Barkdoll, Brian D.; Melville, Bruce W.; Ettema, Robert

Design of Bridge Abutment Scour Countermeasures

Verfügbar unter/Available at: https://hdl.handle.net/20.500.11970/99995

Vorgeschlagene Zitierweise/Suggested citation:
Barkdoll, Brian D.; Melville, Bruce W.; Ettema, Robert (2006): Design of Bridge Abutment Scour Countermeasures. In: Verheij, H.J.; Hoffmans, Gijs J. (Hg.): Proceedings 3rd International Conference on Scour and Erosion (ICSE-3). November 1-3, 2006, Amsterdam, The Netherlands. Gouda (NL): CURNET. S. 45-52.

Design of Bridge Abutment Scour Countermeasures

B. D. Barkdoll[1], B. W. Melville[2], and R. Ettema[3]

[1]Civil & Environmental Engineering Department, Michigan Tech University, Houghton, MI 49931; PH: (906) 487-1981; FAX: (906) 487-2943; email: barkdoll@mtu.edu
[2]Civil & Environmental Engineering Department, University of Auckland, New Zealand; PH: 64 9 373-7599 x88165; FAX: (64) (9) 3737462 ; email: b.Melville@auckland.ac.nz
[3] Civil & Environmental Engineering Department, University of Iowa; PH: 319-335-5224; FAX: 319-335-5660; email: robert-ettema@uiowa.edu

INTRODUCTION

Bridge scour, both at piers and abutments, is one of the leading causes of bridge failure. Scour can lead to the undermining of pier and abutments that, when below the foundation, can lead to the collapse of the structure. Bridge collapse results in costly repairs, disruption of traffic, and possible death of passengers traveling on the bridge when collapse occurs.

Abutments come in various shapes, orientations, and set-back distances, thereby making it difficult to analyze all possible abutment conditions. Abutments can have vertical walls or be of the spill-through variety. The skew angle of the abutment to the waterway can be perpendicular or angled upstream or downstream. In addition, the abutment can encroach out into the waterway, thereby blocking the flow, or be set back from the waterway well onto the floodplain.

The objective of this paper is to review the selection and design of existing bridge abutment countermeasures for older bridges that tend to have vertical walls and be located flush with the main channel banks and be perpendicular to the waterway [1].

SCOUR-INDUCING FLOW PATTERNS

To understand the rationale behind countermeasure design, it is helpful to first review the flow patterns at abutments that cause scour. With reference to Fig. 1, the principle scour-inducing flow patterns are (1) a downward-moving roller caused by impact with the flow striking the leading abutment corner that combines with (2) return flow from the floodplain into the main channel, (3) a secondary vortex following the downward flow mentioned above whose axis as near the bed and parallel to the abutment, (4) increased main-channel velocity due to the contraction caused by the abutment, and (5) a tornado-like wake vortex downstream of the abutment. Shear layer vortices are formed that play a less substantial role in scour as well.

BANK-HARDENING COUNTERMEASURES

Bank-hardening countermeasures are comprised of various hard materials located on the bed and banks in the vicinity of the abutment to increase the ability of the bad or bank to resist scour by the flow. The flow strength is not altered in any significant way. The three methods covered here are riprap, cable-tied blocks, and geobags.

Riprap

Riprap is the most common countermeasure employed and consists of large rocks arranged flush with the bed and banks in several layers of thickness. Failure of riprap beds has been observed due to (1) dislodging of the individual rocks due to excessive stream velocity, (2) dislodging of individual rocks at the edge of the riprap blanket due to the flow undermining and lifting the rocks up and into direct contact with the flow, and (3) sinking of the riprap blanket due to winnowing of the fine bed material up through the rocks where it is carried away by the flow.

Design consists of the specification of the rock size to avoid direct dislodging, riprap blanket thickness, the lateral extent of the blanket to avoid edge failure, the gradation of riprap, and a filter material to avoid winnowing of the fines.

To size the riprap stone the method of [2]:

$$D_{50} = \left(\frac{1.064 U^2 Y^{0.23}}{(S_s - 1) g} \right)^{0.81}$$

where D_{50}=the median riprap size, U=the cross-sectionally averaged water velocity, Y=flow depth, S_s=specific gravity of the riprap material, and g=gravitational constant.

