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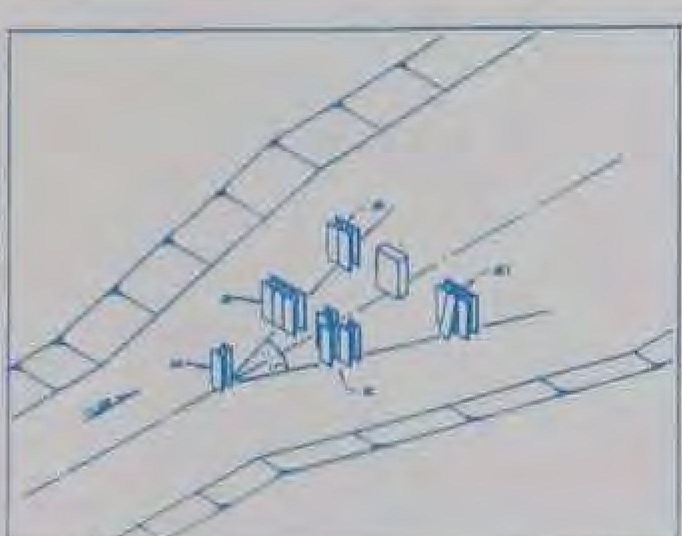

HYDRAULICS
LABORATORY

TECHNICAL REPORT HL-88-11

MUDDY CREEK GRADE CONTROL STRUCTURES MUDDY CREEK, MISSISSIPPI AND TENNESSEE

Hydraulic Model Investigation

by

Charles H. Tate, Jr.

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

May 1988
Final Report

Prepared for US Army Engineer District, Vicksburg
Vicksburg, Mississippi 39180-0060

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report HL-88-11	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION USAEWES Hydraulics Laboratory; 6b. OFFICE SYMBOL (If applicable) CEWES-HS-L	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) PO Box 631 Vicksburg, MS 39180-0631	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION USAED, Vicksburg; 8b. OFFICE SYMBOL (If applicable) CELMK-ED-H	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) PO Box 60 Vicksburg, MS 39180-0060	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Muddy Creek Grade Control Structures, Muddy Creek, Mississippi and Tennessee; Hydraulic Model Investigation

12. PERSONAL AUTHOR(S)
Tate, Charles H., Jr.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final report	FROM ____ TO ____	May 1988	56

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Flow separation; Grade control structures; Riprap chute baffles; Riprap exit flare; Riprap structure; Rock chute

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

Riprap grade control structures were installed at 12 locations along the Muddy Creek drainage system between September 1976 and September 1983 by the US Soil Conservation Service. After scour holes formed immediately downstream of the first four structures, the exit transition of the structure design was changed from a 1:4 exit flare to a 1:8 exit flare. Many of the redesigned structures formed scour holes after completion. The US Army Engineer Waterways Experiment Station used a 1:16-scale model and a 1:24-scale model to study the scour problem and design modifications to the existing structures.

Scour was caused by uneven flow distribution due to flow separation in the exit flare. A series of H-pile baffles were designed for the 1:8 and 1:4 exit flares. Additional studies determined that a 1:16 exit flare with no baffles prevented flow separation within the exit transition resulting in a uniform distribution of flow downstream of the grade control structure.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code); 22c. OFFICE SYMBOL

DD Form 1473, JUN 86 — Previous editions are obsolete. — SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

PREFACE

The model investigation reported herein was authorized by the Headquarters, US Army Corps of Engineers, on 30 September 1983 at the request of the US Army Engineer District, Vicksburg (LMK). The studies were conducted by personnel of the Hydraulics Laboratory (HL), US Army Engineer Waterways Experiment Station (WES), during the period October 1983 to January 1986. All studies were conducted under the direction of Messrs. F. A. Herrmann, Jr., Chief, HL, and J. L. Grace, Jr., Chief of the Hydraulic Structures Division. Tests were conducted by Messrs. C. H. Tate, Jr., J. Cessna, L. East, and N. Ford under the supervision of Mr. G. A. Pickering, former Chief of the Locks and Conduits Branch, and J. F. George, Acting Chief of the Locks and Conduits Branch. This report was edited by Mrs. Marsha Gay, Information Technology Laboratory, WES. This report was prepared by Mr. Tate.

During the course of the investigation, Messrs. Phil Combs and Basil Arthur, LMK, and Messrs. David Ralston, Pete Forsythe, Bill Leeming, John Breuard, Mickey Hayward, Bobby Daniels, Bill Erion, Jim Evans, Quinton Milhollin, Rodney White, Ron Nulton, and Morris Lobrecht, US Soil Conservation Service (SCS), visited WES to discuss model results and correlate these results with concurrent design work. Mr. Richard Peace, SCS, was also involved with the study during implementation of the test results into design of the projects.

COL Dwayne G. Lee, CE, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

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	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	25.4	millimetres
pounds (mass)	0.4535924	kilograms
tons (2,000 pounds, mass)	907.1847	kilograms

Figure 1. Project location

MUDDY CREEK GRADE CONTROL STRUCTURES

MUDDY CREEK, MISSISSIPPI AND TENNESSEE

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. Muddy Creek is located in extreme north Mississippi and south Tennessee and flows generally north from near Ripley, Mississippi, to the Hatchie River just north of the Mississippi-Tennessee State line (Figure 1). Between September 1976 and September 1983, the US Soil Conservation Service (SCS) modified the Muddy Creek drainage system by constructing a trapezoidal channel with 12 riprap grade control structures spaced along the main channel. The first four structures (structure No. 1 being the farthest downstream) and connecting channels were constructed between September 1976 and February 1980, using the procedures in SCS (1976).* Surveys of the structures during 1980 indicated that severe scour, up to 15 ft** deep, had occurred immediately downstream of several structures. Postulated as a cause for the scour was flow separation in the 1:4 exit flare which caused eddies to form along the side slopes, resulting in flow concentrations in the channel. The other grade control structures were constructed with a 1:8 exit flare in an effort to improve exit flow conditions. Heavier riprap was placed at the downstream end of the prismatic section and the upstream portion of the exit flare. However, scour holes again formed immediately downstream of these structures.

Purpose of Model Investigation

2. This model investigation was conducted to determine the flow conditions that were causing the observed scour and to develop modifications

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* US Department of Agriculture, Soil Conservation Service. 1976 (Jan). "Hydraulic Design of Riprap Gradient Control Structures," Technical Release No. 59, Washington, DC.

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

to the existing structures to minimize the scour conditions. Additionally, the model study was used to develop modifications to design criteria to prevent the flow conditions that had caused scour.

PART II: THE MODEL

Description

3. Field observation of the completed Muddy Creek system, consisting of grade control structures No. 1 through 12, indicated that the maximum amount of scour had occurred at structure No. 5, where the channel bottom had scoured significantly with subsequent collapsing of the channel banks immediately downstream from the structure. It was later determined that a local soil layer aggravated the bank caving. This structure was chosen for the initial testing to determine appropriate modifications to minimize downstream scour. The modifications that were developed were specific to the 1:8 exit flare constructed at structures No. 5 through 12. Structure No. 2 was used to determine similar modifications for structures No. 1 through 4, which had exit flares of 1:4. Additional exit flares were tested using structure No. 2 as the base to determine the maximum flare that would not cause flow separation.

4. A 1:16-scale model was initially used to reproduce structure No. 5. Approximately 200 ft of the trapezoidal channel upstream of the structure and approximately 500 ft of downstream channel were reproduced. A moveable sand channel was used for the channel downstream of the grade control structure throughout the study.

5. The grade control structure (Plate 1 and Figure 2) consisted of a 36-ft-long approach transition section that reduced the base width of the channel from 54 ft to 18 ft. The base of the approach transition section had a 1:2 flare, and the side slopes transitioned from 1V on 3H to 1V on 2.5H. The prismatic section with an 18-ft-wide base remained constant for 308 ft where the exit transition section began. The 144-ft-long exit transition section had a 1:8 base flare, and the side slopes transitioned back to the 1V on 3H side slopes. Graded riprap was used to form the grade control structure throughout the study. Riprap gradation A, shown in the following tabulation, was used throughout the structure except for 50 ft either side of the downstream end of the prismatic section (sta 684+56) where riprap gradation B was installed.

6. After tests with structure No. 5 were completed, structure No. 2 was reproduced at a scale of 1:24 due to the larger size of this structure and the limits of the model facility. The model of structure No. 2 reproduced

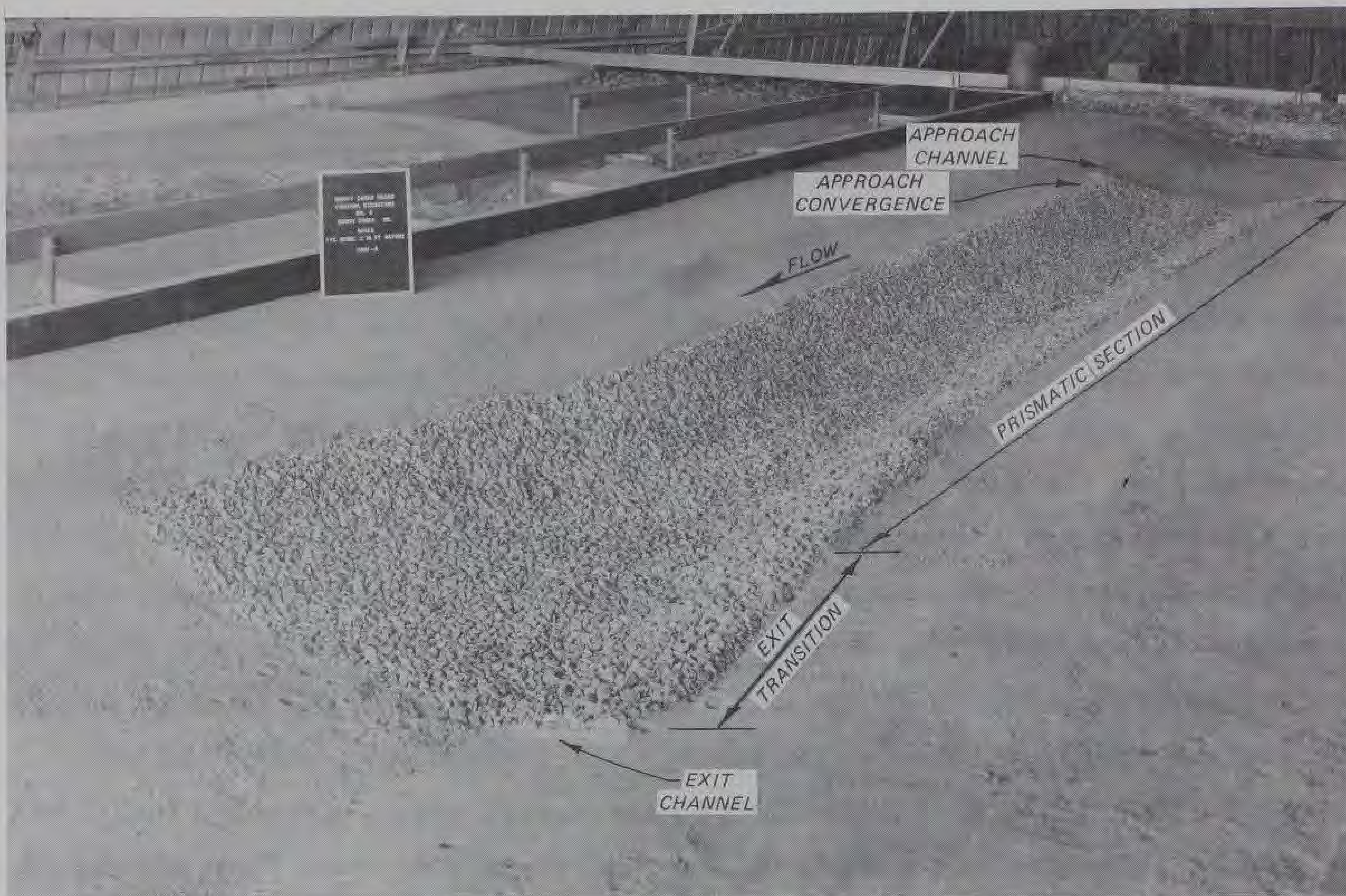

Figure 2. General view, grade control structure No. 5

Gradation	Weight of Stones, lb	Cumulative Percent Lighter by Weight
A	225	100
	85	25-50
	10	5-20
B	1,200	100
	500	40-75
	300	25-50
	125	10-30
	30	0-10

Note: Spalls and rock dust that will pass a 3-in. sieve shall consist of less than 5 percent by weight.

approximately 300 ft of channel upstream and approximately 500 ft downstream of the grade control structure. This structure was similar to structure No. 5 as shown in Plate 2, except that the channel base was 80 ft wide, the prismatic section was 29 ft wide and contained a 3.7-ft vertical drop within the 586-ft-long section, and the exit flare was 1:4. Riprap gradation requirements for structure No. 2 are shown in the following tabulation:

Weight of Stones, lb	Cumulative Percent Lighter by Weight
225	100
125	40-75
85	25-50
60	10-30
10	0

7. Flow to both models was supplied through a circulating system. Discharges were measured with differential pressure manometers and controlled with a manual gate valve. Hydrographs were reproduced with stepped operations to approximate the hydrograph flows and durations.

8. Tailwater elevations, which were set using a moveable tailgate, were determined while flow was passing through the model in a steady state regime.

9. Velocities were measured in the models with pitot-static tubes and with propeller meters. Point gages were used to measure water-surface elevations throughout the models. Flow conditions were observed for all designs tested, with the original designs and the potentially usable designs being recorded photographically.

Scale Relations

10. The accepted equations of hydraulic similitude, based on the Froude criteria, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. These general relations were used for the transference of model data to prototype equivalents:

Characteristic	Dimension*	Scale Relation Model:Prototype	
Length	L_r	1:16	1:24
Area	$A_r = L_r^2$	1:256	1:576

(Continued)

* Dimensions are in terms of length.

Characteristic	Dimension	Scale Relation Model:Prototype	
Velocity	$V_r = L_r^{1/2}$	1:4	1:4.899
Discharge	$Q_r = L_r^{5/2}$	1:1,024	1:2,822
Volume	$V_r = L_r^3$	1:4,096	1:13,824
Weight	$W_r = L_r^3$	1:4,096	1:13,824
Time	$T_r = L_r^{1/2}$	1:4	1:4.899

Model measurements of discharge, water-surface elevations, and velocities can be transferred quantitatively to prototype equivalents by means of the scale relations. Experimental data indicate that the model-to-prototype scale ratio is also valid for scaling stone in the sizes used in this investigation. Evidences of sand scour are considered only qualitatively reliable, since it is not yet possible to reproduce quantitatively in the model the resistance to erosion of fine-grained prototype bed material.

PART III: TESTS AND RESULTS

Structure No. 5

11. Structure No. 5 (Plate 1) was designed to pass 2,335 cfs with the upstream and downstream flow depths being equal to 8.5 ft. Baseline flow conditions were determined for the design condition with the center-line water-surface profile shown in Plate 3. As shown by the water-surface elevations, the flow line dropped through the converging approach as the flow accelerated. Backwater effects from the tailwater were evident in the downstream one-third of the prismatic section. Flow through the prismatic section separated from the side slopes at the upstream end of the exit transition for all flows. The flow separation caused eddies to form on both sides of the exit transition and downstream channel, concentrating the flow to the center of the channel as shown in Photos 1 and 2. Velocity cross sections at several locations upstream of, within, and downstream of the structure are shown in Plate 4. The backwater effect of the tailwater at the downstream end of the prismatic section (sta 684+56) can be seen in Plate 4 in the decreased velocities at sta 684+56 compared to velocities at sta 686+10, which is at the midpoint of the prismatic section. Flow separation is evident in Plate 4 at the downstream end of the structure (sta 683+12) and downstream from the structure (sta 682+00). The upstream flow depth was found to be 8.2 ft rather than 8.5 ft with the design flow. Thus, all subsequent tests with this discharge were conducted with the downstream depth set at 8.2 ft since the channel geometry and slope were identical. Tests with other discharges were also conducted with the upstream and downstream depths equal. Scour tests were conducted using a synthetic hydrograph, shown in Figure 3, since a design hydrograph was not available from the prototype. Significant scour of the channel invert occurred during tests with the hydrograph as the result of the flow concentration (Photo 3).

12. In the type 2 design exit transition, a hump in the invert of the exit transition was tested to determine if this design would force the concentrated flow to spread over the width of the channel. To affect the concentrated flow, the hump had to break the water surface; otherwise the flow remained concentrated downstream of the structure. When the hump did break the water surface, the concentrated flow was split into two jets (Photo 4)

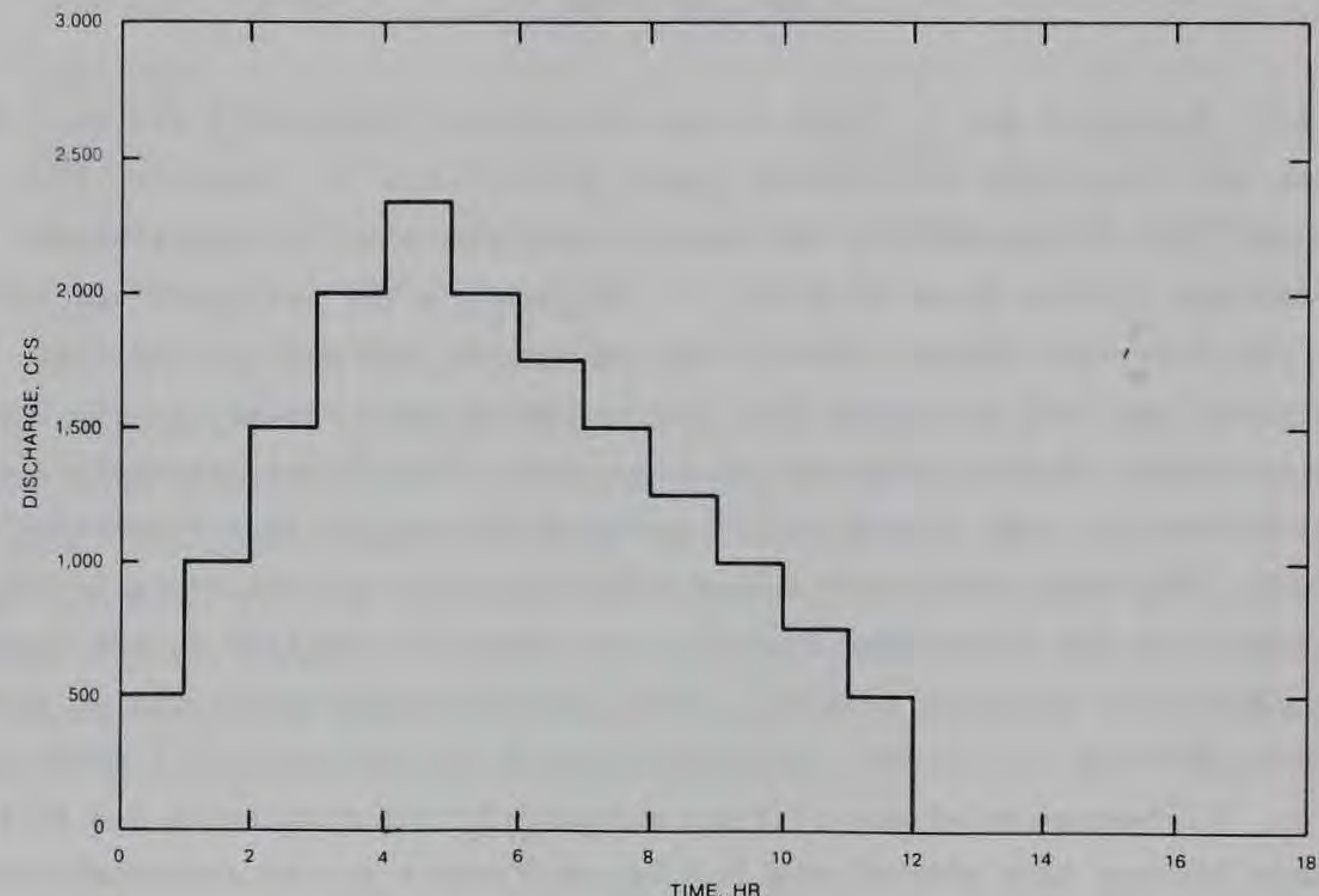

Figure 3. Synthetic hydrograph for scour comparison, Muddy Creek

which scoured the channel invert on both sides of the downstream channel as shown in Photo 5. This design was deemed unsatisfactory.

