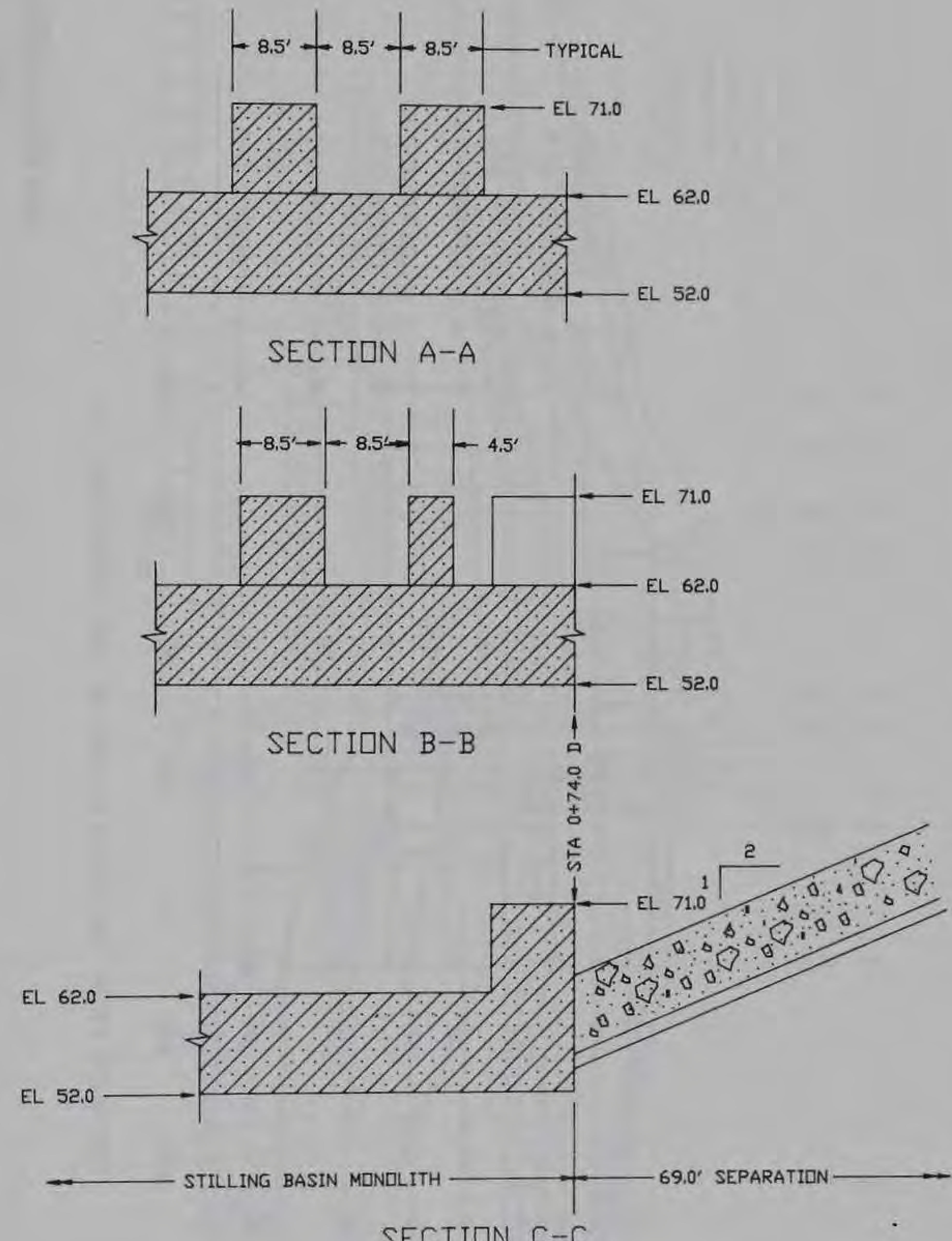
WATER-SURFACE PROFILES
CREST EL 86.0
ALL GATES FULLY OPEN
FOUR-BAY STRUCTURE

NOTE : DISTANCE ON HORIZONTAL SCALE IS MEASURED FROM 1200 FT UPSTREAM TO 1600 FT DOWNSTREAM



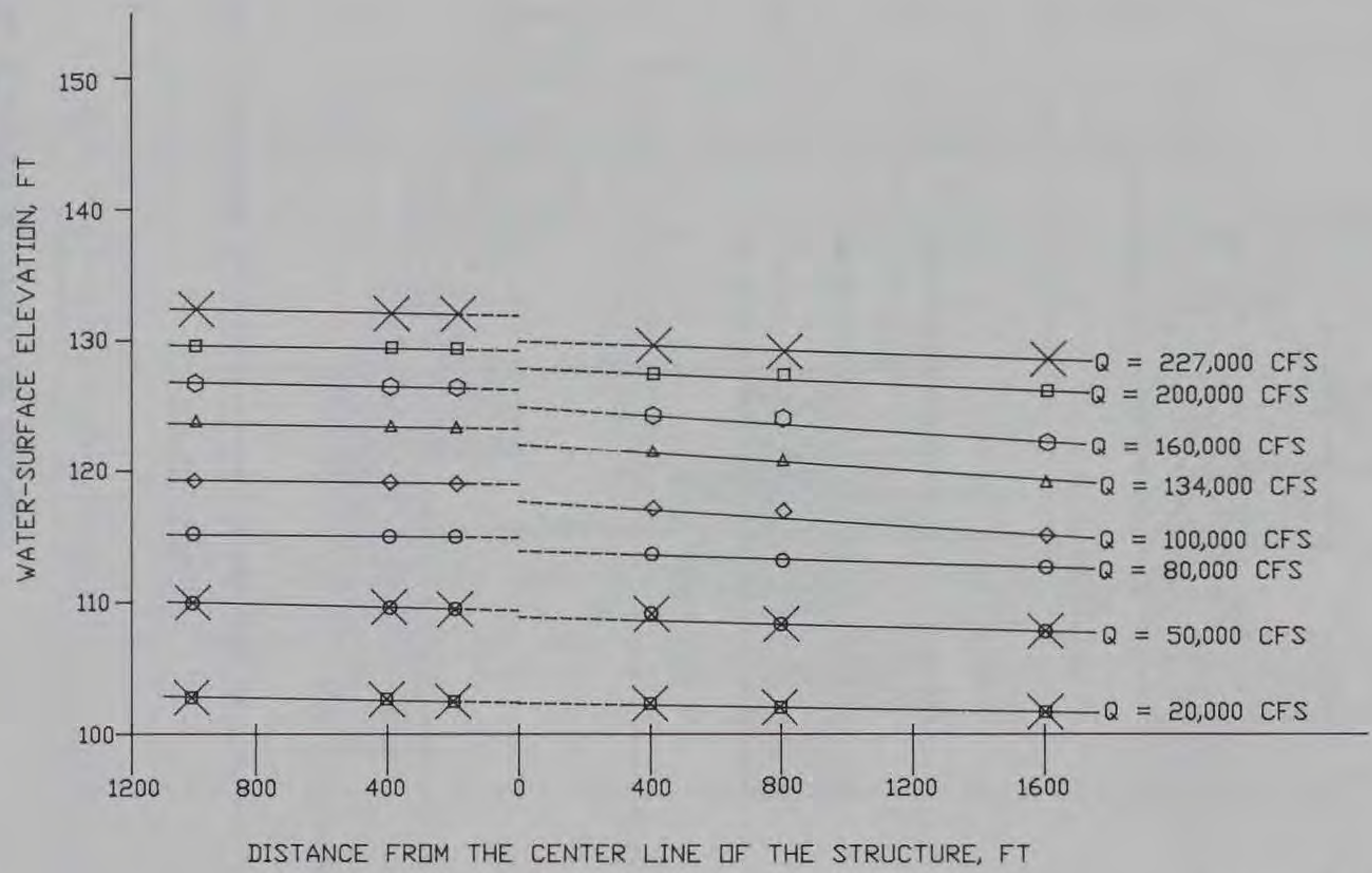
FOUR-BAY STRUCTURE
WITH ONE-HALF BAFFLE PIERS ADJACENT TO THE TRAINING WALL

NOTE: SEE PLATE 7 FOR SECTIONS A-A, B-B, AND C-C



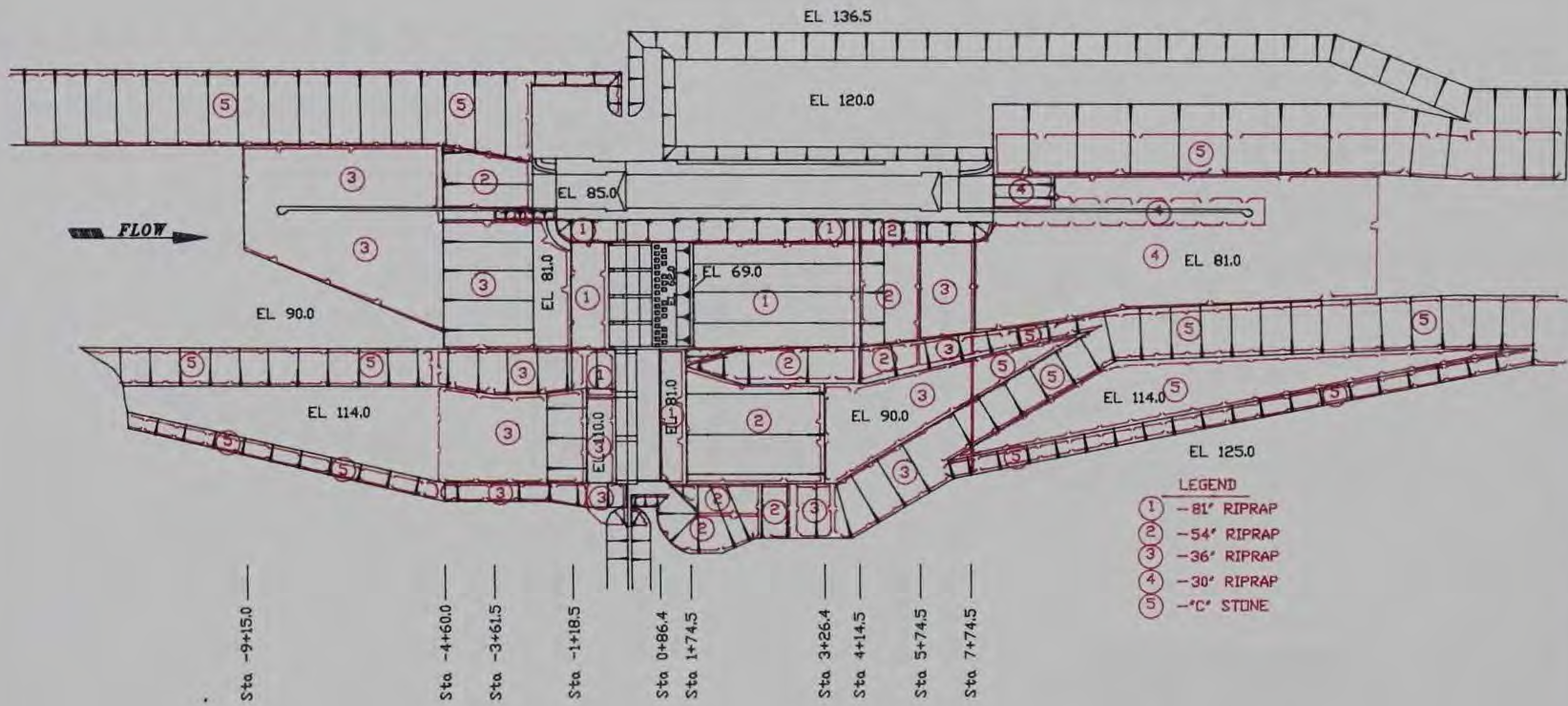
