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LITTLE SIOUX CONTROL STRUCTURE LITTLE SIOUX RIVER, IOWA

Hydraulic Model Investigation

by

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The Little Sioux Project, located in Woodbury, Monona, and Harrison Counties, Iowa, consisted of remedial work on the channel of the Little Sioux River, three existing sills at the mouth of the river, and the construction of a channel control structure about 5.75 miles above the mouth. A model study of the original channel control structure was conducted to develop a satisfactory design for discharges up to 10,000 cfs. Since the construction of the original control structure, the channel has degraded 11 ft and flows exceeding 10,000 cfs

(Continued)

20. ABSTRACT (Continued).

have occurred regularly. Flows exceeding the berm height scoured the side slopes causing the riprap to fail, and convergence of the concentrated flows from the right and left bank berm sections caused the development of a severe scour hole downstream of the stilling basin. High flows during the spring of 1983 caused the structure to fail so another model investigation was necessary to develop a design for the replacement structure and to determine methods to stabilize the area downstream of the structure and the channel side slopes.

Tests on a 1:25-scale hydraulic model of the replacement structure were conducted to develop the design. The model reproduced about 650 ft of topography upstream from the structure, the control structure, and 1,150 ft of topography downstream from the structure. Modifications to the original design were made to produce a structure that provided an acceptable headwater rating curve, and one with adequate energy dissipation in the stilling basin. A notched weir was developed that provided a desired range of headwater elevations for the expected discharges. The weir also produced velocities upstream and downstream from the low-flow notch for discharges less than 1,000 cfs that were considered appropriate for upstream fish migration. Stable riprap designs were determined for the channel bottom downstream from the stilling basin and the channel side slopes.

PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers, US Army, on 10 February 1983 at the request of the US Army Engineer District, Omaha (MRO). The studies were conducted by personnel of the Hydraulics Laboratory, US Army Engineer Waterways Experiment Station (WES), during the period June 1983 to March 1984. 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. Tests were conducted by Messrs. J. E. Hite, Jr., and T. E. Murphy, Jr., under the supervision of Messrs. 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 prepared by Mr. Hite, and edited by Mrs. Beth Burris, Publications and Graphic Arts Division.

During the course of the investigation, Messrs. W. Mellema, A. Harrison, A. Swoboda, E. Kovanic, and L. Wisdom of the Missouri River Division; and F. Vovk, D. E. Hokens, J. Dover, S. Lopez-Luna, M. Parks, W. Deane, T. Temeyer, L. S. Horihan, and R. Singleton of MRO visited the WES to discuss model results and to correlate these results with design studies.

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	2.54	centimetres
miles (US statute)	1.609347	kilometres
pounds (mass)	0.4535924	kilograms
square miles (US statute)	2.589998	square kilometres

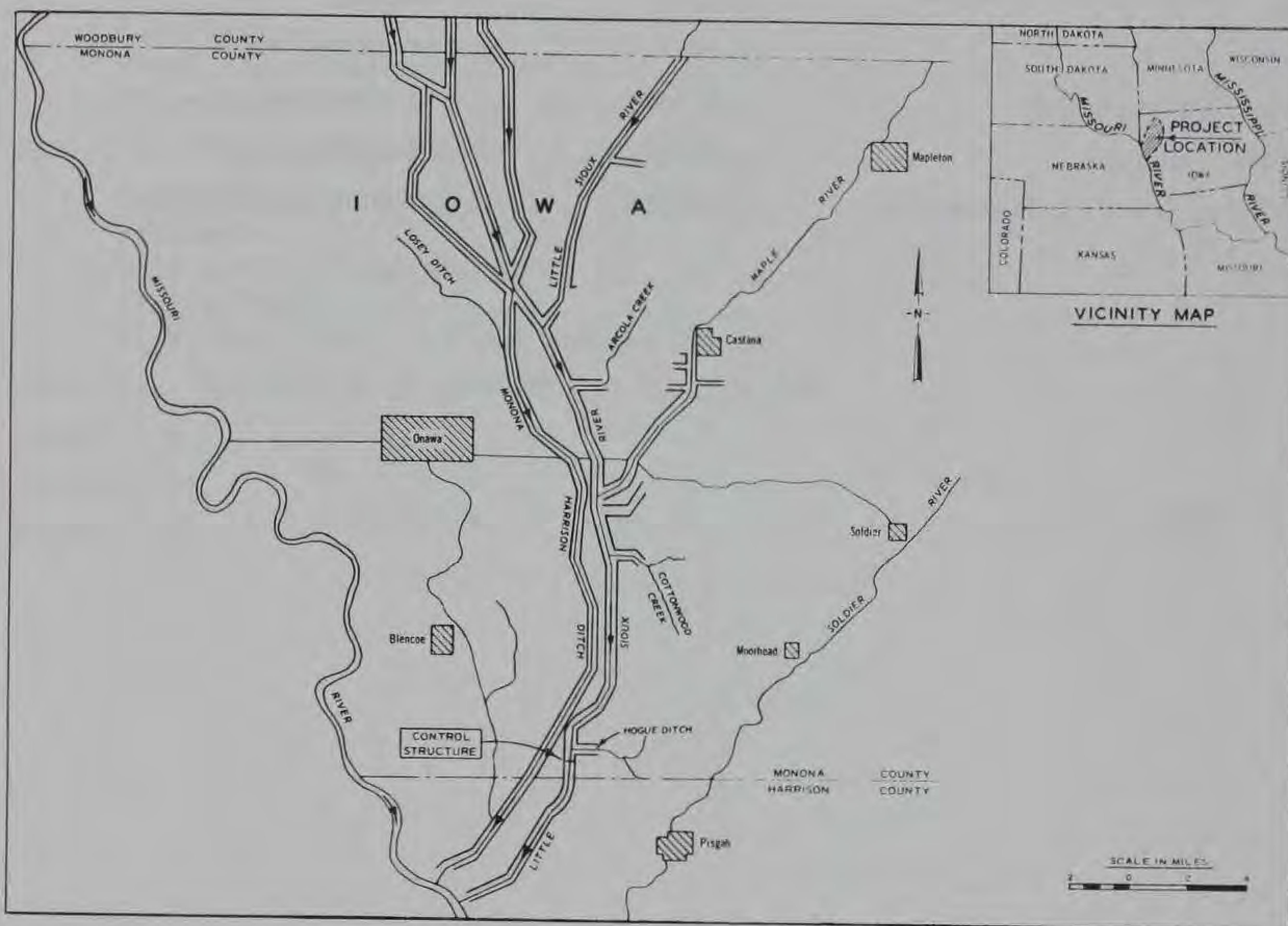

Figure 1. Location map

LITTLE SIOUX CONTROL STRUCTURE

LITTLE SIOUX RIVER, IOWA

Hydraulic Model Investigation

PART I: INTRODUCTION

Background

1. Little Sioux Project is located in Woodbury, Monona, and Harrison Counties, Iowa, along both banks of the Little Sioux River from Smithland, Iowa, to the mouth (Figure 1). The original plan of improvement consisted of remedial work on the channel and three existing sills at the mouth of the river, and construction of a channel control structure (sill 4) about 5.75 miles* above the mouth. Prior to the construction of the three control sills (1959), channel degradation had progressed approximately 3.5 miles from the mouth. Between 1959 and 1962, degradation advanced another 2.5 miles or a total of 6 miles. The erosion and degradation had advanced so far upstream that it was no longer practical to attempt to control its advance by increasing the stage at the mouth through the use of additional sills at that location. The original control structure was designed to stop the degradation of the channel just downstream from the upper limits of the serious erosion.

2. The original control structure (Figure 2) was model-tested** at the US Army Engineer Waterways Experiment Station (WES) between July and December 1962 to determine appropriate length and width of the structure, riprap protection, and upstream and downstream geometries. A satisfactory design was developed for discharges up to 10,000 cfs. WES Technical Report 2-762 stated that failure of the control channel side slopes was possible for a discharge range between 10,000 and 20,000 cfs and a tailwater range from 3 ft below to 3 ft above the channel berms. Since construction of the original control structure the channel has degraded 11 ft, and flows exceeding 10,000 cfs have

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

** T. E. Murphy. 1967 (Feb). "Control Structure, Little Sioux River, Iowa; Hydraulic Model Investigation," Technical Report 2-762, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

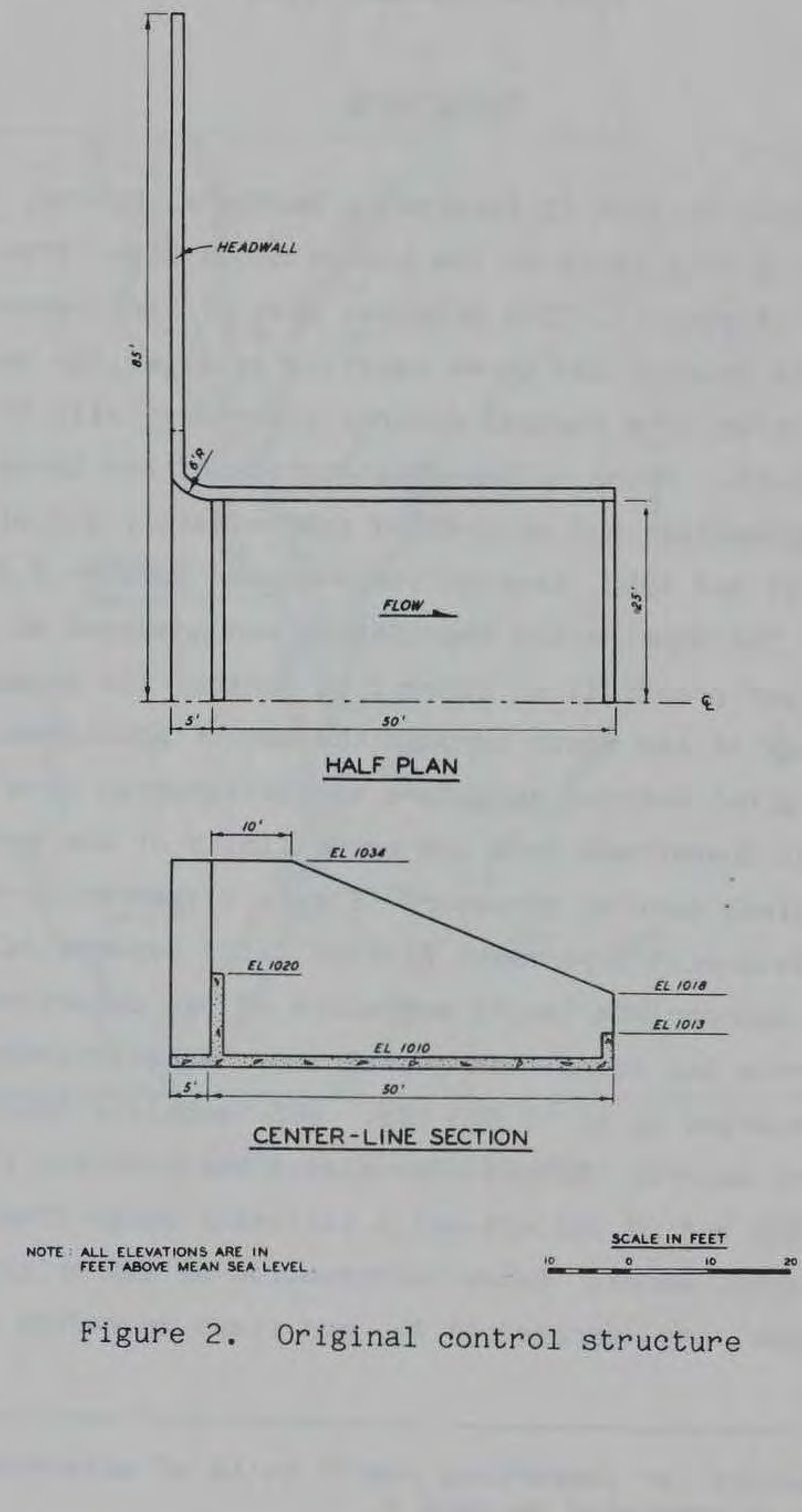
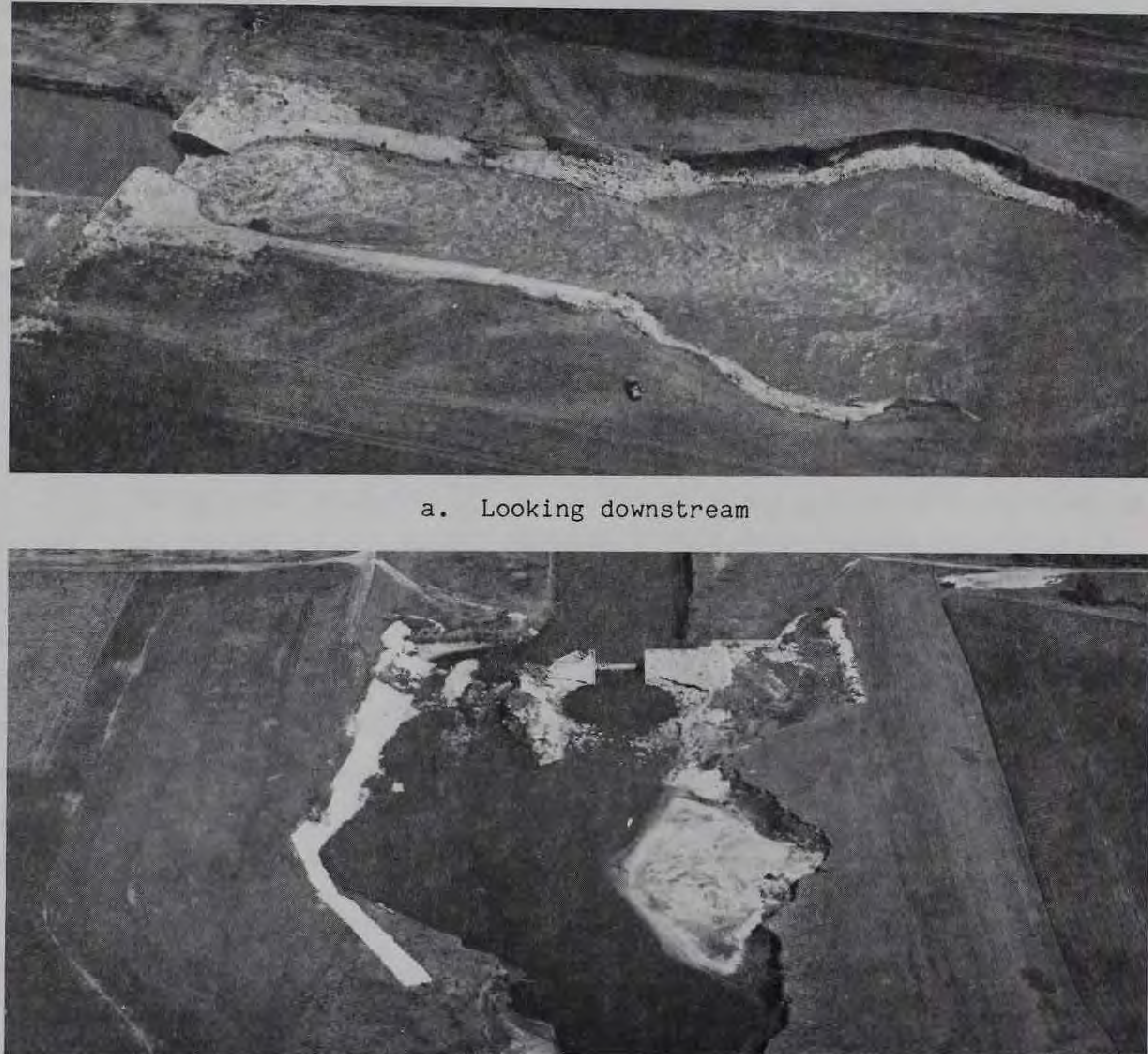


Figure 2. Original control structure

occurred regularly. Flows exceeding the berm height scoured the side slopes causing the riprap to fail. Convergence of the concentrated flows from the right and left bank berm sections caused development of a severe scour hole downstream of the stilling basin. The scour hole has widened; and along with the lateral erosion due to the flows overtopping the berms, the stability of the toes of the levees is being threatened. Figure 3a shows the original structure with scour in the exit channel, and Figure 3b shows the original structure after failure of the right headwall caused by high flows during the spring of 1983.



a. Looking downstream

b. Looking upstream

Figure 3. Original structure, old sill 4

Purpose of Model Study

3. Several schemes to control scour at sill 4 were formulated including utilizing the original structure. High flows during the spring of 1983 caused the existing structure to fail so plans to use this structure were discarded. A model investigation was deemed necessary to determine an effective scheme to stabilize the area downstream of the structure and the channel side slopes. Specifically, tests were conducted to:

- *a*. Determine the hydraulic performance of the structure throughout the entire range of discharges and tailwater elevations anticipated at the project.
- *b*. Investigate how to transition and pass flow from both the berms and channel through the structure.
- *c*. Determine crest elevations, structure widths, and basin lengths for both the central channel and berm portions of the structure.
- *d*. Determine the shape of the crest.
- *e*. Determine the transition losses caused by the structure.
- *f*. Determine the riprap requirements.

PART II: THE MODEL

Description

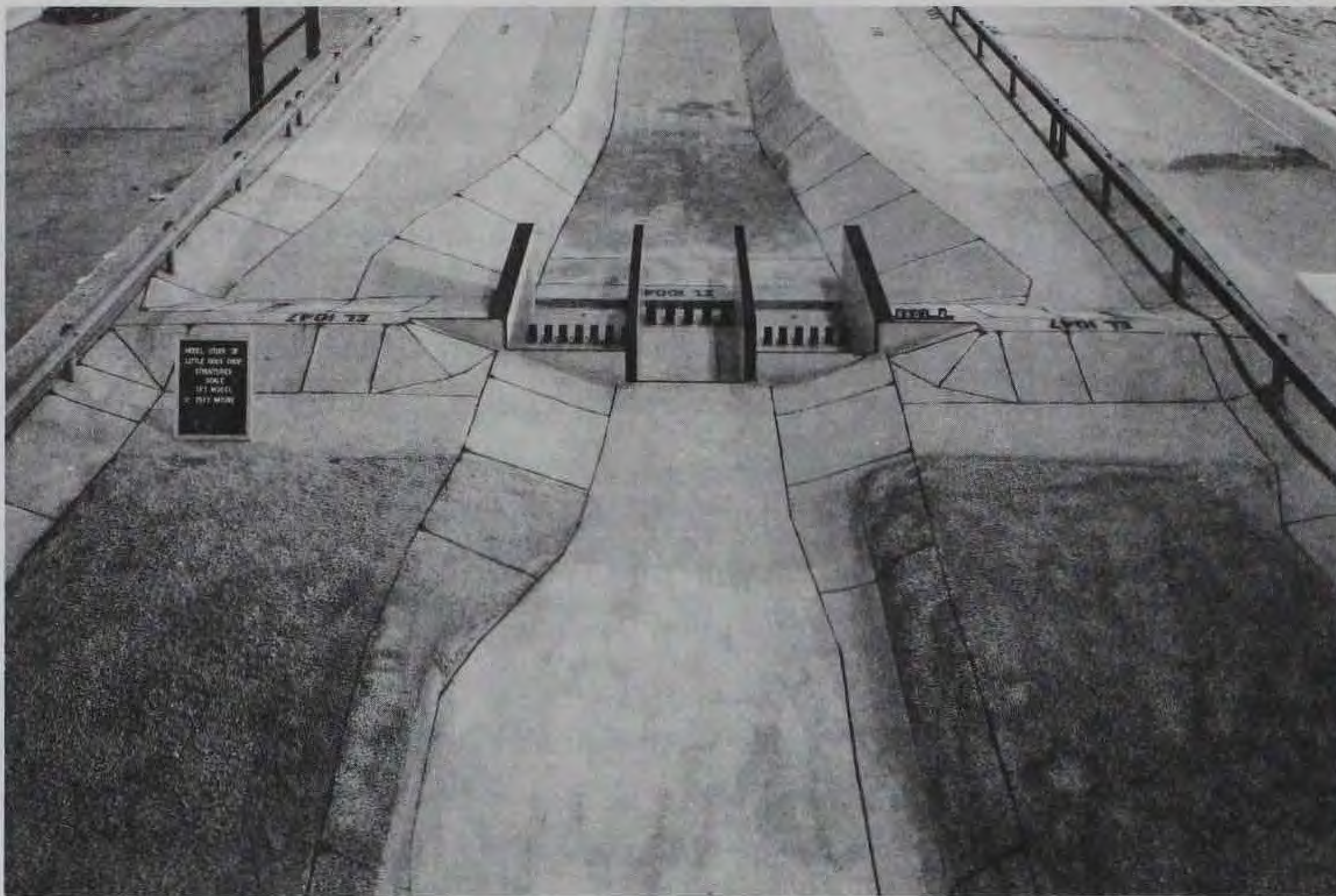
4. The model (Figure 4) was constructed to an undistorted scale of 1:25 and reproduced about 650 ft of topography upstream from the structure, the structure, and 1,150 ft of topography downstream from the structure. The structure was constructed of plastic-coated plywood, and the basin elements were constructed of wood and treated with a waterproofing compound to prevent swelling. Initially, portions of the approach channel, berms, nonoverflow sections, and exit channel were molded in sand and cement mortar to sheet-metal templates to observe the hydraulic performance and discharge characteristics. Other portions of the approach channel were molded of grouted pea gravel to permit modifications to be made readily. In later tests, the cement mortar was replaced with sand and riprap to check the adequacy of the riprap protection. A model layout is shown in Plate 1 and details of the Type 1 design weir and stilling basin (original design) are shown in Plate 2.

Model Appurtenances

5. Water used in operation of the models was supplied by a circulating system. Discharges in the model, measured with venturi meters installed in the inflow lines, were baffled when entering the model. Water-surface elevations and soundings over the sand and riprap beds were measured with point gages. Velocities were measured with pitot tubes mounted to permit measurement of flow from any direction and at any depth. The tailwater in the lower end of the model was maintained at the desired depth by means of an adjustable tailgate. Different designs, along with various flow conditions, were recorded photographically.

Scale Relations

6. The accepted equations of hydraulic similitude, based on the Froudian criteria, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for the transference of model data to prototype equivalents are presented below:



a. Looking downstream

b. Looking upstream

Figure 4. 1:25-scale model of Little Sioux control structure

Characteristic	Dimension*	Model:Prototype
Length	L_r	1:25
Area	$A_r = L_r^2$	1:625
Velocity	$V_r = L_r^{1/2}$	1:5
Discharge	$Q_r = L_r^{5/2}$	1:3,125
Volume	$V_r = L_r^3$	1:15,625
Weight	$W_r = L_r^3$	1:15,625
Time	$T_r = L_r^{1/2}$	1:5

*Dimensions are in terms of length.

Because of the nature of the phenomena involved, certain of the model data can be accepted quantitatively, while other data are reliable only in a qualitative sense. Measurements in the model of discharges, water-surface elevations, velocities, and resistance to displacement of riprap material can be transferred quantitatively from model to prototype by means of the above scale relations. Evidence of scour of the model sand bed, however, is to be considered only as qualitatively reliable since it has not yet been found possible to reproduce quantitatively in a model the relatively greater extent of erosion that occurs in the prototype with fine-grained bed material. Data on scour tendencies provided a basis for determination of the relative effectiveness of the different designs and indicated the areas most subject to attack.

PART III: TESTS AND RESULTS

Initial Tests

7. Initial tests were conducted to determine the headwater rating curve for the proposed structure. The rating curve determined by the model and shown in Plate 3 was slightly less efficient than the curve computed by the US Army Engineer District, Omaha (MRO), for existing tailwater conditions. The rating curve determined by the model without tailwater effect was more efficient than the computed curve, especially with the larger discharges. A tailwater curve furnished by MRO for the initial tests is shown in Plate 4. The capacity of the structure with 1 ft of freeboard and a headwater elevation of 1046* was 43,600 cfs with the existing tailwater.

8. Flow conditions were next observed with discharges of 10,000 cfs, the maximum discharge through the center portion of the structure before flow occurred over the side portions of the structure, and 43,600 cfs, the capacity of the structure, for both existing tailwater conditions and tailwaters expected with degraded channel conditions (6 ft lower than existing tailwater elevations). Inadequate energy dissipation occurred with a discharge of 43,600 cfs. The large contraction of flow at the abutments and piers caused flow to concentrate in the center of the channel. Flow conditions with a discharge of 43,600 cfs are shown in Photo 1. High velocities were measured over the end sill and in the downstream channel. Velocities measured with a discharge of 43,600 cfs and the existing tailwater, el 1036.8, are shown in Plate 5; and velocities with the tailwater resulting from ultimate degraded conditions, el 1030.8, are shown in Plate 6. Velocities over 10 fps were measured in the exit channel and these were considered excessive.

9. Flow conditions with a discharge of 10,000 cfs are shown in Photo 2. Velocities measured with a discharge of 10,000 cfs for the existing tailwater conditions and the tailwater resulting from ultimate degraded conditions are shown in Plates 7 and 8, respectively. Stilling basin performance was considered marginal with a discharge of 10,000 cfs.

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

Abutments

10. Before improvements to stilling basin performance were attempted, the abutments to the structure were modified in an effort to improve entrance conditions. Photo 3 shows the entrance conditions with the original design abutments for a discharge of 43,600 cfs. Contractions of flow at the abutments and at the walls of the center portion of the structure caused a flow concentration in the stilling basins which decreased energy dissipation. Another illustration of this flow condition in the center portion of the structure is shown in Photo 4 for a discharge of 10,000 cfs. Several wing wall designs (Plate 9) were tested to improve flow into the side portions of the structure. Semicircular pier noses (Type 2 pier noses) with a radius of 2.5 ft were attached to the center walls. Calibration data obtained with the various modifications are shown in Plates 10-12. Approach dikes (Plates 13 and 14) were also tested. Velocities measured with the Type 2 approach dikes are also shown in Plates 13 and 14. The velocities over the end sill were slightly less than those measured with the original design (compare Plates 13 and 5) but there was not a significant improvement. The Types 3 and 4 approach wing walls (see Plate 9) were tested with the Type 2 approach dikes and Table 1 shows calibration data obtained with these modifications. The Type 2 approach dikes were removed and the Type 5 design approach wing walls (Plate 9) were tested next. Flow conditions with the Type 5 design approach wing walls for a discharge of 43,600 cfs are shown in Photo 5. These approach wing walls were found to be the simplest and most effective design for reducing the contraction at the abutments, but none of the modifications to the abutments significantly affected the efficiency of the structure with the design discharge because of the high degree of submergence. Therefore the original design abutment (Plate 9) was considered acceptable.

Weir and Stilling Basin

11. Modifications to the weir and stilling basin were made to try and improve the performance of the structure. The walls of the center portion of the structure were lowered from el 1047 to el 1020. This modification was noted as the Type 2 design basin walls (Plate 15). An additional 10-ft length of weir at el 1032 was provided with the Type 2 design weir since the center

walls in the basin that were at el 1047 with the Type 1 design weir were lowered to el 1020. No improvement in performance was observed with the Type 2 design walls and weir. The walls of the center portion of the structure were removed completely (Type 3 design basin walls as shown in Plate 15), and the basin elements remained the same as the Type 1 (original) design stilling basin. No improvement in performance was observed with this modification.

12. A new weir design (Type 3 design weir) was furnished by MRO to try and obtain a desired headwater rating curve. Details of the weir are shown in Plate 16 along with the headwater rating curves obtained for existing tailwater conditions and no tailwater effect. The rating curve was not acceptable. The Type 4 design weir shown in Plate 16 was tested next, and the headwater rating curve obtained with this design was also not acceptable.

13. A desired range of headwater elevations (Plate 17) was furnished by MRO. Since the Types 1-4 design weir headwater rating curves were not within this desired range, several weir designs were tested to try and match the range of headwater elevations desired. The purpose of placing notches in the weir was to produce a headwater elevation at lower discharges that would be beneficial for conditions upstream from the structure. The water level in the channel upstream from the weir needed to be maintained at certain elevations during lower discharges so that drainage into the channel would not cause problems either by erosion at the outlet if the water level was too low or by backwater flooding if the water level was too high. Problems can be encountered with the use of a notched weir if eddies form in the stilling basin for low discharges. These eddies could cause abrasive damage if abrasive materials enter the stilling basin. Headwater rating curves with the Types 5-8 design weirs are shown in Plate 17 along with a description of each design. Tests indicated that it would not be possible to stay within the desired zone of headwaters for all discharges with the Types 5-8 design weirs. However, the Type 8 design weir was considered acceptable by MRO due to the infrequent occurrence of discharges greater than 40,000 cfs.

14. Stilling basin performance was determined by conducting comparative scour tests. Results of these tests were used to evaluate the relative merits of basin modifications. Each scour test consisted of 5 hr of operation (1 hr model time) with a discharge of 46,000 cfs and the existing tailwater (el 1039.9). The scour tests were conducted with these conditions because the

capacity of the structure with the Type 8 design weir was 46,000 cfs. This discharge produced a headwater elevation of 1046, which provided 1 ft of freeboard. Additional computations by MRO indicated that the corresponding tailwater for a discharge of 46,000 cfs was 1039.9. The revised tailwater rating curve is shown in Plate 18. Upon completion of the test, photographs and profiles of the scour in the exit channel were obtained.

15. The first scour test was conducted with the Type 4 design stilling basin walls (Plate 15) and the basin elements (baffle blocks and end sill) of the Types 2 and 4 design basins shown in Plate 19. Photographs of the scour resulting from the test of the Type 2 stilling basin with the Type 4 basin walls are shown in Photo 6. A center-line profile of scour measured after the scour test is shown in Plate 20. The scour in the exit channel was not excessive, which indicates satisfactory basin performance. Additional photographs of flow conditions with the Type 4 design basin walls and the Type 2 design stilling basin are shown in Photos 7 and 8 for discharges of 46,000 and 10,000 cfs, respectively.

16. The stilling basin length was reduced to 100 ft in an effort to reduce construction costs. This shortened basin was designated the Type 3 design stilling basin and the basin walls were designated the Type 6 design (Plate 15). The end sill and baffle block size, spacing, and distance from the end sill remained the same as the Type 2 design stilling basin. Photo 9 shows the scour in the exit channel after a test was conducted. The center-line scour profile is shown in Plate 20. Basin performance was poor and scour in the exit channel was excessive. Thus the basin length was increased back to 130 ft for the remaining tests.

17. Scour tests were continued to determined if the stilling basin wall heights and baffle block height could be reduced to effect economy in construction of the stilling basin. The next scour test was conducted with the stilling basin walls lowered from el 1047 to el 1035 (Type 7 design basin walls, Plate 15) and with the basin elements of the Type 2 design stilling basin. Results from this test are shown in Photo 10 and the center-line scour profile is shown in Plate 20. An increase in scour was observed with this design over that observed with the Type 4 design basin walls. The shortened wall height allowed return flow over the basin walls which decreased the effectiveness of the stilling basin by concentrating the flow. This type of flow concentration is illustrated in Photos 11 and 12 with the Type 5 design basin walls.

18. The Type 8 design basin walls shown in Plate 15 were tested next with the elements of the Type 2 design stilling basin. Scour resulting from this test is shown in Photo 13 and Plate 20. Energy dissipation was hampered by the return flow as experienced with the Type 7 design basin walls which caused an increase in the scour in the downstream channel. The Type 9 design basin walls (Plate 15) were tested next. Scour in the downstream channel was similar to that observed with the Type 4 design basin walls shown in Photo 6. The center-line scour profile (Plate 20) is also similar to that obtained with the Type 4 design basin walls. The Type 9 design basin walls were considered the minimum wall height necessary to prevent return flow from entering the basin sufficient to produce a harmful concentration of flow.

19. The baffle block height was reduced from 10.5 to 8.0 ft while keeping the same width and spacing. A scour test was performed with the reduced height of baffles and the Type 9 design basin walls. Photo 14 shows the scour in the exit channel and the center-line scour profile is shown in Plate 20. The scour was excessive, indicating that 10.5-ft-high baffle blocks are required to produce adequate energy dissipation with the design discharge and existing tailwater. Relatively large baffle blocks spaced close to the end sill have been observed to perform better with highly submerged flows.

20. The Type 8 design weir, Type 9 design basin walls, and Type 2 design stilling basin elements performed satisfactorily for the design discharge of 46,000 cfs, except for the low discharge eddies that formed in the basin. These eddies could cause abrasive damage to the stilling basin if abrasive materials are present in the vicinity of the project. Low-flow training walls, 5 ft high and located as shown in Plate 19, prevented this adverse condition. Photo 15 shows flow conditions in the basin without the low-flow training walls for a discharge of 1,000 cfs and tailwaters of 1014 and 1010.5. Sand was placed in the basin to highlight the eddy action and confetti was used to show surface currents. The low-flow training walls prevented the strong abrasive eddies from forming for a discharge of 1,000 cfs and tailwaters of 1014 and 1010.5 as shown in Photo 16. Confetti indicates that the flow circulation in the areas adjacent to the center notch is minimal and sand movement on the floor of the basin in these areas did not indicate severe eddy action.

21. Additional tests were conducted with the Type 9 design weir. This weir was tested to determine if it would produce flow conditions that were

favorable for upstream fish migration. A low notch in the weir was necessary to satisfy requirements for fish passage. Details of this design are shown in Plate 21 along with headwater rating curves for existing, and ultimate degraded, channel tailwater conditions. Headwater elevations measured for discharges less than 10,000 cfs were lower with the Type 9 design weir than with designs previously tested. Stilling basin performance was considered satisfactory for the design discharge of 46,000 cfs. There was some concern over unsymmetrical flow in the basin due to the low-flow notch being placed off-center; therefore a 5-ft-high training wall located 55.67 ft from the left sidewall (Plate 22) was installed in the basin. This wall was required to prevent eddies that could cause abrasive damage with discharges less than 2,500 cfs. Photo 17 shows the dry bed with the Type 9 design weir and modified approach channel. Flow conditions with discharges of 500 and 1,000 cfs through the low-flow notch are shown in Photos 18 and 19, respectively. These discharges were within the range desired for fish migration through the structure. Due to the configuration of the Type 9 design weir, a low-flow training wall that was necessary for previous designs was not required on the right side of the basin. Symmetrical flow was not achieved in the basin with these low discharges; however, energy dissipation was adequate due to the size of the basin. The eddies that formed in the basin with the low flows (Photo 19b) were mild; and once discharges greater than 2,500 cfs occur, any material that may have settled in the basin should be washed out.

22. As mentioned, the discharges required for fish migration were between 500 and 1,000 cfs. Velocity measurements requested for use in further evaluating fish migration and obtained in and adjacent to the low-flow notch at 0.2 and 0.8 of the depth of flow for discharges of 1,000 and 500 cfs are shown in Plates 23 and 24, respectively. Tables 2 and 3 show the remaining velocity measurements obtained at other depths for discharges of 1,000 and 500 cfs, and Plate 25 shows the locations of these velocity measurements. The maximum velocity measured with a discharge of 1,000 cfs and existing tailwater was 13.7 fps and occurred at the notch (Table 2). The maximum velocity measured with a discharge of 500 cfs and existing tailwater was 6.6 fps and occurred at several locations in and adjacent to the notch. These velocities were not excessive and were considered appropriate for fish migration.

23. Table 4 presents calibration data obtained with the Type 9 design weir for low flows and tailwaters higher than the existing values. These were

measured to determine the effect of the tailwater on the headwater elevation. These data are plotted and shown in Plate 21 for comparison with the existing tailwater.

Riprap Tests

24. Initial riprap tests were conducted with the Type 8 design weir, Type 2 design stilling basin, and Type 9 design basin walls. The Type 1 riprap gradation (Plate 26) was placed as shown in Photo 20. A D_{50} size stone of 12 in. and a blanket thickness of 18 in. were used for all riprap areas. A test was conducted with the design flow of 46,000 cfs and ultimate, degraded tailwater elevation of 1035 for 1-hr model time, equivalent to 5 hr prototype time, to determine the adequacy of the riprap protection. Results of this test are shown in Photo 21. The riprap was displaced in areas below the stilling basin and on the channel side slopes immediately downstream from the basin although it is not obvious in Photo 21. Flow observations with the Type 9 design weir requested by MRO interrupted riprap tests; and when riprap tests were continued, the Type 9 design weir was the adopted design. Thus the remaining riprap tests were conducted with the Type 9 design weir and each test consisted of the following conditions:

Discharge	TW El	Prototype Hours of Operation
20,000	1024.4	5
38,000	1032	5
46,000	1035	5

25. The Type A riprap plan shown in Plate 27 was tested initially with the Type 9 design weir. The only difference between the Type A riprap plan and the initial riprap plan shown in Photo 20 was the shortened length of channel side slopes protection. Tests verified that the 18-in. blanket thickness was inadequate below the stilling basin and on the channel side slopes immediately downstream from the basin.

26. The Type B riprap plan shown in Plate 28 was tested next. The riprap immediately downstream from the basin was replaced with the Type 2 riprap gradation shown in Plate 29 and placed as shown in Plate 30 and Photo 22. A 100-ft length of riprap on the channel side slope beginning at the end of the stilling basin was replaced with the Type 3 gradation shown in Plate 31. Riprap was also removed from the top bank and portions of the levee for the

Type B riprap plan as shown in Plate 28, since velocities were very small in these areas. During tests with the Type B riprap plan, a scour hole developed just downstream from the basin exposing the riprap protection on the downward slope and undermining some of the riprap on the left channel side slope. Results of the riprap tests are shown in Photo 23. The toe of the riprap on the side slopes downstream from the channel bottom riprap was truncated at el 1005 and the location of the bottom of the scour hole was el 995.5. If the toe of the riprap on the side slopes is placed lower than the maximum anticipated channel bottom scour, the riprap would not be undermined and would remain stable. The model will not indicate as much depth of scour as will occur in the prototype with flow throughout the life of the project.

27. The Type C riprap plan (Plate 32) and Type D riprap plan (Plate 33) were tested to determine what effect varying the length of a level blanket of riprap downstream from the stilling basin would have on the scour depth. The top of the riprap blanket was placed at el 1005 and remained at this elevation for 100 ft, and then the riprap was sloped downward 1V on 3H to el 996 for the Type C riprap plan. These details are shown in Plate 30 for the Type C riprap plan. Results from the riprap test with the Type C riprap plan revealed that the bottom of the scour hole was at el 998.3 and occurred 107.5 ft downstream from the stilling basin. Results from this test are shown in Photo 24.

28. An additional 50 ft of the Type 3 riprap gradation was placed downstream of the Type 2 riprap gradation and was designated the Type D riprap plan as shown in Plate 33. At the end of the additional 50 ft, the Type 3 riprap gradation was sloped downward 1V on 3H from el 1005 to el 996. Results from this test are shown in Photo 25. The elevation at the bottom of the scour hole resulting from the riprap test with the Type D riprap plan was 1000.3 and occurred 190 ft downstream from the stilling basin. Thus, extending the 27-in. blanket thickness of the riprap 50 ft downstream (Type D riprap plan) caused a reduction in scour of the channel bottom. Although the depth of scour in the model does not simulate the depth of scour that will occur in the prototype, the relative scour does indicate a reduction of energy at the end of the riprap with the Type D plan.

Flow Conditions with Recommended Design

29. Flow conditions with the recommended structure (Plate 22) are shown

in Photos 26 and 27 for discharges of 46,000 and 10,000 cfs, respectively. Velocities measured with the recommended structure are shown in Plates 34 and 35 for a discharge of 46,000 cfs and velocities measured with a discharge of 10,000 cfs are shown in Plates 36 and 37. Acceptable flow conditions occurred with the maximum discharge of 46,000 cfs although some scour in the exit channel should be expected when this discharge occurs.

PART IV: DISCUSSION OF RESULTS AND CONCLUSIONS

30. Model tests conducted with the original design structure revealed that performance of the structure was inadequate and unacceptable. Energy dissipation in the stilling basin was poor and high velocities were present in the exit channel. Modifications to improve entrance flow conditions did not significantly improve the efficiency of the structure or the energy dissipation in the stilling basin.

31. Modifications were made to the original design to produce a structure that provided an acceptable headwater rating curve and adequate energy dissipation. The Type 9 design weir (Plates 21 and 22) provided the desired range of headwater elevations for the discharges expected at the project, and velocities upstream and downstream from the low-flow notch of the Type 9 design weir were considered appropriate for fish migration with discharges less than 1,000 cfs. The elements of the stilling basin were also modified to improve energy dissipation. The baffle blocks should be 10.5 ft high and placed 23 ft upstream from the end sill as shown in Plate 19. A 5-ft-high low-flow training wall is necessary to prevent abrasive eddies from forming in the basin with discharges less than 2,500 cfs. This location of the wall is shown in Plate 22. Details of the adopted structure developed from the model tests are shown in Plate 22; and the completed prototype structures is shown in Figure 5. The capacity of this structure was determined to be 46,000 cfs, which provided sufficient freeboard on the upstream levees.

Figure 5. New prototype structure about 1,000 ft downstream of old structure (removed); flow is from left to right

32. The low-flow notch was placed near the left wall so that debris can be removed if it becomes lodged against the structure. Placement of the low-flow notch in this location requires that a training wall be placed in the basin to prevent abrasive eddies from forming.

33. Riprap tests indicated that a 48-in. blanket thickness is required on the channel bottom downstream from the stilling basin. A 27-in. blanket thickness is required on the channel side slopes for a distance of 100 ft starting at the end of the stilling basin, and the remaining side-slope protection requires a blanket thickness of 18 in. This type of side-slope protection is shown in the Types B, C, and D riprap plans.

34. Tests of the channel bottom riprap revealed that extending the channel bottom riprap blanket farther downstream and transitioning to a smaller size reduced the amount of scour. The Type D riprap plan (Plate 33) provided satisfactory protection with the least amount of scour downstream from the riprap. If the Type B riprap plan (Plate 28) is used in the prototype, the toe of the riprap on the side slopes should be extended to at least the same depth as the sloping riprap immediately downstream from the stilling basin. Model tests indicated that the Types B, C, and D riprap plans will provide adequate protection for the structure; and selection of one of these plans would depend on the amount of scour that is acceptable in the exit channel downstream from the riprap protection.

Table 1

Comparison of Headwater Elevations

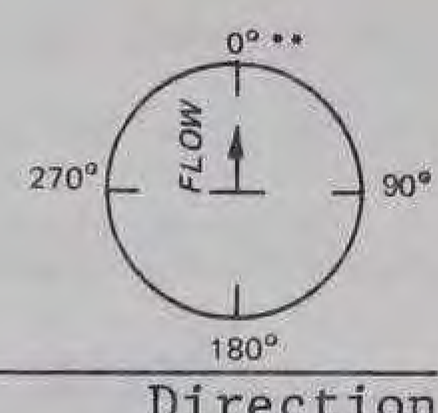
Design	Discharge cfs	Tailwater Elevation	Headwater Elevation
Type 2 approach dikes	20,000	1029.2	1036.7
	20,000	*	1036.5
	30,000	1033.0	1040.3
	30,000	*	1040.1
	43,600	1036.8	1045.5
	43,600	*	1044.4
Type 2 approach dikes and Type 3 approach wing walls	20,000	1029.2	1036.7
	20,000	1030.6	1037.0
	30,000	1033.0	1040.6
	30,000	1035.2	1041.1
	30,000	*	1039.8
	43,600	1036.8	1045.2
	43,600	1039.0	1045.9
	43,600	*	1043.8
Type 2 approach dikes and Type 4 approach wing walls	20,000	1029.2	1036.8
	20,000	1030.6	1036.9
	20,000	*	1036.4
	30,000	1033.0	1040.7
	30,000	1035.2	1041.3
	30,000	*	1040.0
	43,600	1036.8	1045.2
	43,600	1039.0	1045.8
	43,600	*	1043.7

* No tailwater effect.

Table 2

Velocities in Vicinity of Low-Flow Notch

Discharge 1,000 cfs, TW El 1014



Location Number*	Elevation	Velocity fps	Direction deg
1	1015.6	<2	60
2	1014.6	2.7	60
3	1008.9	3.4	60
4	1008	2.7	60
5	1007.5	2.7	60
11	1015.6	4.0	45
12	1014.6	4.0	45
13	1008.9	4.5	45
14	1008	5.0	45
15	1007.5	4.5	45
21	1015.6	4.0	10
22	1014.6	4.5	10
23	1008.9	5.8	10
24	1008	5.0	10
25	1007.5	5.4	10
26	1015.6	5.4	0
27	1014.6	5.4	0
28	1008.9	5.8	0
29	1008	6.6	0
30	1007.5	5.8	0
31	1015.6	4.5	350
32	1014.6	4.5	350
33	1008.9	5.0	350
34	1008	5.0	350
35	1007.5	5.4	350
41	1015.6	3.4	300
42	1014.6	4.0	300
43	1008.9	4.0	300
44	1008	4.0	300
45	1007.5	4.0	300
51	1015.6	2.7	280
52	1014.6	2.7	280

(Continued)

* See Plate 25 for location of velocities.

