Use of Spurs and Guidebanks for Highway Crossings

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ABSTRACT

Bridge engineers often need to protect bridge abutments from scour; maintain, stabilize, and improve the alignment of a stream approaching a bridge crossing; protect the bank of a stream along a highway; maintain a stream in a given location; maintain or decrease the width of a stream; protect highway approaches to a bridge crossing across flood plains; and improve the hydraulic characteristics of the bridge opening. Spurs and guidebanks are structures river engineers use to fill this need. Other names for spurs are dikes, jetties, spur dikes, retards, and dyke fields. Spurs and guidebanks are described and design recommendations based on a literature review are given.

A spur is a structure or embankment projected into a stream from the bank at some angle and for a short distance to deflect flowing water away from critical zones, to prevent erosion of the bank, and to establish a more desirable channel alignment or width. By deflecting the current from the bank and causing sediment deposits behind them, a spur or a series of spurs may protect the stream bank more effectively and at less cost than riprapping the bank. Also, by moving the location of any scour away from the bank, failure of the riprap on the spur can often be repaired before damage is done to structures along and across the rivers. Conversely, failure of riprap on the bank may immediately endanger structures.

Spurs are used to protect highway embankments that form the approaches to a bridge crossing. Often these highway embankments cut off the overbank flood flows causing these flows to run parallel to the embankment enroute to the bridge opening. Spurs constructed perpendicular to the highway embankment keep the potentially erosive current away from the embankment thus protecting it. Spurs as used in this report encompass the terms dikes, jetties, groins, and spur dikes that are also used to describe these structures.

Spurs are also used to channelize a wide, poorly defined stream into a well-defined channel that neither aggrades nor degrades, thus maintaining its location from year to year. Spurs on streams with suspended sediment discharge can cause deposition to establish and maintain the new alignment. The use of spurs in this instance may decrease the length necessary for the bridge opening and may make a more suitable, stable channel approach to the bridge. This decreases the cost of the bridge structure.

Guidebanks are a type of spur used at waterway crossings to straighten the flow, increase the discharge through the bridge opening, and to move the location of deep scour away from the abutments of the crossing.

When using spurs and guidebanks, the bridge engineer must understand the characteristics of the river. Some of these river characteristics are river form (e.g., meander or braided); sediment discharge (e.g., quantity, size distribution, and mode of movement--suspended or contact); magnitude and time distribution of floods; size of the bed and bank material; and geometry of the river cross sections. Except for a short description of river form, river characteristics are beyond the scope of this paper. The reader is referred to the literature review for further information (1-12).

STREAM FORM

For spurs used to protect embankments, improve river alignment, and so forth, or for a highway crossing or encroachment, knowledge of the plan and profile of a stream is useful in understanding stream morphology. River forms (i.e., plan view appearance of streams) are many and varied (2,3) and are the result of many interacting variables. Small changes in a variable can change the form and profile of a river, adversely affecting a highway crossing or encroachment. Conversely the highway crossing or encroachment can inadvertently change river form or profile and affect adversely the river environment.

All classifications of river form are subdivisions of two major river forms--braided and meandering. A braided stream consists of multiple and interlacing channels [see Figure 1 (9)]. In general, a braided channel has a steeper slope, a large bed-material load in comparison with its suspended load, and relatively small amounts of silts and clay in the bed and banks. Also a braided stream is difficult to work with because it is unstable, changes the alignment of its channels rapidly, carries large quantities of sediment, is wide and shallow even at flood flow, and is unpredictable. The potential width of a braided river may be much greater than casual observation indicates. Under certain geologic conditions, however, some braided streams may be stable enough for stable islands to form and for the channels that form the braids to shift relatively slowly or only when large floods occur. The shifting of the channels that form the braids of a braided river can change the angle of attack of the flow on bridge piers, abutments, and the stream banks. At high flow the flow often will have zero angle of attack but at low flow, because of channel shifts, have large angles of attack. If river spurs and guidebanks are carefully used, they can improve flow condition at a crossing or encroachment.

A meandering channel consists of alternating S-shaped bends. This is a static definition; in reality the meandering river is subjected to both lateral and longitudinal movement caused by the formation and destruction of bends. Even straight channels have a meandering current (Figure 1) that tends to develop alternate bars that may ultimately lead to the development of a meandering channel. The meandering channel is defined by E.W. Lane (4) as one in which channel alignment consists principally of pronounced bends that have not been shaped predominantly by the varying nature of the terrain through which the channel passes. Mathes (8) stated, "meander is here applied to any letter-S channel pattern, fashioned in alluvial materials, which is free to shift its location and adjust its shape as part of a migratory movement of the channel as a whole down the valley."

A meandering river consists of pools and crossings. The thalweg, or main current of the channel, flows from the pool through the crossing to the next pool forming the typical S-curve. In the pools, the

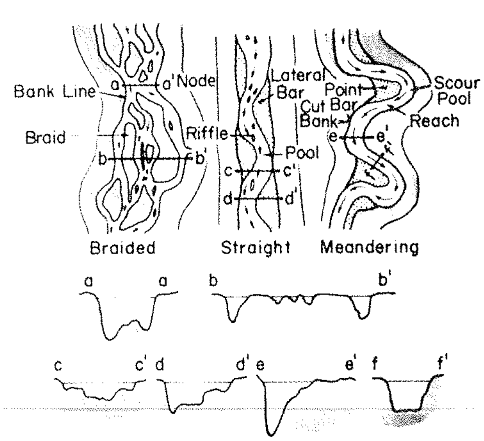


FIGURE 1 River channel patterns (9).

channel cross section is somewhat triangular, and point bars form on the inside of the bends (Figure 1). In the crossings, the channel cross section is more rectangular and depths are shallower. At low flows the local slope is steeper and velocities are higher in the crossing than in the pool. At low stages the thalweg is located close to the outside of the bed. At higher stages the thalweg tends to straighten. More specifically the thalweg to some degree moves away from the outside of the bend encroaching on the point bar. In the extreme case, chute channels develop across the point bar during large flood flows.