CROSS SECTION OF BAFFLE PIERS AND TRAINING WALL

PLATE 8



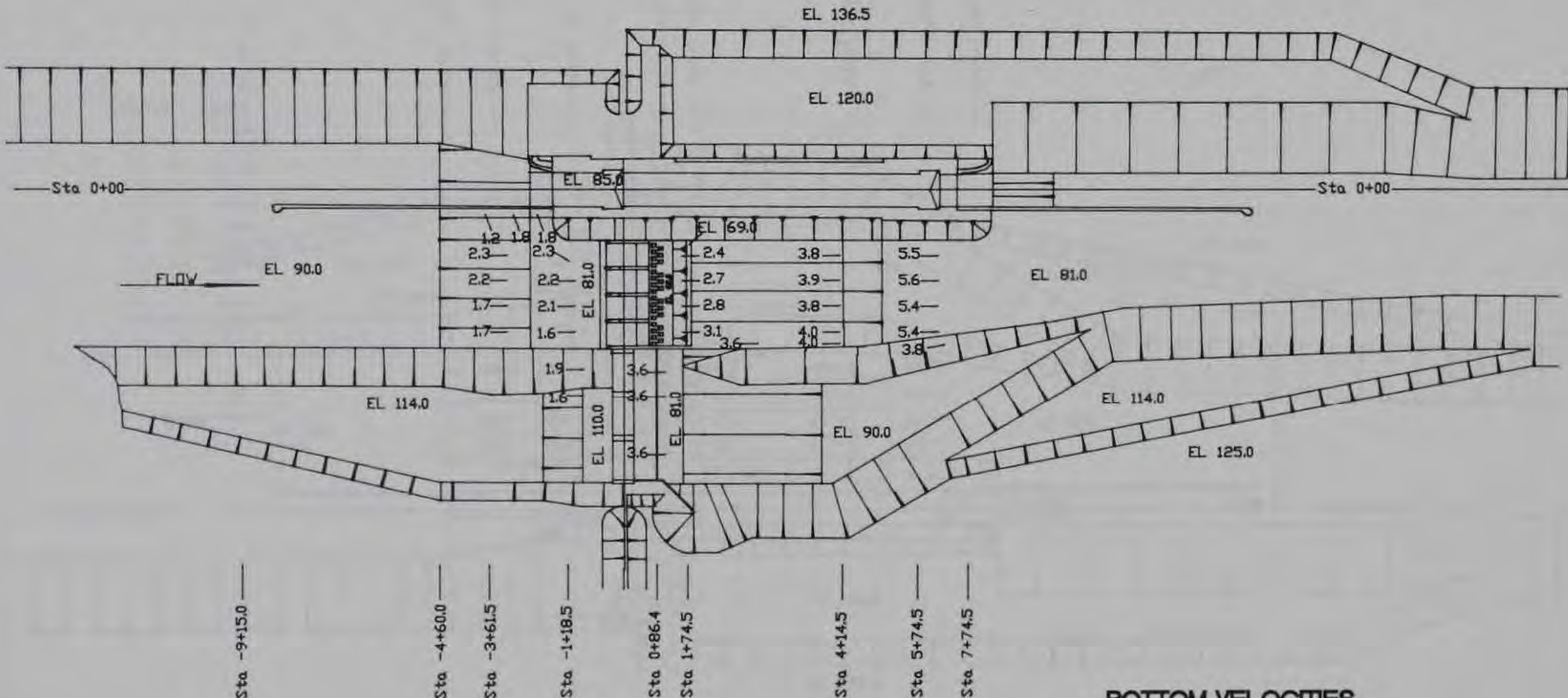
WATER-SURFACE PROFILES
CREST EL 85.0
ALL GATES FULLY OPEN
FOUR-BAY STRUCTURE

NOTE : DISTANCE ON HORIZONTAL SCALE IS MEASURED FROM 1200 FT UPSTREAM TO 1600 FT DOWNSTREAM



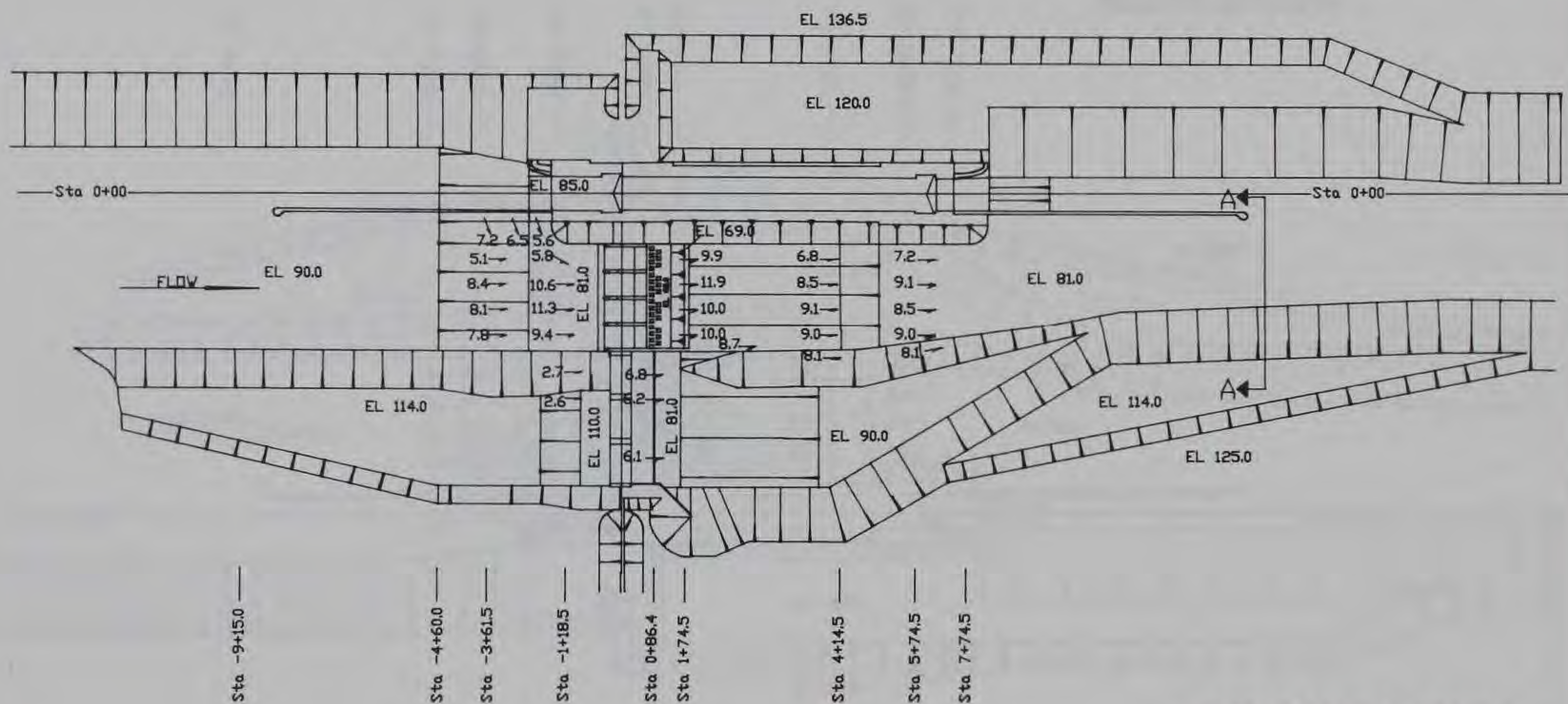
RECOMMENDED RIPRAP PROTECTION PLAN

4 SPILLWAY GATES, 3 HINGE GATES



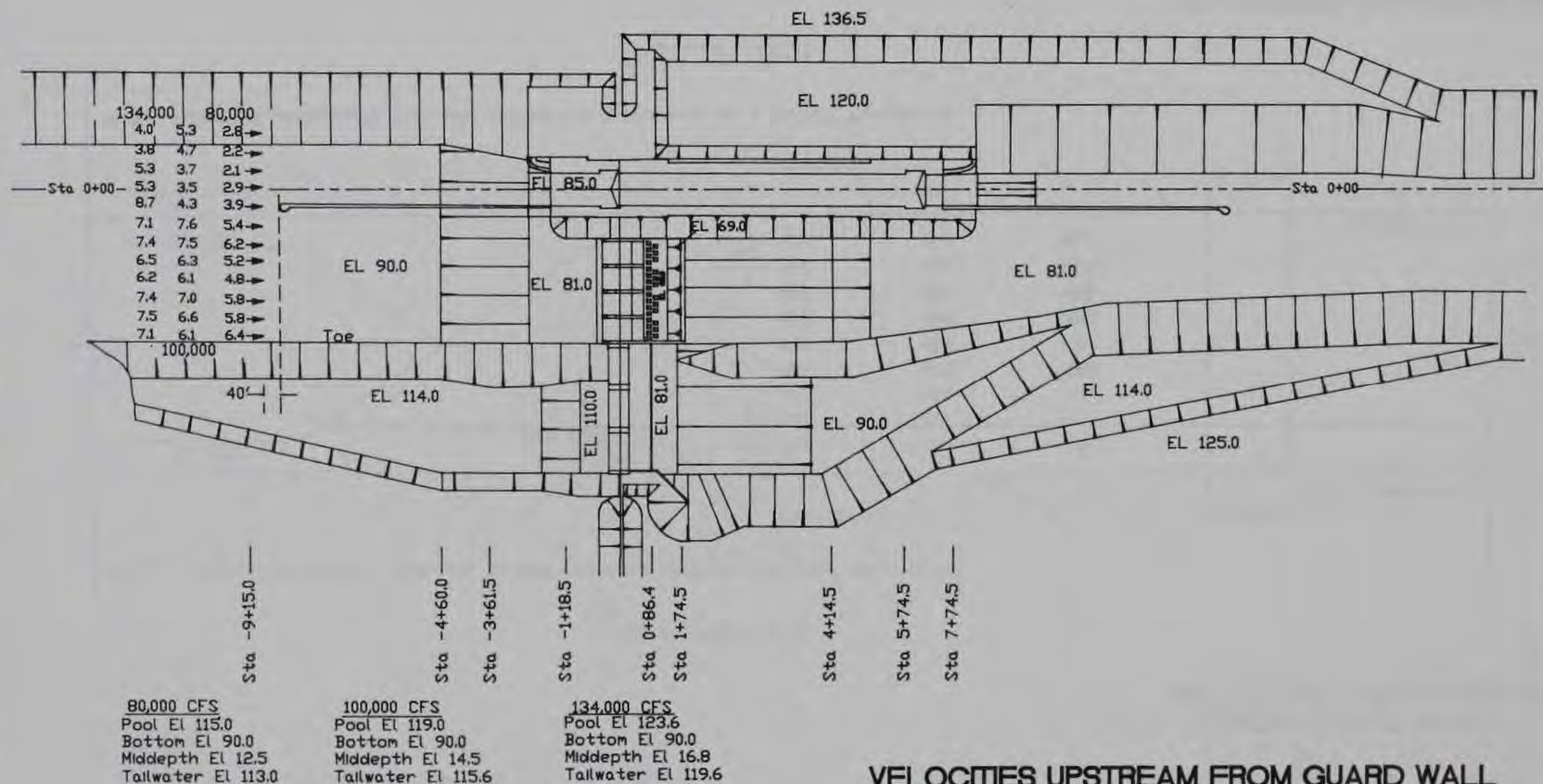