The thickness of the riprap blanket, t=1.5D_{100}, or where D_{100} is the largest size of riprap stone [3]).

The lateral extent of the riprap blanket can be found by

$$W_{\min} = C_1 (d_s - d_b + D_{50})$$

where W_{min}=the minimum riprap blanket extent across the channel, C_1 = 1.68 and 1.19 at the upstream and downstream corners of the riprap layer, respectively, d_s= depth of equilibrium scour, and d_b= the depth of the riprap blanket bottom below the average channel bed level (Fig. 2). d_s can be found for bedform-dominated cases by

$$d_s = C_2 H$$

where H is maximum bed-form height and C_2 = 1.2 and 1.0 for the upstream and downstream corners of the riprap layer, respectively (van Ballegooy et al. 2005). Otherwise, add other scour components to d_s.

The proper gradation of riprap can be found using the criteria of [4] summarized in Table 1.

Table1. Riprap gradation for bridge protection

Stone Size Range	Percentage of Gradation Smaller than
$1.5D_{50}$ to $1.7D_{50}$	100
$1.2D_{50}$ to $1.4D_{50}$	85
$1.0D_{50}$ to $1.1D_{50}$	50
$0.4D_{50}$ to $0.6D_{50}$	15

To design the filter material the pore space should be finer than the natural riverbed material. See [5] and [6] for more details

Cable-tied Blocks

Cable-tied block consist of a series of blocks linked together with cable to hold them together as a coherent mat. Design issues include primarily the block size, lateral extent, and edge treatment.

Block size can be estimated by the following equation:

$$\frac{H_b}{y} = \left[\frac{a_{cb}\rho}{(\rho_{cb} - \rho)(1 - p)}\right] Fr^2$$

in which H_b=the height of the block, y=flow depth, a_{cb} = 0.1, ρ_{cb} is the block density, ρ is the fluid density, and Fr=the Froude Number.

CTB blocks are typically manufactured as a truncated pyramid shape with a square base and top. The spacing between CTB units should be adequate to allow the mattress to have a sufficient degree of flexibility, and that block shape should not inhibit mat flexibility.

Typically, synthetic filters are used beneath CTB mats.

Lateral extent of the cable-tied block mattress can be determined from

$$W = 1.55(d_s - d_b)$$

where W is apron width, d_s is scour depth (= mat settlement depth) at the outer edge of the mat, and d_b is the placement (burial) depth of the mat. See Fig. 3.

To prevent the uplifting of the leading edge blocks the size can be determined by

$$\frac{H_b}{Y} = \frac{158}{(S_{cb} - 1)} Fr^2 \frac{n^2}{Y^{0.33}}$$

where S_{cb} is the specific gravity of the blocks and n is the Manning coefficient. Care needs to be taken to ensure that the leading edge of the mat remains buried.

Geobags

Geobags are bags of pervious material that are filled with a pervious granular material (sand or gravel) that are used as bank hardening elements, thereby possessing enough weight to hold sediment in place, but allowing the flow of water through them to reduce uplifting pressure to reduce the likelihood of uplifting of the bag or winnowing of the fines underneath. The bag material can be a geosynthetic fabric such as the filter layer of riprap discussed above.

Design considerations include sizing, linking of bags, angle of placement and placement extent [7].

Minimum sizing can be determined by that of equivalent riprap as mentioned above. The individual bags should be tied together to help them function as a single mattress thereby allowing flexibility to conform to the irregular bed shape. The geobag mattress should have a maximum slope of 2H:1V with a toe extending a downward length equal to at least 2 bags into the riverbed.

FLOW-ALTERING COUNTERMEASURES

Three new flow-altering countermeasures are described next that do not attempt to increase the bank's ability to resist erosion, but to reduce the flow's energy to scour. These methods are (1) parallel walls, (2) spur dikes, and (3) abutment collars.

Parallel Wall Countermeasure

The design parameters for the parallel wall scour countermeasure are the wall length, width and protrusion into the main channel [8]. Each of these is discussed next. See Fig. 4 for a sketch of the design dimensions.

