CONTROL OF SCOUR AT HYDRAULIC STRUCTURES

by

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Much work has been done on the development of energy dissipators for outfalls from hydraulic structures, and many good designs have been developed. However, whether for use 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 which 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 nice trapezoidal channel with bottom elevation the same, or even in some cases higher, than the top of the end sill and with bottom width the same as the energy dissipator, and then attempt to stabilize this channel with riprap. Although large size 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.

Tests conducted at the 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, preferrably 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 provides additional factors of safety against riprap failure and costly maintenance.

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. Figure 1 is a drawing of 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.

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 as is shown in 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 which proved stable for the structure in fig. 1 is shown in fig. 3.

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.

An ideal way to develop a riprap plan for a particular structure was followed in the case of the Branched Oak Dam outlet conduit also in Nebraska. A 1:10-scale model of this 6-ft-diameter 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, as shown in fig. 4, and subjected to flows of 1240 cfs and 1500 cfs (design discharge) for periods of about 47 minutes. The above figures are prototype equivalents and the 47-minute periods represent actual operation of the model for periods of 15 minutes. 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. At the end of the test the condition of the channel was as is shown in fig. 5. A survey was made of the channel and then a riprap plan which essentially conformed to the eroded channel was developed. This plan, shown on 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.

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

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.

The Vicksburg District of the Corps of Engineers has pioneered in the use of low-water weirs to serve as aids in channel maintenance by retarding or eliminating tree growth. In addition, the weirs provide secondary benefits including pools for limited irrigation, recreation and watering of livestock. Also these pools act as retardants to the lowering of groundwater that would otherwise result from channel improvement projects.

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 cut-off wall. Riprap is provided in the immediate vicinity of the sheet pile cut-off wall.

These weirs are designed to provide 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 relationship at each weir. At certain weirs where at moderate discharges there is even a few tenths of a foot drop from headwater to tailwater, 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 creating scour pockets, a typical example of which is shown in fig. 8. Further 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 action and wave action inherent in the flow immediately downstream from the structure.

A plan which 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 relationship is uncertain, such as at the downstream weir of a particular series, it is suggested that this plan be installed initially.

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 existing scour and not to restore the channel to its original condition. Let the flow expansion remain and perform its useful function of energy dissipation.

Usually an engineer prepares a technical paper because he has developed rules as to how to accomplish a particular task. Unfortunately in this case you have been told what should be done but little general guidance has been given as to exactly how this should be done, except for the three specific situations. Obviously, if a project warrants a model study, then the model should be used to determine the expansion required to permit containment of scour with rock of a size that is economical for the particular location. However, few small drainage structures warrant model studies. Certainly any riprap plan that provides for expansion will be better than a plan that does not provide for expansion. If enough people put in practice the principle of providing a flow expansion immediately following a hydraulic structure, development of design rules naturally will follow.