13. The type 3 design exit transition involved installing baffles in the exit transition by driving H-piles in the invert. For each exit flare design, the same baffle design was used throughout the exit transition. Nominal 14-in. H-piles were arranged in various locations extending the full depth of design flow (8.2 ft) above the channel invert. Test results indicated that the maximum effectiveness of the baffles was achieved when the downstream baffles intercepted the interference wake of the upstream baffles. These wakes are similar to the bow wakes of ships. Theoretical work by Kostyukov (1959)* indicates that for the flow conditions in the exit transition, the wake angle was approximately 19 deg 28 min. Adjustments in the

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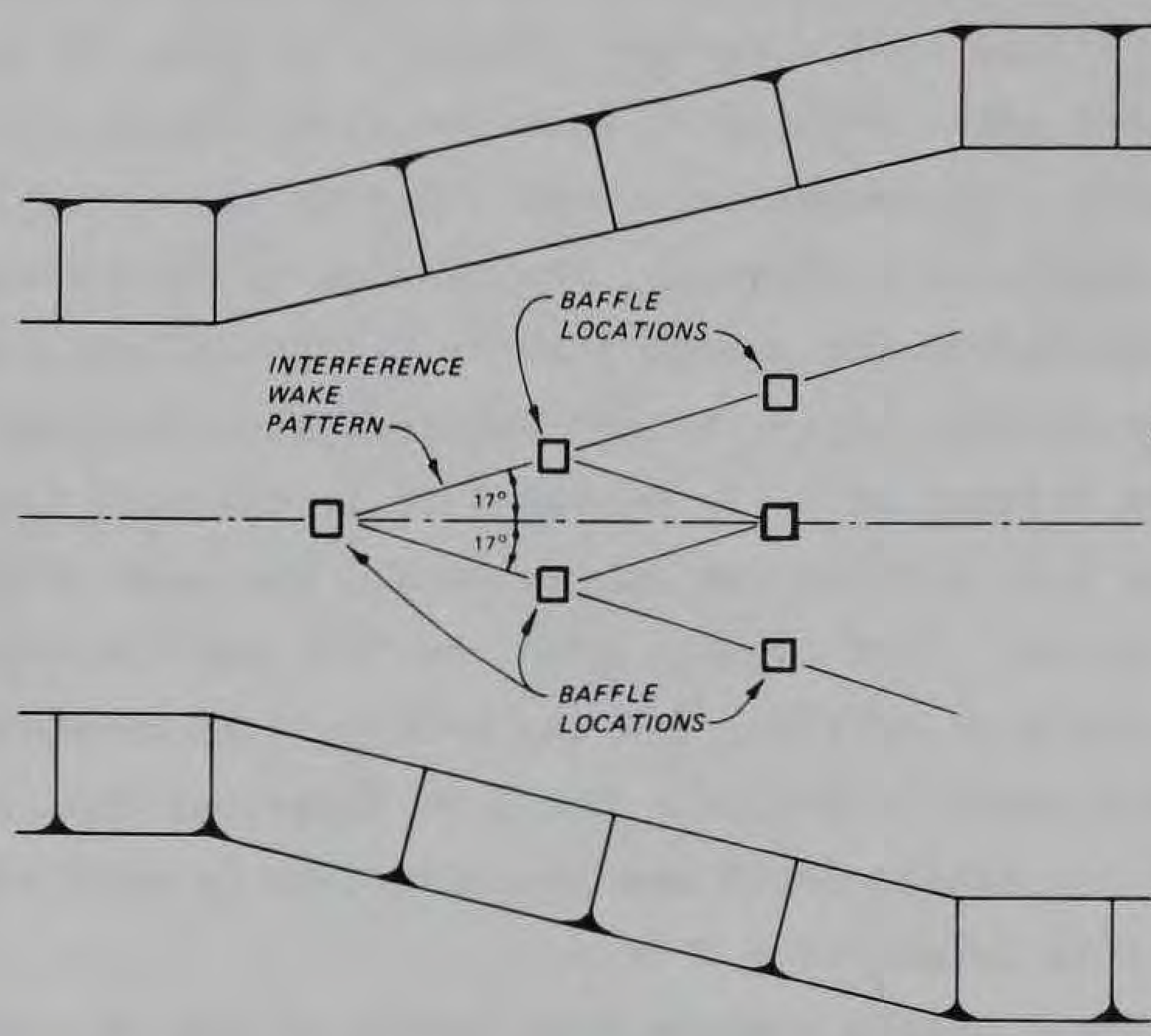
* A. A. Kostyukov. 1959. Theory of Ship Waves and Wave Resistance, State Union Publishing House for the Shipbuilding Industry, Leningrad; Translated by Max Oppengheimer, Jr., Chairman, Department of Modern Languages, State University College, Fredonia, NY, published by E.C.I., Iowa City, IA.

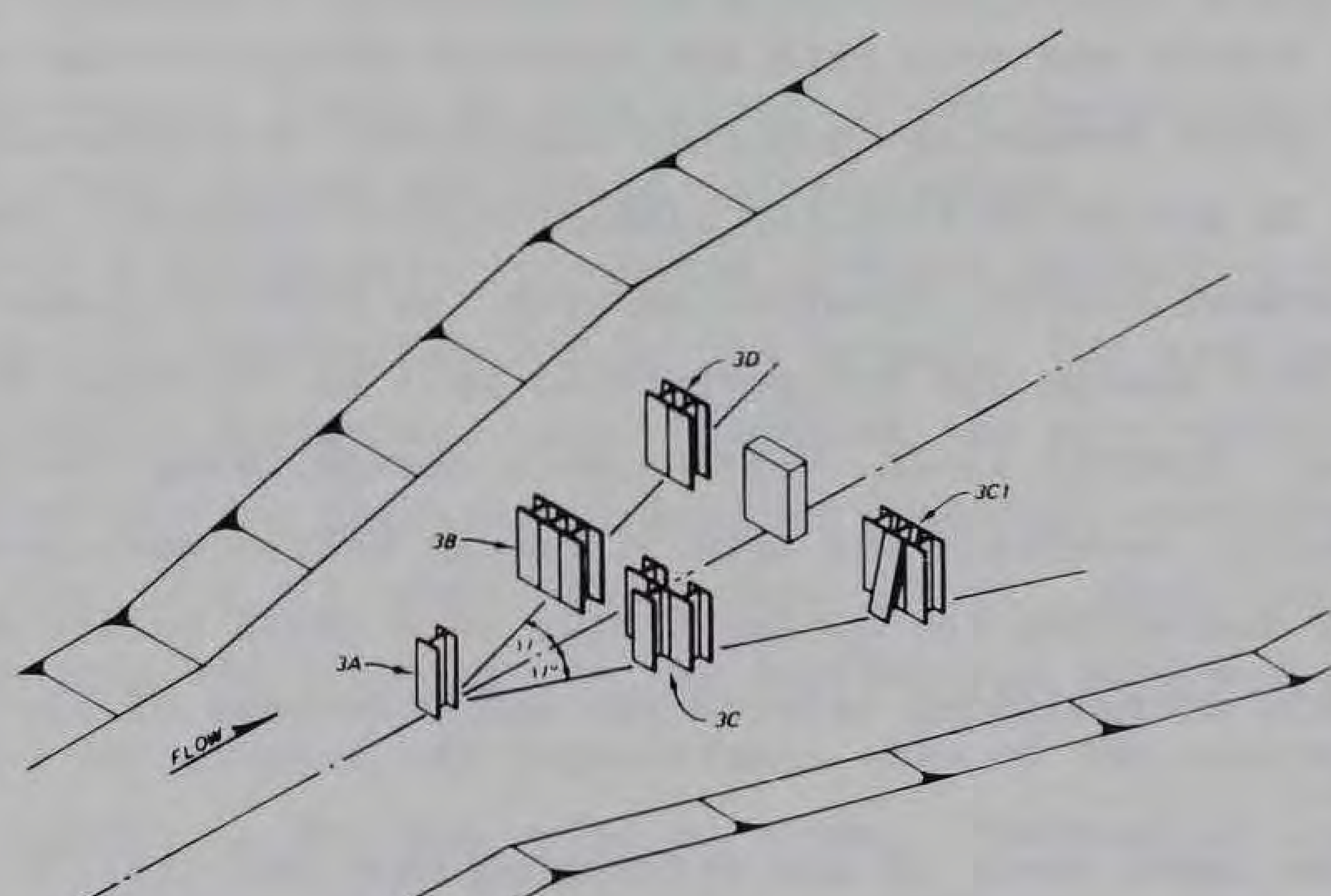
model showed that the downstream baffles should be located at 17-deg angles to provide maximum interference (Figure 4a). Single H-piles were tested as the type 3A design exit with minimal effect on the downstream scour. Figure 4b illustrates the various baffle designs tested. The type 3B design exit transition incorporated three H-piles at each location (Figure 4b), resulting in a substantial reduction in downstream scour. Due to the minimal amount of scour produced by the synthetic hydrograph, the testing procedure was changed to subjecting each design to the design flow of 2,335 cfs for a 24-hr period (prototype). The optimum baffle height was determined by testing the type 3B design baffles at heights of 4, 5, 6, and 8 ft in the exit transition. Scour produced with the 6-ft baffles was approximately the same as that produced with the 8-ft baffles. Test results with the 5-ft baffles were significantly worse than with the 6-ft baffles, and the 4-ft baffles provided the least improvement over the as-built design. Based on these results, a baffle height of 75 percent of the design depth was determined to be most effective. This resulted in a baffle height of 6.2 ft.

14. Additional baffle designs were tested to try to reduce the potential for the baffles to collect debris. In the type 3C design the outside H-piles in each baffle were offset downstream such that the downstream flange of the center H-pile was even with the upstream flange of the outside H-piles (Figure 4b). Scour resulting from this design was approximately the same as with the type 3B design baffles for similar baffle heights. The type 3D design incorporated baffles constructed with two H-piles placed adjacent to each other. This design did not perform as well as the type 3B or the type 3C design baffles. Nominal 12-in. H-piles were tested using the type 3C arrangement with inferior results. The type 3C design baffle was also modified (type 3C1 baffle) by installing the center H-pile on a 4V:1H batter as seen in Figure 4b. This streamlining reduced the effectiveness of the baffles significantly.

15. From these tests it was determined that the type 3C design exit with the 6.2-ft-tall baffles (Figure 5) was the most effective design in reducing scour downstream of structure No. 5. The semiwedge shape of the baffles should reduce the amount of debris that collects on the baffles. Some debris should pass over the baffles during high flow events. Center-line water-surface elevations are shown in Plate 5 with the design flow. Velocity cross sections are shown in Plate 6. Velocities upstream of sta 686+10 were



a. Baffle locations for maximum interference



b. Baffle designs

Figure 4. Type 3 series exit transition

the same as those measured with the original design. Surface currents are shown in Photos 6 and 7. Photo 8 shows the scour resulting from the synthetic hydrograph, which can be compared to Photo 3, which shows the scour from the original design.

16. Due to the dimensional similarity of structures No. 5 through 12 (Table 1), the arrangement developed as type 3C was dimensionalized based on the length of the exit transition. This design, shown in Plate 7, should provide acceptable flow conditions downstream of structures No. 5 through 12.

Figure 5. Type 3C baffle

Structure No. 2

17. Flow conditions at structure No. 2 (Plate 2) were similar to those observed at structure No. 5. Flow separation occurred at the upstream end of the exit transition, forming eddies on both sides of the outlet channel which concentrated the flow to the center of the channel. Stage-discharge relations indicated that the design flow resulted in an approach depth of 7.6 ft instead of the 8.5 ft used for the design. Consequently, the design tailwater depth that was used for the model tests was 7.6 ft. The water-surface profile for the as-built condition is shown in Plate 8, and the velocity cross sections at the indicated stations are shown in Plate 9. Concentration of the flow to the center of the exit channel is clearly shown at sta 425+00 and 424+00.

18. The baffle pattern developed for the 1:8 exit flare for grade control structures No. 5 through 12 was tested in structure No. 2 with the 1:4 exit flare. Each row of baffles had one additional baffle added to each end because of the wider flare. This was designated the type 4 design exit

transition (Plate 10). Test results indicated that a small portion of the flow concentrated at each side of the exit flare between the side slopes and the baffles, causing excessive scour on the sides of the channel downstream of the riprap structure.

19. Two additional baffles were added in a fourth row (type 5 design exit transition, Plate 10) in an attempt to reduce the velocities along the sides of the channel. Little improvement was achieved with this modification. The end baffles on the fourth row were moved 3.5 ft toward the side slopes (type 6 design exit transition, Plate 10) in another effort to reduce the velocities along the sides of the channel. Again, little improvement was obtained. The same end baffles on the fourth row were moved an additional 3.5 ft towards the side slopes (type 7 design exit transition, Plate 10). This design was successful in reducing flow concentrations along the sides of the exit transition, but this baffle arrangement (Figure 6) created a significant backwater effect in the prismatic section of the grade control structure. The baffle arrangement was modified (type 8 design exit transition, Figure 7 and Plate 10) by removing the third row of baffles and repositioning the fourth row next to the second row of baffles. This modification was made to reduce the backwater effect observed in the type 7 design exit transition while maintaining satisfactory velocities along the side slopes of the exit transition. Satisfactory flow conditions were observed throughout the grade control structure for the various test flows. Scour resulting from a 24-hr prototype test with the design flow (Photo 9) indicated that a pronounced scour pattern developed just downstream of the riprap. This was due to the relatively short distance between the downstream baffles and the end of the riprap.

20. Additional designs were tested based on two baffles in the upstream row, three in the second row, four in the third row, and flanking baffles as in the third row of the type 8 design exit transition. The type 3C baffles were used for all of these tests. This concept was not successful in reducing flow concentrations in the center of the channel. Therefore, the type 8 design exit transition was reinstalled in the model and an additional 30 ft of riprap of 2-in. average size was placed at the downstream end of the grade control structure to protect the channel invert. Scour tests indicated that the additional riprap provided adequate protection at the end of the grade control structure (Photo 10). Velocity cross sections, shown in Plate 11,

Figure 6. Type 7 exit transition

Figure 7. Type 8 exit transition

indicated improved velocity distribution at the downstream end of the structure compared to the original design. The center-line water-surface profile with the design flow is provided in Plate 12. Surface currents are shown in Photos 11 and 12.

21. The dimensionalized type 8 design is shown in Plate 13 as the recommended design for structures No. 1 through 4.

Exit Flare Modifications

22. Additional tests were conducted to determine the maximum flare in the exit transition where uniform flow distribution would be present without the use of baffles. Structure No. 2 was used as the base structure upstream of the exit transition. Initially, tests were conducted with a 1:10 exit flare. Test results indicated that the 1:10 exit flare was too abrupt an expansion due to flow separation at the upstream end of the exit flare and resulting flow concentrations in the center of the channel.

23. Tests were conducted with the exit flare reduced to 1:12. Satisfactory flow conditions were observed as the flow tended to spread with the expanding exit transition. However, minor irregularities on the exit transition side slopes triggered flow separation near the side slopes. Flow conditions with discharges of 1,266 and 3,166 cfs are shown in Photos 13 and 14, respectively.

24. The exit flare was reduced to 1:16 in an effort to produce uniform flow distribution throughout the exit transition and a design less sensitive to minor irregularities on the exit transition side slopes. Improved flow conditions were observed in the 1:16 exit transition. Flow conditions with discharges of 1,266 and 3,166 cfs are shown in Photos 15 and 16, respectively. A comparison of velocities recorded at the downstream end of the exit transition with the 1:12 and 1:16 exit flares (Plate 14) indicated a slightly better distribution of flow with the 1:16 exit flare. A center-line water-surface profile with the design discharge for structure No. 2 with the 1:16 exit flare is shown in Plate 15.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

25. Flow separation with resultant flow concentration in the exit transitions was determined to be the reason for scour downstream of the grade control structures on Muddy Creek. The flow separation was the result of the exit flaring too abruptly for the flow to follow the side slopes. Eddies formed on both sides of the exit channel, forcing additional flow concentration in the center of the exit channel with resulting higher velocities along the bottom of the channel. Tests were conducted to determine what modifications were required to these existing grade control structures with 1:4 and 1:8 exit flares to reduce or eliminate significant scour problems previously observed at these structures. Since the exit flares were fixed, different types of modifications involving baffle piers or a hump placed in the exit transition were tested in an attempt to produce a uniform distribution of flow at the end of the grade control structure.

26. Test results indicated that a baffle arrangement with the height of the baffle piers being 75 percent of the design depth was the most effective design in producing a uniform distribution of flow in the exit channel without any significant backwater effect in the grade control structure. Recommended baffle arrangements are shown in Plates 7 and 13 for the 1:8 and 1:4 exit flares, respectively. The use of a hump in this situation was ineffective in disturbing the central flow concentration unless the hump reached the water surface. When the hump did reach the water surface, two jets were formed which produced more scour than the original design.

27. For this type of grade control structure without the use of baffles, test results indicated that flow separation occurred at the upstream end of the exit transition if the exit flare was greater than a 1:12 ratio. Minor irregularities (differential settlement or vegetation) on the side slopes of a 1:12 flare caused flow separation and flow concentration, indicating that this was approximately the critical flare ratio below which incipient flow separation occurred. Additional tests indicated that the 1:16 exit flare was the maximum exit flare that provided satisfactory flow conditions without making the flow sensitive to minor irregularities on the side slopes, and therefore was the recommended design.

28. The addition of a 1:16 exit transition flare resulted in a fairly long structure when the structure design was based on the equal energy

concept. It is possible that by using steeper slopes, a shorter (less expensive) structure could be designed that would also result in uniform outlet flow conditions. Additional research would be required to develop design parameters for such a structure.

Table 1

Details and Data for Rock-Lined Sections

Structure No.	Design Discharge cfs	Prismatic Section Slope	Length of Upstream Transition ft	Prismatic Section ft Width	Prismatic Section ft Length	Drop ft	Length of Downstream Transition ft	Channel Width Exit and Inlet ft	Rock Riprap tons
1	4,600	0.0053	45	35	690	3.7	90	80	10,000
2	3,166	0.0063	51	29	586	3.7	102	80	8,000
3	3,166	0.0063	51	29	586	3.7	102	80	8,000
4	3,166	0.0063	51	29	746	4.7	102	80	10,250
5	2,335	0.0063	36	18	308	2.0	144	54	5,400
6	2,335	0.0063	36	18	308	2.0	144	54	5,600
7	2,275	0.0064	35	17	309	2.0	140	52	5,400
8	2,103	0.0064	36	14	306	2.0	144	50	5,100
9	2,103	0.0064	35	15	261	1.7	140	50	4,600
10	1,850	0.0067	33	13	329	2.2	132	46	5,000
11	1,850	0.0068	32	14	286	1.9	128	46	4,700
12	1,850	0.0068	32	14	273	1.9	128	46	4,600