The length of the parallel wall should be $0.5_a L$, where L_a is the abutment length (perpendicular to flow direction). The maximum steepness of the side wall angle should be the angle of repose for the rock employed. The height of the wall should be sufficient to have the top of the wall be above the top of the lowest portion of the bridge decking. The wall width should be wide enough to accommodate the wall height and the sidewall angle of the rock wall. The bottom of the rock wall should be even with the abutment such that no part of the wall should protrude out into the main channel. The wall should be parallel to the river banks. Thus, if the river section is straight, then the wall should be straight as well, but if the river section is curved, then the wall should also be curved and parallel to the river banks. See Fig. 5 for a sketch of a curved wall. The thickness of the apron should be at least two times the diameter of the size of rocks used for the wall. The width of the apron should be at least 4 times the wall height. The apron should extend the full length of the wall. At the upstream end, the apron should join the floodplain.

Spur Dike Countermeasure

The design parameters for spur dikes as abutment scour countermeasures are dike length, spacing, and width [9]. See Fig. 6 for a definition sketch.

There should be at least three dikes used: two shorter dikes at the upstream and downstream corners of the abutment and a longer dike located upstream of the abutment. For wide abutments (parallel to the flow) there may need to be additional short dikes as well (see discussion on dike spacing below).

The top length of the dike (perpendicular to flow direction) should be equal to the abutment length, L_a, (perpendicular to the flow). For the shorter dikes this length extends from the abutment face out into the main channel. For the longer dike upstream of the abutment, the length is longer than L_a. The dike should extend the same distance into the river that the shorter dikes do and extend back onto the floodplain a distance sufficiently far to not affect the river flow. The bottom dike length is determined by the angle of the wall face. Care should be taken, however, on narrower rivers not to block too much of the river width with the dikes. Therefore, the dikes should not extend further out into the main channel than one-fourth of the river width.

Dikes should be located at the abutment corners and extending out into the main channel. Since dike spacing should be less than the abutment length, L_a, an intermediate dike may be needed depending if the abutment width (parallel to flow direction) is longer then the abutment length, L_a.

The maximum steepness of the side wall angle should be the angle of repose for the rock employed.

Dike width is determined by the dike face angle, which should be less than the angle of repose of the rock used to construct the dike.

Abutment Collar Countermeasure

The design parameters for abutment collars are the elevation, upstream, downstream, and lateral extents [9] and [10]. See Fig. 7 for a definition sketch.

The collar should be located at an elevation of $0.08y_m$ below the mean main channel bed level, where y_m is the main channel bankful flow depth (Fig. 7).

The minimum collar width should be $0.23L_a$, where L_a is the abutment length perpendicular to the flow direction (Fig. 7).

The collar should extend to a location $0.6L_a$ upstream from the upstream abutment corner, where L is the abutment length perpendicular to the flow direction (Fig. 7).

The collar should extend at least as far downstream as the downstream end of the abutment.

ACKNOWLEDGMENTS

This work was performed under the National Academy of Sciences, Transportation Research Board, National Cooperative, Highway Research Project # 24-18A.

REFERENCES

[1] Barkdoll, B. D. Melville, B. W. and Ettema, R. 2006, A Review of Bridge Abutment Scour Countermeasures, *Proceedings of the 2006 World Environmental and Water Resources Congress, May 21-25, 2006, Omaha, Nebraska.*

[2] Pagan-Ortiz, J.E. (1991) "Stability Of Rock Riprap For Protection At The Toe Of Abutments Located At The Flood Plain," *Report No. FHWA-Rd-91-057*, Federal Highway Administration, U.S. Department Of Transportation, Washington, D.C., U.S.A.,125 pp.

[3] Lagasse, P. F., Zevenbergen, L. W., Schall, J. D., Clopper, P. E. (2001). Bridge Scour and Stream Instability Countermeasures. Publication No. FHWA NHI 01-003, Hydraulic Engineering Circular No. 23, U. S. Department of Transportation, Federal Highway Administration. Pages 2.7, 2.9, 4.6, 6.16 - 6.18, Design Guidelines 1, 9, 10.

[4] Brown and Clyde 1989 "Design of riprap revetment," Hydraulic Engineering Circular 11 (HEC-11), Report No. FHWA-IP-89-016, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., U.S.A.