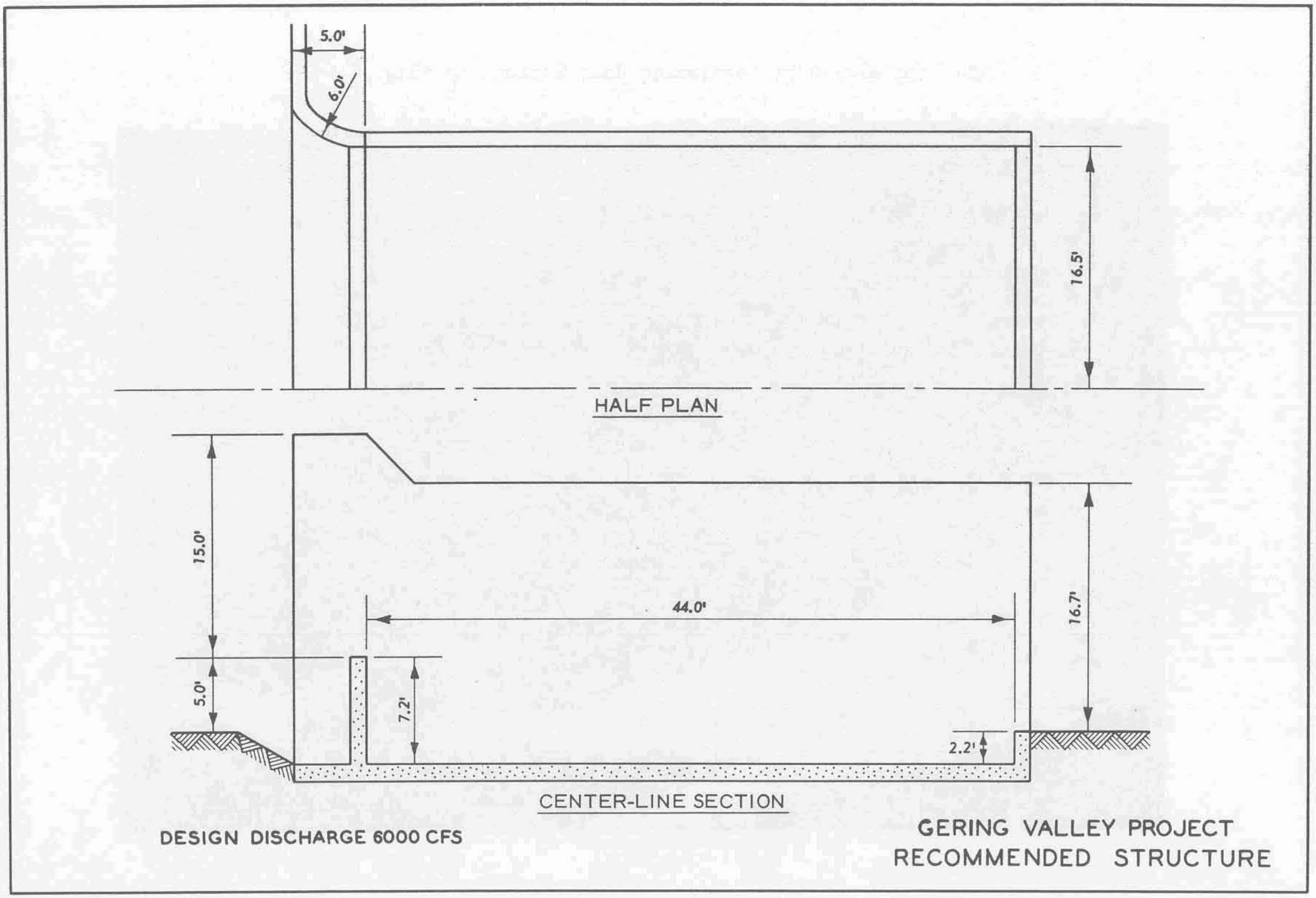
