MISCELLANEOUS PAPER H-71-5

CONTROL OF SCOUR AT HYDRAULIC STRUCTURES

by

T. E. Murphy

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Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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ARMY-MRC VICKSBURG, MISS.

Foreword

This report is essentially a paper prepared by Mr. Thomas E. Murphy, Chief of the Structures Branch, Hydraulics Division, U. S. Army Engineer Waterways Experiment Station, for presentation at the Mississippi Water Resources Conference held in Jackson, Miss., 14-15 April 1970. It has been reviewed and approved by the Office, Chief of Engineers, for publication and distribution under the Engineering Studies Program, ES 840, "Riprap Protection at Hydraulic Structures."

Directors of the Waterways Experiment Station during preparation and publication of this paper were COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE. Technical Directors were Messrs. J. B. Tiffany and F. R. Brown.

Contents

Conversion Factors, British to Metric Units of Measurement

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
pounds	0.45359237	kilograms
cubic feet per second	0.02831685	cubic meters per second

Summary

A case is made for providing for or preforming a scour hole in which flow from a hydraulic structure can expand and dissipate its excess energy in turbulence rather than in a direct attack on the channel boundaries. Examples are given which demonstrate that riprap schemes providing for flow expansions make it feasible to stabilize the channels with rock of an economical size and provide factors of safety against riprap failure and costly maintenance.

CONTROL OF SCOUR AT HYDRAULIC STRUCTURES

Introduction

1. Much work has been done on the development of energy dissipators for outfalls from hydraulic structures, and many good designs have been developed. However, even though these dissipators are used with structures ranging from relatively small drainage culverts to major spillways, in none of these designs is it contemplated that all of the excess energy of the efflux will be destroyed within the dissipator. This is proper since a structure that provided complete dissipation would be excessively costly and thus a poor design. Seldom does a designer ignore the fact that secondary dissipation outside of the structure itself is necessary but also seldom is due consideration given methods for accomplishing this. Common practice is to provide a trapezoidal outlet channel with bottom elevation the same as, or in some cases higher than, the top of the end sill and with bottom width the same as that of the energy dissipator and then attempt to stabilize this channel with riprap. Although large and thus costly rock is used in the area immediately below the dissipator, it is here that a great number of failures occur and costly maintenance is required to prevent damage to the structure or adjacent installations.

2. Tests conducted at the U. S. Army Engineer Waterways Experiment Station have demonstrated the advantages in providing for or preforming a "scour hole" in which flow can expand and dissipate its excess energy in turbulence rather than in a direct attack on the channel bottom and sides. Even a relatively small amount of expansion, preferably both vertically and horizontally, will greatly reduce the severity of the attack on the channel boundaries. This makes it possible to stabilize the channel with rock of an economical size and provide additional factors of safety against riprap failure and costly maintenance.

Gering Valley Drop Structures

3. A model investigation of drop structures for the Gering Valley

project in Nebraska was one of the first studies conducted at the Waterways Experiment Station in which the principle of providing an expansion in the channel immediately below the structure was applied. Series of these drop structures are used to lower velocities in a network of easily eroded drainage channels and thus stabilize the channel beds and minimize bank erosion. Fig. 1 shows a typical structure designed for a 5-ft* drop and a discharge of 182 cfs per foot of weir. Basically this structure consists of a vertical weir of a certain length extending 5 ft above the channel bottom and connected to the top banks by confining walls. Stilling action occurs on a concrete apron depressed a specific distance below the channel and terminated by an end sill with its top at the elevation of the channel. Design rules for these structures are given in WES Technical Report No. 2-760.**

4. A particular advantage of this drop structure is that it performs satisfactorily under a wide range of discharge and tailwater conditions. However, energy dissipation within the structure is only partial and considerable turbulence extends into the exit channel (fig. 2). Even with very large rock, a stable channel could not be maintained immediately below the structure when the channel bottom was horizontal at the elevation of the end sill and the same width as the structure. However, provision at the elevation of the end sill of a horizontal expansion of 6 ft on each side of the channel and allowance for a 10-ft vertical expansion permitted a stable channel to be maintained with rock of a reasonable size. The riprap plan that proved stable for the structure in fig. 1 is shown in fig. 3.

5. Since completion of the Gering project, design conditions have been experienced by at least one structure and several of the drop structures have been subjected to medium flows. Performance has been excellent and no maintenance has been required.

Branched Oak Dam Outlet Conduit

6. An ideal way to develop a riprap plan for a particular structure

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* A table of factors for converting British units of measurement to metric units is presented on page vii.

** T. E. Murphy, "Drop Structure for Gering Valley Project, Scottsbluff County, Nebraska; Hydraulic Model Investigation," Technical Report No. 2-760, Feb 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

was followed in the case of the Branched Oak Dam outlet conduit, also in Nebraska. A 1:10-scale model of this 6-ft-diam conduit was constructed at the Waterways Experiment Station, primarily for study of the vertical shaft intake structure; however, the model also was used to verify the performance of the stilling basin. Then the exit channel was molded in sand (fig. 4) and subjected to flows of 1240 and 1500 cfs (design discharge) for periods of about 47 min. The above figures are prototype equivalents and the 47-min periods represent actual operation of the model for periods of 15 min. This operation time was used since past experience had indicated that the sand under direct attack in the model would be moved within this period, although deterioration of the channel would continue at a decreasing rate for many hours. The condition of the channel at the end of the test is shown in fig. 5. A survey was made of the channel; then a riprap plan that essentially conformed to the eroded channel was developed. This plan (fig. 6) provided for both vertical and horizontal expansion of the flow and contained the excess turbulence (fig. 7) within the riprapped portion of the channel.

7. The rock from which the riprap blankets were formed in the prototype varied in weight from 5 to 50 lb. The adequacy of this size rock was verified by tests in the model.

8. The small rock required was not only economical to buy and handle but also permitted good coverage with a relatively thin blanket. Blanket thickness should be about 1.5 times the diameter of the maximum size rock; thus the smaller the maximum size rock required, the less total volume of rock required for the blanket. Thus savings in rock costs probably offset the cost of excavation required to preform the "scour hole." Certainly the likelihood of costly maintenance has been reduced considerably by adoption of this plan.

Low-Water Weirs in Drainage Channels

9. The Vicksburg District, Corps of Engineers, has pioneered in the use of low-water weirs to create pools in drainage channels that serve as aids in channel maintenance by retarding or eliminating tree growth. In addition, the pools created by the low-water weirs provide secondary

benefits for limited irrigation, recreation, and watering of livestock. Also, these pools act as retardants to the lowering of the groundwater that would otherwise result from channel improvement projects.

