USE OF VANES FOR CONTROL OF SCOUR AT VERTICAL WALL ABUTMENTS

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ABSTRACT: Rock vanes are single-arm structures angled to the flow with a pitch into the streambed such that the tip of the vane is submerged even during low flow. Vanes have primarily been used in recent years for treatment of bank erosion in stream stability projects. These structures roll the water away from the eroding banks, thus limiting erosion of the channel banks. They have proven to be very effective treatments over a range of flow conditions. In this project, the effectiveness of vanes for preventing scour at single-span bridges with vertical wall abutments was evaluated based on laboratory experiments. The vanes were tested in small-scale experiments in a recirculating flume and subjected to a range of flow conditions, including bank full and a number of overbank flows, which were forced to return to the channel at the abutment. The results showed that the vanes were highly effective in moving the scour away from the abutment into the center of the channel under all flow conditions tested. Based on the experimental results, optimum design settings for the vane angle and height, most effective number of vanes, and distance upstream for placement of the first vane were determined.

INTRODUCTION

Mitigation measures for scour at bridges include armoring techniques as well as flow alteration devices. At small, single span bridges with vertical wall abutments, scour mitigation is often difficult because the use of armor, such as riprap and grout bags, fills a significant portion of the waterway beneath the bridge, which may then result in additional contraction scour. In addition, the channel may have migrated over the years such that the flow in the channel approaches the bridge at an angle, which increases scour problems. Replacing these bridges is expensive and the replacement of numerous small bridges is not economically possible.

A variety of flow alignment devices, such as vanes and cross vanes, have been used in recent years primarily as treatment for bed and bank erosion in stream stability projects. These structures roll the water away from the eroding banks and, in the case of cross vanes, also provide bed controls, thus limiting degradation of the channel bed. These structures have proven to be very effective treatments over a range of flow conditions. The use of these structures to align flow through a bridge opening could have the effect of moving scour away from the abutments into the center of the channel. The objective of this project was to evaluate the effectiveness of vanes for controlling scour at bridge abutments and to suggest design parameters based on laboratory experiments.

BACKGROUND

Mitigation against scour at bridges has been the focus of much research in the past 5–10 years. There are basically two methods of mitigating against scour: (1) armor the piers or abutments to withstand shear stresses during high flow events; and (2) alter the flow alignment to break up vortices and reduce velocities in the vicinity of the piers or abutments. Other than design constraints, considerations in choosing the appropriate method of mitigation include maintenance and inspection requirements, enhancement of the physical environment, and construction methods required. Design specifications for many of these mitigation techniques can be found in Hydraulic Engineering Circular (HEC)-23 (Lagasse et al. 1997).

Armoring techniques for piers and abutments include riprap, precast concrete units, grout-filled bags, foundation extensions, concrete aprons, and gabions. Riprap is by far the most commonly used of the armoring methods. Armor tends to work moderately well at abutments in most river types and conditions. Problems encountered with armoring at piers include movement of sediment through the armor and an inability to keep the armor in place. At abutments, armor can constrict the channel, causing additional contraction scour.

Flow altering devices at piers and upstream of the bridge have been tested in the field as well as in the laboratory, where they have met with limited success. Such techniques include the use of sheet piles and sacrificial piles placed upstream of piers and circular shields or collars constructed around the pier. Recent experimentation on sacrificial piles (Melville and Hadfield 1999) showed that this method of reducing scour at bridges is only effective for clear-water conditions and for approach flow angles <20°. In the field, these types of devices have been problematic, particularly in that they tend to develop debris and ice accumulations and their effect on scour at high flow angles of attack can be minimal and, in fact, harmful.

In addition to the flow altering devices described above, it is possible to alter flow alignment upstream of the bridge such that the main flow is concentrated away from the bridge abutments, thereby reducing the velocities and shear stresses on the sediments around the bridge foundations. This type of flow alignment is possible through the use of vanes and other similar structures placed in the channel. Vanes have been used in various forms (e.g., Iowa vanes and bendway weirs) for many years to control bank erosion.