Bridges stabilize or fix the river cross section at a given time and place, but the nature of a meandering or braided river is to shift its channel. Bends of a meandering stream move downstream. In some rivers, this movement is slow; in others it is relatively rapid, depending on the magnitude of flow and the nature of the bed and bank material. This movement changes the angle of attack of the flow on the piers and abutments, and can bring the flow against the approach embankment (if one exists) and cut behind the abutments.

SPUR DESIGN CONSIDERATIONS

The physical quantities to consider in designing spurs are form, angle (θ) to the bank, length (L) of spurs, spacing (S) between spurs, materials, spur crest elevation, cross section, and scour. Figure 2 shows a definition sketch for spurs and guidebanks. These design considerations will be described in the following sections.

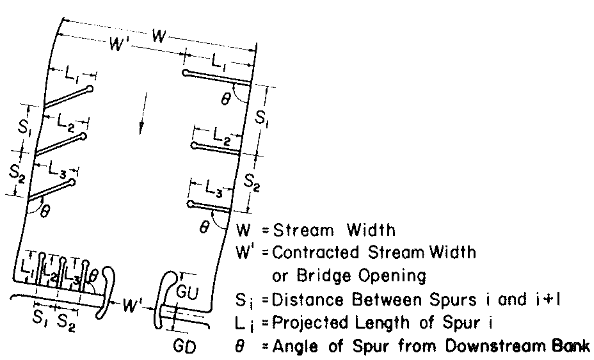


FIGURE 2 Definition sketch for spurs and guidebanks.

Types of Spurs

Types of spurs are shown in Figure 3. The straight spur (13-16) is set at some angle (θ) to the bank and normally has a round nose to provide more volume and area for scour protection at the outer end. The T-head spur (13,14,16-18) is a straight spur with a rectangular guide vane set at the outer ends. The angle (θ) to the bank is normally 90 degrees. The angle (α) varies and is set by the degree of deflection of the current that is desired. However, α that would set the T-head at angles to the flow larger than 10 degrees are not recommended. The length (a) varies, and no particular length was recommended in the literature reviewed.

L-head and wing or trails spurs (14,16,18-21) provide more protection to the bank. The length (a) should close 45 to 65 percent of the gap between spurs (19,21). As with T-heads the angle α should be set so that the L-head has an angle 10 degrees or less to the stream lines of the flow. L-heads are designed to provide more deposition between spurs and decrease scour around their ends and provide greater protection to the banks. This is rather obvious when their recommended length closes 45 to 65 percent of the opening between spurs. This small opening increases their costs but also makes them more effective in channelization. The straight spur is more cost-effective. Hockey shape and inverted hockey shape (14,19) (also called J-shape and inverted L) do not appear to have any advantage over straight or T-shape, as their scour holes are more extensive in area than the T-shape (19).

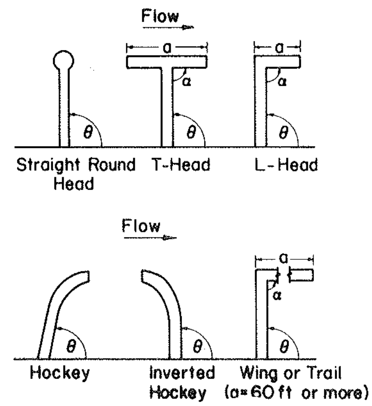


FIGURE 3 Forms of spurs.

The straight spur with a round nose should be used for most bank protection. To protect concave banks at bends, short (30 to 50 ft) straight spurs are effective if the bank between is armored or naturally resists erosion. To channelize and guide the flow, T-head spurs with the head set at a small α to the flow are recommended. They should be less expensive if the head of the T is made relatively long as the spacing can be increased, decreasing the number of shanks. L-head spurs may also be used.

Angle of Spur to the Bank

The angle (θ) of the spur to the bank (internal angle from downstream bank to spur, Figure 2) given

in the literature ranges from 30 to 120 degrees (15-17, 22-24). Spurs with angles larger than 90 degrees are termed repelling spurs and those with angles less than 90 degrees are termed attracting spurs (14,17). There is also an example of a downstream pointing spur that caused bank failure (17). Mamak (23) and Neill (15) state that the best results (deflecting flow and trapping load) are obtained with spurs inclined upstream (θ from 100 to 110 degrees). The angle for T-head spurs is normally 90 degrees and deflection of the current is provided by the angle (α) of the head to the shank. The study by Franco (20) where angles of 60, 90, and 120 degrees were studied showed that for channelization to improve navigation, the normal or downstream angled spurs performed best. But the downstream angled spurs "produced a greater tendency for scouring at their bank end than dikes (spurs) angled upstream."

In general a spur at 90 degrees to the bank is the most economical for bank protection. For channeling or directing, flow angles of 100 to 110 degrees may be more effective. There does not appear to be a significant advantage to streamlining angling a spur downstream. However, the upstream spur in a series might be angled downstream to decrease the scour depth and move the scour hole to a preferred location.