10. Since a large number of these weirs are required, efforts have been made to keep the cost per weir at a bare minimum. A design frequently used consists of a 5.5-ft-high by 100-ft-long earth plug in the channel terminated by a sheet pile cutoff wall. Riprap is provided in the immediate vicinity of the sheet pile cutoff wall.

11. These weirs are designed to provide the desired pools during periods of low flow but to be drowned or submerged at moderate discharges. However, due to many factors, it is difficult to accurately predict the headwater-tailwater-discharge relation at each weir. At certain weirs, where there is even a few tenths of a foot drop from headwater to tailwater at moderage discharges, scour holes as deep as 20 to 25 ft have developed. With the bottom width of the outlet channel essentially the same as the width of the weir, it is inevitable that the channel banks are undercut by these scour holes and scour pockets are created, a typical example of which is shown in fig. 8. Even after ultimate development of the scour hole, the deterioration of the banks, which could lead to flanking of the structure, will continue due to eddy currents and wave action inherent in the flow immediately downstream from the structure.

12. A plan that makes allowance for development of a scour hole but provides for containment of bank deterioration is shown in fig. 9. Since only a few of the weirs have developed scour holes and required excessive maintenance, this plan, which would increase the initial cost, is not considered warranted at all weirs. However, as soon as it becomes evident that maintenance will be required at a particular weir, it has been recommended that the work be performed so as to approach the configuration shown in fig. 9. Further, where the headwater-tailwater-discharge relation is uncertain, such as at the downstream weir of a particular series, it is suggested that this plan be installed initially.

Termination of Riprap Blanket

13. Another advantage of the provision for flow expansion is found

in the termination of the riprap blanket. Undercutting and raveling of the downstream end of a horizontal riprap blanket (fig. 10) are problems. Once started, raveling usually will continue until the entire blanket is lost. The undercutting is caused primarily by turbulence created by the riprap and can be eliminated by gradually reducing the size of the rock until the rock in the downstream end of the blanket blends with the natural streambed material. However, this requires a long riprap blanket to first dissipate the excess energy from the structure and then develop the velocity profile natural to the particular stream. If the riprap blanket is sloped away from the structure so as to permit expansion of the flow, the attack of the current on the rock is less severe and the turbulence created by the rock is considerably less than in the case of a horizontal blanket. Raveling at the end of a sloping blanket is seldom a problem, although the scour hole may develop to an elevation below the riprap (fig. 11). Thus, placement of the rock so as to provide flow expansion permits protection of the concrete structure against undercutting by a relatively short riprap blanket. Furthermore, the size of the rock in the blanket need not be as large as is required with a horizontal blanket.

Recommendations

14. Instead of preforming a scour hole or installing a riprap plan which provides for development of scour, it has been suggested that the flow be allowed to develop its own expansion area and then the riprap be installed for containment. Although essentially this is to be done for a few low-water weirs that will require maintenance, this procedure has many disadvantages and is not recommended as a common practice. First, it seldom is convenient to place the riprap at the optimum stage of development of the scour hole. Further, a riprap blanket with adequate filter carefully placed in the dry, as usually is feasible in initial construction, requires far less rock and is much more effective than is a blanket formed by dumping rock into the water, the usual maintenance procedure. Also, the need to remobilize equipment and resources often makes the cost of subsequent installation of riprap considerably greater than would be the cost of

the riprap plus the added excavation during initial construction. An exception to placement of the riprap during initial construction might be made in the case of small, easily accessible drainage structures where it is feasible to do maintenance work in the dry. However, in any case where an existing structure requires maintenance, it is strongly urged that, if at all feasible, the maintenance be performed to contain the scour but maintain the existing scour hole, letting it perform its useful function of energy dissipation.

15. The writer is aware that this paper does not present a new idea; plunge pools and flow expansions have been discussed in technical literature and used for energy dissipation. However, their use has not been generally adopted. Most designers provide a uniform channel leading away from a hydraulic structure just because "that is the way it has been done at other projects." The prime purpose of this paper is to make designers aware of the advantages of providing even a small area for flow expansion. Preparation of the paper was prompted by the results of model tests that demonstrated that large reductions in rock size are feasible when a riprap scheme provides for flow expansion. However, it is not advocated that designers immediately start specifying smaller rock but, until better criteria for the design of riprap protection at hydraulic structures are developed, it is suggested that flow expansions be provided in riprap schemes as added safety factors. Certainly, if a structure is investigated by hydraulic model tests, the procedure followed in the Branched Oak tests should be used for development of the riprap scheme.