Vanes are single-arm structures angled to the flow with a pitch into the streambed such that the tip of the vanes is submerged even during low flow. When properly positioned, vanes induce secondary circulation of the flow, thereby promoting the development of scour pools. Vanes are typically constructed from large boulders to protect riverbanks from erosion (Rosgen 1994, 1996). Rosgen found from field experience that optimum results were obtained when the vane was oriented upstream at an angle of 20°–30° from the bank. At the bank the vanes should correspond to floodplain level and pitch down to intersect the bed of the river no more than one-third

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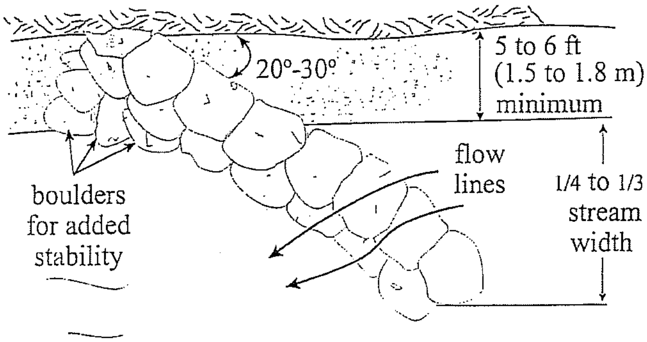

FIG. 1. Guidelines for Vane Design [after Rosgen (1996) and Brown and Johnson (1999)]

of the way across the channel (Fig. 1). The vanes create quiescent conditions at the bank face, even during flood flows, while the faster overspilling flow is directed back into midchannel. Several vanes are required around an eroding meander bend to prevent further bank failure. Collectively they generate an outer bank secondary flow cell, which opposes that resulting from bend curvature. As a consequence, downwelling and scouring occur in midchannel, just downstream of the toe of the vanes, while the base of the bank is backfilled with sediment. Designs for these structures is now being incorporated into state guidelines on waterway construction [e.g., Brown and Johnson (1999)].

Small isolated submerged vanes, known as Iowa vanes, have been used for many years to deflect flows and sediment to control spiral flow in bends and erosion at banks. A variety of experimental studies (Odgaard and Kennedy 1983; Odgaard and Lee 1984; Odgaard and Mosconi 1987) have yielded the following guidance in the design of these types of vanes. Submerged vanes were found to be effective over a wide range of flow depths from two to eight times the vane height. The discharge was determined not to be a primary design parameter; discharge is used only to determine velocity. The ratio of the vane height to flow depth should be between 0.2 and 0.5 at the erosion causing flow rates. The length should be about three to four times the vane height, with an optimum angle of about 20° from the primary direction of flow. Lateral spacing of the vanes should be less than about twice the flow depth. Vanes are typically constructed from large rocks or wood, with footers of adequate depth to resist erosional forces. The ability of submerged (Iowa) vanes to reduced scour at bridge piers was recently tested at the University of Auckland, Auckland, New Zealand (Lauchlan 1999).

Bendway weirs are low elevation stone sills very similar to vane structures used to improve lateral stream stability and flow alignment problems (Lagasse et al. 1997). Bendway weirs are typically not visible at bank-full flow. They redirect flow by causing the flow to pass perpendicularly over the weir. They are made from stone, tree trunks, or grout-filled bags. Based on HEC-23 (Lagasse et al. 1997), a brief summary of design guidelines is given. The weir height should be 30–50% of the flow depth at the mean annual high water level. The angle from the upstream bank tangent line to the centerline of the weir should be about 50°–85° (this high angle is because of the placement of the weirs at channel bends). The length should not exceed one-third the mean channel width, with typical values between one-tenth and one-fourth the channel width. Spacing of the weirs is dependent on the channel radius of curvature, weir length, and channel width. The top width of the weir should be two to three times the D_{100} of the rocks used to construct the weir. At least three weirs are used to direct flow around a bend.

Spurs and groins are frequently used to protect river banks. Lagasse et al. (1995) recommended that spurs be placed at 70° from the channel bank. The crests can be horizontal or sloping. Maza Alvarez (1989) suggested that slope-crested groins should be sloped at 0.1–0.25 (5.7°–14°) toward the center of the river channel. Sloping the crest of the groin has the advantage of causing much less scour around the tip of the spur and sediment deposition between adjacent spurs occurs more quickly. Maza Alvarez (1989) developed a method for determining the spacing between groins. He found that, for a straight channel, spurs should be spaced according to four to six times the length of the spur. The length of the groin should be greater than the mean flow depth of the reach but less than a fourth of the bank-full width. For curved reaches, the suggested spacing is 2.5 to four times the groin length. In terms of channel geometry, the spacing is $W < S < 1.5W$, where W = channel width and S = spacing of the groins. The development of the spacing criteria was based on flow expansion around the groins.