** 0 deg represents flow in downstream direction; 180 deg represents flow in upstream direction.

Table 2 (Continued)

Location Number	Elevation	Velocity fps	Direction deg
53	1008.9	3.4	280
54	1008	3.4	280
55	1007.5	3.4	280
56	1015.5	<2	80
57	1014.5	<2	80
58	1008.9	<2	80
59	1008	<2	80
60	1007.5	<2	80
61	1015.5	4.0	70
62	1014.5	5.0	70
63	1008.9	6.2	70
64	1008	6.2	70
65	1007.5	6.2	70
66	1015.5	4.0	45
67	1014.5	5.4	45
68	1008.9	6.6	45
69	1008	6.9	45
70	1007.5	7.3	45
71	1015.5	5.4	30
72	1014.5	5.8	30
73	1008.9	6.9	30
74	1008	7.3	30
75	1007.5	7.3	30
76	1015.5	4.5	10
77	1014.5	5.8	10
78	1008.9	6.9	10
79	1008	6.9	10
80	1007.5	7.3	10
81	1015.5	5.8	0
82	1014.5	5.8	0
83	1008.9	6.9	0
84	1008	7.3	0
85	1007.5	7.6	0
86	1015.5	5.0	350
87	1014.5	5.8	350
88	1008.9	7.6	350
89	1008	8.3	350
90	1007.5	8.6	350

(Continued)

Table 2 (Continued)

Location Number	Elevation	Velocity fps	Direction deg
91	1015.5	5.4	330
92	1014.5	6.6	350
93	1008.9	6.9	330
94	1008	7.3	330
95	1007.5	7.6	330
96	1015.5	4.5	315
97	1014.5	5.0	315
98	1008.9	5.4	315
99	1008	5.8	315
100	1007.5	5.4	315
101	1015.5	4.5	300
102	1014.5	5.0	300
103	1008.9	5.4	300
104	1008	5.8	300
105	1007.5	5.8	300
106	1015.5	3.4	280
107	1014.5	4.0	280
108	1008.9	4.5	280
109	1008	4.0	280
110	1007.5	4.0	280
111	1014.9	--	--
112	1014	12.0	Variable
113	1008.75	13.0	Variable
114	1008	12.4	Variable
115	1007.5	12.4	Variable
116	1014.9	--	--
117	1014	11.2	45
118	1008.75	11.7	45
119	1008	12.0	45
120	1007.5	11.5	45
121	1014.9	--	--
122	1014	12.2	30
123	1008.75	13.3	30
124	1008	13.4	30
125	1007.5	13.4	30

(Continued)

Table 2 (Continued)

Location Number	Elevation	Velocity fps	Direction deg
126	1014.9	10.4	10
127	1014	11.1	10
128	1008.75	12.9	10
129	1008	13.7	10
130	1007.5	13.5	10
131	1014.9	9.0	0
132	1014	10.2	0
133	1008.75	12.4	0
134	1008	12.7	0
135	1007.5	12.9	0
136	1014.9	10.0	0
137	1014	10.6	0
138	1008.75	12.2	0
139	1008	12.9	0
140	1007.5	13.0	0
141	1014.9	--	--
142	1014	11.8	330
143	1008.75	13.0	330
144	1008	13.0	330
145	1007.5	13.0	330
146	1014.9	--	--
147	1014	11.7	330
148	1008.75	12.6	330
149	1008	12.9	330
150	1007.5	12.9	330
151	1014.9	--	--
152	1014	12.2	300
153	1008.75	12.7	300
154	1008	12.7	300
155	1007.5	12.7	300
156	1013.1	<2	Variable
157	1012.2	<2	Variable
158	1006.8	<2	Variable
159	1006	<2	Variable
160	1005.5	<2	Variable

(Continued)

Table 2 (Continued)

Location Number	Elevation	Velocity fps	Direction deg
161	1013.1	<2	Variable
162	1012.2	<2	Variable
163	1006.8	<2	Variable
164	1006	<2	Variable
165	1005.5	<2	Variable
166	1013.15	4.5	0
167	1012.3	<2	90
168	1007.2	<2	90
169	1006.5	<2	90
170	1006	<2	90
171	1013.2	7.6	90
172	1012.4	8.0	90
173	1007.6	8.3	90
174	1007	8.6	90
175	1006.5	7.6	90
176	1013.2	9.9	0
177	1012.4	10.9	0
178	1007.2	6.2	0
179	1007	2.7	0
180	1006.5	<2	0
181	1013.2	10.7	0
182	1012.4	12.7	0
183	1007.2	12.9	0
184	1007	10.9	0
185	1006.5	10.5	0
186	1013.2	4.5	0
187	1012.4	10.9	0
188	1007.2	11.6	0
189	1007	9.7	0
190	1006.5	8.9	0
191	1013.2	9.4	0
192	1012.4	9.7	0
193	1007.2	10.9	0
194	1007	9.9	0
195	1006.5	8.0	0

(Continued)

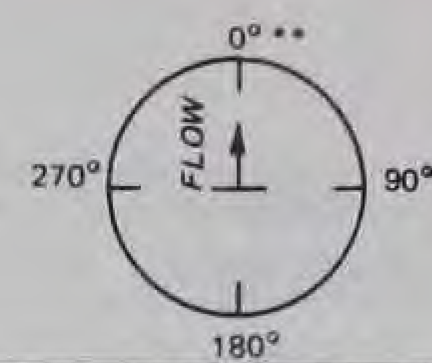
Table 2 (Concluded)

Location Number	Elevation	Velocity fps	Direction deg
196	1013.2	9.7	0
197	1012.4	10.5	0
198	1007.2	11.2	0
199	1007	10.9	0
200	1006.5	9.4	0
201	1013.2	9.7	0
202	1012.4	10.9	0
203	1007.2	8.6	0
204	1007	9.2	315
205	1006.5	7.6	315
206	1013.15	4.5	0
207	1012.3	4.0	315
208	1007.2	<2	Variable
209	1006.5	<2	Variable
210	1006	<2	Variable
211	1013.1	<2	Variable
212	1012.2	<2	Variable
213	1006.8	<2	Variable
214	1006	<2	Variable
215	1005.5	<2	Variable
216	1013.1	<2	Variable
217	1012.2	<2	Variable
218	1006.8	<2	Variable
219	1006	<2	Variable
220	1005.5	<2	Variable

Table 3

Velocities in Vicinity of Low-Flow Notch

Discharge 500 cfs, TW El 1013



Location Number*	Elevation	Velocity fps	Direction deg
1	1013.3	<2	45
2	1012.6	<2	45
3	1008.4	<2	45
4	1008	<2	45
5	1007.5	<2	45
11	1013.3	<2	30
12	1012.6	<2	30
13	1008.4	2.7	30
14	1008	2.7	30
15	1007.5	2.7	30
21	1013.3	2.7	0
22	1012.6	2.7	0
23	1008.4	2.7	0
24	1008	2.7	0
25	1007.5	2.7	0
26	1013.3	2.7	0
27	1012.6	2.7	0
28	1008.4	2.7	0
29	1008	2.7	0
30	1007.5	2.7	0
31	1013.3	2.7	350
32	1012.6	2.7	350
33	1008.4	2.7	350
34	1008	2.7	350
35	1007.5	2.7	350
41	1013.3	2.7	315
42	1012.6	2.7	315
43	1008.4	3.4	315
44	1008	3.4	315
45	1007.5	2.7	315

(Continued)

* See Plate 25 for location of velocities.

** 0 deg represents flow in downstream direction; 180 deg represents flow in upstream direction.

Table 3 (Continued)

Location Number	Elevation	Velocity fps	Direction deg
51	1013.3	<2	280
52	1012.6	<2	280
53	1008.4	<2	280
54	1008	<2	280
55	1007.5	<2	280
56	1013.3	<2	85
57	1012.6	<2	85
58	1008.4	<2	85
59	1008	<2	85
60	1007.5	<2	85
61	1013.3	2.7	45
62	1012.6	2.7	45
63	1008.4	3.4	45
64	1008	3.4	45
65	1007.5	2.7	45
66	1013.3	3.4	30
67	1012.6	4.0	30
68	1008.4	4.0	30
69	1008	4.0	30
70	1007.5	4.0	30
71	1013.3	4.0	30
72	1012.6	4.0	30
73	1008.4	4.5	30
74	1008	4.5	30
75	1007.5	4.0	30
76	1013.3	3.4	10
77	1012.6	4.0	10
78	1008.4	4.0	10
79	1008	4.5	10
80	1007.5	4.5	10
81	1013.3	4.0	0
82	1012.6	4.0	0
83	1008.4	5.0	0
84	1008	4.5	0
85	1007.5	4.5	0

(Continued)

Table 3 (Continued)

Location Number	Elevation	Velocity fps	Direction deg
86	1013.3	4.0	350
87	1012.6	4.0	350
88	1008.4	5.0	350
89	1008	5.0	350
90	1007.5	5.4	350
91	1013.3	3.4	315
92	1012.6	4.5	315
93	1008.4	5.0	315
94	1008	4.5	315
95	1007.5	4.5	315
96	1013.3	3.4	315
97	1012.6	4.0	315
98	1008.4	4.5	315
99	1008	4.0	315
100	1007.5	4.0	315
101	1013.3	2.7	280
102	1012.6	2.7	280
103	1008.4	3.4	280
104	1008	3.4	280
105	1007.5	3.4	280
106	1013.3	<2	270
107	1012.6	<2	270
108	1008.4	<2	270
109	1008	<2	270
110	1007.5	<2	270
111	1013.1	6.6	45
112	1012.4	6.2	45
113	1008.4	6.6	45
114	1008	6.2	45
115	1007.5	6.2	45
116	1013.1	--	--
117	1012.4	5.4	45
118	1008.4	5.4	45
119	1008	5.4	45
120	1007.5	6.2	45

(Continued)

Table 3 (Continued)

Location Number	Elevation	Velocity fps	Direction deg
121	1013.1	4.0	10
122	1012.4	5.0	10
123	1008.4	5.8	10
124	1008	6.2	10
125	1007.5	6.6	10
126	1013.1	5.0	0
127	1012.4	5.4	0
128	1008.4	6.2	0
129	1008	6.6	0
130	1007.5	6.6	0
131	1013.1	4.5	0
132	1012.4	5.0	0
133	1008.4	5.8	0
134	1008	6.2	0
135	1007.5	6.2	0
136	1013.1	4.5	355
137	1012.4	5.0	355
138	1008.4	5.8	355
139	1008	6.2	355
140	1007.5	6.6	355
141	1013.1	4.5	330
142	1012.4	5.4	330
143	1008.4	6.2	330
144	1008	6.6	330
145	1007.5	6.6	330
146	1013.1	--	--
147	1012.4	5.8	330
148	1008.4	6.2	330
149	1008	6.2	330
150	1007.5	6.6	330
151	1013.1	--	--
152	1012.4	5.0	345
153	1008.4	5.8	345
154	1008	5.8	345
155	1007.5	6.2	345

(Continued)

Table 3 (Continued)

Location Number	Elevation	Velocity fps	Direction deg
156	1012.7	<2	Variable
157	1011.8	<2	Variable
158	1006.7	<2	Variable
159	1006	<2	Variable
160	1005.5	<2	Variable
161	1012.7	<2	Variable
162	1011.8	<2	Variable
163	1006.7	<2	Variable
164	1006	<2	Variable
165	1005.5	<2	Variable
166	1012.7	<2	Variable
167	1011.9	<2	Variable
168	1007.1	<2	Variable
169	1006.5	<2	Variable
170	1006	<2	Variable
171	1012.8	<2	0
172	1012.0	<2	0
173	1007.5	<2	Variable
174	1007	<2	Variable
175	1006.5	<2	Variable
176	1012.8	5.0	0
177	1012.0	5.0	0
178	1007.5	5.0	45
179	1007	5.8	45
180	1006.5	5.0	45
181	1012.8	4.0	0
182	1012.0	5.0	0
183	1007.5	6.6	0
184	1007	6.2	0
185	1006.5	5.4	0
186	1012.8	5.4	0
187	1012.0	5.8	0
188	1007.5	5.8	0
189	1007	4.5	0
190	1006.5	<2	0

(Continued)

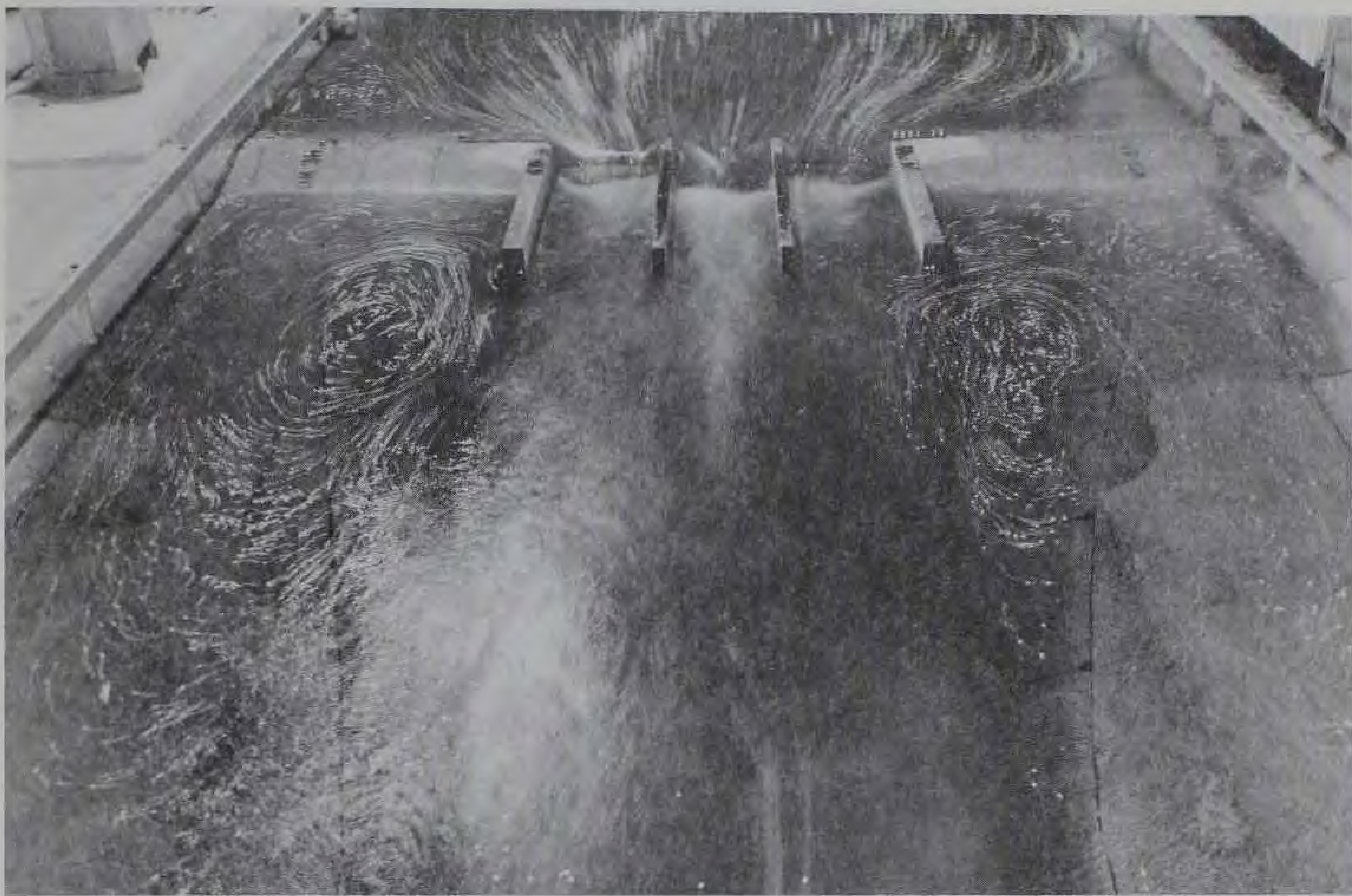
Table 3 (Concluded)

Location Number	Elevation	Velocity fps	Direction deg
191	1012.8	5.0	0
192	1012.0	5.0	0
193	1007.5	3.4	0
194	1007	<2	0
195	1006.5	<2	0
196	1012.8	2.7	0
197	1012.0	<2	0
198	1007.5	<2	0
199	1007	<2	0
200	1006.5	<2	0
201	1012.8	<2	Variable
202	1012.0	<2	Variable
203	1007.5	<2	Variable
204	1007	<2	Variable
205	1006.5	<2	Variable
206	1012.7	<2	Variable
207	1011.9	<2	Variable
208	1007.1	<2	Variable
209	1006.5	<2	Variable
210	1006	<2	Variable
211	1012.7	<2	Variable
212	1011.8	<2	Variable
213	1006.7	<2	Variable
214	1006	<2	Variable
215	1005.5	<2	Variable
216	1012.7	<2	Variable
217	1011.8	<2	Variable
218	1006.7	<2	Variable
219	1006	<2	Variable
220	1005.5	<2	Variable

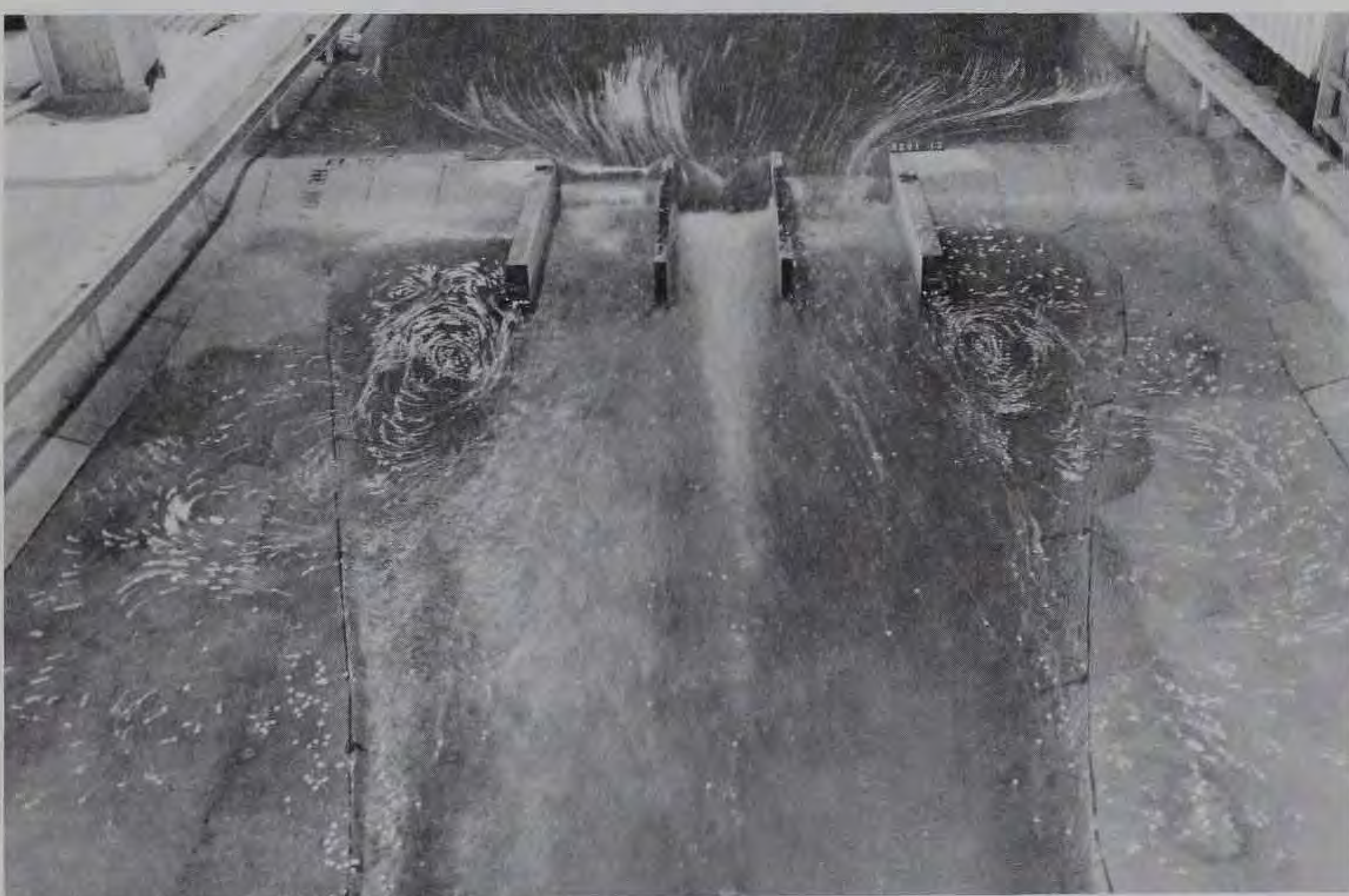
Table 4

Headwater Elevations Measured with Assumed Higher Tailwater Elevations for the Type 9 Design Weir

Discharge cfs	Tailwater Elevation	Headwater Elevation
500	1015.6	1016.0
1,000	1016.0	1017.9
1,500	1016.4	1020.6
2,500	1017.4	1023.0

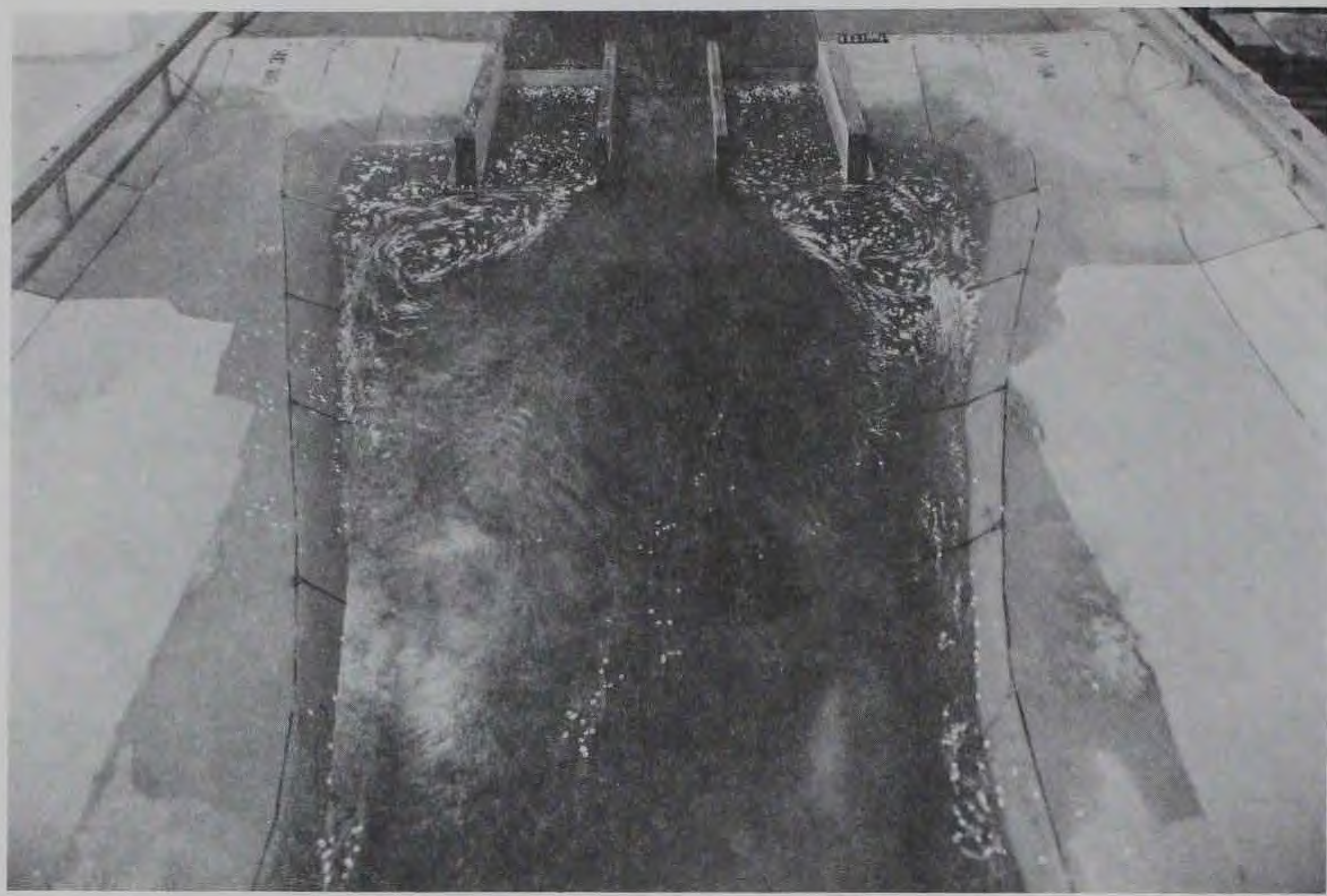


a. Existing tailwater el 1036.8

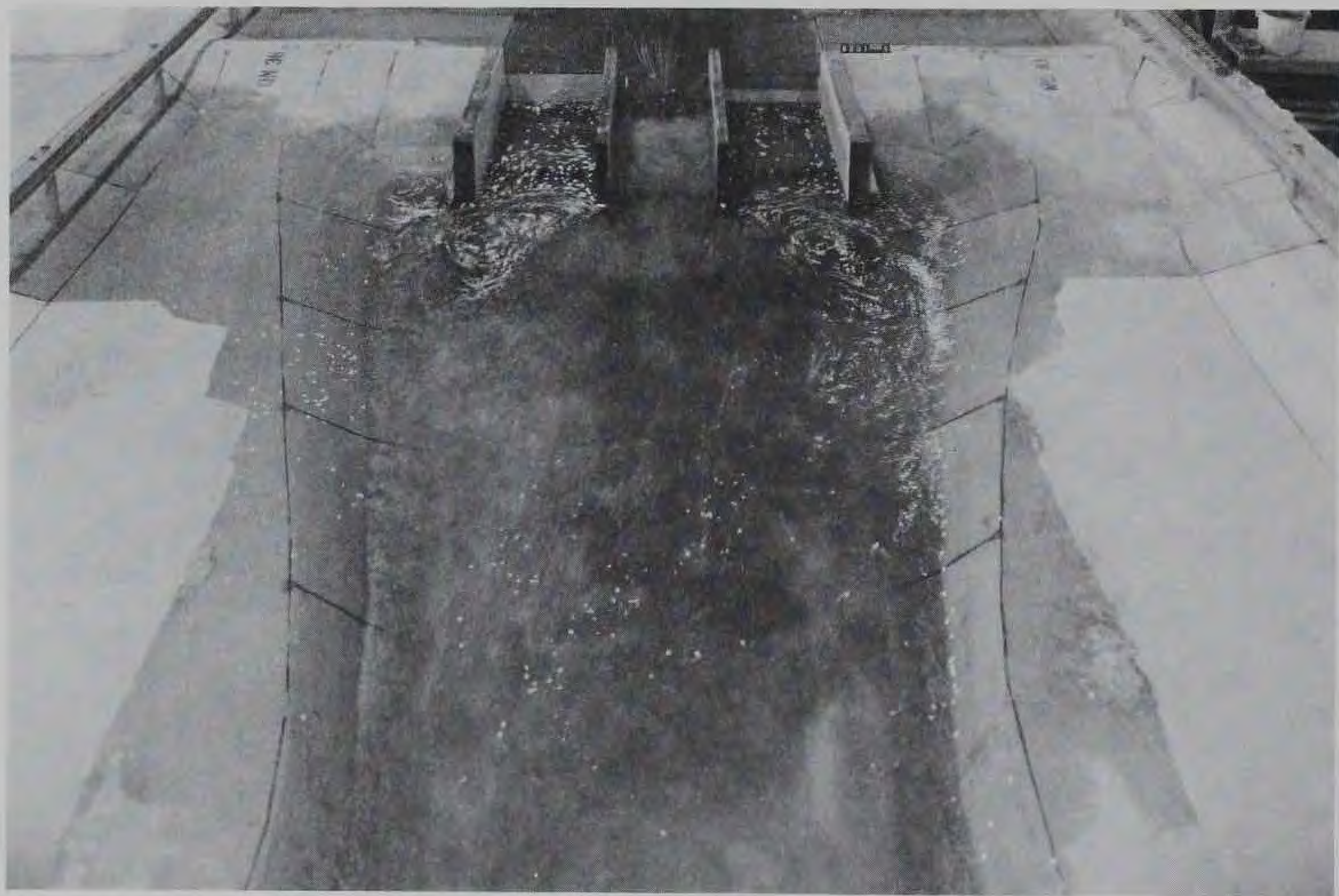


b. Tailwater el 1030.8 with ultimate degraded conditions

Photo 1. Flow conditions with the original design structure; discharge 43,600 cfs



a. Existing tailwater el 1023.5



b. Tailwater el 1017.5 with ultimate degraded conditions

Photo 2. Flow conditions with the original design; discharge 10,000 cfs

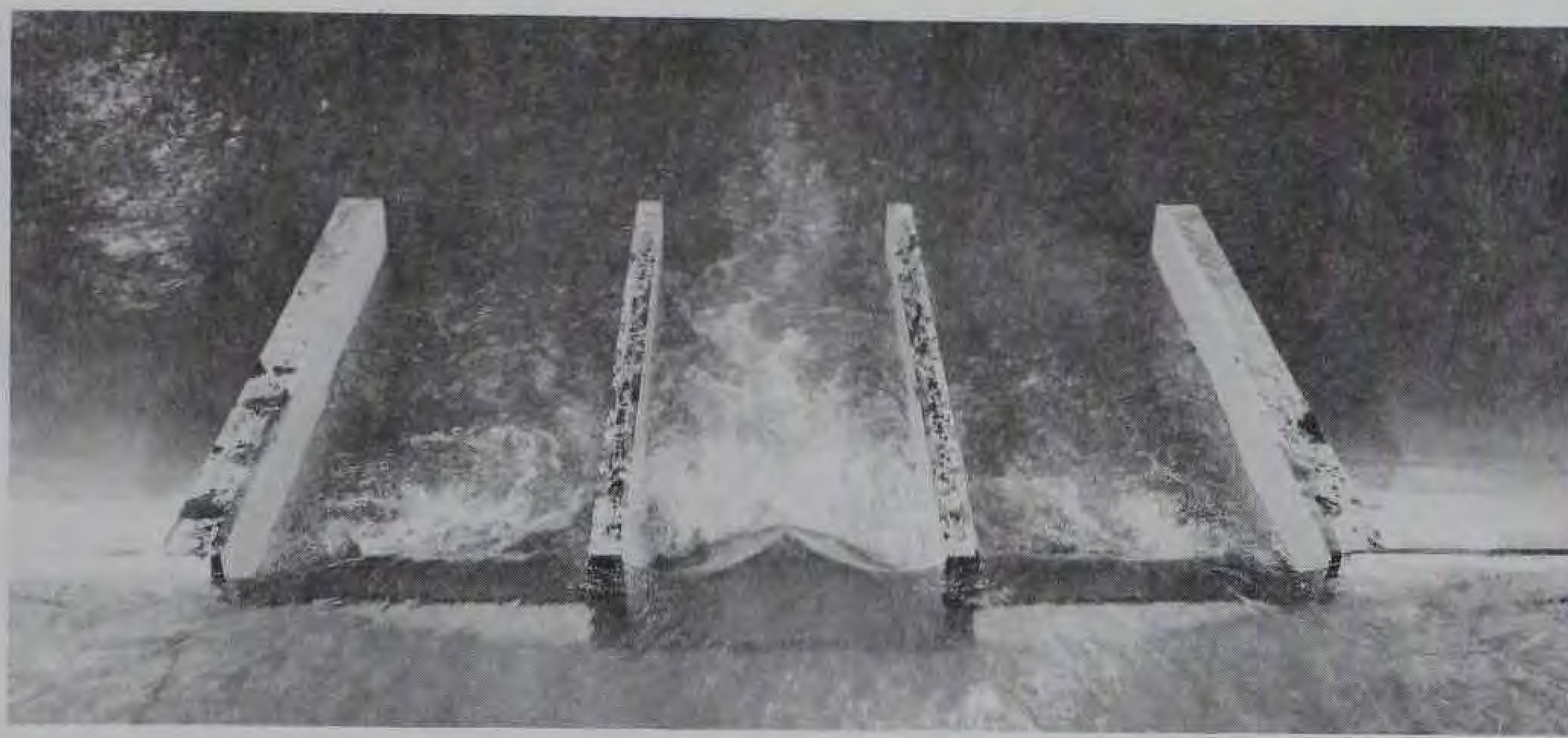
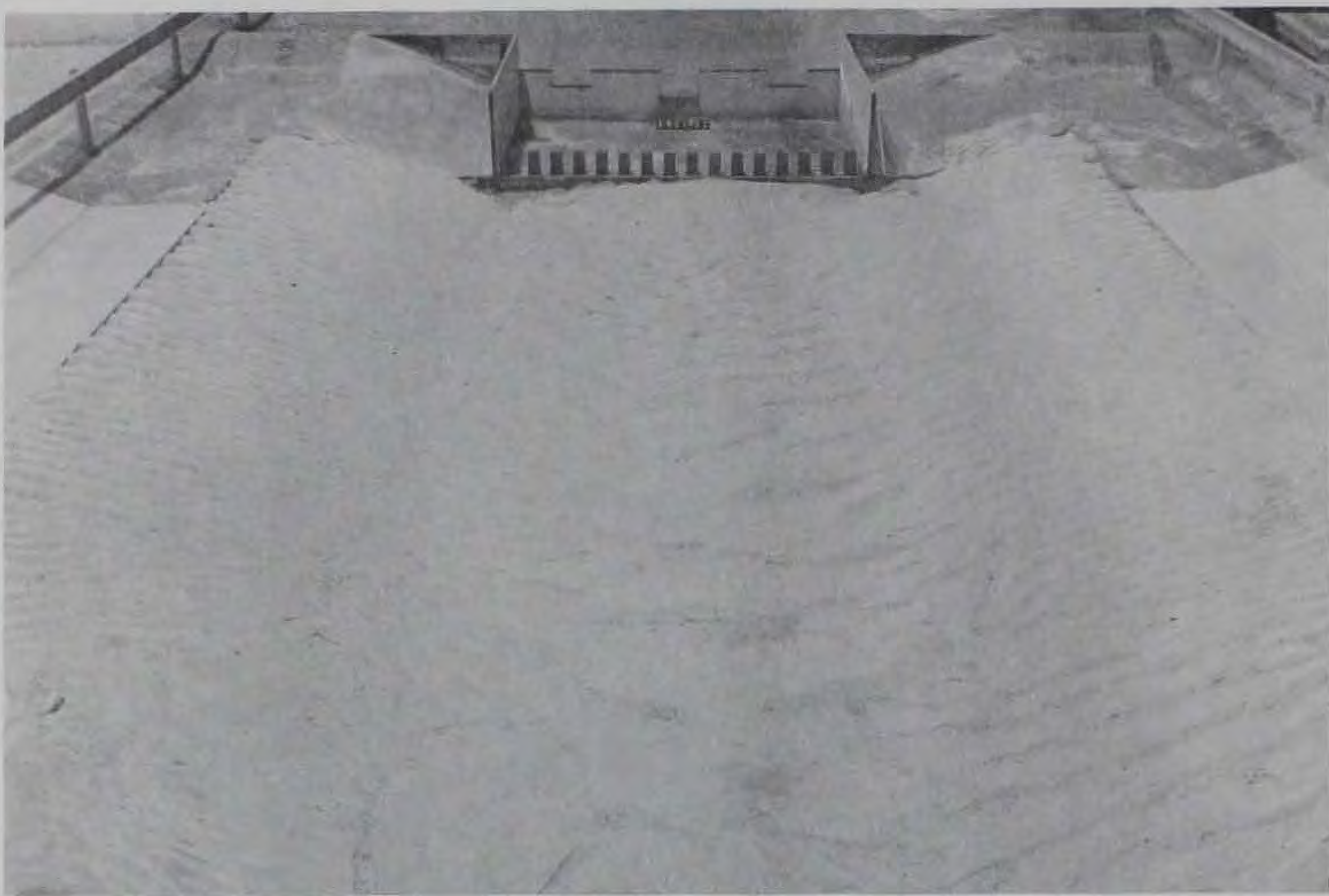


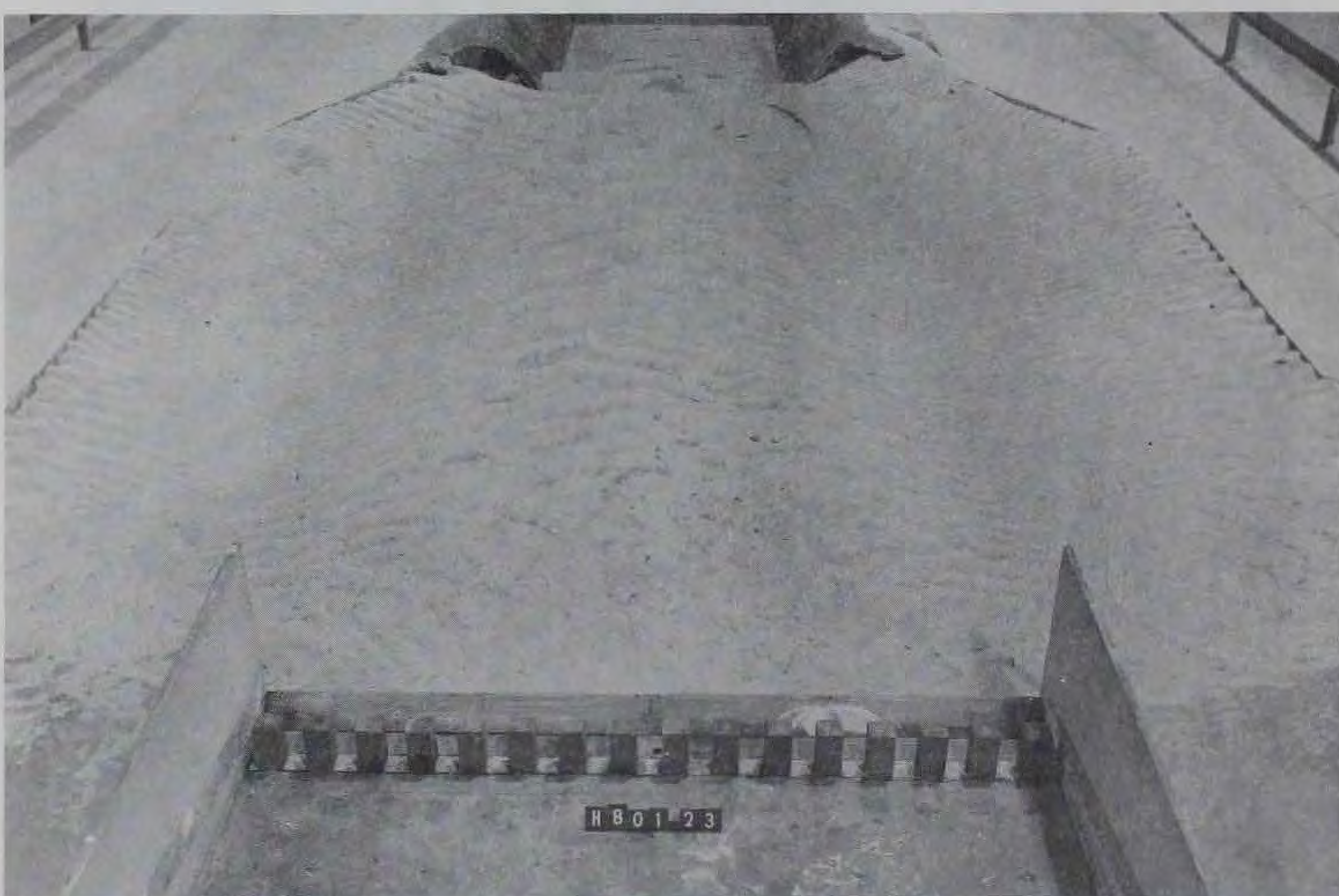
Photo 3. Entrance conditions with original design; discharge 43,600 cfs, tailwater el 1036.8

Photo 4. Flow conditions at walls of original design center structure; discharge 10,000 cfs, tailwater el 1023.5

Photo 5. Entrance conditions with Type 5 approach wing walls; discharge 43,600 cfs, tailwater el 1036.8

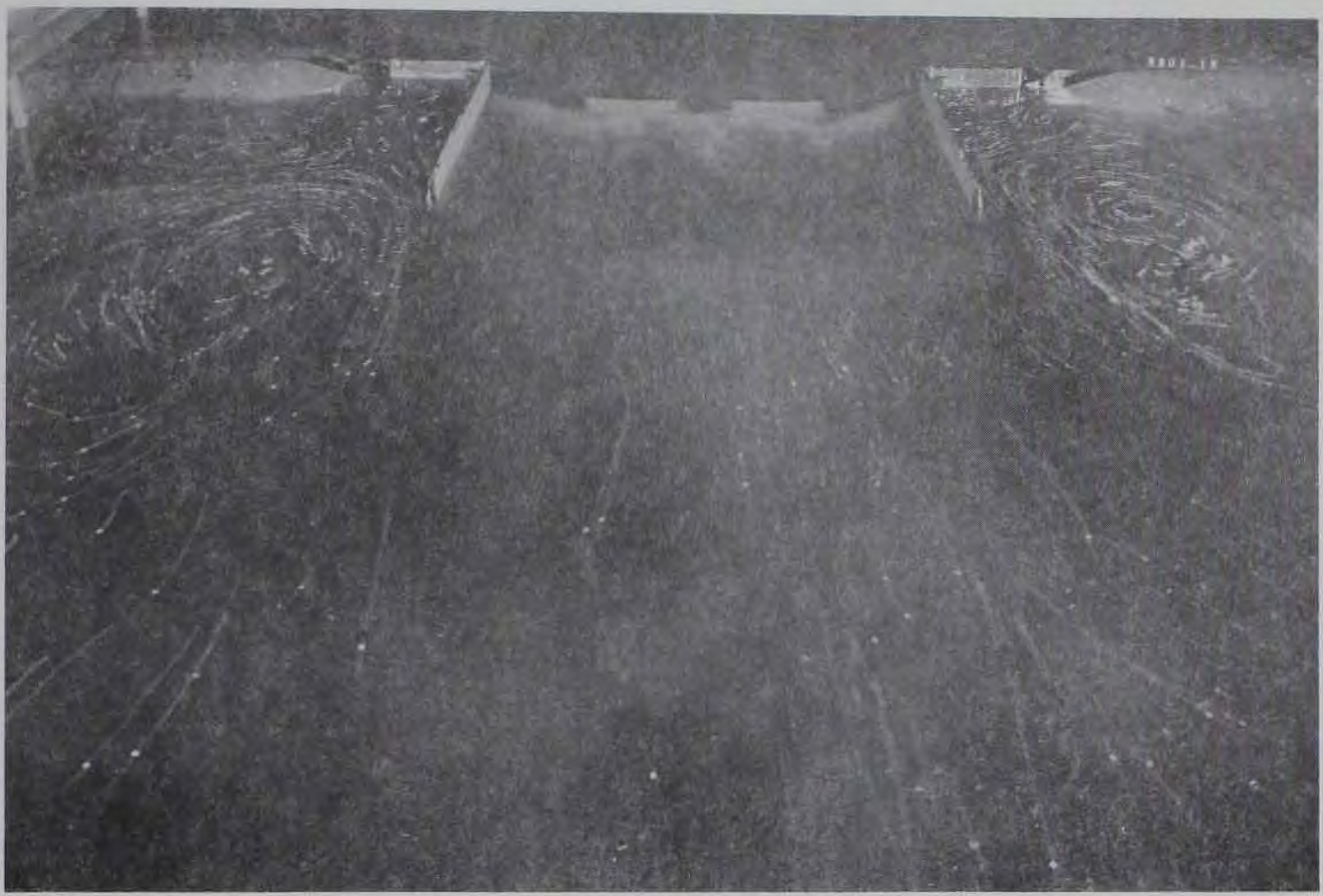


a. Looking upstream

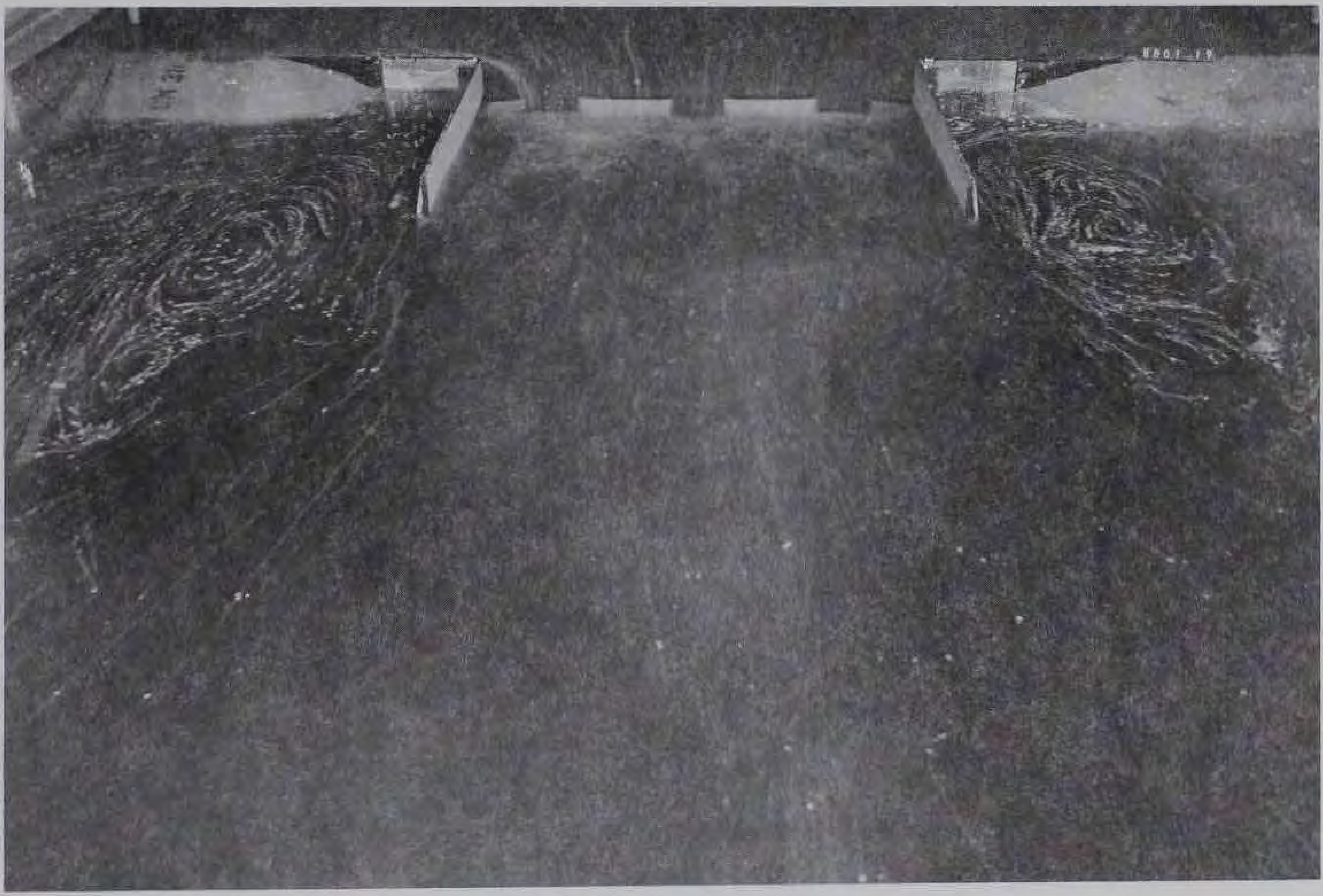


b. Looking downstream

Photo 6. Type 2 design stilling basin, Type 4 design basin walls. View of scour in exit channel after 5 hr of operation; discharge 46,000 cfs, tailwater el 1039.9