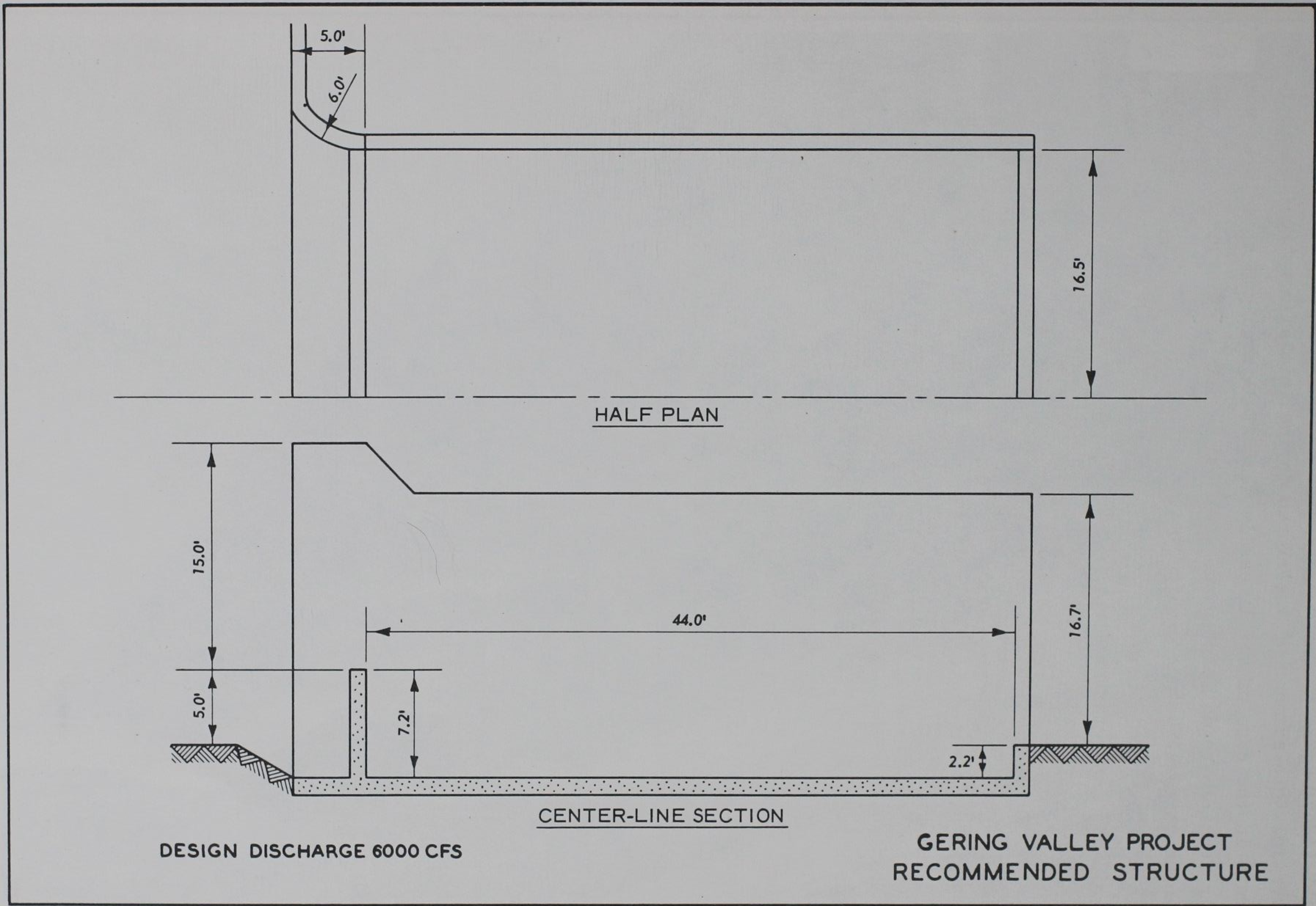

5.0'
6.0'
16.5'
HALF PLAN
15.0'
5.0'
7.2'
44.0'
16.7'
2.2'
CENTER-LINE SECTION
DESIGN DISCHARGE 6000 CFS