EXPERIMENTAL PROGRAM

A 15-m-long, 1.5-m-wide, and 0.9-m-deep (50-ft-long, 5-ft-wide, and 3-ft-deep) recirculating flume was used to simulate flow patterns and the resulting scour at bridge abutments. A Venturi meter and manometer were used to provide discharge measurements. A point gauge was used to measure flow depths in the flume. Flow velocity was measured with an acoustic Doppler velocity meter attached to the overhead carriage.

A bridge abutment model was developed for the flume and was roughly modeled after several scour prone, single-span bridges with vertical wall abutments north of Baltimore. Although it was not intended that the tests would represent a particular bridge, the scaling was chosen to be representative of the range of characteristics for the bridges and rivers under investigation. The bridges were selected by Maryland State Highway personnel as ones where scour at the abutments was a concern and where the installation of vanes would be feasible. For these bridges, setback of the abutments from the stream channel ranged from 0 to 4.6 m. Channel width-to-depth ratios were on the order of 10–12, with channel widths <25 m and depths varying from 1 to 1.6 m. The median sediment size was in the coarse gravel range, with a channel slope around 0.002. Based on HEC-River Analysis System (RAS) output, the flow conveyed in the floodplain was up to 20% at the highest flows (i.e., either the 100-year event or the event that overtops the bridge deck, whichever is smallest).

Tests on scour at bridge abutments were carried out by modeling the channel [76 cm (2.5 ft)] and one floodplain [76 cm (2.5 ft)] to maintain sensible scaling. Fig. 2 shows the cross section of the channel with bank-full depth at 9 cm. Although the floodplain would have limited width, as it was to be relatively smooth, it could transmit discharges comparable to a wider, rougher, floodplain. Consequently, return flows to the river at the bridge abutment, due to the embankment contracting the flow, would be representative of field conditions. The floodplain was roughened appropriately to convey the necessary flow using "L" brackets and to provide fully rough, turbulent flow. The model abutment was a vertical wall type with setback from the channel representative of the field sites (about 25 cm) and aligned with the flow. The floodplain and channel bank were rigid with a mobile channel bed. It was anticipated that this rigid condition would not limit the results of the experiments given that the purpose of the vanes is to move the higher shear stresses into the midchannel away from the banks, thus causing erosion to occur toward the center of the channel and deposition to occur along the banks in the vicinity of the vanes. A 1-mm uniform sand was chosen to minimize the occurrence of bed forms and to provide a sediment size that would approximately scale to field size. All flows were to be

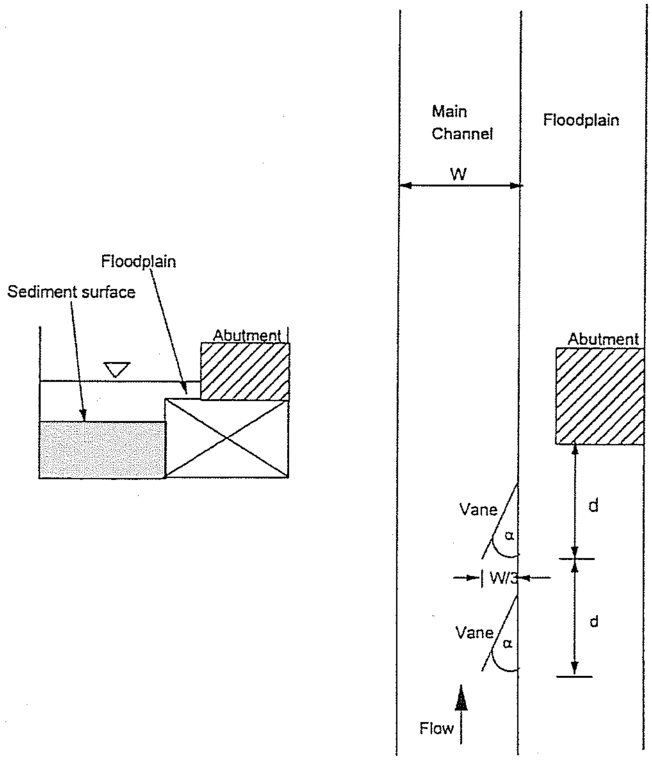

FIG. 2. Experimental Flume Setup

run at incipient sediment motion to provide maximum scour conditions and a consistent velocity ratio from one experiment to the next. The slope was set at 0.002 (approximately the same as in the field), because there was no skew between the vertical and horizontal scales. The tests were run over a range of flood flows to determine peak flow effects.