[5] Melville, B., van Ballegooy, S., Coleman, S., and Barkdoll, B. (2006) Countermeasure Toe Protection at Spill-Through Abutments, ASCE *J. Hydraulic Engineering* Vol. 132, No. 3, March 2006, pp. 235-245

[6] Melville, B., van Ballegooy, S., Coleman, S., and Barkdoll, B. (2005). "Scour Countermeasures for Wing-wall Abutments", ASCE *J. Hydraulic Engineering*, Vol. 132, No. 6, June 2006, pp. 563-574.

[7] Korkut,R., Martinez, E.J., Ettema, R., and Brian Barkdoll (2006) "Geobag Performance As Scour Countermeasure For Wingwall Abutments." ASCE J. Hydraulic Engineering, in press.

[8] Li, H., Barkdoll, B.D., Kuhnle, R., and Alonso, C. (2006) "Parallel Walls as an Abutment Scour Countermeasure" ASCE *J. Hydraulic Engineering*, Vol. 132, No. 5, May 2006, pp. 510-520.

[9] Li, H., Kuhnle, R., and Barkdoll, B.D. (2006) "Spur Dikes and Collars as Abutment Scour Countermeasures: An Experimental Study" ASCE J. Hydraulic Engineering, accepted.

[10] Hua Li, Brian Barkdoll, and Roger Kuhnle, 2005, Bridge Abutment Collar as a Scour Countermeasure, Proceedings of the 2005 World Water and Environmental Resources Congress, May 15-19, 2005, Anchorage, Alaska.

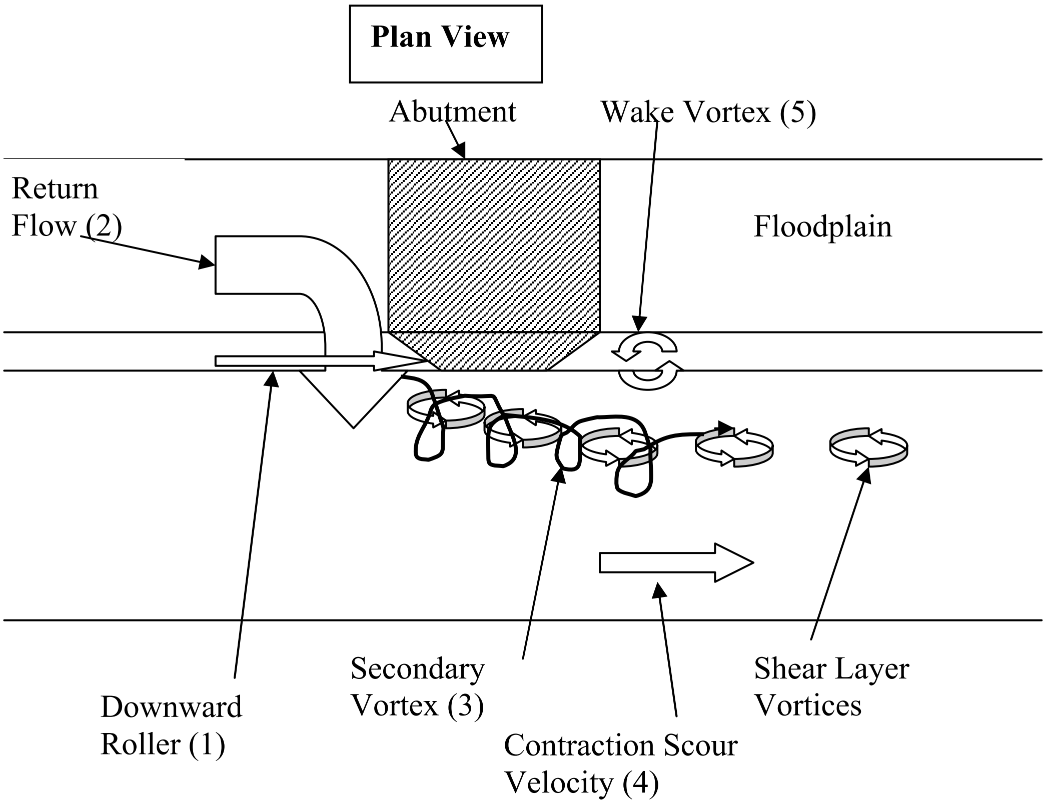


Fig. 1. Scour inducing flow patterns.