BOTTOM VELOCITIES
DISCHARGE 35,000 CFS
CREST EL 85
TAINTER GATE OPENINGS 4 FT
HINGE GATES FULLY OPEN
POOL EL 122
TAILWATER EL 95

NOTE: VELOCITIES 4 FT ABOVE BOTTOM OF CHANNEL



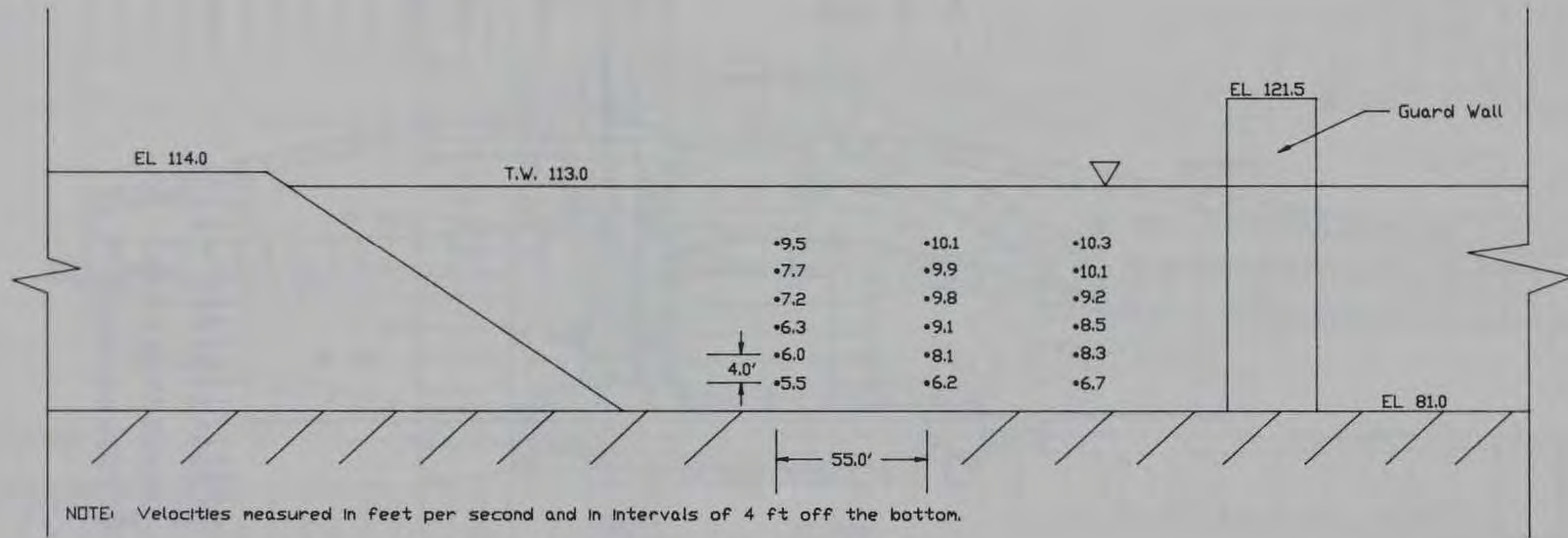
BOTTOM VELOCITIES
DISCHARGE 160,000 CFS
CREST EL 85
ALL GATES FULLY OPEN
POOL EL 126.7
TAILWATER EL 122.5

NOTE: VELOCITIES 4 FT ABOVE BOTTOM OF CHANNEL
VELOCITIES AT SECTION A-A ARE SHOWN IN PLATES 13 AND 14.