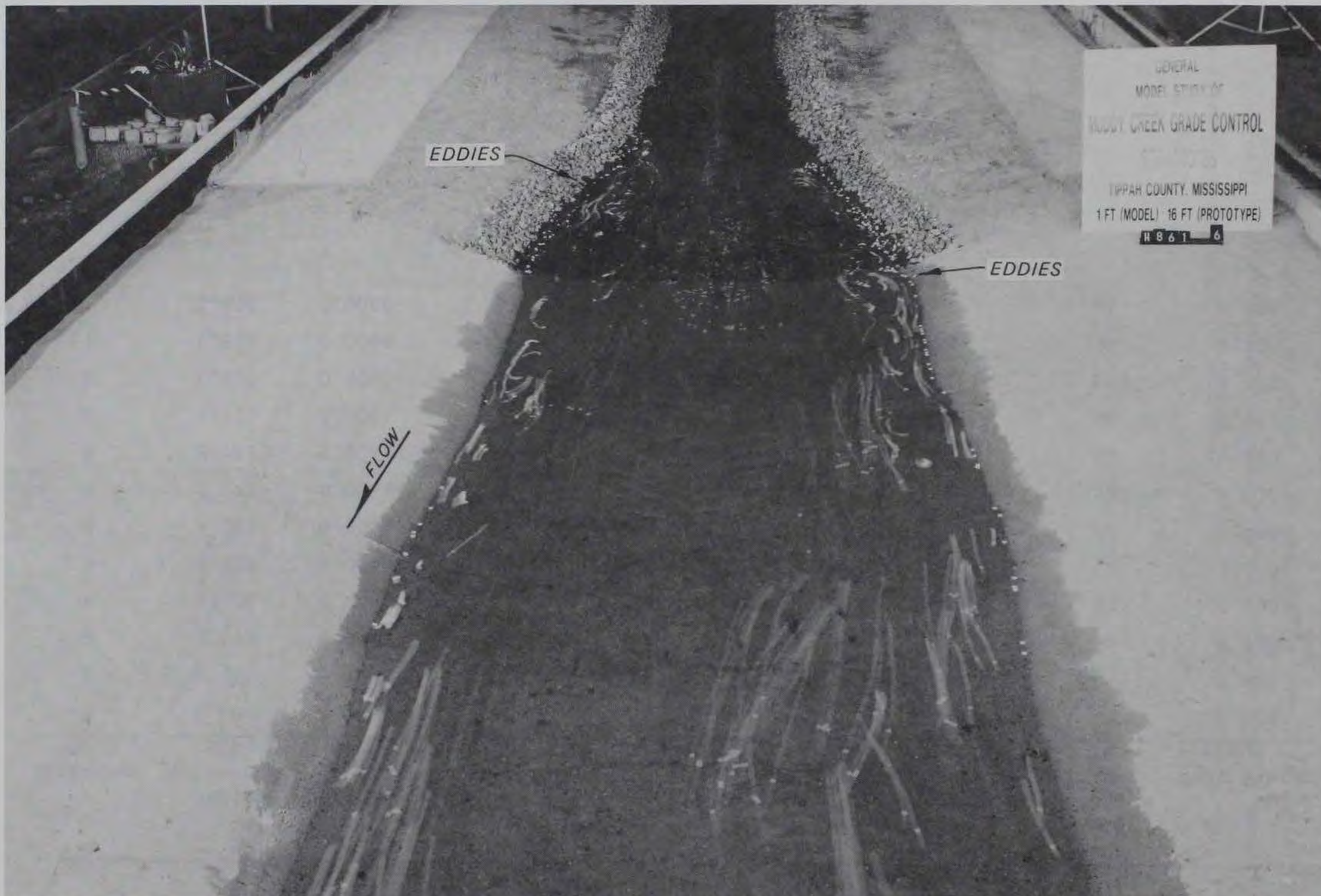


Photo 1. Grade control structure No. 5 at 1,000-cfs flow, original design

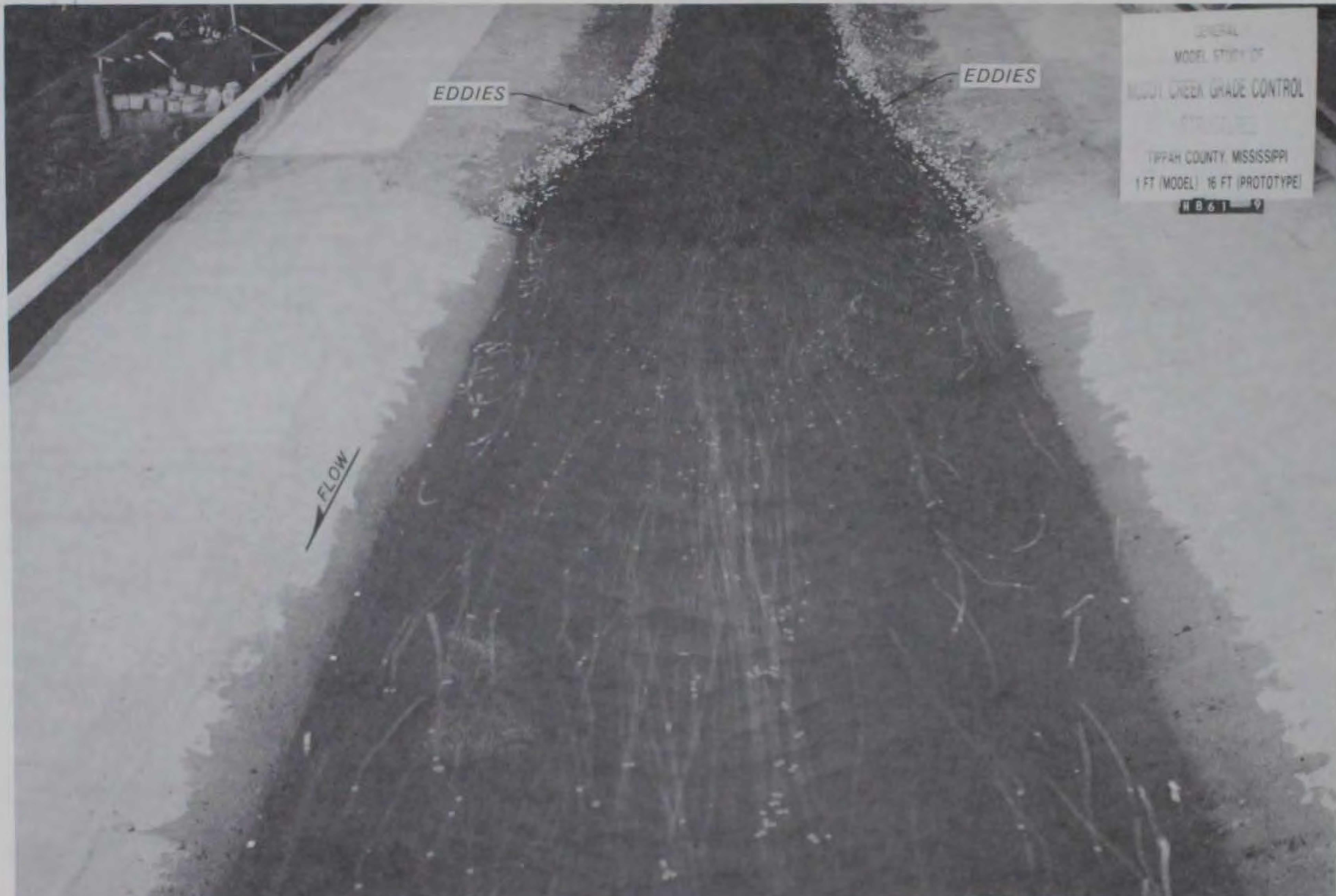


Photo 2. Grade control structure No. 5 at design flow (2,335 cfs), original design

Photo 3. Scour resulting from the synthetic hydrograph, original design

Photo 4. Type 2 exit transition at 2,000-cfs flow

Photo 5. Scour resulting from the synthetic hydrograph, type 2 exit transition design

Photo 6. Type 3C exit transition (6.2-ft tall baffles) at 1,000-cfs flow

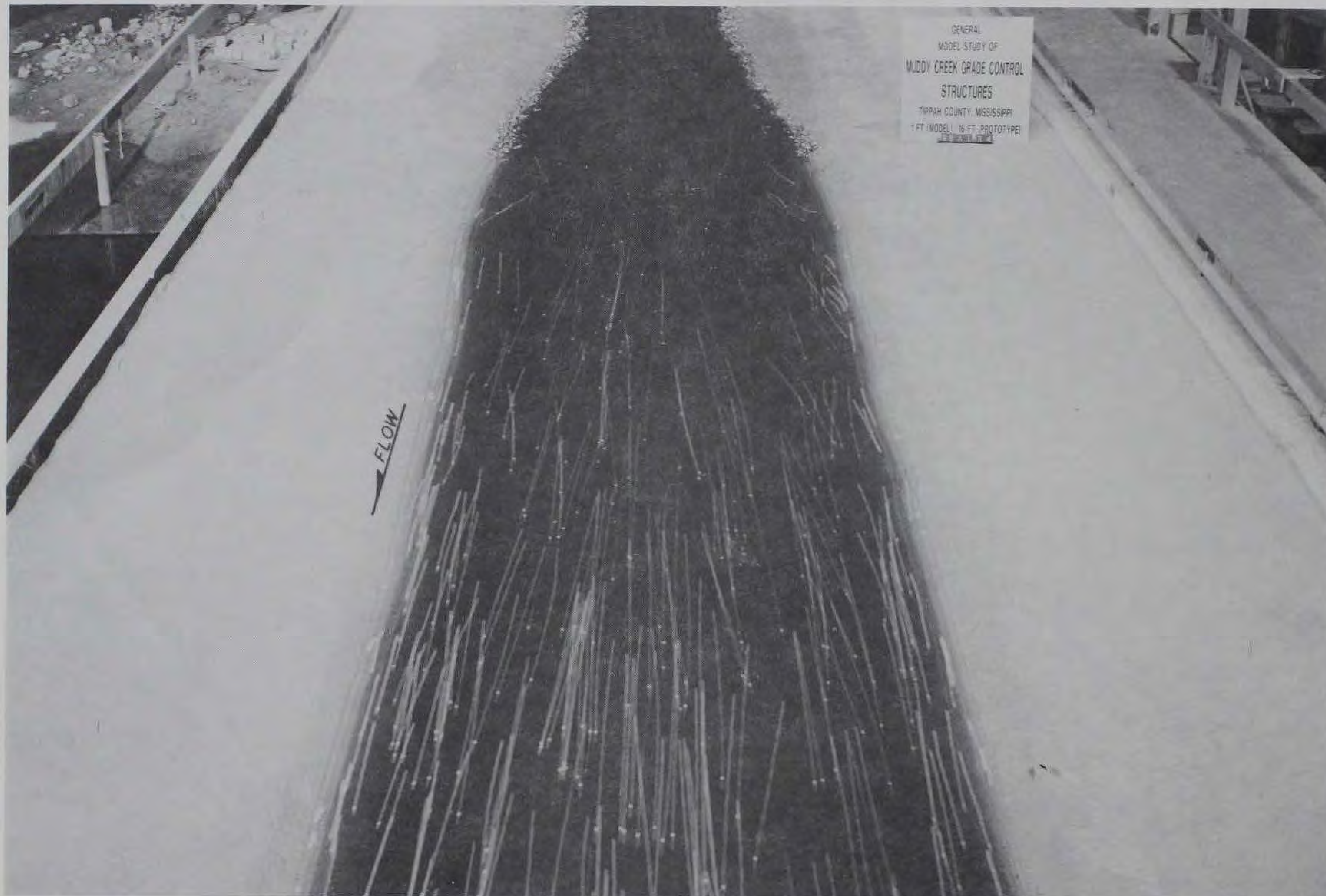


Photo 7. Type 3C exit transition (6.2-ft-tall baffles) at design flow (2,335 cfs)

Photo 8. Scour resulting from the synthetic hydrograph, type 3C exit transition (6.2-ft-tall baffles)

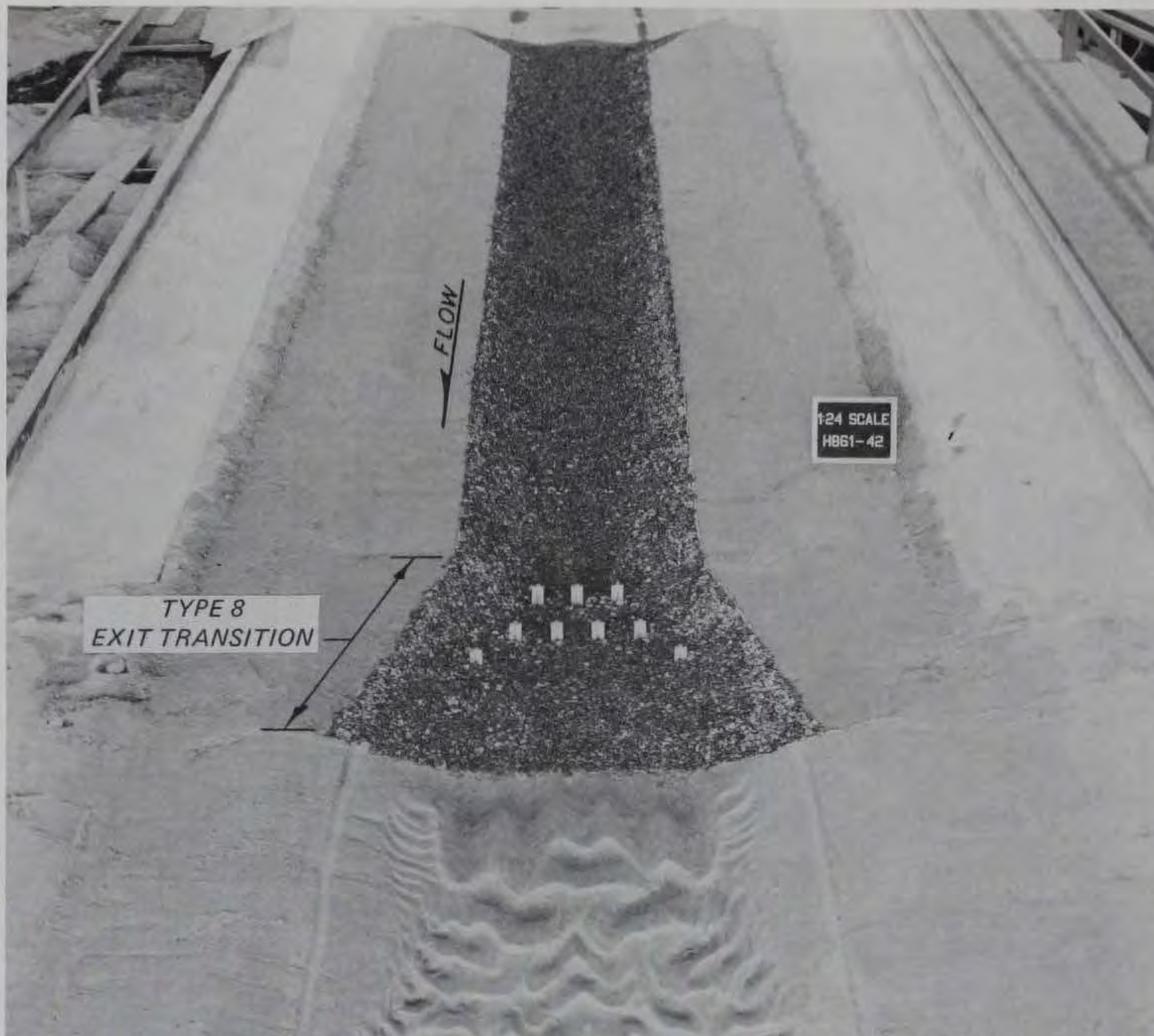


Photo 9. Scour resulting from the design flow (3,166 cfs) type 8 exit transition, 24-hr prototype time

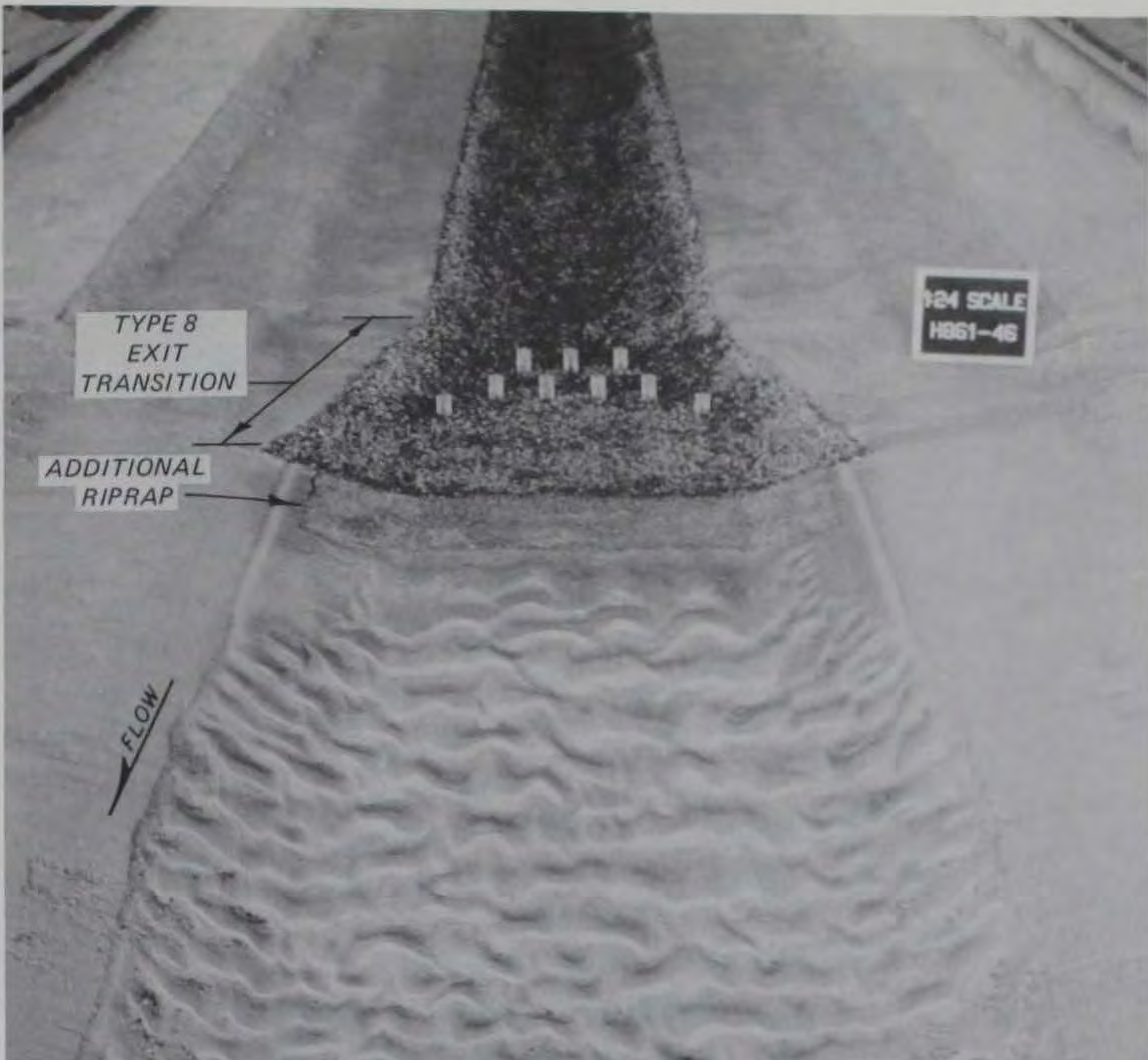


Photo 10. Scour resulting from the design flow (3,166 cfs), type 8 exit transition with additional riprap in the exit channel, 24-hr prototype time

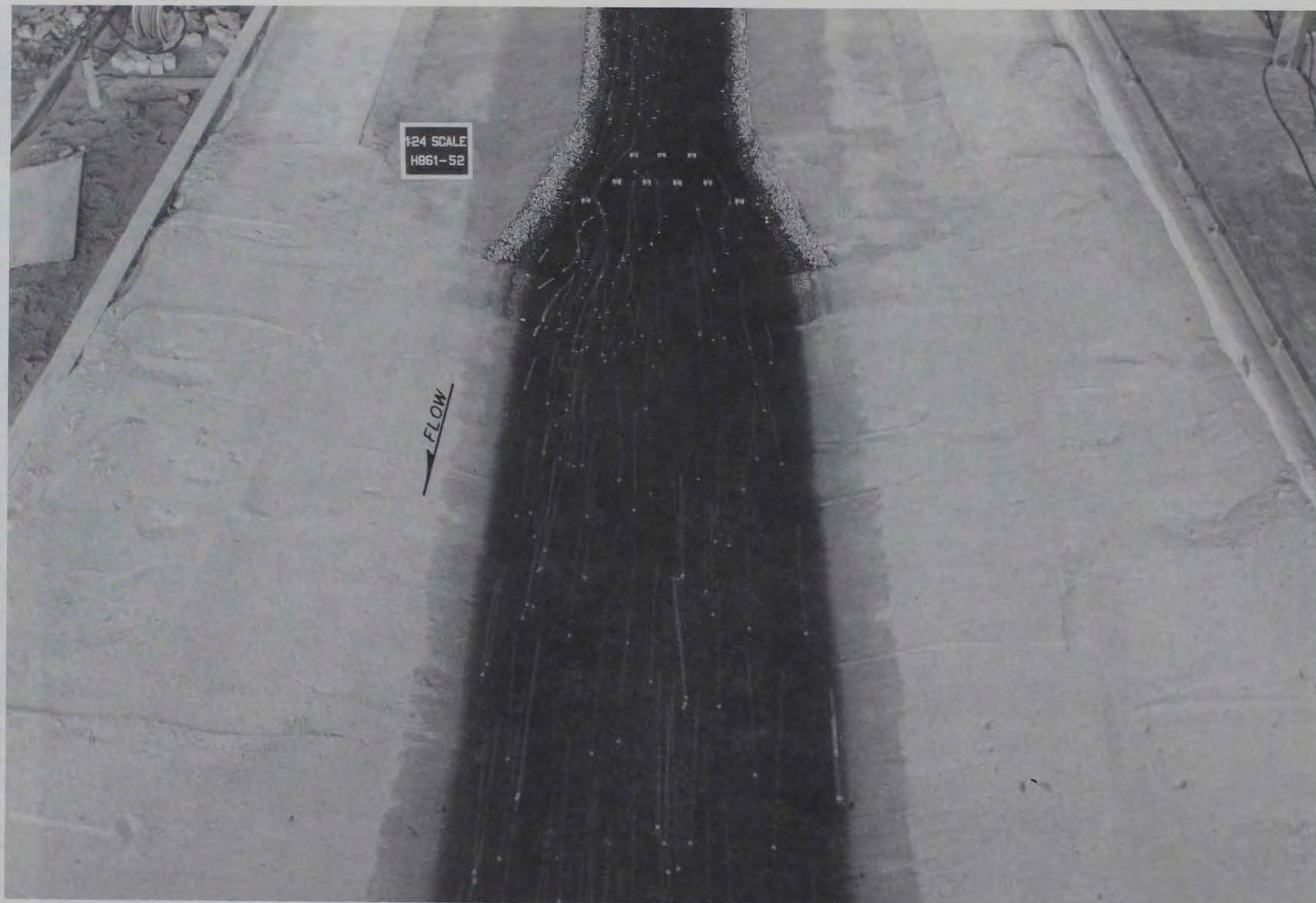


Photo 11. Type 8 exit transition with additional riprap at 1,266 cfs (0.4 design flow)

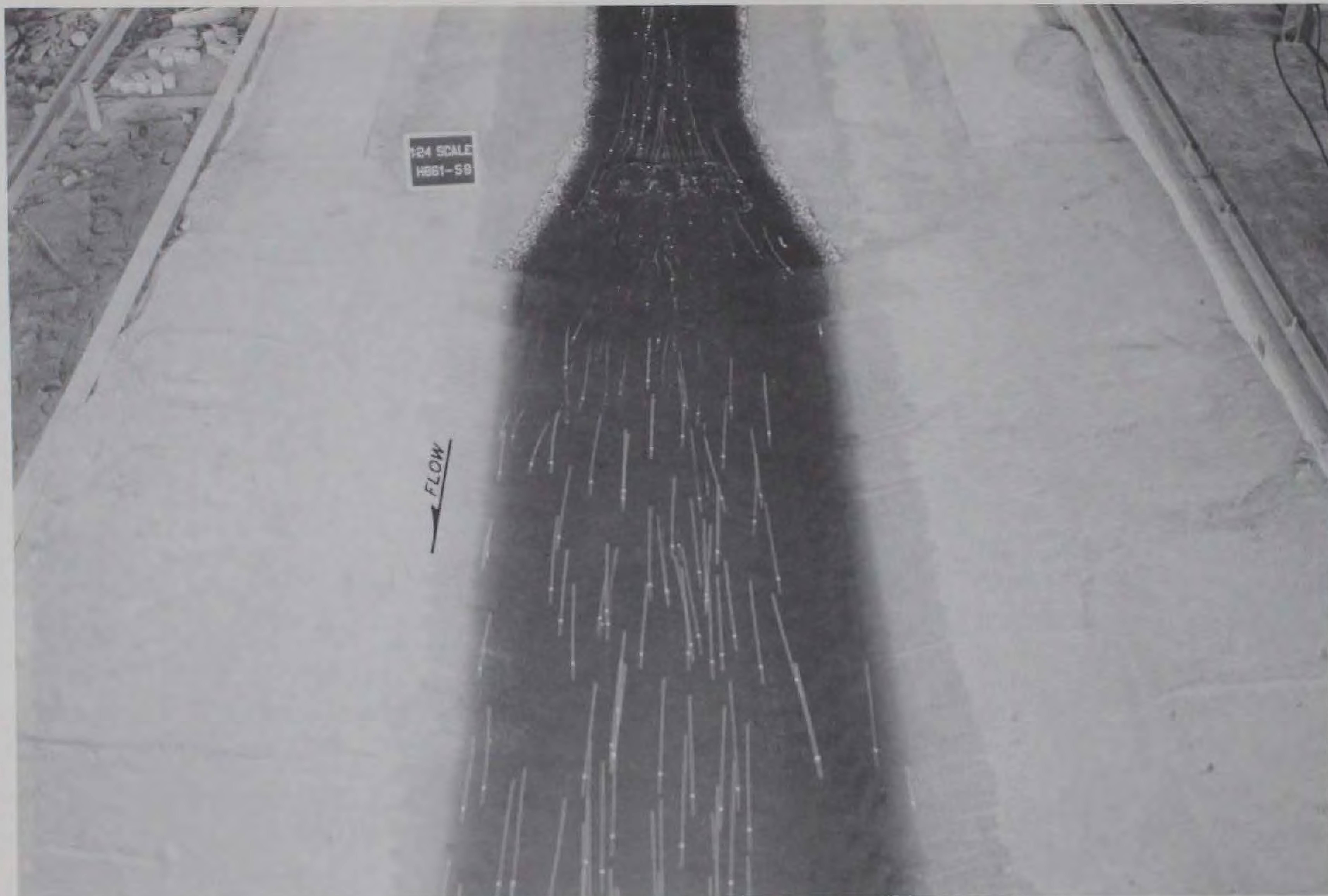


Photo 12. Type 8 exit transition with additional riprap at 3,166 cfs (design flow)