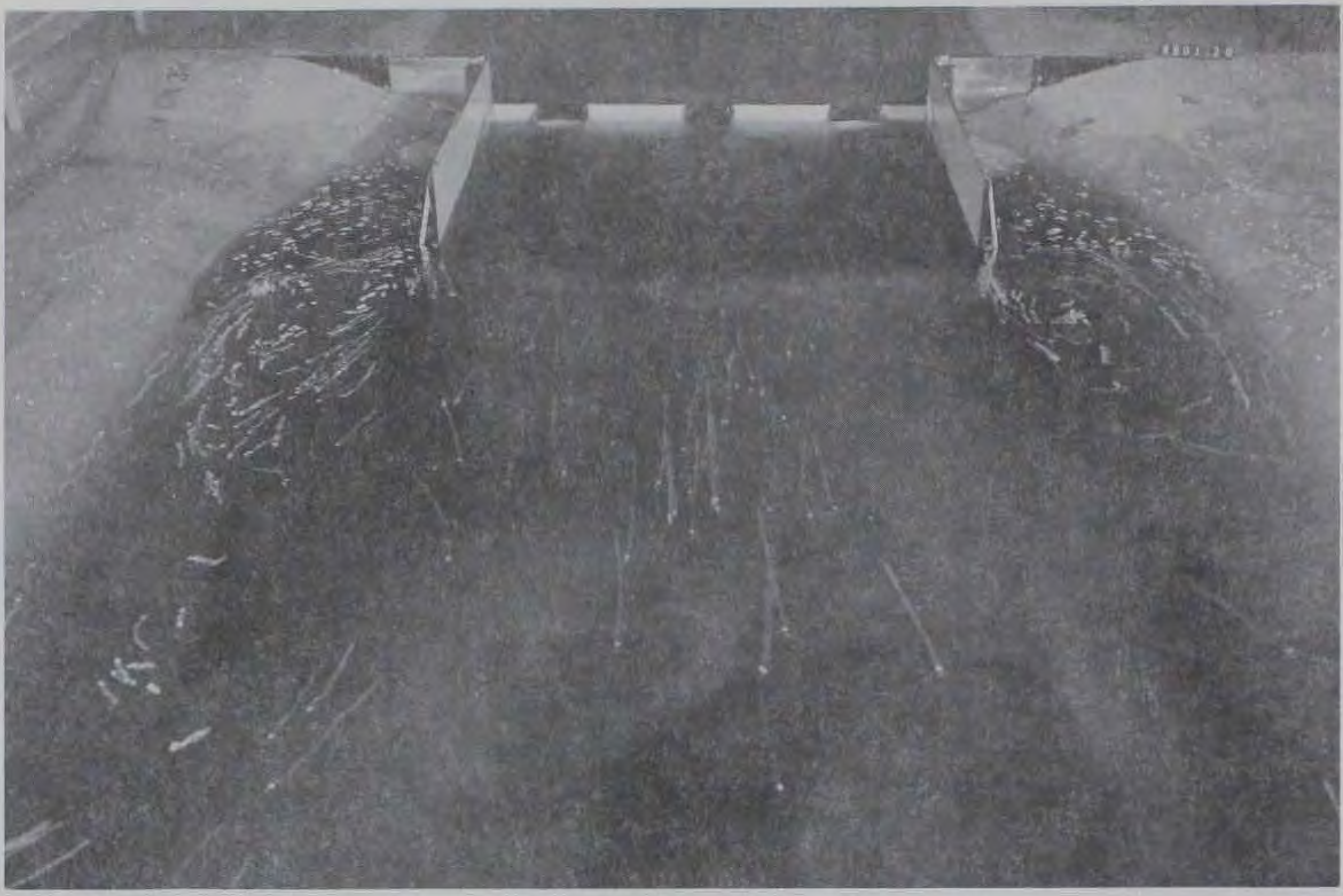


a. Tailwater el 1039.9

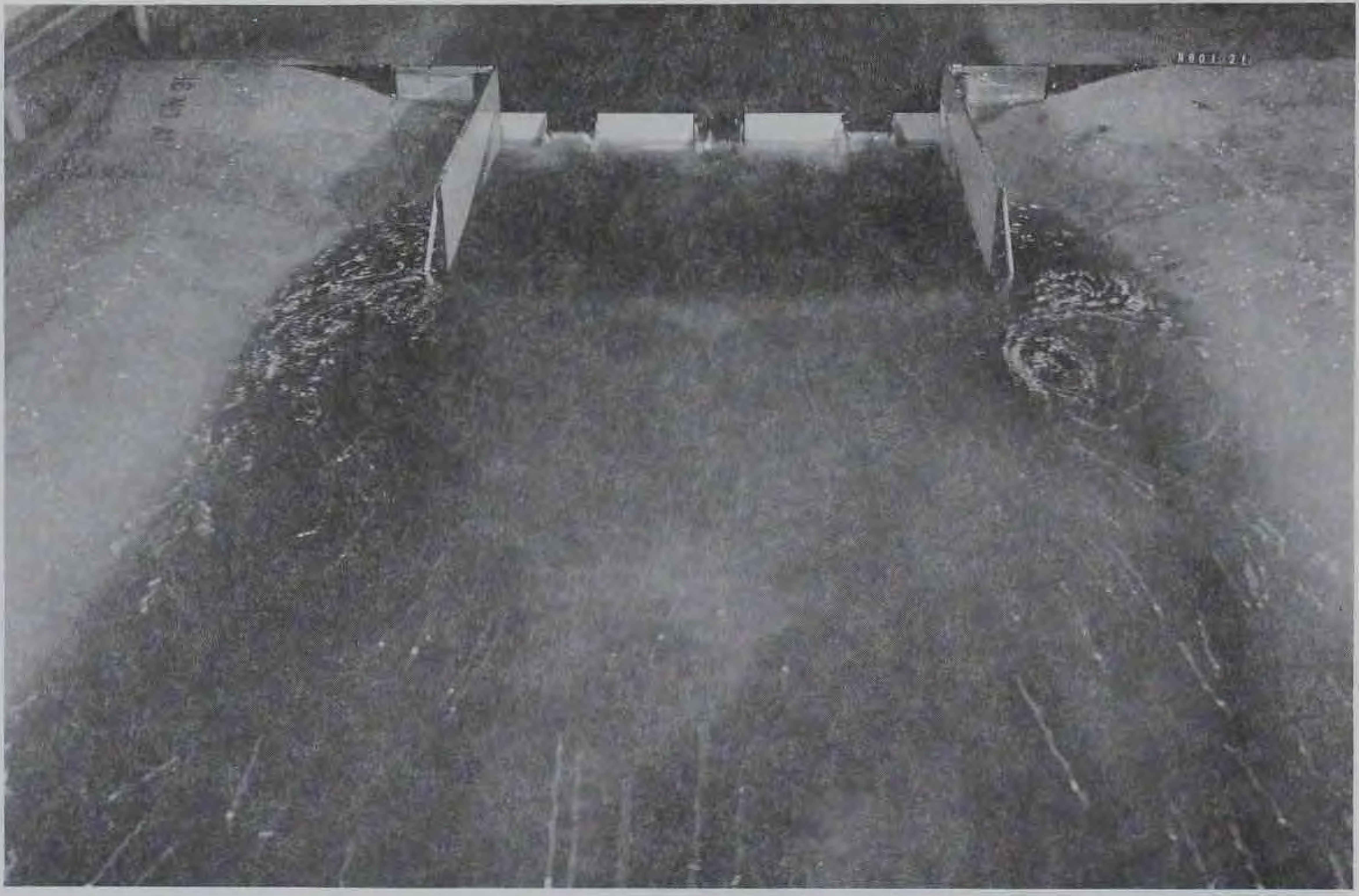


b. Tailwater el 1035.0

Photo 7. Flow conditions with Type 2 design stilling basin and Type 4 design basin; discharge 46,000 cfs



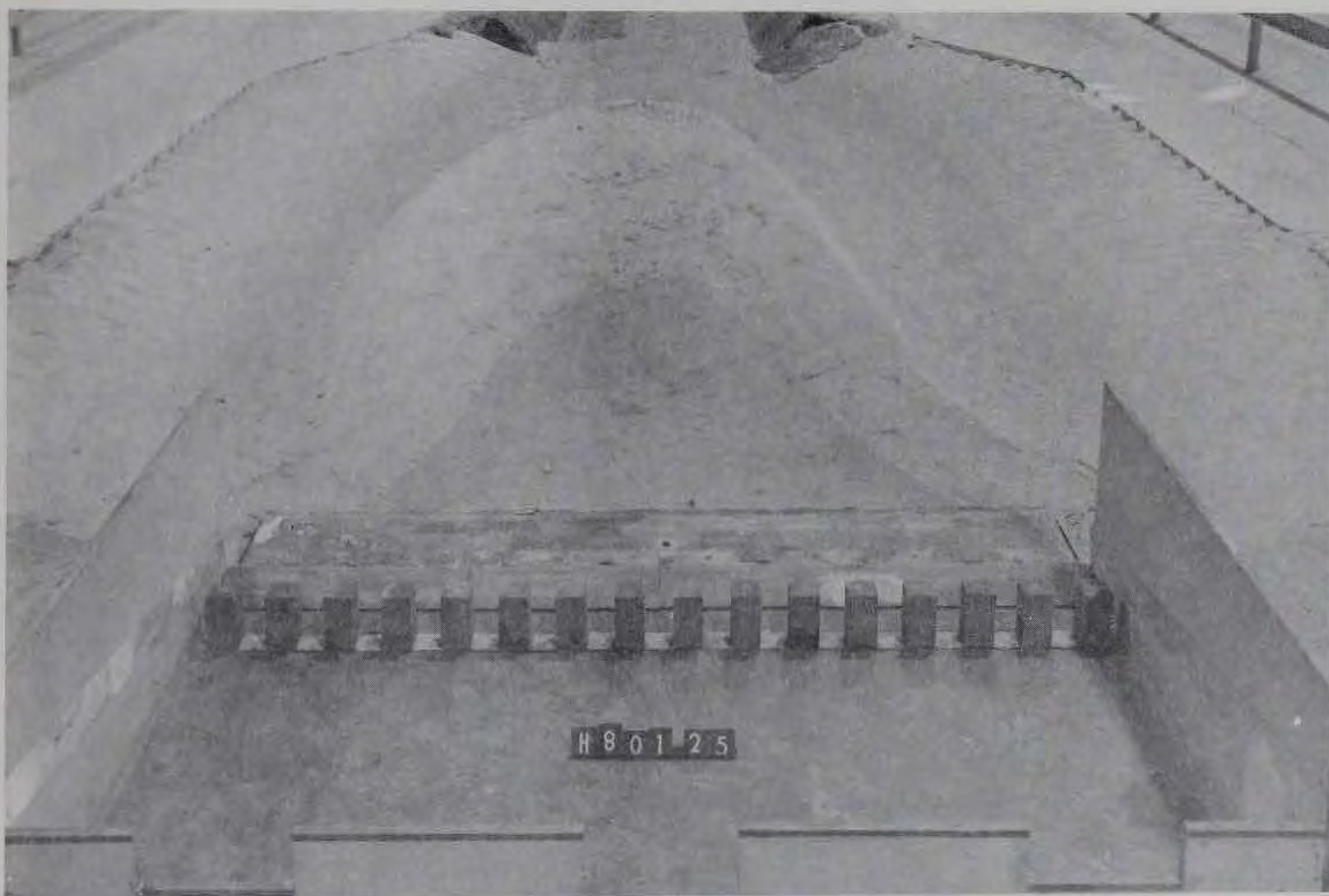
a. Tailwater el 1024.0



b. Tailwater el 1018.0

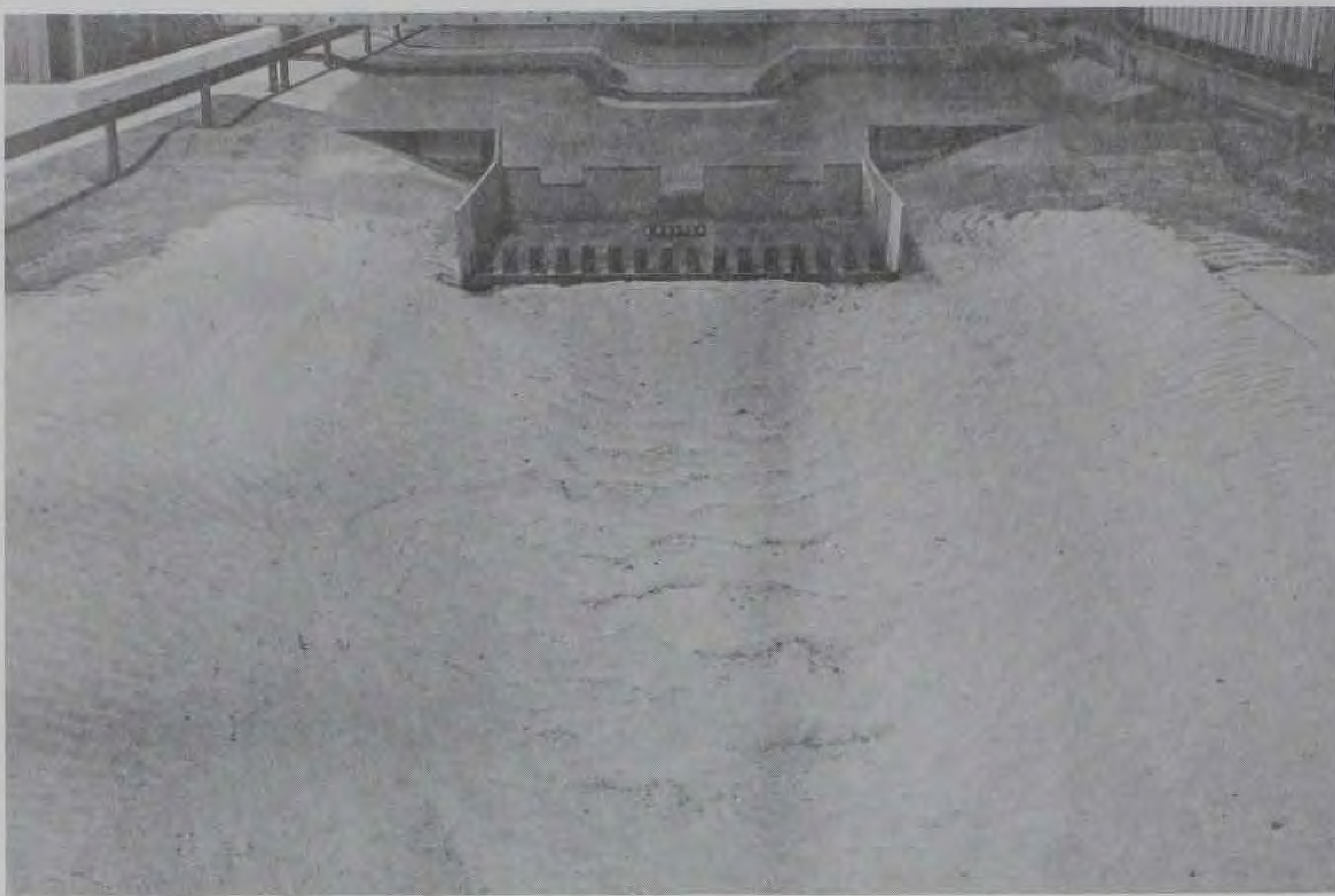
Photo 8. Flow conditions with Type 2 design stilling basin and Type 4 design basin walls; discharge 10,000 cfs

a. Looking upstream

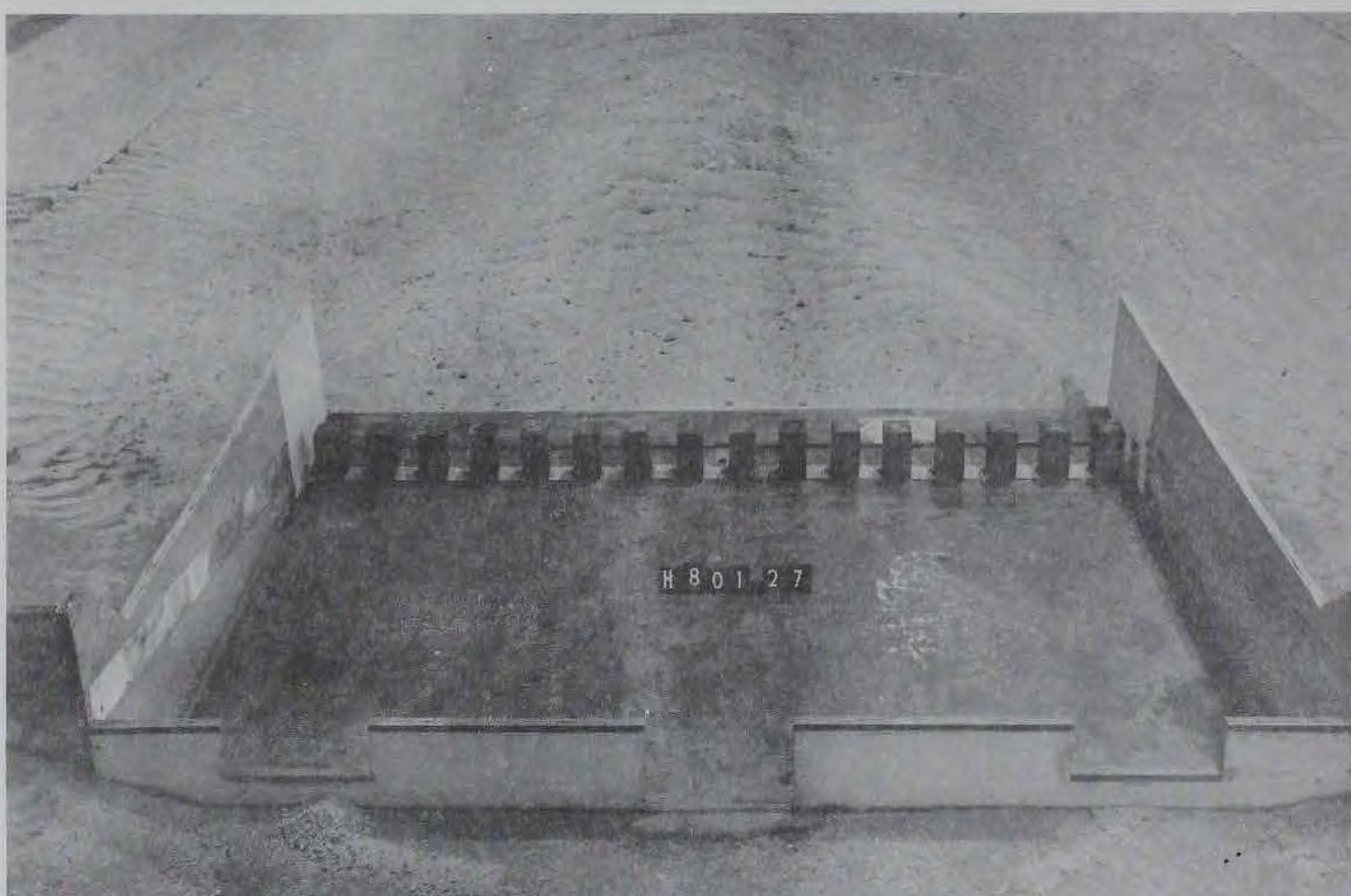


b. Looking downstream

Photo 9. Type 3 design stilling basin, Type 6 design basin walls. View of scour in exit channel after 5 hr of operation; discharge 46,000 cfs, tailwater el 1039.9

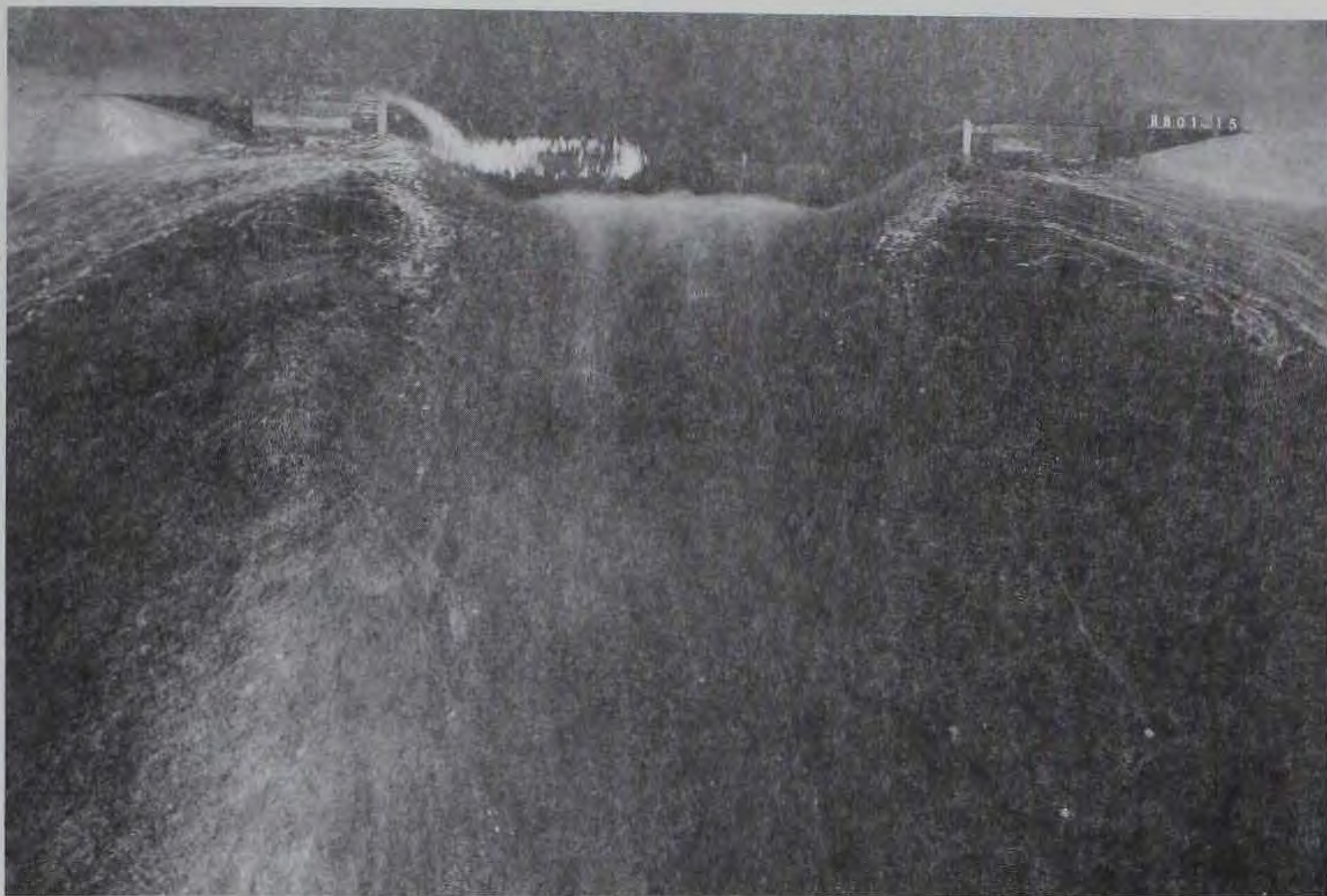


a. Looking upstream

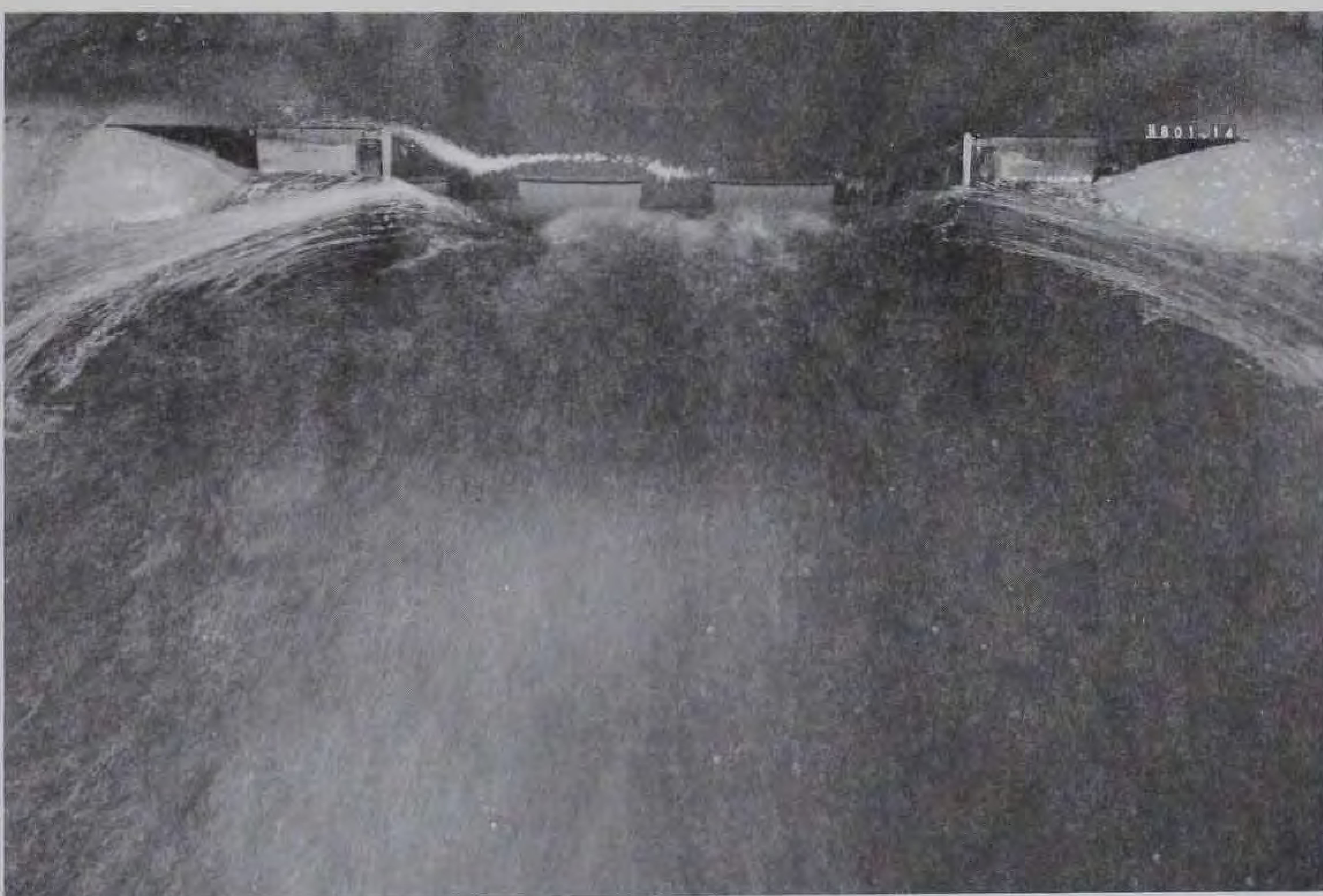


b. Looking downstream

Photo 10. Type 2 design stilling basin; Type 7 design basin walls. View of scour in exit channel after 5 hr of operation; discharge 46,000 cfs, tailwater el 1039.9

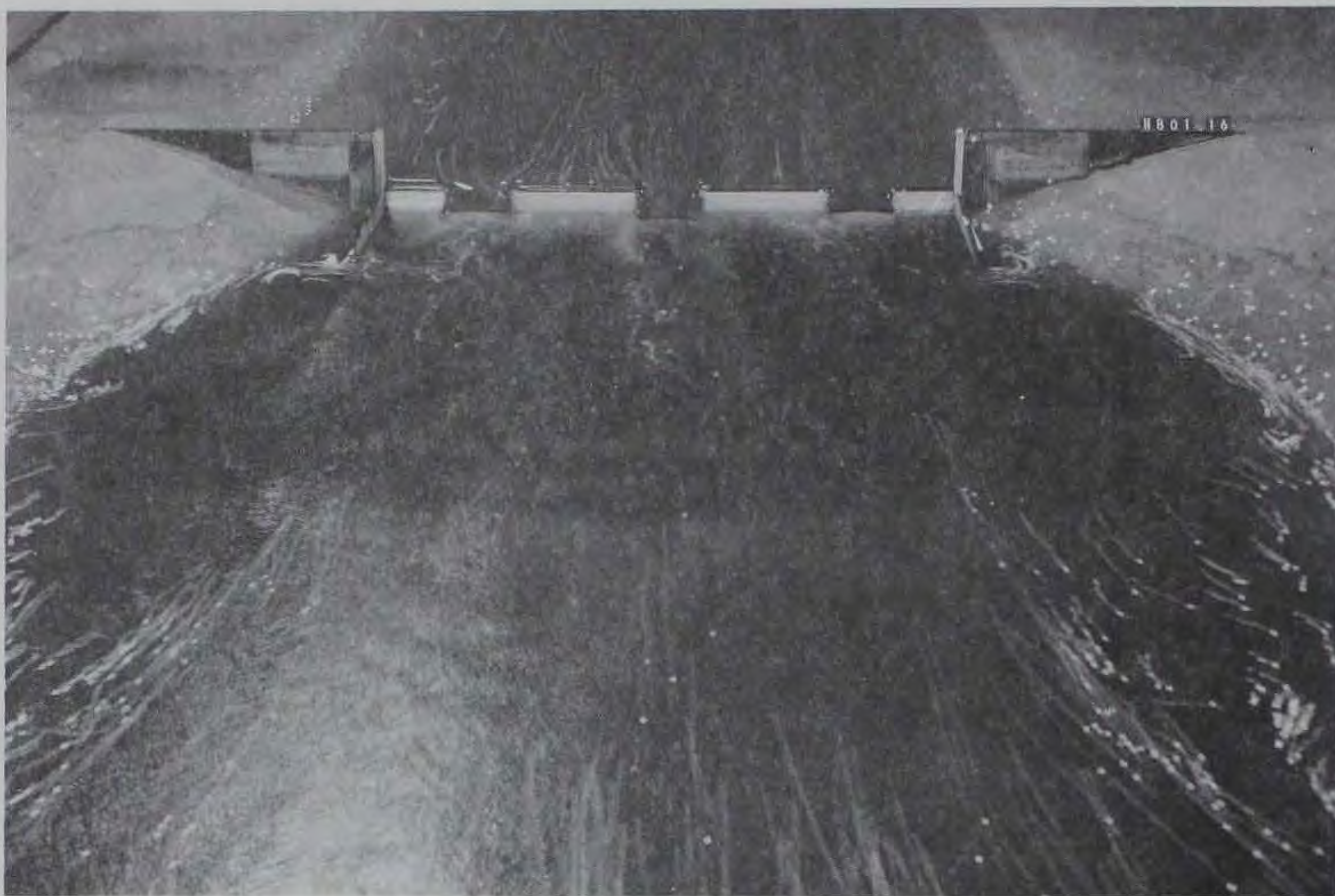


a. Tailwater el 1039.9

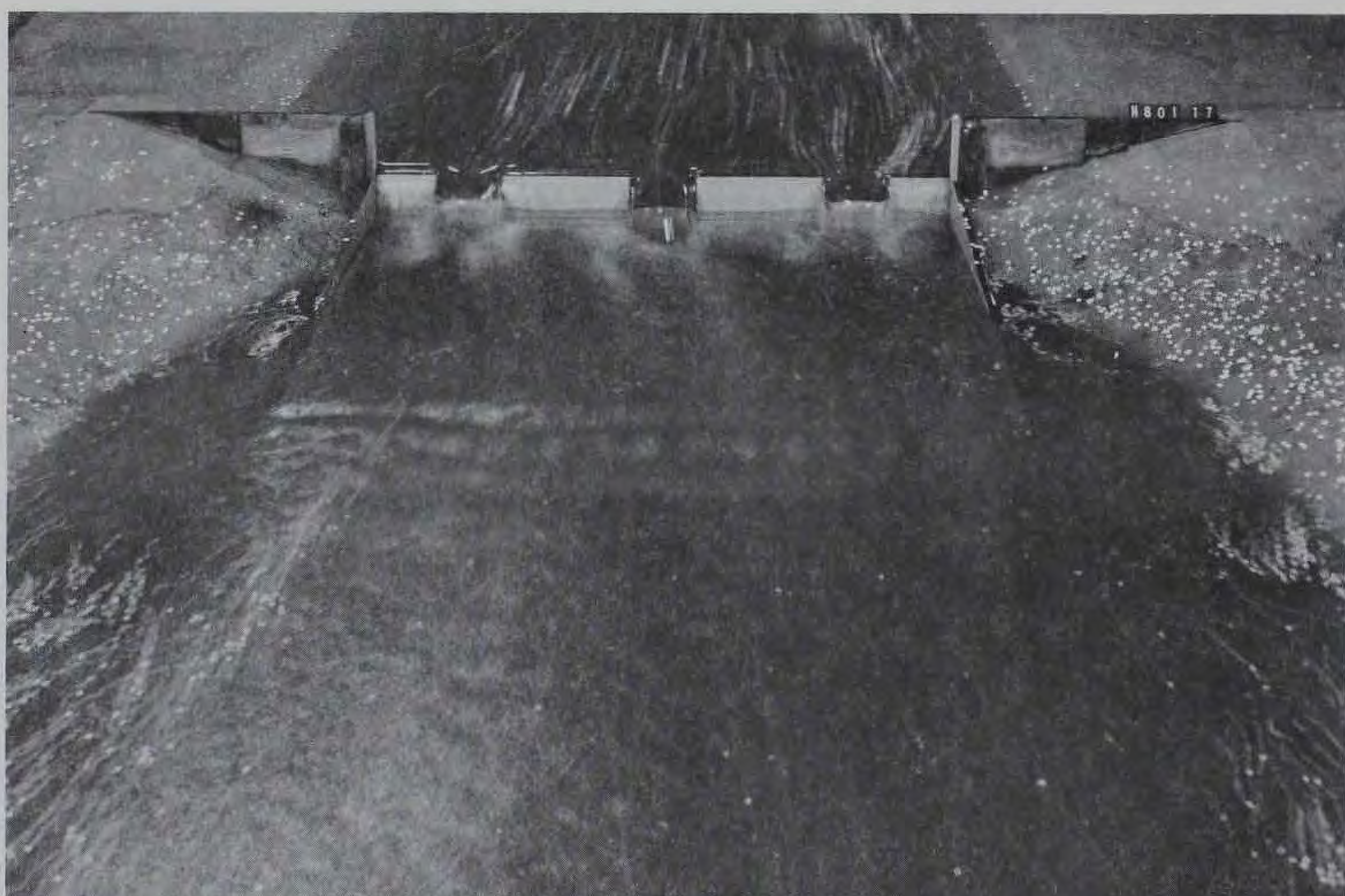


b. Tailwater el 1035.0

Photo 11. Flow concentration caused by reduced wall heights; discharge 46,000 cfs



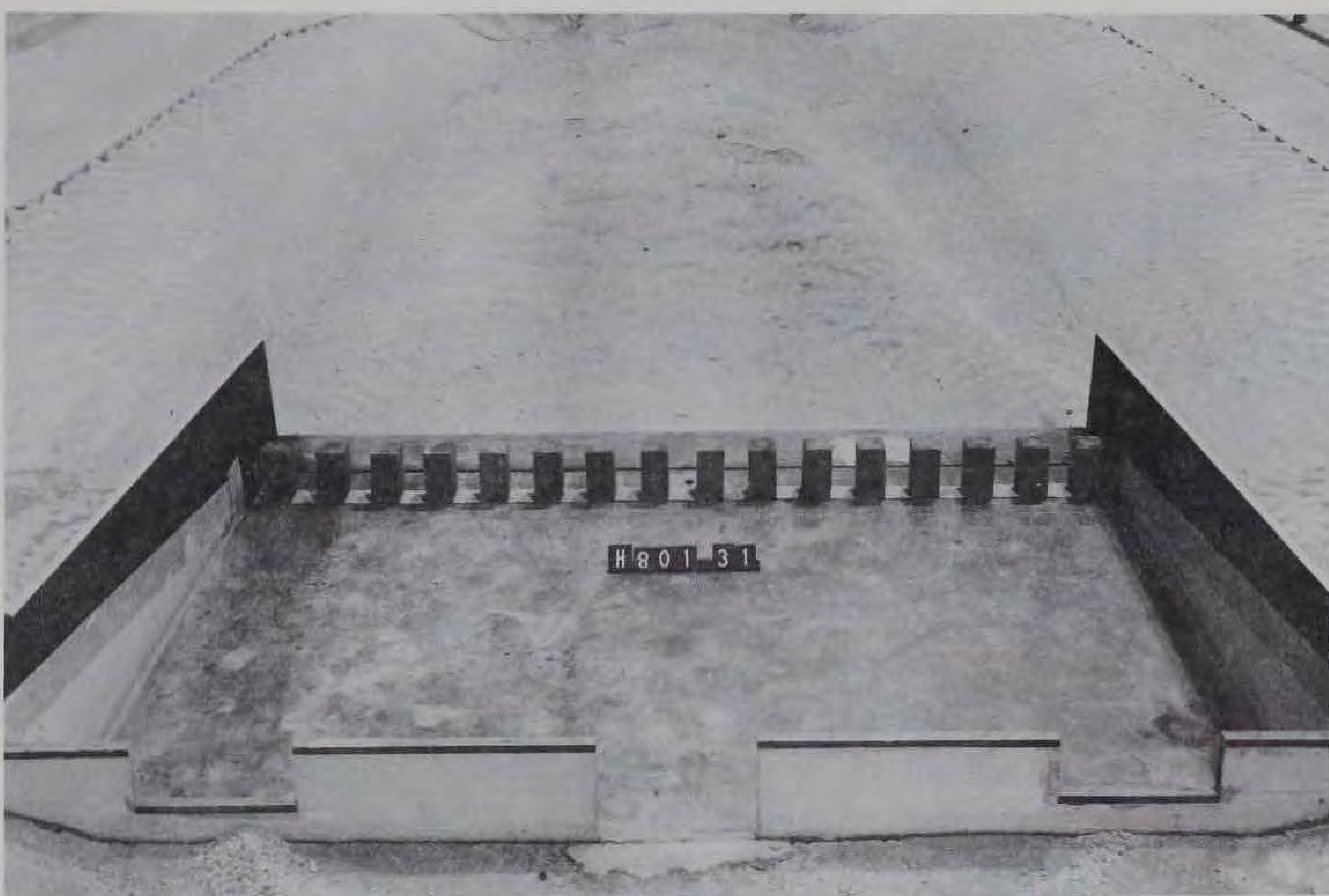
a. Tailwater el 1024.0



b. Tailwater el 1018.0

Photo 12. Flow concentration caused by reduced wall heights; discharge 10,000 cfs

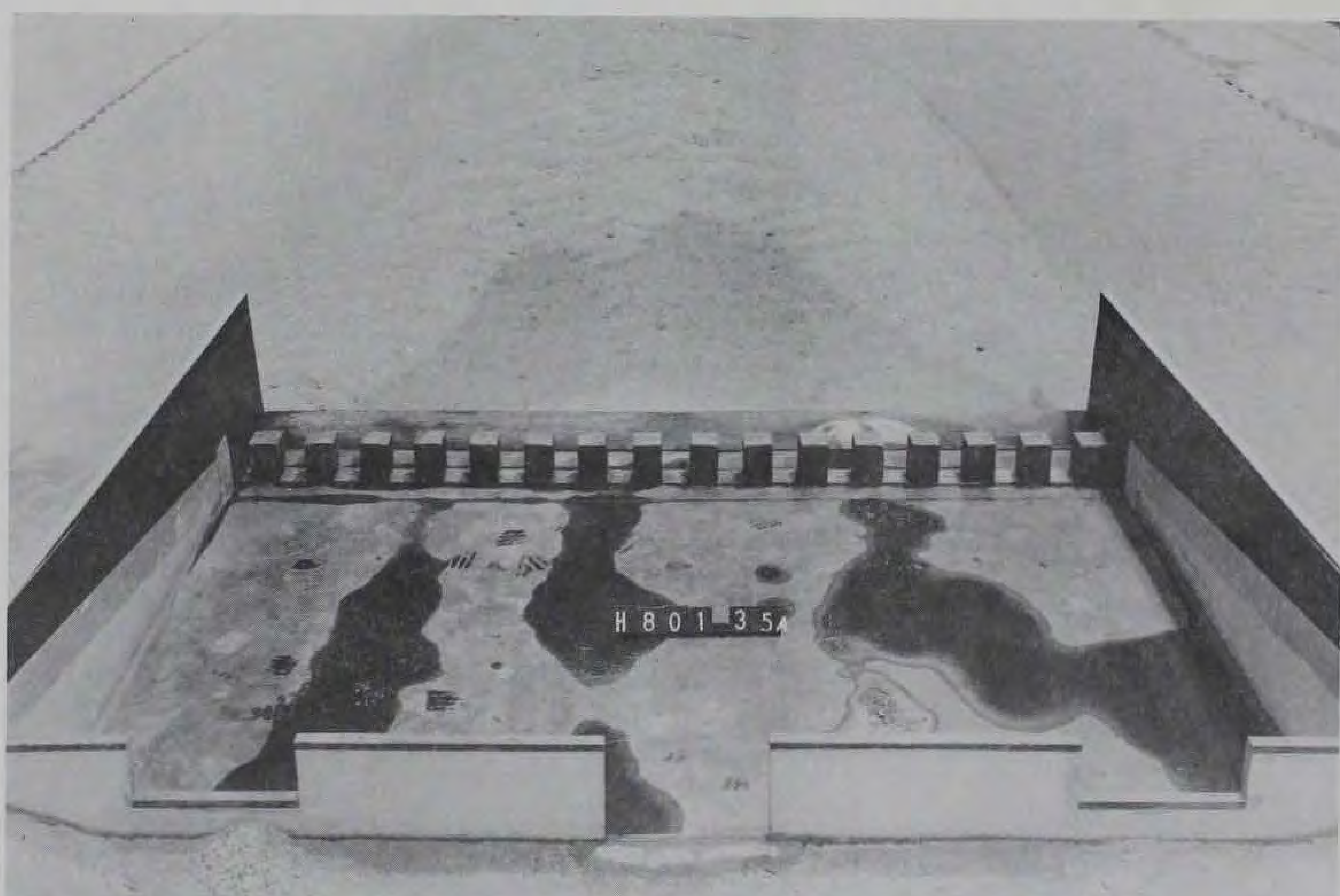
a. Looking upstream



b. Looking downstream

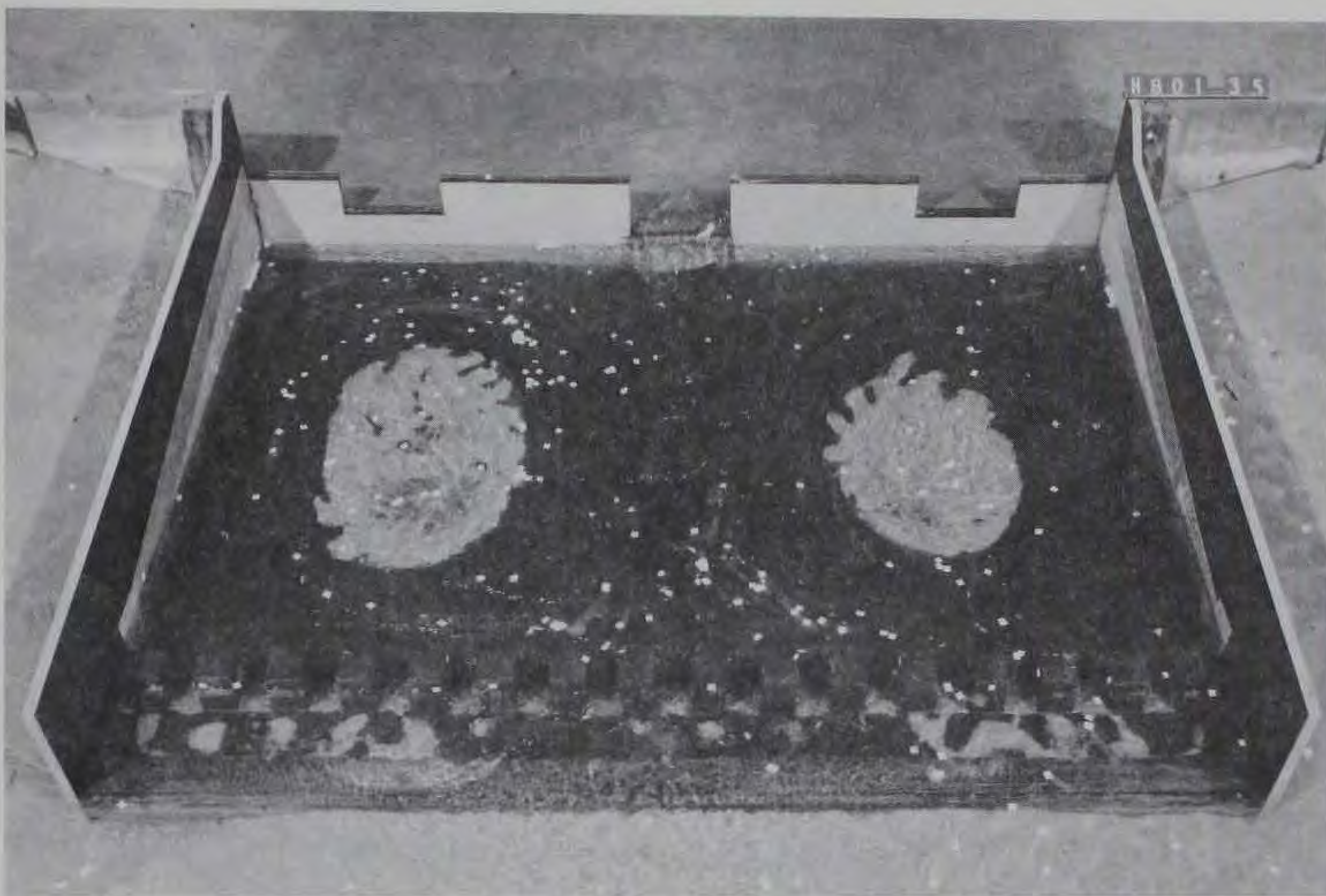
Photo 13. Type 2 design stilling basin, Type 8 design basin walls. View of scour in exit channel after 5 hr of operation; discharge 46,000 cfs, tailwater el 1039.9

a. Looking upstream

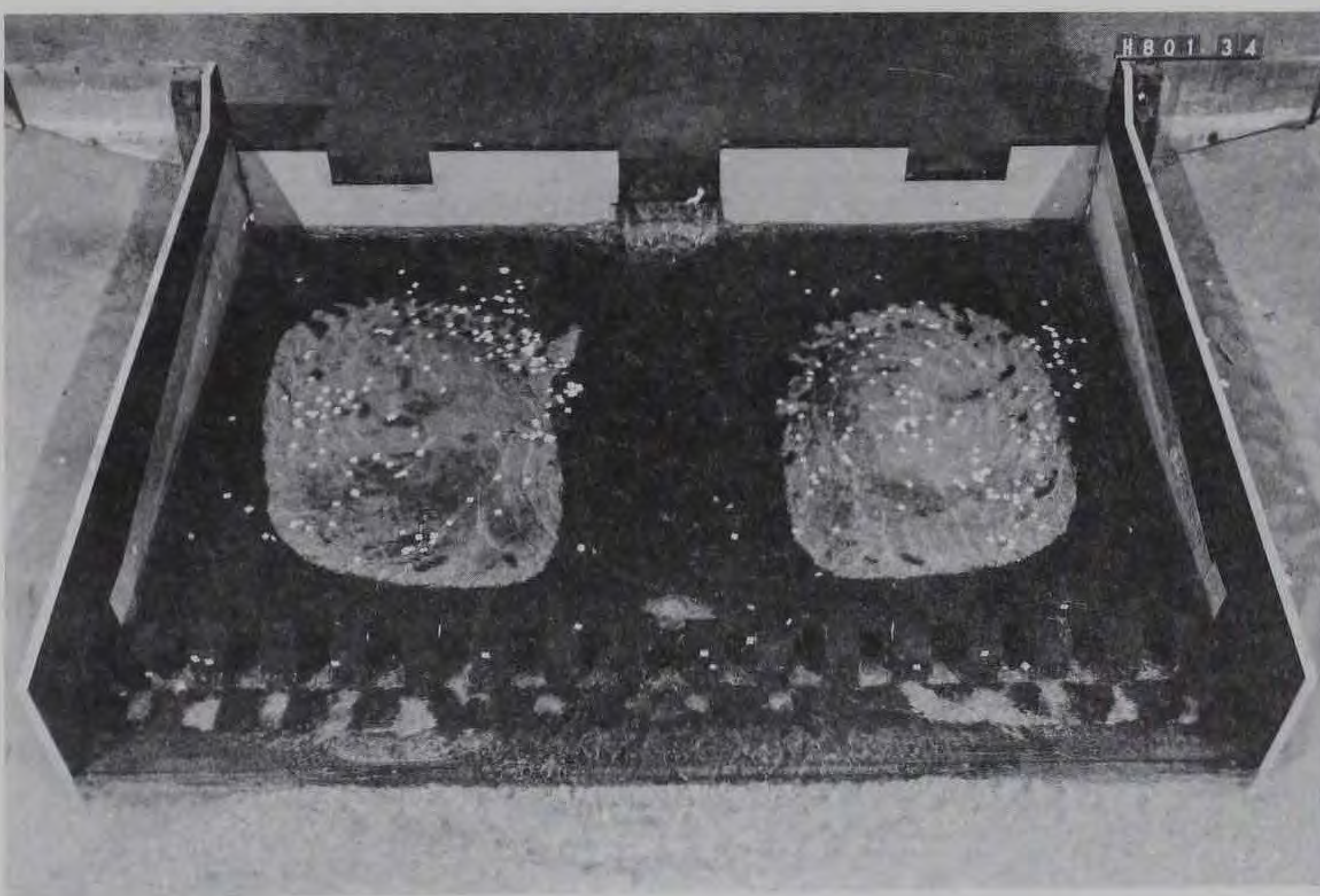


b. Looking downstream

Photo 14. Type 2 design stilling basin, Type 9 design basin walls. Baffle blocks 8 ft high. View of scour in exit channel after 5 hr of operation; discharge 46,000 cfs, tailwater el 1039.9