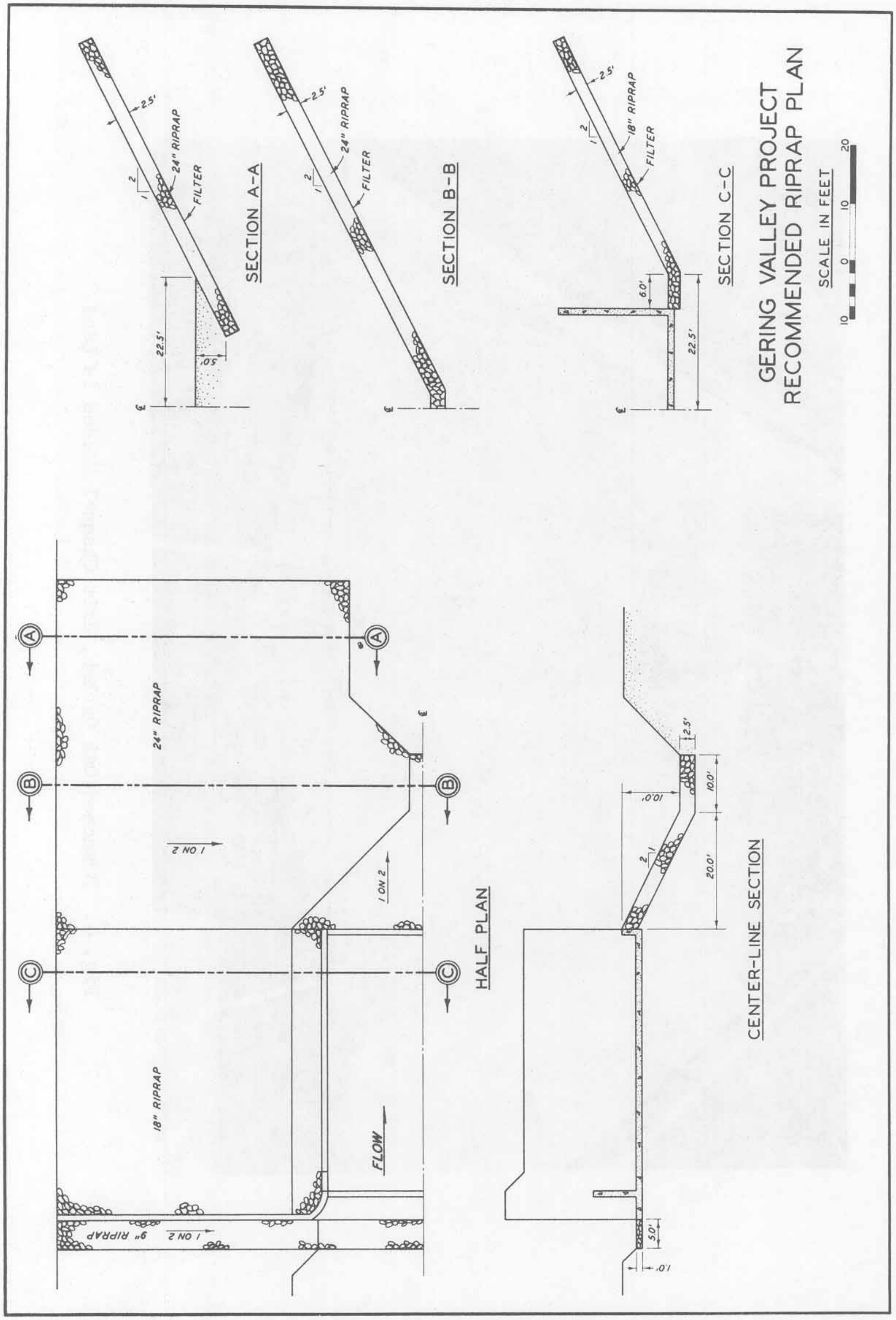