Photo 13. 1:12 flare exit transition at 0.4 design flow

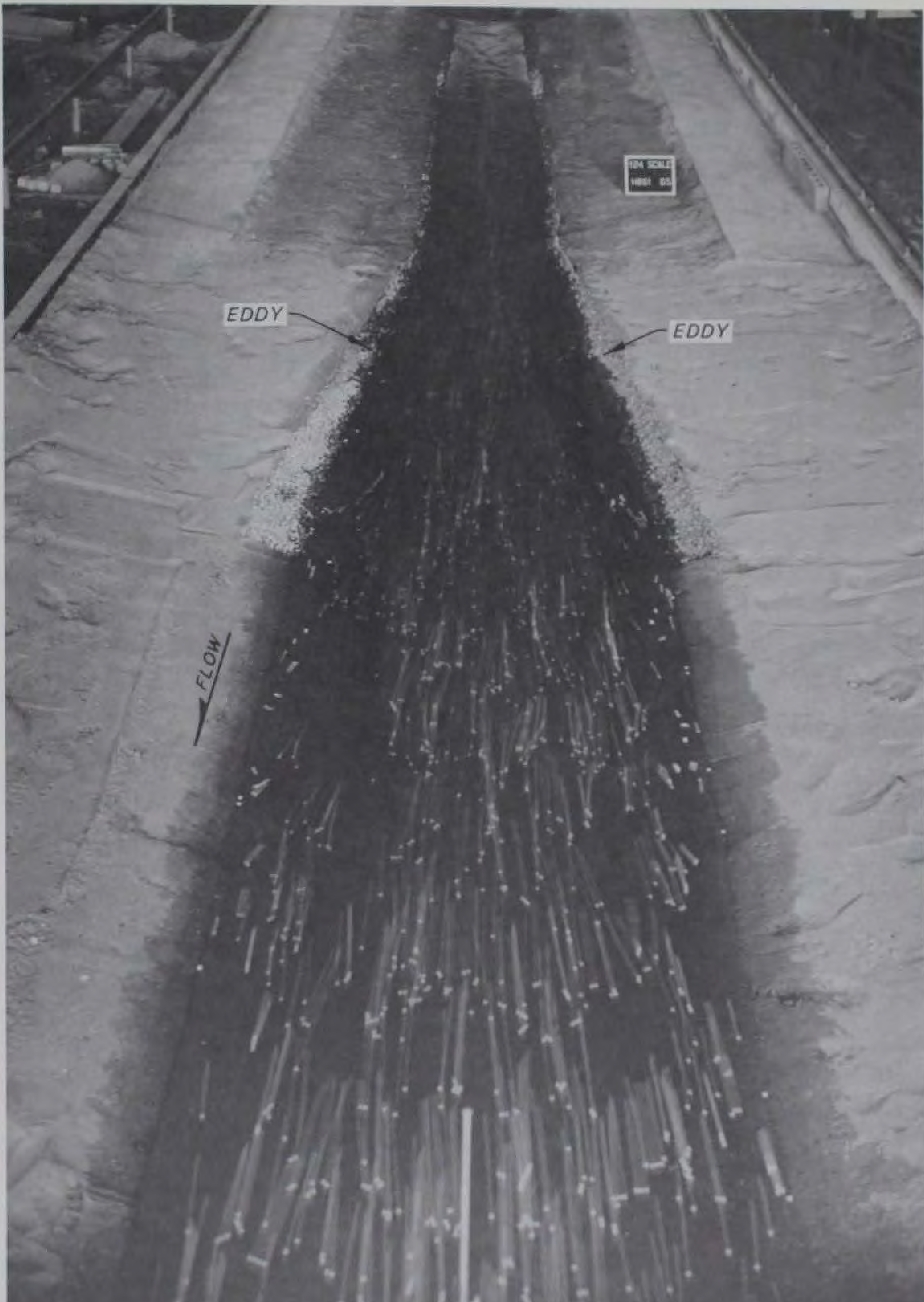


Photo 14. 1:12 flare exit transition at design flow

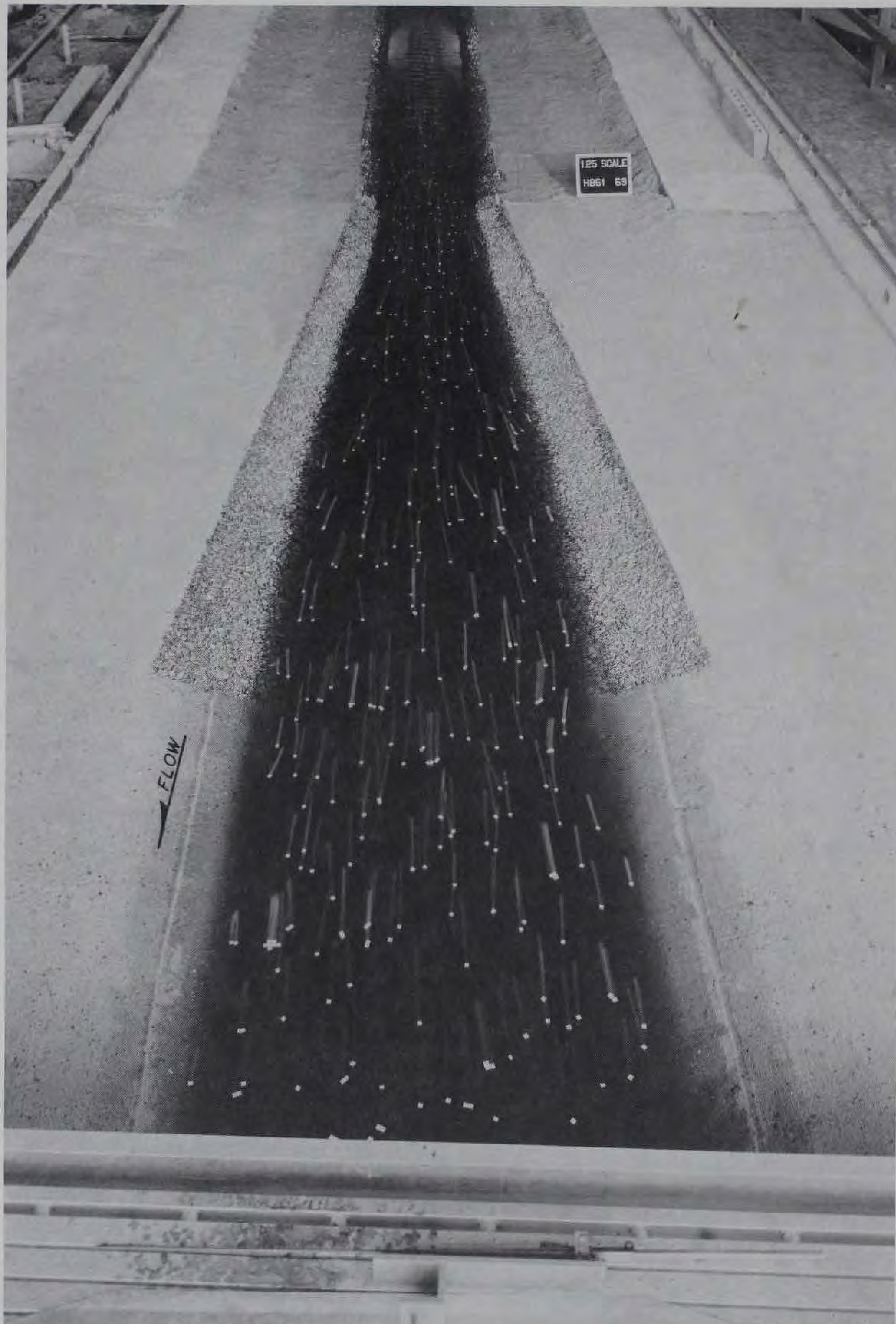


Photo 15. 1:16 flare exit transition at 0.4 design flow

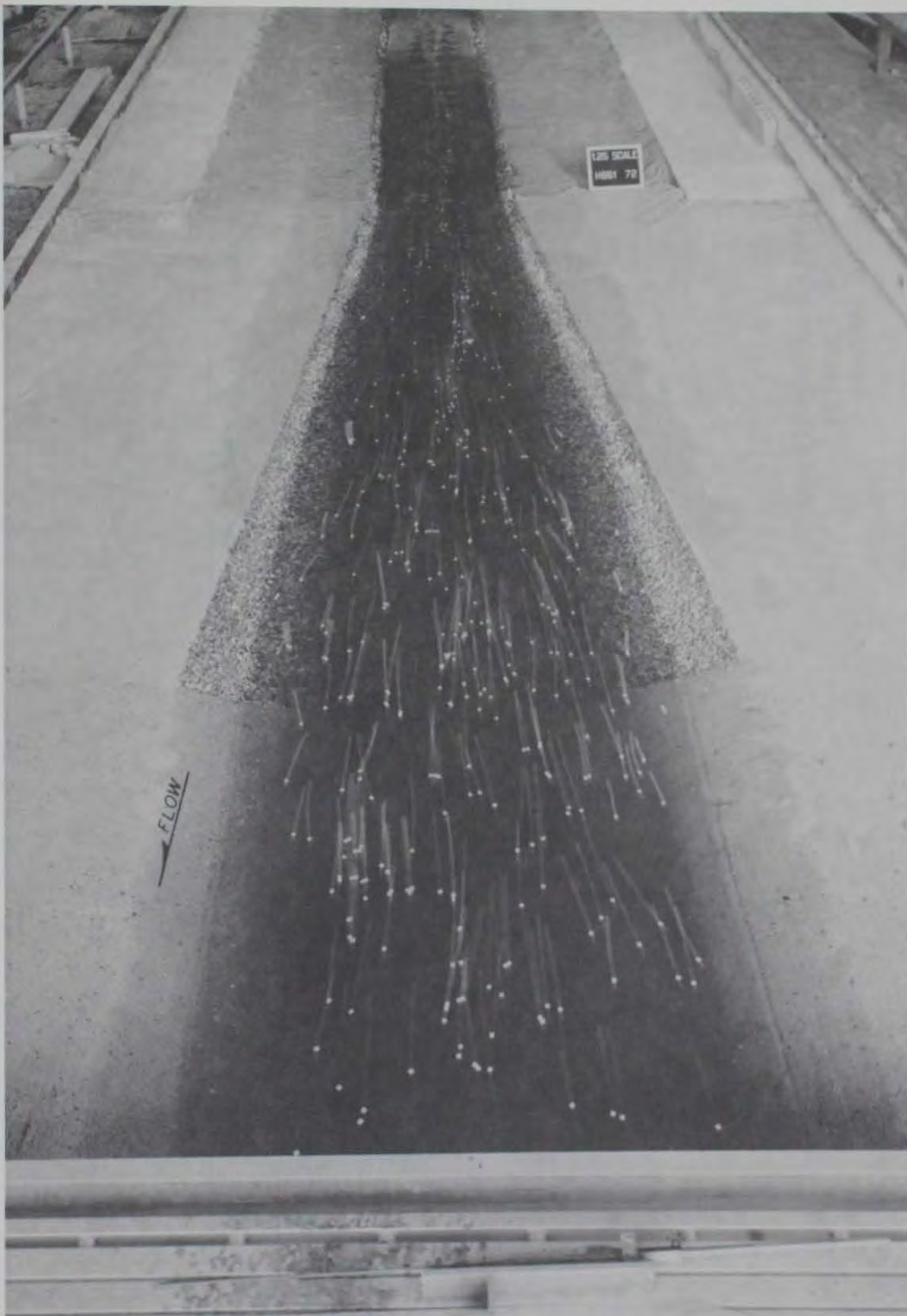


Photo 16. 1:16 flare exit transition at design flow

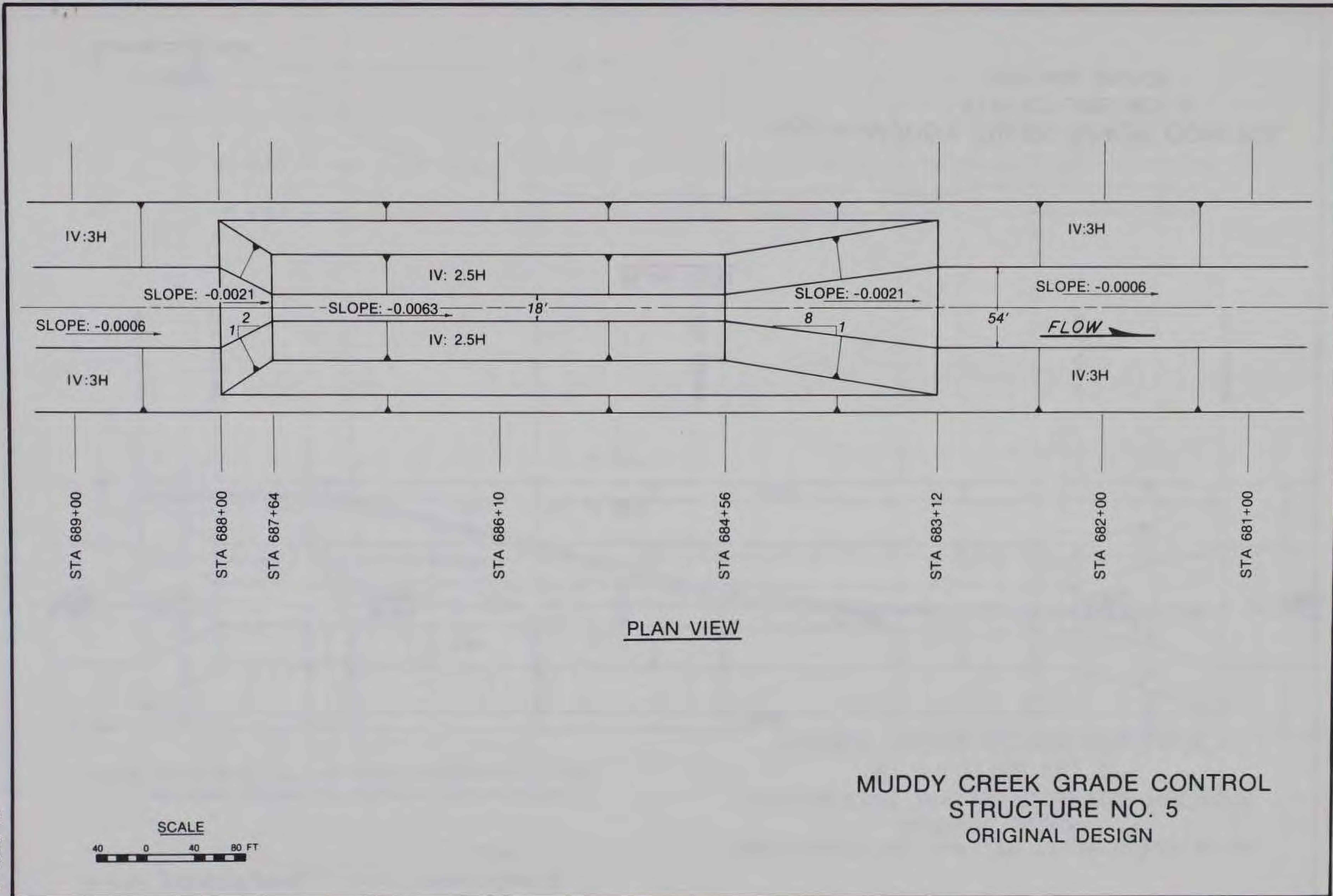
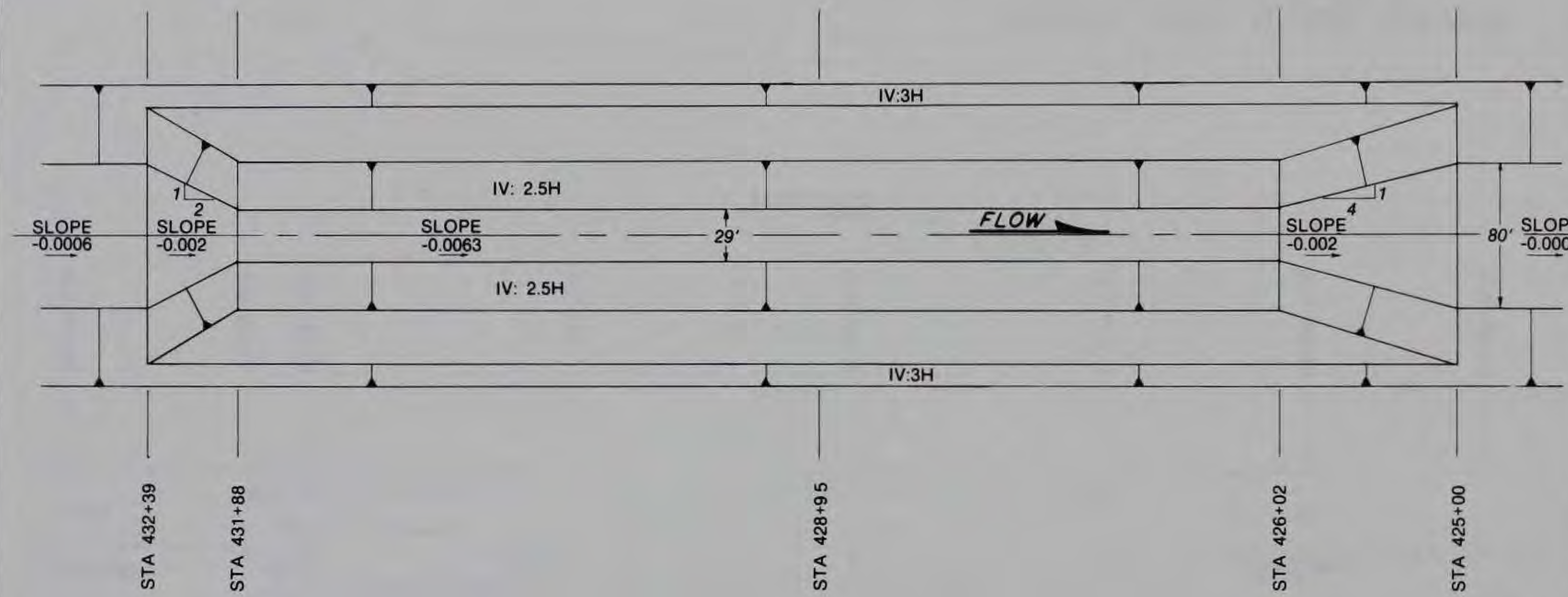

IV:3H
IV:3H
IV: 2.5H
IV: 2.5H
IV:3H
IV:3H
SLOPE: -0.0021
SLOPE: -0.0006
SLOPE: -0.0063
18'
SLOPE: -0.0021
SLOPE: -0.0006
54'
FLOW
2
1
8
1
STA 689+00
STA 688+00
STA 687+64
STA 686+10
STA 684+56
STA 683+12
STA 682+00
STA 681+00
PLAN VIEW
SCALE
40 0 40 80 FT
MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 5
ORIGINAL DESIGN