VELOCITIES UPSTREAM FROM GUARD WALL
ALL GATES FULLY OPEN

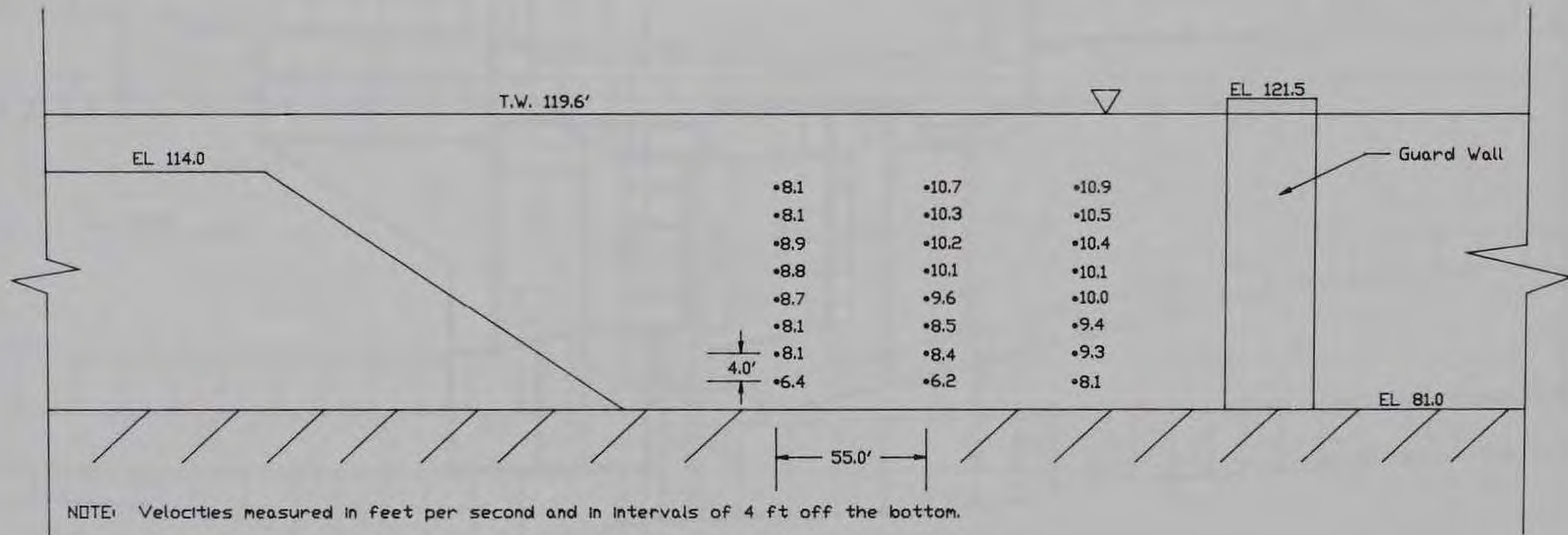
NOTE: Velocities were taken middepth and at 40-ft intervals from the toe.