5.0'
6.0'
16.5'
HALF PLAN
15.0'
44.0'
16.7'
5.0'
7.2'
2.2'
CENTER-LINE SECTION
DESIGN DISCHARGE 6000 CFS
GERING VALLEY PROJECT
RECOMMENDED STRUCTURE

Fig. 1

Fig. 2. Gering Drop Structure, Discharge 6000 cfs



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

Fig. 3

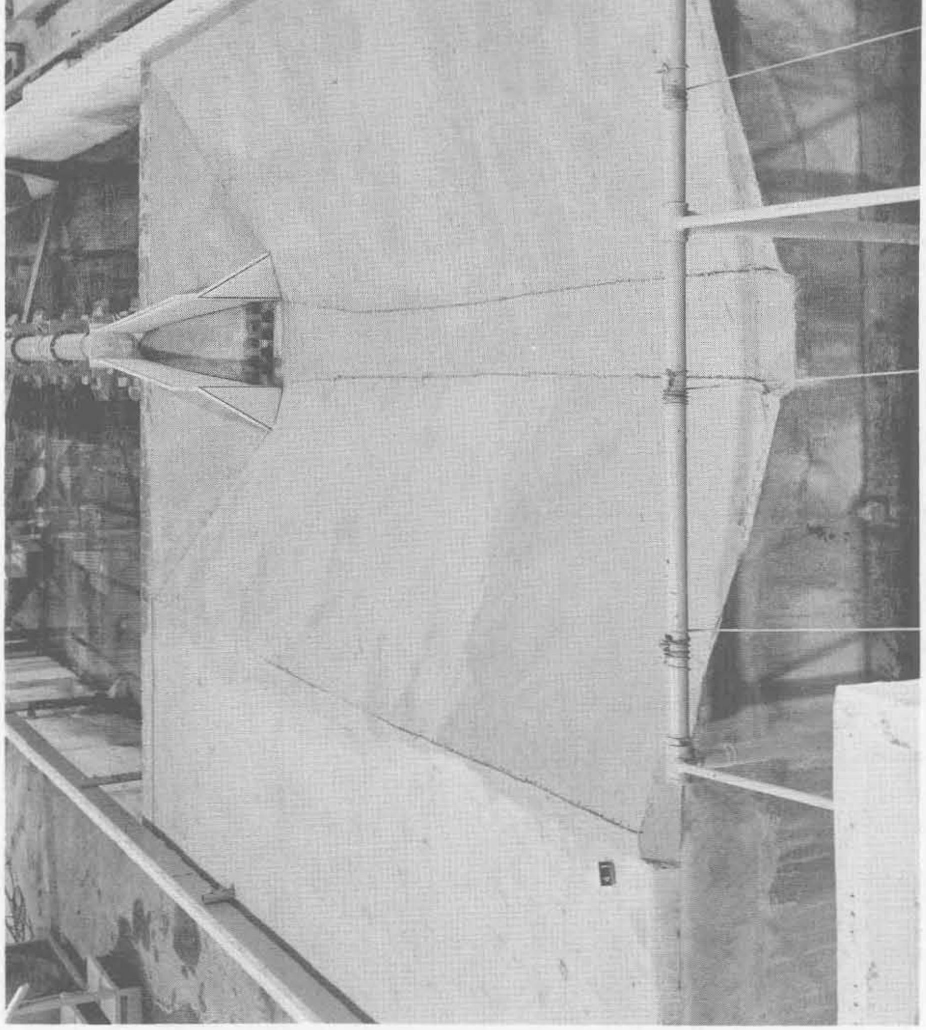