PLATE 1

PLATE 2

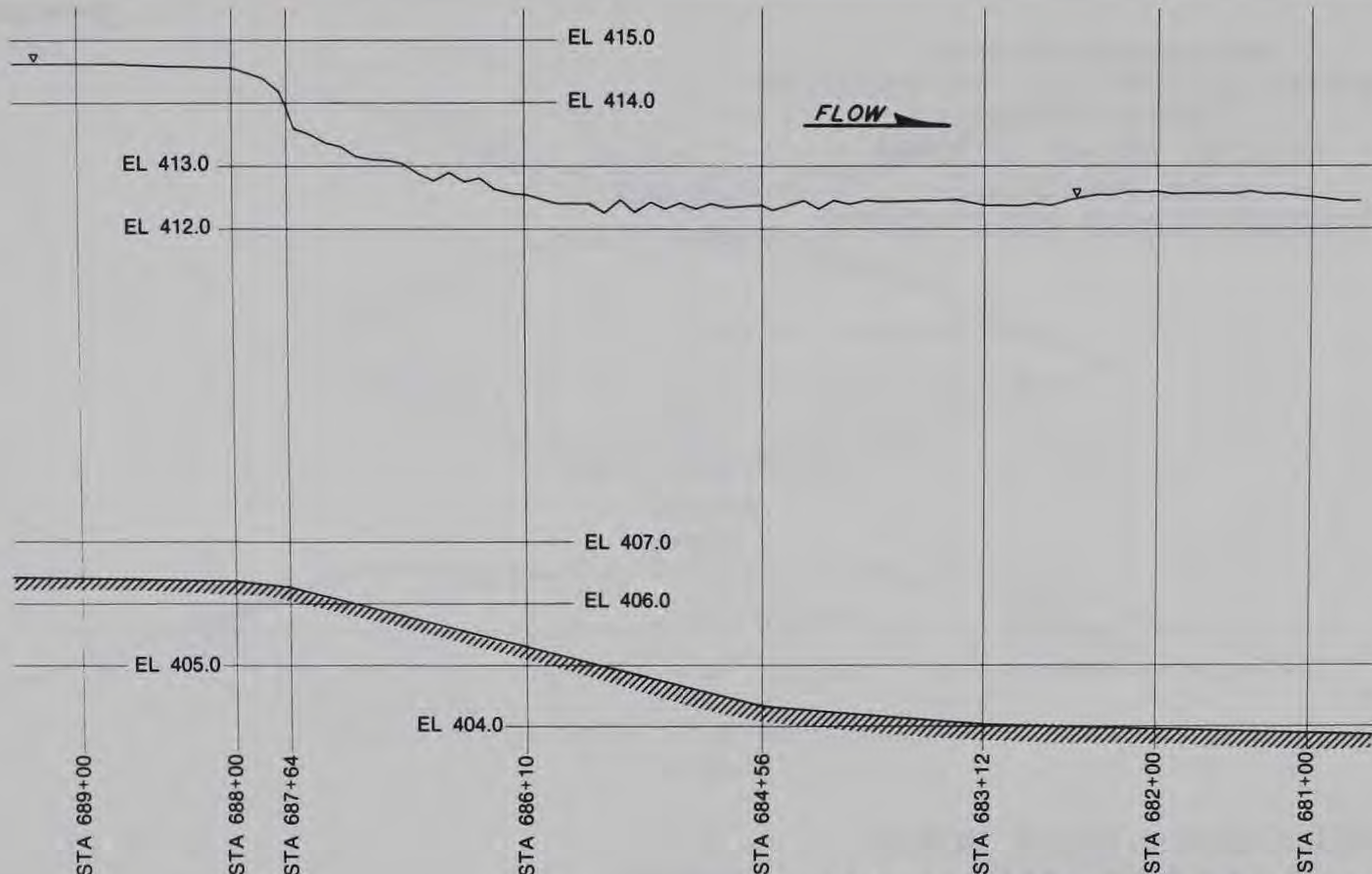


PLAN VIEW

SCALE

40 0 40 80 FT

MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 2
ORIGINAL DESIGN



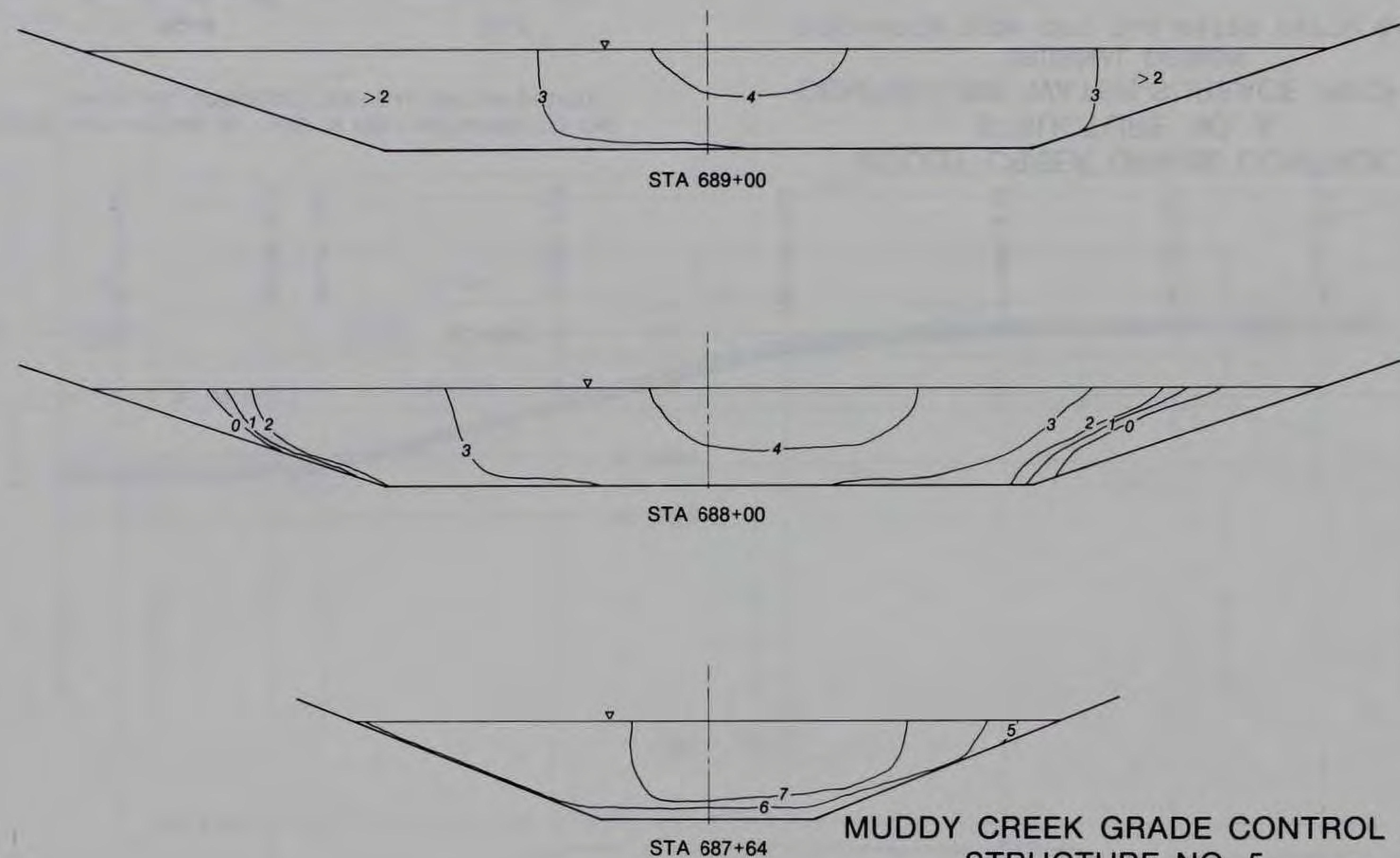
NOTE: ELEVATIONS (EL) ARE IN FEET REFERRED TO THE NATIONAL GEODETIC VERTICAL DATUM (NGVD).

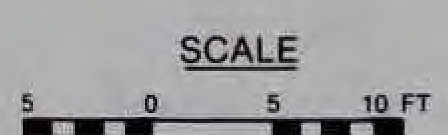
SCALE
HORIZONTAL 40 0 40 80 FT

SCALE
VERTICAL 1 0 1 2 FT

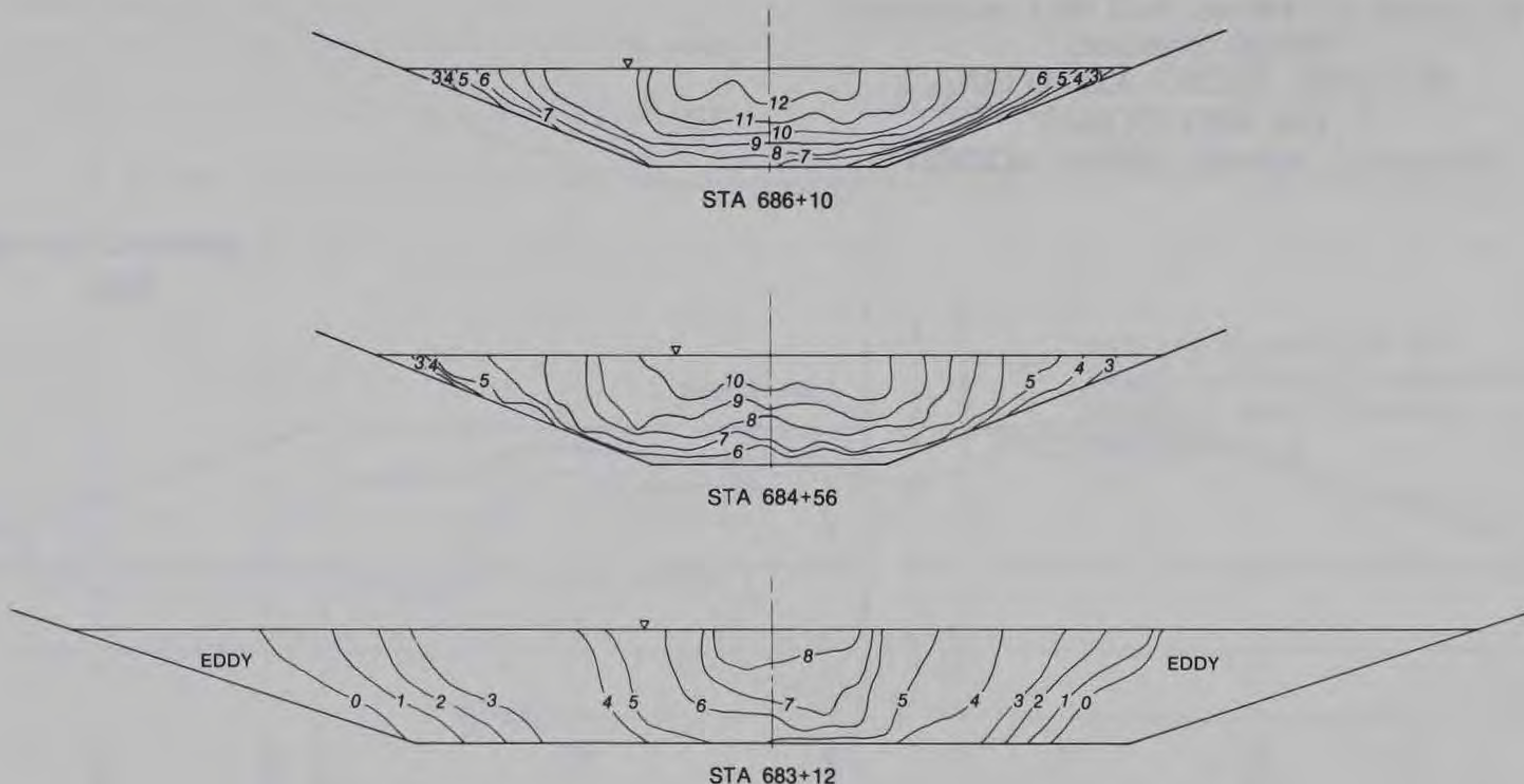
MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 5
CENTER-LINE WATER-SURFACE PROFILE
ORIGINAL DESIGN
DISCHARGE 2,335 CFS, TAILWATER DEPTH 8.5 FT

PLATE 4
(Sheet 1 of 3)





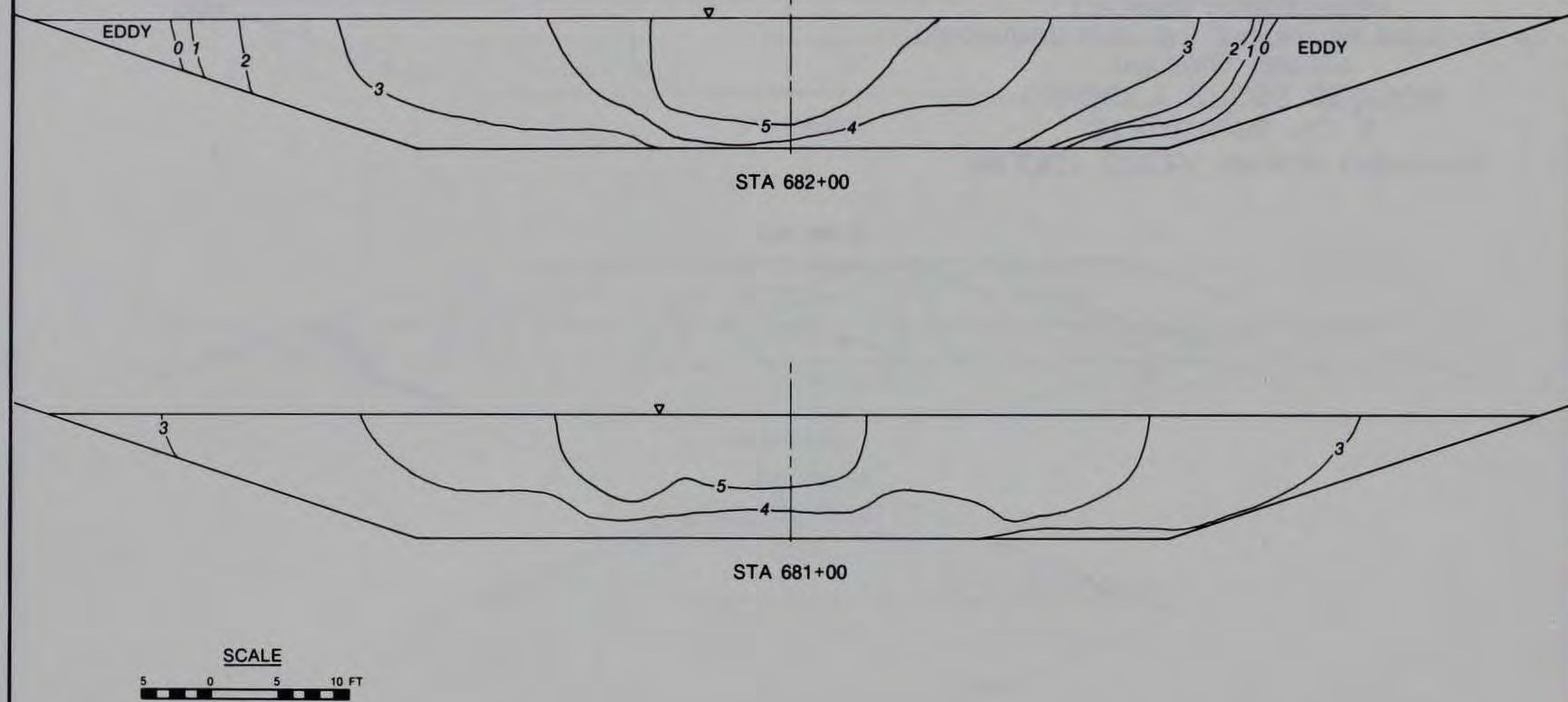
MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 5
VELOCITY CROSS SECTION
ORIGINAL DESIGN
DISCHARGE 2,335 CFS, TAILWATER DEPTH 8.5 FT
LOOKING DOWNSTREAM



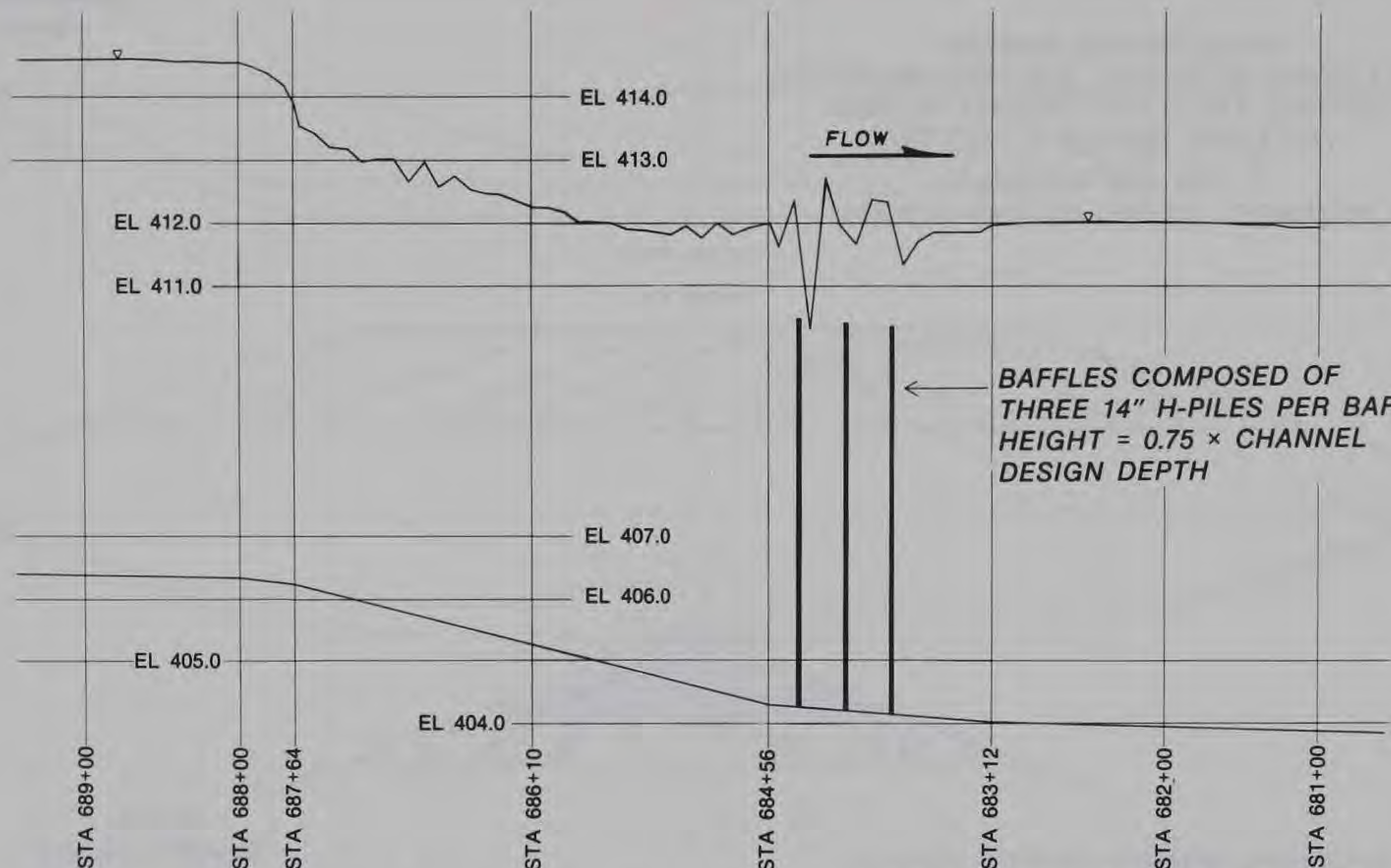
MUDDY CREEK GRADE CONTROL STRUCTURE NO. 5
VELOCITY CROSS SECTION
ORIGINAL DESIGN
DISCHARGE 2,335 CFS, TAILWATER DEPTH 8.5 FT
LOOKING DOWNSTREAM

SCALE
5 0 5 10 FT

PLATE 4
(Sheet 2 of 3)



MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 5
VELOCITY CROSS SECTION
ORIGINAL DESIGN
DISCHARGE 2,355 CFS, TAILWATER DEPTH 8.5 FT
LOOKING DOWNSTREAM

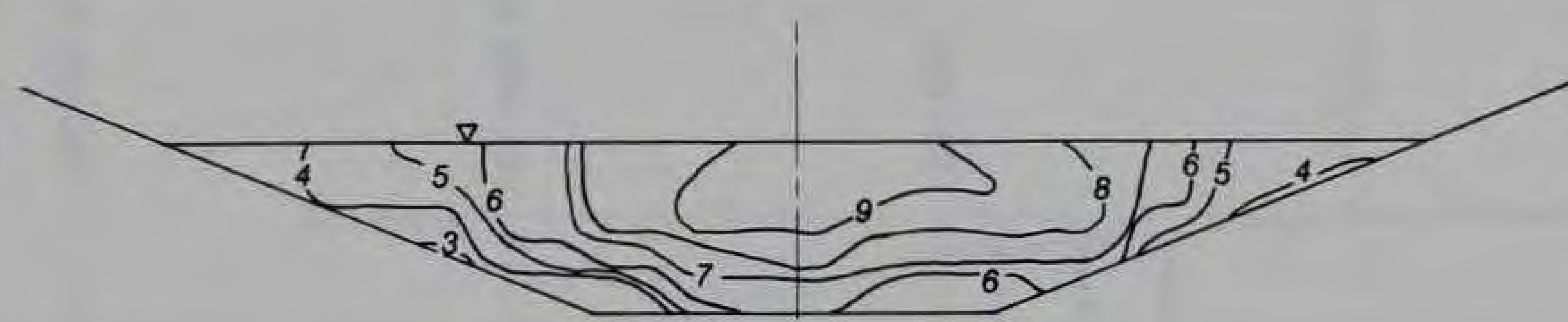


NOTE: ELEVATIONS (EL) ARE IN FEET REFERRED TO THE NATIONAL GEODETIC VERTICAL DATUM (NGVD).