Length of Spur

The length of a spur depends on its location (e.g., straight reach, concave bank of bend, along embankments), amount of contraction of stream width, economics, and purpose of the spur. The length is also closely related to the spacing because spacing is expressed as some multiplier of the projected length. If spurs are too short, the spacing is close and construction is expensive. If they are too long they may contract the flow too much, or the spacing may be so large that a meander loop may form between two spurs. The spurs in the literature reviewed ranged from 60 ft to hundreds of feet long (8,22,24, 25) and no rules were given.

On the Missouri River spurs were used to change a braided shallow stream to a single channel consisting of gentle curves. A fixed width and depth of channel was desired and spurs long enough to establish this width and depth were built. In some cases, spurs 1,000 ft long or more were built. For other streams where only a small shift in channel is required or a bank is to be protected, short spurs (50 ft or less) are built Neill (15) states

> [T]he length of bank protected by each spur appears to be at least twice its projected length perpendicular to the current...whether to choose fewer long spurs or a greater number of short ones depends upon their disturbing effects on the opposite bank and the channel upstream and downstream. For earthwork the longest spur that will not produce excessive erosion and disturbance should be used, since the major cost of this type is in the slope revetment.... In lieu of a series of short spurs, consideration should be given to...riprapping the bank.

For channel control, the length depends on the desired flow and channel considerations. The maximum permissible length can be established by determining the optimum channel width for the bankfull discharge. Optimum channel width is determined by scour, sediment transport, minimum flow disturbance, and maximum allowable velocity.

For protecting banks of straight reaches, long radius bends, and braided channels, the minimum length is 50 ft and the maximum length should be less than 10 to 15 percent of bankfull channel width (W). Maximum length can be greater than 15 percent of W but only after analyzing the effect of this more severe constriction on the flow and the channel. The 50 ft length appears to be the most economical minimum length. With spurs shorter than 50 ft, it is probably cheaper to riprap the bank. With more information, such as costs of spurs versus cost of riprapping the bank, a more realistic length can be determined.

The maximum length is not only limited by stream contraction and economics, but also by spacing. If spur spacing (S) is limited by the meander wave length, it is not economical to establish spur lengths longer than 1/6 to 1/2 S to protect banks.

Number of Spurs

The number of spurs to protect stream banks or to contract the stream should not be less than three. For protection of embankments across the stream one or two spurs may be sufficient.

Spacing Between Spurs

Spacing (S) between spurs is primarily related to the length of the spur, although the velocity of flow, angle of flow streamlines with the spurs, curvature of the bank, and purpose of the spur also affect spur spacing. The literature provides considerable information on spacing distance between spurs in feet or as a function of spur length (9,14, 15-17,19,20,21,23,24,26-29). Actual distances range from 200 to 4,000 ft. The recommended spacing (S) is from 1.5 to 6 L_i where L_i is the upstream projected spur length into the flow, Figure 2. The spacing is, in general, a function of the length of the next upstream spur. Spacing distance (S_i) equal to 1.5 to 2 L is recommended to obtain a well-defined deeper channel for navigation and flood control. If these spacings are used, dredging to keep a deep channel is decreased or eliminated. For protecting banks longer spacings are used (S_i = 2 to 6 L_i). With T-head spurs, the recommended S_i is from 3 to 4 L_i for navigation channels. A 1918 report on practice (24) gives S as a function of channel width. In this case S ranges from 0.75 to 1 W.

To base spacing on length of spur is logical because flume and wind tunnel studies have shown that the separation zone downstream of a vertical barrier in the flow ranges from 7 to 11 times the barrier height. The distance between spurs (S) to protect the banks of straight reaches, long radius bends, or braided channels from erosion may be 3 to 4 times the upstream spur length. To obtain a well-defined channel the spacings should be 1.5 to 2 times the upstream spur length. However, the spacing should not be longer than 0.5 times the meander wave length of the stream.

If spurs are placed on the concave side of bends, spacing may be 4 to 6 spur lengths. Their use here is to move the high velocity flow away from the bank. The spurs must be short (20 to 30 ft) to be effective and not disrupt the flow around the bend. In addition the bank may need riprap, but the spur, by decreasing the velocity, will decrease the size of riprap needed. Spurs placed on embankments across streams may be 6 to 10 times spur length or greater if the velocity along the embankments is low. If the velocity is high the spacing should be from 4 to 6 L.

Elevation of Spur

Height recommendations depend on the purpose of the spur, the amount of contraction of the flow, the magnitude and importance of the overbank flow, and possible ice problems (21,24,27-29). Related to the elevation of the spur is whether it is level, slopes up from a low point on the streamward end to the bank, or is set at the same elevation or stepped up or stepped down in elevation going from the upsteam spur to the downstream spur. In stepped down fields the spurs decrease in elevation in the downstream direction. The sloping crest spur gives a gradually increasing flow area as stage increases. This type of crest reduces high velocities for the higher stages, helps force the flow into its low water alignment more effectively, and does not hold the flow concentrated at one location over a large change in stage. For these reasons, a sloping crest is often preferred (19).

Laboratory studies by the U.S. Army Corps of Engineers (20) indicated that for navigation purposes the best spur system has level individual crests but each downstream spur is at a lower elevation. However, sloping-crest spurs can be designed to be as effective as level-crest spurs. To control the navigation channel, level-crest spurs should be placed normal to the flow or angled downstream, whereas, sloping-crest spurs should be normal or angled upstream.