GERING VALLEY PROJECT
RECOMMENDED STRUCTURE

Fig. 1

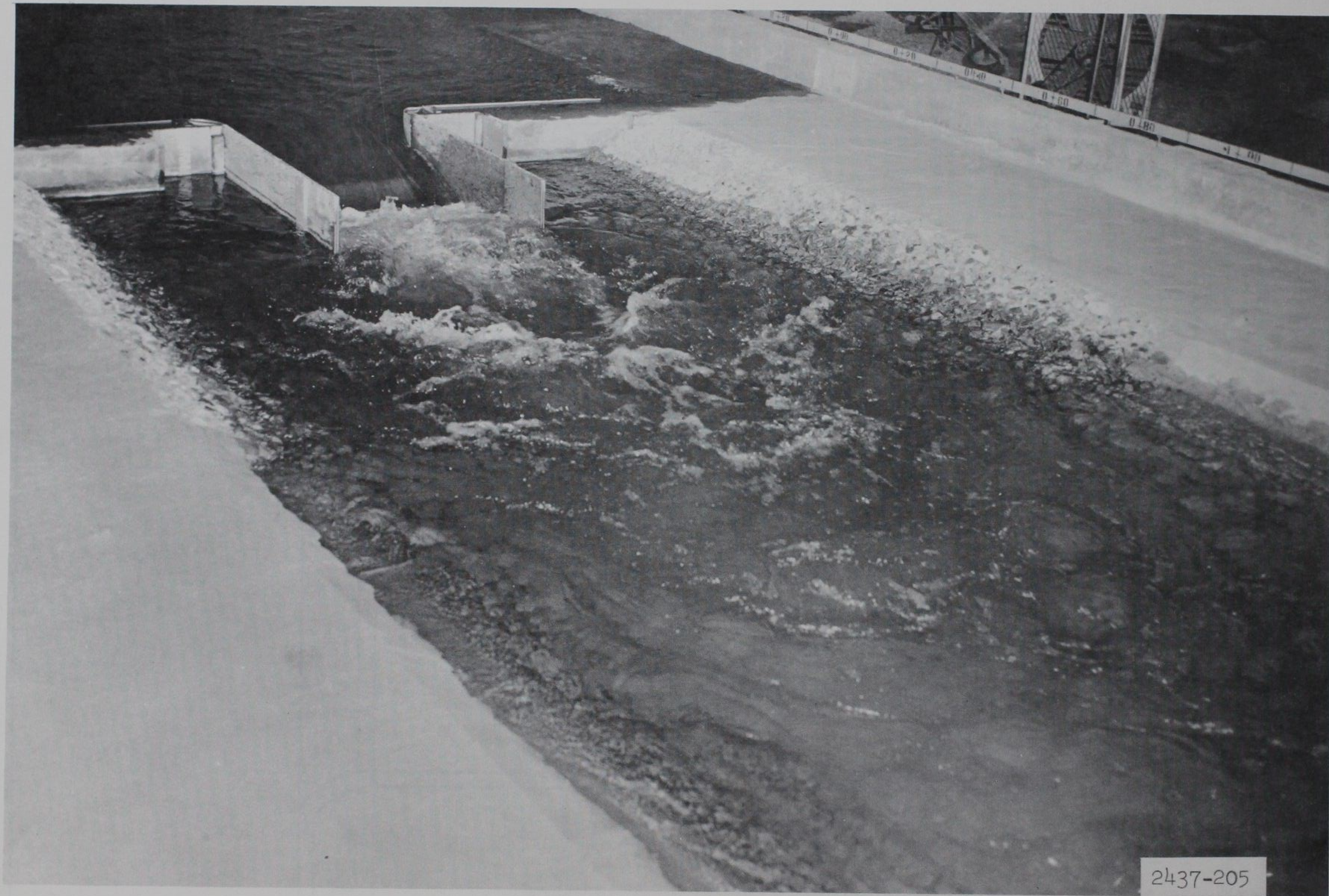
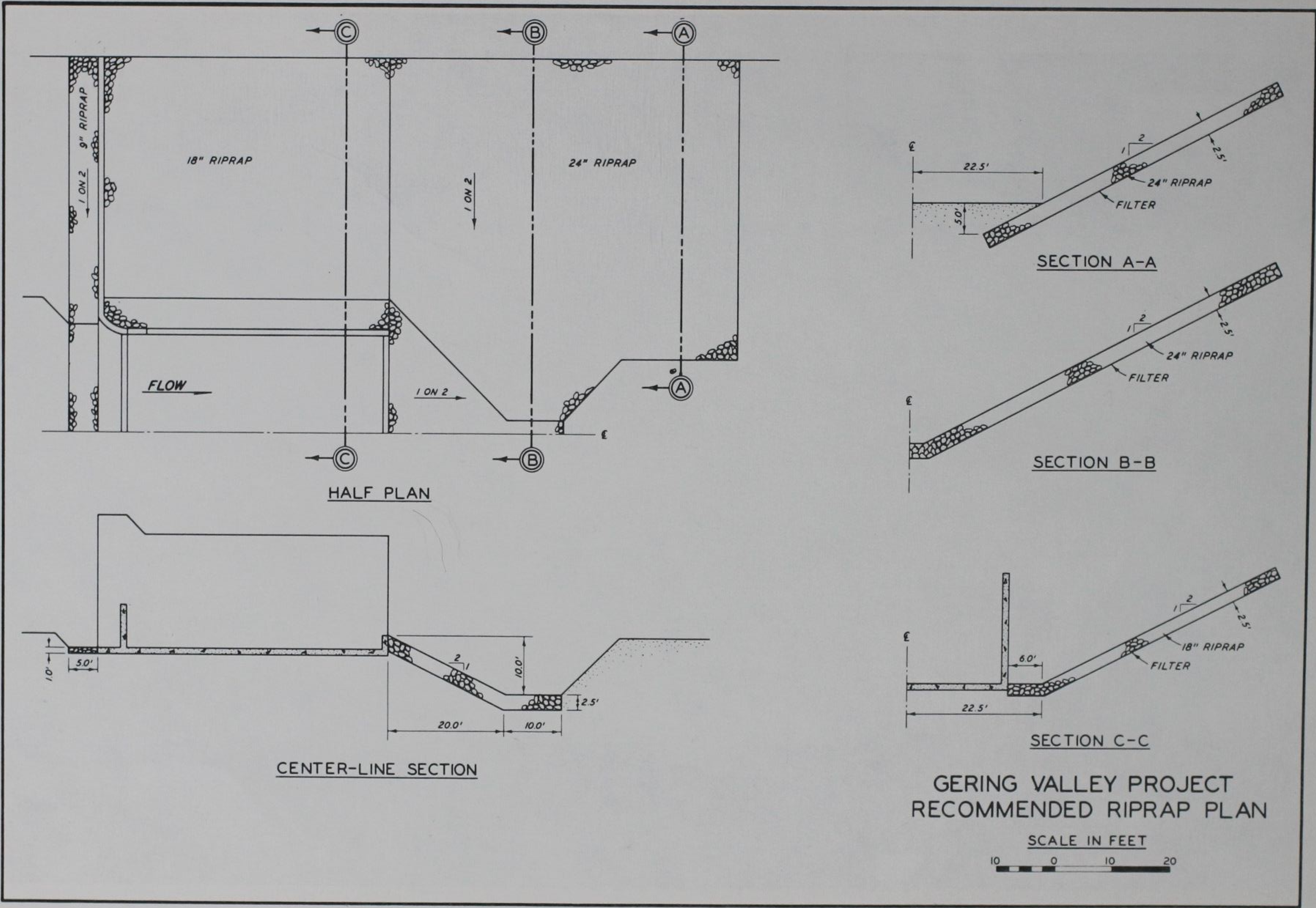