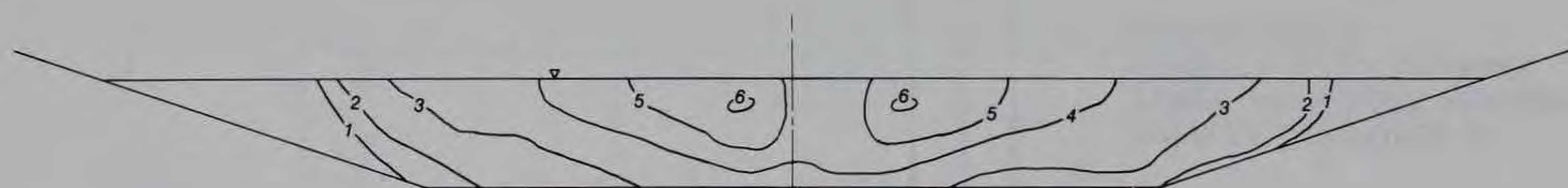
SCALE
HORIZONTAL 40 0 40 80 FT

SCALE
VERTICAL 1 0 1 2 FT

MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 5
CENTER-LINE WATER-SURFACE PROFILE
RECOMMENDED DESIGN, TYPE 3C
DISCHARGE 2,335 CFS, TAILWATER DEPTH 8.2 FT

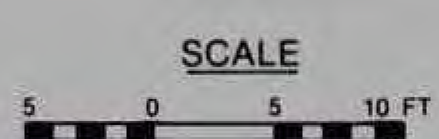


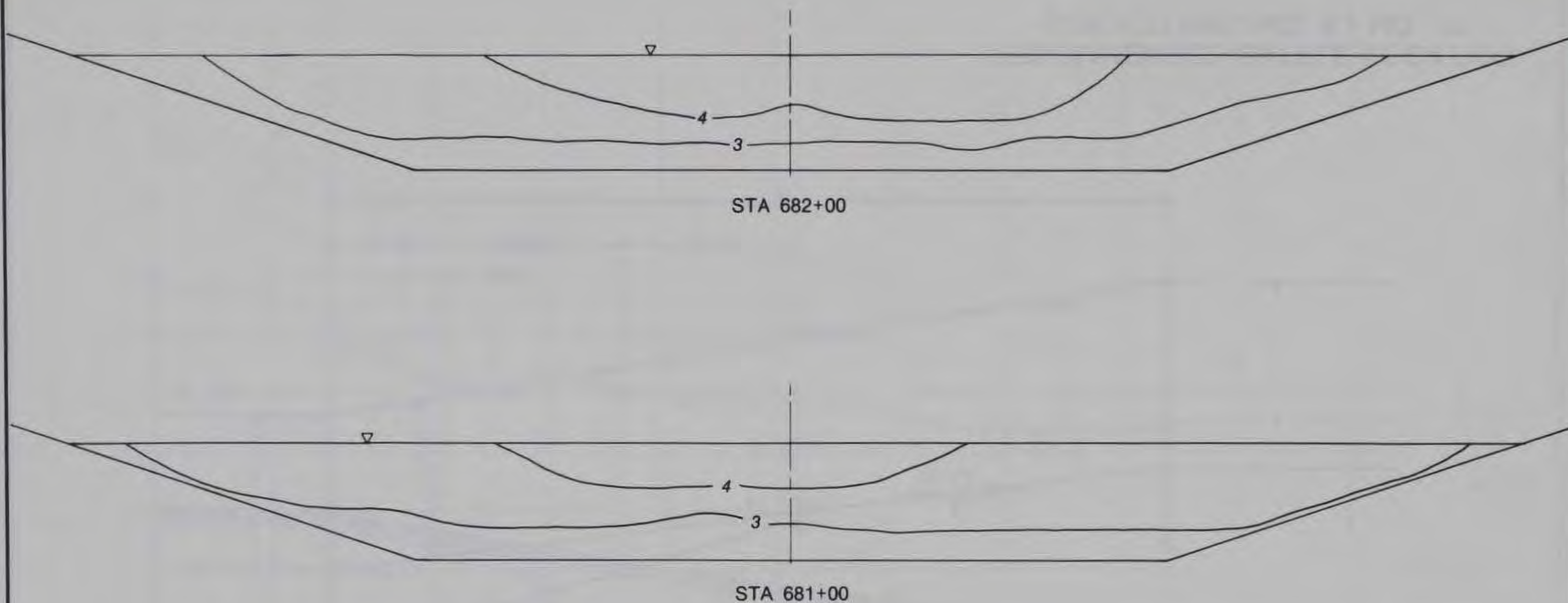
STA 684+56

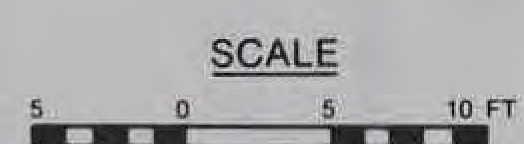


STA 683+12

MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 5
VELOCITY CROSS SECTION
DESIGN: TYPE 3C, 6.2-FT-TALL BAFFLES
DISCHARGE 2,335 CFS, TAILWATER DEPTH 8.2 FT
LOOKING DOWNSTREAM

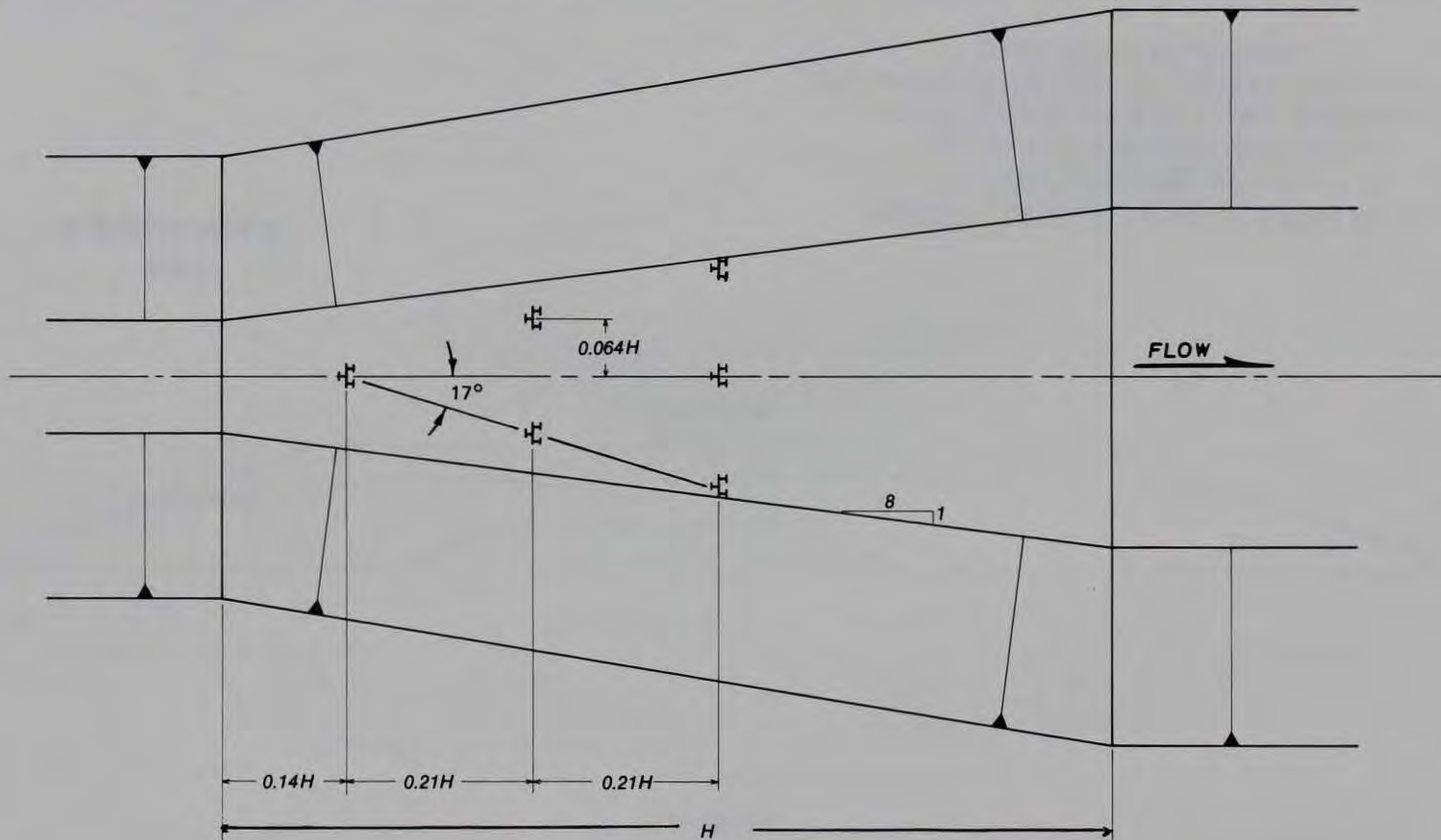




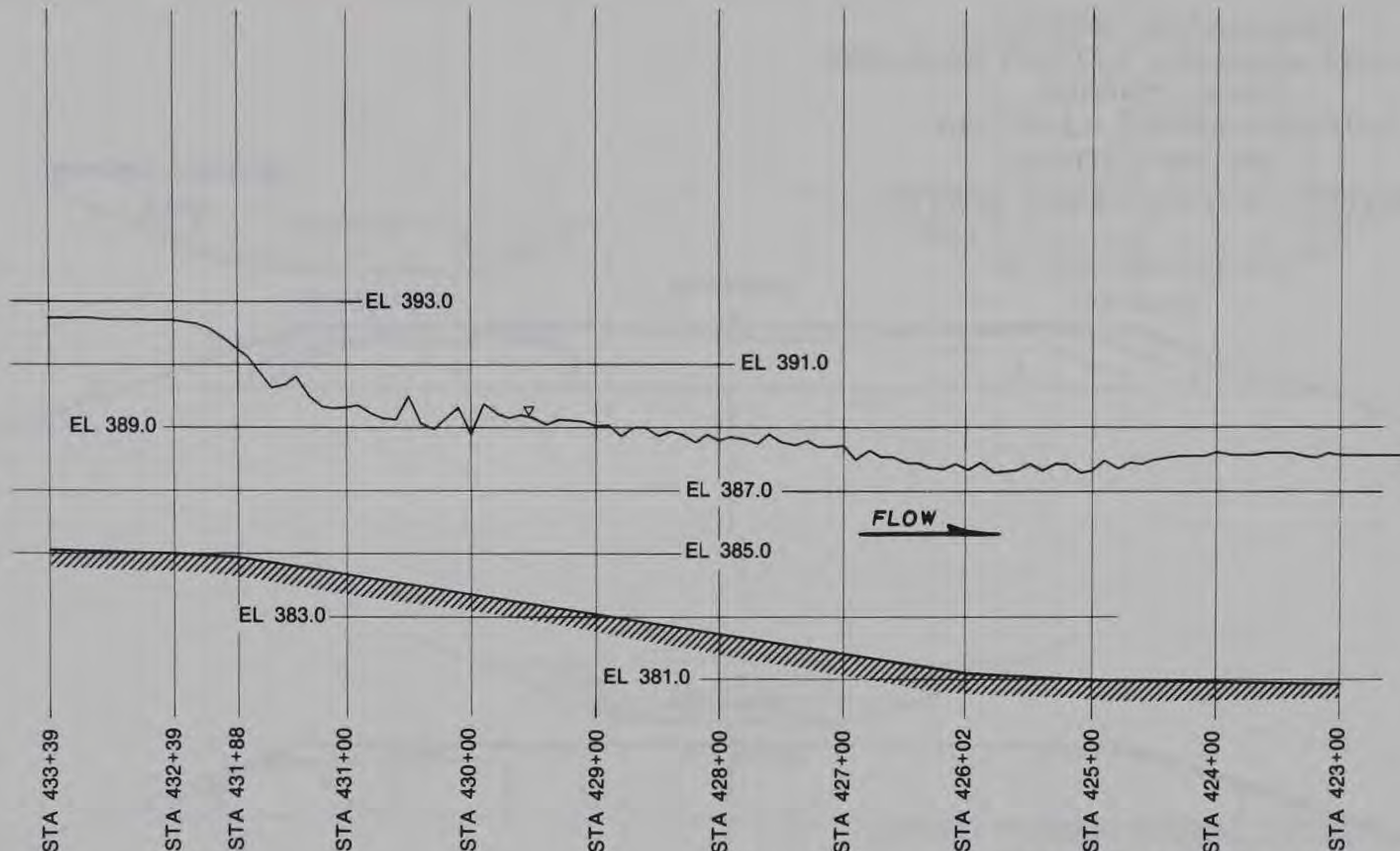


MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 5
VELOCITY CROSS SECTION
DESIGN: TYPE 3C, 6.2-FT-TALL BAFFLES
DISCHARGE 2,355 CFS, TAILWATER DEPTH 8.2 FT
LOOKING DOWNSTREAM

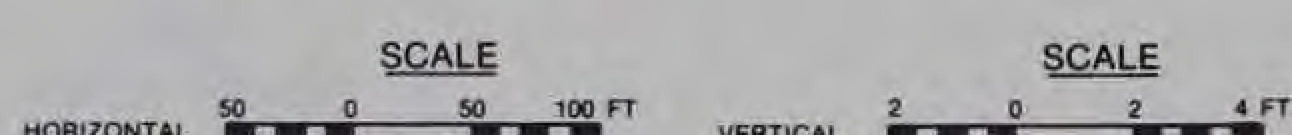
PLATE 6
(SHEET 2 of 2)



RECOMMENDED BAFFLE LOCATION
STRUCTURES NO. 5 - NO. 12

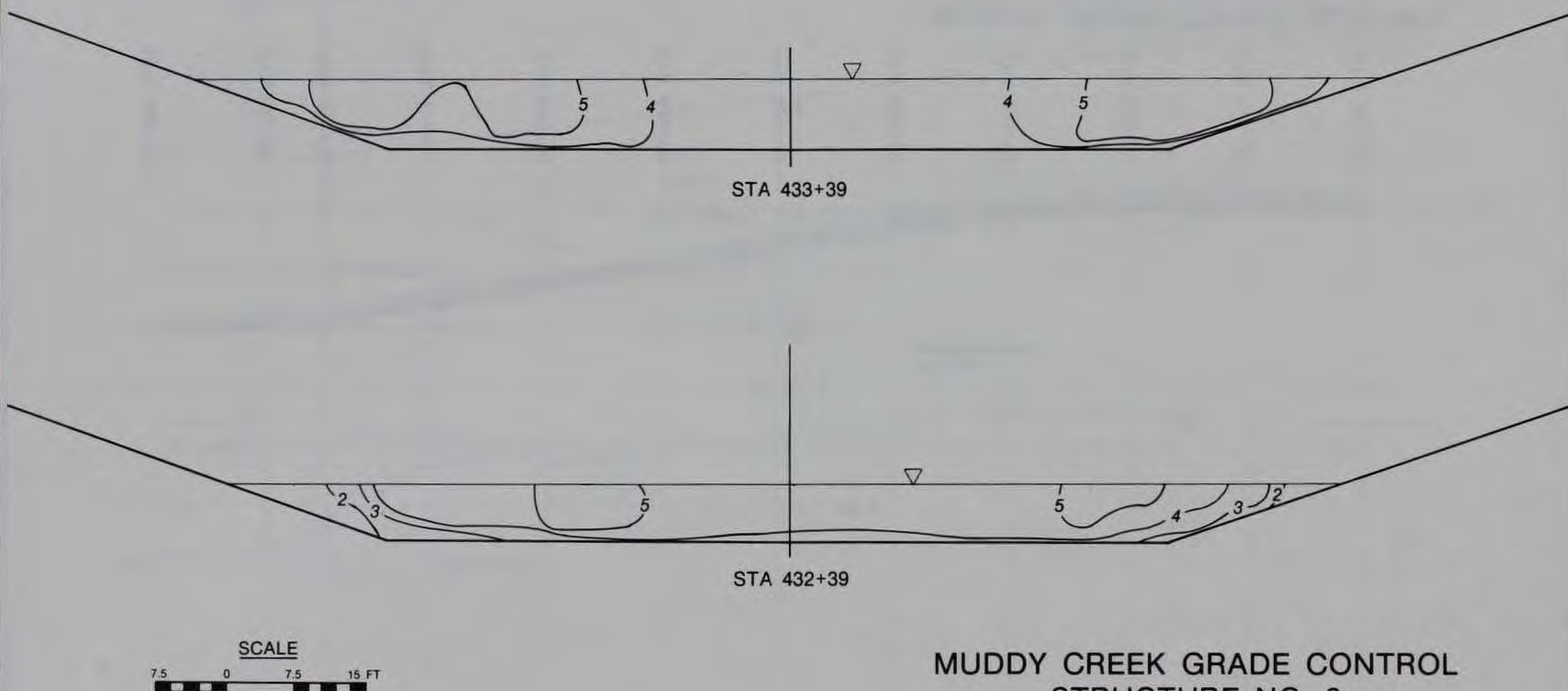


NOTE: ELEVATIONS (EL) ARE IN FEET REFERRED TO THE NATIONAL GEODETIC VERTICAL DATUM (NGVD).

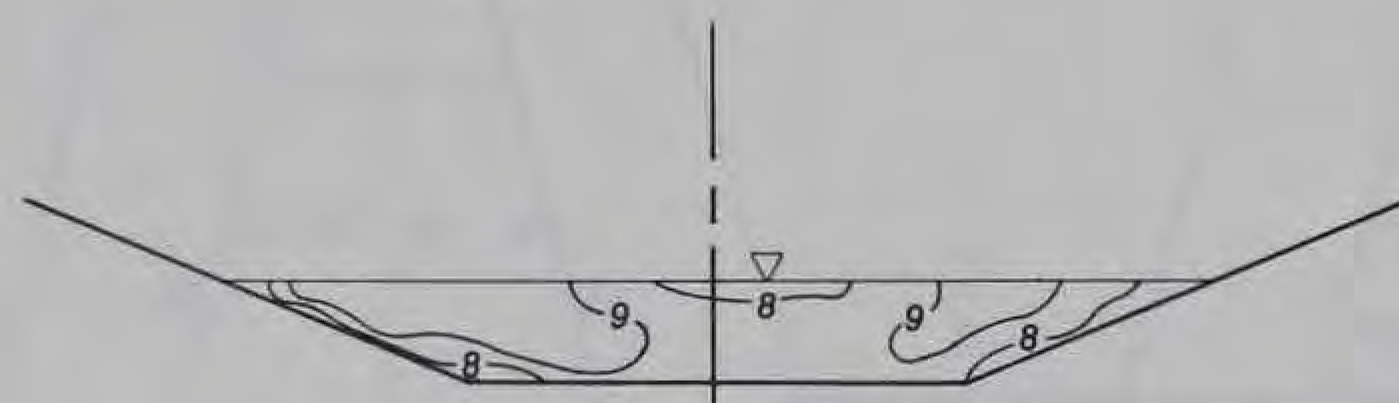


MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 2
CENTER-LINE WATER-SURFACE PROFILE
ORIGINAL DESIGN
DISCHARGE 3,166 CFS, TAILWATER DEPTH 7.6 FT

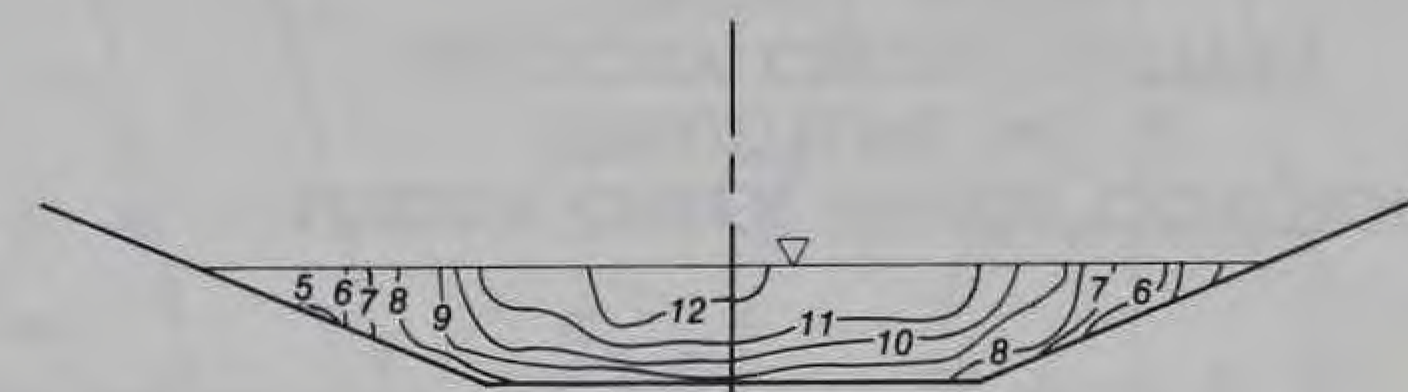
PLATE 8



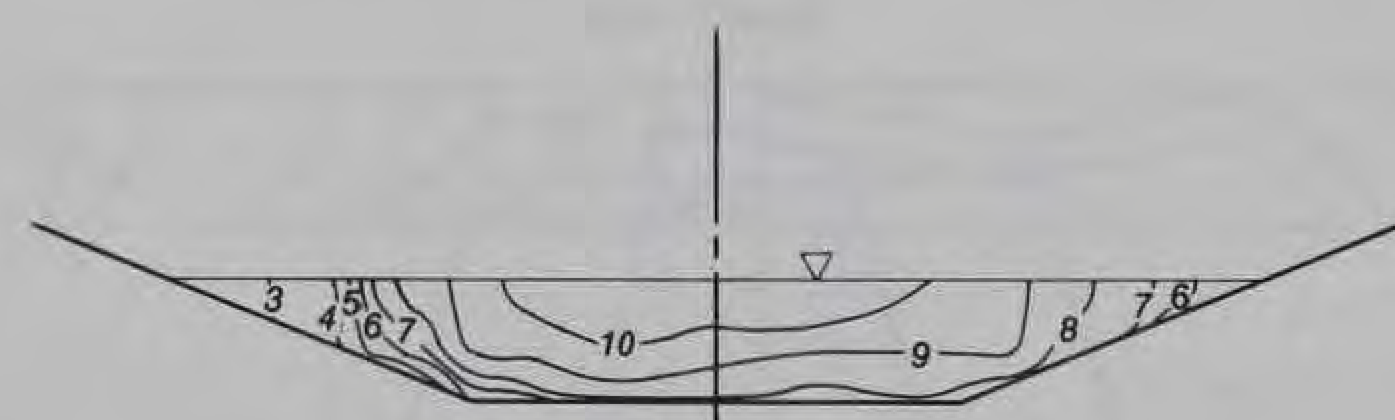
MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 2
VELOCITY CROSS SECTION
ORIGINAL DESIGN
DISCHARGE 3,166 CFS, TAILWATER DEPTH 7.6 FT
LOOKING DOWNSTREAM