The elevation of the crests on the lower Mississippi is from 4 to 15 ft above low water elevation (21,24,29). On the Columbia River elevations are from 1 ft below bank level to one-half flood stage elevation (28). These elevations appear adequate to maintain a navigable channel in a meandering river system. When spurs are set at elevations where they are overtopped frequently, the top and downstream slope of the shank have to be riprapped, which increases their cost.

The L-headed spur may be constructed with the head at a lower elevation than the stem. Fenwick (19) states that "it was found...that little benefit was derived from building the L-head above the water surface." This makes them a little less expensive. He also states "L-heads are expensive so that additional testing and experience are needed to show whether their merits are sufficient to recommend their general use in connection with channel contraction."

On braided channels or where side channels are cut off by using spurs, their elevations are set at bankfull stage. Also, when spurs are used for protecting banks their elevation is bankfull stage or slightly higher to prevent the flow from scouring the bank. In these cases the crest may be sloping to increase flow area, particularly at the large discharges.

With aufeis the elevation of the spurs should be higher than the expected elevation of the ice. Otherwise the ice can build up and cause the stream to flow over the top of the spur. The spurs would no longer confine the flow to the channel, and during the spring breakup the water could cut a new channel through the ice. If the spurs were lower than the aufeis elevation, the new channel could be on the flood plain behind the spurs or on top of them. In the first instance the spurs would no longer be effective in maintaining a channel, and in the second the spurs would need riprap on the crown and on both upstream and downstream sides. With aufeis the spur crest could be level or sloping depending on aufeis elevation and bank height. If the outer or streamward end were above the aufeis, the crest could be level or sloping to the bank.

Construction Materials

Materials used to construct spurs may be rock or earth banks covered with rock (9,21,23,29,30,32); timber, steel, or concrete piles (9,18,20-22,24,29-31); trees (30); sand bags (30); automobile bodies (30); brownlow weeds (18); brush (15,23,32); Kelner steel jacks; and so forth. They may be pervious or impervious (18,20,21,25,29,30,31,33). Permeability of spurs is a relative term in that impervious spurs, because of cost, are not made watertight. A study on the Apalachicola River (34) indicated that stone spurs were more effective than pile spurs in river control for navigation. Typical details of the spurs are shown in Figures 4-7.

The size of riprap for spurs of rock can be determined by estimating the velocity of flow along, across, and around the end of the spur. Several methods may be used to determine the appropriate size of stone to resist this velocity (9,28,33,34-42).

Cross Section (Crest Width and Slope)

Typical cross sections of pile and stone spurs are given in Figures 4 and 5. Data on cross sections may be found in numerous publications (17,18,20,21,23,24,28-32,34). Crest widths range from 3 to 20 ft and side slopes from 1:1.15 to 1:5. The top width of rock or rock-covered earth spurs is often controlled by the equipment placing them. A 3-ft width is a minimum and larger widths are used to facilitate hauling and placing. Winkley (21) states that on the lower Mississippi River crown width for stone placed by trucks is from 14 to 20 ft and a minimum 5-ft crown is used for stone placed by barges. Side slopes are slightly less than the angle of repose of the material but can be determined by the method described by Stevens and Simons (39).

Scour

Scour may be the result of constricted flow caused by a bridge or spurs used to channelize the flow or by local acceleration of the flow going around the spur or abutment. The former is called general scour and the latter local scour. Also, a river reach may be subjected to a long-term degradation or aggradation of the bed elevation. This long-term degradation or aggradation at a bridge crossing or

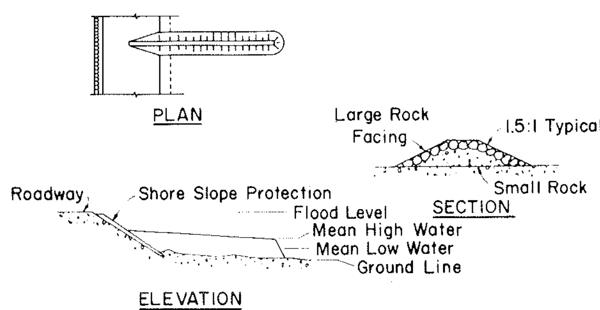


FIGURE 4 Typical stone or earth spur.

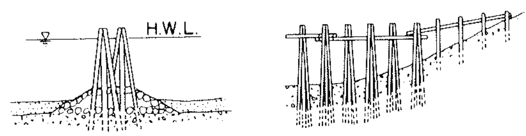


FIGURE 5 Timber pile spur.

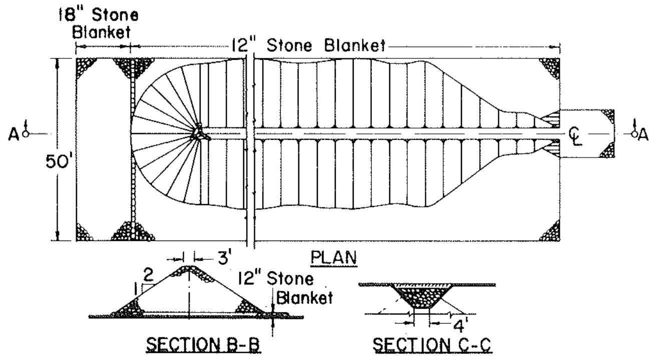


FIGURE 6 Typical stone spur (34).