The Froude number was maintained within an acceptable range so that the velocity ratio could be maintained at the desired value. The velocity ratio V/V_c, where V = velocity and V_c = critical velocity for incipient motion, is used to distinguish between live-bed and clear-water scour. The value of V_c can be approximated using the Neill (1968) equation

$$V_c = 6.19y^{1/6}D^{1/3} \quad (1)$$

where y = flow depth (m); and D = sediment size (m). The value of V_c was then verified in the flume prior to any experimental runs. The value of V/V_c was held at approximately 1 in the laboratory experiments for the following reasons: (1) the maximum scour depth occurs at approximately V/V_c = 1 (Chiew 1984); and (2) this velocity (in addition to using a 1-mm grain size) would help to prevent bed forms.

A total of 37 experimental runs were conducted. Each experiment was run for 4 h. Although this length of time at incipient motion does not yield the maximum scour depth, it does provide approximately 75% of the total scour based on the Laursen (1963) equation as recommended by Umbrell et al. (1998). Because the objective of the experiments was to determine the change in the scour pattern with the use of vanes and weirs rather than the determination of the maximum scour depth, it was decided that a 4-h time interval provided a consistent and adequate time period.

A 2D finite-element flow model of the Navier-Stokes equations was used to roughly model the flow separation and reattachment caused by the vane to provide an appropriate initial placement for a single vane upstream of the scaled bridge. A 2D model was considered adequate for this purpose. For the given scaled model and the selected range of flow conditions, this distance was found to range from 0.94 to 1.25 m. It was desired to keep the entire abutment within the influence of the flow separation zone. Thus, the vane was initially placed such that the distance from the upstream corner of the abutment to the upstream tip of the vane was 0.94 m.

Six initial runs were conducted with the abutment in place, but with no vanes upstream, over a range of flow conditions to determine the scour depth and pattern that would occur without vanes. With a vane in place, subsequent experiments were conducted to assess the effect of overbank flow returning to the channel and to examine the ability of the vane to modify flow at the channel bed under flood conditions. The bank angle, vane location, number of structures, and structure height were varied and tested over the range of flows. The resulting scour depths and channel bed topography were measured and recorded at the end of each 4-h period.

The general flume layout for the vanes is given in Fig. 2. The vanes were constructed from marine plywood, spanned one-third of the channel width, and were attached to the bank so that flow was not permitted between the structure and the bank. The upstream tip of the vane was set at the bed level. In each experiment, flow depths and velocities were measured at several cross sections upstream of and at the bridge. The resulting velocities given in Table 1 are the average flow velocities in the approach flow (i.e., upstream and out of the influence of the bridge abutment and vanes). The flow depths recorded in Table 1 were taken in the main channel in the approach flow. Depths in the floodplain can be calculated by subtracting the bank-full flow depth (9 cm) from the total depth.

RESULTS

The summary of the data collected from the experiments on the vanes is given in Table 1. A set of runs were conducted with no vane in place to assess the scour depth caused by the abutment itself (runs 1–6 in Table 1). In each of these runs, a scour hole, caused by the abutment, formed immediately adjacent to the abutment. For the runs with a vane in place (runs 7–37 in Table 1), the vanes placed upstream of the abutment caused a reduction in velocity along the channel bank and effectively moved the abutment scour further out into the channel away from the abutment. A scour hole was observed at the upstream tip of the vane and immediately downstream of the vane, toward midchannel. At lower flows, the scour holes created by the abutment and the vane remained separate. At higher flows, the two scour holes formed by the vane and the abutment joined to form one elongated scour hole away from the abutment toward the center of the channel. Fig. 3 shows the movement of the scour away from the bank for a single cross section with and without a vane in place (runs 5 and 15). At the highest flows (e.g., runs 10 and 11), a scour hole also developed just upstream of the vane because of secondary currents [as described by Hey (1995)]. In addition, a minor secondary scour trough developed at the abutment.

Fig. 4 shows a plot of the effect of the various angles α on scour depth compared to the case in which no vane was used (runs 7–21). The scour depth in Fig. 4 is measured at the position of maximum scour depth at the abutment for the no-vane case so that the reduction in scour at the abutment through the use of a vane could be clearly shown. Table 1 shows the percent scour reduction for each flow depth using the vane angles of 20°, 25°, and 30° (runs 7–21). Scour at the abutment is reduced by 62, 58, and 90% for the highest flow at angles of 20°, 25°, and 30°, respectively. From Fig. 4, the optimum angle of the vanes from the bank is approximately 25°–30°. This is in close agreement with prior field observations and studies [e.g., Brown and Johnson (1999)], which indicate that the angle should be between 20° and 30° to provide maximum bank protection. From Table 1, it can be seen