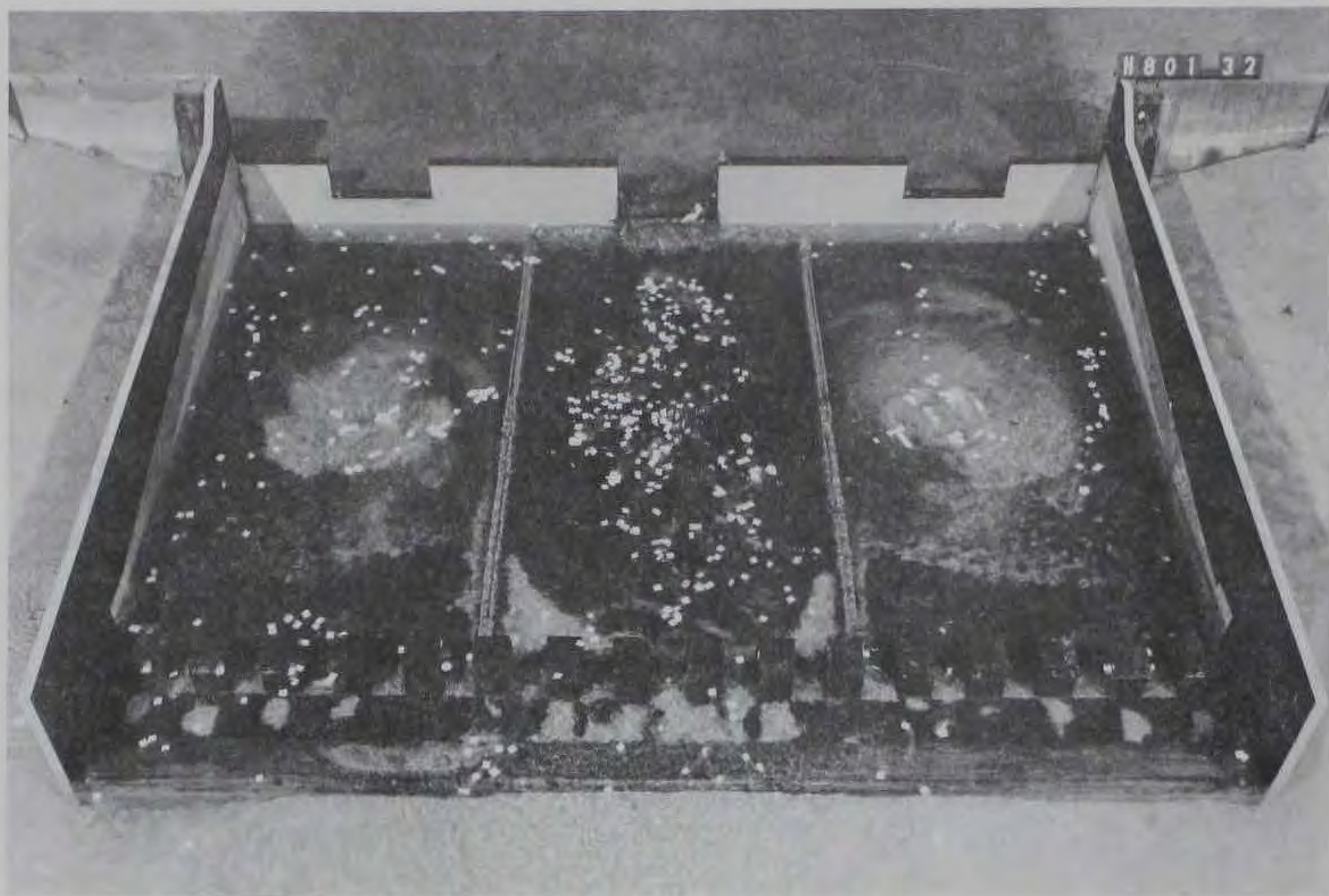


a. Tailwater el 1014.0

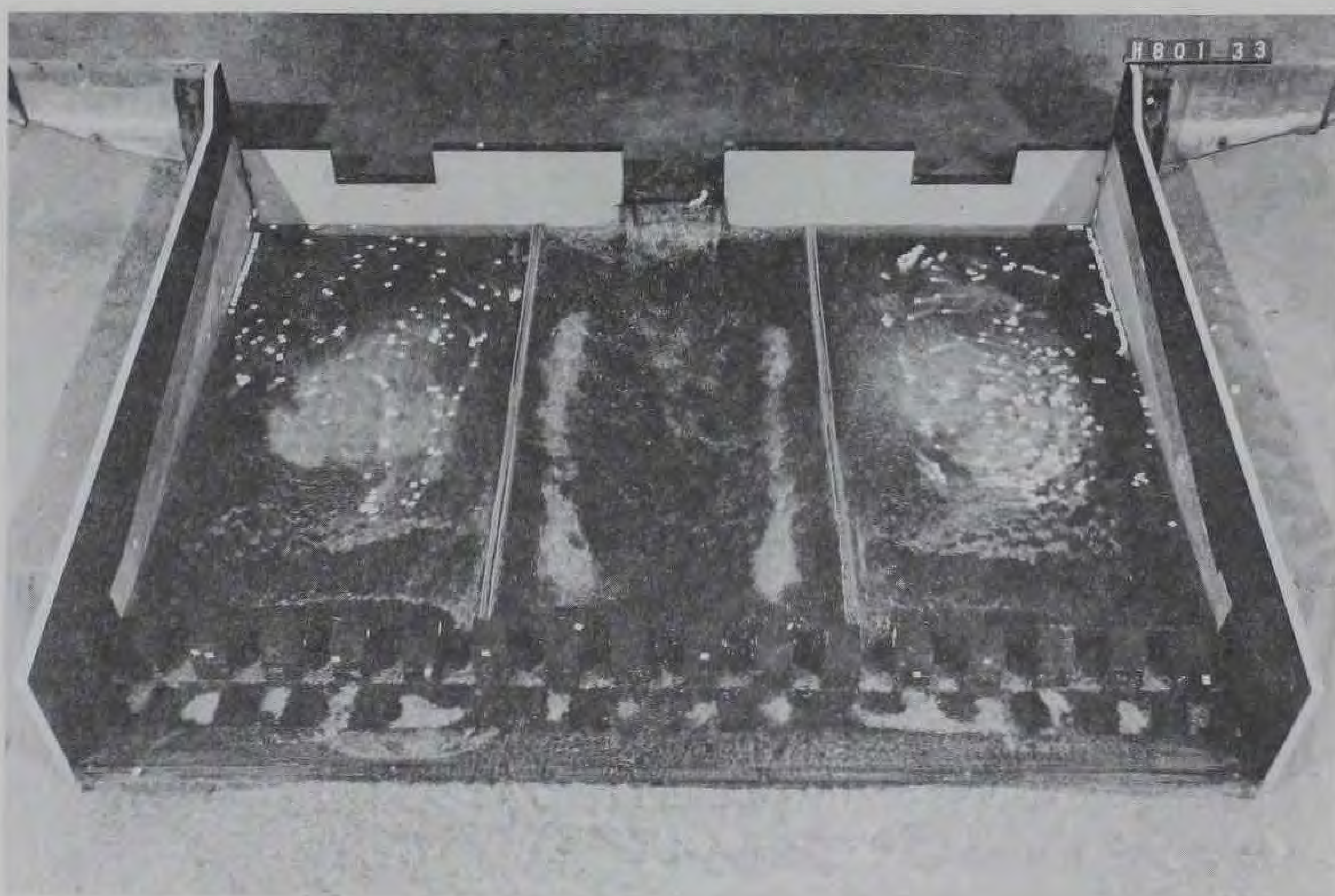


b. Tailwater el 1010.5

Photo 15. Type 8 design weir, Type 2 design stilling basin, Type 8 design basin walls. Eddies in basin; discharge 1,000 cfs

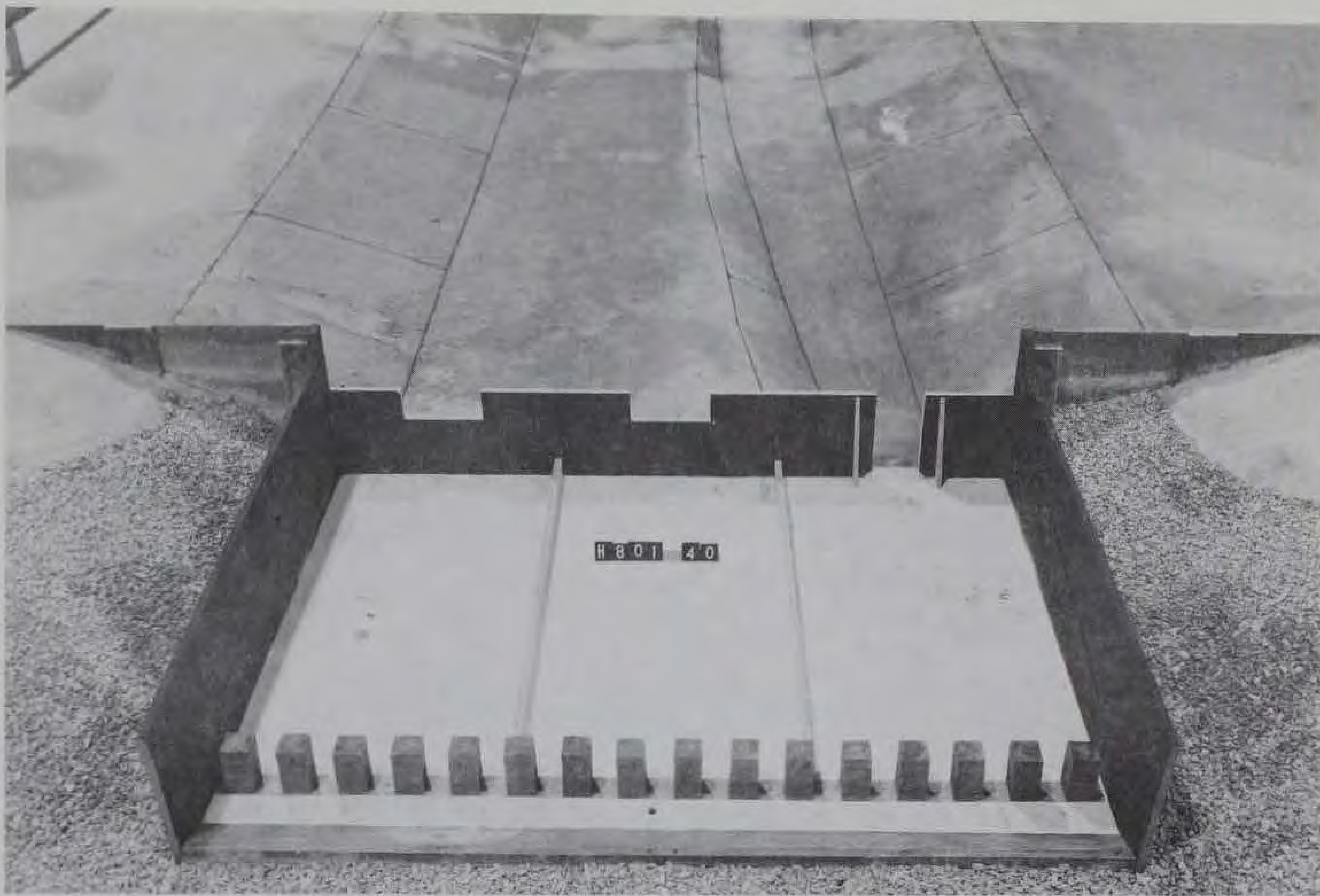


a. Tailwater el 1014.0

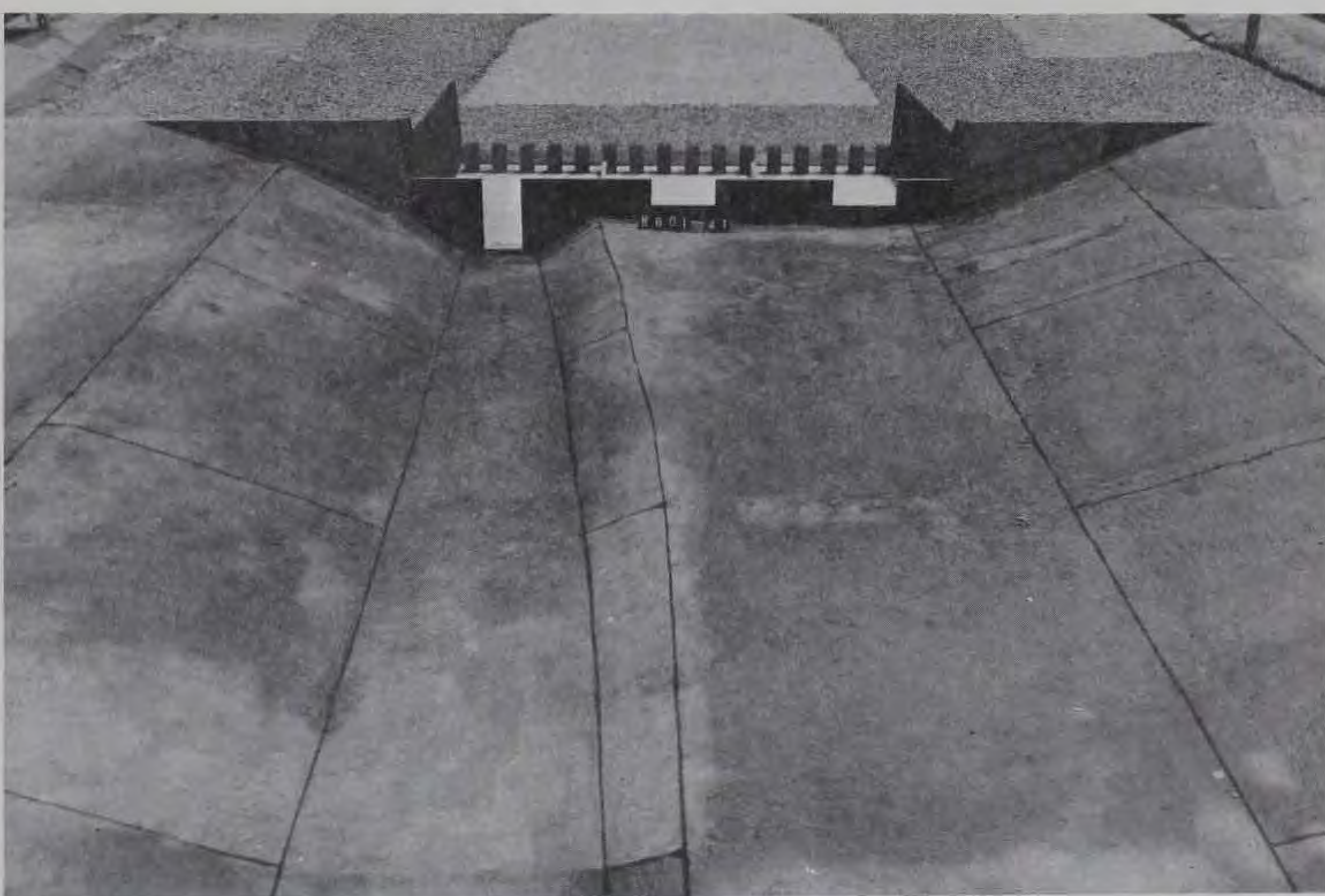


b. Tailwater el 1010.5

Photo 16. Type 8 design weir, Type 2 design stilling basin, Type 8 design basin walls. Flow conditions with 5-ft-high training walls in basin; discharge 1,000 cfs

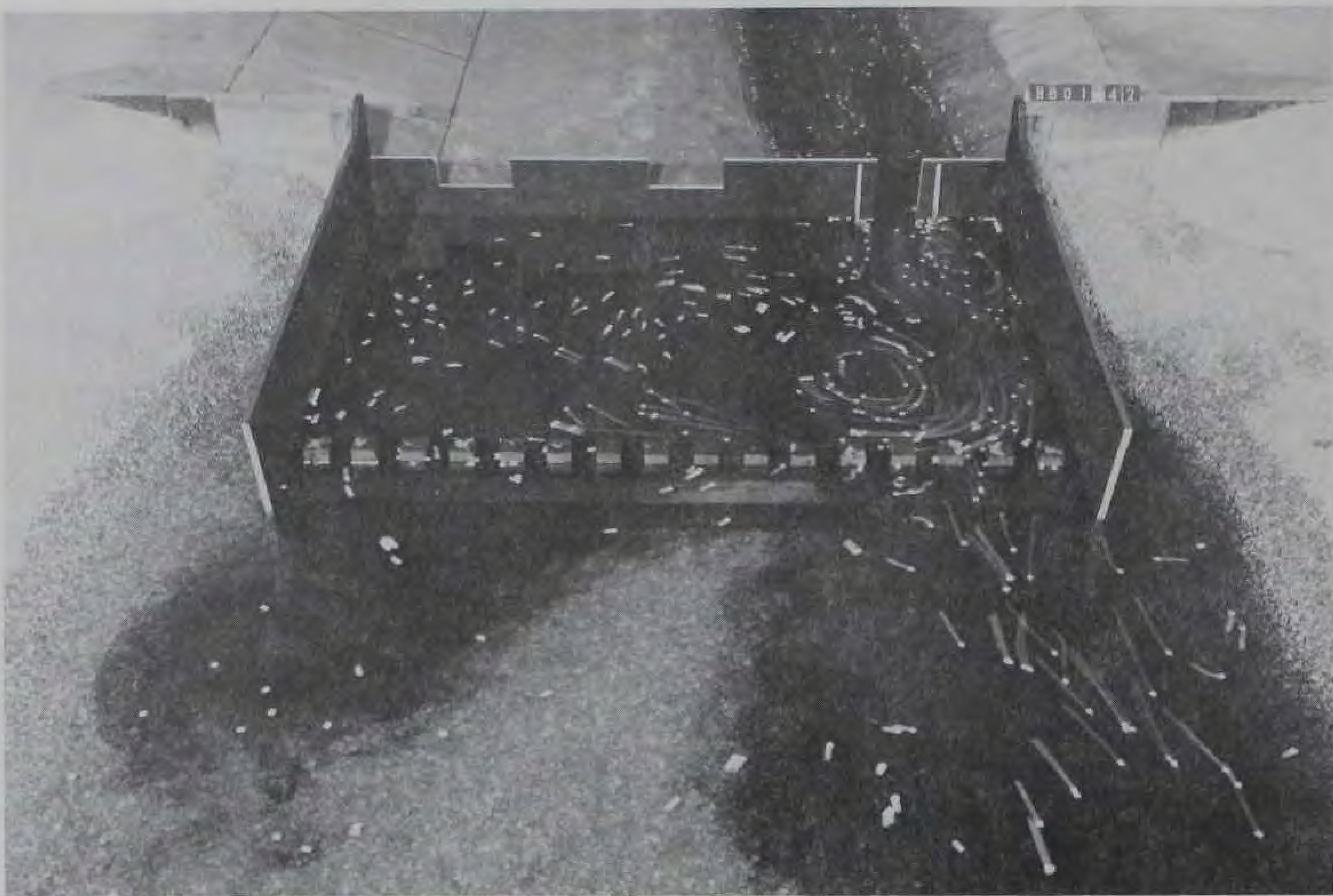


a. Looking upstream

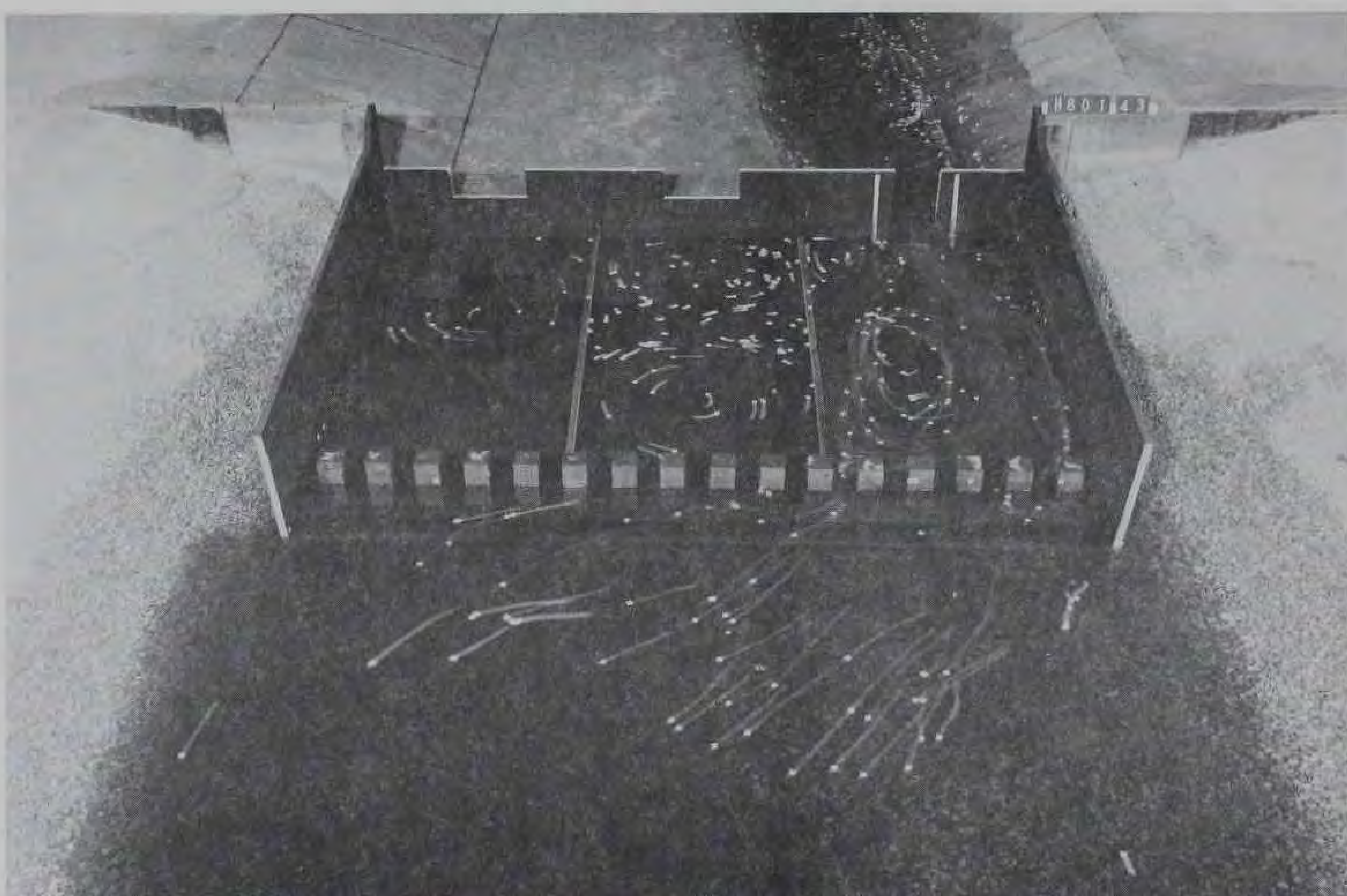


b. Looking downstream

Photo 17. Type 9 design weir and modified approach channel

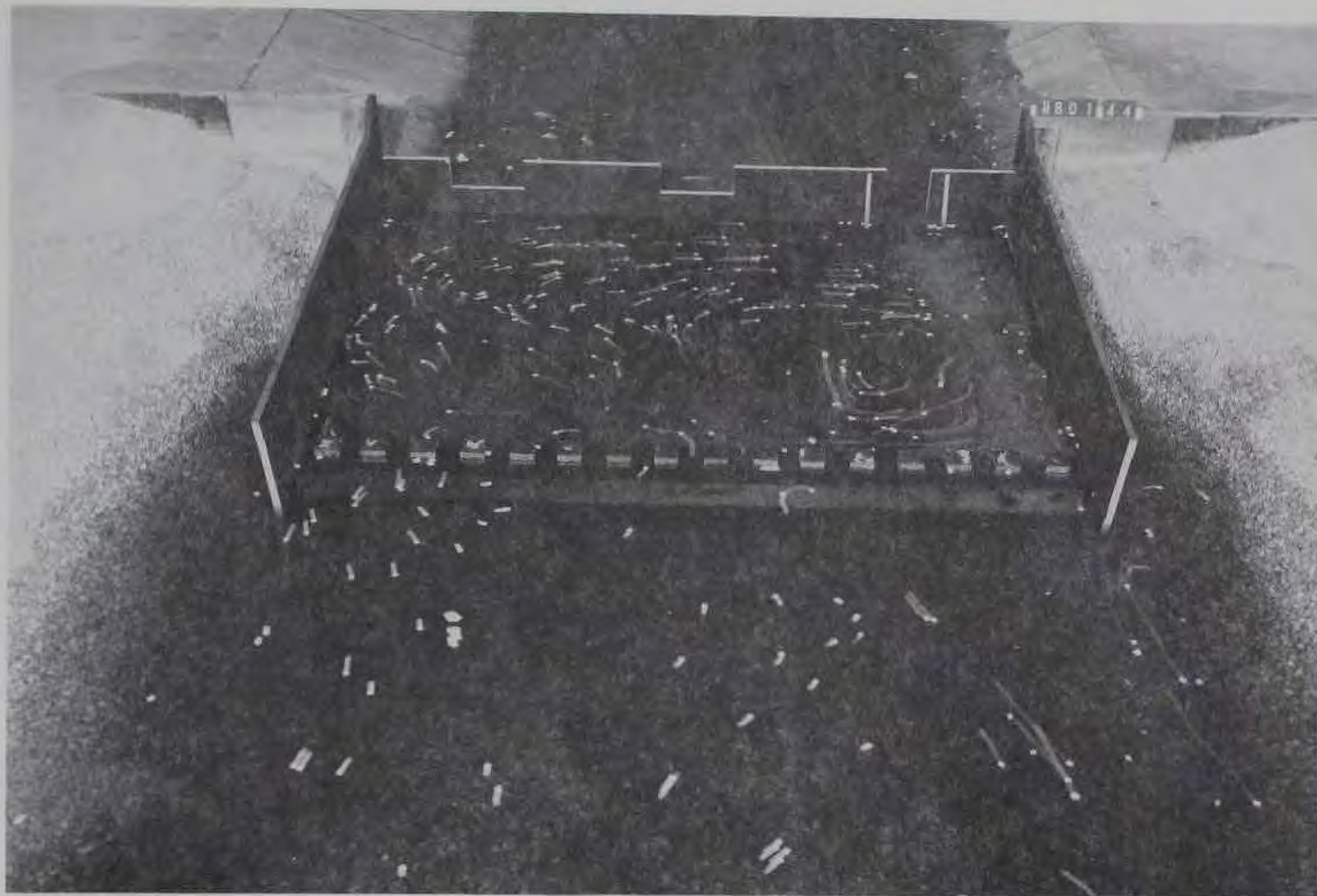


a. Tailwater el 1013.0

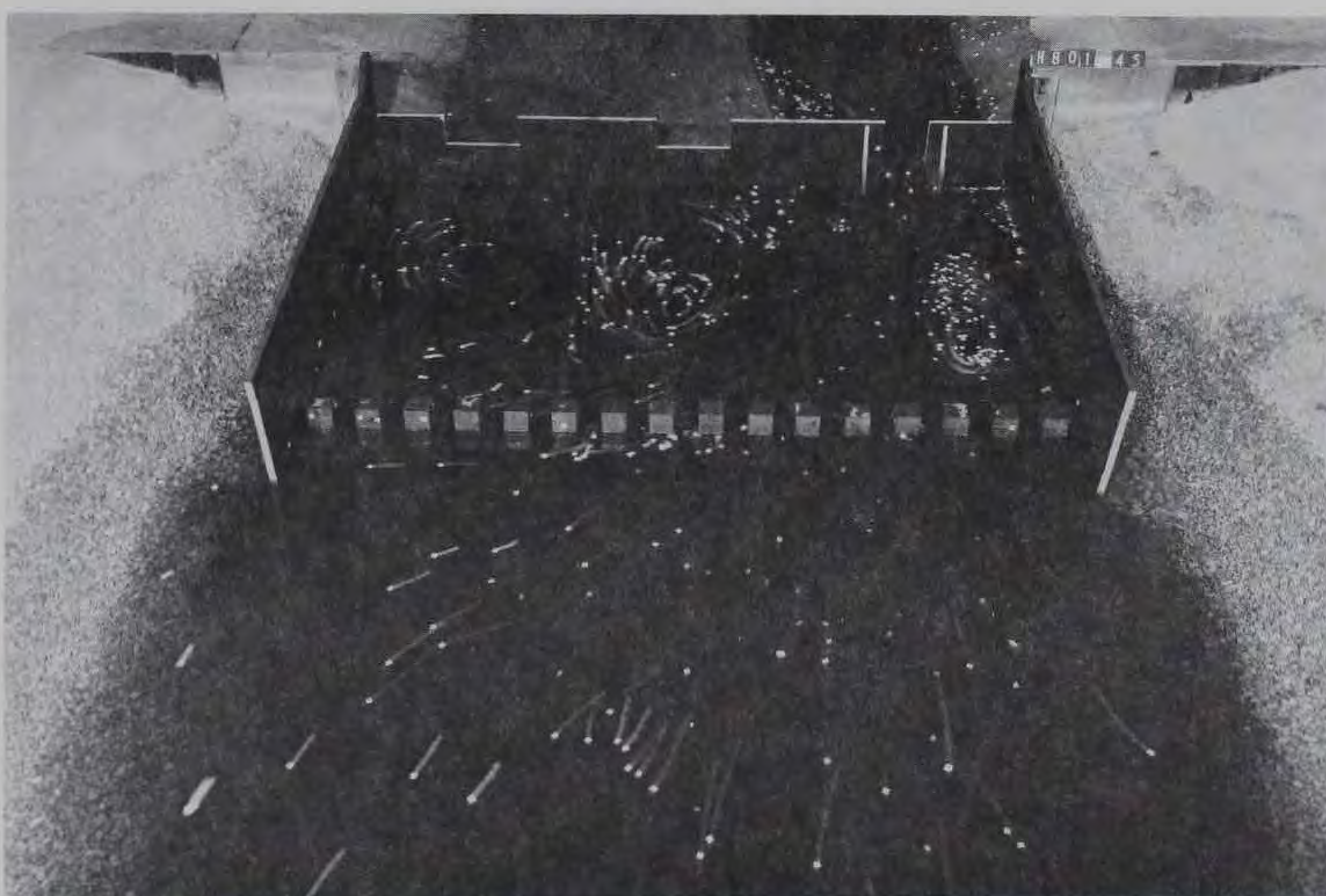


b. Tailwater el 1010.0

Photo 18. Type 9 design weir, Type 2 design stilling basin, Type 9 design basin walls, 5-ft-high training wall. Recommended design; discharge 500 cfs

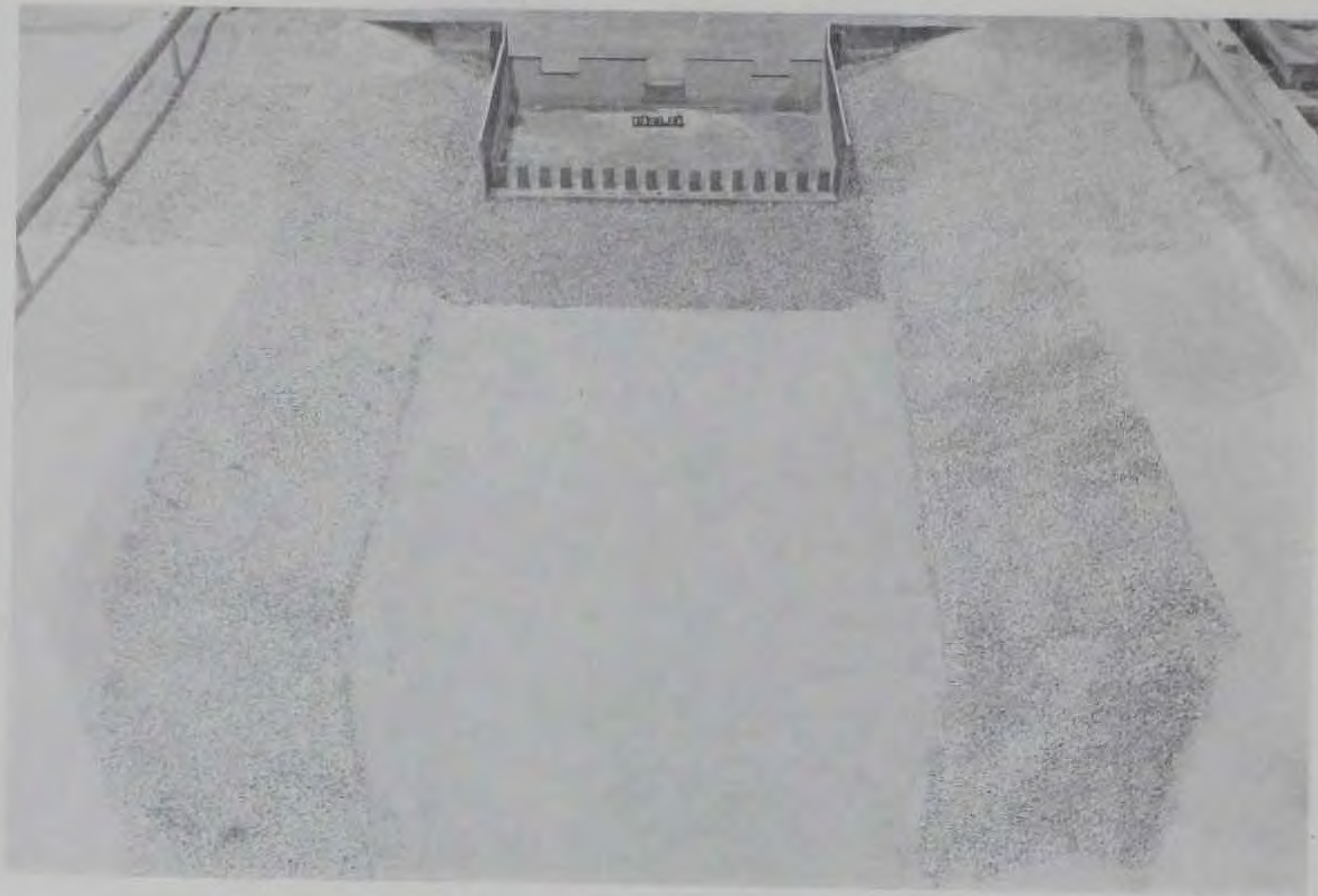


a. Tailwater el 1014.0

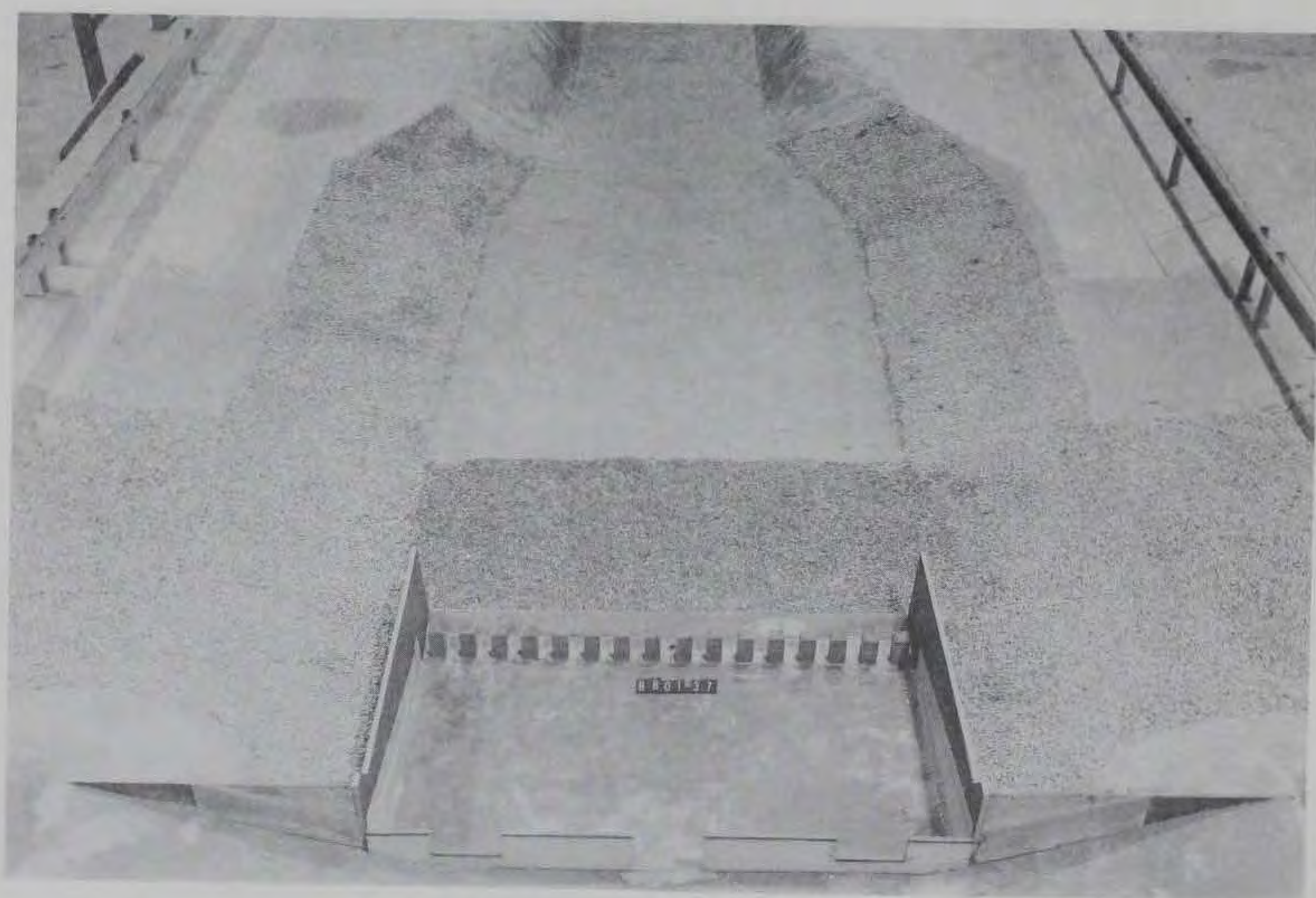


b. Tailwater el 1010.5

Photo 19. Type 9 design weir, Type 2 design stilling basin, Type 9 design basin walls, 5-ft-high training wall. Recommended design; discharge 1,000 cfs