Fig. 2. Gering drop structure, discharge 6000 cfs



GERING VALLEY PROJECT
RECOMMENDED RIPRAP PLAN
SCALE IN FEET
10 0 10 20
HALF PLAN
18" RIPRAP
24" RIPRAP
9" RIPRAP
1 ON 2
FLOW
CENTER-LINE SECTION
5.0'
1.0'
10.0'
20.0'
2.5'
SECTION A-A
22.5'
5.0'
24" RIPRAP
FILTER
2.5'
SECTION B-B
SECTION C-C
6.0'
18" RIPRAP

Fig. 3

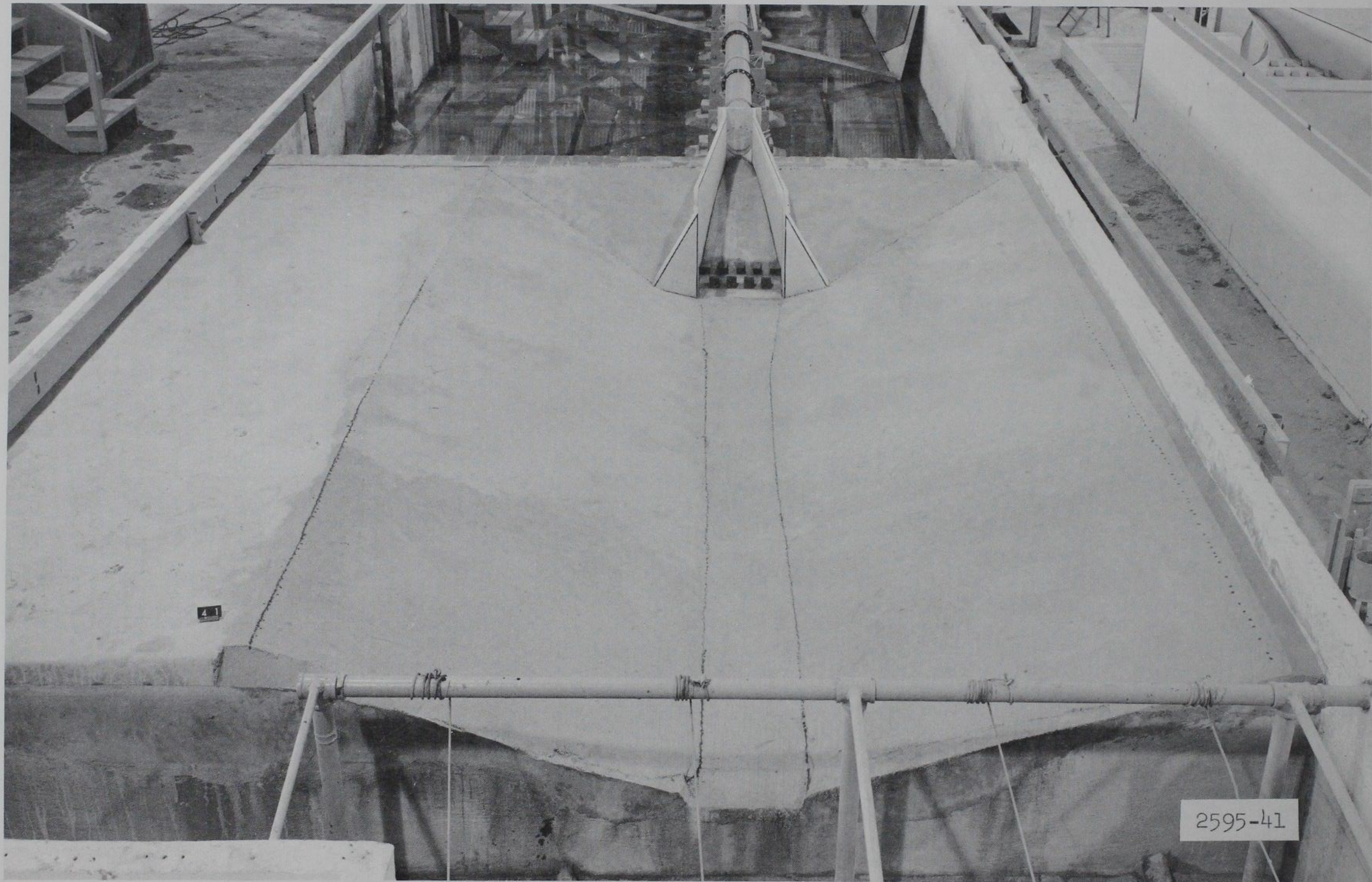


Fig. 4. Branched Oak outlet, exit channel molded in sand

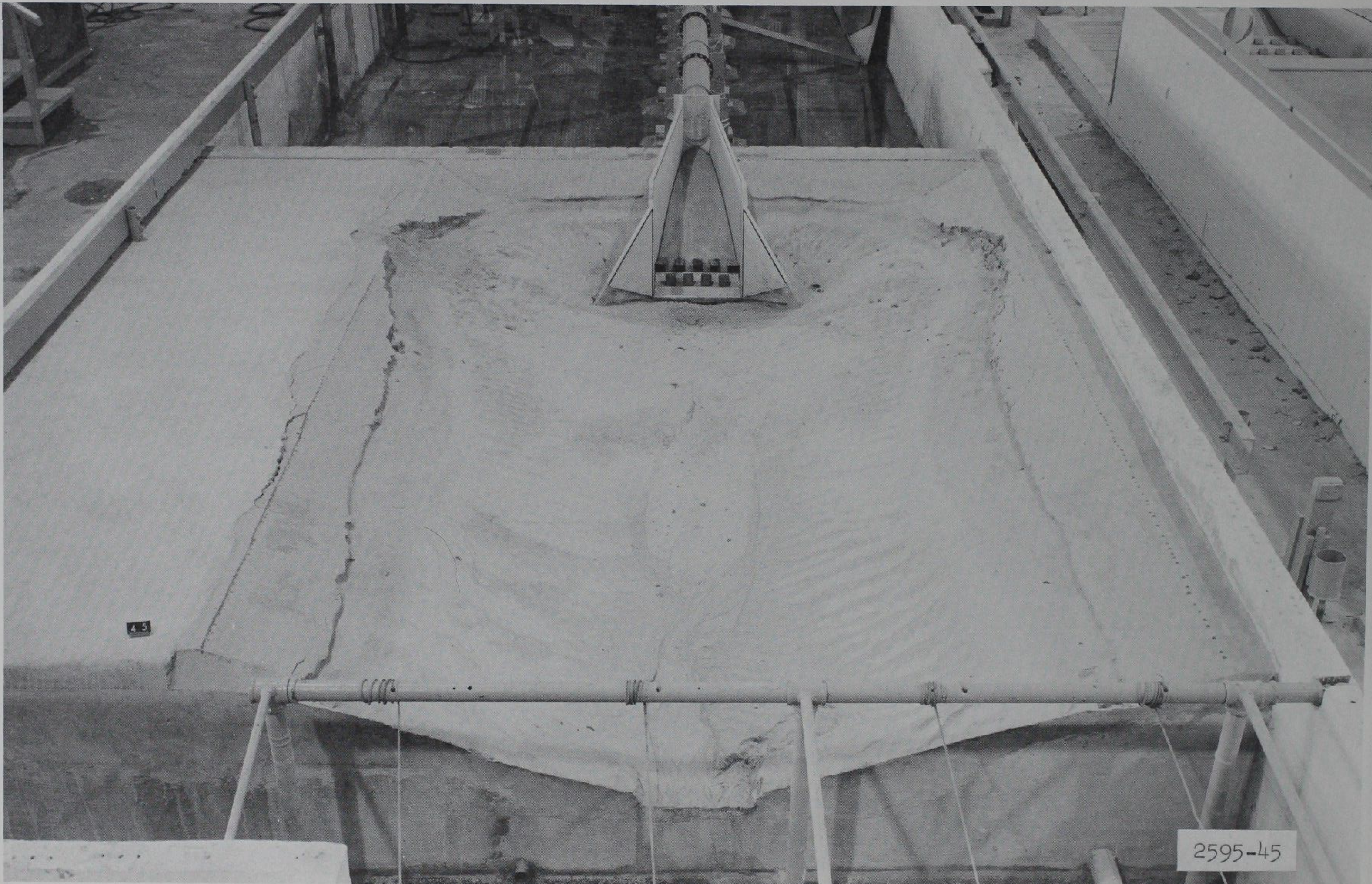
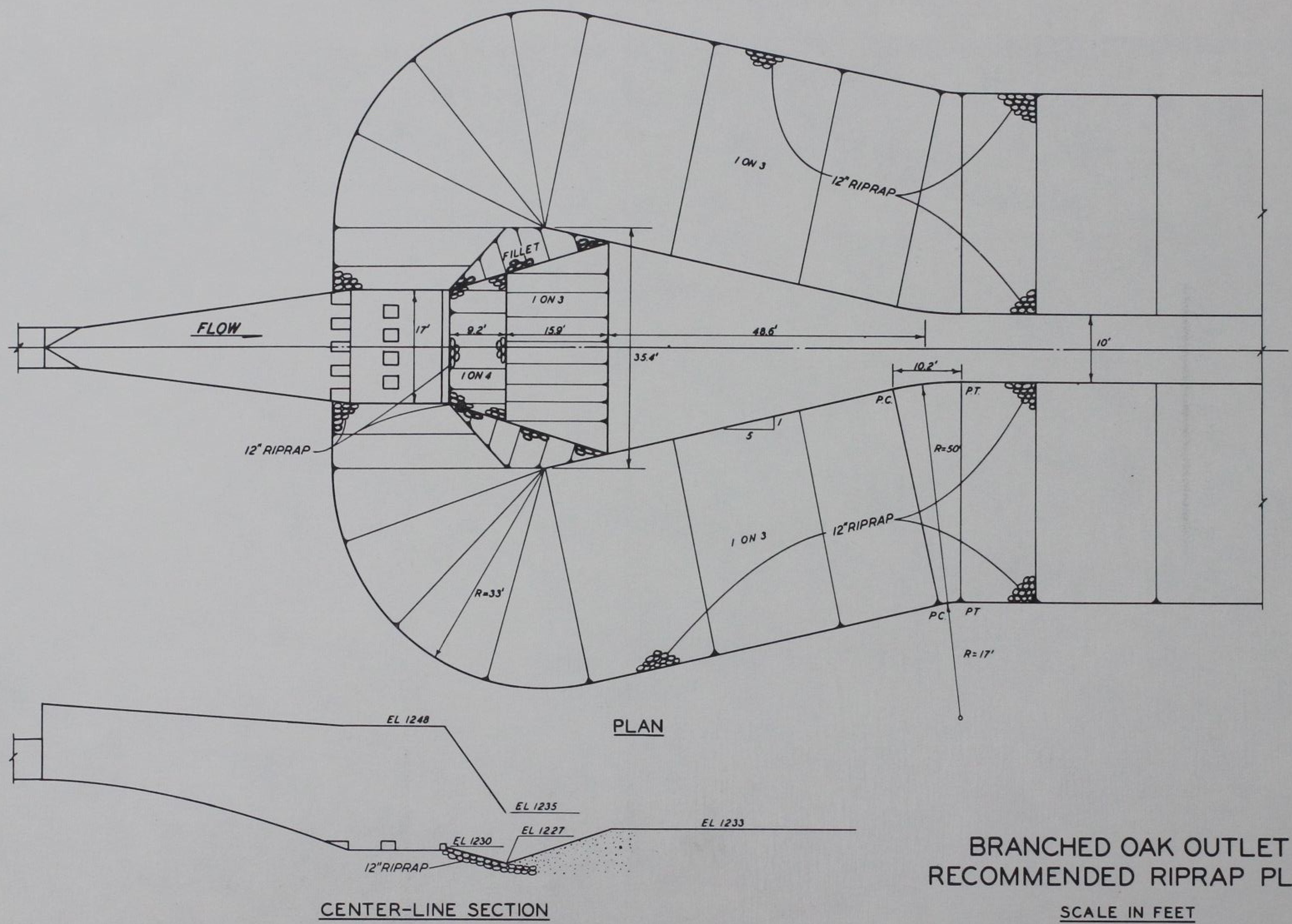