STA 431+88



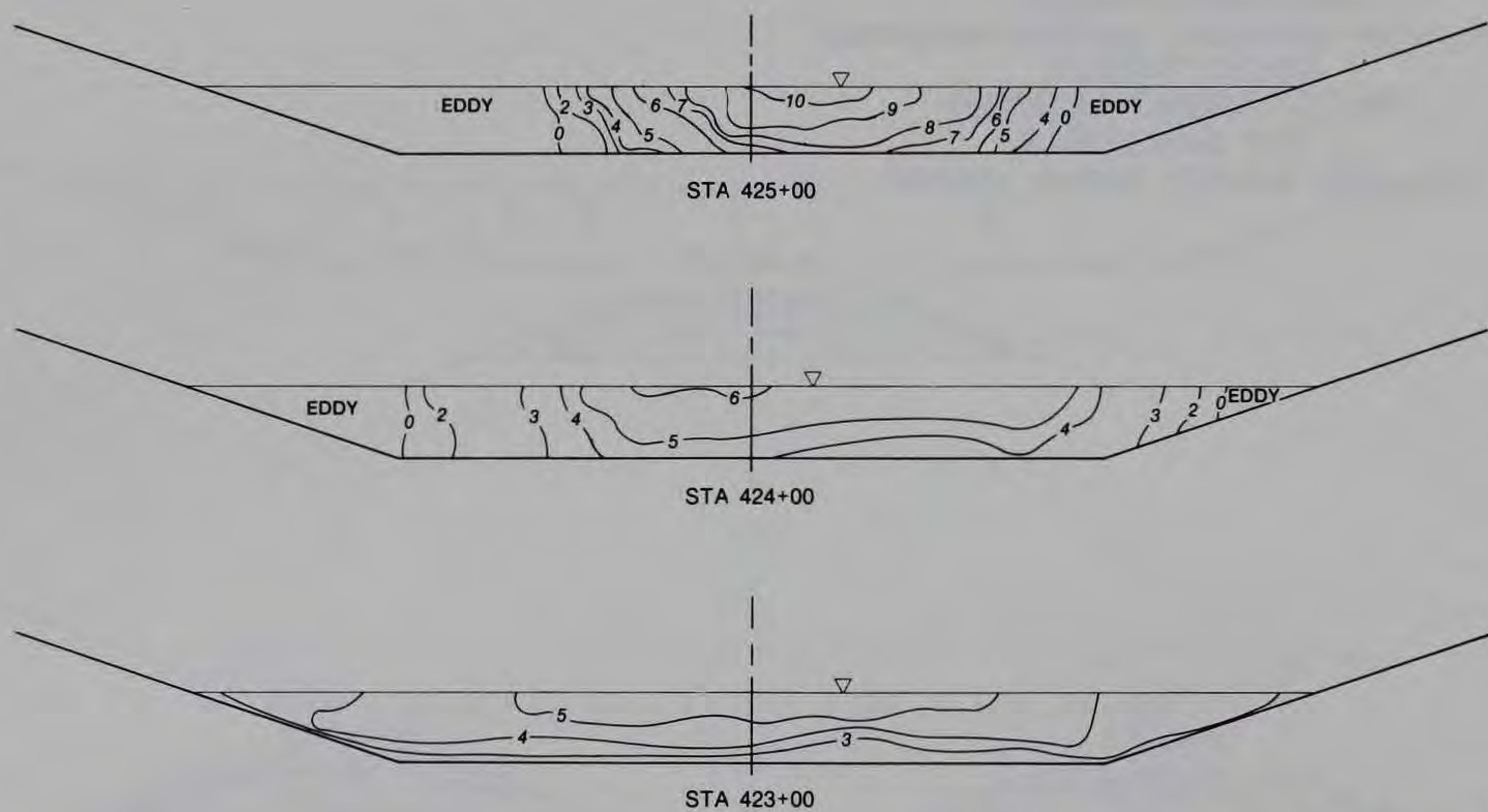
STA 428+95



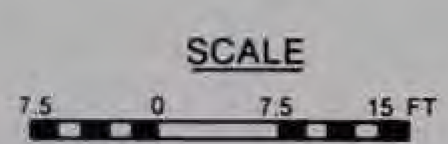
STA 426+02

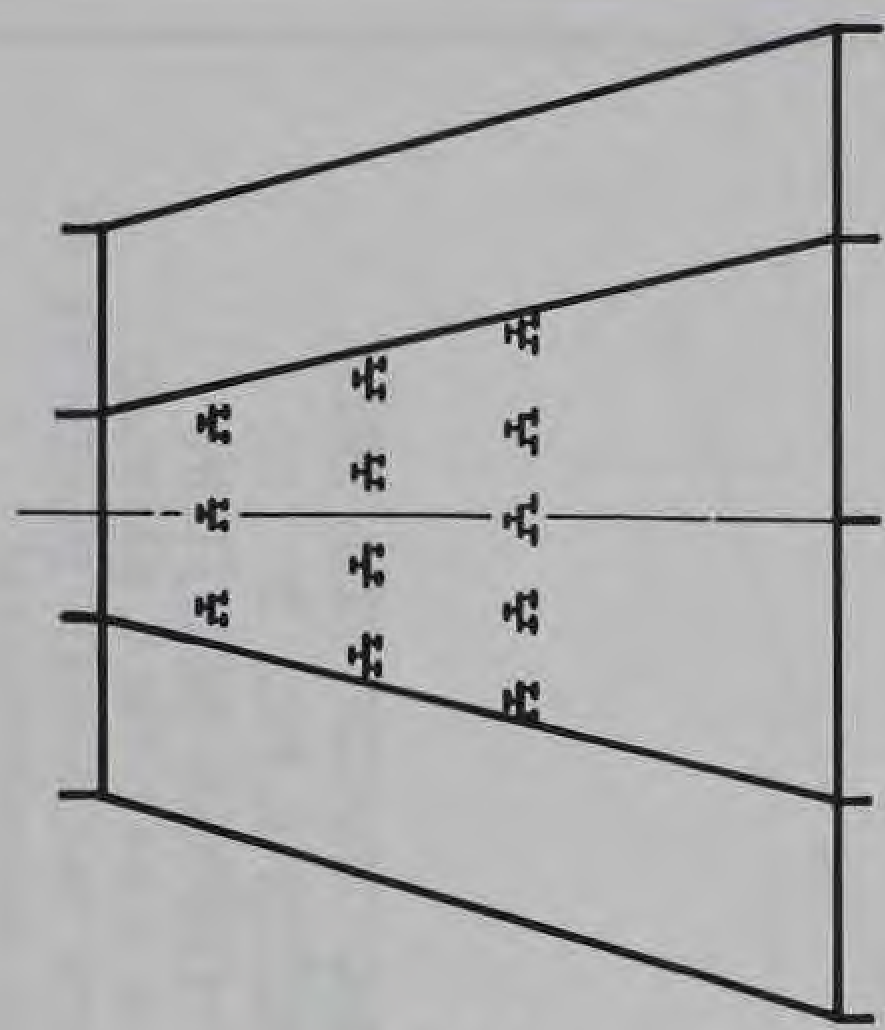
MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 2
VELOCITY CROSS SECTION
ORIGINAL DESIGN
DISCHARGE 3,166 CFS, TAILWATER DEPTH 7.6 FT
LOOKING DOWNSTREAM

SCALE
7.5 0 7.5 15 FT

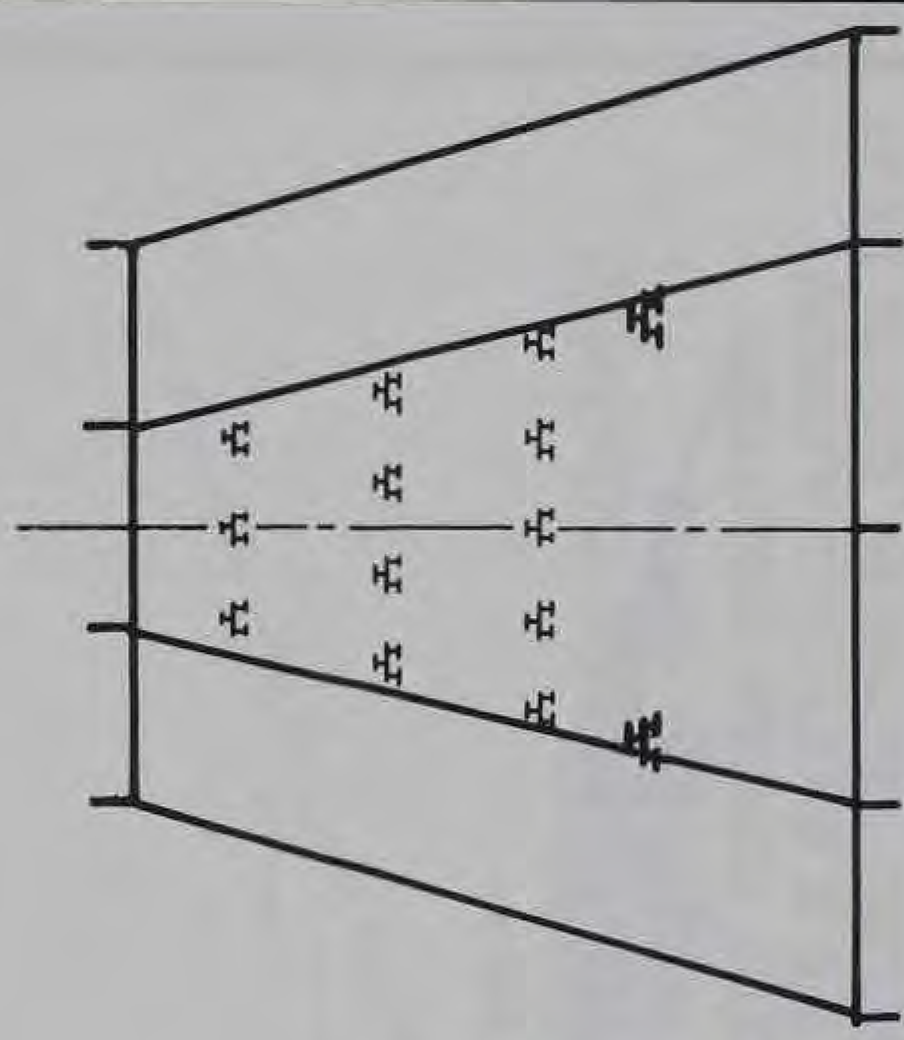


MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 2
VELOCITY CROSS SECTION
ORIGINAL DESIGN
DISCHARGE 3,166 CFS, TAILWATER DEPTH 7.6 FT
LOOKING DOWNSTREAM