TABLE 1. Experimental Data from Vane Experiments

Run number	Height	Angle (degrees)	Number of vanes	Distance (m)	Discharge (m^3/s)	q_0/q_m	Mean velocity (cm/s)	Flow depth (cm)	Froude number	Maximum scour depth (cm)	Position of maximum scour (cm)	Scour depth at abutment (cm)	Percent reduction in scour
1	—	—	—	—	0.017	0.000	22.9	9	0.24	0	0	0	—
2	—	—	—	—	0.030	0.023	25.0	15	0.21	1.4	0	1.4	—
3	—	—	—	—	0.037	0.067	31.2	19	0.23	1.4	30.5	1.4	—
4	—	—	—	—	0.053	0.120	31.4	22	0.21	3.5	12.7	3.5	—
5	—	—	—	—	0.057	0.147	30.2	25	0.19	6.9	10.2	6.9	—
6	—	—	—	—	0.064	0.194	33.7	28	0.20	8.6	10.2	8.6	—
7	Bank full	20	1	0.94	0.021	0.033	23.9	15	0.20	0.9	45.7	2.0	−42.9
8	Bank full	20	1	0.94	0.044	0.125	27.5	19	0.20	2.3	15.2	0.9	35.7
9	Bank full	20	1	0.94	0.057	0.140	31.9	22	0.22	5.3	15.2	1.1	68.6
10	Bank full	20	1	0.94	0.068	0.174	27.9	25	0.18	5.8	17.8	3	56.5
11	Bank full	20	1	0.94	0.084	0.189	33.9	28	0.20	6.8	25.4	3.3	61.6
12	Bank full	25	1	0.94	0.024	0.026	23.8	15	0.20	0	0	0.5	64.3
13	Bank full	25	1	0.94	0.035	0.110	23.9	19	0.18	1.8	45.7	0.4	71.4
14	Bank full	25	1	0.94	0.057	0.137	29.8	22	0.20	4.5	24.8	1.9	45.7
15	Bank full	25	1	0.94	0.067	0.147	32.9	25	0.21	5.6	25.4	2.7	60.9
16	Bank full	25	1	0.94	0.070	0.223	32.2	28	0.19	6.5	25.4	3.6	58.1
17	Bank full	30	1	0.94	0.026	0.011	22.3	15	0.18	1.1	45.7	0.5	64.3
18	Bank full	30	1	0.94	0.035	0.082	22.8	19	0.17	1	45.7	0.5	64.3
19	Bank full	30	1	0.94	0.057	0.128	32.1	22	0.22	4.9	27.9	0.8	77.1
20	Bank full	30	1	0.94	0.059	0.151	30.8	25	0.20	5.2	25.4	1.3	81.2
21	Bank full	30	1	0.94	0.067	0.181	33.6	28	0.20	5.3	24.1	0.9	89.5
22	Bank full	25	1	0.41	0.047	0.114	28.8	22	0.20	3.6	15.2	1.1	68.6
23	Bank full	25	1	0.41	0.062	0.164	32.6	25	0.21	6.5	20.3	5.2	24.6
24	Bank full	25	1	0.41	0.081	0.209	33.3	28	0.20	8.4	20.8	6.7	22.1
25	Bank full	25	1	1.25	0.047	0.102	27.8	22	0.19	0	0	0.2	94.3
26	Bank full	25	1	1.25	0.061	0.141	31.7	25	0.20	2.9	22.9	0.5	92.8
27	Bank full	25	1	1.25	0.054	0.177	21.3	28	0.13	6.5	15.2	1.7	80.2
28	Bank full	25	2	0.94/0.94	0.049	0.135	30.4	22	0.21	1.2	35.6	0.8	77.1
29	Bank full	25	2	0.94/0.94	0.069	0.167	34.4	25	0.22	5.1	34.4	1.7	75.4
30	Bank full	25	2	0.94/0.94	0.079	0.180	33.0	28	0.20	7.4	38.1	2.5	70.9
31	Bank full	25	2	1.25/1.25	0.070	0.159	32.1	28	0.19	4.6	27.9	0.4	95.3
32	Bank full	25	3	1.25·3	0.072	0.23	27.6	28	0.17	5.3	25.4	0.8	90.7
33	−1 cm	25	1	1.25	0.070	0.251	29.9	28	0.18	7.5	15.2	2.8	67.4
34	+1 cm	25	1	1.25	0.070	0.255	28.3	28	0.17	4.6	25.4	0.3	96.5
35	Bank full	25	1	1.25	0.075	0.234	28.7	28	0.17	4.8	25.4	4.8	44.2
36	Bank full	35	1	1.25	0.073	0.251	28.9	28	0.17	4.9	30.5	4.9	43.0
37	Bank full	45	1	1.25	0.072	0.316	28.7	28	0.17	4.5	35.6	4.5	47.7

Note: q_0 = unit discharge in overbanks; q_m = unit discharge in main channel; runs 35–37 for abutment at 35° skew; distance for vanes measured from upstream corner of abutment to upstream tip of vane; and position of maximum scour measured laterally from abutment.