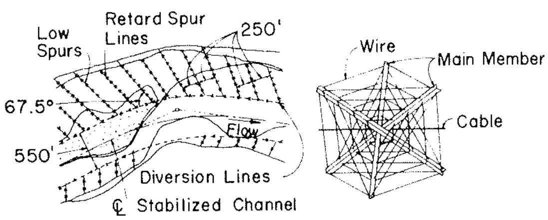


FIGURE 7 Typical spur field layout using Kelner jacks.

highway encroachment must be anticipated by studying the morphology of the river and its morphological changes over time. Otherwise foundation depths of piers, abutments, and spurs may be inadequate if degradation occurs.

General scour at contractions occurs because as the flow area becomes smaller than the normal stream, the average velocity and bed shear stress increase; hence stream power increases locally at the contraction and more bed material is transported through the contracted section than is transported into the section. As the bed level is lowered, the velocity decreases, shear stress decreases, and equilibrium is restored when the transport rate of sediment through the contracted section is equal to the incoming rate.

Laursen (5) developed Equation 1 for general scour at a contraction, where, in addition to channel flow, there is overbank flow into the contracted channel

$$y_2/y_1 = (Q_t^{6/7}/Q_c)[(W_1/W_2)^{6(2+f)/7(3+f)}][(n_2/n_1)^{6f/7(3+f)}] \quad (1)$$

where y_2 is the depth of the constriction and y_1 is the normal upstream (uncontracted) depth, Q_c is the approach channel flow rate and Q_t is the contracted channel flow rate, which is greater than the approach channel flow by the amount of flow on the floodplain. The variable n is the Manning roughness coefficient, W is the channel width, and the exponent f is given below.

V_{*c}/ω	f
<0.5	0.25
1	1
>2	2.25

Here V_{*c} is the shear velocity, $\sqrt{\tau_o/\rho}$, in the approach channel where τ_o is the shear on the bed, ρ is the water density, and ω is the fall velocity of the bed material. When there is no overbank flow $Q_t = Q_c$. There are other equations for general scour at constructions such as Straub's (43).

Local scour occurs in the bed of the channel around embankments because of the actions of the accelerated flows and vortex systems induced by the obstructions to the flow. Local scour occurs in conjunction with or in the absence of general degradation, aggradation, and scour due to contractions.

The basic mechanism causing local scour is the vortex of fluid resulting from the pileup of water on the upstream edge and subsequent acceleration of flow around the nose of the spur. The action of the vortex is to erode bed materials away from the base region. If the transport rate of sediment away from the local region is greater than the transport rate into the region, a scour hole develops. As depth increases, the strength of the vortex decreases, the transport rate decreases, and equilibrium is reestablished and scouring ceases.

The depth of local scour varies with time because the sediment transported into the scour hole from upstream varies, depending upon the presence or absence of dunes. The time required for dune motion is much longer than the time for local scouring action. Thus, even with steady state conditions the depth of scour is likely to fluctuate with time when there are dunes traveling on the channel bed: the larger the dunes, the more variable the depth of the scour hole. When the crest of a dune reaches the local scour area, the scour hole will fill and the scour depth will be decreased temporarily. When a dune trough approaches, there will be less sediment supply and the scour depth will increase. A mean scour depth between these oscillations is referred to as equilibrium scour depth. It is not uncommon (as determined in laboratory tests) to find maximum depths to be 30 percent greater than equilibrium scour depth. The depth that would be reached if no sediment was transported into the scour hole is the "clear water" scour.

Most of the detailed studies of scour around embankments have been made in laboratories. There are few case studies for scour at field installations. According to the studies of Liu et al. (44), the equilibrium scour depth for local scour is determined by

$$d_s/d_1 = 1.1(L/(d)_1)^{0.4}(F_1)^{0.33} \quad (2)$$

where L is the spur length (measured normal to the wall of a flume), d_1 is upstream depth, d_s is depth of scour measured from mean streambed elevation, and F_1 is the upstream Froude number determined as

$$F_1 = V_1/\sqrt{gd_1} \quad (3)$$

The lateral extent of the scour hole can almost always be determined from the depth of scour and the natural angle of repose of the bed material.

Field data for scour at embankments for various size rivers are scarce, but data collected at rock spurs on the Mississippi indicate that

$$d_s/d_1 = (4F_1)^{0.33} \quad (4)$$

determines the equilibrium scour depth. The data are scarce primarily because equilibrium depths were not measured. Dunes as high as 20 to 30 ft move down the Mississippi and their movement is slow compared with the time required to form local scour holes. Nevertheless, it is believed that these data represent the limit in scale for scour depths compared with laboratory data and provide a basis for credible extrapolation of laboratory studies to field installations.

If $L/d_1 > 25$, then scour depth is independent of L/d_1 and depends only on the Froude number and depth of flow. Accordingly, it is recommended that Equation 2 be applied for spurs with $0 < L/d_1 < 25$ and Equation 4 be used for $L/D_1 > 25$. In applying Equation 2 the spur length L is measured from the high water line at the valley bank perpendicular to the end of the spur.

It should be recalled that maximum depth of scour is about 30 percent greater than equilibrium scour depth. The lateral extent of scour can be determined from the angle of repose of the material and scour depth. If the spur is angled downstream, the depth of scour will be reduced because of the streamlining effect. Spurs that are angled upstream will have deeper scour holes. The calculated scour depth should be adjusted in accordance with the curve of Figure 8, which is patterned after Ahmad (9,13).

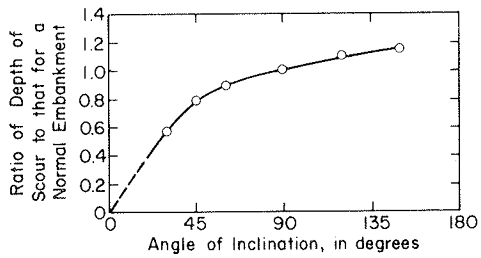


FIGURE 8 Scour reduction due to embankment inclination (9).