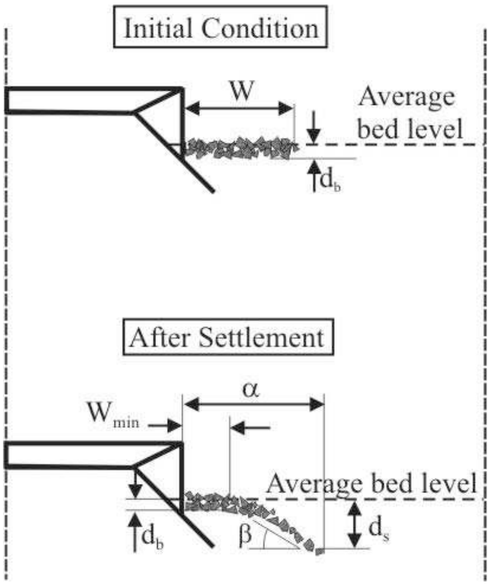


Fig. 2. Riprap apron settlement

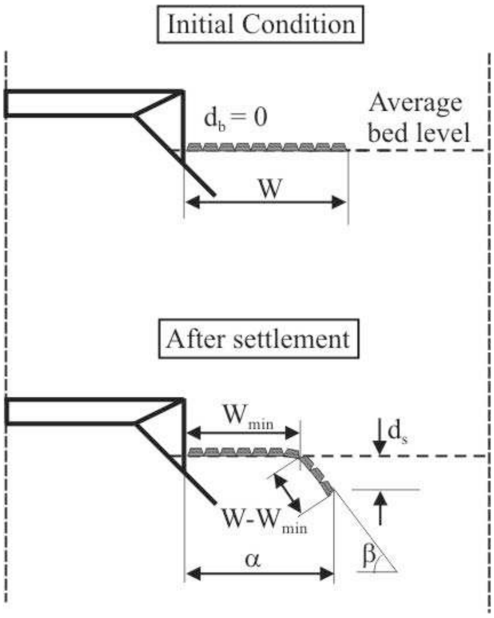
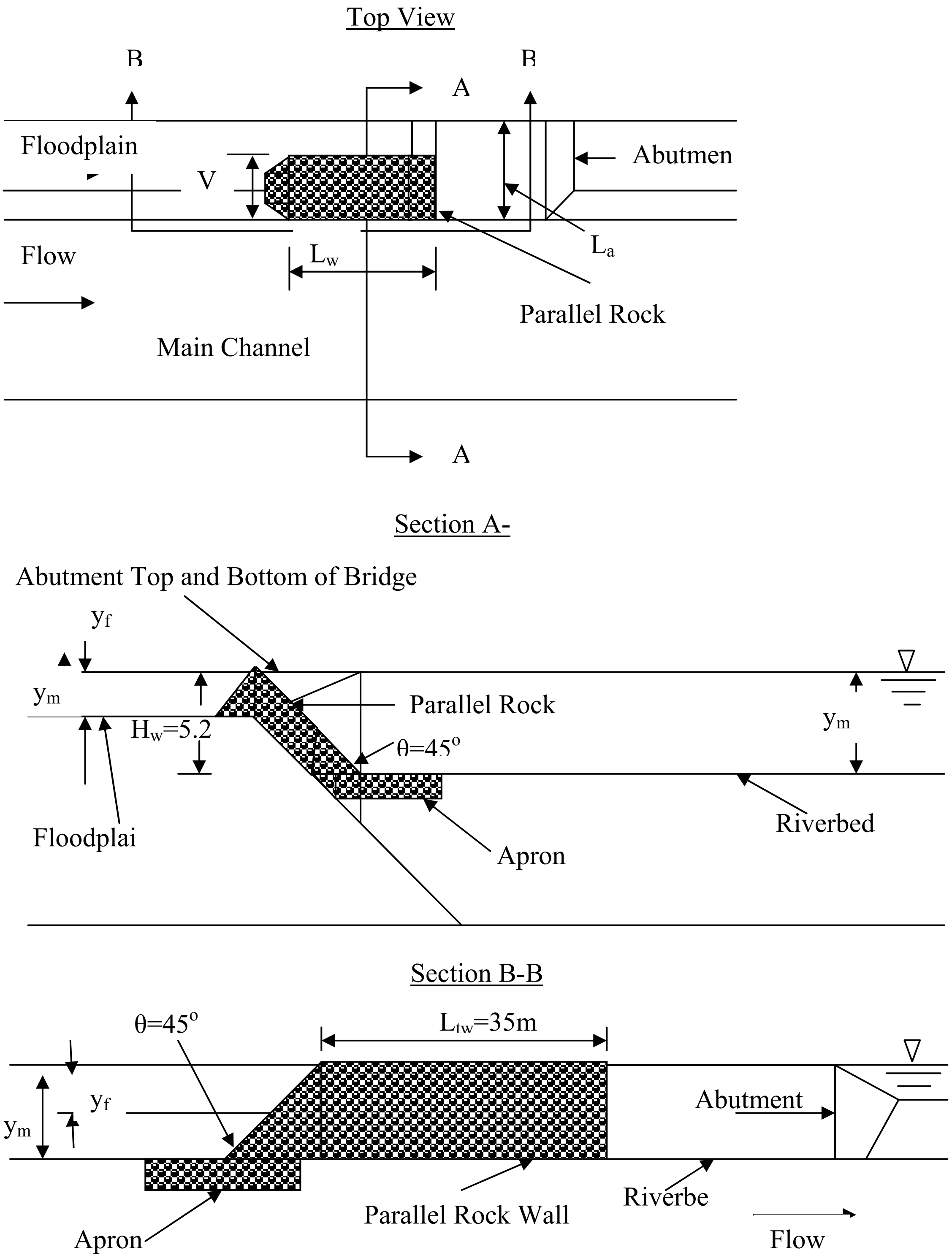