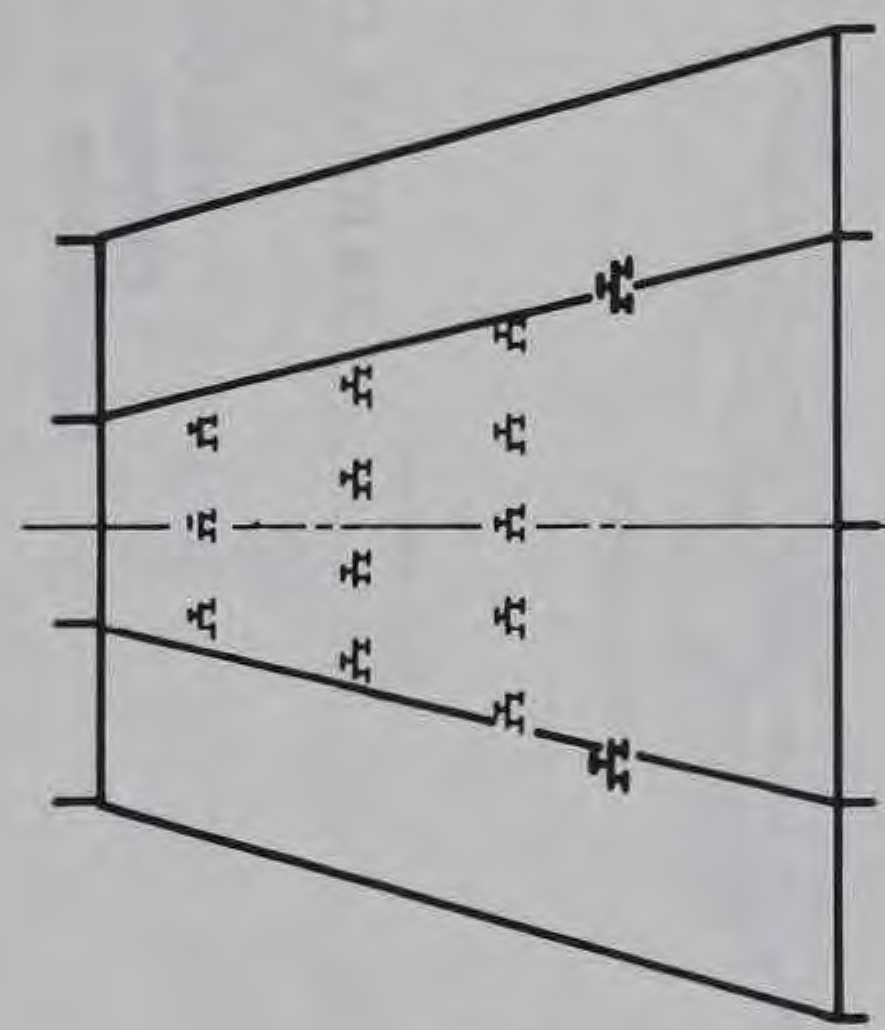




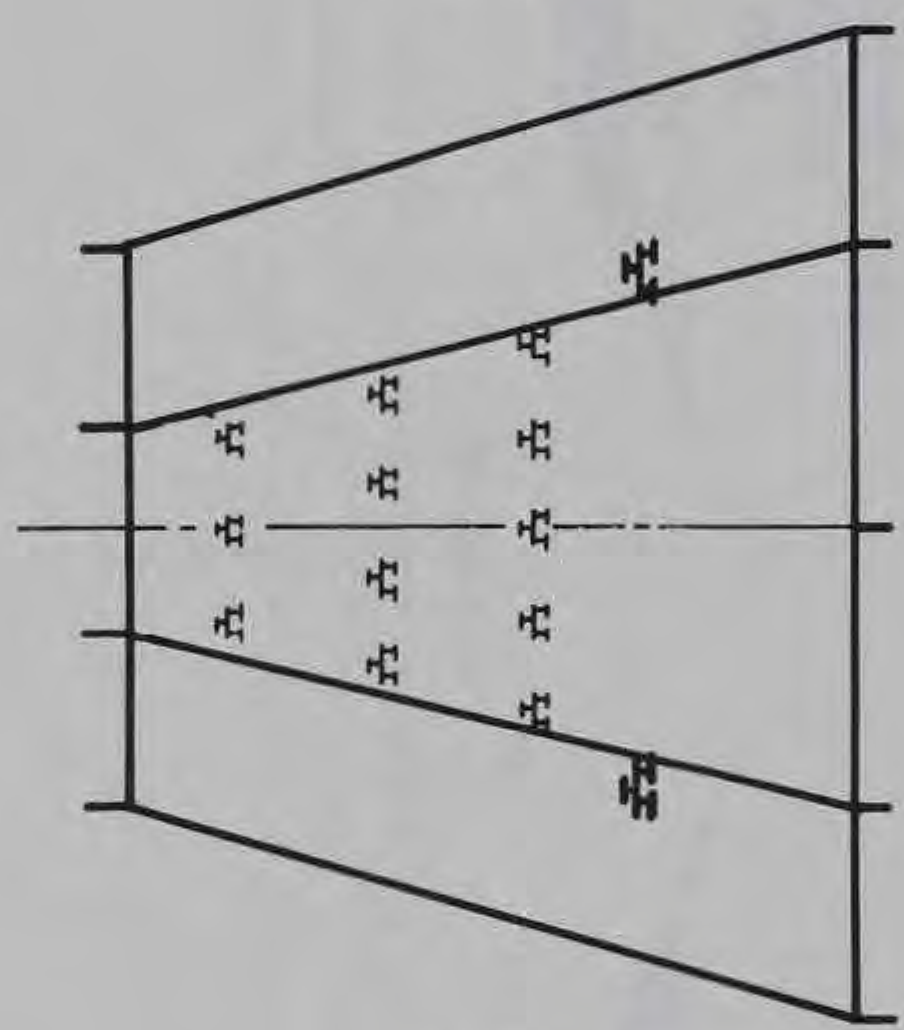
TYPE 4



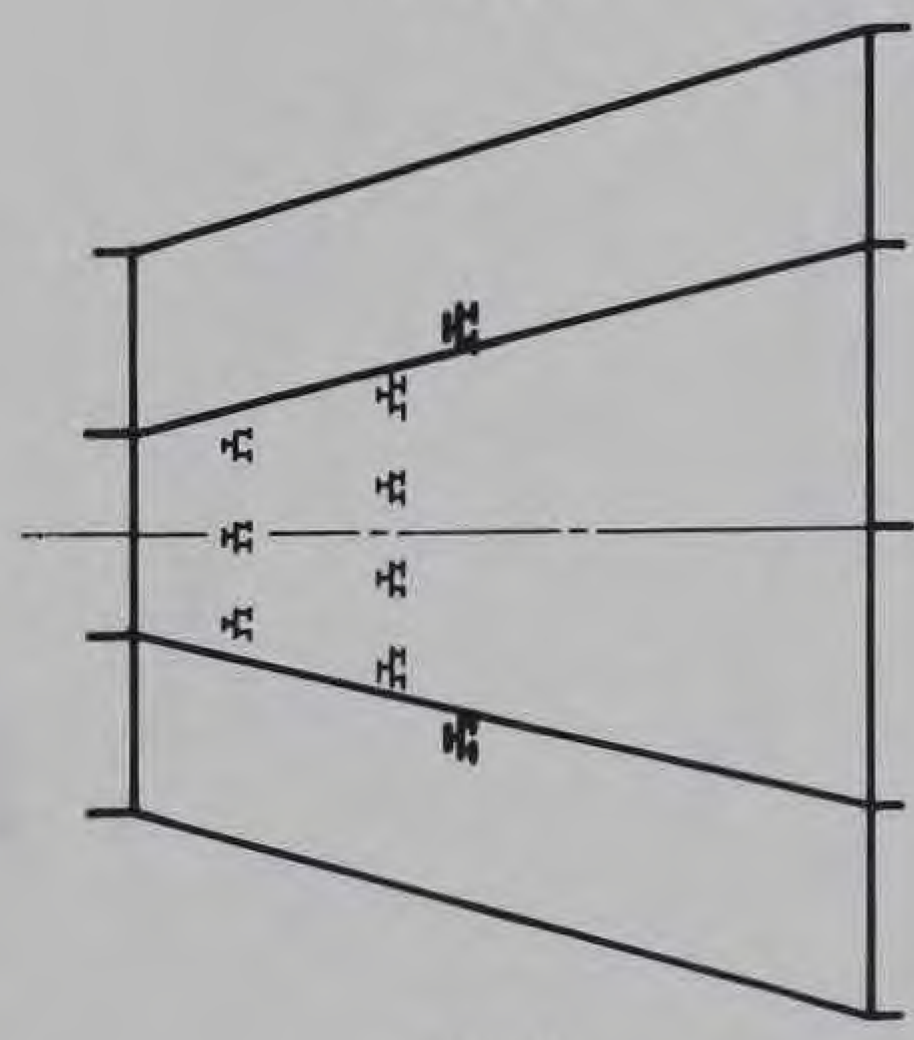
TYPE 5



TYPE 6

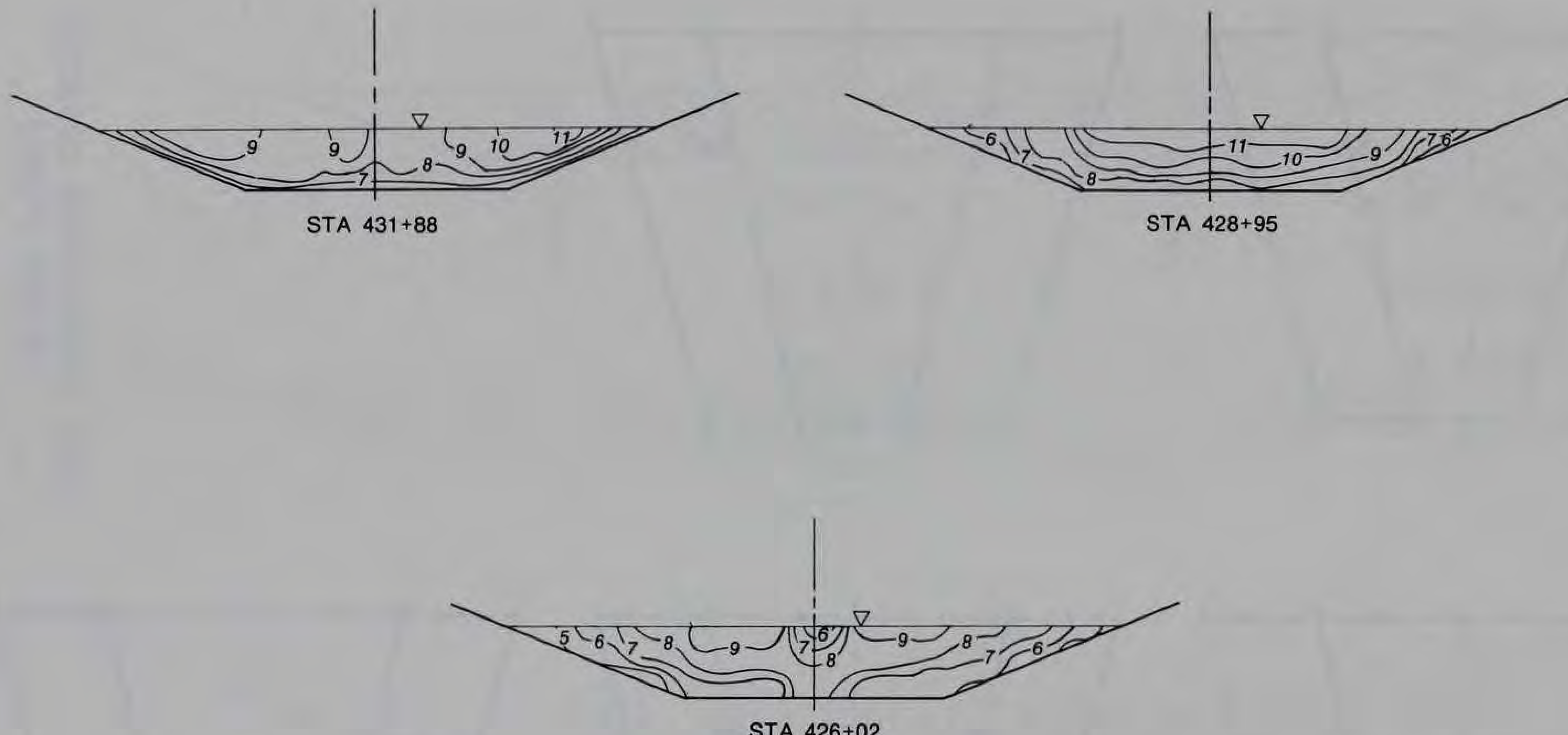


TYPE 7



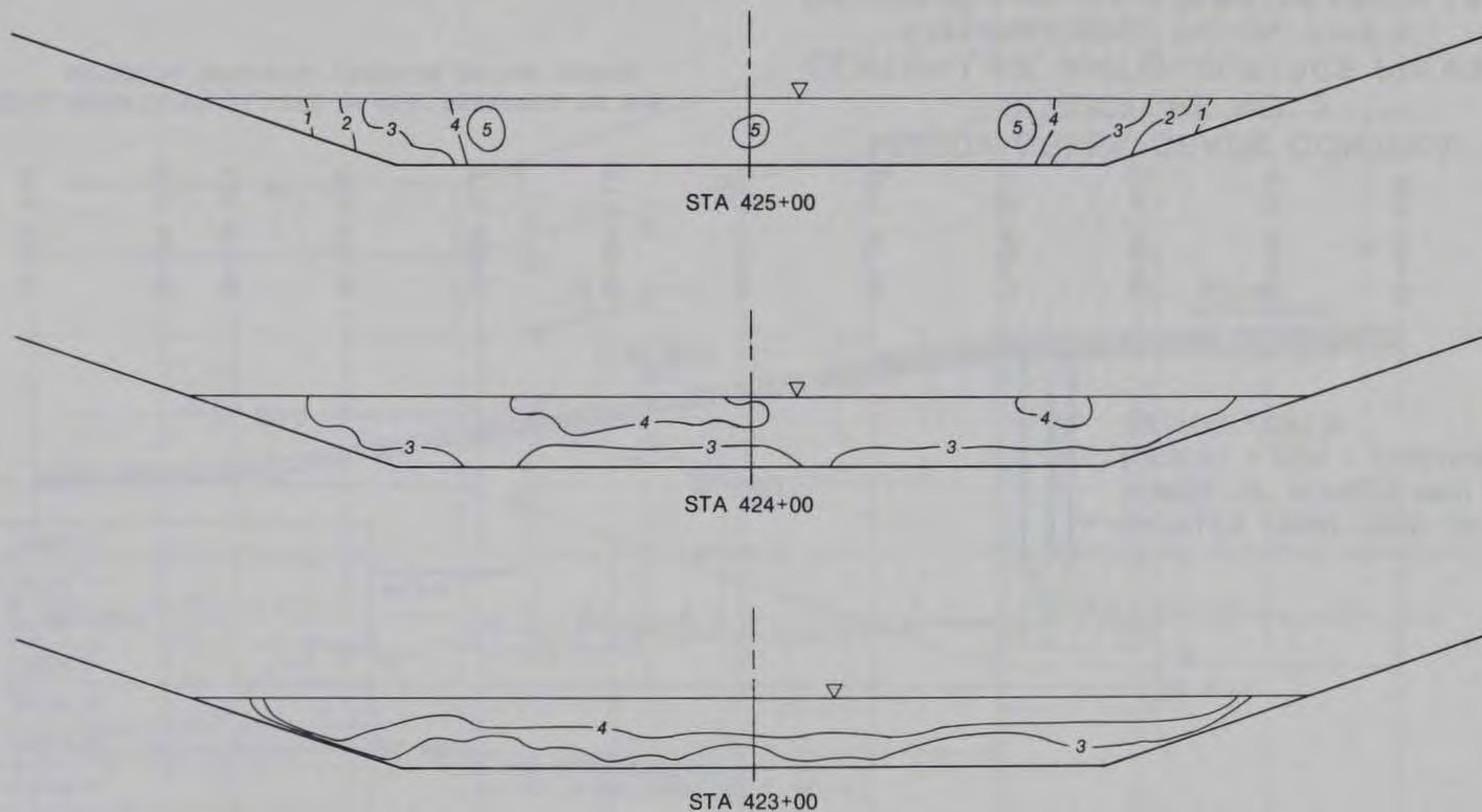
TYPE 8

EXIT TRANSITION DESIGNS
1:4 EXIT FLARE



MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 2
VELOCITY CROSS SECTION
DESIGN: TYPE 8, 6.4-FT-TALL BAFFLES
DISCHARGE 3,166 CFS, TAILWATER DEPTH 7.6 FT
LOOKING DOWNSTREAM

SCALE
7.5 0 7.5 15 FT



MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 2
VELOCITY CROSS SECTION
DESIGN: TYPE 8, 6.4-FT-TALL BAFFLES
DISCHARGE 3,166 CFS, TAILWATER DEPTH 7.6 FT
LOOKING DOWNSTREAM

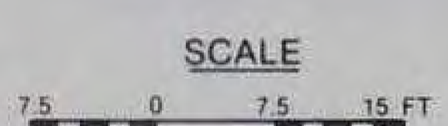
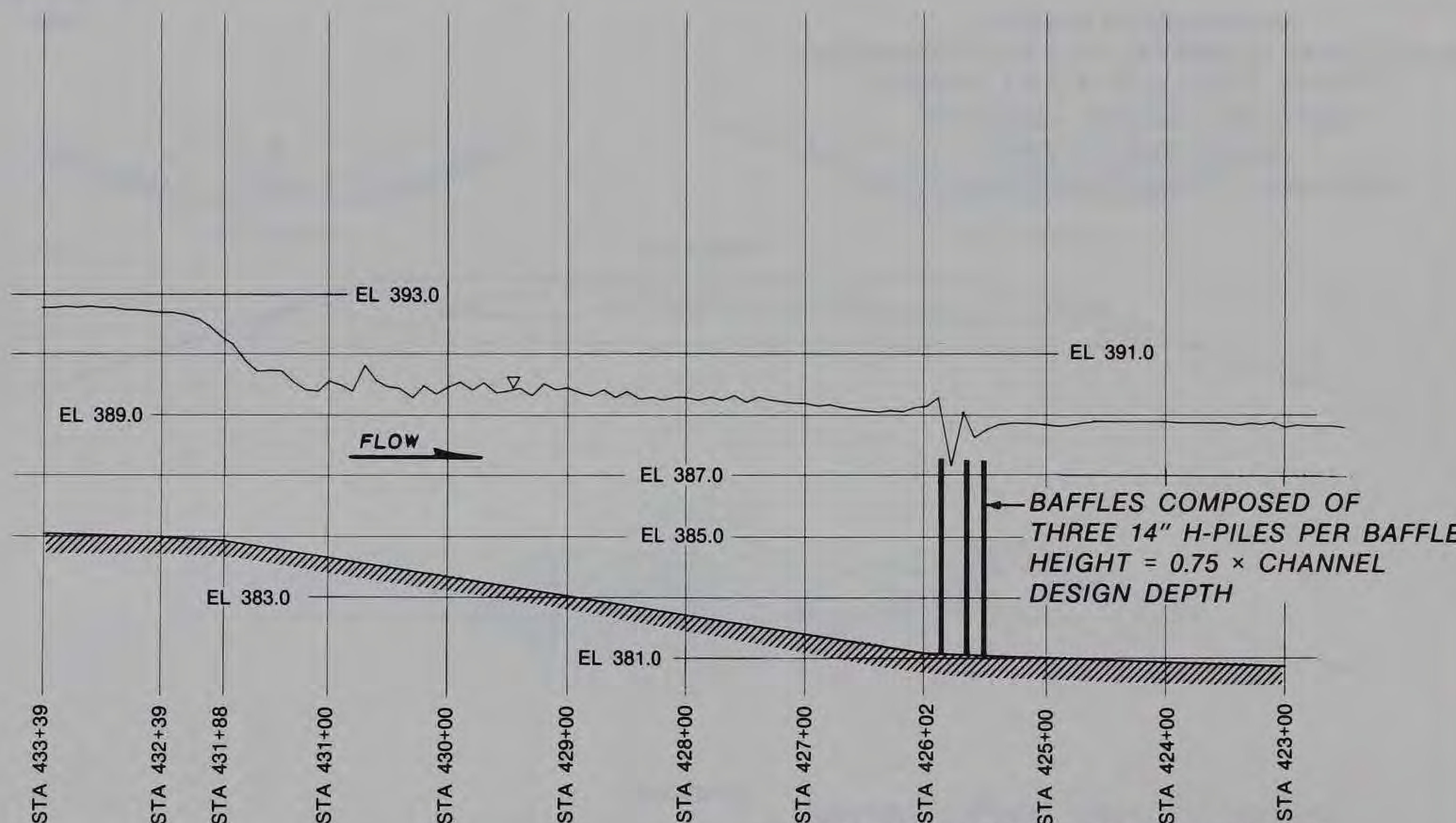


PLATE 11
(Sheet 2 of 2)

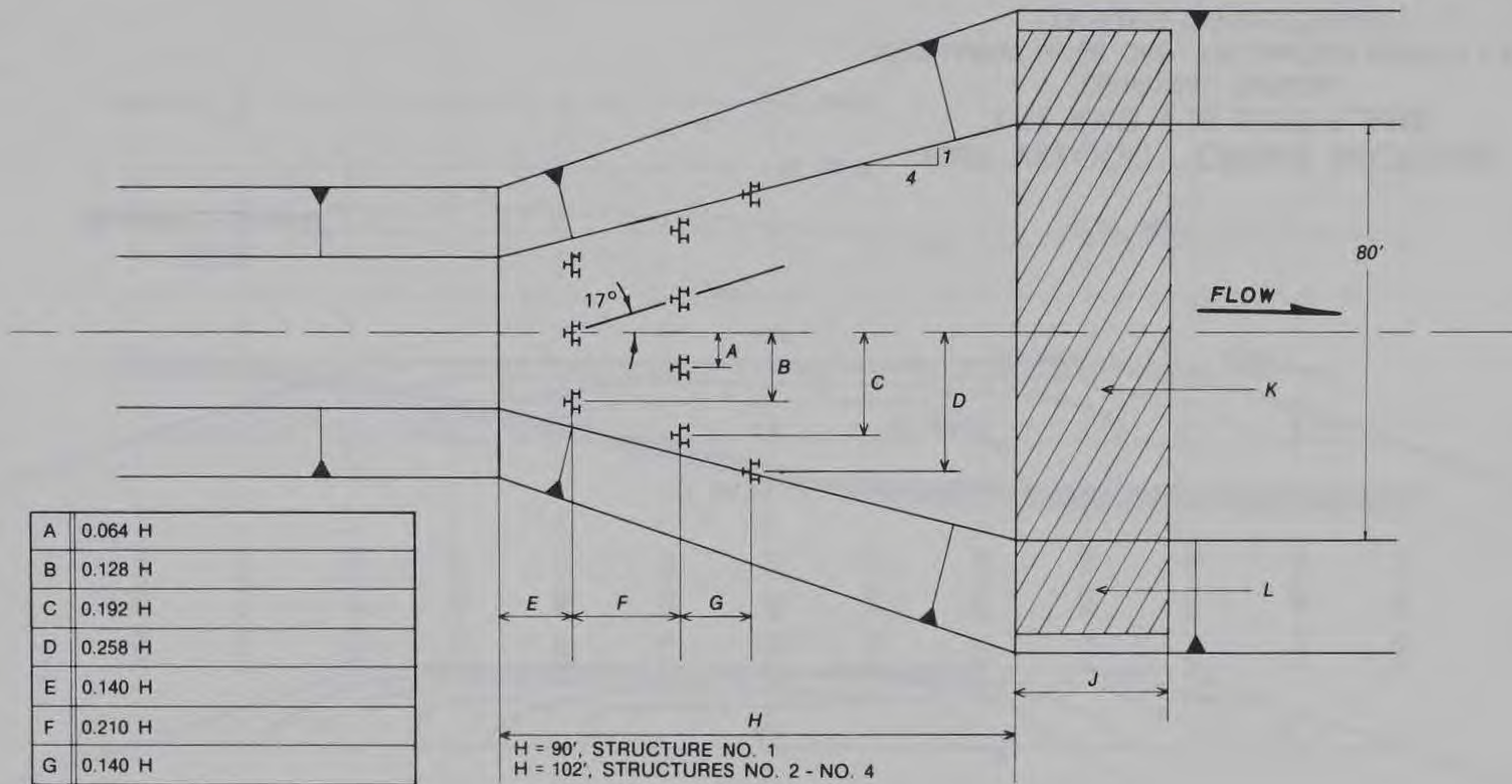


NOTE: ELEVATIONS (EL) ARE IN FEET REFERRED TO THE NATIONAL GEODETIC VERTICAL DATUM (NGVD).

SCALE
HORIZONTAL 50 0 50 100 FT

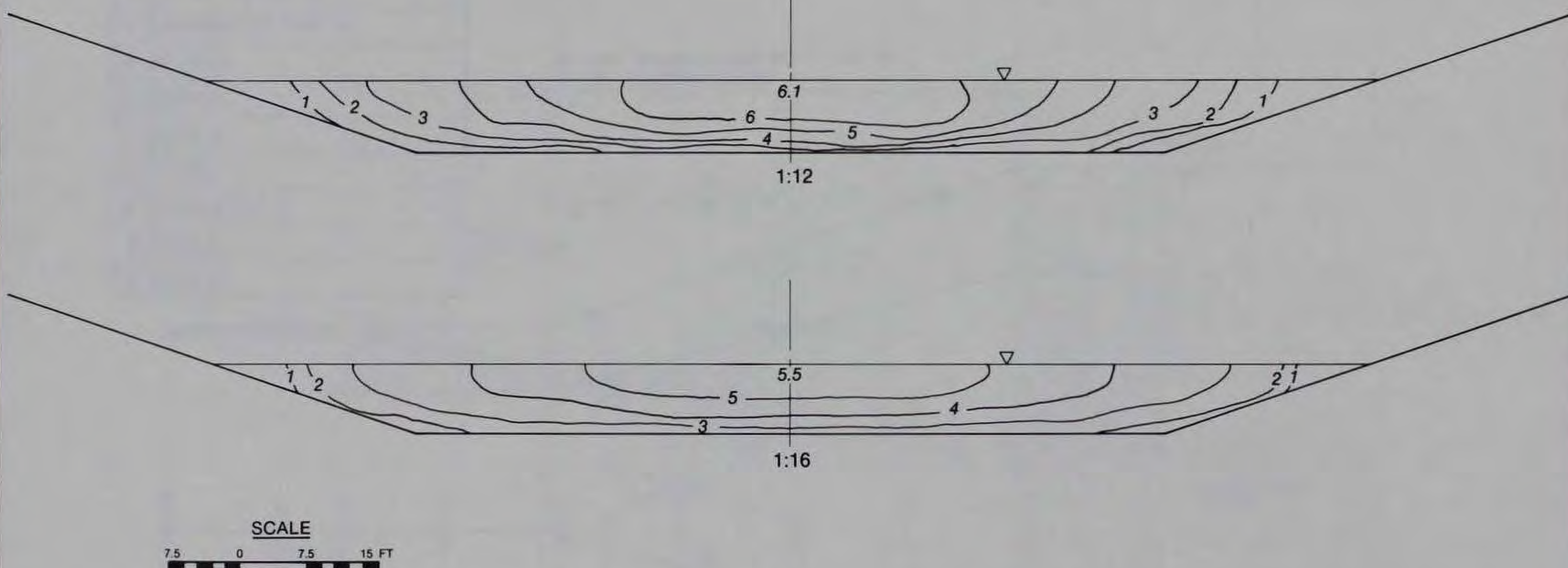
SCALE
VERTICAL 2 0 2 4 FT

MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 2
CENTER-LINE WATER-SURFACE PROFILE
RECOMMENDED DESIGN, TYPE 8
DISCHARGE 3,166 CFS, TAILWATER DEPTH 7.6 FT

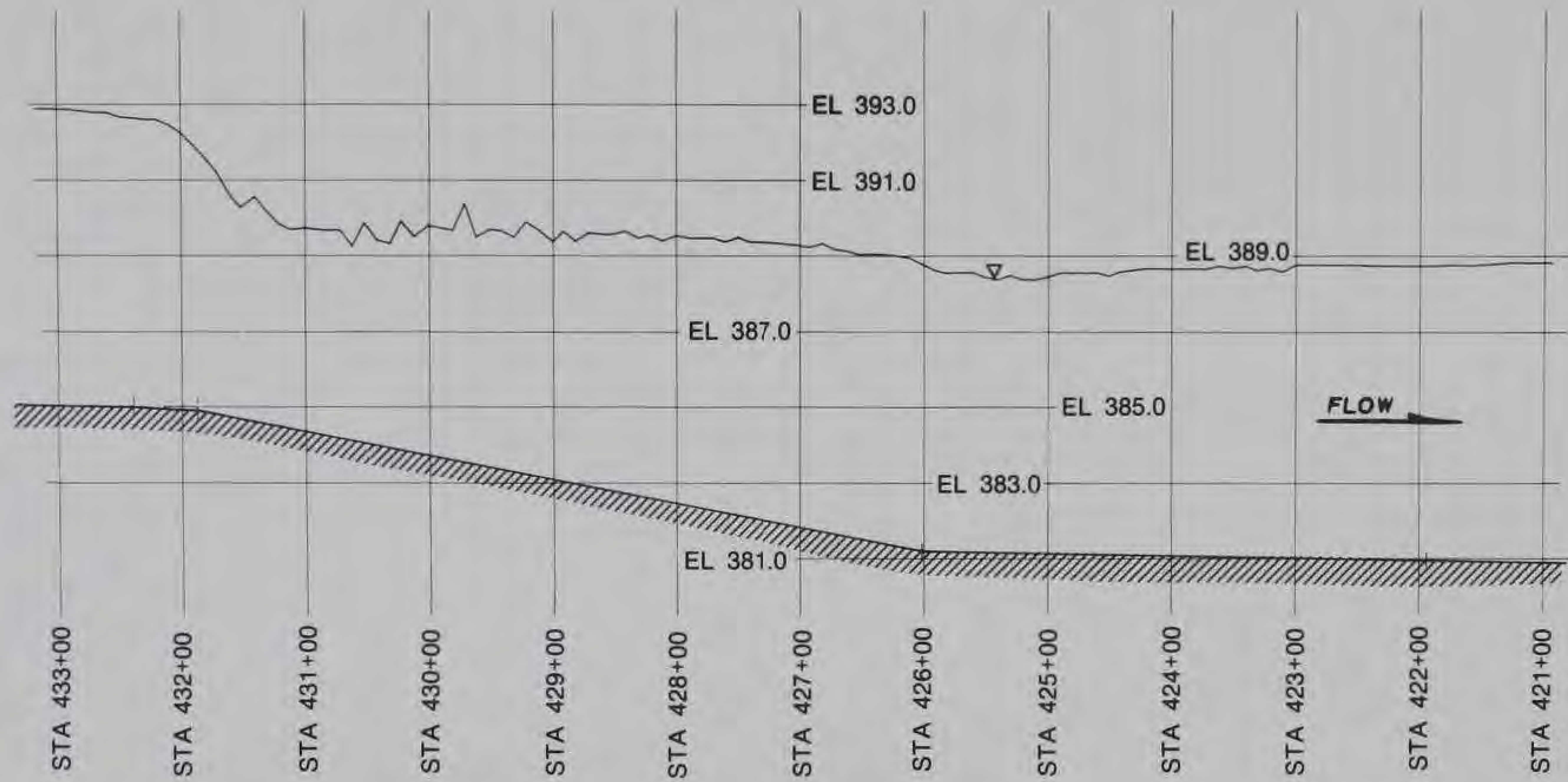


A	0.064 H
B	0.128 H
C	0.192 H
D	0.258 H
E	0.140 H
F	0.210 H
G	0.140 H
H	TRANSITION LENGTH
J	30 FT MINIMUM
K	RIPRAP: NOT LESS THAN 2 IN. AVERAGE SIZE
L	6 FT VERTICALLY UP SLOPE 18 FT HORIZONTALLY

RECOMMENDED BAFFLE LOCATION
STRUCTURES NO. 1 - NO. 4



EXIT VELOCITY CROSS SECTIONS
1:12 AND 1:16 EXIT FLARE
ORIGINAL DESIGN
DISCHARGE 3,166 CFS, TAILWATER DEPTH 7.6 FT
LOOKING DOWNSTREAM



NOTE: ELEVATIONS (EL) ARE IN FEET REFERRED TO THE NATIONAL GEODETIC VERTICAL DATUM (NGVD).

SCALE

HORIZONTAL 60 0 60 120 FT

SCALE

VERTICAL 2 0 2 4 FT

MUDDY CREEK GRADE CONTROL
STRUCTURE NO. 2
CENTER-LINE WATER-SURFACE PROFILE
1:16 EXIT FLARE
DISCHARGE 3,166 CFS, TAILWATER DEPTH 7.6 FT