SECTION A-A

VELOCITIES DOWNSTREAM FROM GUARD WALL

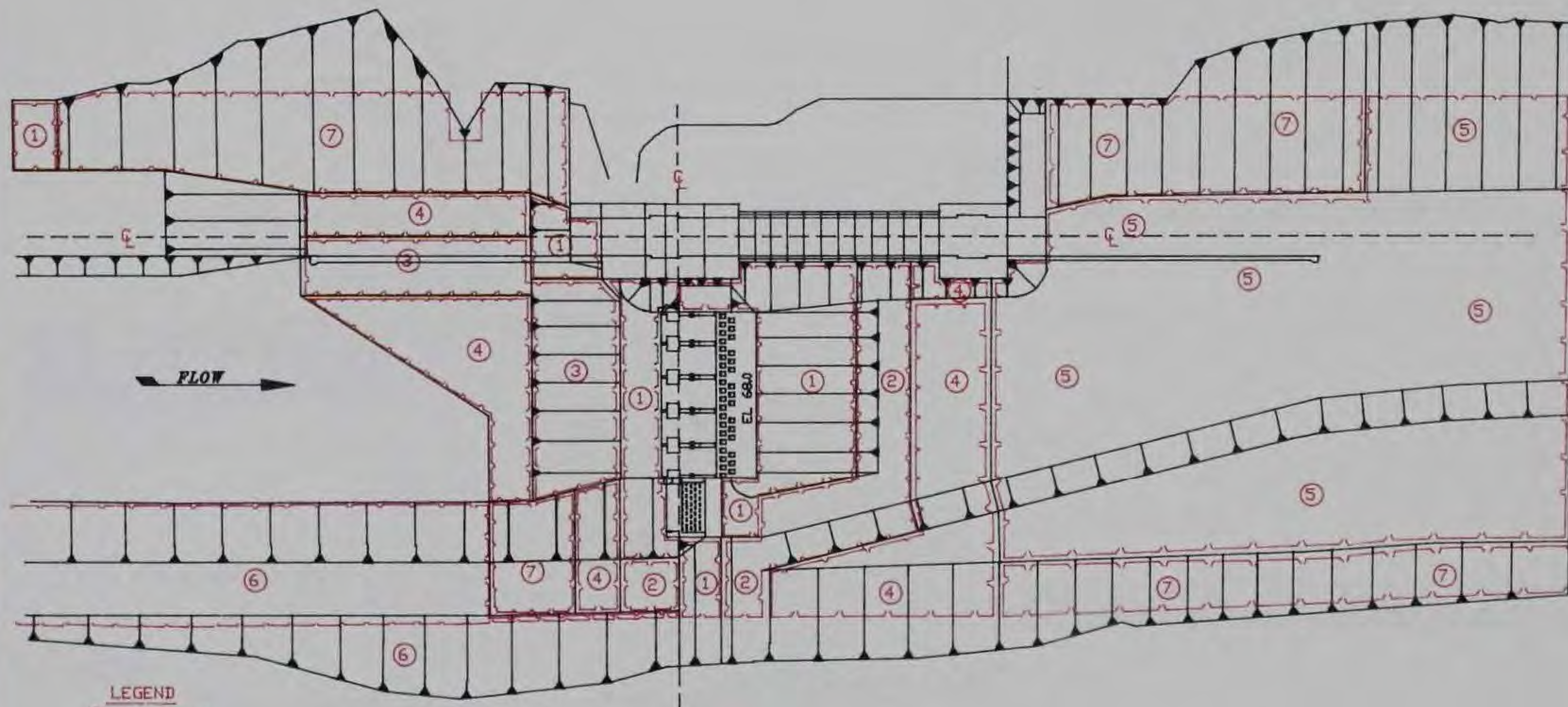
FOUR-BAY STRUCTURE
ALL GATES FULLY OPEN
DISCHARGE 80,000 CFS



SECTION A-A

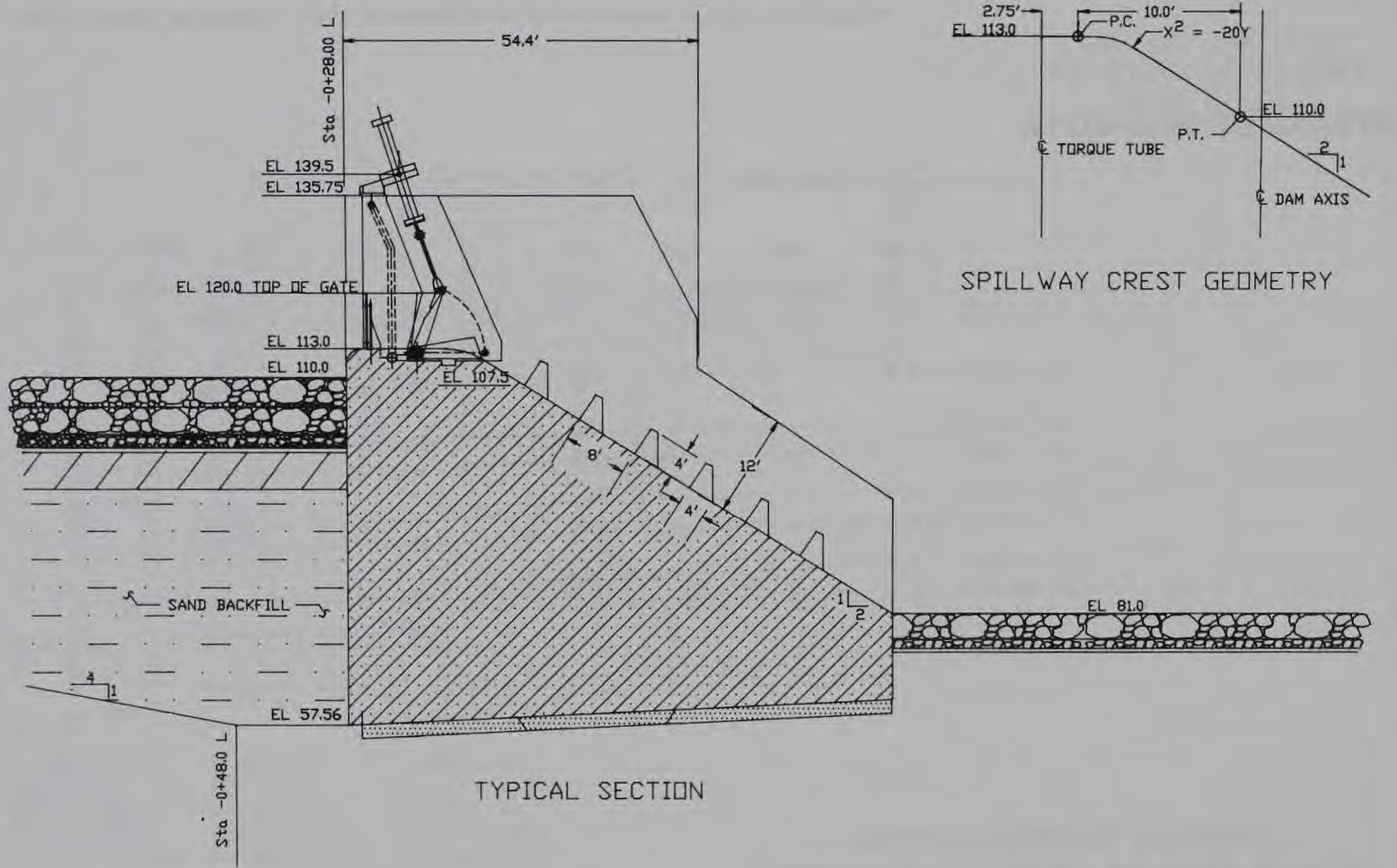
VELOCITIES DOWNSTREAM FROM GUARD WALL

FOUR-BAY STRUCTURE
ALL GATES FULLY OPEN
DISCHARGE 134,000 CFS

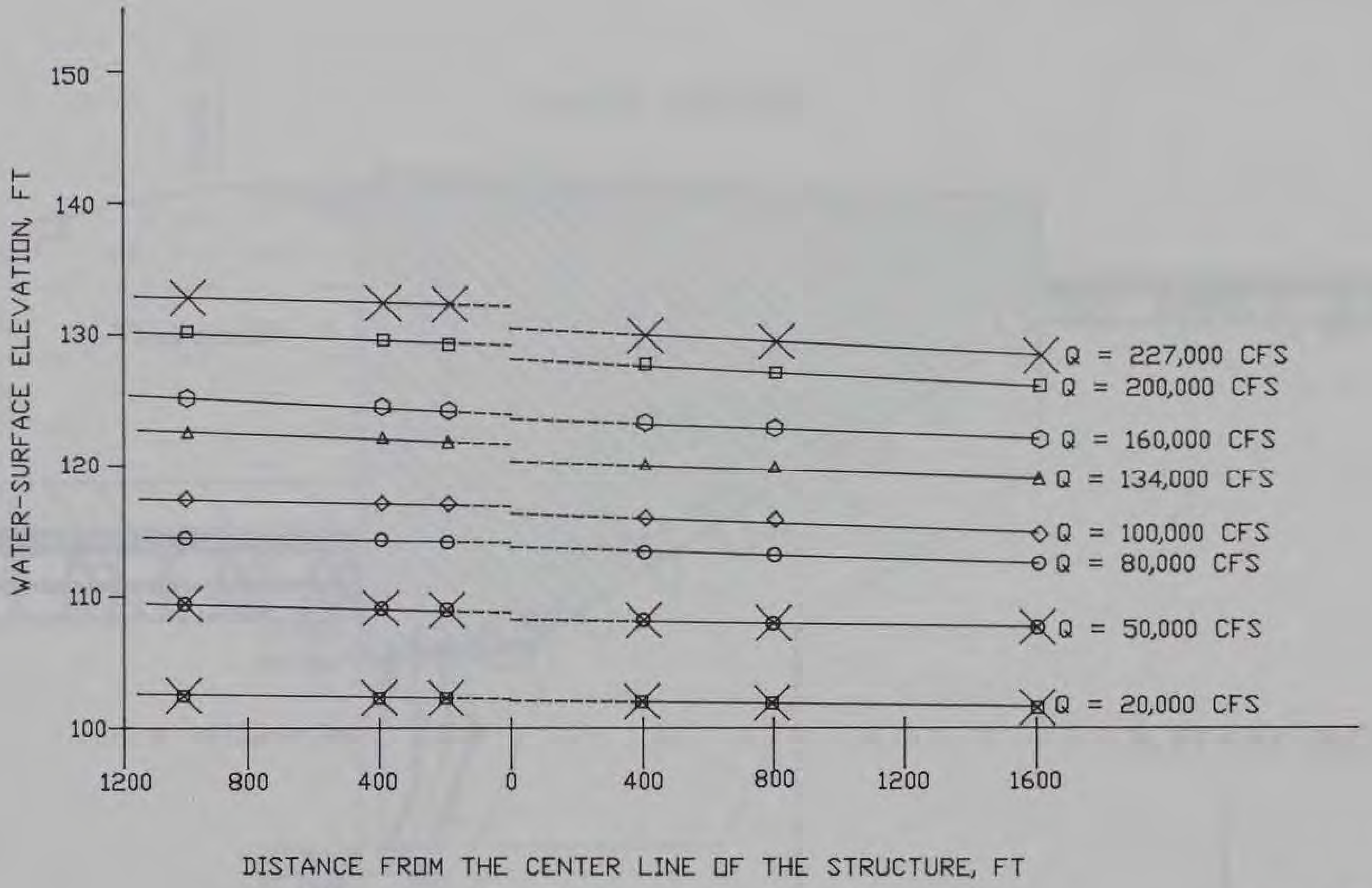


LEGEND
(1) 81" RIPRAP
(2) 54" RIPRAP
(3) 48" RIPRAP
(4) 36" RIPRAP
(5) 30" RIPRAP
(6) 18" GRADED STONE 'C'
(7) 16" RIPRAP