Fig. 4. Branched Oak Outlet, Exit Channel Molded in Sand

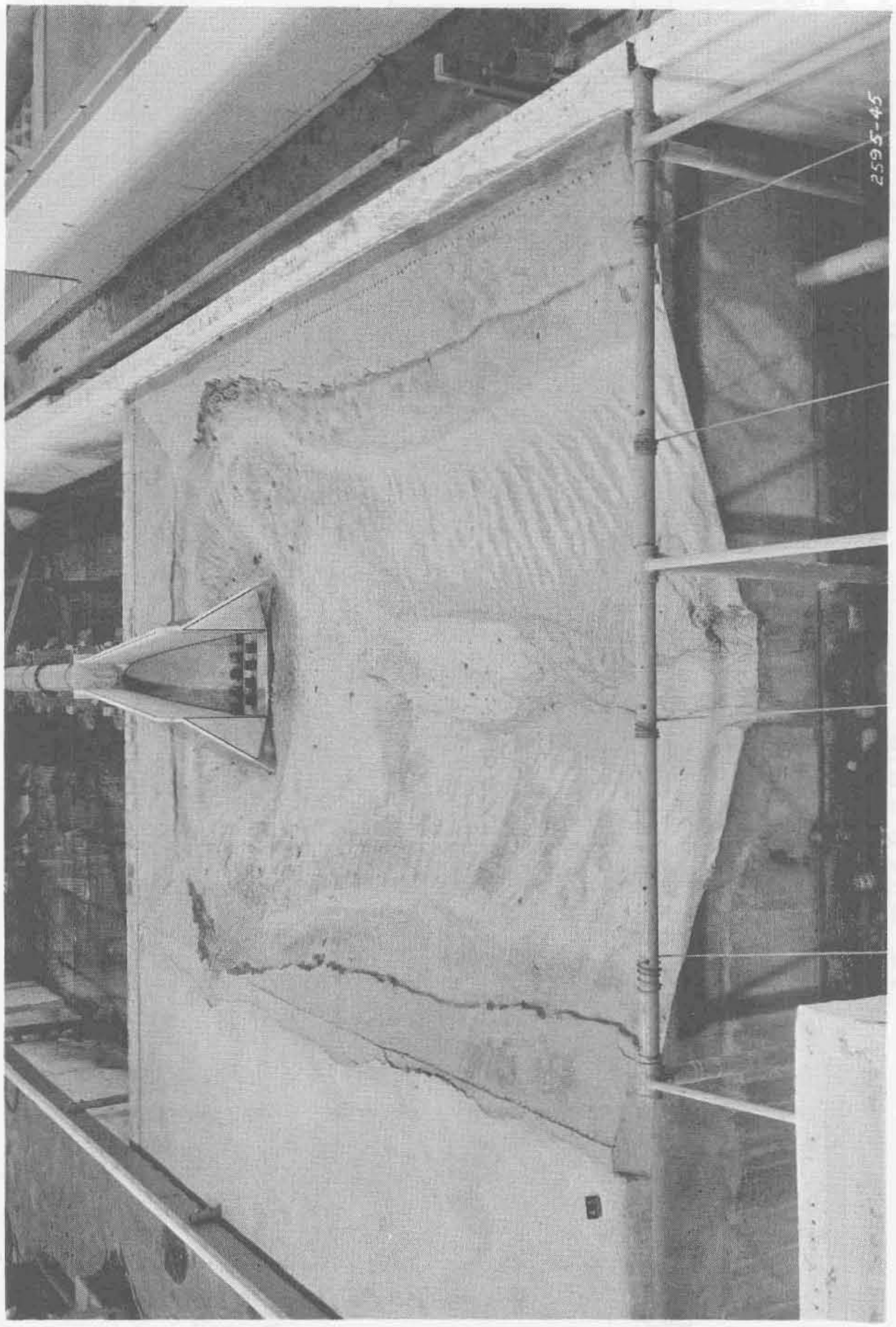
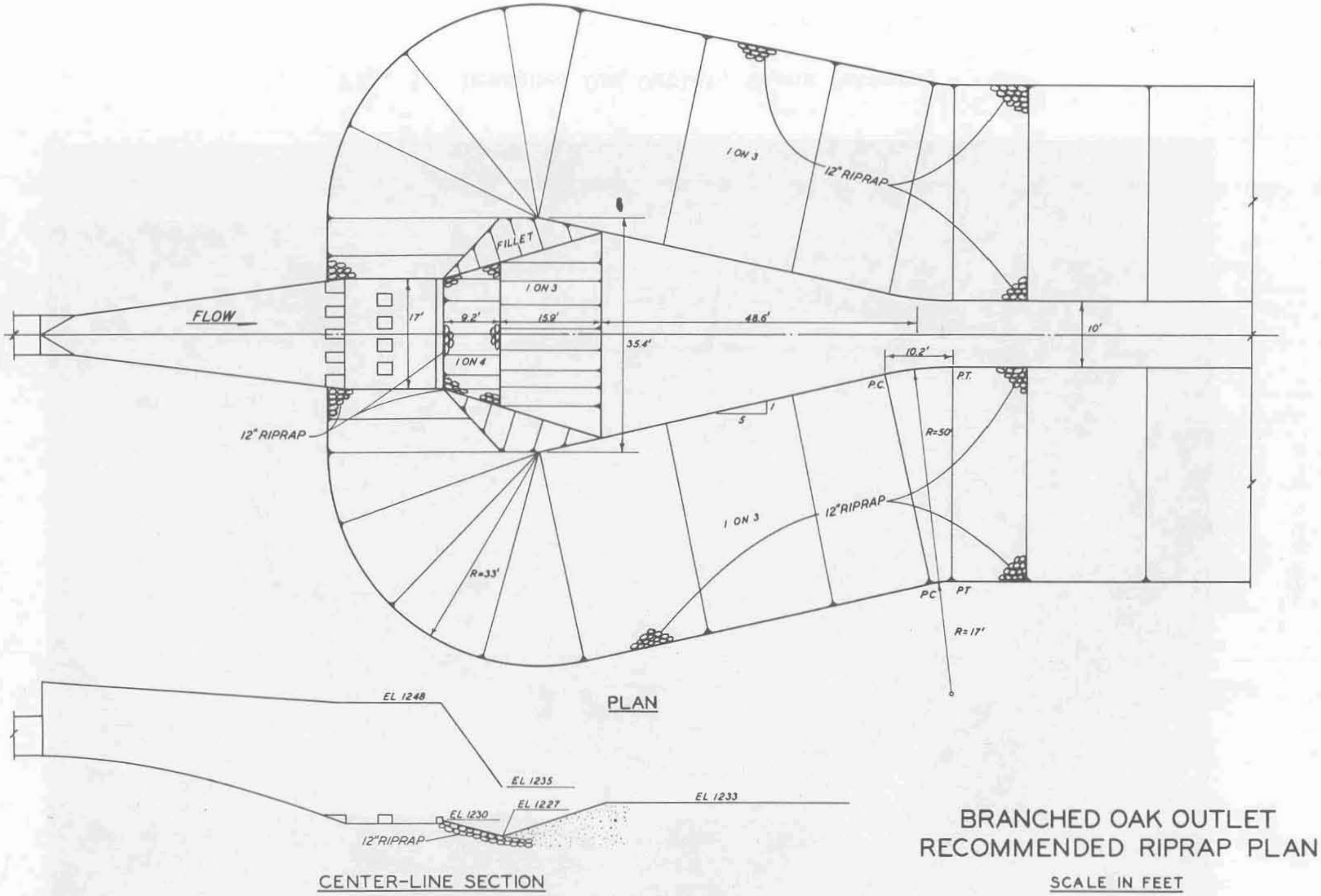