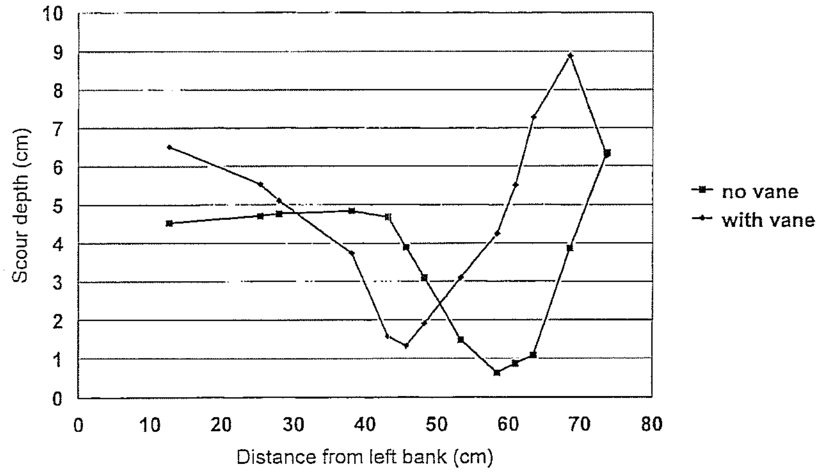

FIG. 3. Location of Abutment Scour with and without Vane (Runs 5 and 15) Showing Movement of Scour Hole Away from Abutment When Vane Is In Place (Abutment Toe Is Located at 75 cm)

that the position of maximum scour occurs considerably further from the abutment than for the no-vane case, about 20% further for the high flows or approximately one-third of the channel width away from the abutment.

In Fig. 5, the effect of the location of the vane upstream of the abutment on scour depth is shown for a constant angle of 25° (runs 14–16 and 22–27). The vane location d was measured from the upstream end of the abutment to the upstream tip of the vane, as shown in Fig. 2. The 0.94- and 1.25-m placements were chosen based on the 2D computational experiments described previously. The 0.41-m placement was such that the vane was just upstream of the abutment. For the