Fig. 5. Branched Oak outlet, scour pattern

Fig. 6



BRANCHED OAK OUTLET
RECOMMENDED RIPRAP PLAN

SCALE IN FEET

10 0 10 20

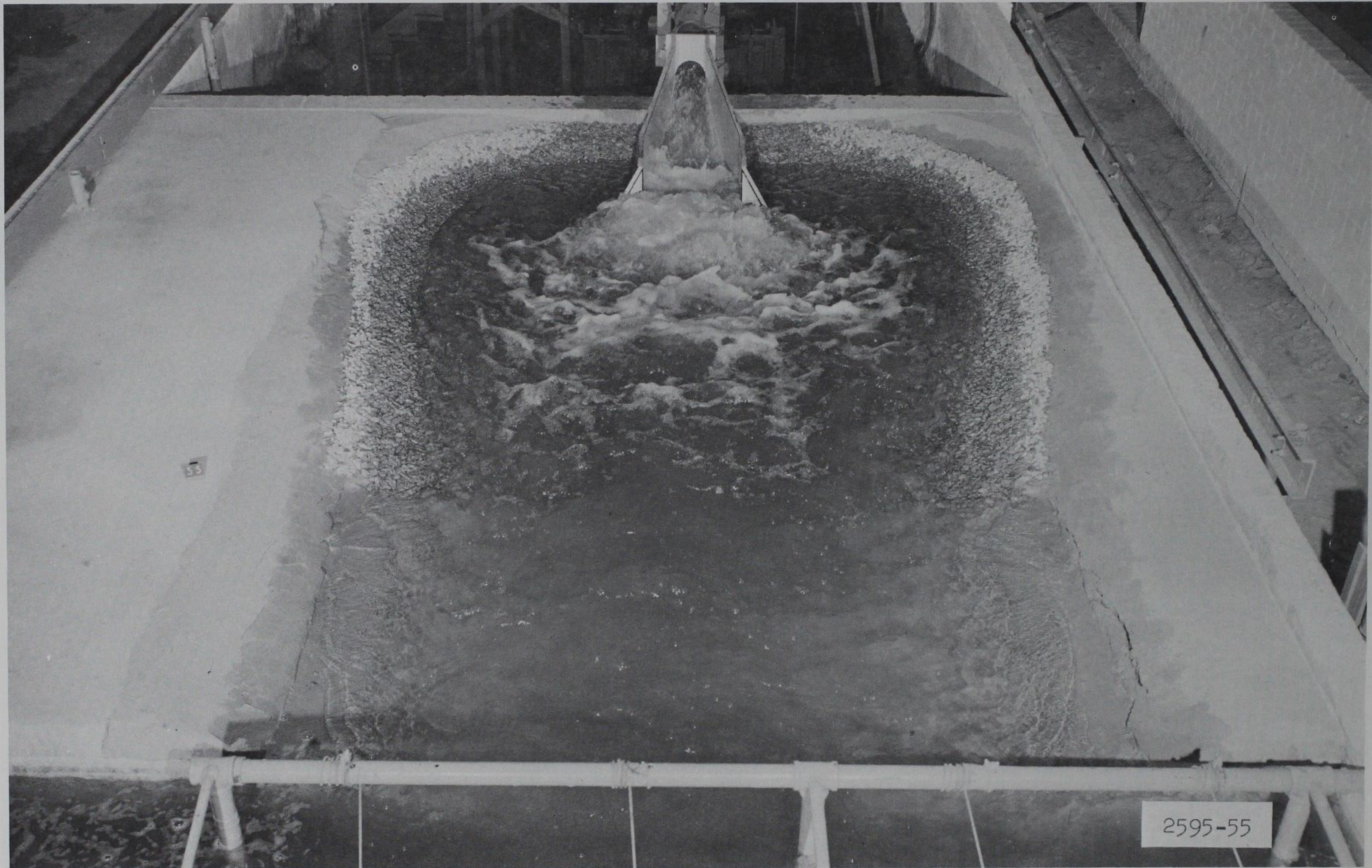
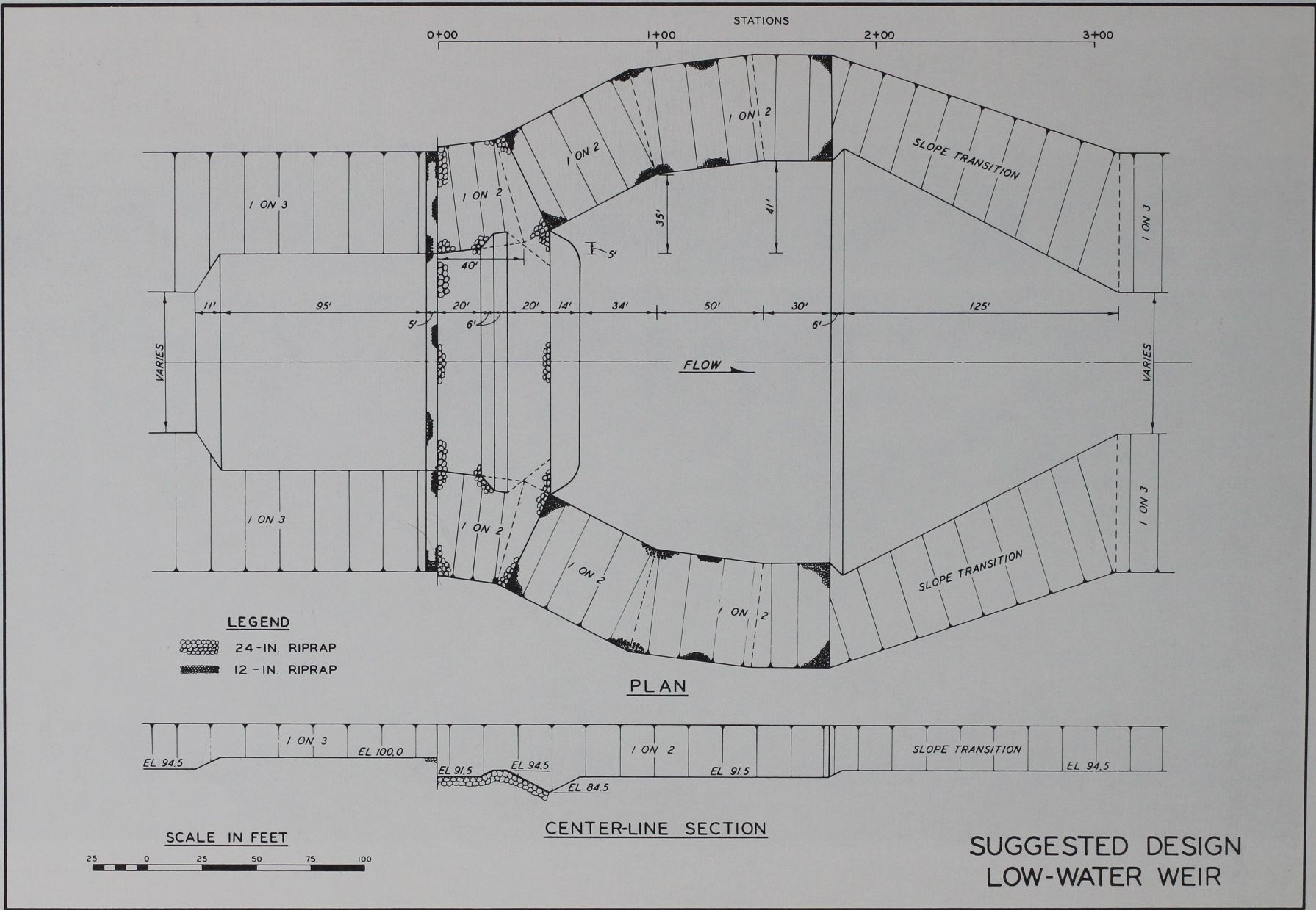