MODIFIED RIPRAP PROTECTION PLAN
WITH FIVE-GATED SRUCTURE AND BAFFLE CHUTE

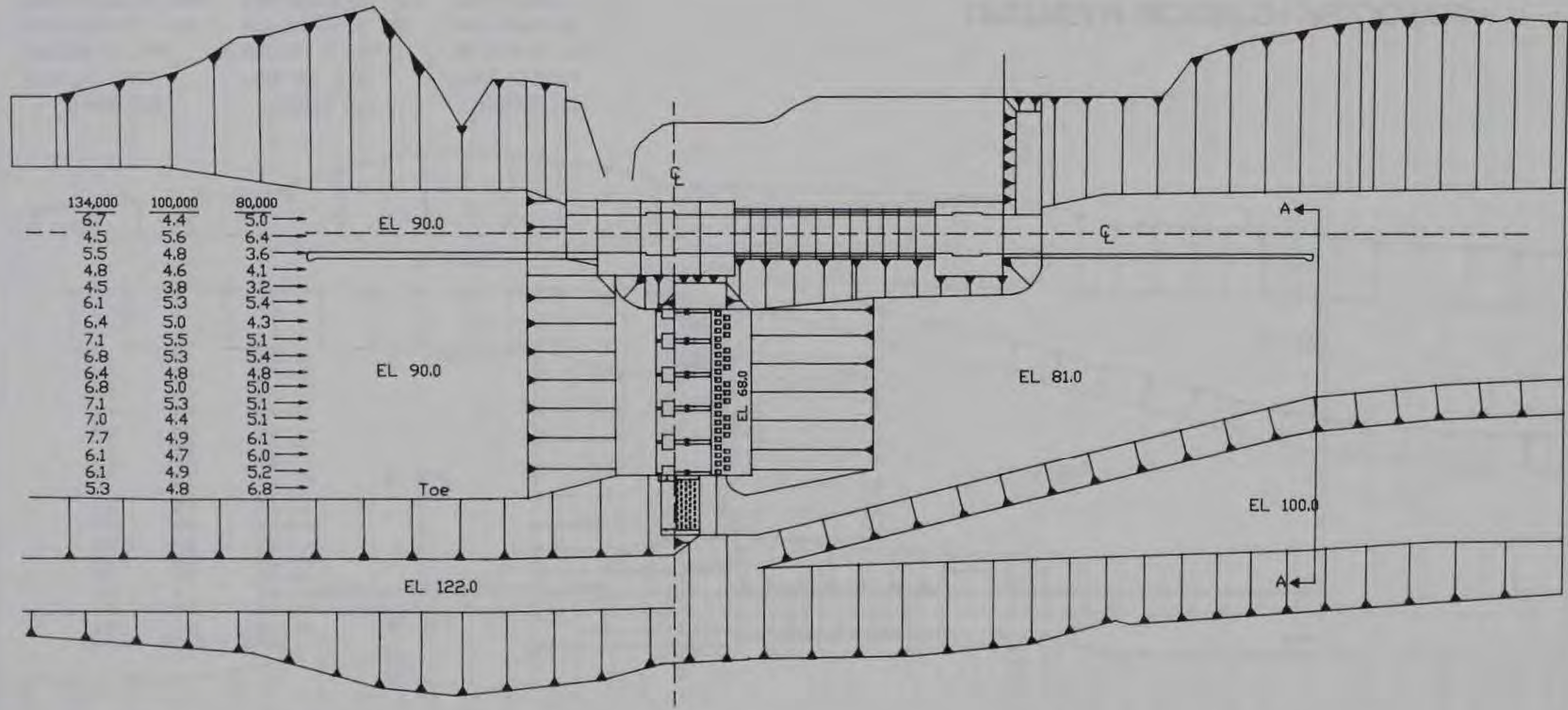


HINGE-GATED CREST WITH BAFFLE CHUTE



WATER-SURFACE PROFILES
CREST EL 85.0
ALL GATES FULLY OPEN
FIVE-BAY STRUCTURE

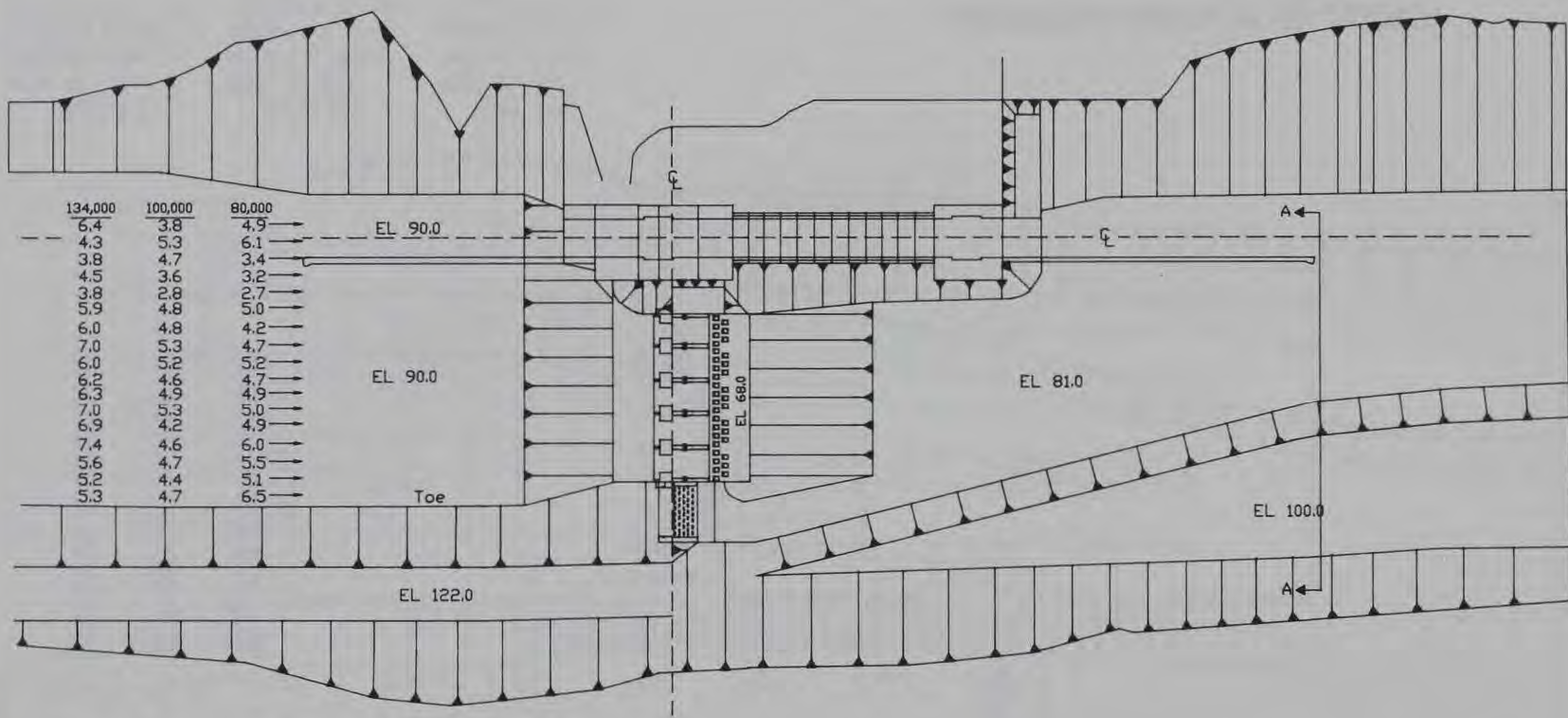
NOTE : DISTANCE ON HORIZONTAL SCALE IS MEASURED FROM 1200 FT UPSTREAM TO 1600 FT DOWNSTREAM



134,000 CFS	100,000 CFS	80,000 CFS
POOL EL 123.6	POOL EL 119.0	POOL EL 115.0
BOTTOM EL 90.0	BOTTOM EL 90.0	BOTTOM EL 90.0
MIDDEPTH EL 16.8	MIDDEPTH EL 14.5	MIDDEPTH EL 12.5
TAILWATER EL 119.6	TAILWATER EL 115.6	TAILWATER EL 113.0

NOTE: ELEVATIONS IN FEET

UPSTREAM SURFACE VELOCITIES
FIVE-GATED STRUCTURE AND BAFFLE CHUTE
ALL GATES FULLY OPEN



134,000 CFS	100,000 CFS	80,000 CFS
POOL EL 123.6	POOL EL 119.0	POOL EL 115.0
BOTTOM EL 90.0	BOTTOM EL 90.0	BOTTOM EL 90.0
MID-DEPTH EL 16.8	MID-DEPTH EL 14.5	MID-DEPTH EL 12.5
TAILWATER EL 119.6	TAILWATER EL 115.6	TAILWATER EL 113.0