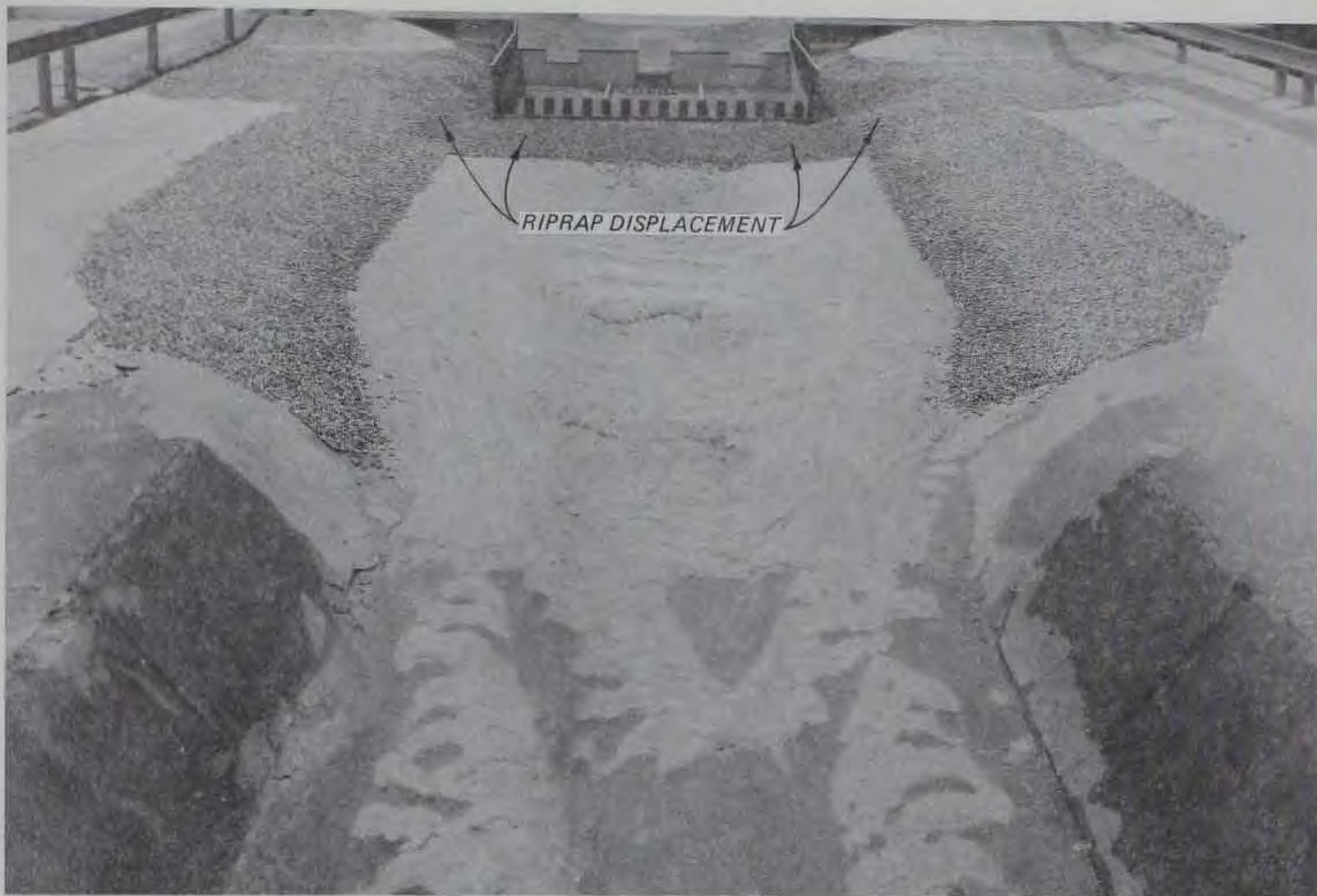


a. Looking upstream

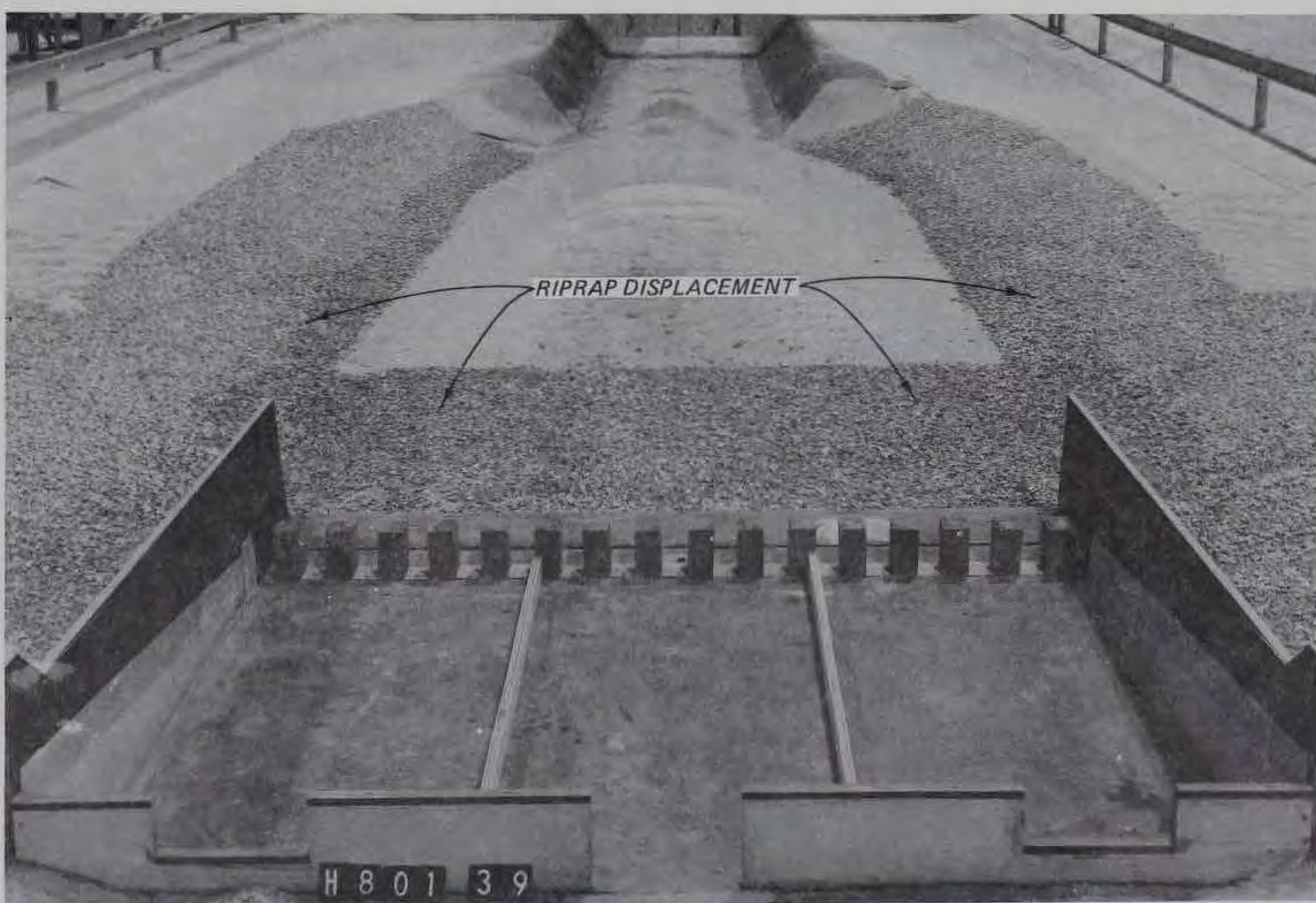


b. Looking downstream

Photo 20. Type 1 riprap plan

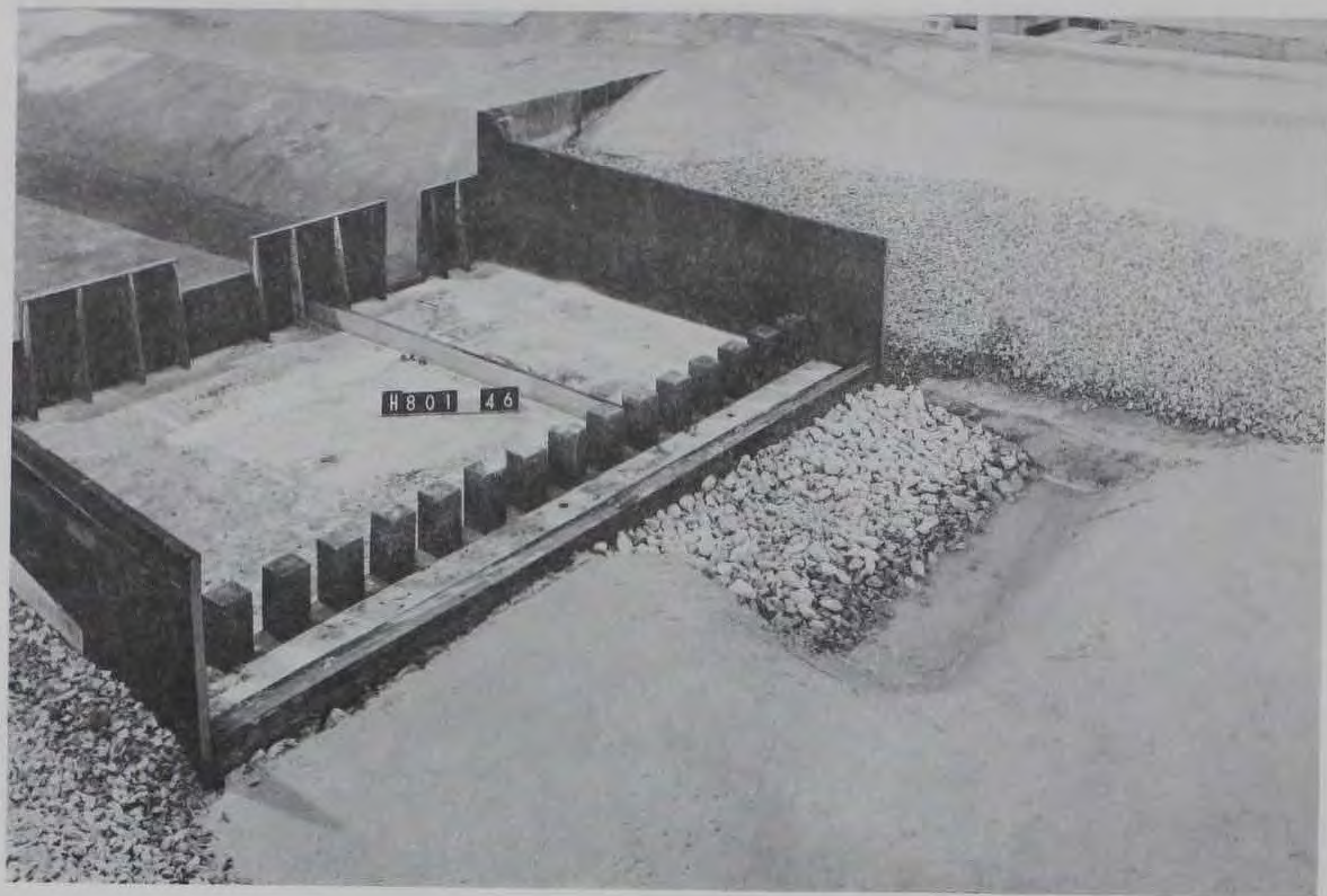


a. Looking upstream



b. Looking downstream

Photo 21. Results of riprap tests with Type 1 riprap plan

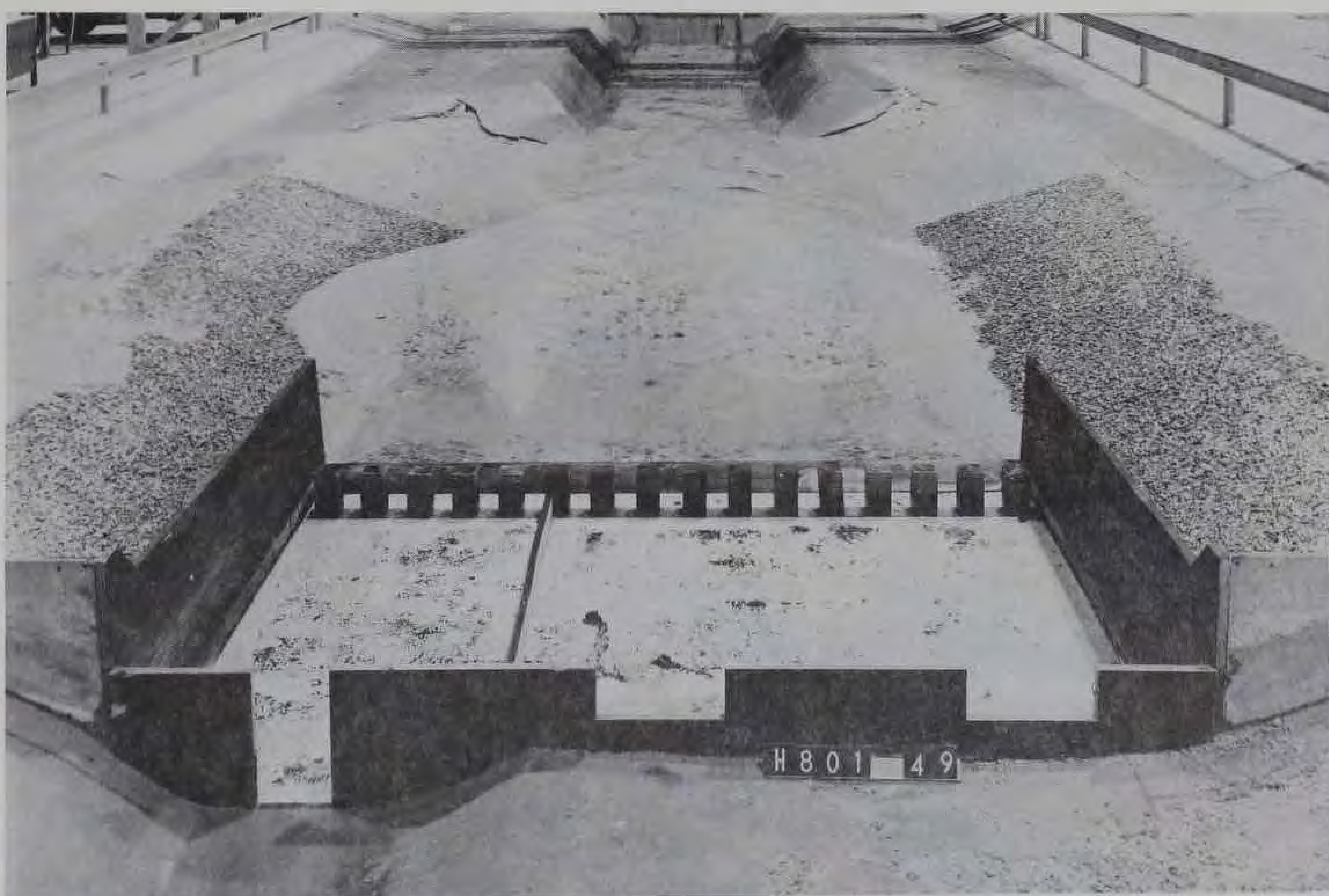


a. Looking upstream

b. Looking downstream

Photo 22. Type B riprap plan

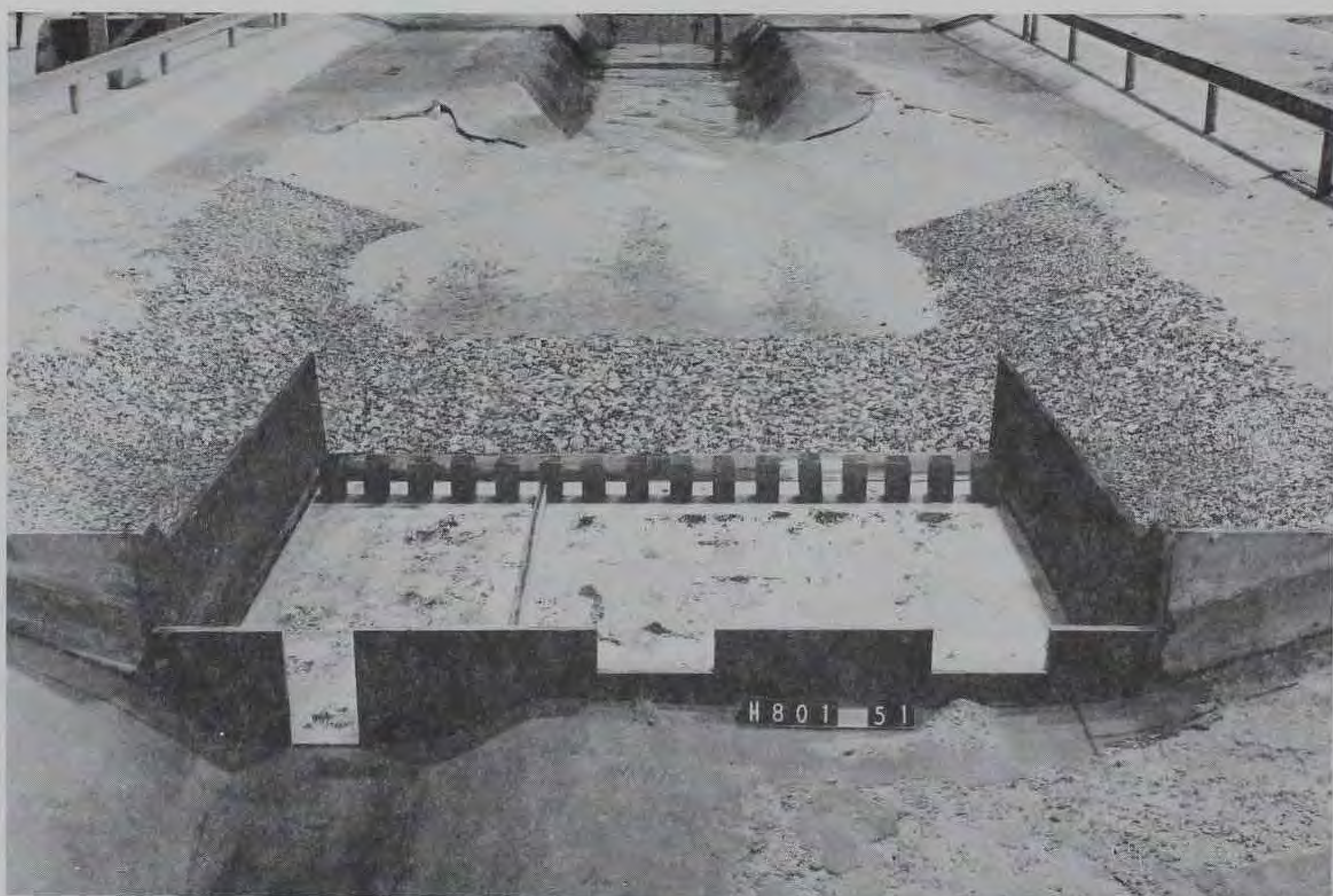
a. Looking upstream



b. Looking downstream

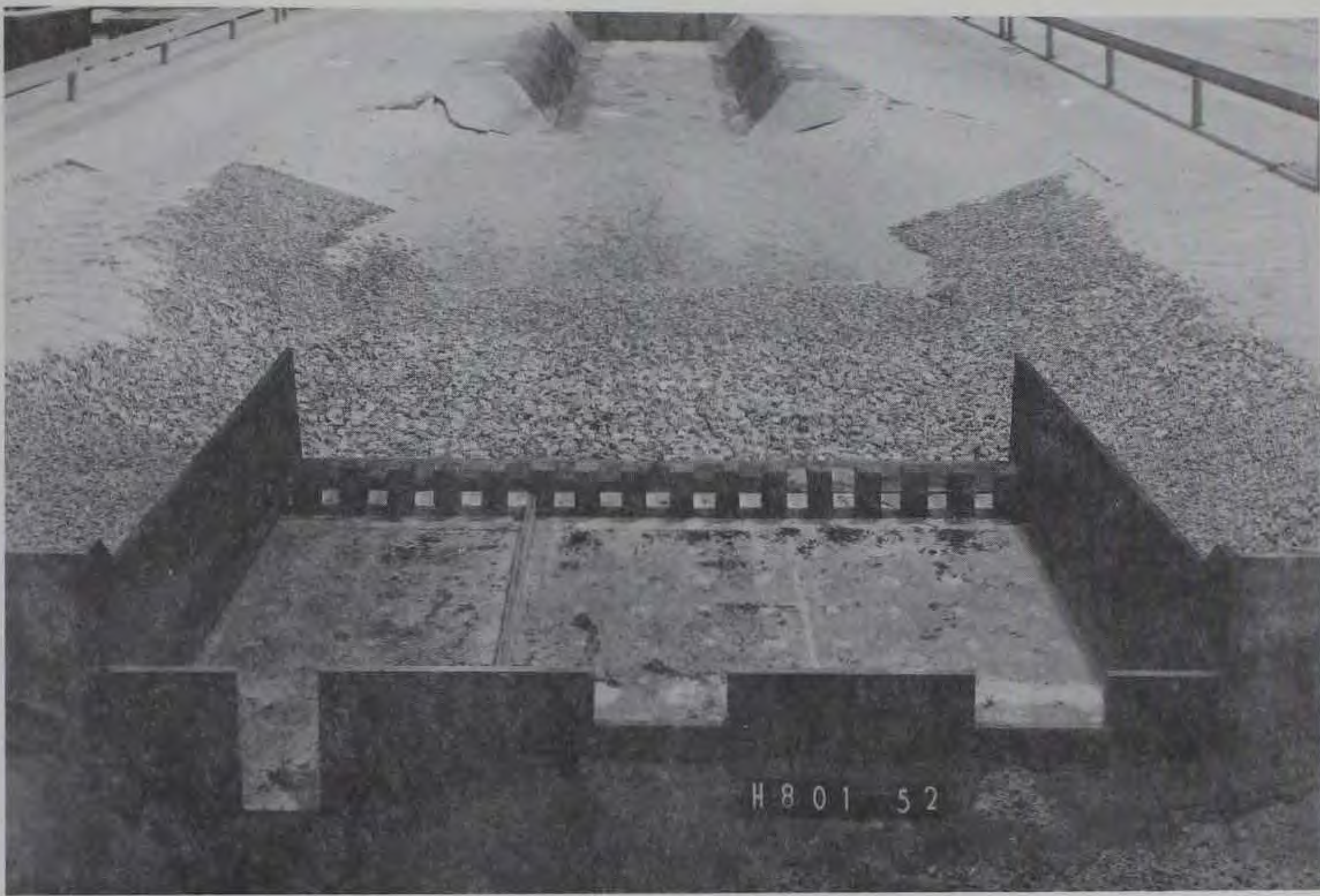
Photo 23. Results of riprap test with Type B riprap plan

a. Looking upstream



b. Looking downstream

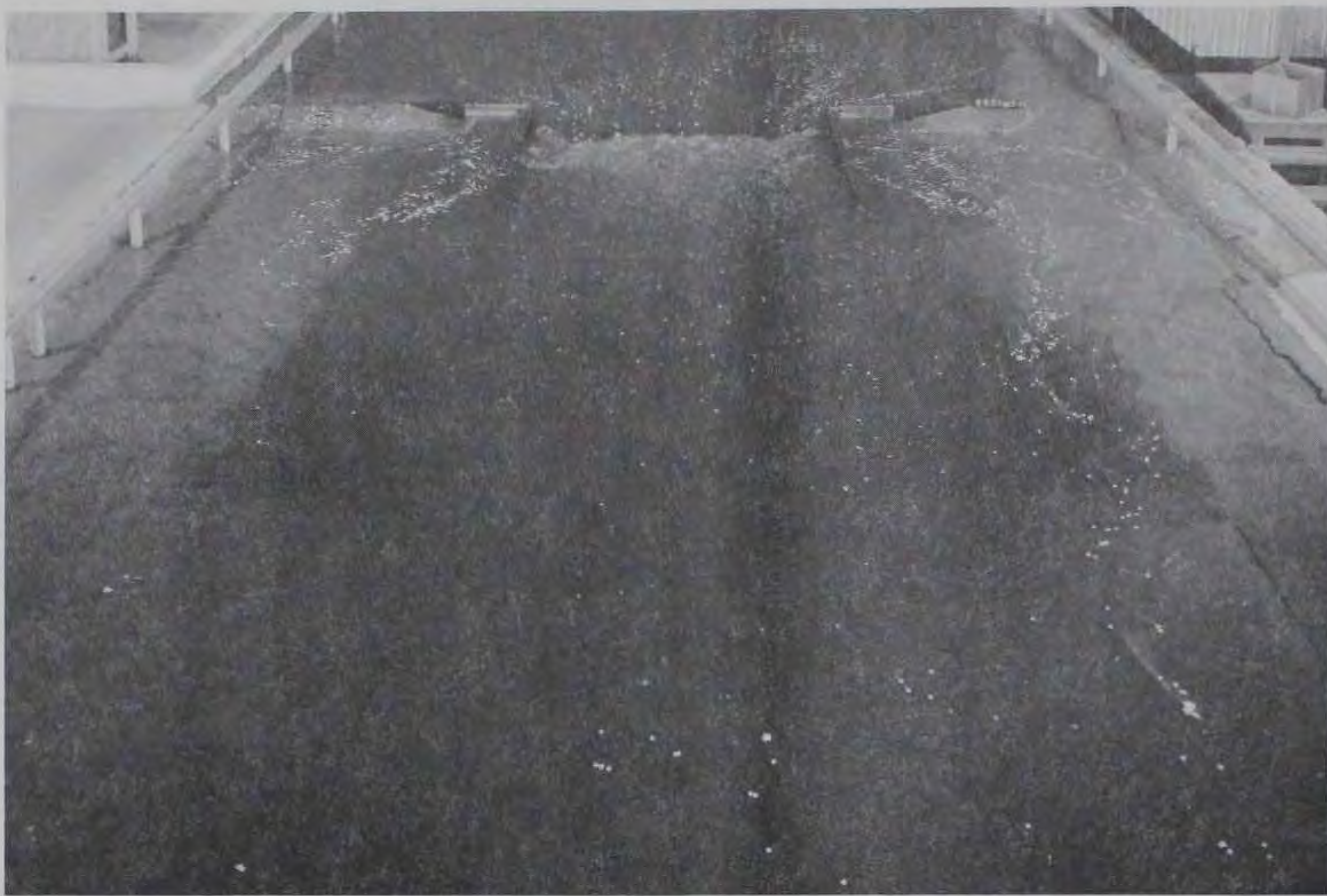
Photo 24. Results of riprap test with Type C riprap plan



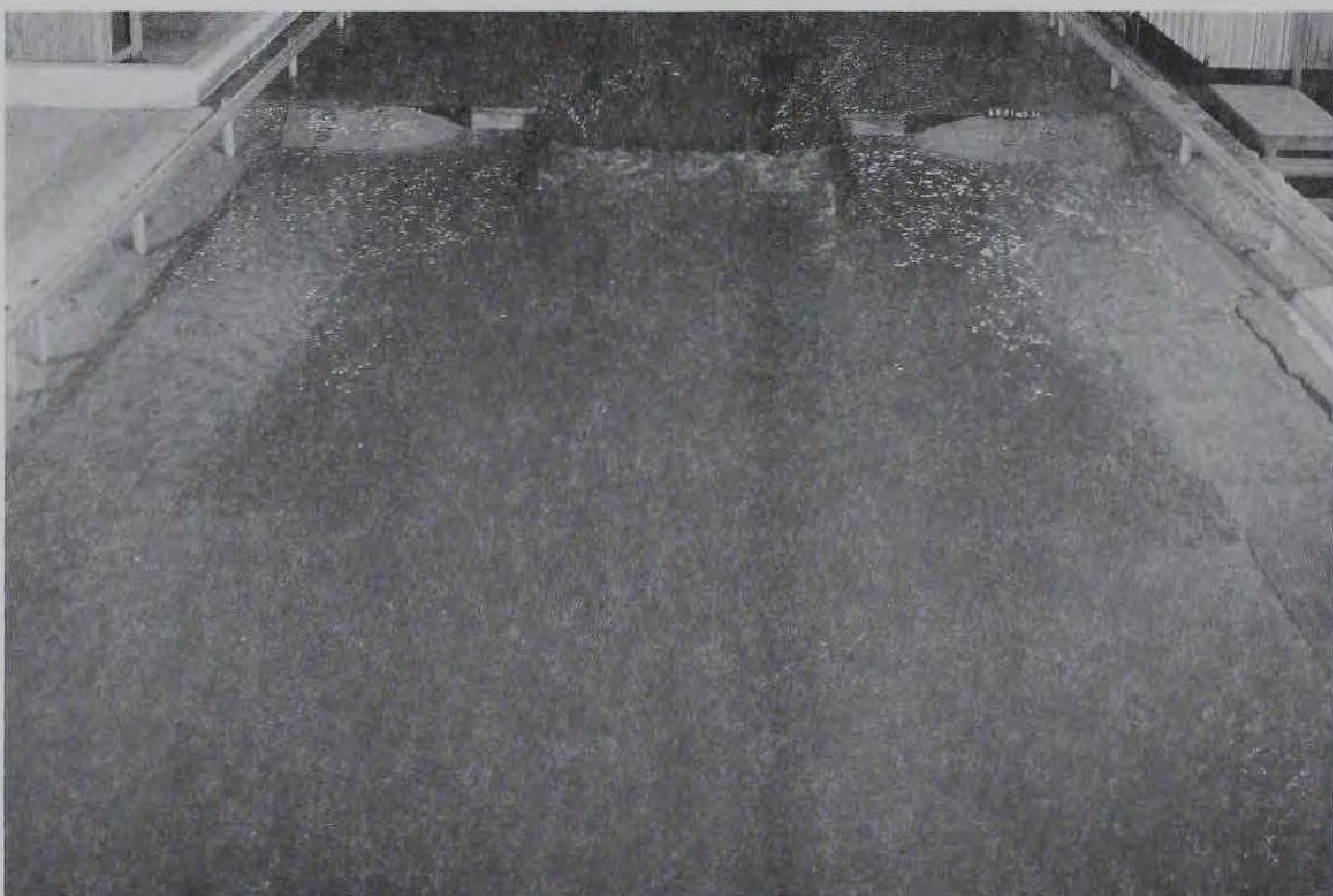
a. Looking upstream

b. Looking downstream

Photo 25. Results from riprap test with Type D riprap plan

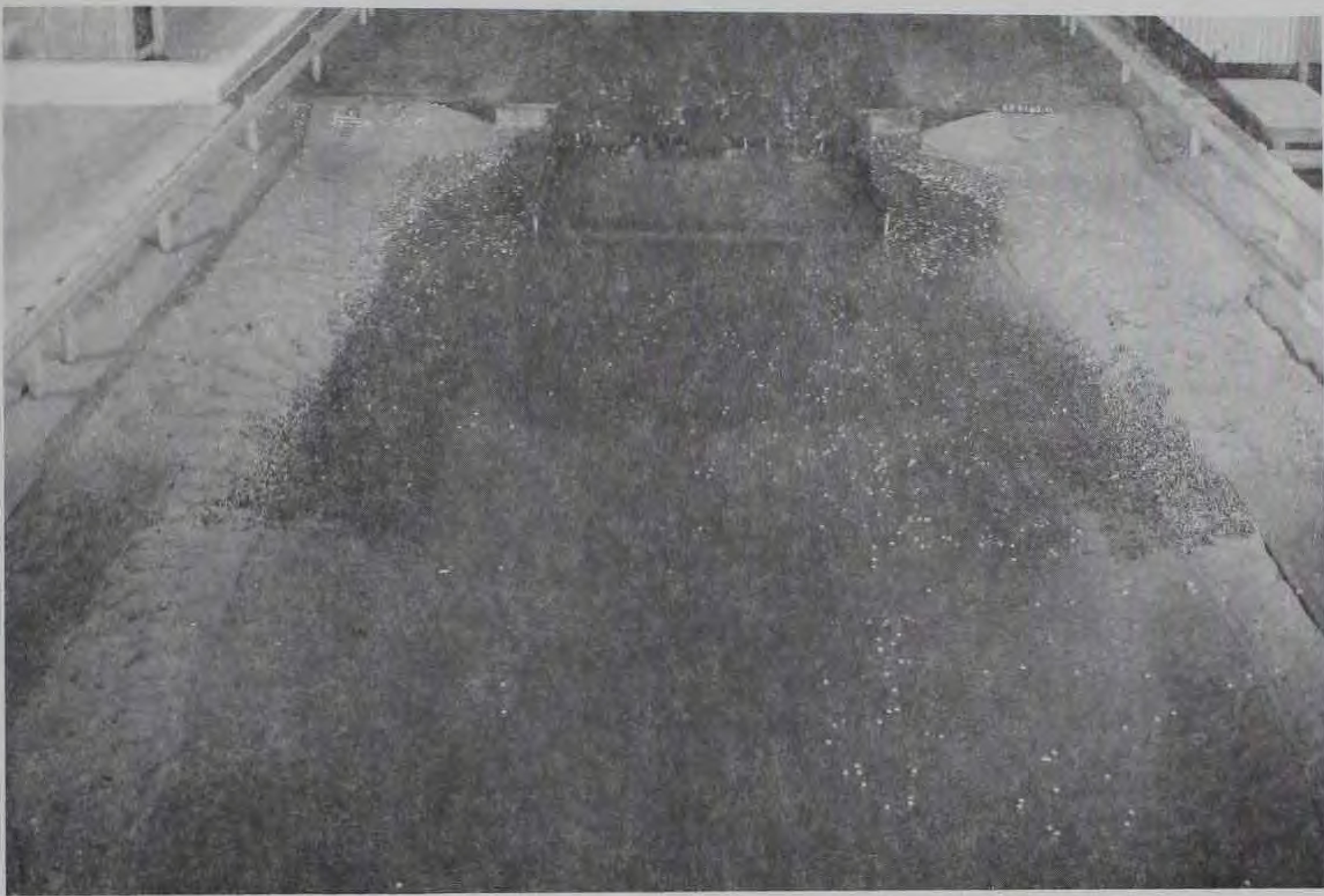


a. Tailwater el 1039.9

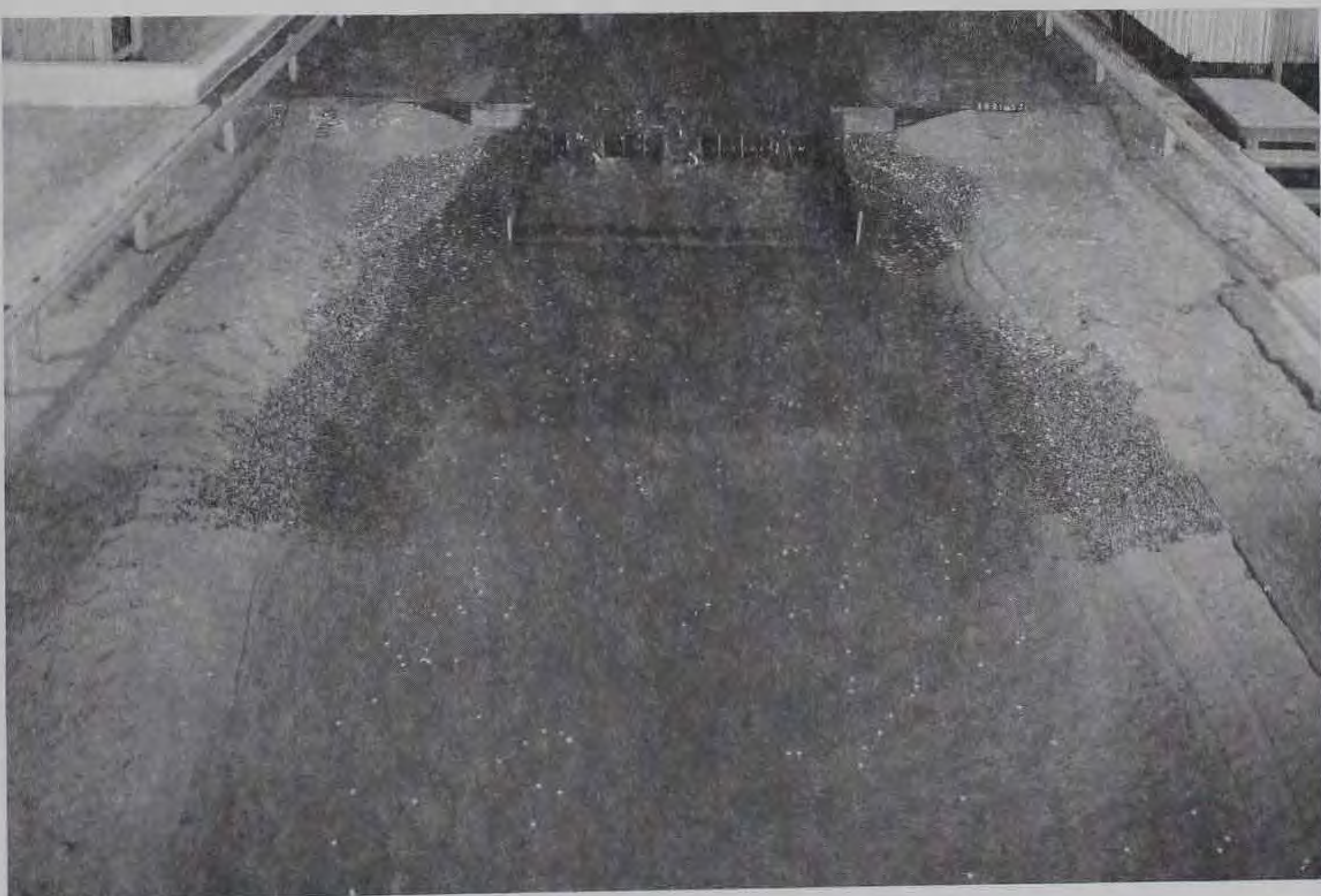


b. Tailwater el 1035.0

Photo 26. Recommended structure, flow conditions; discharge 46,000 cfs

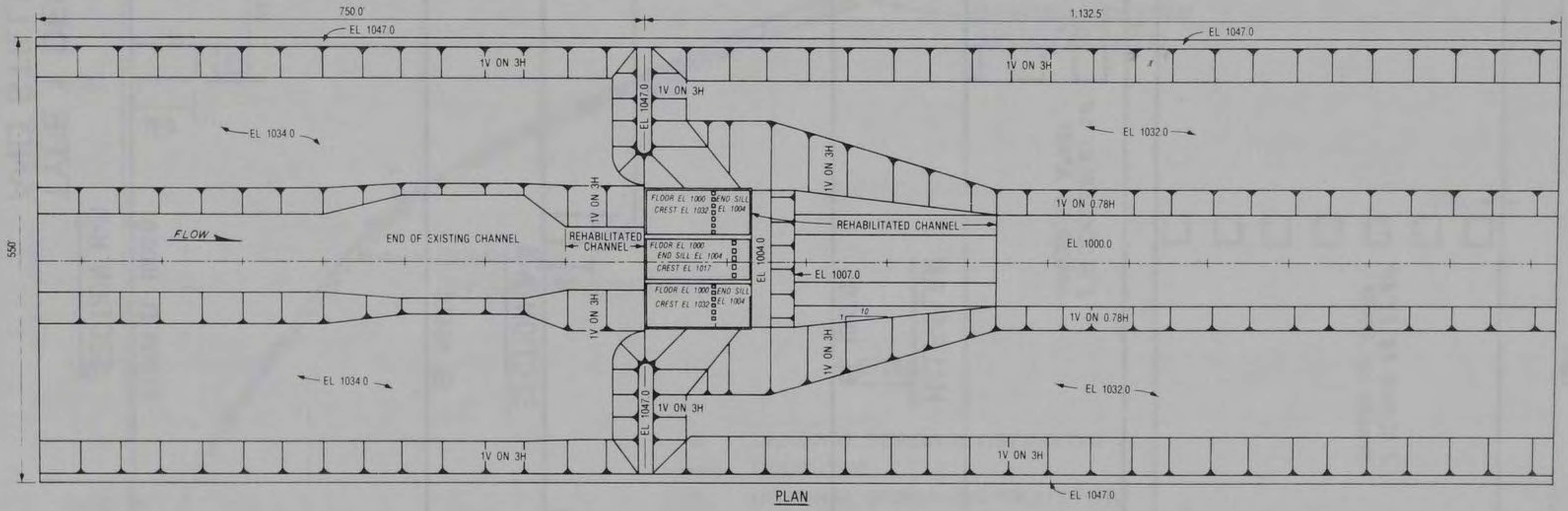


a. Tailwater el 1024.0

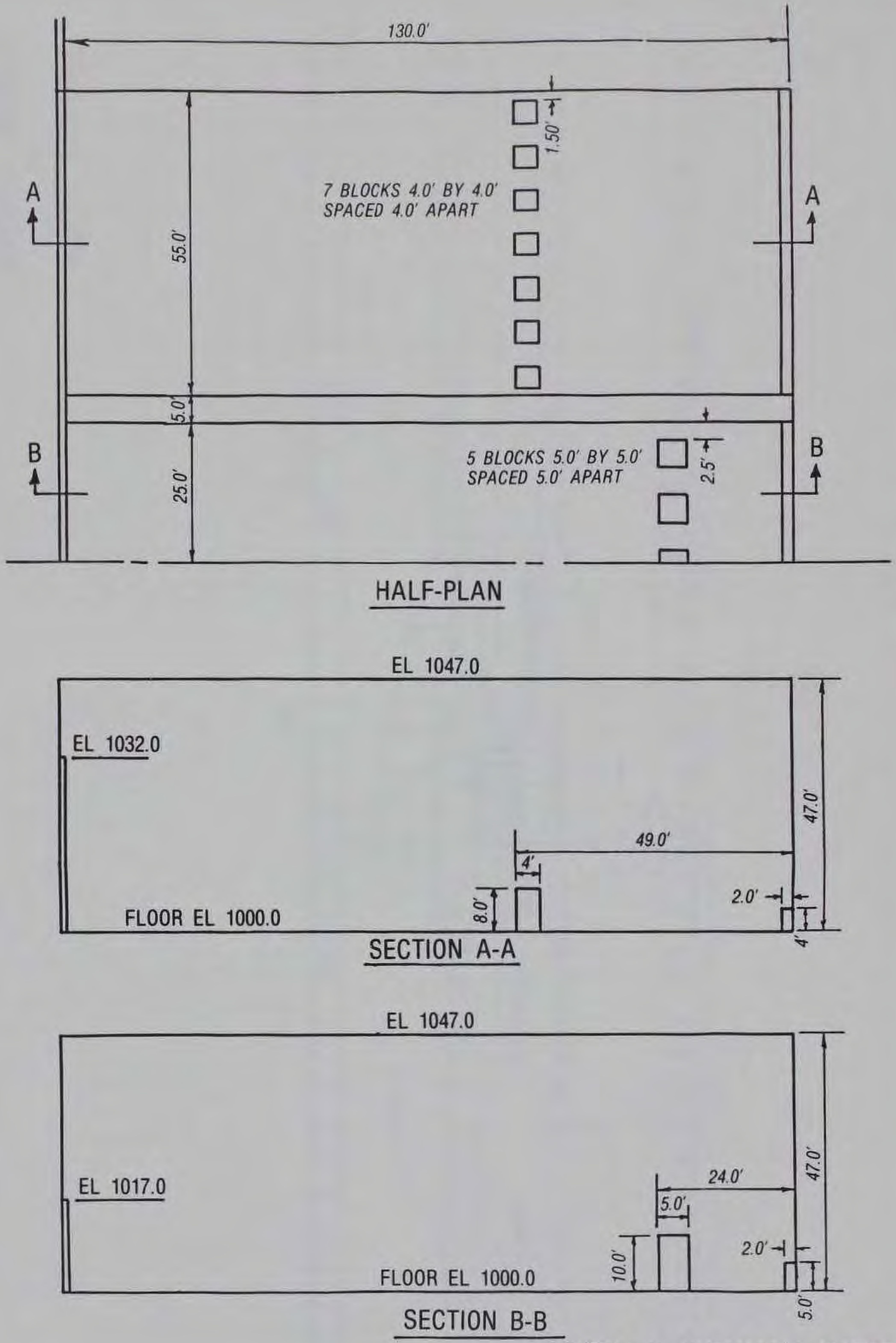


b. Tailwater el 1018.5

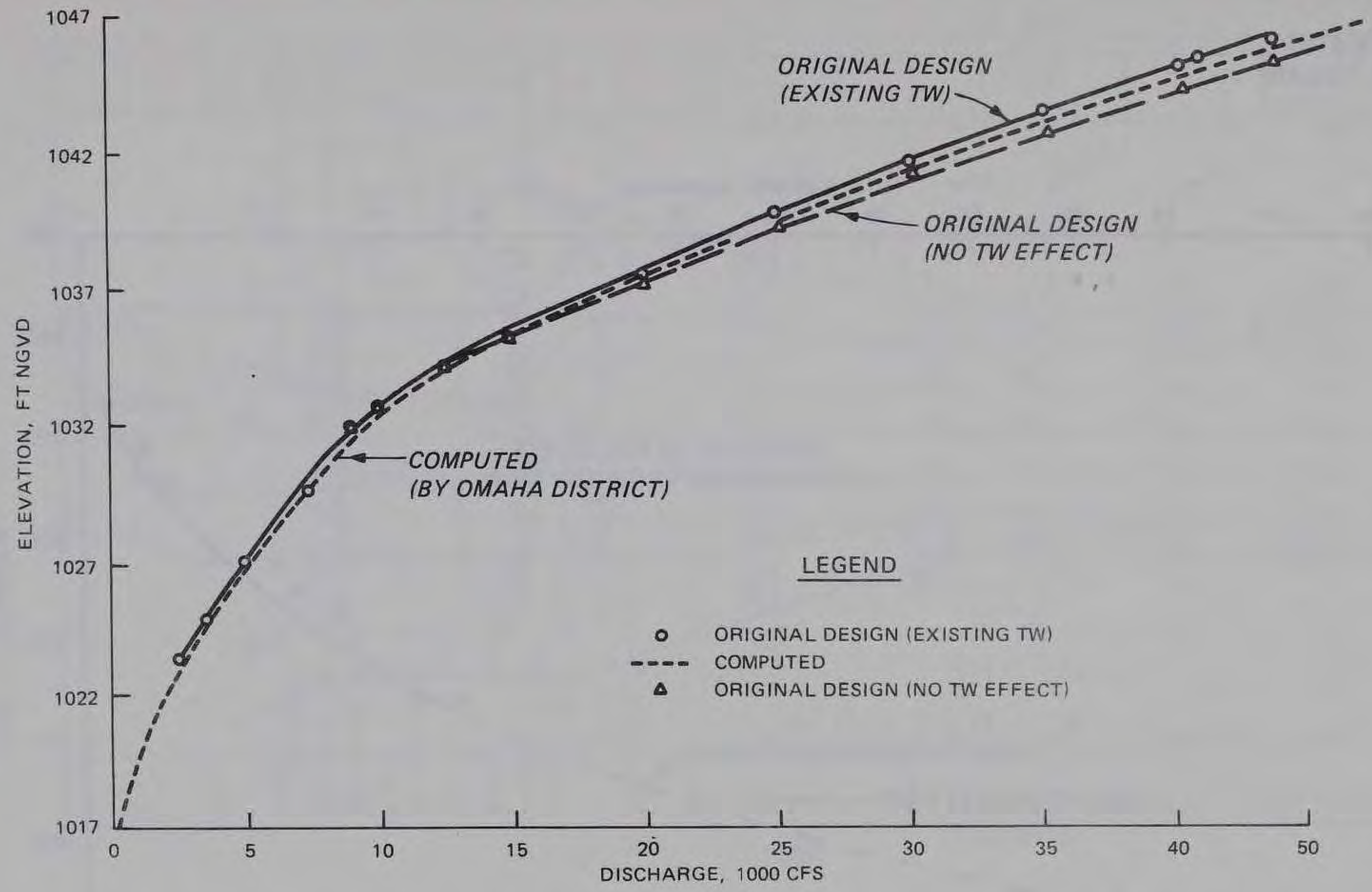
Photo 27. Recommended structure, flow conditions; discharge 10,000 cfs



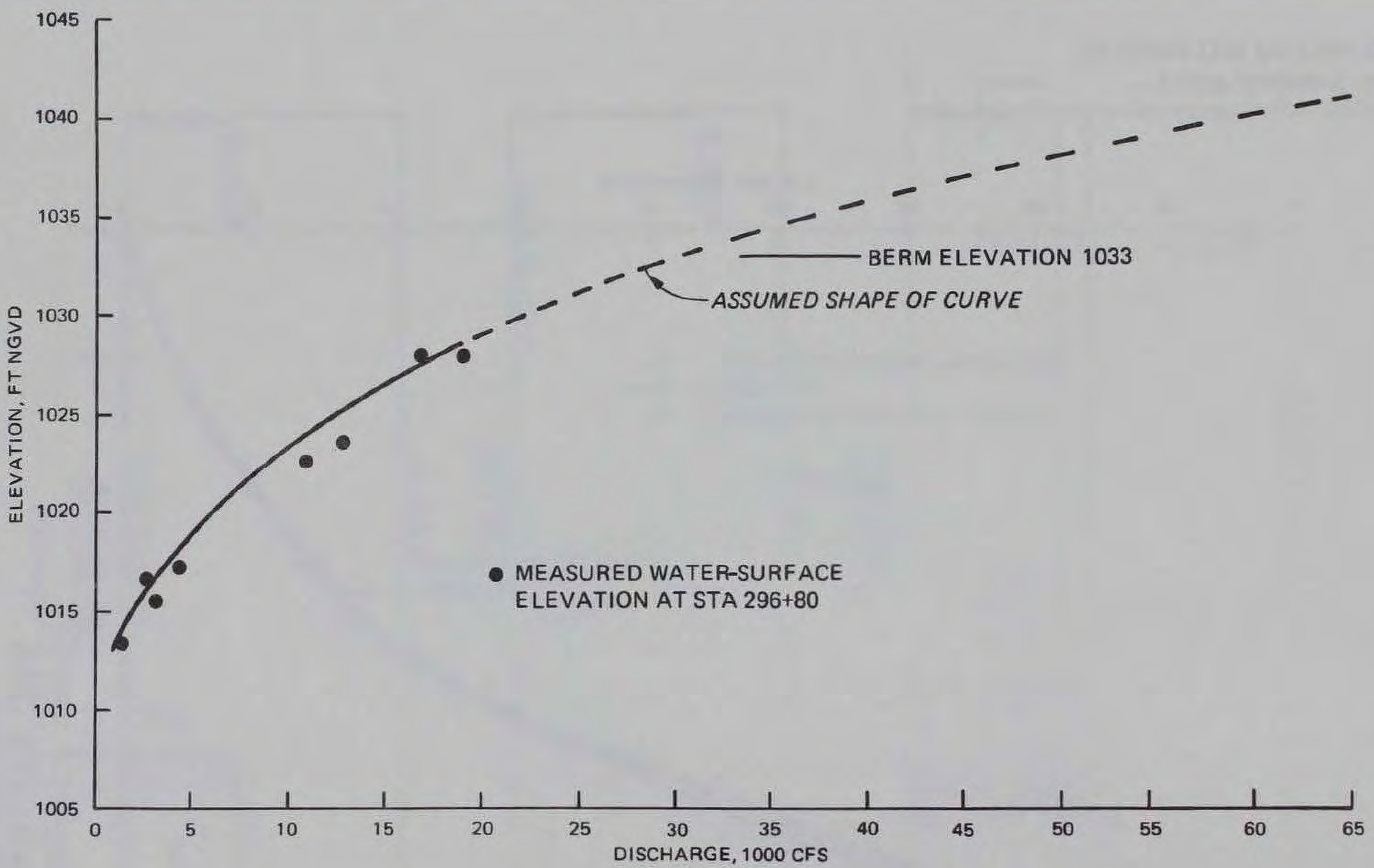
MODEL LAYOUT OF ORIGINAL DESIGN



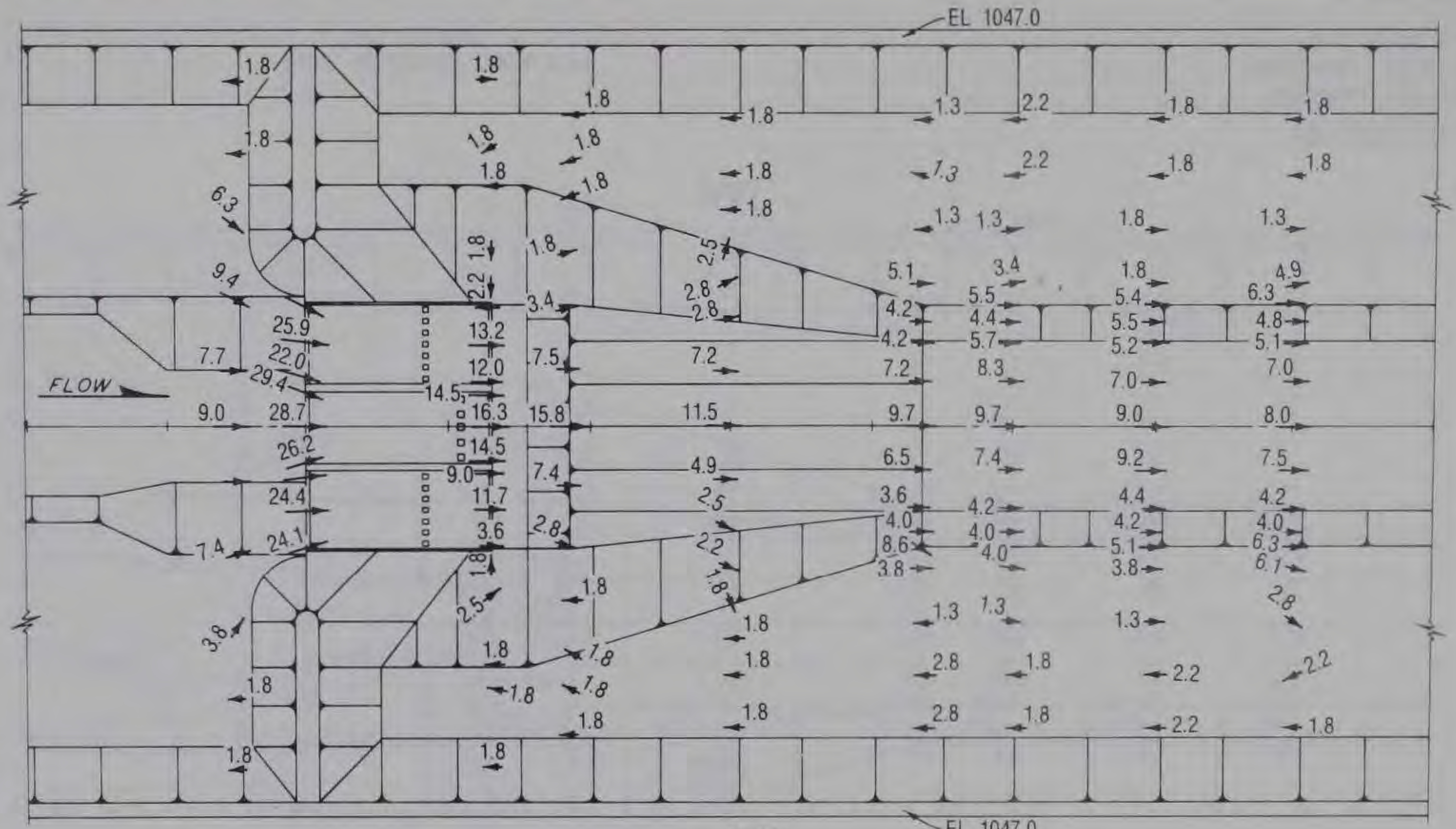
TYPE 1 DESIGN WEIR
AND STILLING BASIN
(ORIGINAL DESIGN)



