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Sediment management and flow patterns at river bend due to triangular vanes attached to the bank

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Abstract

Triangular vanes are hydraulic structures used for bank protection and habitat restoration for fish and other aquatic organisms. There are limitations on the design criteria for this newly-introduced structure; therefore, the main goal of this paper is to present test results carried out on different alternatives of multiple vanes with different spaces between the vanes under different hydraulic conditions in a 90-degree mild flume bend. In addition, 3D components of flow velocity were measured in tests with and without an installed single vane. The triangular vanes create a counterclockwise secondary flow cell near the outer bank, which counteracts the clockwise main secondary flow cell in the bend for a distance of about 5*le* (*le* is the vane's effective length) downstream of the vane's position. With multiple vanes in place, the thalweg was found to be shifted toward the flume midway from the outer bank. Moreover, by increasing the space between the triangular vanes, the scour around the vane's tip and its development to the outer bank increased. Therefore, it is concluded that triangular vanes perform best when they are spaced at 5*le* or less.

Keywords: Triangular vanes; River restoration; Bank erosion; River bend; In-stream structures

1. Introduction

Human interferences in rivers such as sand mining, infrastructure building, artificial cutoffs, etc., lead to the destruction of dynamic equilibrium. This can cause bank erosion and lateral migration of the river. Bank erosion causes disturbance of private and public lands, damages aquatic and riparian ecosystems, and degrades water quality. In addition, the eroded sediments will deposit downstream in flood control and navigation channels and valuable wetland areas (Biedenharn et al., 1997; Julien, 2002).

In-stream structures (W-weir, U-weir, J-hook vane, cross vane, vanes, deflectors, and root wad structures) are proposed in order to enhance and restore habitat for fish and other aquatic organisms, protect stream banks, enhance recreational boating, and manage sediment (Hey, 1992, 1994, 1996; Rosgen, 2006; Shields, 1983).

Studies conducted on in-stream structures over the past decades include the following: Shields et al. (2004) investigated performance of large woody debris structures in sand-bed channels. Rosgen (2006) described the design and application of the cross vane, W-weir and J-hook vane. Bhuiyan and Hey (2007), Bhuiyan et al., (2007), Pagliara et al. (2014), Scurlock et al. (2011, 2012) and Shields et al. (1995) investigated weirs. Pagliara and Kurdistani (2013) and Puckett (2007) studied flow pattern and scour downstream of cross vane structures. Bhuiyan et al. (2009) studied the effects of bank attached vanes and W-weirs on sediment transport in meandering channels. Pagliara et al. (2013) studied the erosion patterns downstream of J-hook vane structures in straight horizontal channels under clear water conditions. Radspinner et al. (2010) evaluated the performance of in-stream structures using a survey. State employees from Transportation and Natural Resources Departments, U.S. Forest Service employees, private consultants, and federal agencies from across the U.S. were contacted to share their experiences and opinions regarding the use of these structures. The results indicate that these structures are being used extensively in at least 76% of the physiographic provinces of the United States Geological Survey (USGS). Information from 39 case studies suggests that successful projects involve multiple structures located in rivers with relatively high aspect ratios. Respondents indicated that in the areas of cost, performance, maintenance, and environmental enhancement, in-stream structures are preferable to the most common alternative: riprap revetment. However, results from case studies and

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Notation

The following symbols are used in this paper

b	flume width
d	distance of maximum scour depth of vane's tip from the outer bank
ds_1	maximum scour depth at tip of triangular vane
ds_2	maximum scour depth of thalweg
d_{16}	sediment size for which 16% of sampled particles are finer
d_{50}	sediment size for which 50% of sampled particles are finer
d_{84}	sediment size for which 84% of sampled particles are finer
Fr	Froude number
h	flow depth of bend upstream straight reach
le	effective length of triangular vane
Q	flow discharge
r	radius of curvature
S_0	space between triangular vanes
u_0	flow average velocity in the bend upstream straight reach
u, v, w	components of the mean velocities in longitudinal, lateral and vertical directions
$\bar{u}$	depth-averaged longitudinal velocity
Y	lateral distance of each point from the outer bank
α	angle of triangular vane to the upstream bank

discussions with practitioners highlight widespread ambiguity in the design, construction, and maintenance of these structures. A large number of these projects fail due to inadequate design guidelines.