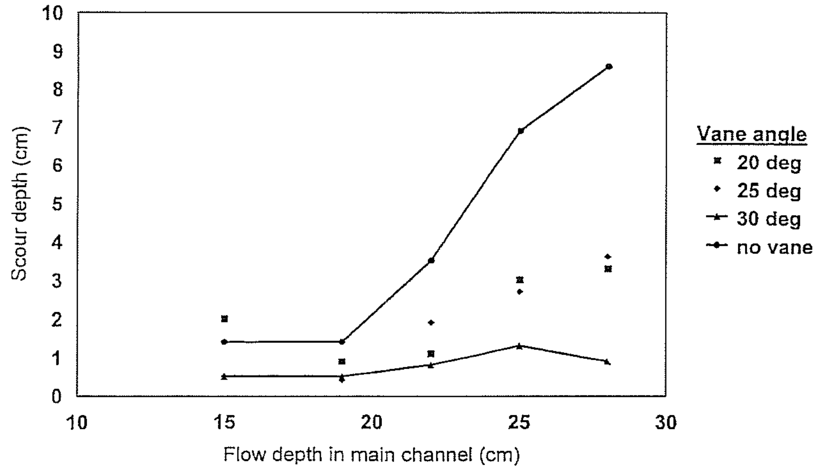

FIG. 4. Effect of Angle on Scour Depth

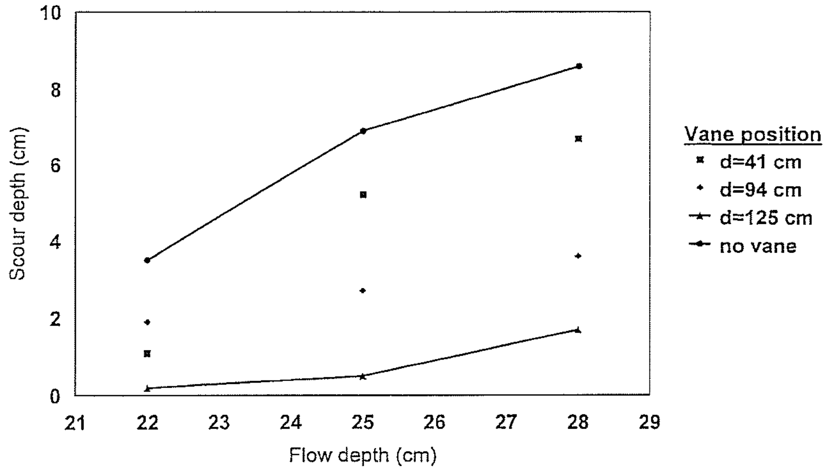

FIG. 5. Effect of Vane Placement on Scour Depth at Abutment ($\alpha = 25°$)

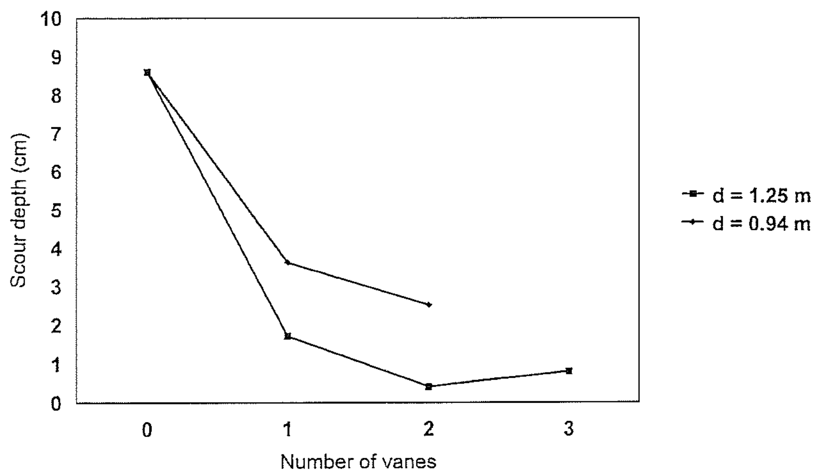

FIG. 6. Effect of Number of Vanes on Scour Depth at Abutment

highest flow, scour is reduced by 22, 58, and 80% for vane placements of 0.41, 0.94, and 1.25 m, respectively. The data and figures show that the 1.25 m position provides the most scour control in moving the scour away from the abutment.

Fig. 6 (runs 28–32) shows the effect of the number of vanes on scour for a constant angle of 25°. The use of two vanes rather than one provides somewhat greater hydraulic control in that the scour position is moved further away from the abutment. It appeared that the addition of a second vane upstream started deflecting the flow further upstream so that the downstream vane became more effective in realigning the flow. For the scale model, the first vane was placed such that the distance from the upstream end of the abutment to the upstream tip of the vane was 0.94 m. The next vane upstream was placed at 0.94 m from the upstream end of the adjacent vane to the upstream tip of the vane (Fig. 2). The spacing experiments were repeated using the 1.25-m spacing. The 1.25-m placement using two vanes provided optimum detachment area from the banks (Fig. 6) with a 95% reduction in scour for the highest flow as compared to 80% reduction for a single vane placed 1.25 m upstream.

The height of the vane at the bank was varied from bank full to ± 1 cm [corresponding to about ± 15 cm (0.5 ft) in the field] for one high flow (runs 33–34). This variation in height was chosen based on recommendations (*Watershed* 1992) that additional control can be gained by raising the height of the vane slightly [about 15 cm (0.5 ft)] above bank-full elevation. The results showed that raising the vane above the bank-full elevation provides additional flow control, which yields a lower scour depth and larger distance between the maximum scour depth and the abutment. Scour is reduced by 67%. For the same case (i.e., 25° angle, 1.25-m placement, and single vane), but with the vane at bank-full height (run 27), scour had been reduced by 58% for the same flow depth. Thus, raising the vane elevation above bank full provided about 9% additional scour reduction.

Three additional experiments were run to briefly examine the changes in parameters for a skewed abutment with respect to the flow lines in the river (runs 35–37). With the abutment skewed at 35° to the stream channel, a single vane was angled at 25°, 35°, and 45° to the channel bank and the resulting scour depth and position measured for a single flow depth and rate. Although the angle of the vane made very little difference with respect to the resulting scour depth, the distance of the maximum scour hole depth from the abutment changed markedly, about 10 cm further away from the abutment over the 10° range of angles. However, the overall scour depth and the position of the scour hole showed very little change over the case of the unskewed abutment with a vane in place. The conclusion is that the angle of the vane to the bank should be held at 25°–30° (as determined in runs 7–21 above) regardless of the skew of the abutment.