Winkley (21) states, "Attempts have been made to predict by analytical means the extent and depth of the scour hole caused by a dike (spur), but there have not yet been a sufficient number of correlations to enable design to be based on such forecasts with confidence. This hole seems to scour to the optimum depth of the river."

The scour depth calculated from the above equations for wide braided rivers with many channels may not be the maximum. The maximum depth of scour at a spur may occur at flows much less than bankfull. For this case, depth of scour should be calculated by determining the depth of flow for the largest expected channel in the braided river. This depth is transposed to the tip of the spur. This depth of scour should be compared with the scour depth calculated from the previous equations and the largest scour depth used.

Scour is controlled by placing a stone blanket around the toe at the outer edge. This blanket must have sufficient rock to armor plate the scour hole after it forms. For scour that occurs when the shank is overtopped, excess stone is put at the downstream toe of the shank to armor plate any scour hole that forms.

It should be noted that most scour prediction equations are for sand bed streams. In gravel bed streams the scour hole will be armored by selective transport of the material forming the bed. Thus, the blanket to control scour on spurs in gravel bed streams need not be as thick or as large as for sand bed streams.

Riprap

The nose of the spur must be riprapped. Also if the shank is set lower than bankfull level, so that overtopping will be frequent, its crest and downstream toe must be riprapped. If the shank is constructed of gravel and cobbles, it may not need to be riprapped to protect it from overtopping by the design flood.

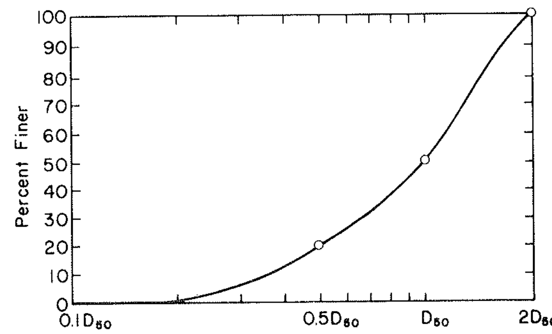


FIGURE 9 Suggested gradation for riprap (5).

Riprap should be placed on the upstream side of the shank if it is made of erodible soil and it is anticipated that flow will occur along it.

Riprap can be designed by using the Bureau of Public Roads (37), U.S. Army Corps of Engineers (36), or Stevens and Simons (9,41) methods. Quantities of riprap should be sufficient to allow for some removal of material. If large-size material is not available, gabions (wire baskets) are used to protect against scour.

Riprap gradation should follow a smooth, size-distribution curve such as that shown in Figure 9. Riprap must be placed on the spur at its outer end to protect it from the high velocity flow around it. This riprap must be carried around the spur nose in both the upstream and downstream direction until the predicted velocities on these side slopes are less than critical for the base material forming the spur. If it is probable that the spur will be overtopped frequently, the top and downstream slope of the spur shank must be riprapped.

The thickness of riprap should be sufficient to accommodate the largest stones in the riprap, and in a well-graded riprap with no voids, that thickness should be adequate. If strong wave action is of concern, however, the thickness should be increased by 50 percent. Filters should be placed under the stone unless the material forming the core of the structure is coarse gravel or of such a mixture that it forms a natural filter. Two types of filters are commonly used: gravel filters and plastic filter cloths.

When gravel filters are used, a layer or blanket of well-graded gravel should be placed over the embankment before placing the riprap. Sizes of gravel in the filter blanket should be from 3/16 in. to an upper limit depending on the gradation of the riprap; maximum sizes would be about 3 to 3.5 in. Thickness of the filter may vary depending on the riprap thickness but should not be less than 6 to 9 in. Filters that are one-half the thickness of the riprap are quite satisfactory. Suggested specifications for gradation are as follows:

$D_{50}(\text{Filter})/D_{50}(\text{Base}) < 40,$

$5 < D_{50}(\text{Filter})/D_{50}(\text{Base}) < 40,$ and

$D_{15}(\text{Filter})/D_{85}(\text{Base}) < 5.$

Plastic filter cloths are being used with considerable success beneath riprap and other revetment materials such as articulated concrete blocks. The cloths are generally in 100-ft long rolls, 12 to 18 ft wide. The plastic is overlapped 8 to 12 in. with pins at 2 to 3 ft intervals along the seam to pre-

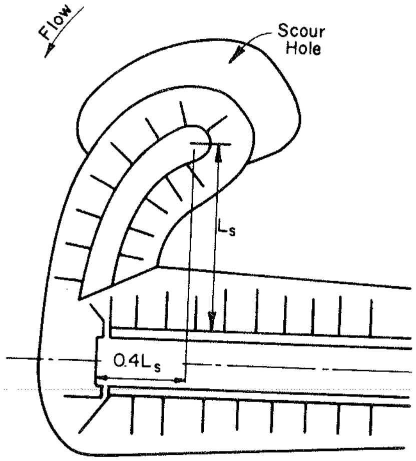


FIGURE 10 Typical guidebank (48).

vent separation. Care must be exercised to prevent damage when placing riprap over the plastic cloth filters. Experiments and results with various cloth filters were reported by Calhoun, Compton, and Strohm (45) in which specific manufacturers and brand names are listed. Stones weighing as much as 3,000 lb have been placed on plastic filter cloths with no apparent damage.