COMPARISION OF
HEADWATER RATING CURVES



INITIAL TAILWATER RATING CURVE



PLAN

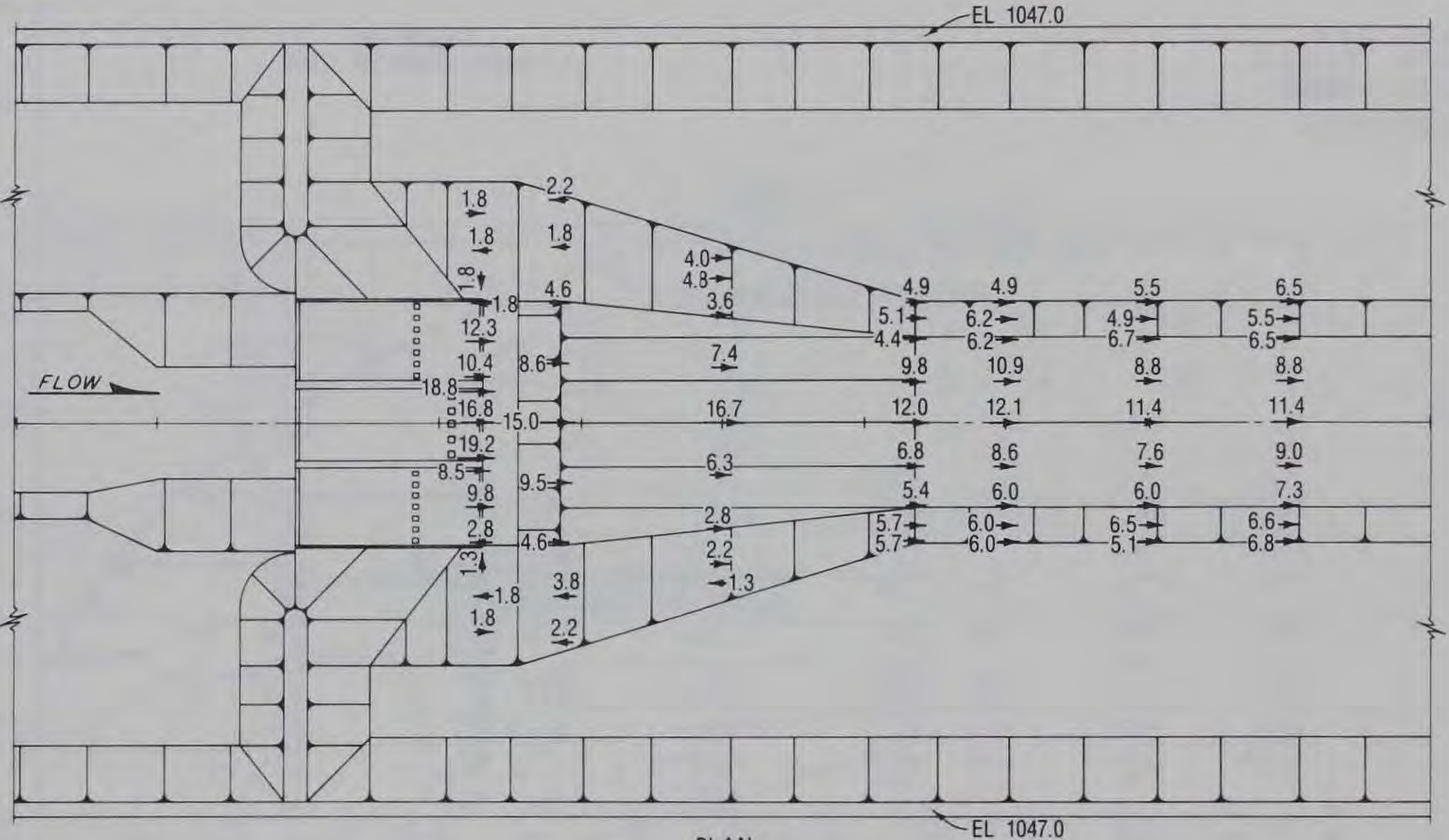
NOTE: VELOCITIES TAKEN 1 FT OFF BOTTOM

VELOCITIES

ORIGINAL DESIGN

DISCHARGE 43,600 CFS

TW EL 1036.8



PLAN

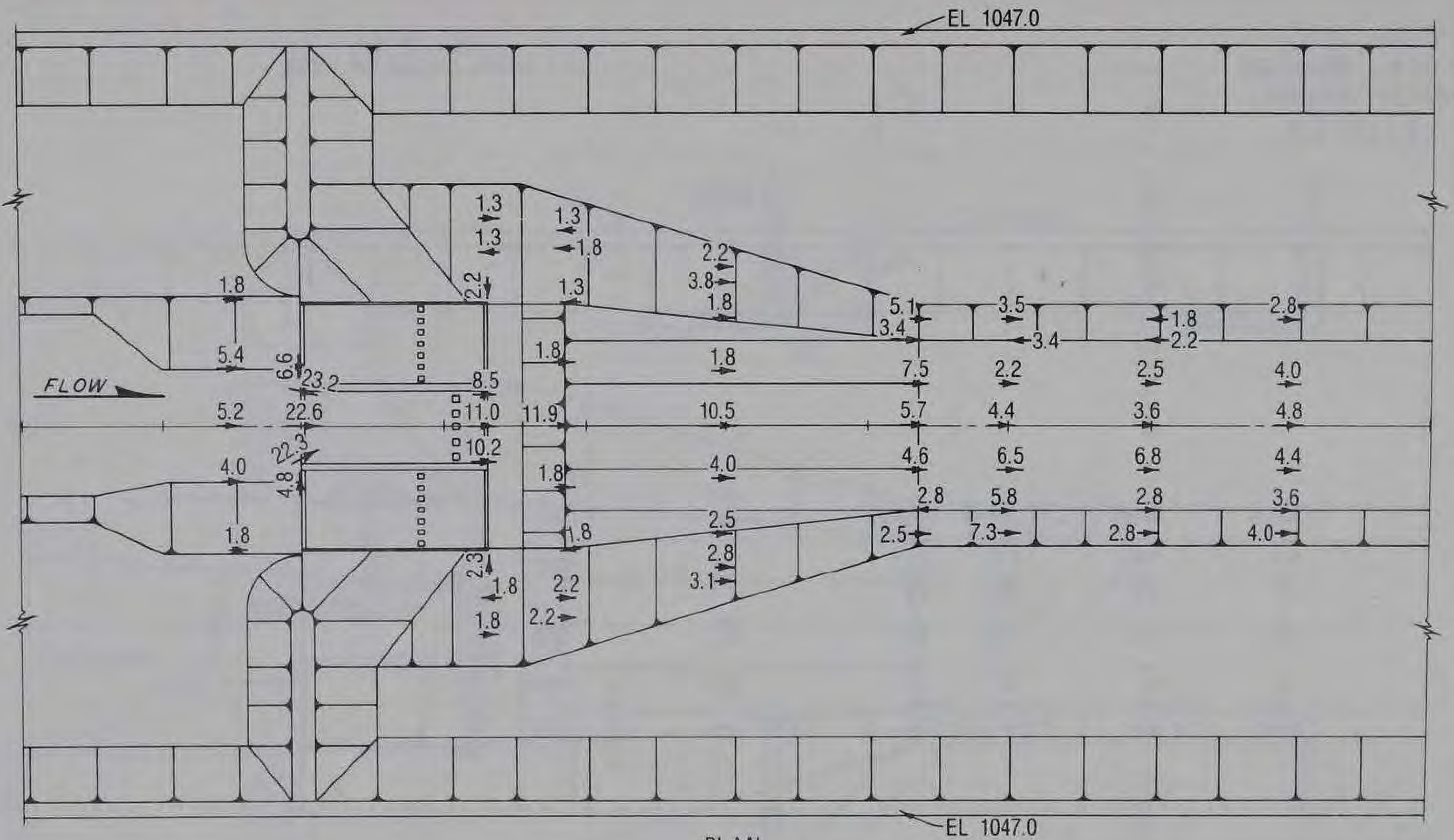
NOTE: VELOCITIES TAKEN 1 FT OFF BOTTOM

VELOCITIES

ORIGINAL DESIGN

DISCHARGE 43,600 CFS

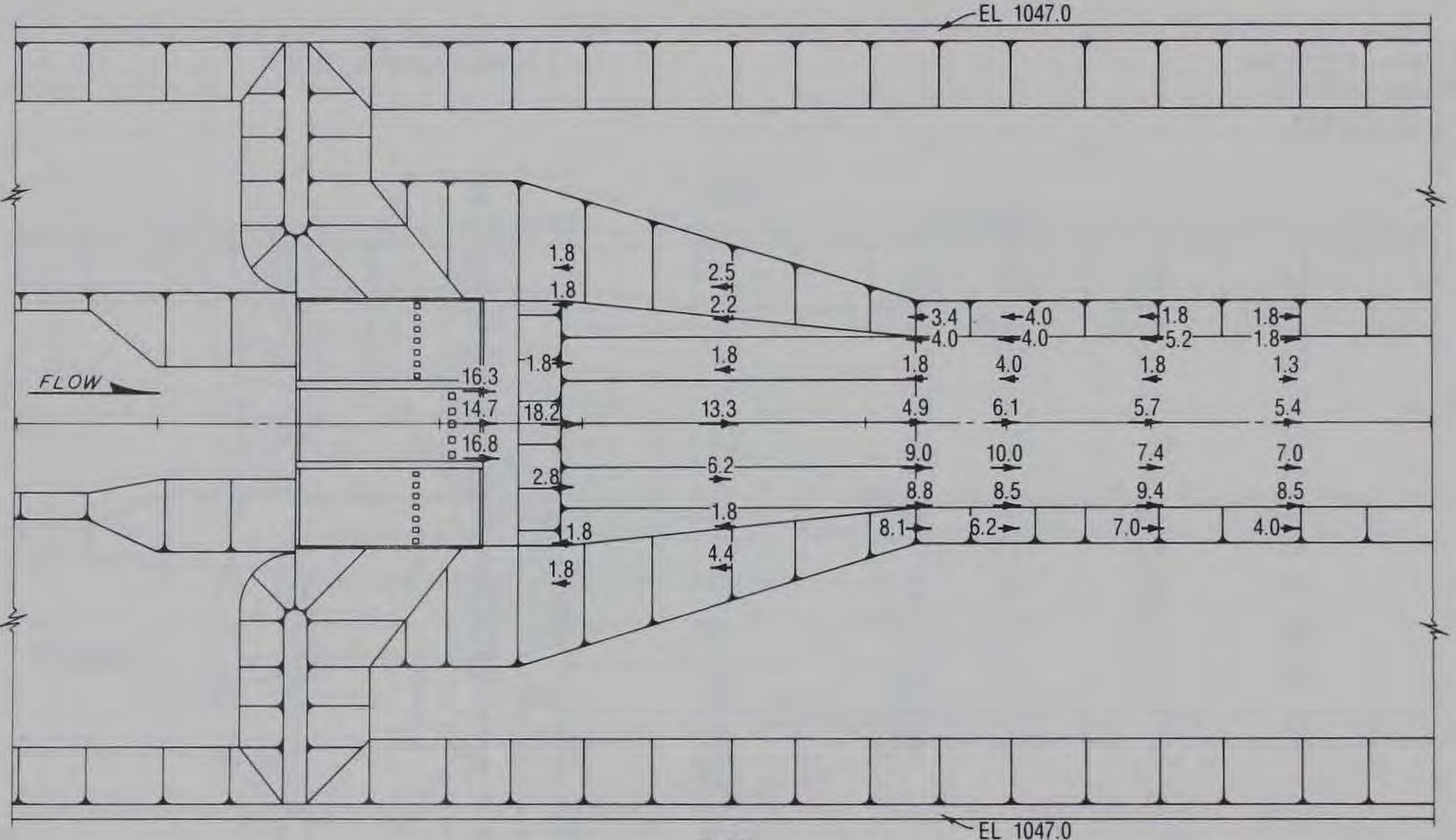
TW EL 1030.8



PLAN

NOTE: VELOCITIES TAKEN 1 FT OFF BOTTOM

VELOCITIES
ORIGINAL DESIGN
DISCHARGE 10,000 CFS
TW EL 1023.5



PLAN

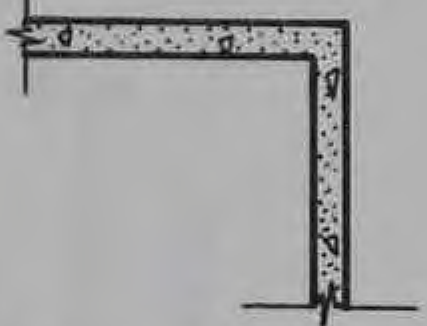
NOTE: VELOCITIES TAKEN 1 FT
OFF BOTTOM

VELOCITIES

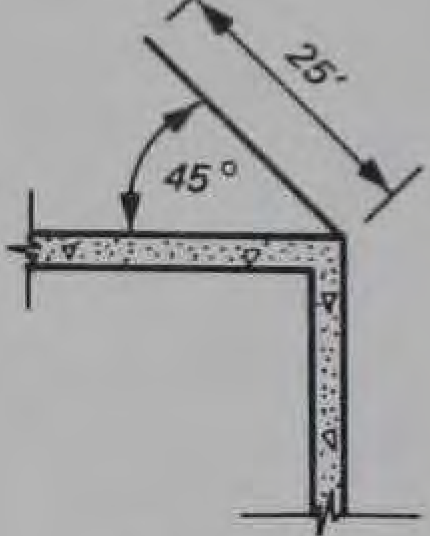
ORIGINAL DESIGN

DISCHARGE 10,000 CFS

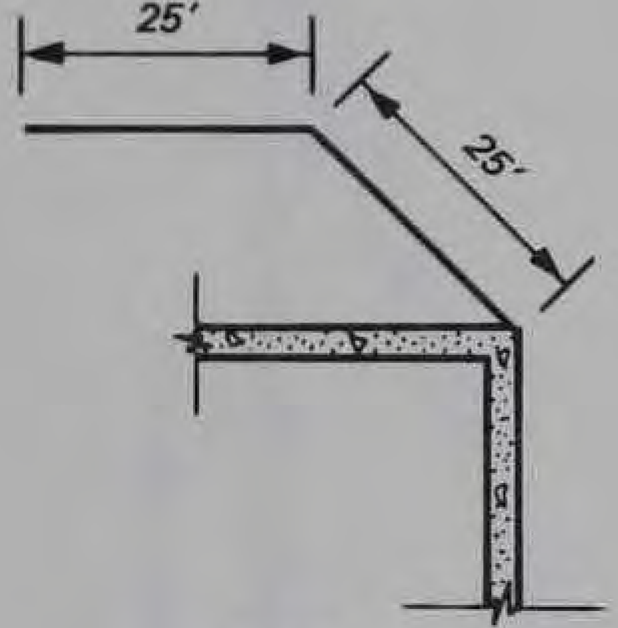
TW EL 1017.5



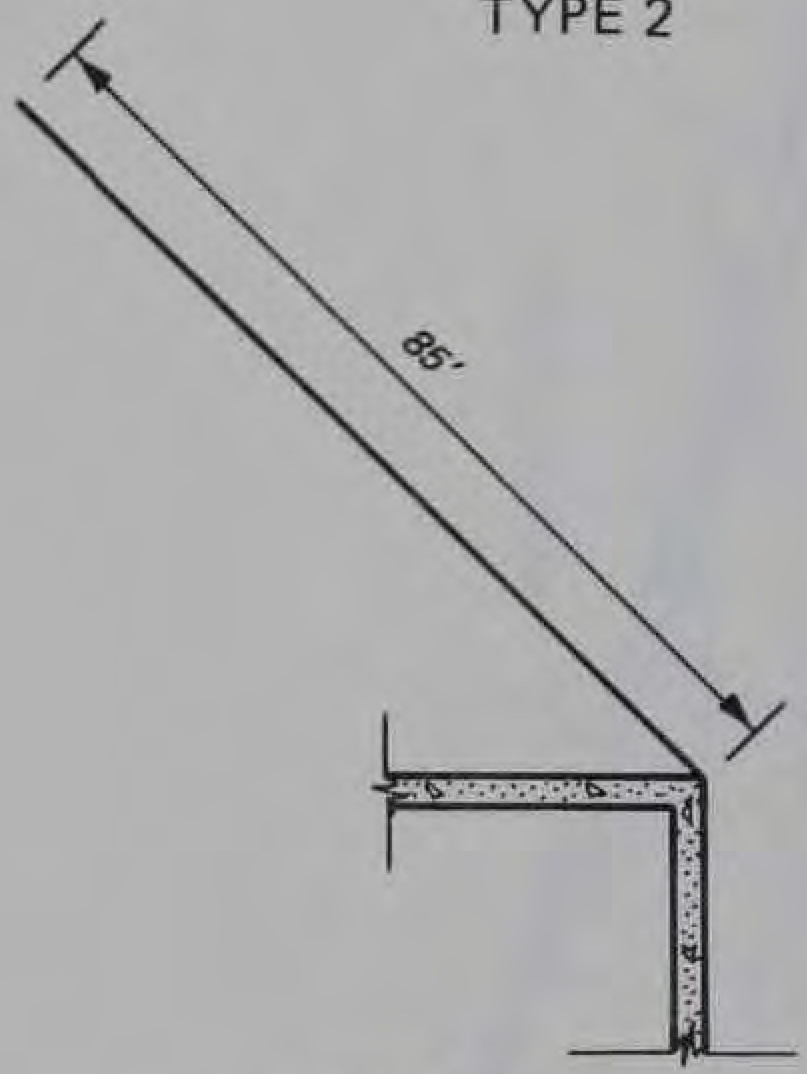
TYPE 1 (ORIGINAL) DESIGN



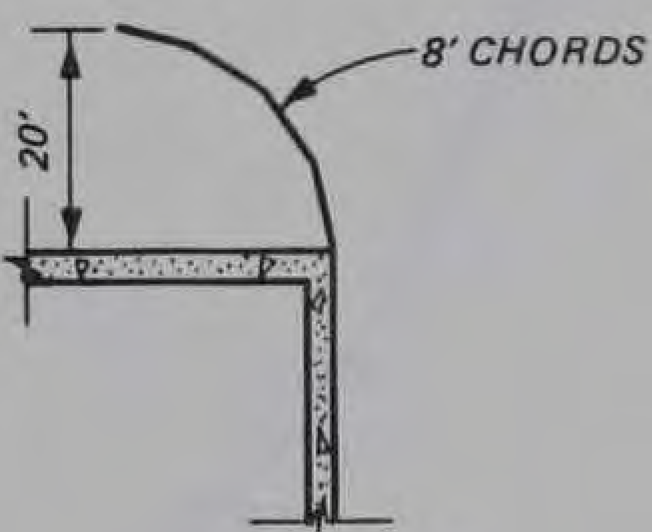
TYPE 2



TYPE 3

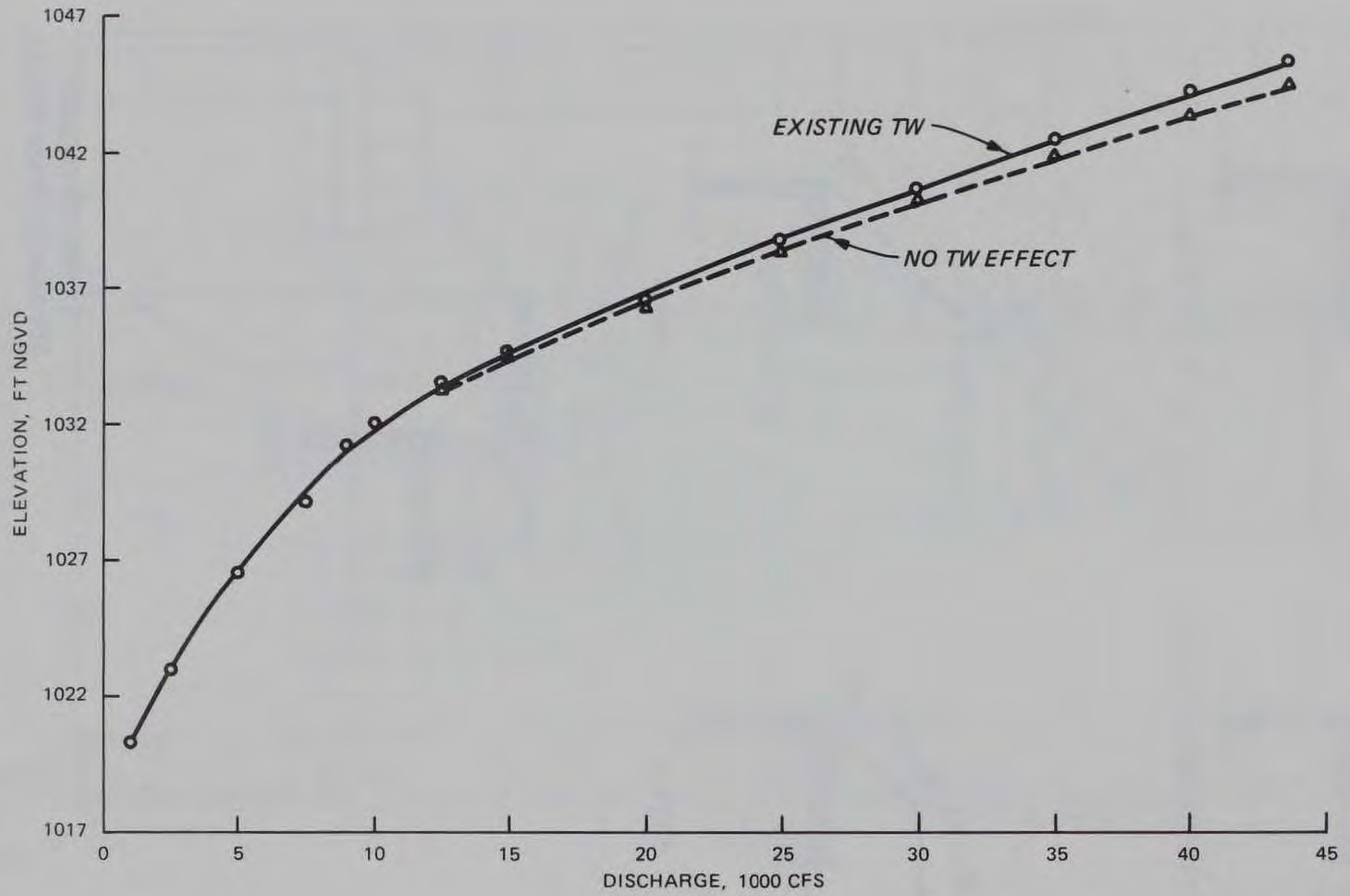


TYPE 4

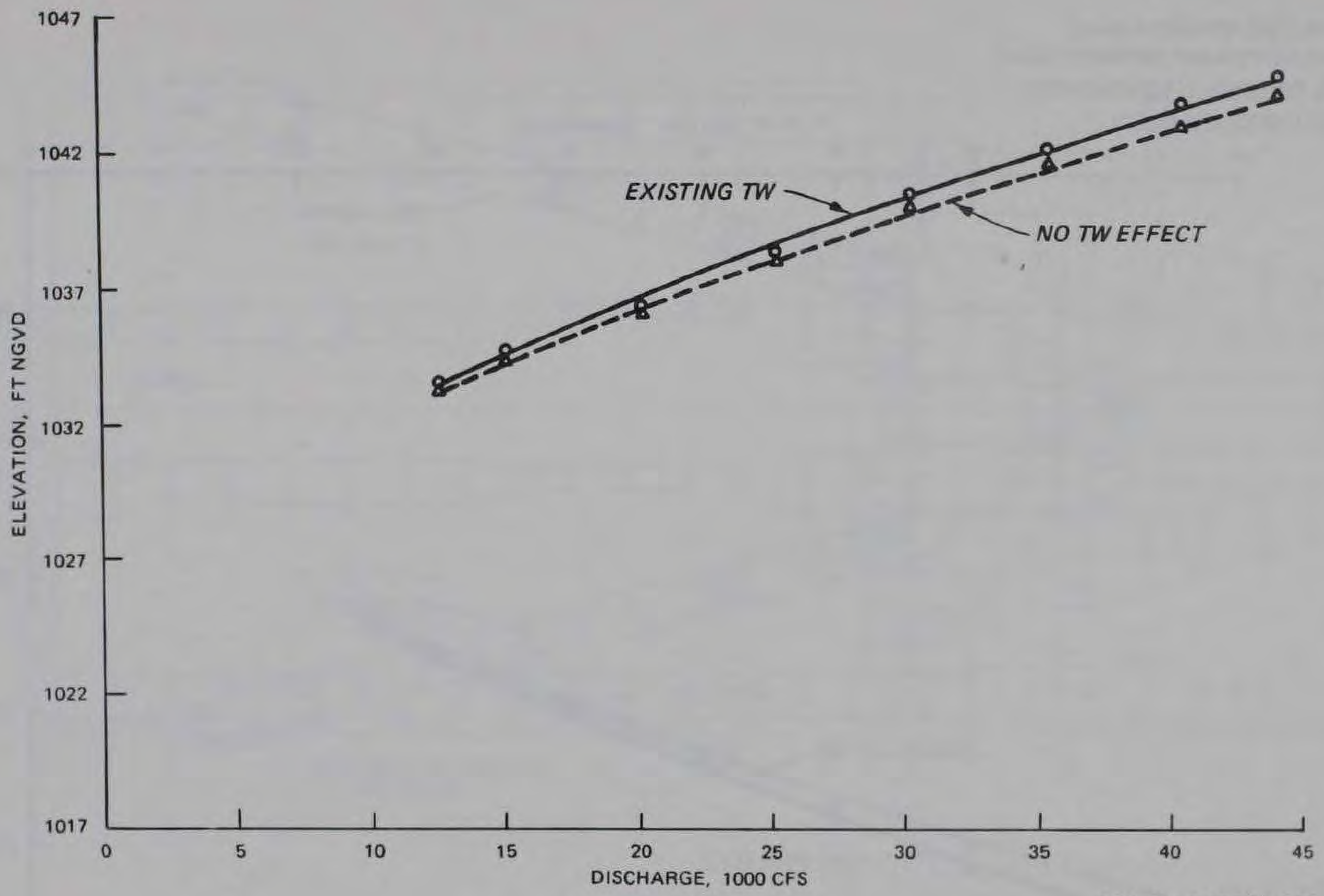


TYPE 5

**TYPES 1-5 DESIGN
APPROACH WING WALLS**

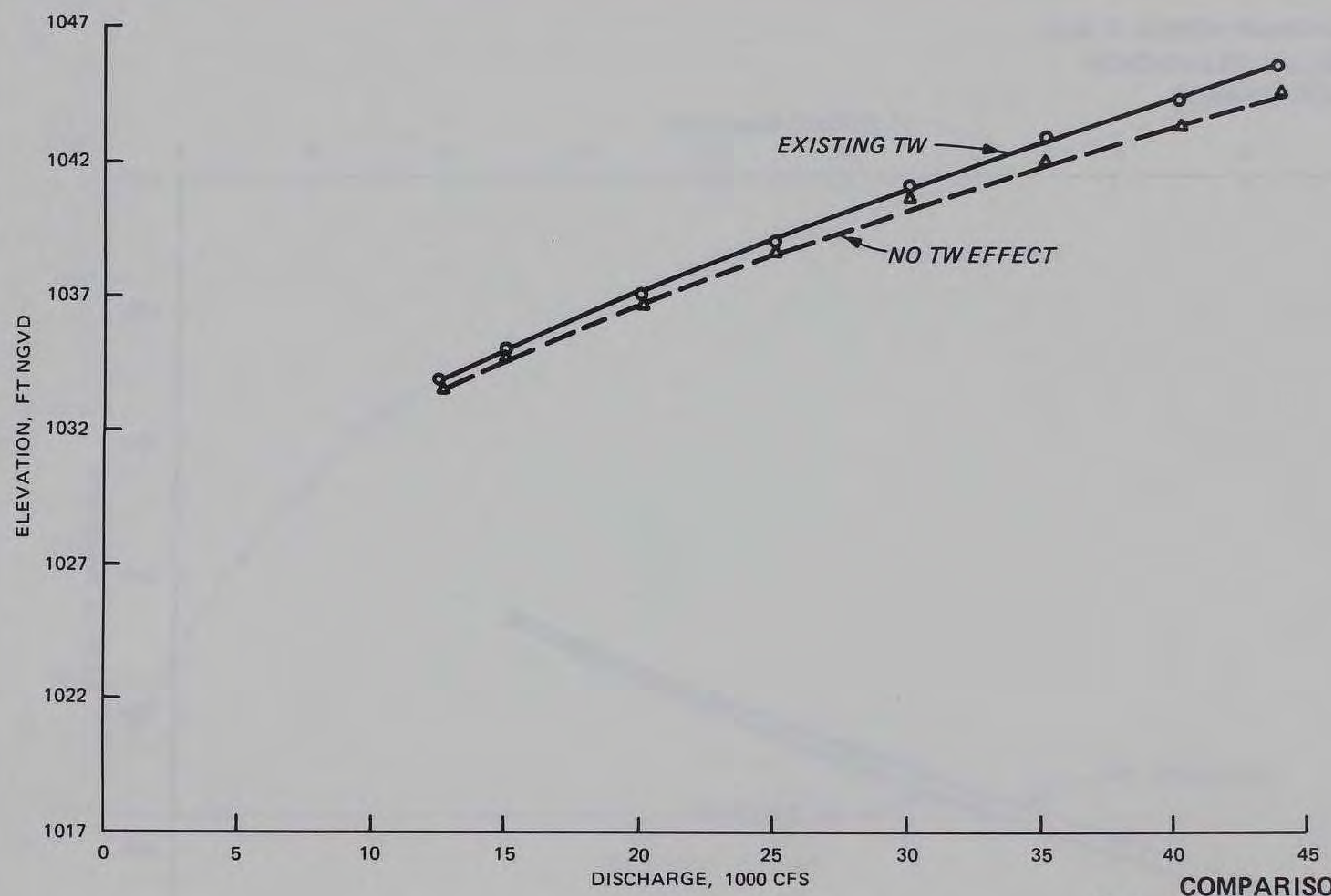


COMPARISON OF HEADWATER RATING CURVES
TYPE 2 DESIGN PIER NOSES



COMPARISON OF
HEADWATER RATING CURVES
TYPE 2 DESIGN APPROACH WING WALLS

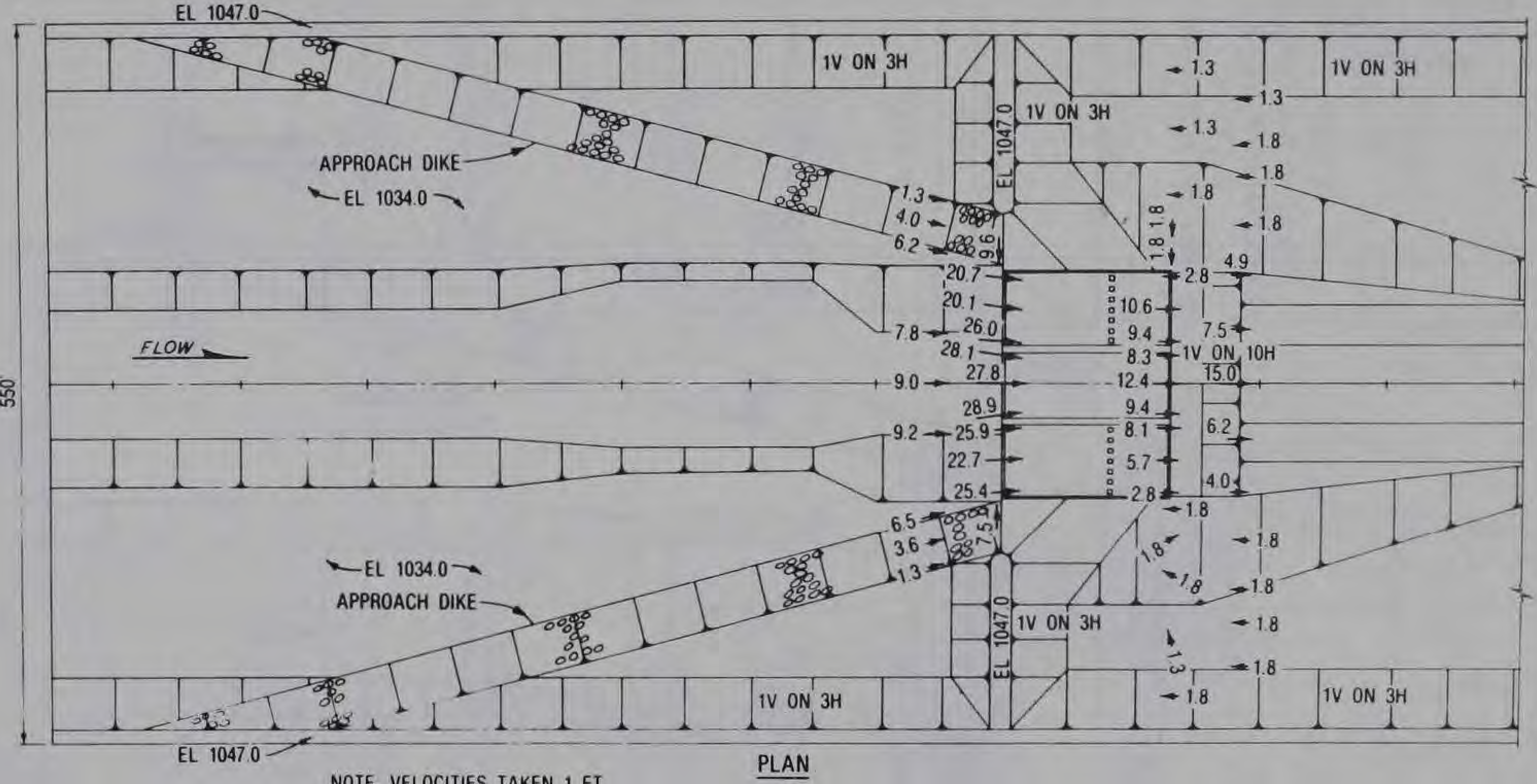
PLATE 11



COMPARISON OF HEADWATER RATING CURVES

TYPE 2 DESIGN APPROACH WING WALLS

TYPE 2 DESIGN PIER NOSES



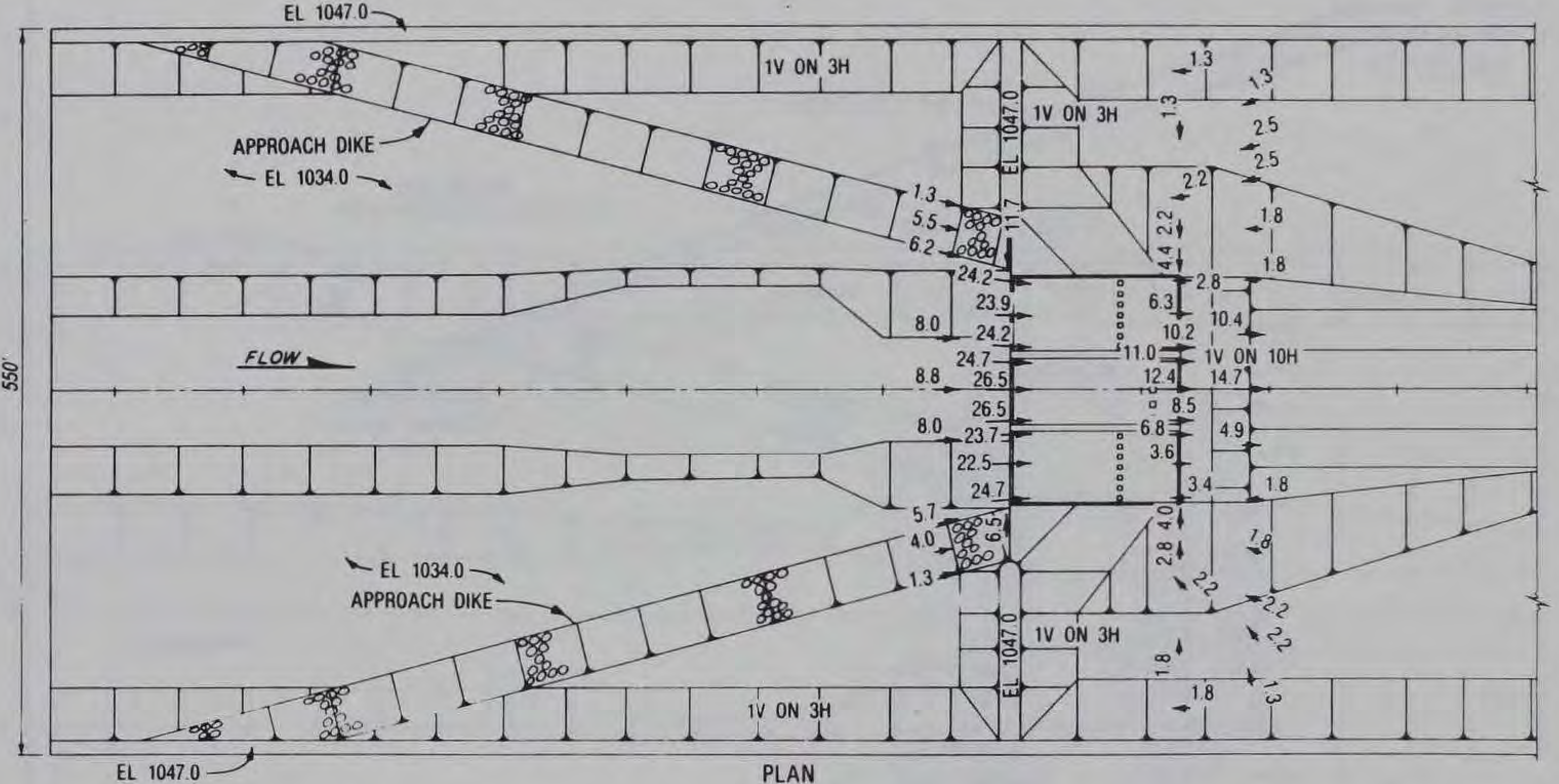
NOTE: VELOCITIES TAKEN 1 FT OFF BOTTOM

VELOCITIES

TYPE 2 DESIGN APPROACH DIKE

DISCHARGE 43,600 CFS

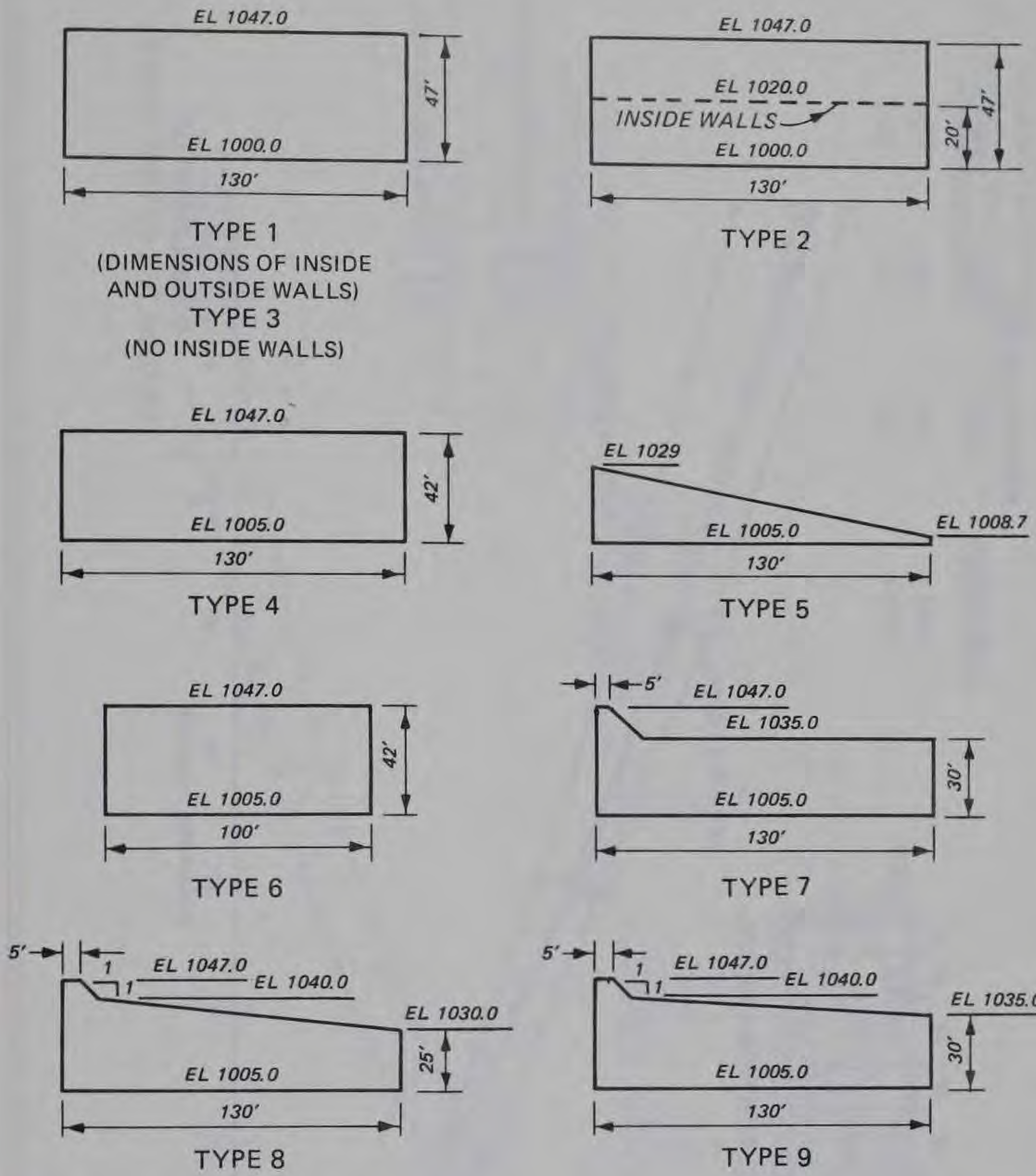
TW EL 1036.8



PLAN

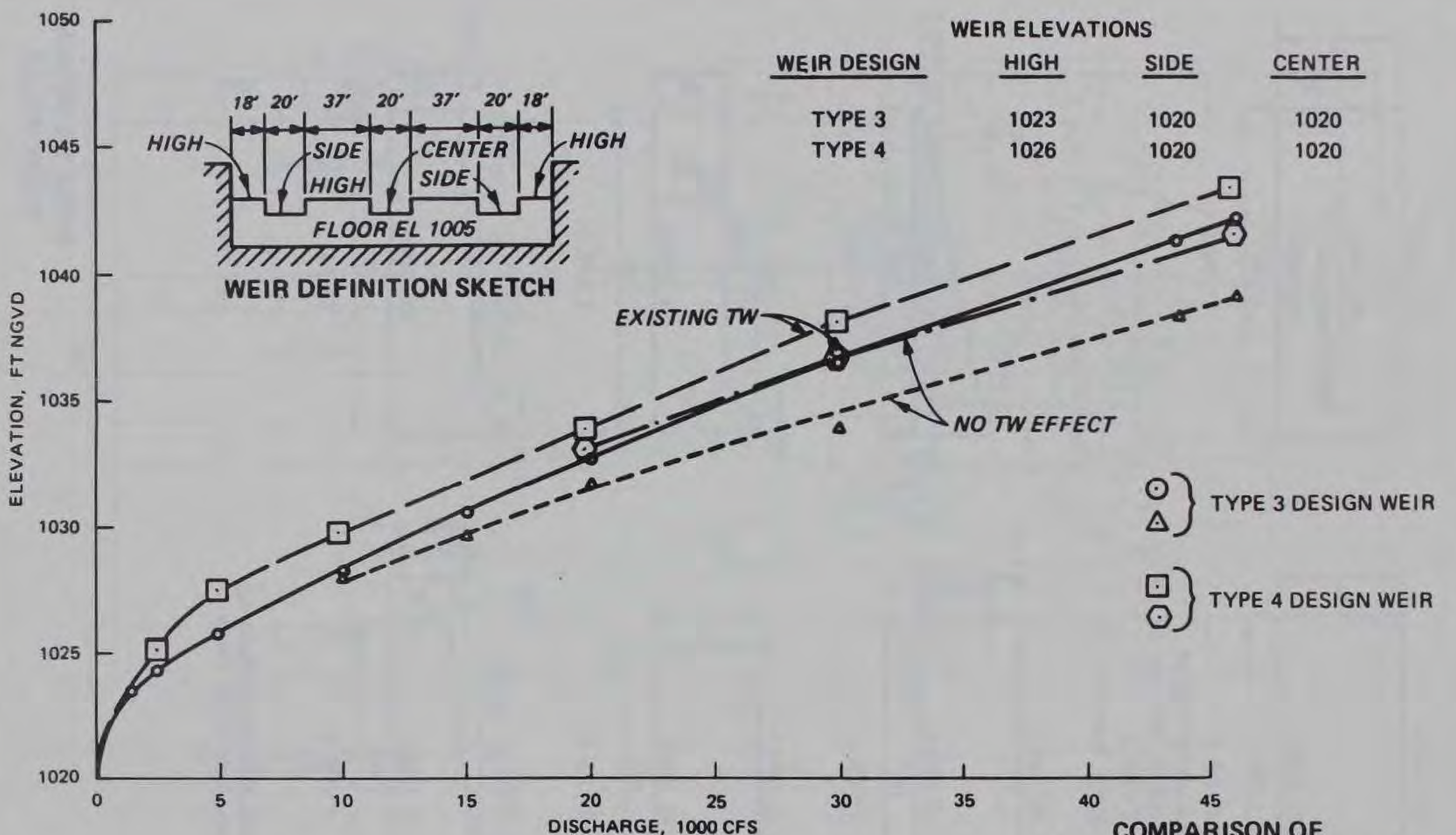
NOTE: VELOCITIES MEASURED 1 FT
OFF BOTTOM