Fig. 3. CTB apron settlement


Top View

Section A-

Section B-B

Fig. 4. Design dimensions for parallel rock wall.

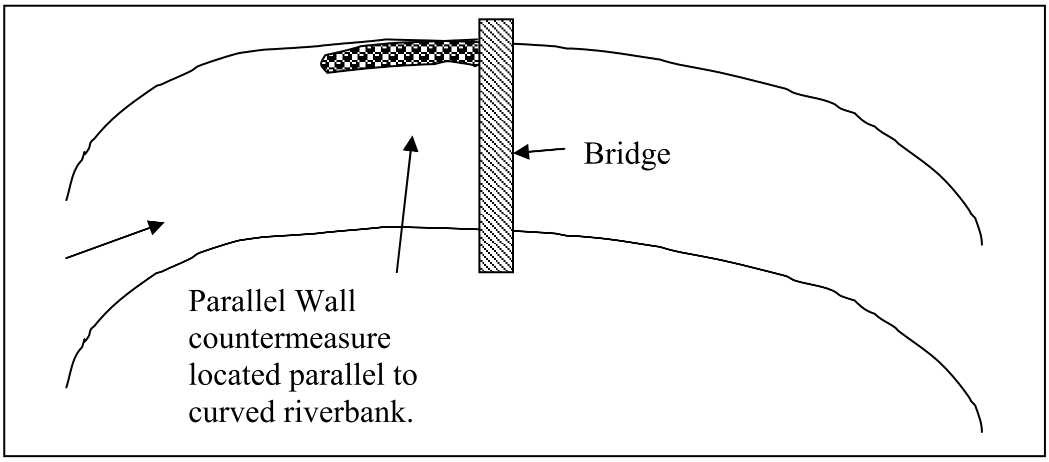


Fig. 5. Parallel Wall countermeasure located on river bend. Wall kept parallel to riverbank.