Filters can be placed under water by using steel rods as weights fastened along the edges. Additional intermediate weights assist in sinking the cloth in place. The durability of filter cloths has not yet been established because they have been used only since about 1967. However, inspections of test installations indicate little or no deterioration in the few years that have elapsed.

DESIGN CONSIDERATIONS FOR GUIDEBANKS

Guidebanks have been used in many parts of the world on both sand bed and gravel streams to guide the flow of water through a bridge opening and to move the scour away from the abutments (1,9,15,17,46-48). Guidebanks are placed at the upstream ends of the bridge abutments to guide the stream through the bridge opening. In some situations they are also placed on the downstream side (see Figure 1). Flow disturbances, such as eddies and cross flow, will be eliminated by properly constructed guidebanks and the waterway under the bridge will be more efficient. They are also used to protect highway approach embankments and to reduce or eliminate local scour at abutments and adjacent piers. The effectiveness of spur dikes is a function of river geometry, quantity of flow on the floodplain, and size of bridge opening. A typical guidebank is shown in Figure 10.

The recommended shape of a spur dike is a quarter ellipse with a major to minor axis ratio of 2.5. The major axis should be approximately parallel to the main flow direction. For bridge crossings normal to the river, the major axis would be normal to the highway embankment. However, for skewed crossings, the spur dike should be at an angle to the embankment for the purpose of streamlining the flow through the bridge opening. An illustration of spur dikes for a skewed crossing is shown in Figure 11.

The length of a spur dike, L_S, required depends on quantity of flow on the floodplain, width of bridge opening, and skewness of the highway crossing. Shorter spur dikes may be used where floodplain flow is small or scour potential is minor at piers and embankment ends.

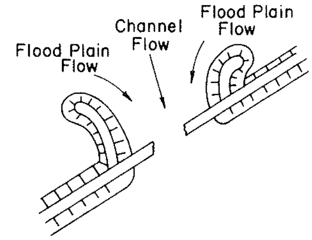


FIGURE 11 Spur dikes at skewed highway crossing.

The principal factors to consider in designing guidebanks are whether they will be convergent or parallel to the opening, plan shape, upstream and downstream length, cross section, crest elevation, scour, and riprap.

Convergent or Parallel

American practice is to give guidebanks an elliptical form convergent to the opening, whereas in Pakistan and India guidebanks are straight and parallel to the opening with a curved section at the upstream and downstream ends. The form of the elliptical guidebank is given in Figure 10, and the design dimensions as determined by Karaki (48) are given in Figure 12. Mahmood (personal communication) stated that parallel guidebanks straighten the flow more effectively than convergent ones. Straight guidebanks probably do a better job of straightening the flow, which could be important if piers are placed in the opening, and of reducing the attack on the abutments. Elliptical guidebanks move the scour hole further upstream and downstream of the bridge opening.

Plan Shape

The plan shape of the guidebanks depends on the type of channel (meander or braided), direction of the streamlines of the flow approaching the opening, and location of the crossing. Neill (15) summarizes the plan shape for guidebanks for bridge openings, Figure 13. In general, the designer should pick the shape that best fits the streamlines of the flow in the channel. If the streamlines are curving, a straight guidebank on the concave side and a curved guidebank on the convex side may be best. For short

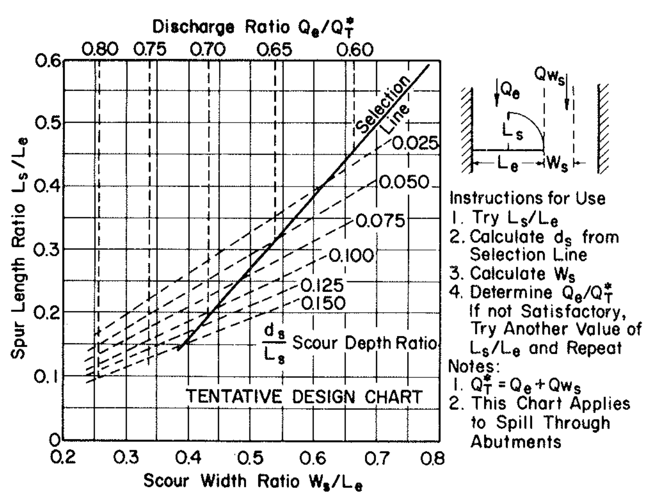
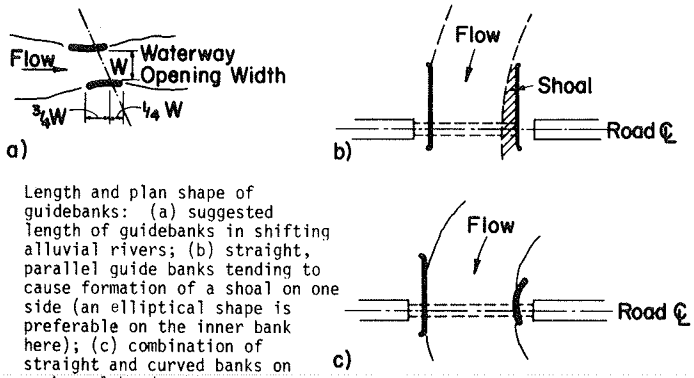


FIGURE 12 Guidebank design procedure (48).



Length and plan shape of guidebanks: (a) suggested length of guidebanks in shifting alluvial rivers; (b) straight, parallel guide banks tending to cause formation of a shoal on one side (an elliptical shape is preferable on the inner bank here); (c) combination of straight and curved banks on a channel bend.

FIGURE 13 Guidebank plan (15).