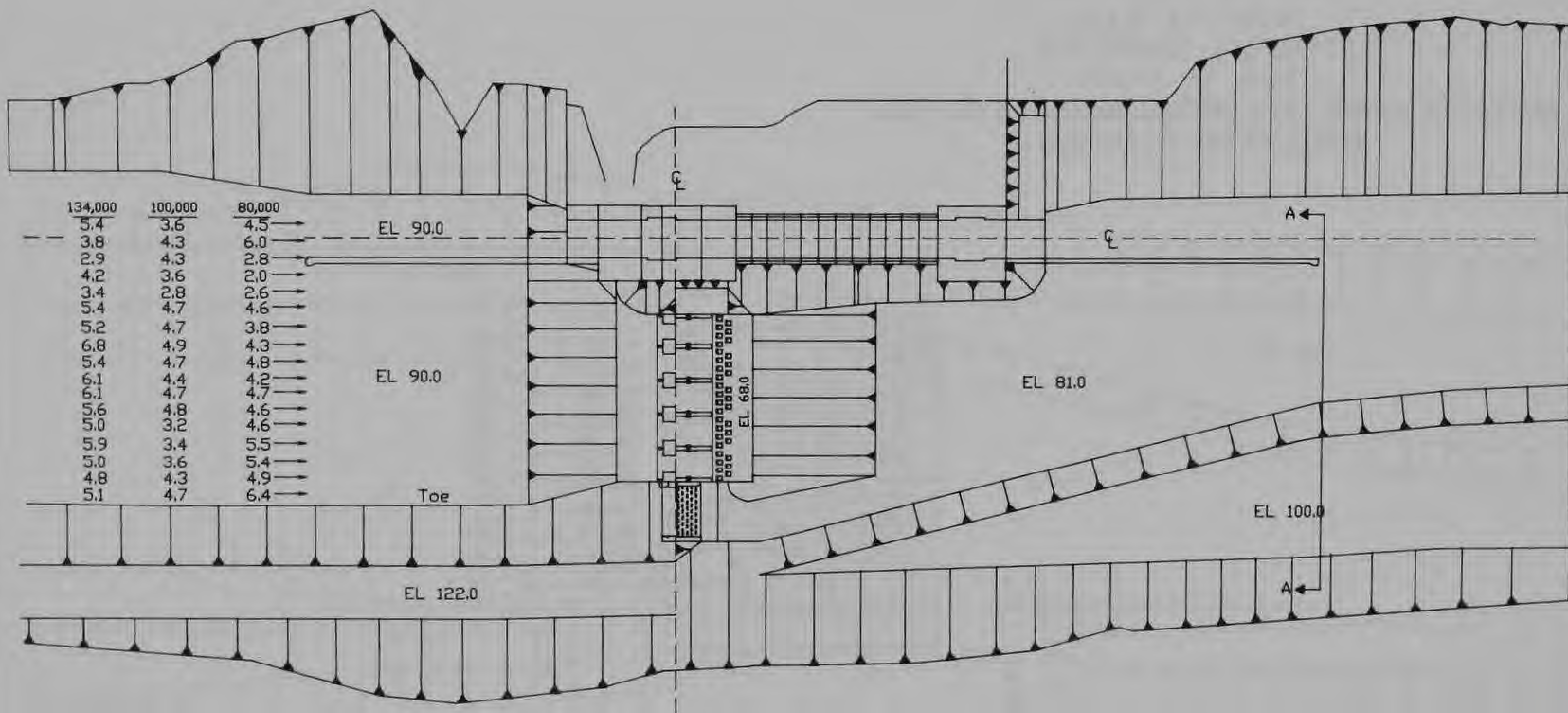
NOTE: ELEVATIONS IN FEET

VELOCITIES TAKEN AT MIDDEPTH

UPSTREAM MIDDEPTH VELOCITIES

FIVE-GATED STRUCTURE AND BAFFLE CHUTE

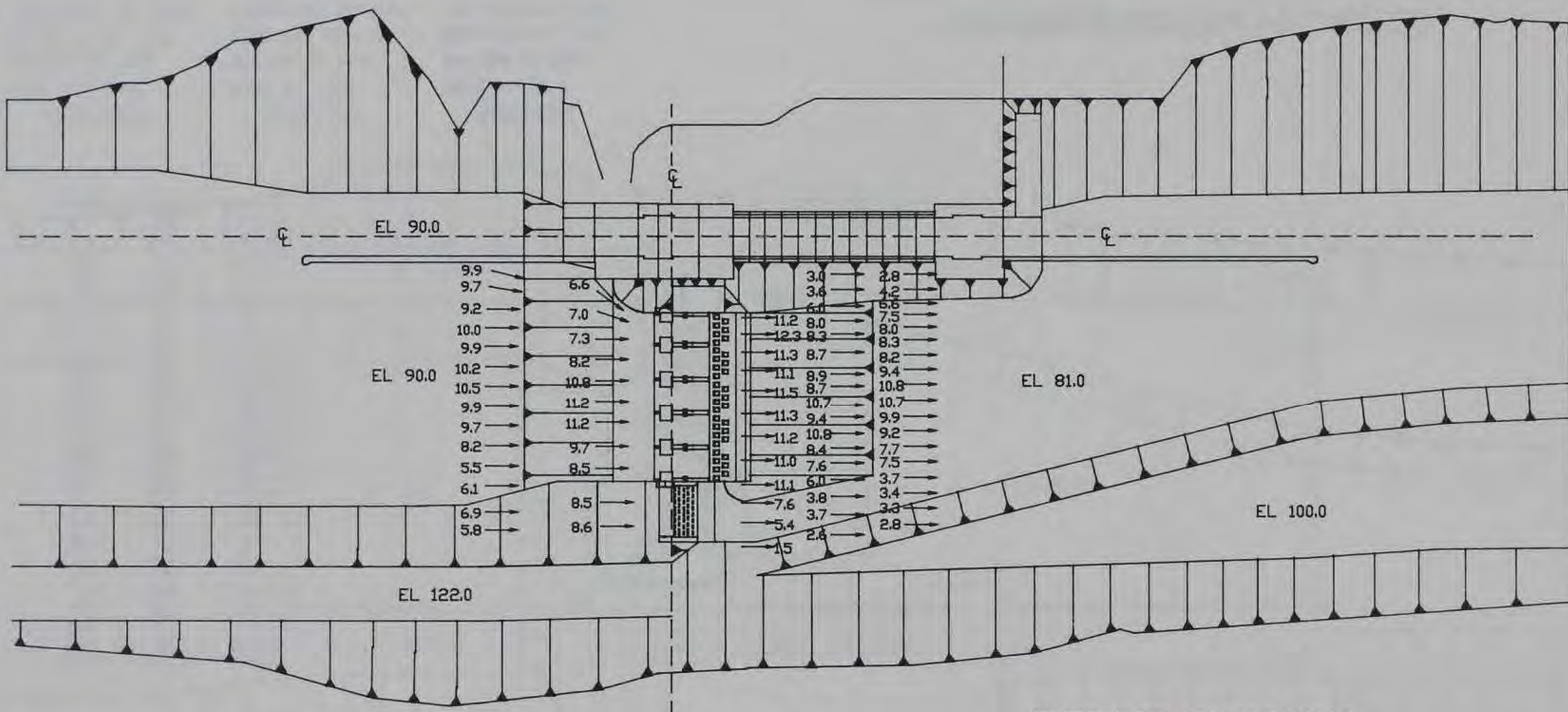
ALL GATES FULLY OPEN



134,000 CFS	100,000 CFS	80,000 CFS
POOL EL 123.6	POOL EL 119.0	POOL EL 115.0
BOTTOM EL 90.0	BOTTOM EL 90.0	BOTTOM EL 90.0
MIDDEPTH EL 16.8	MIDDEPTH EL 14.5	MIDDEPTH EL 12.5
TAILWATER EL 119.6	TAILWATER EL 115.6	TAILWATER EL 113.0

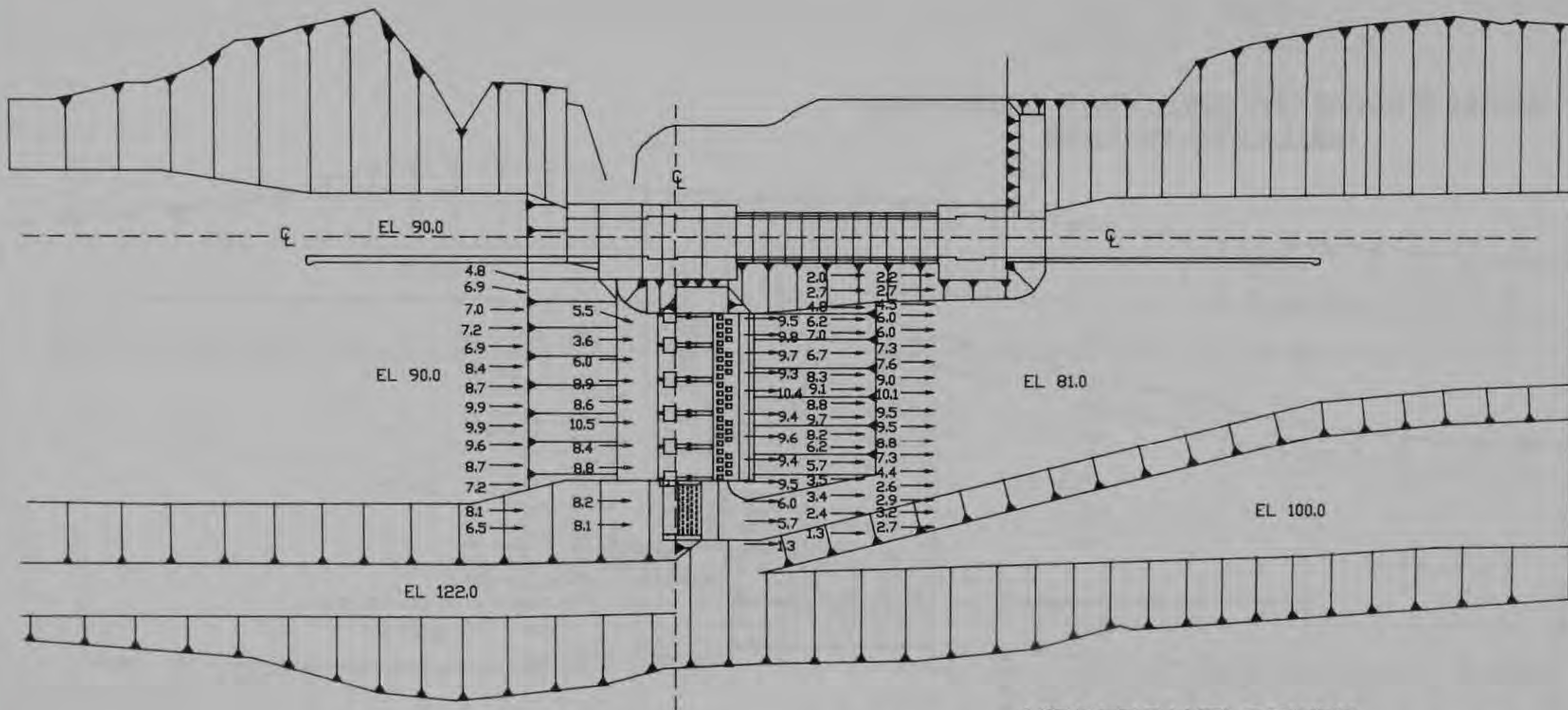
NOTE: ELEVATIONS IN FEET
VELOCITIES TAKEN 4 FT ABOVE CHANNEL BOTTOM
VELOCITIES AT SECTION A-A ARE SHOWN IN PLATES 24 AND 25.