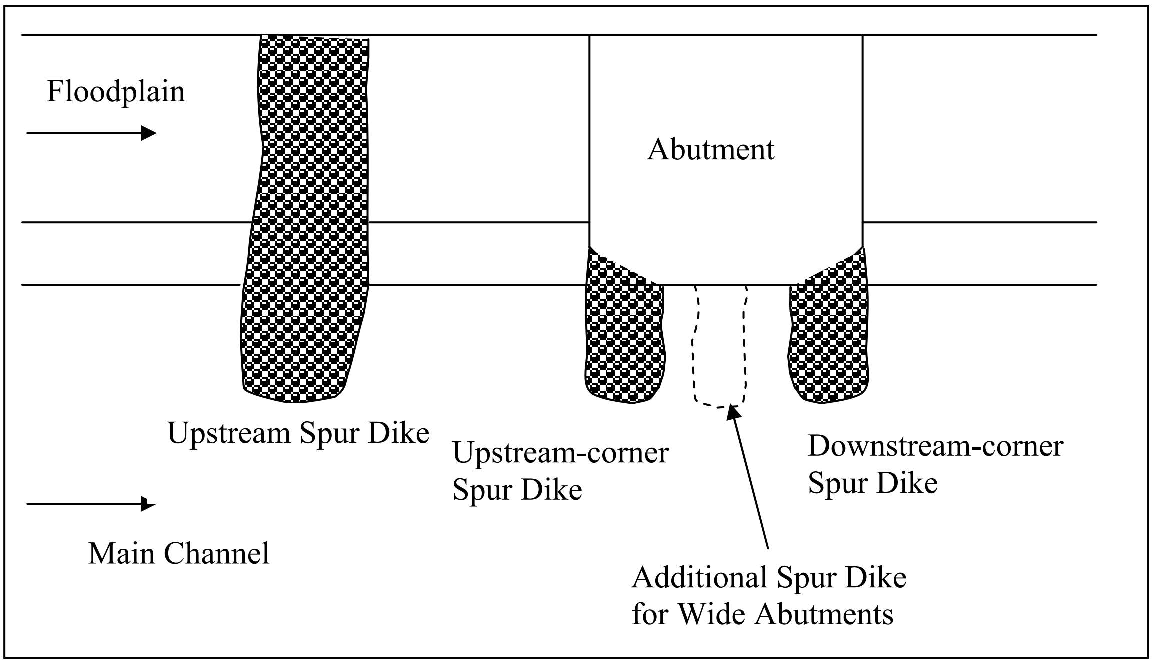


Fig. 6. Definition sketch for spur dike countermeasure design

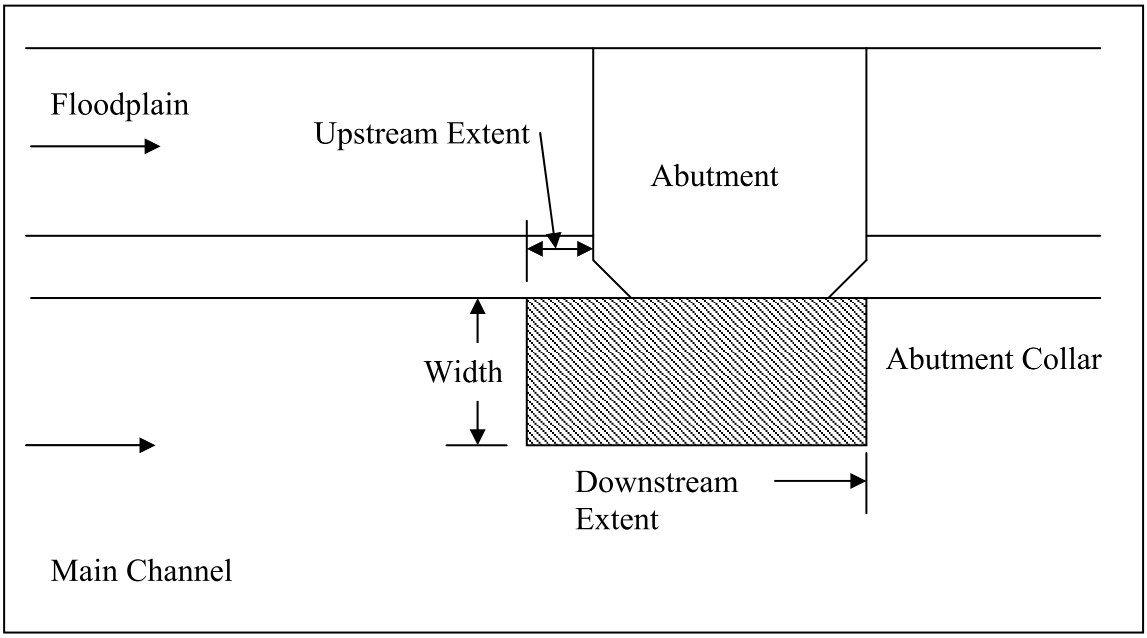


Fig. 7. Definition sketch of abutment collar countermeasure.