VELOCITIES
TYPE 2 DESIGN APPROACH DIKES
DISCHARGE 43,600 CFS
TW EL 1039.0

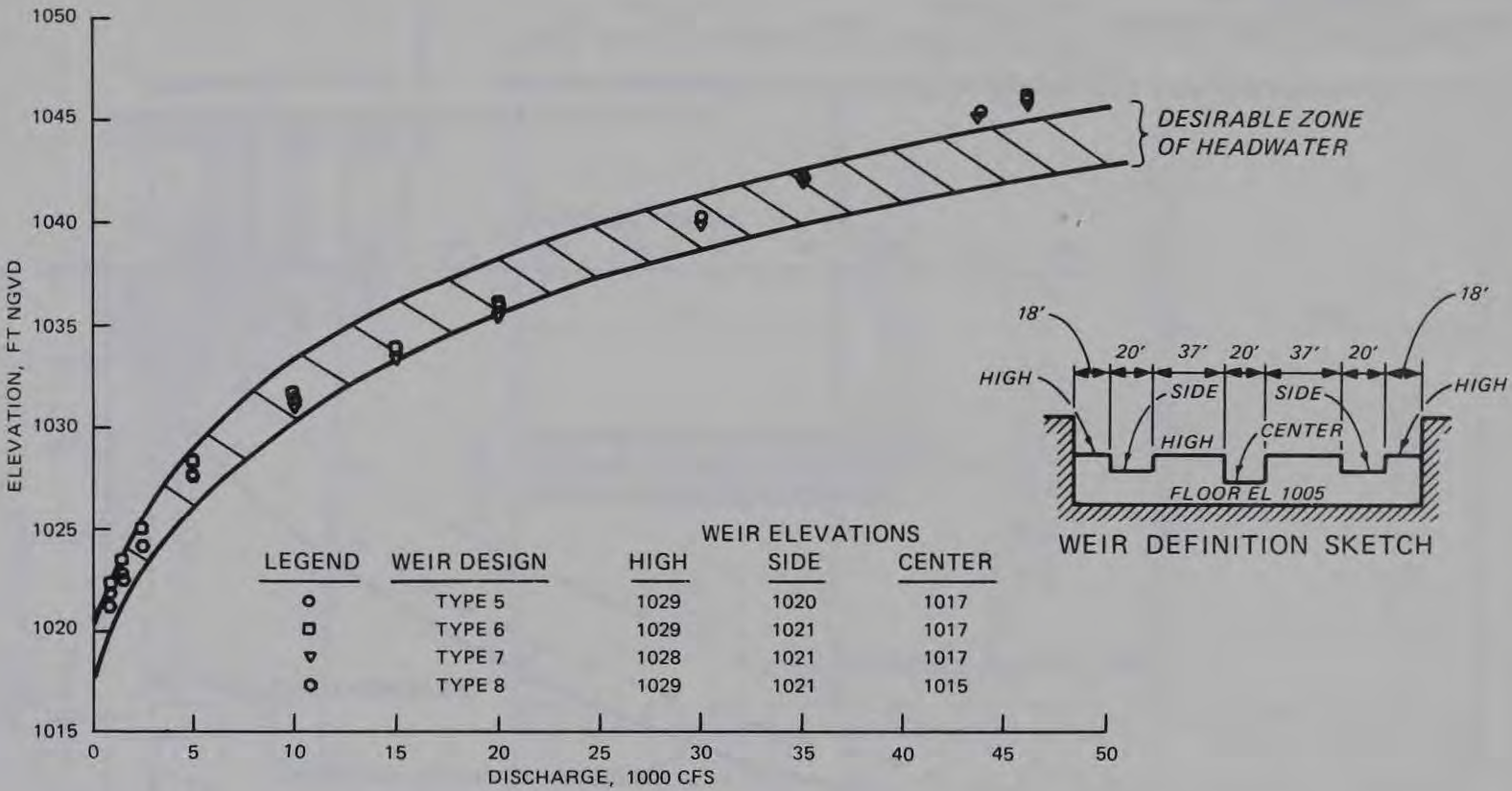


NOTE: TYPES 3-9 DESIGNS HAVE NO WALLS INSIDE THE BASIN

TYPES 1-9 DESIGN BASIN WALLS

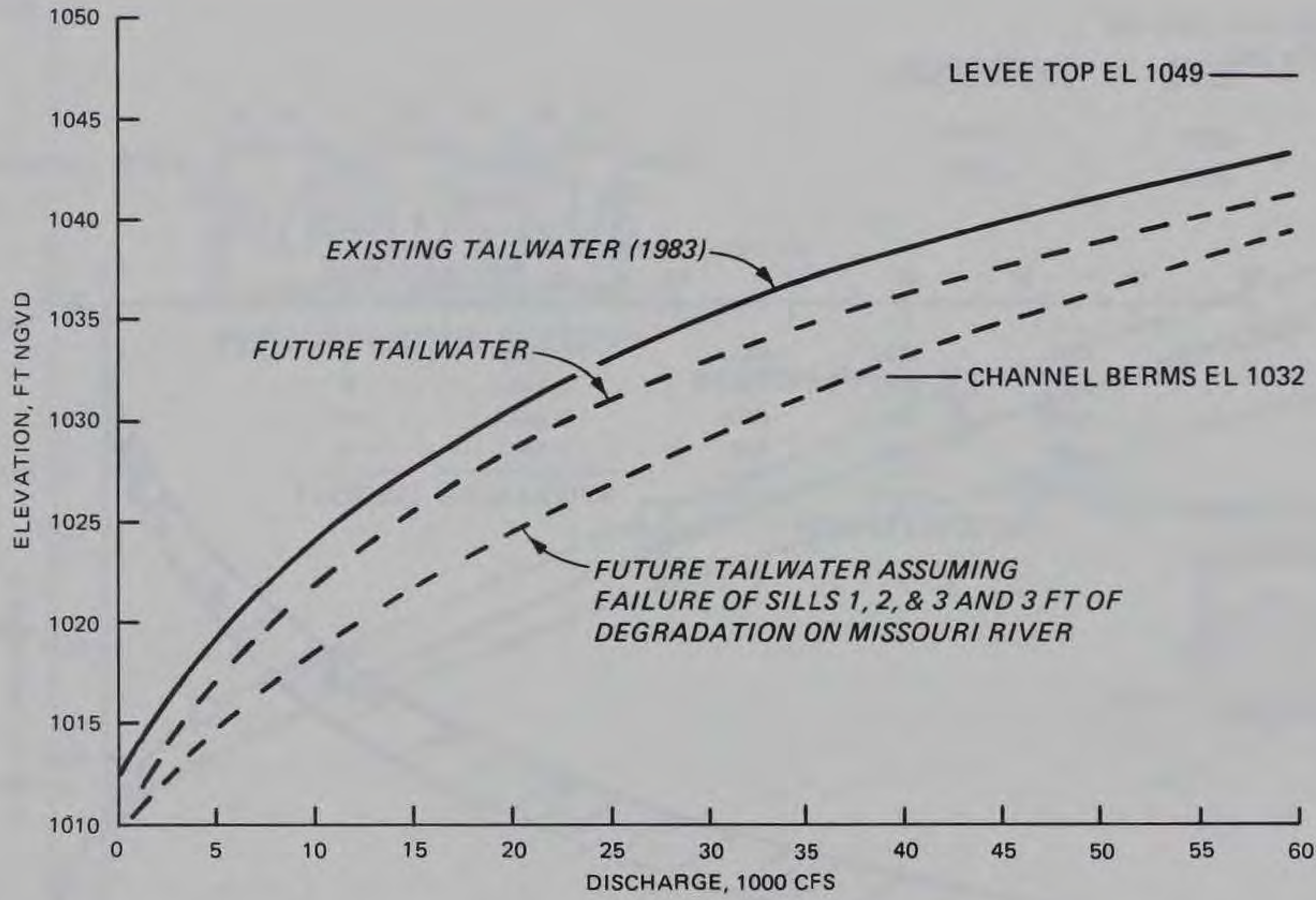


COMPARISON OF HEADWATER RATING CURVES



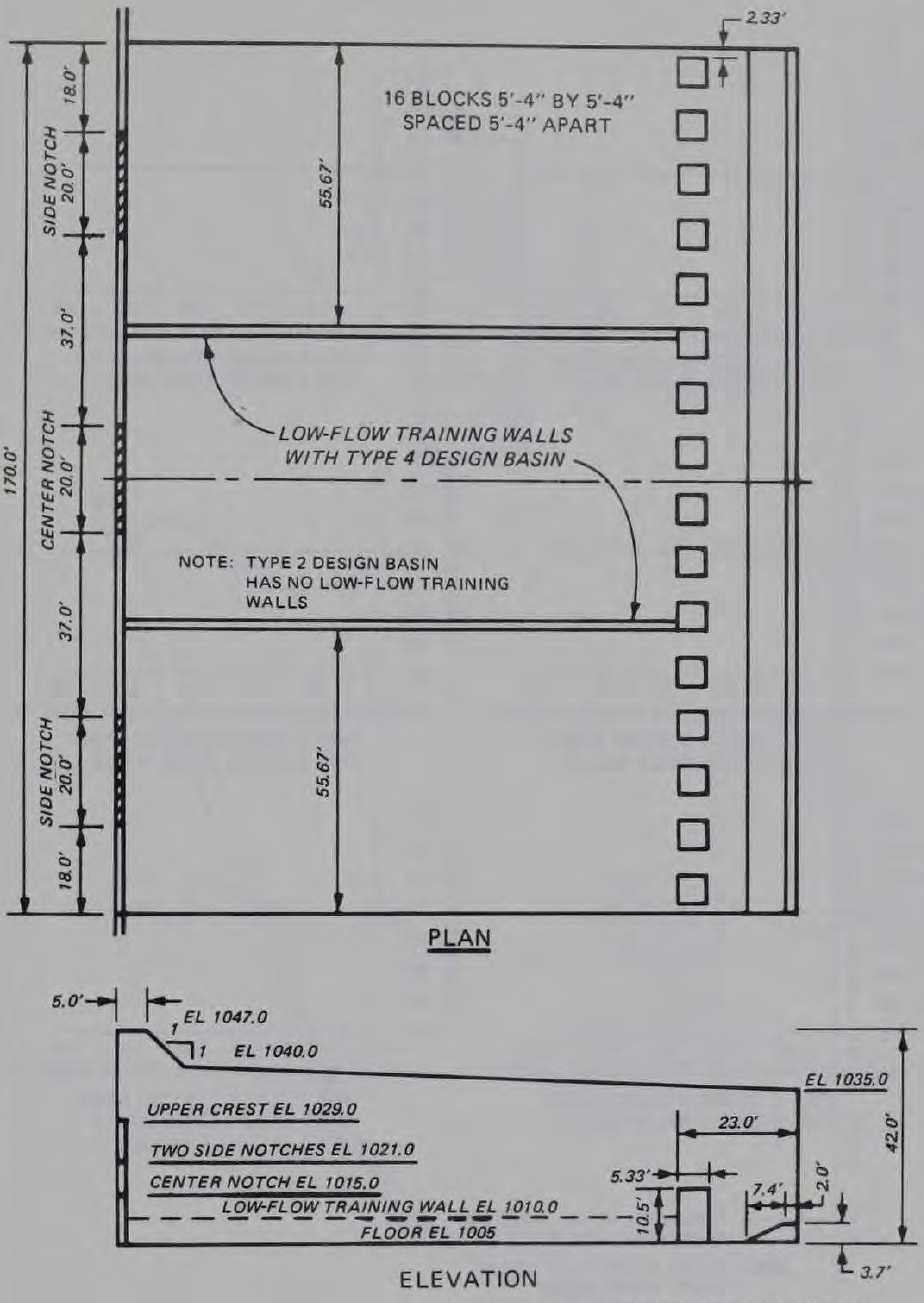
LEGEND	WEIR DESIGN	WEIR ELEVATIONS HIGH	SIDE	CENTER
○	TYPE 5	1029	1020	1017
□	TYPE 6	1029	1021	1017
▽	TYPE 7	1028	1021	1017
○	TYPE 8	1029	1021	1015

COMPARISON OF
HEADWATER RATING CURVES
TYPES 5-8 DESIGN WEIRS

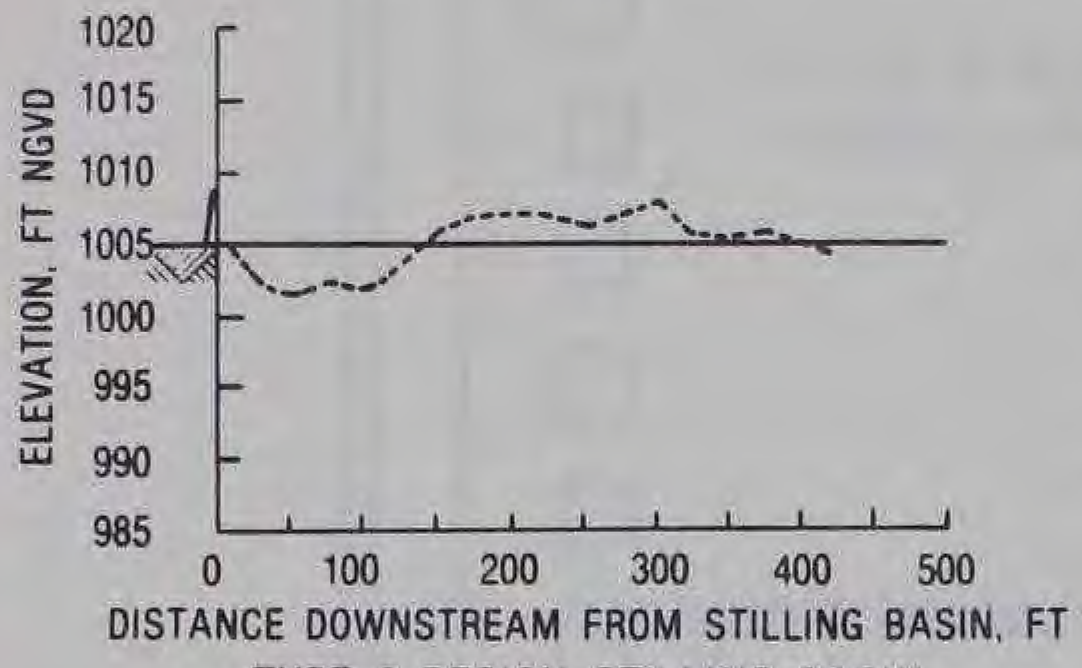


*STA 296+00 IS LOCATED 600 FT
DOWNSTREAM FROM CREST OF OLD CONTROL STRUCTURE

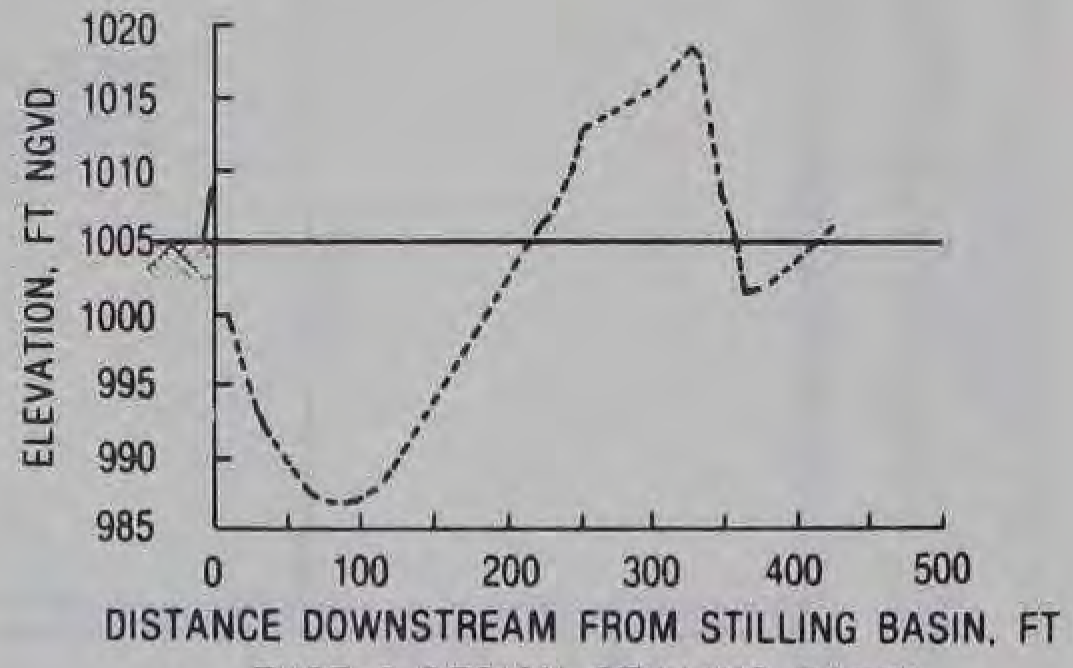
TAILWATER RATING CURVES
AT STA 296+00



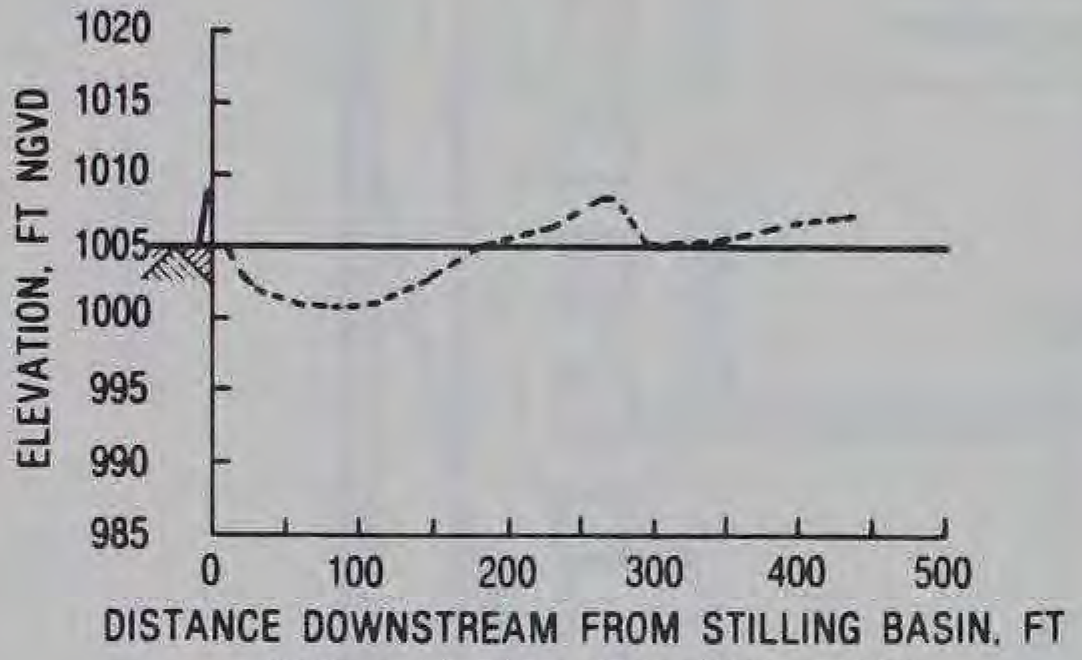
TYPE 8 DESIGN WEIR,
TYPES 2 AND 4 DESIGN
BASIN ELEMENTS
TYPE 9 DESIGN BASIN WALLS



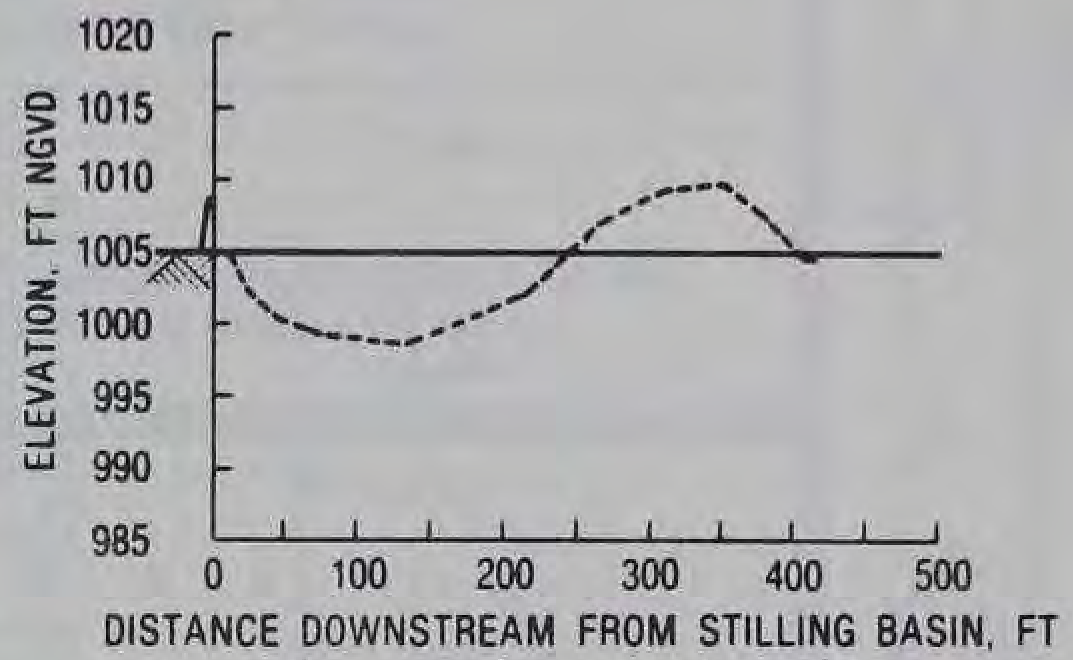
TYPE 2 DESIGN STILLING BASIN
TYPE 4 DESIGN BASIN WALLS



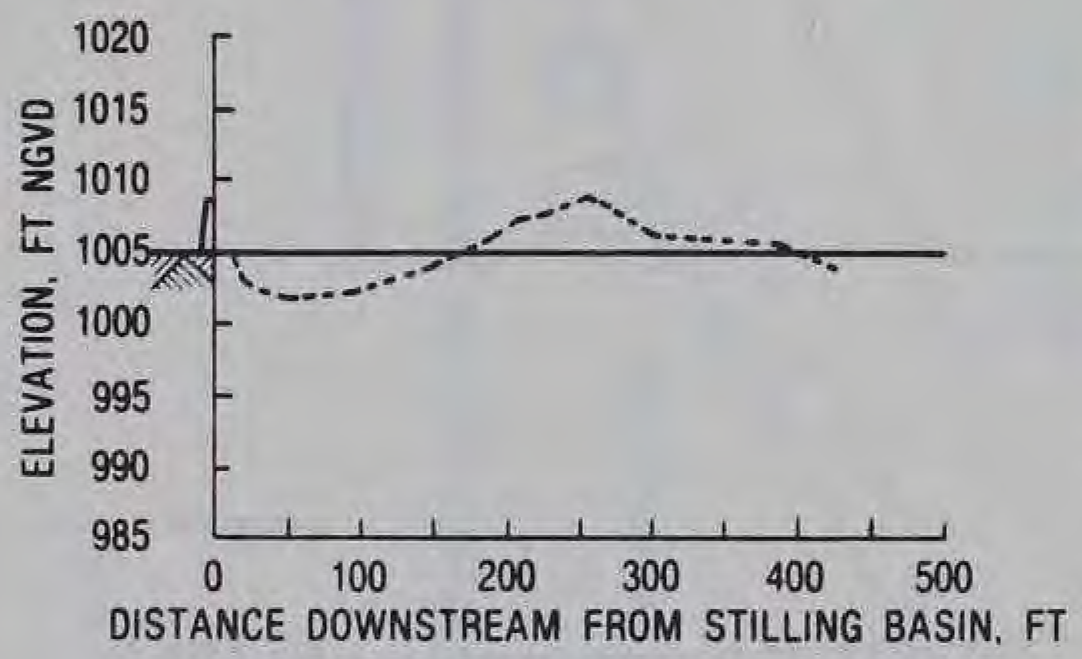
TYPE 3 DESIGN STILLING BASIN
TYPE 6 DESIGN BASIN WALLS



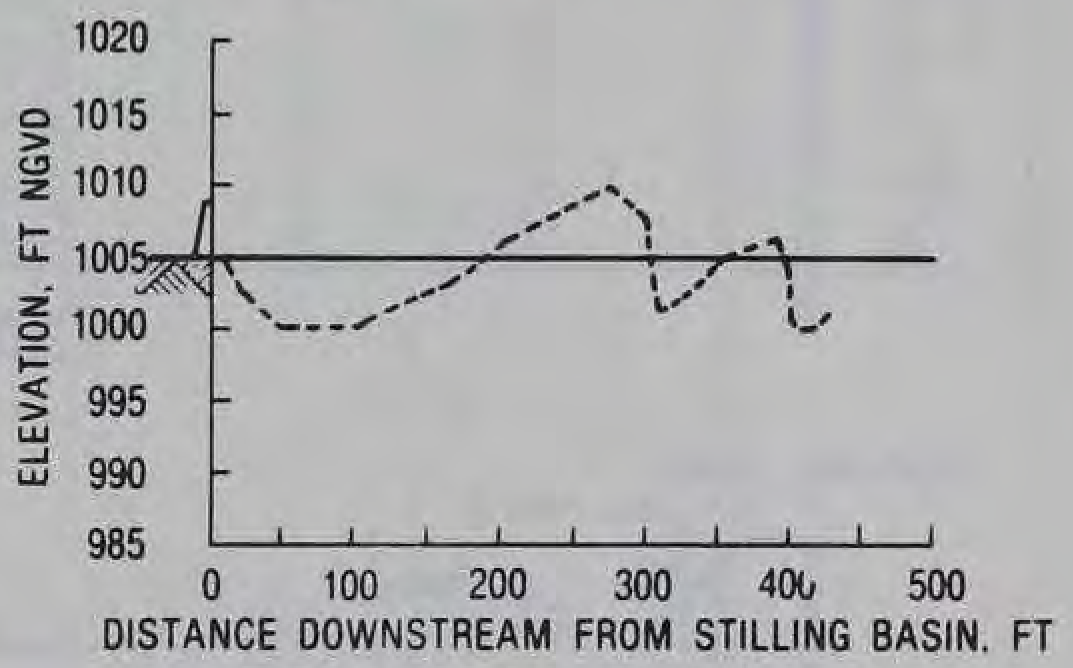
TYPE 2 DESIGN STILLING BASIN
TYPE 7 DESIGN BASIN WALLS



TYPE 2 DESIGN STILLING BASIN
TYPE 8 DESIGN BASIN WALLS



TYPE 2 DESIGN STILLING BASIN
TYPE 9 DESIGN BASIN WALLS

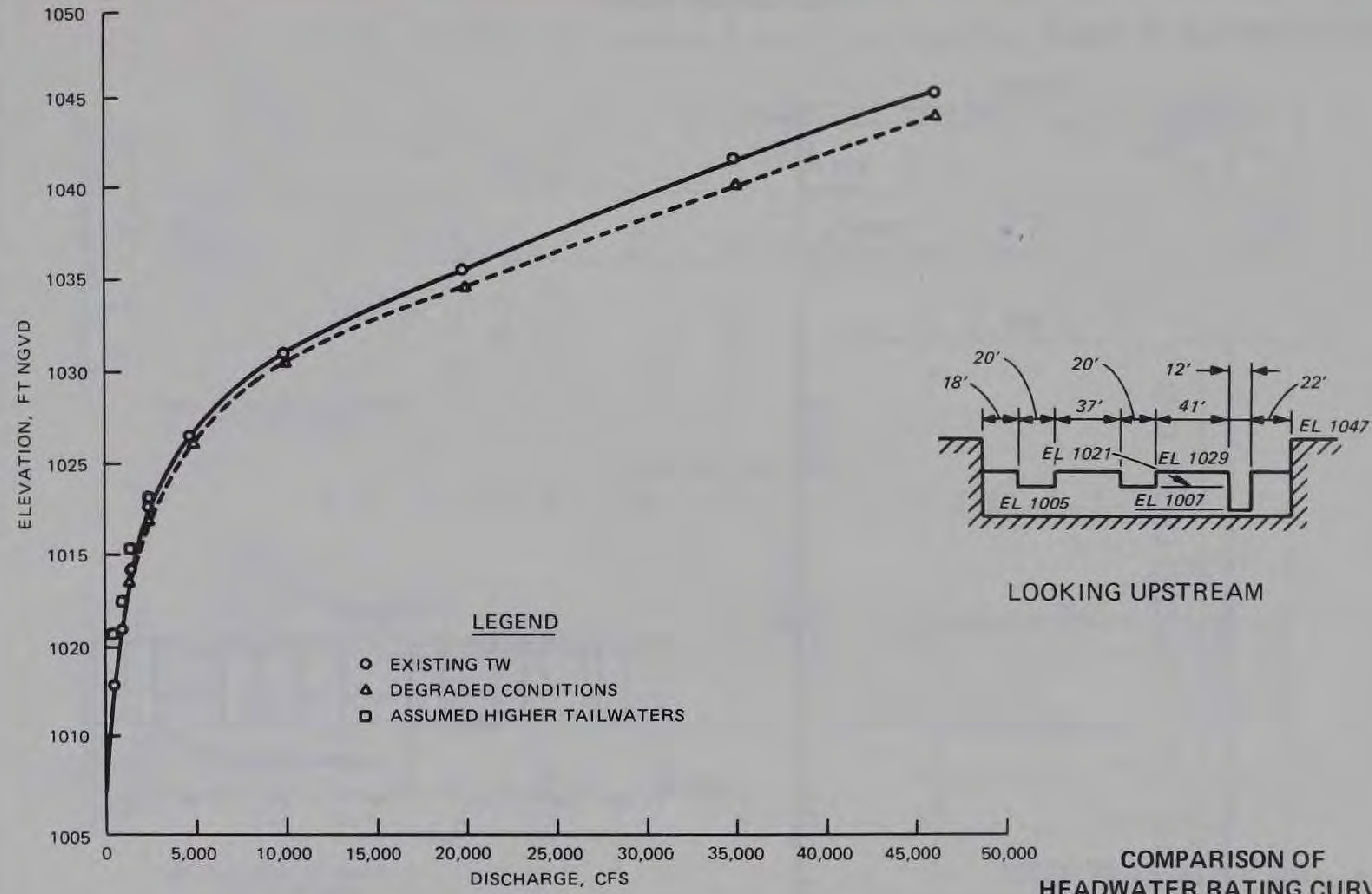


TYPE 2 DESIGN STILLING BASIN
TYPE 9 DESIGN BASIN WALLS
BAFFLE BLOCKS 8 FT HIGH

——— TOPOGRAPHY BEFORE SCOUR TEST
- - - - - - TOPOGRAPHY AFTER SCOUR TEST

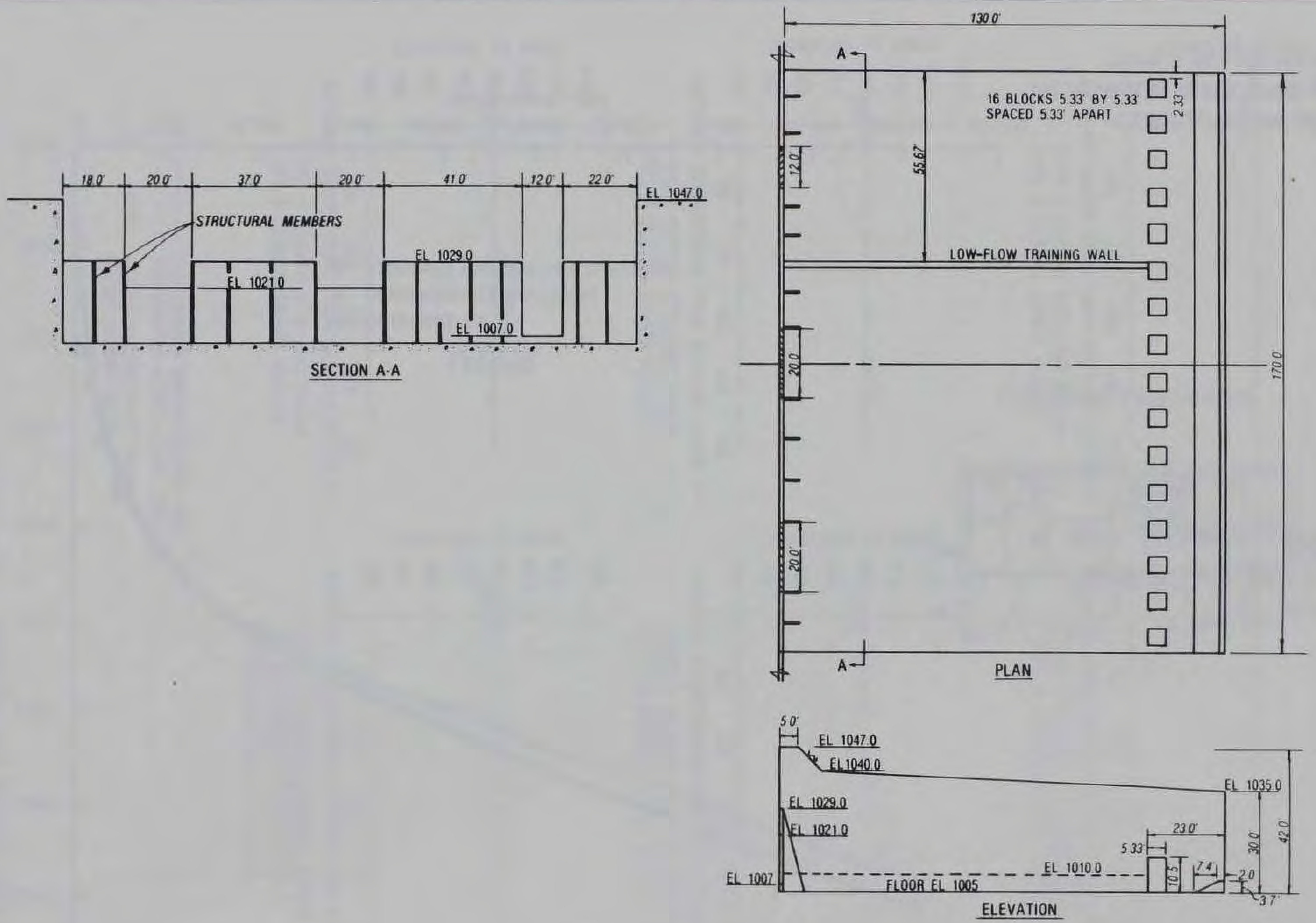
NOTE: BAFFLE BLOCKS 10 FT HIGH EXCEPT WHERE NOTED

CENTER-LINE SCOUR PROFILES

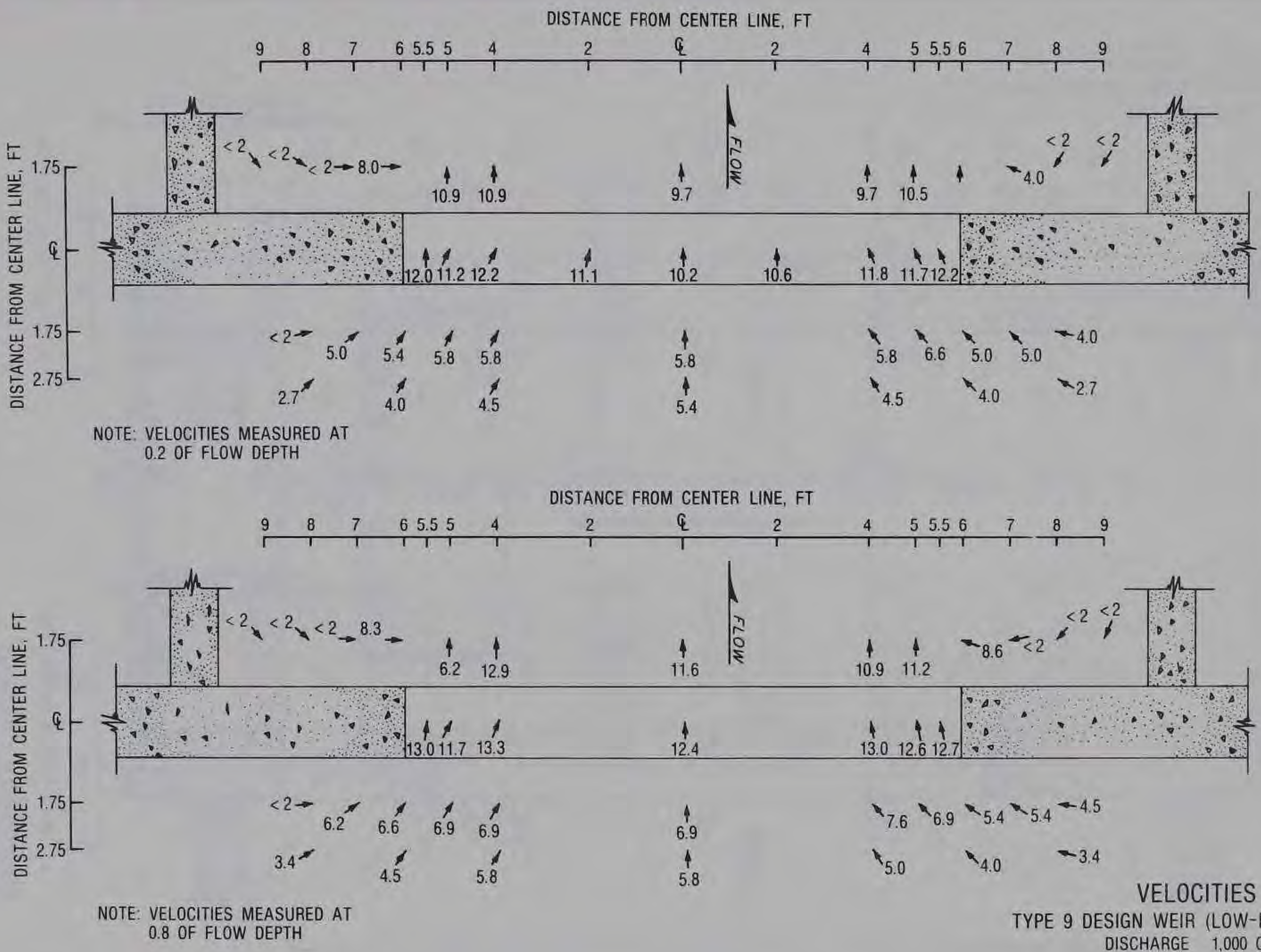


COMPARISON OF HEADWATER RATING CURVES

TYPE 9 DESIGN WEIR



DETAILS OF RECOMMENDED DESIGN

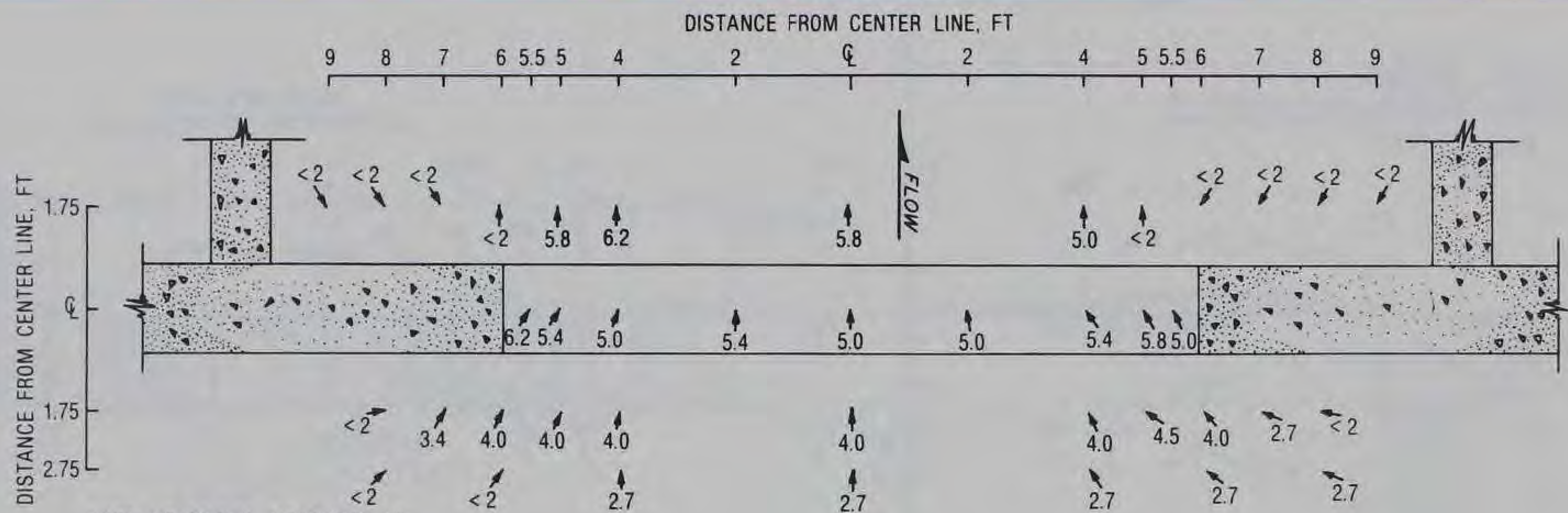


VELOCITIES

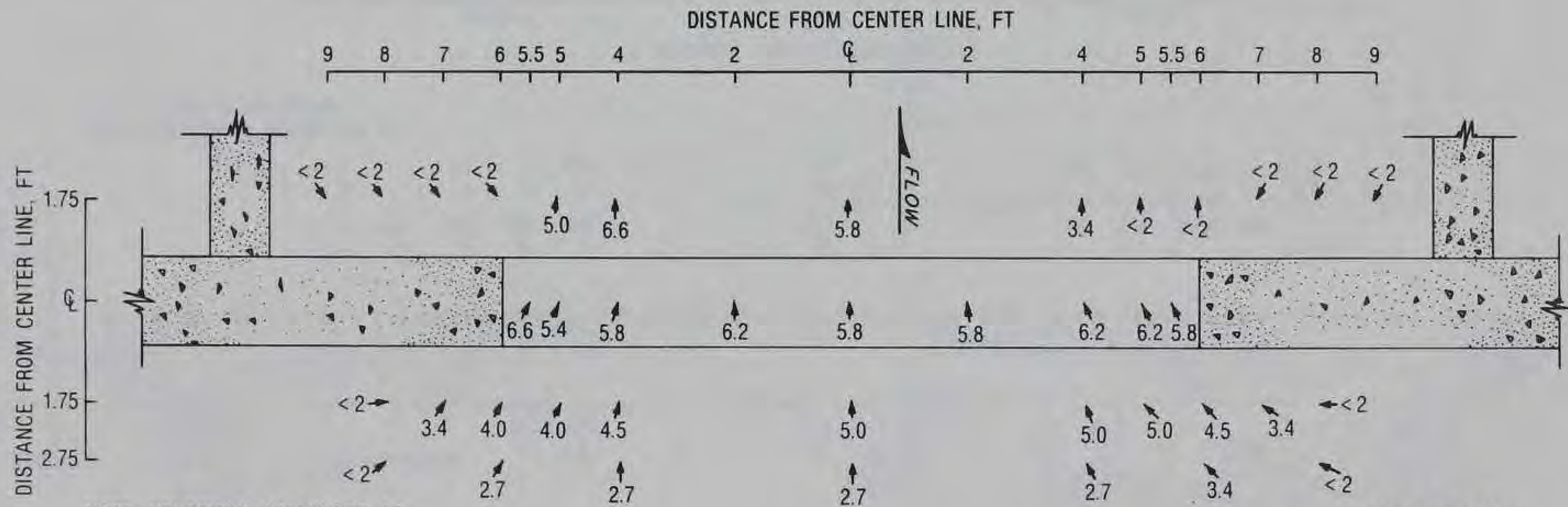
TYPE 9 DESIGN WEIR (LOW-FLOW NOTCH)

DISCHARGE 1,000 CFS

TW EL 1014



NOTE: VELOCITIES MEASURED AT 0.2 OF FLOW DEPTH



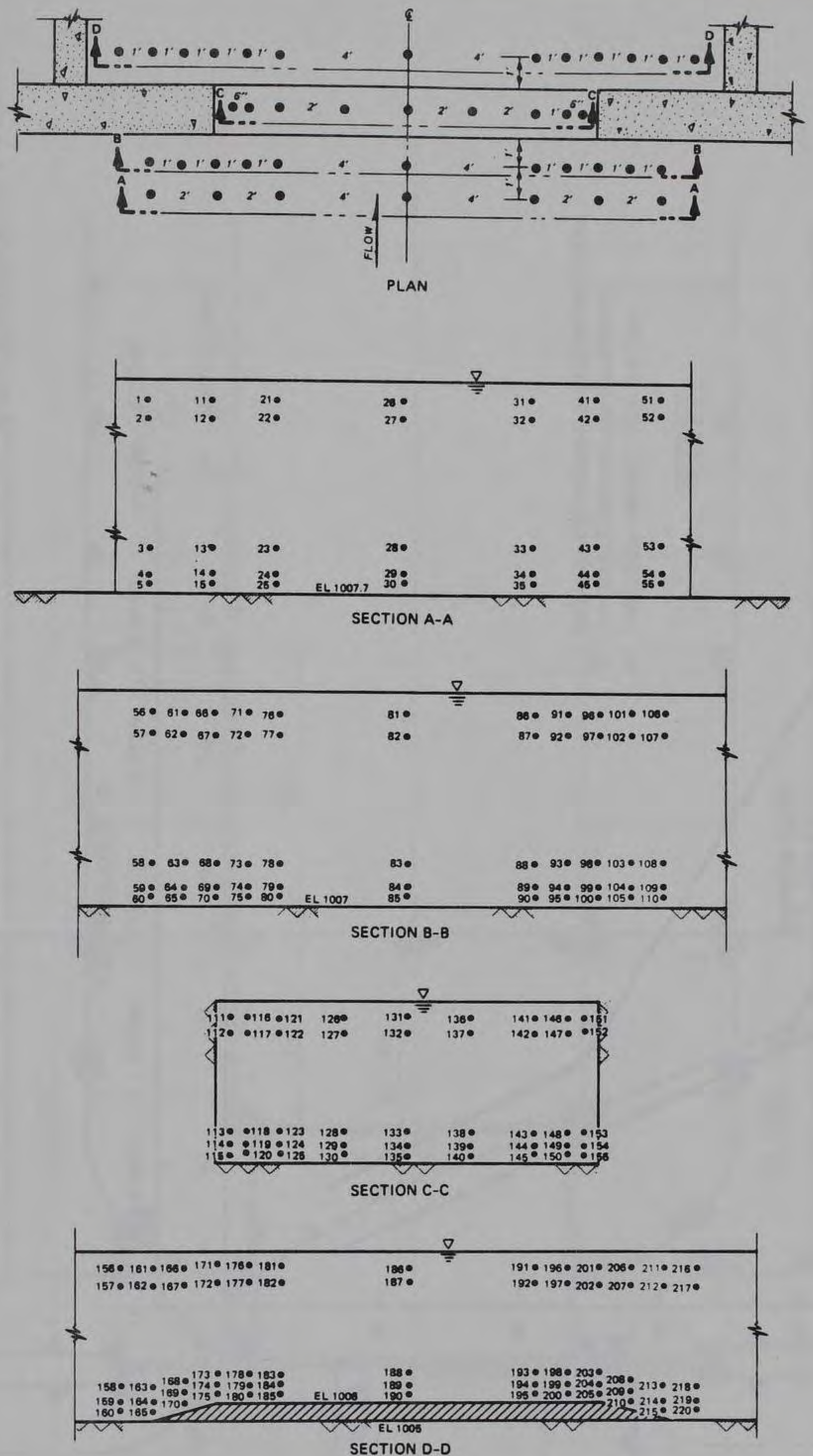
NOTE: VELOCITIES MEASURED AT 0.8 OF FLOW DEPTH

VELOCITIES

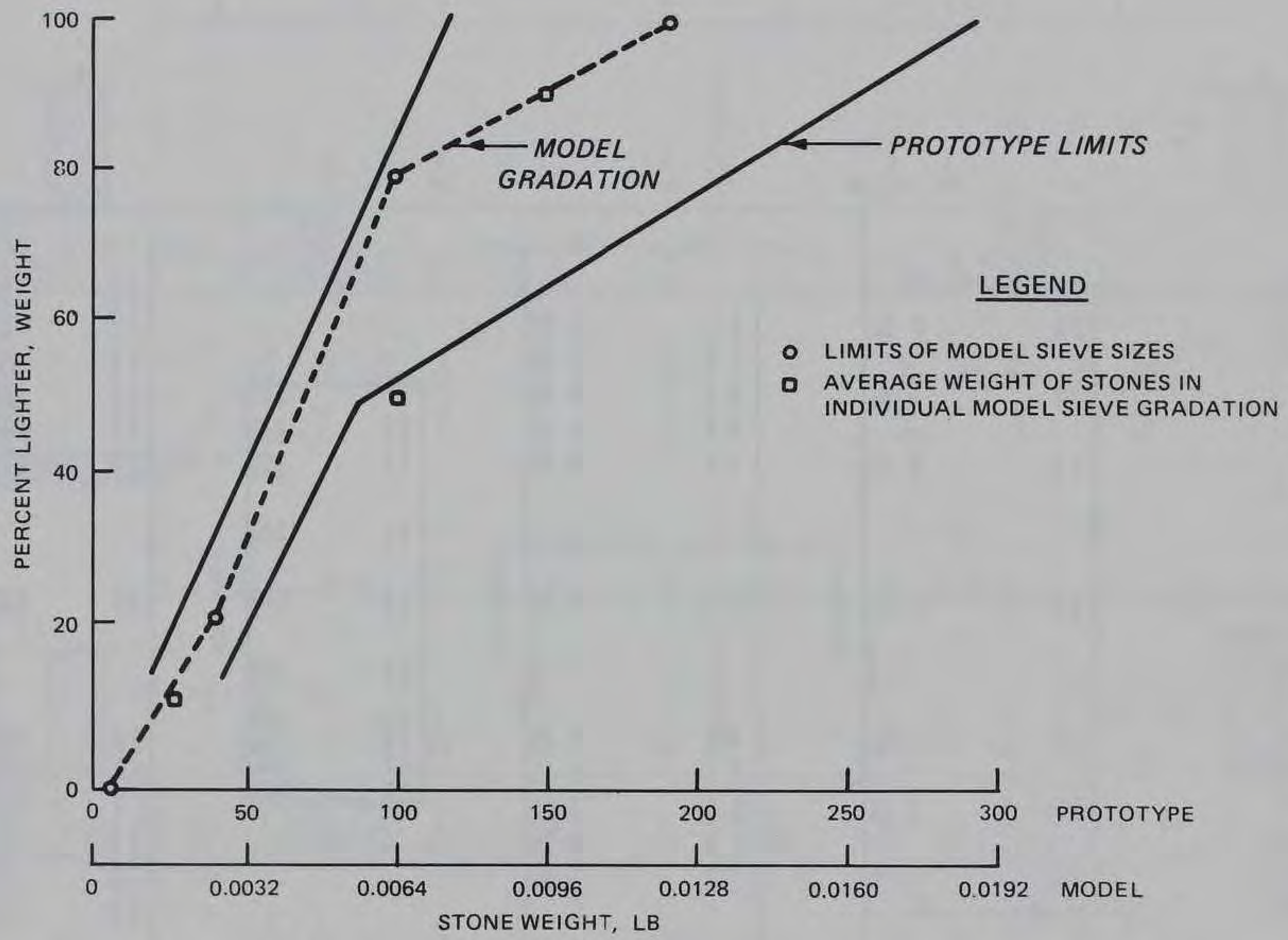
TYPE 9 DESIGN WEIR (LOW-FLOW NOTCH)

DISCHARGE 500 CFS

TW EL 1013



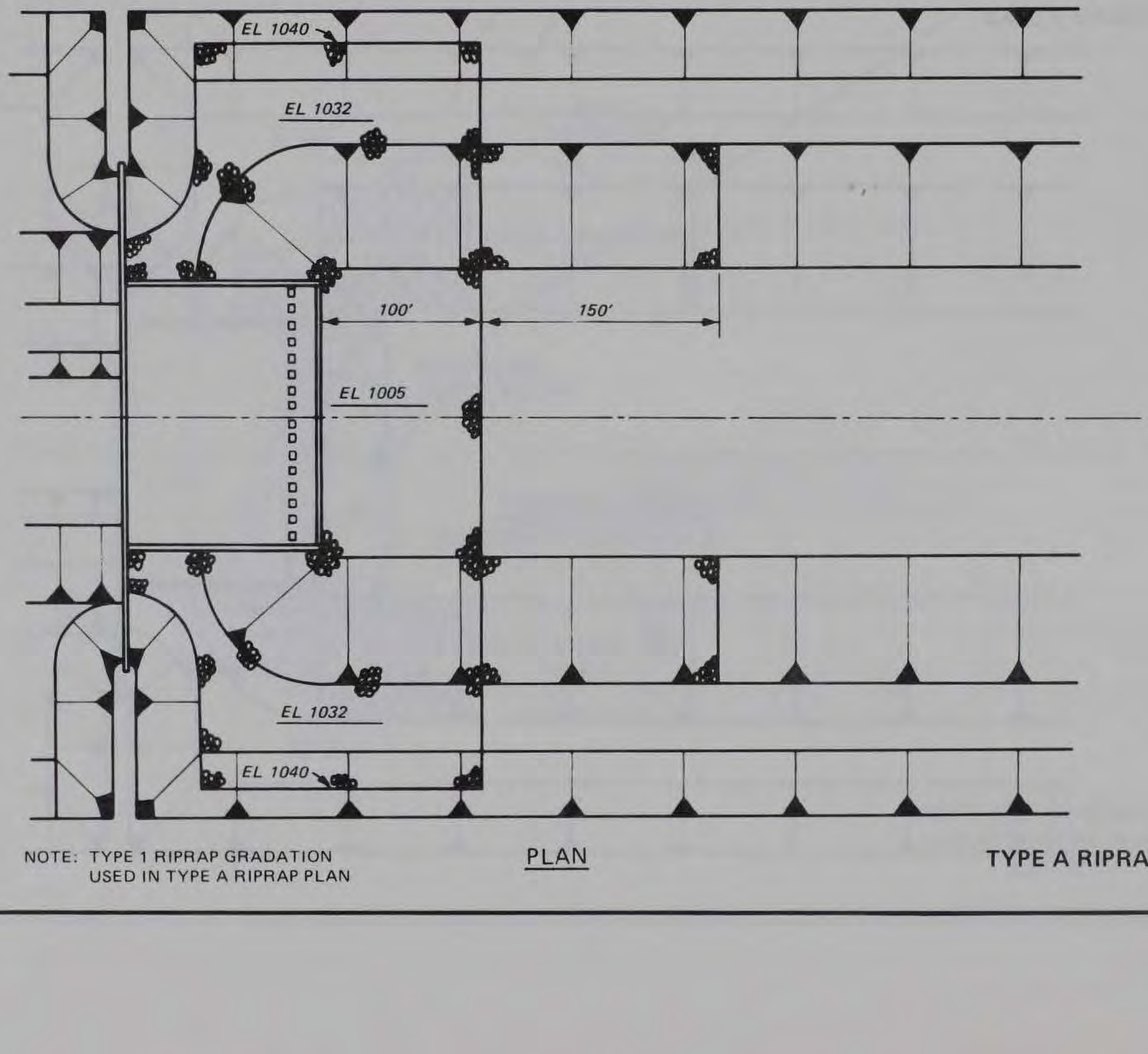
VELOCITY LOCATIONS
IN VICINITY OF LOW-FLOW NOTCH
(LOOKING DOWNSTREAM)



TYPE 1 RIPRAP GRADATION

BLANKET THICKNESS = 18 IN.