UPSTREAM BOTTOM VELOCITIES
FIVE-GATED STRUCTURE AND BAFFLE CHUTE
ALL GATES FULLY OPEN



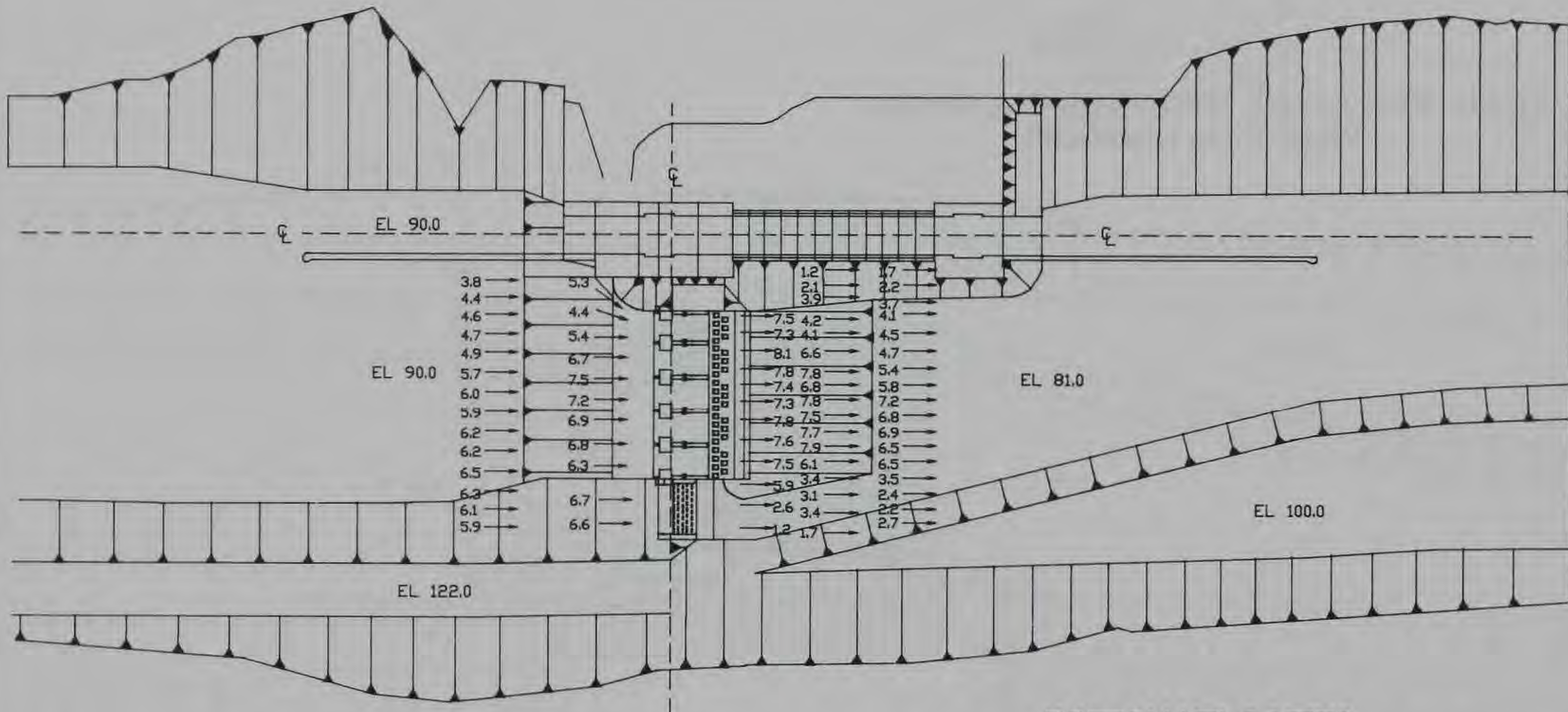
SURFACE VELOCITIES
FIVE-GATED STRUCTURE AND BAFFLE CHUTE
CREST EL 85.0
DISCHARGE 160,000 CFS
POOL EL 126.6
TAILWATER EL 122.5
ALL GATES FULLY OPEN

NOTE: ELEVATIONS IN FEET



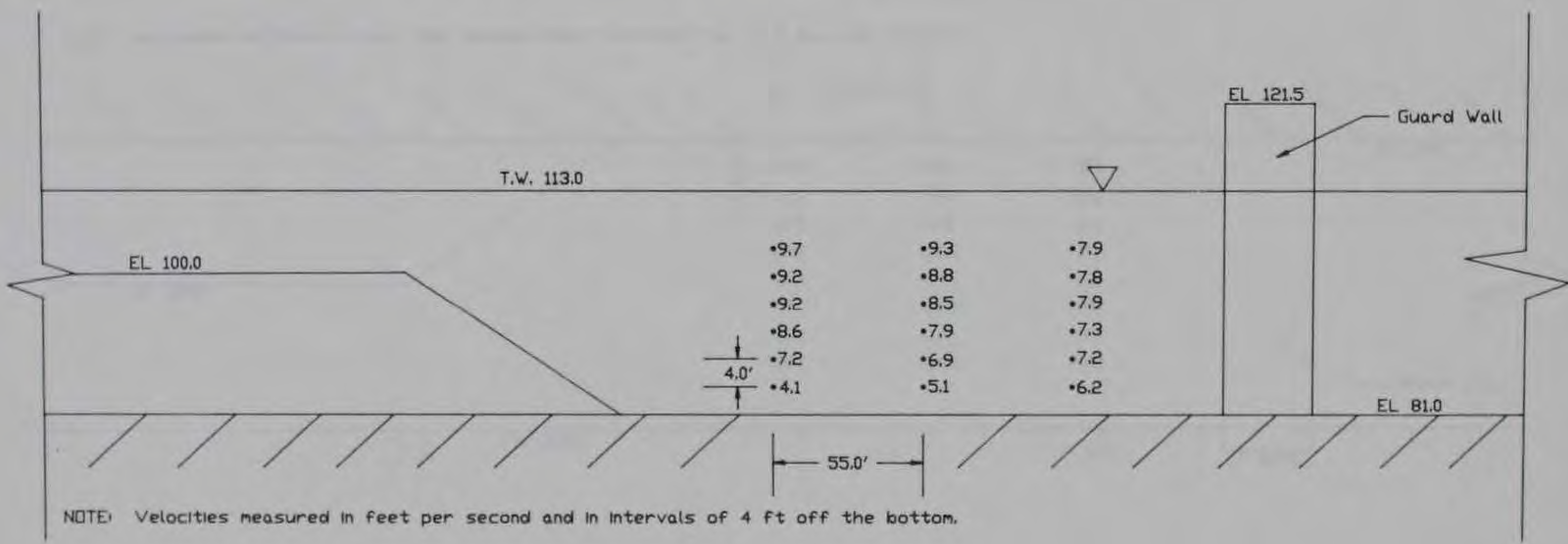
NOTE: ELEVATIONS IN FEET

MIDDEPTH VELOCITIES
FIVE-GATED STRUCTURE AND BAFFLE CHUTE
CREST EL 85.0
DISCHARGE 160,000 CFS
POOL EL 126.6
TAILWATER EL 122.5
ALL GATES FULLY OPEN



BOTTOM VELOCITIES
FIVE-GATED STRUCTURE AND BAFFLE CHUTE
CREST EL 85.0
DISCHARGE 160,000 CFS
POOL EL 126.6
TAILWATER EL 122.5
ALL GATES FULLY OPEN

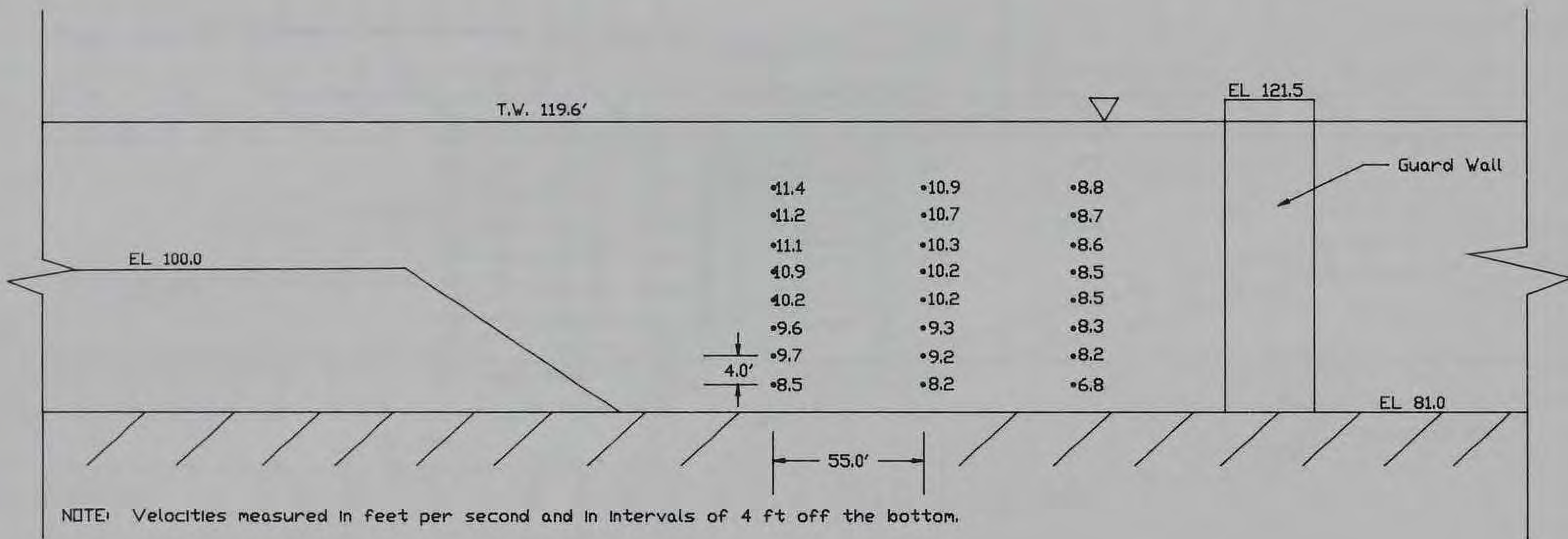
NOTE: ELEVATIONS IN FEET
VELOCITIES TAKEN 4 FEET ABOVE CHANNEL BOTTOM



SECTION A-A

VELOCITIES DOWNSTREAM FROM GUARD WALL

FIVE-BAY STRUCTURE
ALL GATES FULLY OPEN
DISCHARGE 80,000 CFS



SECTION A-A

VELOCITIES DOWNSTREAM FROM GUARD WALL

FIVE-BAY STRUCTURE
ALL GATES FULLY OPEN
DISCHARGE 134,000 CFS