Fig. 5. Branched Oak Outlet, Scour Pattern



BRANCHED OAK OUTLET
RECOMMENDED RIPRAP PLAN

Fig. 6

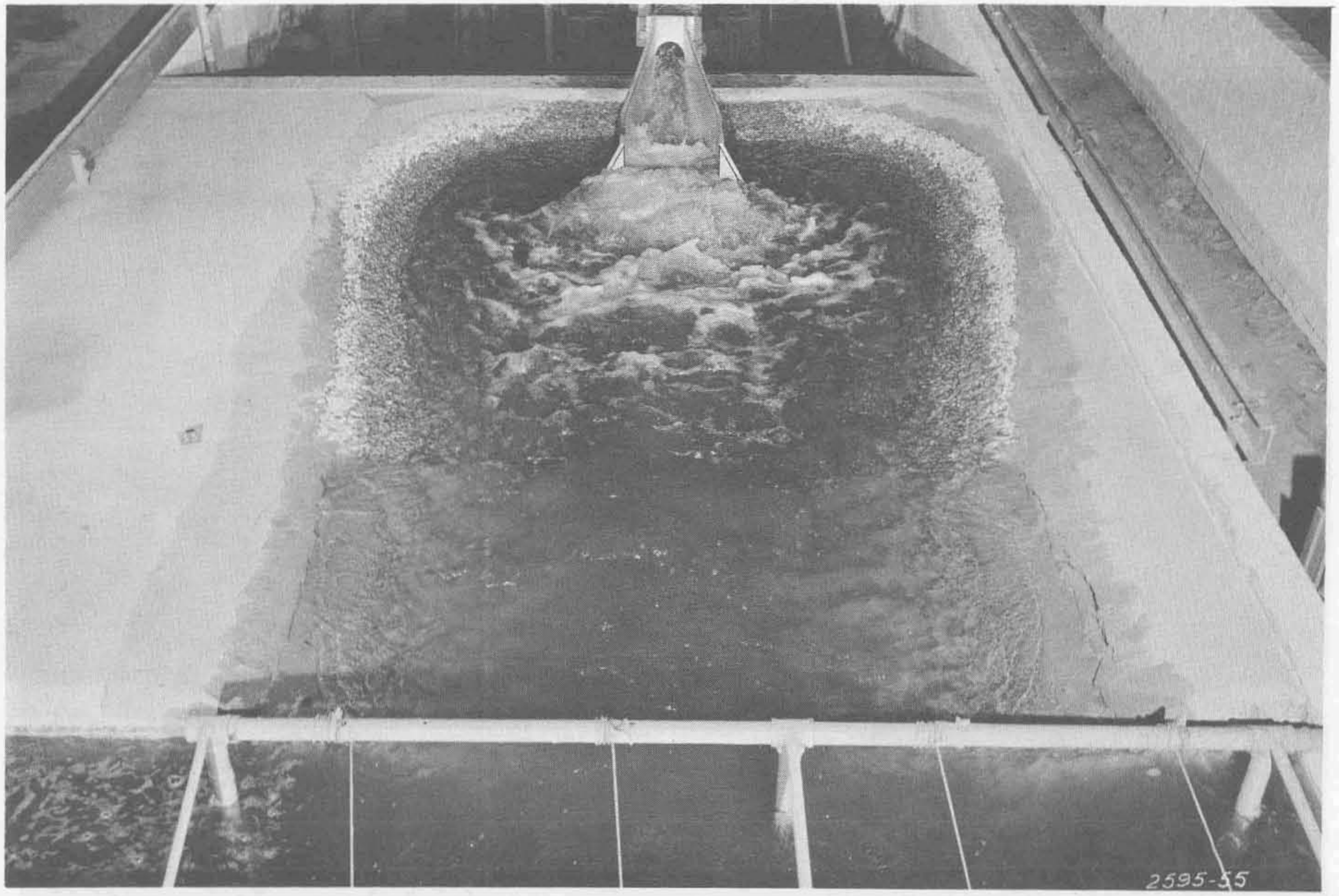


Fig. 7. Branched Oak Outlet, Design Discharge 1500 cfs

Fig. 8. Typical Scour Pocket, Boeuf River at Highway 144

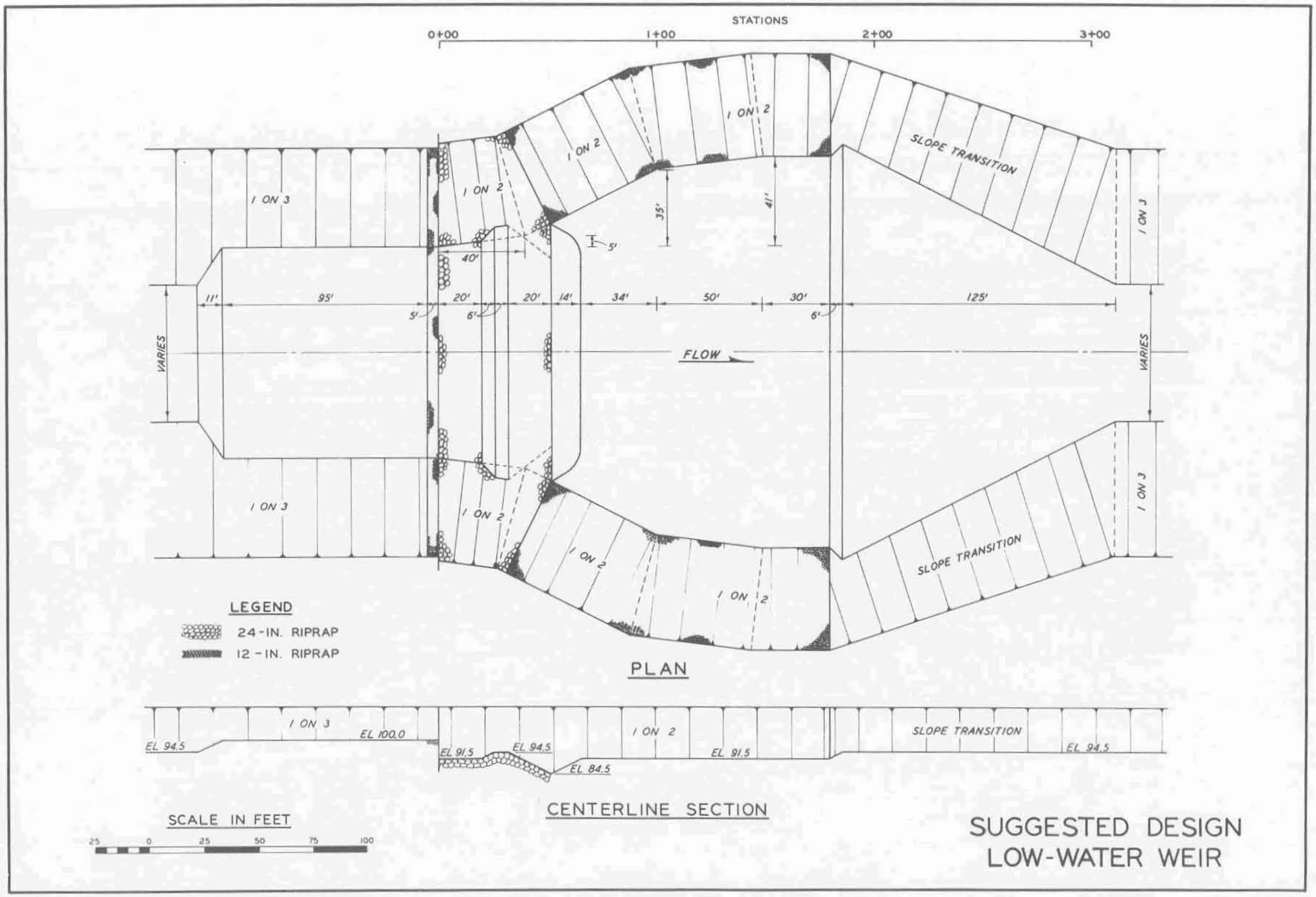

STATIONS
0+00
1+00
2+00
3+00
1 ON 3
1 ON 2
1 ON 2
1 ON 2
SLOPE TRANSITION
1 ON 3
35'
41'
5'
40'
11'
95'
5'
20'
6'
20'
14'
34'
50'
30'
6'
125'
VARIES
FLOW
VARIES
1 ON 3
1 ON 2
1 ON 2
1 ON 2
SLOPE TRANSITION
1 ON 3
LEGEND
24-IN. RIPRAP
12-IN. RIPRAP
PLAN
1 ON 3
EL 94.5
EL 100.0
EL 91.5
EL 94.5
EL 84.5
1 ON 2
EL 91.5
SLOPE TRANSITION
EL 94.5
CENTERLINE SECTION
SCALE IN FEET
25
0
25
50
75
100
SUGGESTED DESIGN
LOW-WATER WEIR

Fig. 9