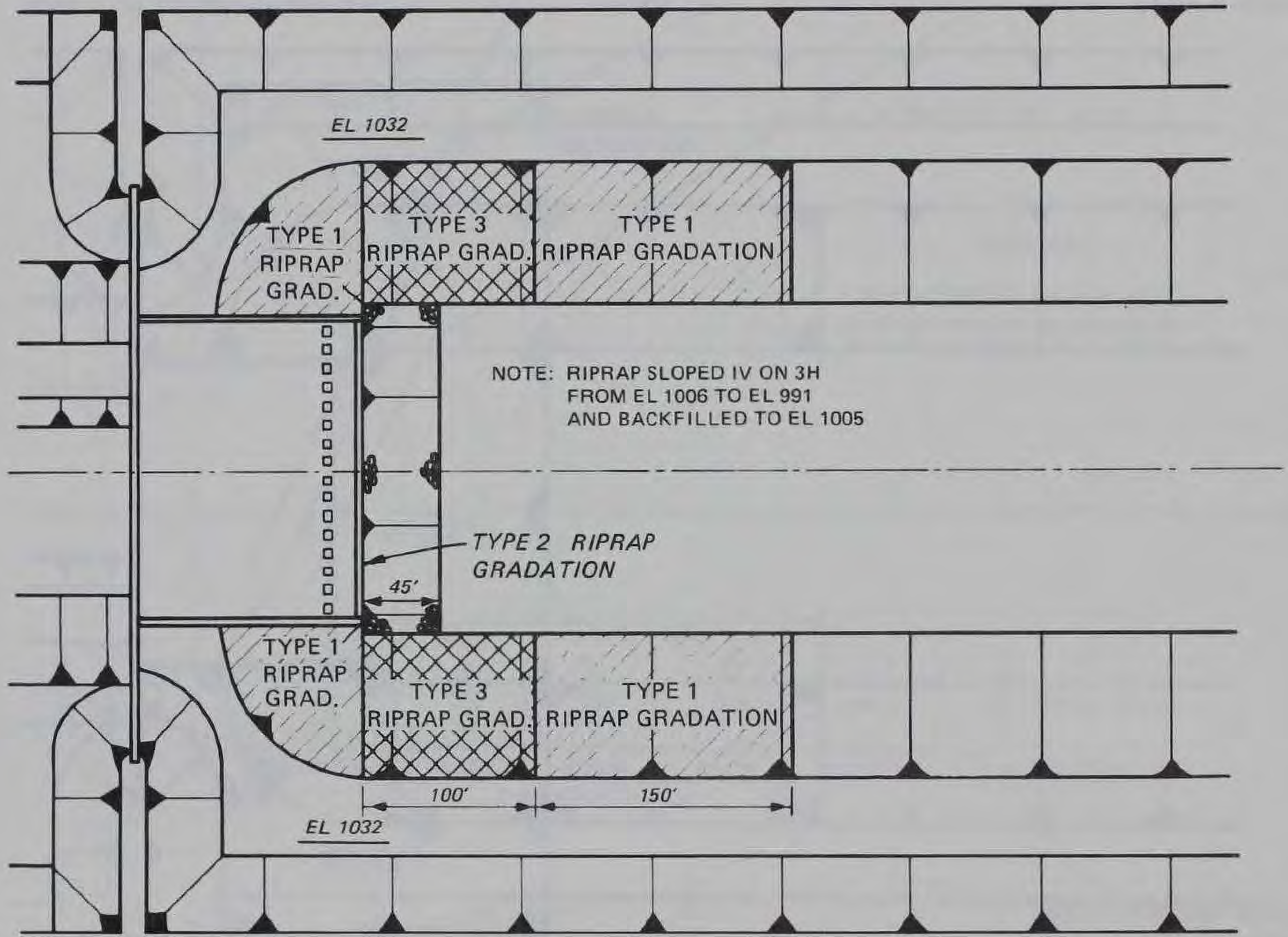
D_{50} = 12 IN.



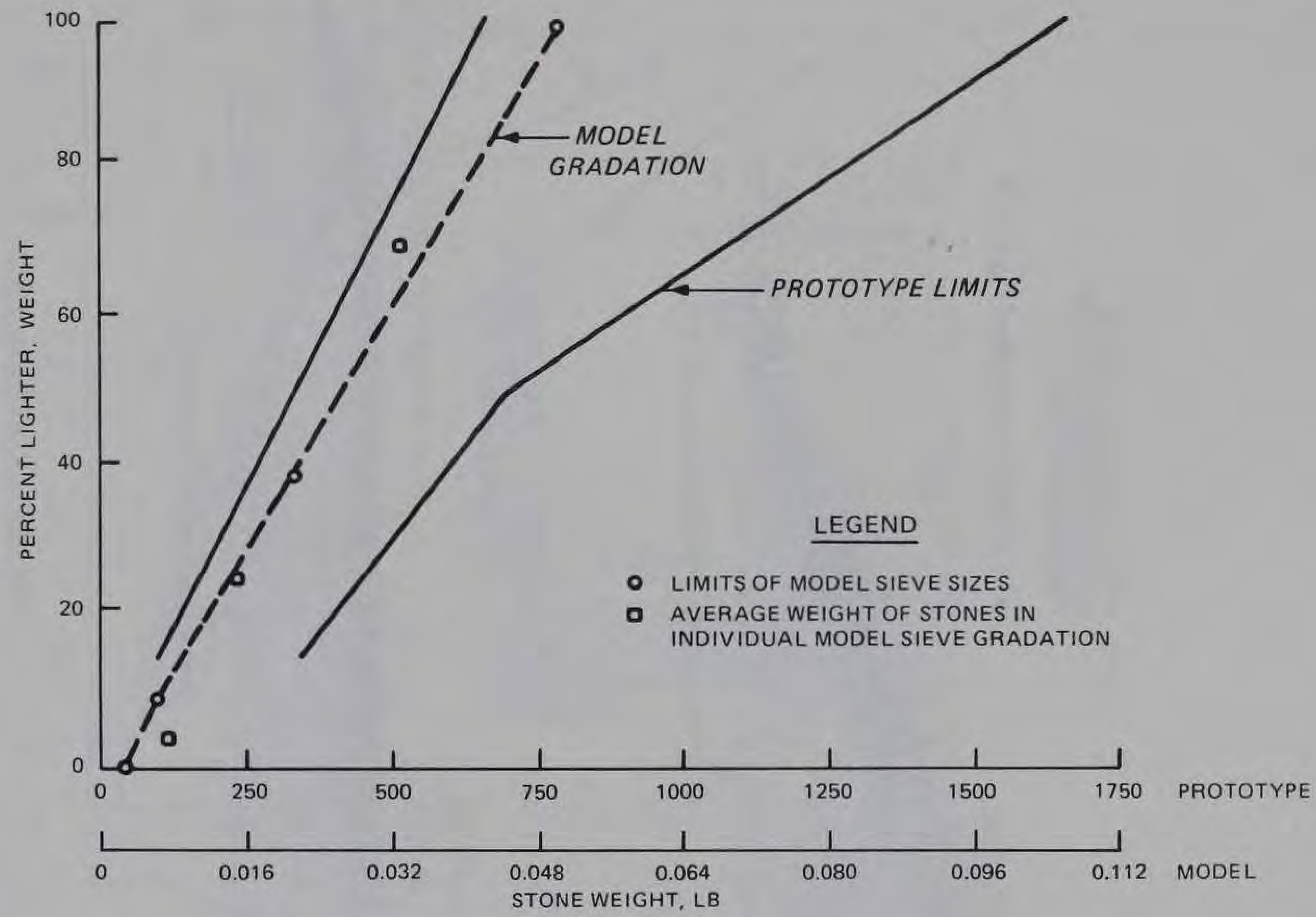
NOTE: TYPE 1 RIPRAP GRADATION
USED IN TYPE A RIPRAP PLAN

PLAN

TYPE A RIPRAP PLAN



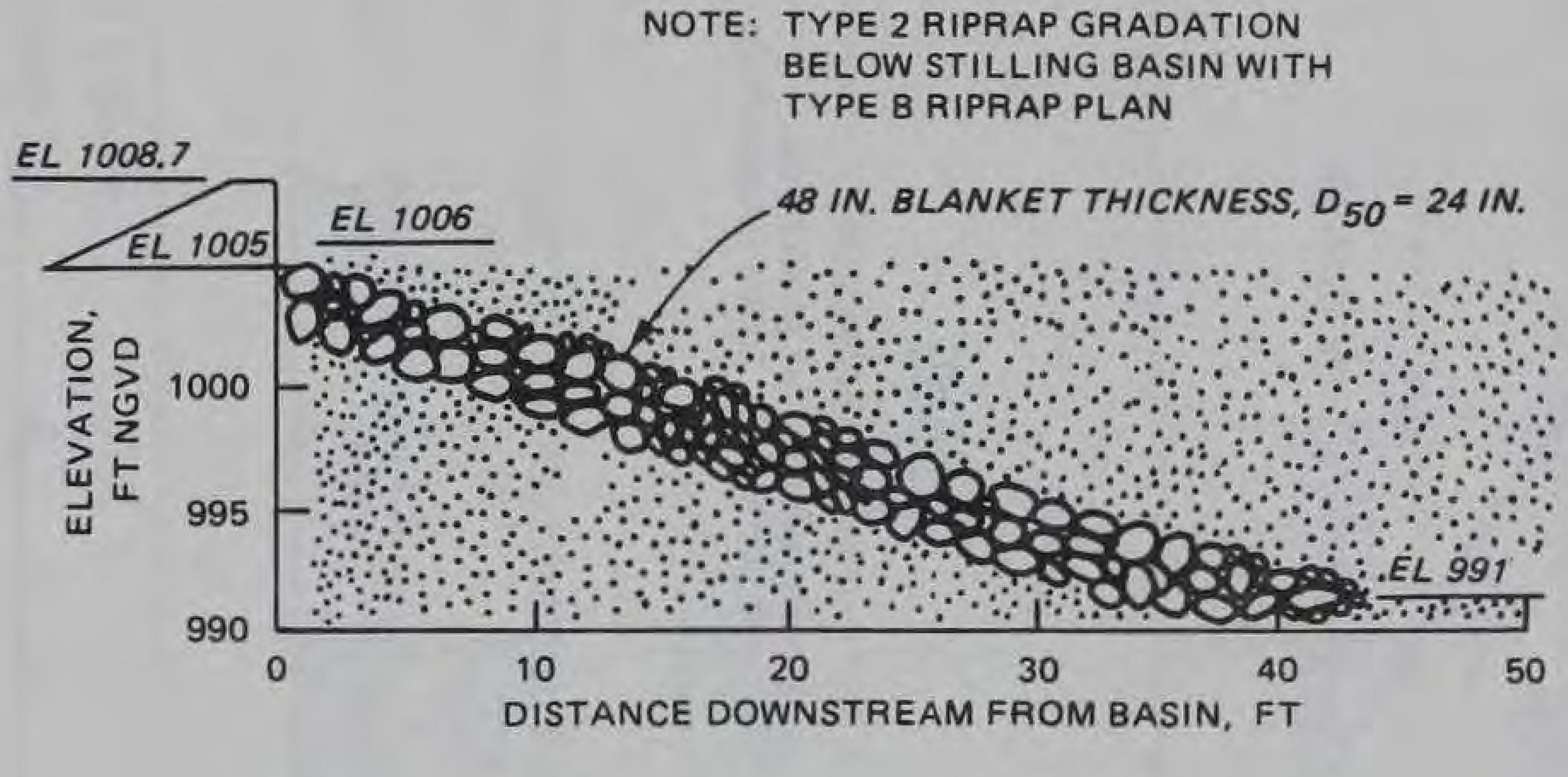
TYPE B RIPRAP PLAN

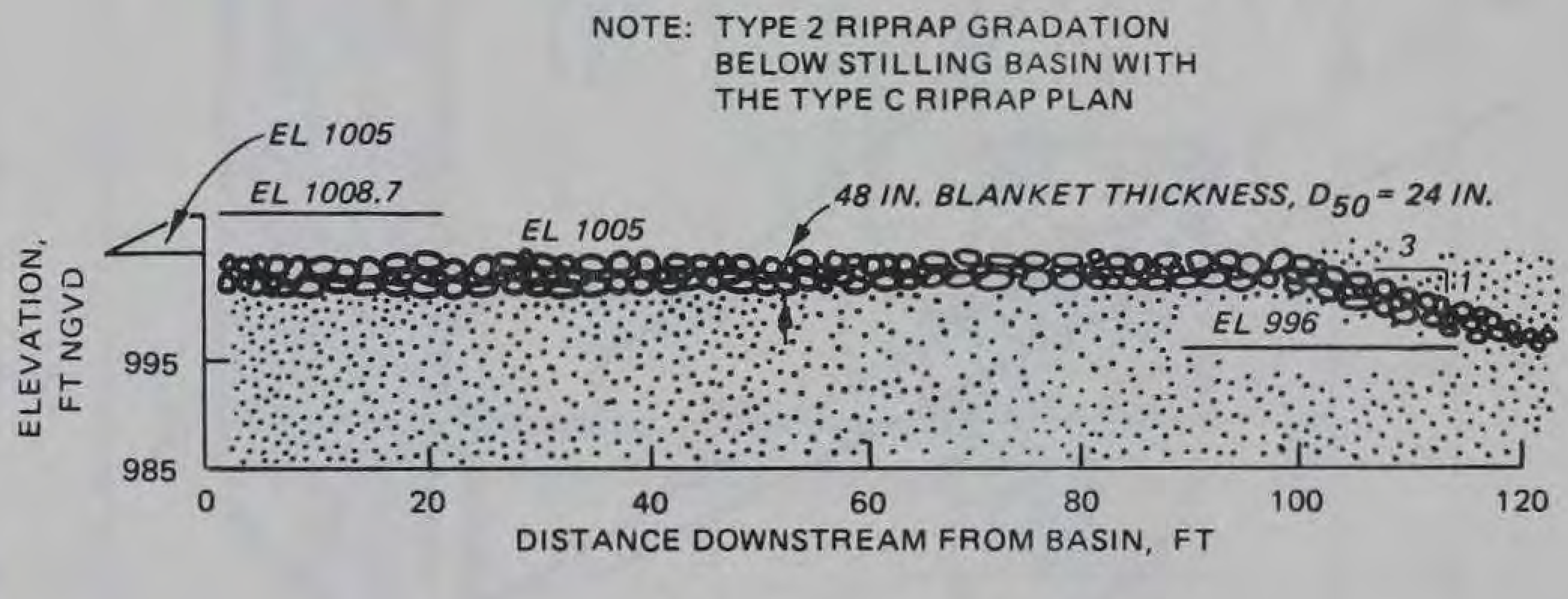


TYPE 2 RIPRAP GRADATION

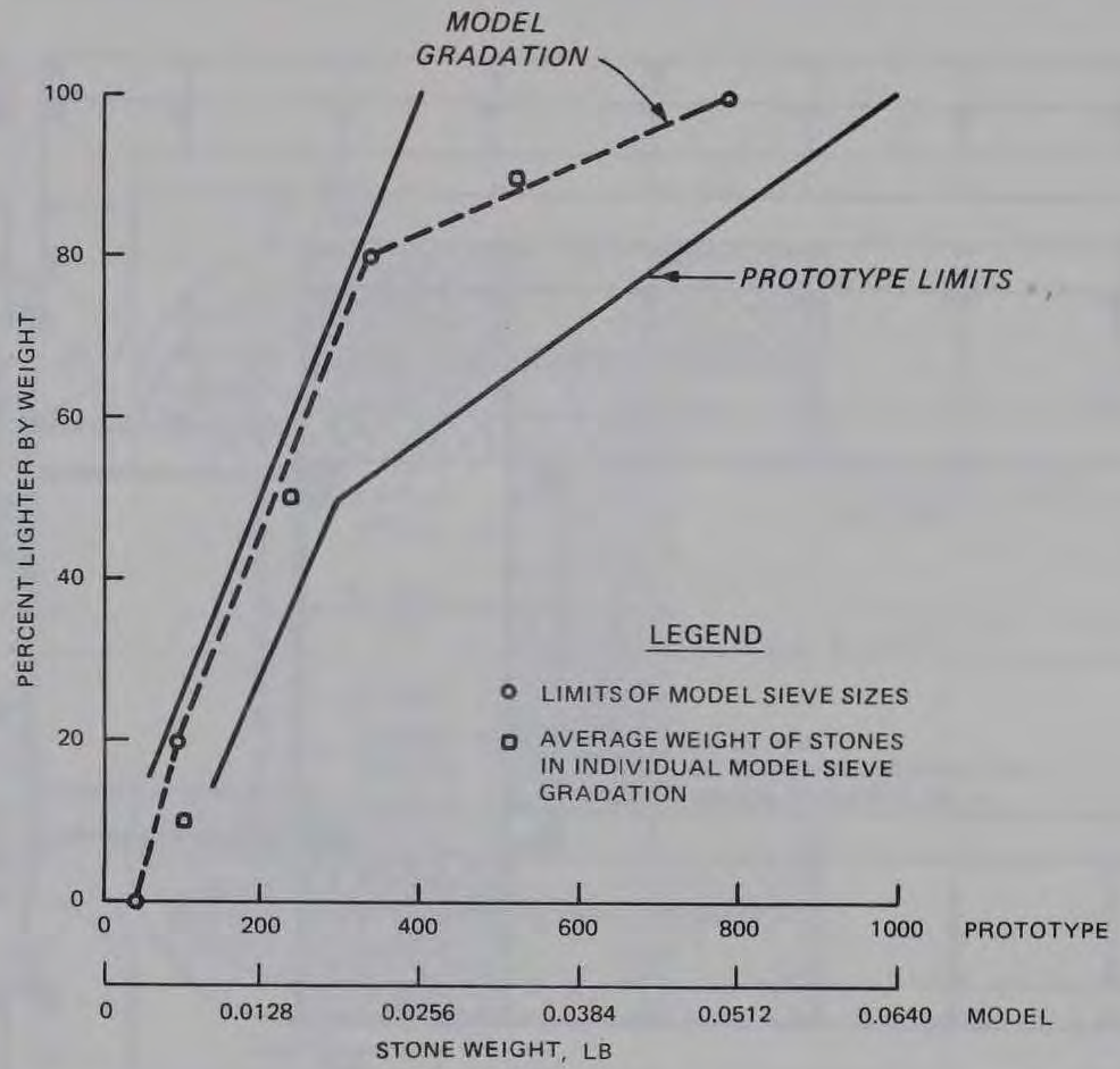
BLANKET THICKNESS = 48 IN.

D_{50} = 24 IN.





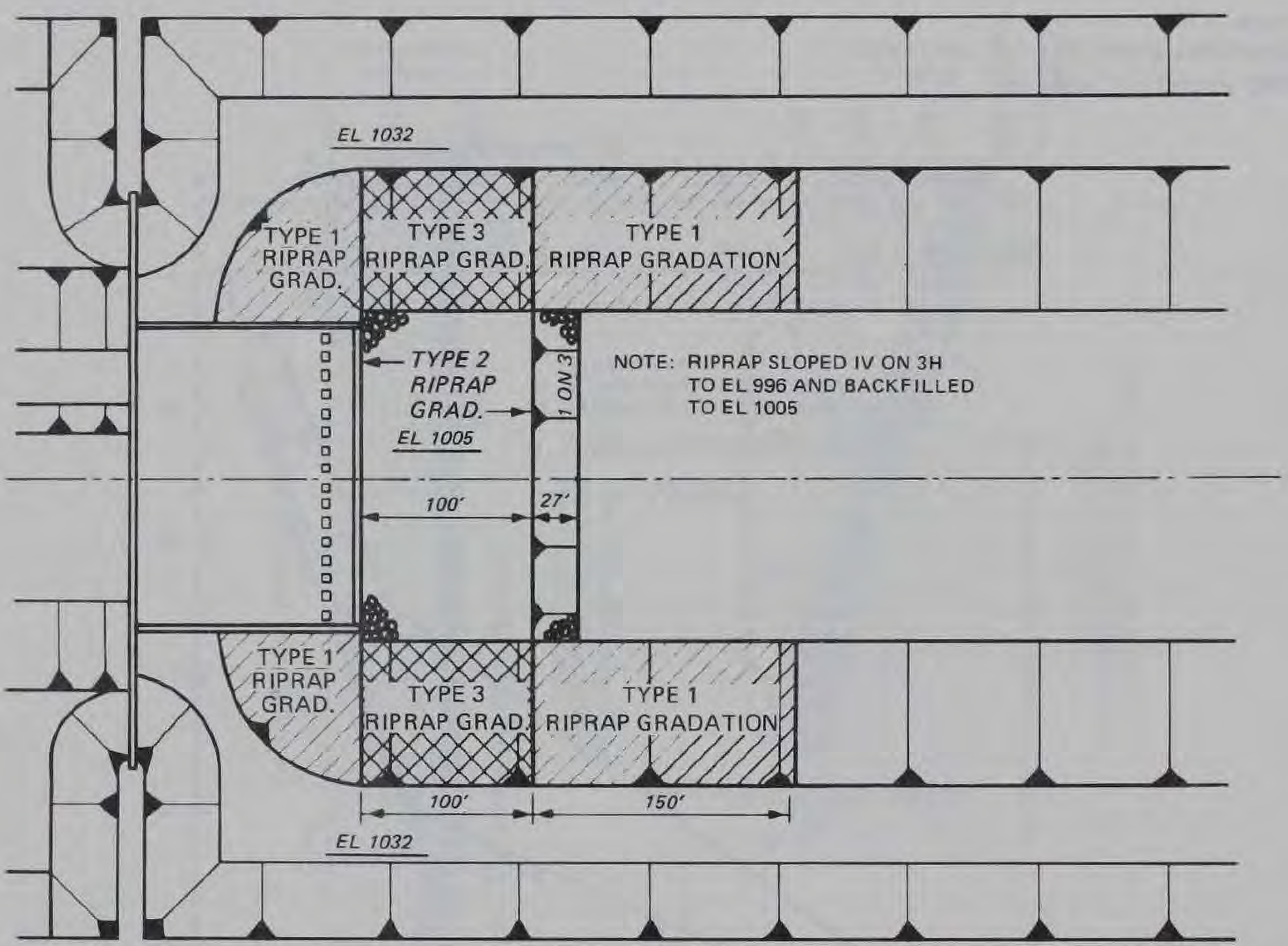
RIPRAP DETAILS
BELOW STILLING BASIN
TYPES B AND C RIPRAP PLANS



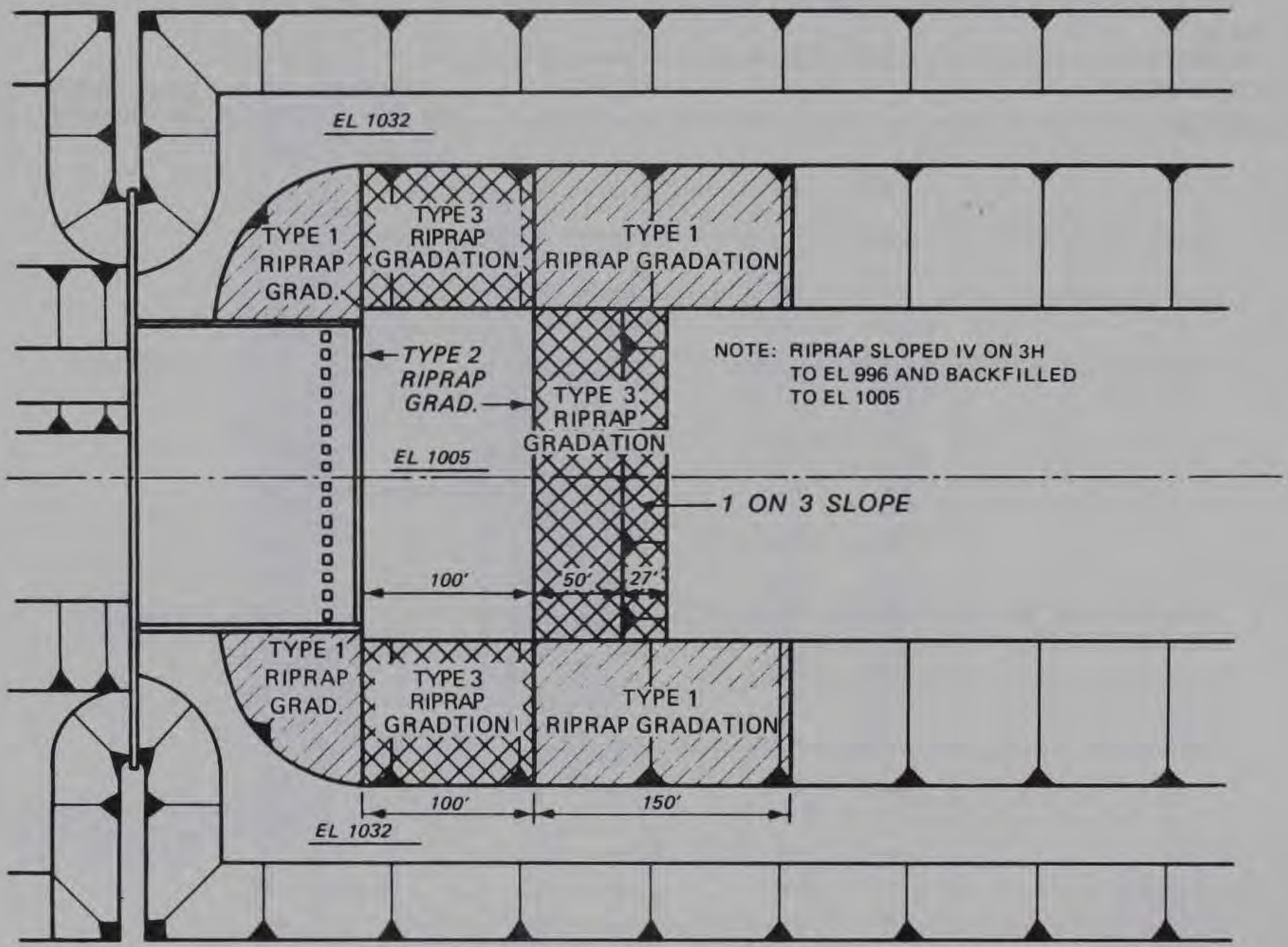
TYPE 3 RIPRAP GRADATION

BLANKET THICKNESS = 27 IN.

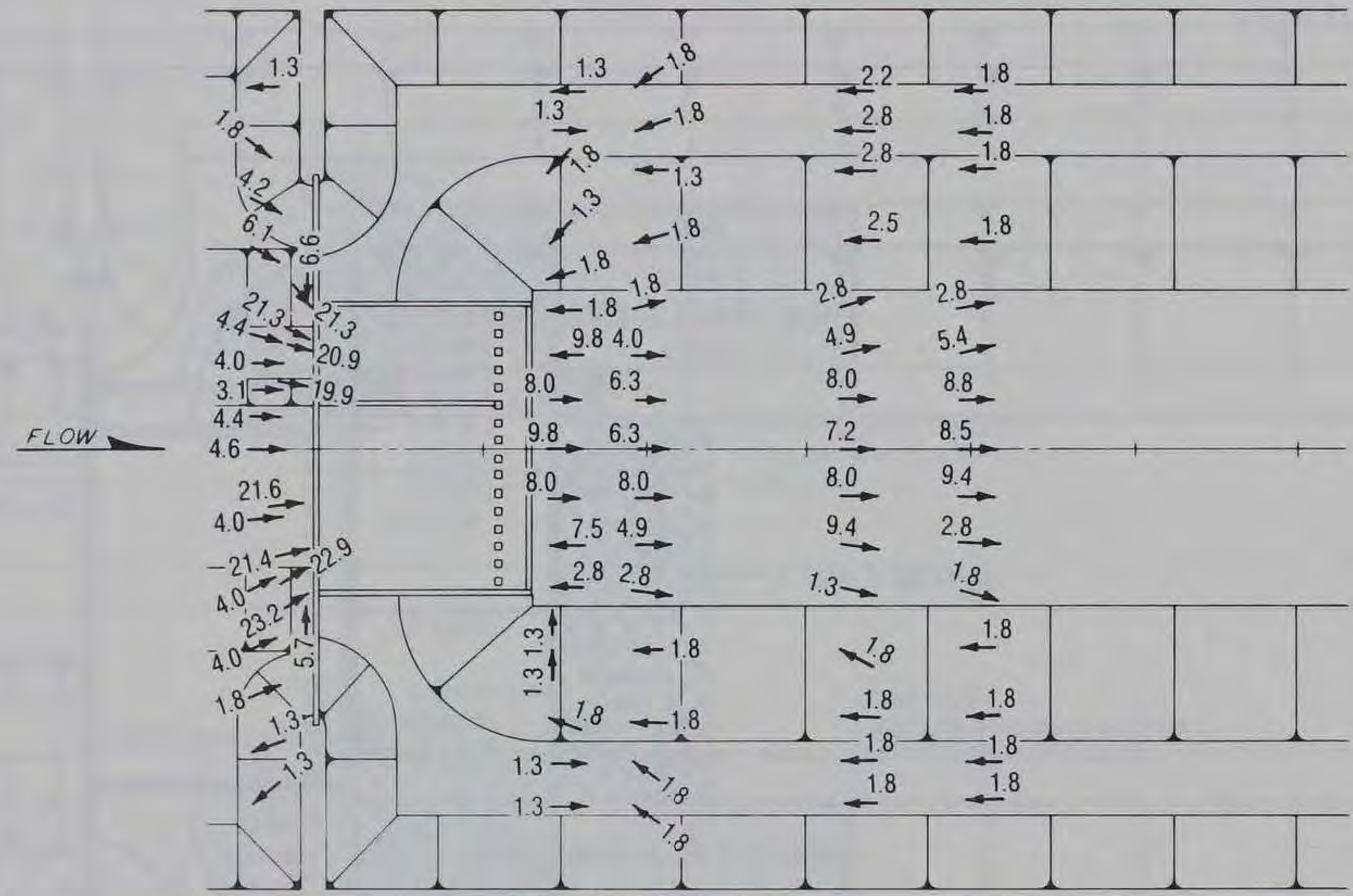
D_{50} = 18 IN.



TYPE C RIPRAP PLAN



TYPE D RIPRAP PLAN



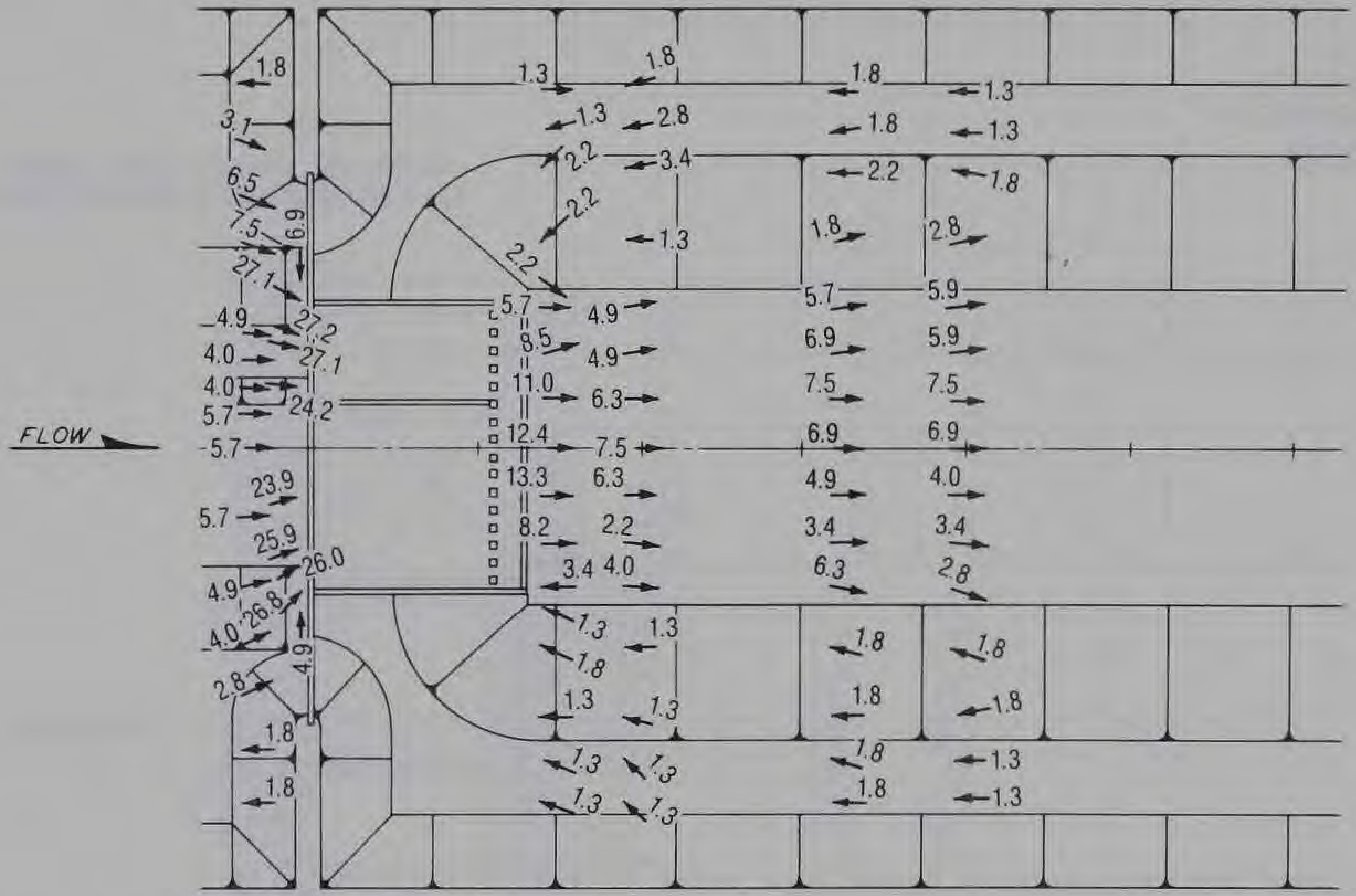
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND TAKEN 1 FT OFF THE BOTTOM

VELOCITIES

RECOMMENDED DESIGN

DISCHARGE 46,000

TW EL 1039.9



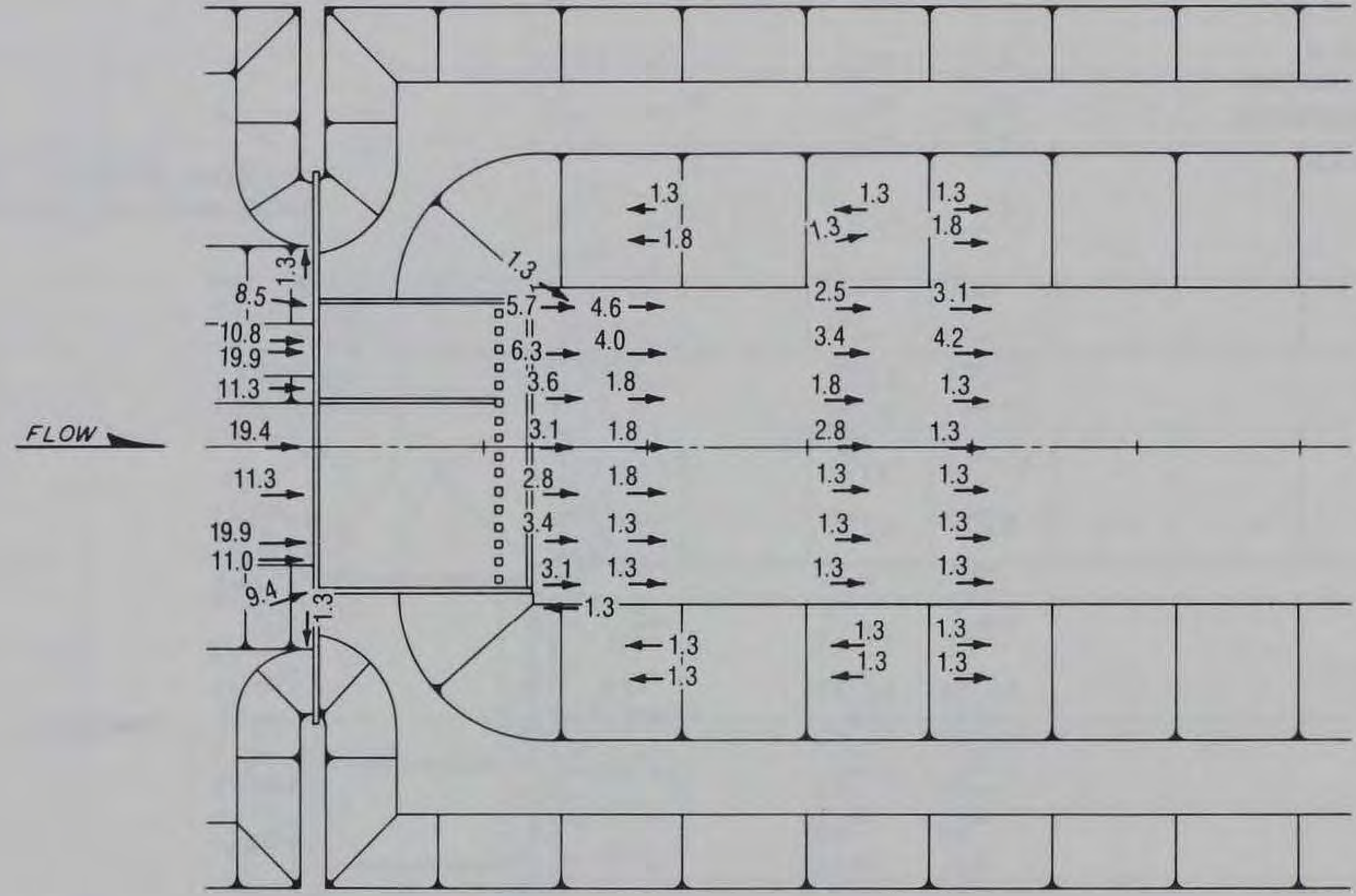
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND TAKEN 1 FT OFF THE BOTTOM

VELOCITIES

RECOMMENDED DESIGN

DISCHARGE - 46,000 CFS

TW EL 1035.0

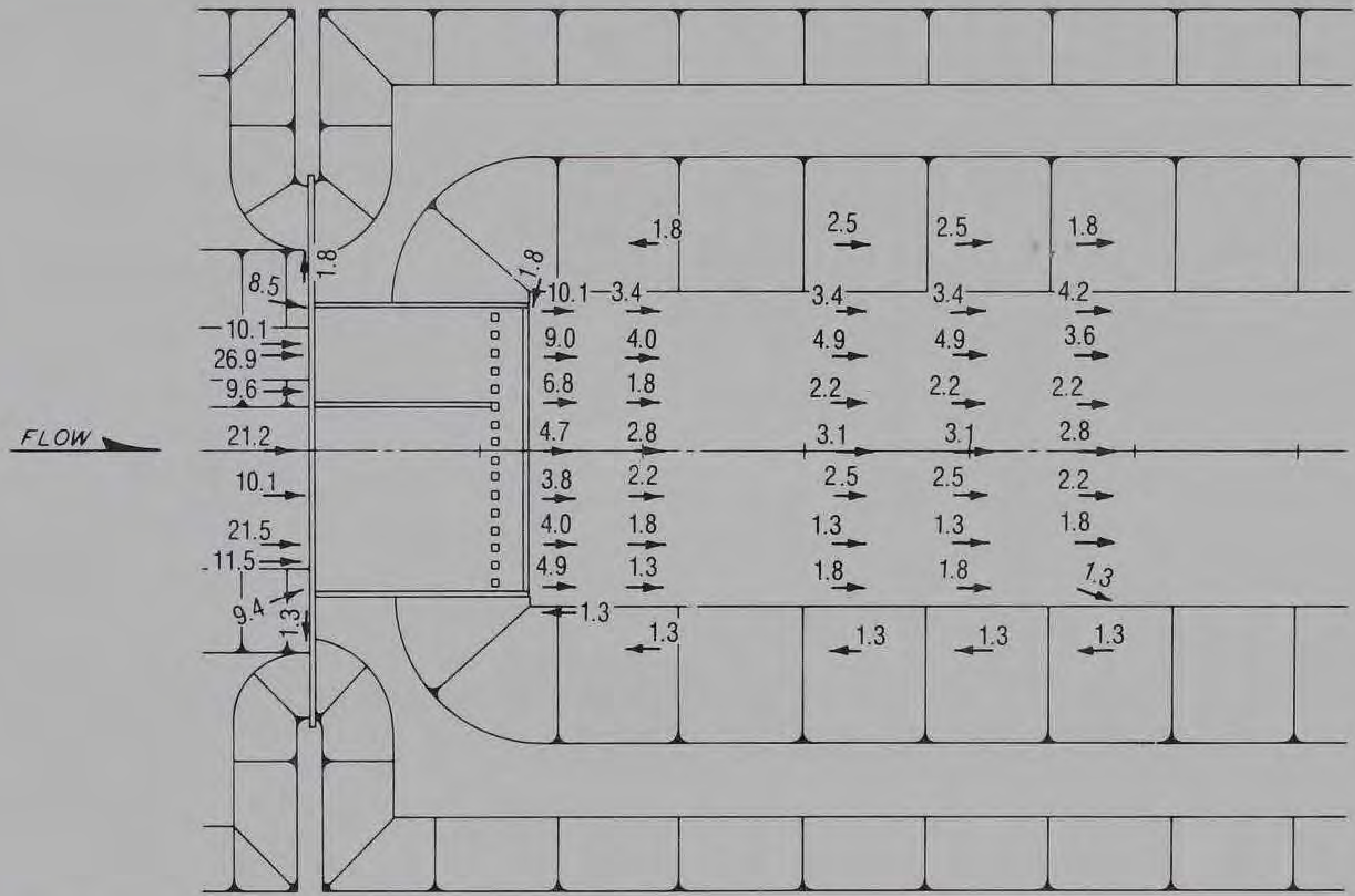


NOTE: VELOITIES ARE IN PROTOTYPE FEET PER SECOND TAKEN 1 FT OFF THE BOTTOM

VELOCITIES

RECOMMENDED DESIGN

DISCHARGE 10,000
TW EL 1024.0



NOTE: VELOITIES ARE IN PROTOTYPE FEET PER
SECOND TAKEN 1 FT OFF THE BOTTOM

VELOCITIES
RECOMMENDED DESIGN
DISCHARGE 10,000
TW EL 1018.5