DESIGN OF VANES FOR SCOUR CONTROL AT ABUTMENTS

Based on the results of the experiments, general preliminary design guidelines can be established for the use of vanes to reduce scour at single-span bridges with vertical wall abutments set back from the main channel banks. All vanes will require appropriate footings to withstand expected scour in the channel. The Maryland Department of the Environment guidelines (Brown and Johnson 1999) suggest that footings be placed at least 2 rock diameters beneath the lowest vane rock. Additional guidance on the footing depth can be gleaned from observing channel scour along the thalweg upstream and downstream of the bridge over no less than a research 20 times the channel width. The vane footers should be at least as deep as the deepest scour observed along the thalweg. It should be kept in mind that vanes provide scour reduction by aligning the flow in such a manner as to reduce velocities and shear stresses in the vicinity of the foundation. They do not armor the foundation against scour. Although these structures have been shown to be very effective in reducing scour at bridge abutments in a laboratory setting, other parameters—such as changing angle of attack with increasing flood level, debris and ice accumulations, and interactions with existing armoring—have not been tested and could influence the effectiveness of the structures. In addition, vanes do not reduce the total scour that occurs in the vicinity of the abutment; rather, they move the scour away from the abutment into the center of the channel. The following paragraphs briefly outline the design.

Angle Adjacent to Bank

The angle of the vane adjacent to the bank should be set at $25° < \alpha < 30°$ (Fig. 2) to provide maximum flow control along the bed adjacent to the bank during overbank flow events. If the vanes are to be placed on a channel bend, then the vanes should be oriented at 25°–30° to the tangent line of the bend at the attachment point on the bank. If the bridge abutments are skewed with respect to the channel, the vane angle α should be the same as for the unskewed case (with $25° < \alpha < 30°$, measured as in Fig. 2).

Upstream Location

The distance from the upstream end of the abutment to the upstream tip of the vane adjacent to the bank is a function of the length of the vane. Assuming that the length is such that it extends about one-third the channel width into the channel and is set at $\alpha = 30°$, then the distance is also a function of channel width. This optimum distance is given by $d = 2W$, where W = channel width and d = projected distance along the bank from the upstream corner of the abutment to the upstream tip of the vane, with $d \geq 0$ (see Fig. 2).

Number of Structures

In general, two structures provide somewhat greater flow control than a single structure. Thus, where applicable, two structures can be placed on the same side of the channel as the affected abutment upstream of the bridge. The spacing between the structures should be based on the same calculation as the spacing between the bridge abutment and the vane except that the distance will be from the upstream tip of the first vane (furthest downstream vane) to the upstream tip of the second vane upstream (Fig. 2).

Height of Structures

The height of vanes at the bank should be at the bank-full elevation, pitching down to the channel invert at its tip. Raising the height of the structure slightly above the bank-full elevation, about 15 cm (0.5 ft), will provide somewhat more hydraulic control during overbank events. However, a structure raised above bank full may also cause additional scour or bank erosion (this was not tested because of the rigid bank and floodplain). Thus, careful judgment should be exercised when raising the structure higher than the bank-full elevation.

CONCLUSIONS

The results of the scaled experiments described here showed that vanes appropriately placed in a stream channel upstream of a vertical wall bridge abutment with setback move the abutment scour away from the bank and abutment toward the center of the channel. The vane forces the flow to separate from the channel bank at the vane, causing reduced velocities and shear stresses at the bank and increased velocities in the center of the channel. If the vane is placed such that the abutment is within the influence of the vane, then scour is greatly reduced in the lower velocity area along the abutment. It should be recognized that, although scour is reduced along the abutment wall, scour still occurs in the channel away from the abutment. The experiments showed that, for higher flows, the maximum scour depth occurred about one-third the channel width away from the abutment, or about 20% further away from the abutment than for the no-vane case. The vanes do not armor against scour or significantly reduce scour overall; rather, they cause the scouring to occur toward the center of the channel, away from the abutment. In addition, for most flow conditions, the scour hole is elongated compared to that without a vane. For multiple span bridges, the use of vanes may tend to exacerbate pier scour as the vanes cause the maximum abutment scour depth to be moved from the abutment out into the channel.

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