TABLE 1 Radius of Curvature for the Curved Portion at the Upstream End of Straight Guidebanks

Sand Classification	Probable Maximum Abnormal Scour Below Bed Level (ft)	Radius of Curvature (ft) Fall per Mile of River (in.)[a] 3	6	9	12	18
Very coarse	Under 20	200	250	300	350	400
	Over 20	250	310	375	440	500
Coarse	Under 30	300	360	425	490	550
	Over 30	350	430	510	590	670
Medium	Under 40	400	425	550	625	700
	Over 40	450	550	650	750	850
Fine	Under 50	500	590	675	760	850
	Over 50	600	725	825	925	1,020
Very fine	Under 60	600	700	800	900	1,000
	Over 60	800	900	1,000	1,100	1,200

[a]These are average values; slopes may be much steeper locally.

guidebanks the ellipse of Karaki (48) can be used. The radius of curvature for the curved portion at the upstream end of straight guidebanks is given in Table 1 (17).

Upstream and Downstream Length

The upstream and downstream lengths for straight guidebanks are as follows:

	Reference
GU = 0.75 to 1 W'	2
GD = 0.25 W'	6, 29
GU + GD ≤ 150'	32
GU + GD = W'	24
GU = 1 to 1.1 W'	6
GD = 0.1 to 0.2 W'	6
GU = 1.25 to 1.5 W'	6
GU = 0.75 W'	29

In general, the lengths are given as a function of W', the width of the opening. This width is established by determining the desired opening for the design flow taking into account scour. In determining the opening width, local scour caused by a low flow meandering in too large an opening must be considered.

The diagram in Figure 11 can be used to design and select the length for an elliptical guidebank. It is not necessary that both guidebanks on the upstream side be the same length. For some flow conditions a short curved guidebank on one side and a long straight bank on the other may be the best solution.

Other Factors

The remaining factors to consider in designing guidebanks (cross section, crest elevation, scour, and riprap) are similar to those for spurs with two exceptions.

1. The crest elevation should be 1 ft higher than the elevation of the design flood taking into consideration the effect of the contraction of the flow; this is because the design flow should not overtop the guidebank.
2. For elliptical guidebanks, the depth of scour is given in the design procedure shown in Figure 12. For straight guidebanks the design considerations are the same as for spurs.

CONCLUSIONS

1. Spurs and guidebanks are effective methods of protecting bridge abutments from scour, maintaining and improving the alignment of a stream, stabilizing and maintaining a stream in a given location, and improving the hydraulic characteristics of a bridge opening to increase its flow-passing ability and to decrease scour.
2. Spurs can provide a narrow, more consistent channel for braided channels with zero or small angle of attack of the flow on the pier and abutments; this decreases cost. For a meandering channel, spurs can stabilize a longer reach of river and prevent meander loops from moving down and eroding the abutments or approach embankments.
3. Spurs may decrease the cost of protecting banks by eliminating or decreasing the amount of

riprap needed to protect banks on river crossings or encroachments.

4. Guidebanks provide a more efficent (less headloss) flow of water through a bridge opening. They also decrease scour depth and move the scour energy away from the abutments.

5. In the design of spurs and guidebanks, the following must be considered: stream form, angle of the structure to the bank, shape and form, length, spacing between spurs, construction materials, riprap design, crest elevation, top width and cross section, and scour.

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Publication of this paper sponsored by Committee on Hydrology, Hydraulics and Water Quality.

Design Guidelines for Spur-Type Flow-Control Structures

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ABSTRACT

A study investigating the applicability and design of spur-type flow-control and stream-bank stabilization structures has been conducted to establish design guidelines for the use of spurs. The study was conducted jointly by the Sutron Corporation and the Pennsylvania State University for FHWA. The findings and recommendations are presented, and recommendations for the general application of spur-type flow-control structures are given in relation to the function of the spur, the erosion mechanisms that are countered by spurs, the environmental conditions best suited for the use of spurs, and potential negative impacts produced by spurs. An introduction to the most common types of spurs is given, and design guidelines for establishing spur permeability, the required extent of protection, spur length, spur spacing, spur orientation, and spur height are presented. An example outlining a recommended procedure for establishing the geometric layout of spurs within a spur scheme is presented also.

Spurs are defined as permeable or impermeable linear structures that project into a channel to alter flow direction, induce deposition, or reduce flow velocities along a channel bank. Spurs can be classified as permeable or impermeable; they can be classified further by function as retardance structures, retardance-diverter structures, and diverter structures. Retardance and retardance-diverter structures are permeable; diverter structures are impermeable. Retardance spurs are designed to reduce the flow velocity in the vicinity of the bank as a means of protecting the channel bank. Retardance-diverter structures retard the flow along the channel bank, but they also deflect flow currents away from the bank. Diverter spurs, on the other hand, function by diverting the primary flow currents away from the channel bank. Design guidelines primarily for retardance-diverter and diverter spurs are dealt with in this paper.

In the past, little guidance has been available for the design of spur-type structures. Few design guidelines have been available; those that are available are limited in scope and generally inaccessible to highway design engineers. The design of these structures has been based primarily on the designer's experience and numerous rules of thumb. Although actual field design experience is indispensable when flow-control structures are designed, many highway design engineers have only limited experience in this field, indicating a need for some design guidance. A study was sponsored by FHWA to address this need.

The FHWA study included considerations of the overall applicability of spur-type flow-control and stream-bank stabilization structures, the applicability and attributes of individual spur types, criteria for the selection of a specific spur type, and guidelines for the design of spurs. Guidelines for the actual design of spur systems are covered in