Fig. 7. Branched Oak outlet, design discharge 1500 cfs

Fig. 8. Typical scour pocket, Boeuf River at Highway 144



SUGGESTED DESIGN
LOW-WATER WEIR

Fig. 9

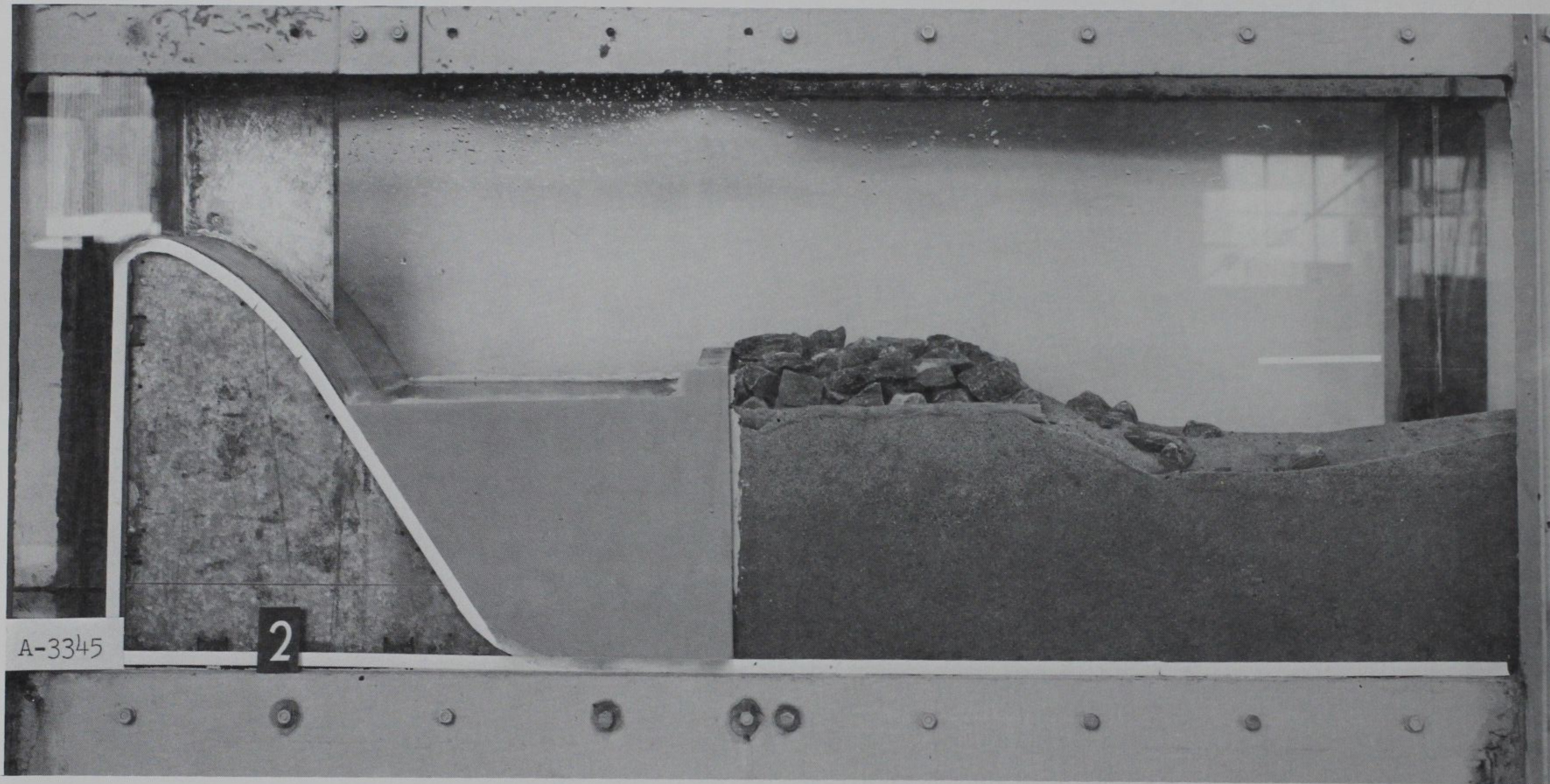


Fig. 10. Horizontal riprap blanket raveling at downstream end

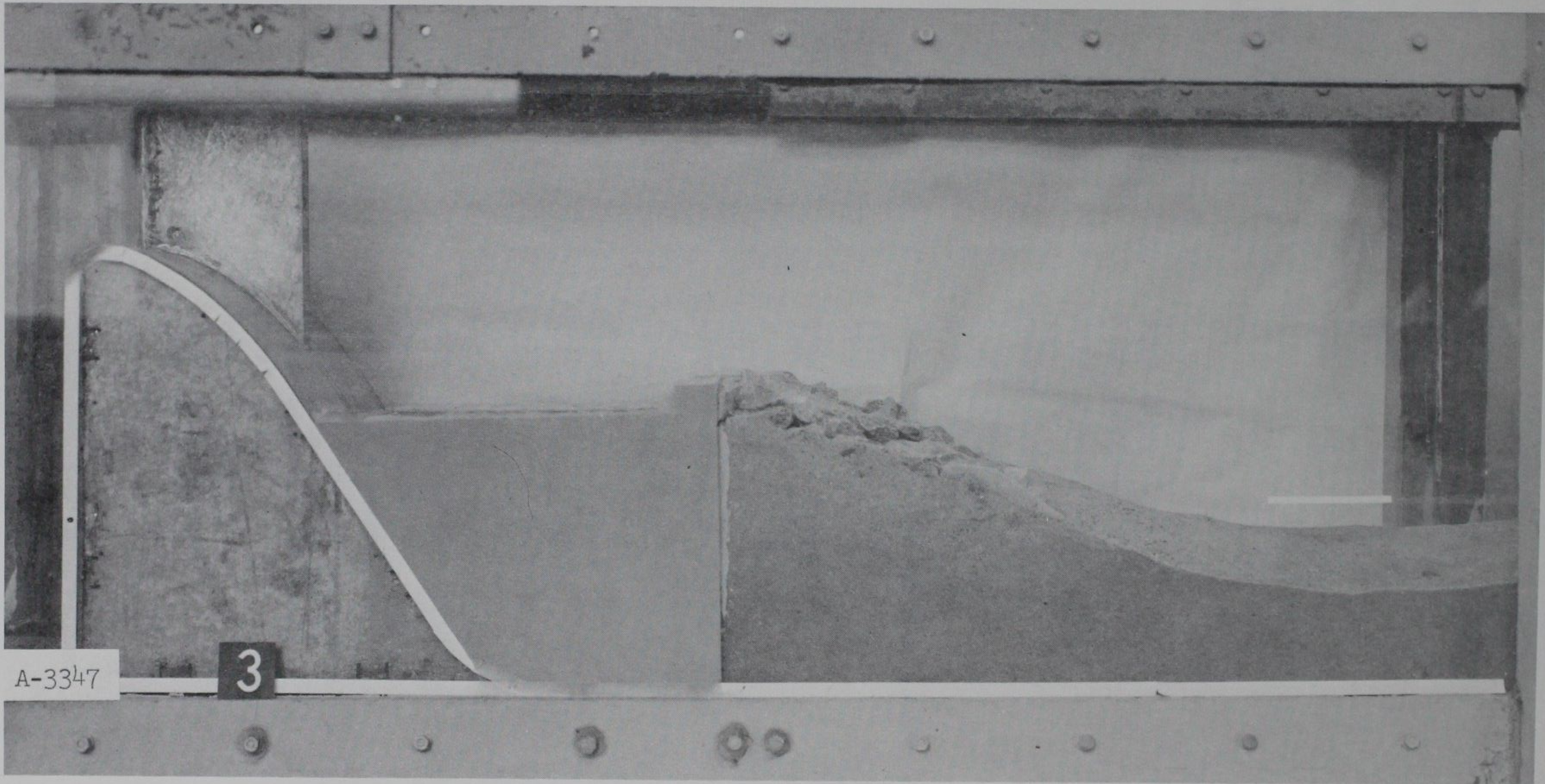


Fig. 11. Sloping riprap blanket remains stable even with deep scour

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13. ABSTRACT

A case is made for providing for or preforming a scour hole in which flow from a hydraulic structure can expand and dissipate its excess energy in turbulence rather than in a direct attack on the channel boundaries. Examples are given which demonstrate that riprap schemes providing for flow expansions make it feasible to stabilize the channels with rock of an economical size and provide factors of safety against riprap failure and costly maintenance.

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