Triangular vanes are in-stream structures oriented upstream at an angle of 20°–30° to the flow and inclined into the stream bed such that the vane tips are submerged even during low flow (Hey, 1992, 1994, 1996; Maryland Water Management Administration, 1999; Rosgen, 1996, 2006). Although the structure has been mentioned in many documents, the first systematic study on the effects of the vanes was published by Bhuiyan et al. (2010). In their experimental tests, both single and multiple vanes with an effective length of one-third of the channel's width were tested. The results demonstrated that when a single or an array of such vanes is installed, the scour hole at the base of the outer bank is infilled and the thalweg is relocated toward the center of the river. Among the different types of vanes, installed vanes with an angle of 30° were found to have the best performance. They concluded that more research and studies must be conducted to determine the appropriate space between the triangular vanes because of shortage of precise criteria and information about the appropriate space between them. Therefore, the present study expands on the experimental works of Bhuiyan et al. (2010) to resolve some shortcomings in the design of triangular vanes attached to the banks as a new and efficient countermeasure against bank erosion.

2. Experimental setup

The experiments were carried out in a single-bend laboratory flume of constant width, $b = 70$ cm, and central angle of 90°. The bend is connected to an upstream straight reach 5 m long and a downstream straight reach 3 m long. Also, the ratio of the curvature's radius to the flume's width (r/b) equals 4 (Fig. 1). The flume sidewalls were made of plexiglass. A slide gate was installed at the end of the flume to control the flow depth. The flow discharge was measured by an ultrasonic flowmeter, Digi Sonic E + model (accuracy of ±0.01 l/s).

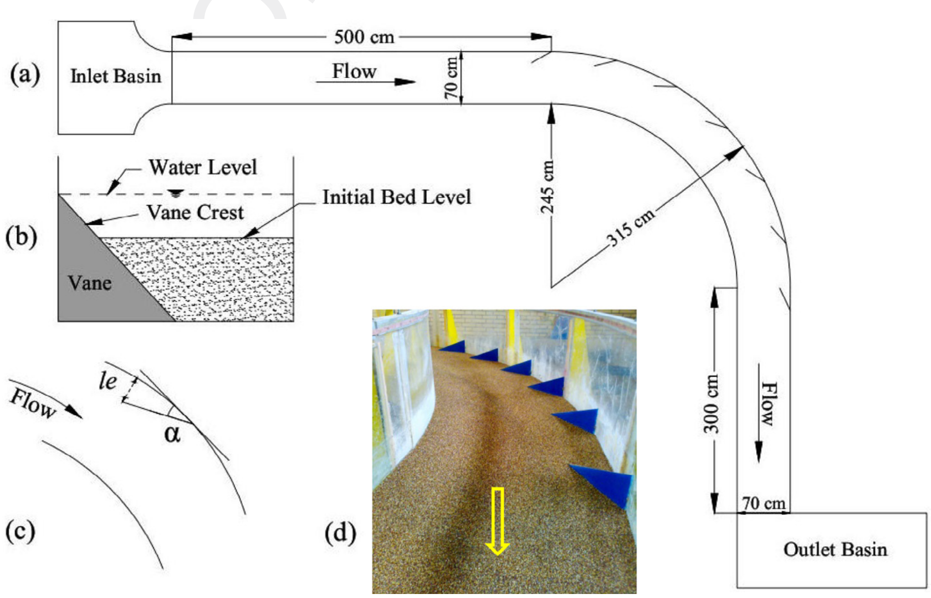

Fig. 1. (a) Plan view of the flume and the triangular vanes layout in the outer bank; (b) cross-sectional view of the single vane; (c) sketch of the vane parameters; (d) photograph of the vanes in the bend for space of 4*le* before starting of test.

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