Ain Shams Engineering Journal (2015) 6, 775–783

Ain Shams University

Ain Shams Engineering Journal

www.elsevier.com/locate/asej
www.sciencedirect.com

CIVIL ENGINEERING

Submerged vane-attached to the abutment as scour countermeasure

Mahmood Shafai Bejestan [a,*], Kheirollah Khademi [b], Hossein Kozeymehnezhad [c]

[a] *Shahid Chamran University, Ahwaz, Iran*
[b] *Jundi Shapour Technical University, Dezful, Iran*
[c] *University of Birjand, Birjand, Iran*

Received 29 August 2014; revised 12 February 2015; accepted 17 February 2015
Available online 30 May 2015

KEYWORDS

Abutment;
Scour;
Vane;
Bridge;
River

Abstract Over the past few decades, the cause of many bridge failures has been reported to be abutment scour. A large number of studies have been conducted to develop countermeasures to ensure the safety of existing bridges. A submerged vane is a measure that has recently been studied and found to be a promising scour mitigation technique for river bank erosion. Therefore, the main purpose of this study was to evaluate the performance of a submerged vane in the case of abutments. Several tests were conducted with and without vanes. Different vane positions and angles were examined. A single vane attached to the upstream nose of an abutment was found to be the most effective at decreasing, shifting, and warding off a scour hole. The results showed that the most appropriate vane angle was 40°. The efficiency of the new measure could reach 95% under some flow conditions.

1. Introduction

Bridge abutments redirect the incoming flow and cause disturbances in river flow patterns. Thereby, three-dimensional flows are formed around abutments. Many vortexes are developed around abutments, which eventually causes bed sediment to be picked up and transported downstream, creating scour holes at bridge abutments. In a case where the scour depth is deeper than the abutment foundation, the abutment, or even the bridge, may collapse. Over the past few decades, many studies have been conducted to understand the mechanism of this phenomenon and determine the important hydraulic variables associated with the scour (Melville [1]; Melville [2]; Melville and Coleman [3]; Barbhuiya and Dey [4]. At the upstream face of an abutment, a pressure gradient is developed due to the stagnation of the approaching flow, which drives the fluid downward, creating a primary vortex along the abutment. According to Ricky et al. [5] the down-flow will reach the bed surface and pick up sediment particles, which then will be washed away by the primary vortex in a spiral around the abutment. To date, various methods for estimating the scour depth at abutments have been developed by many authors

* Corresponding author. Tel.: +98 611330635.
E-mail addresses: m_shafai@yahoo.com (M. Shafai Bejestan), khademi1344@yahoo.com (K. Khademi), Hkhozeymeh@birjand.ac.ir (H. Kozeymehnezhad).
Peer review under responsibility of Ain Shams University.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.asej.2015.02.006
2090-4479 © 2015 Faculty of Engineering, Ain Shams University. Production and hosting by Elsevier B.V.

Notations

d	flow depth	V	flow velocity
D_{50}	median particle size of the bed material	y	maximum scour depth after 13 h of running test and F_r = 0.22
F_r	Froude number	y_s	maximum scour depth after each test
g	acceleration of gravity	α	angle of vane attached to the upstream nose of abutment
H	height of the vane		
h	hours		
l	abutment length		
P_r	percent reduction of scour depth for each alternative compare to the base line test for the same flow condition		

(e.g., Chang and Davis [6]; Richardson and Davis [7]; Sturm [8]; Sui et al. [9]. The development of techniques to prevent scour at bridges has also been given attention. In general, there are two methods of controlling scour in river engineering practice: (1) armoring or covering the river bed material around the abutments and (2) modifying the approaching flow patterns in the vicinity of abutments to reduce the strength of the downflow vortex or redirecting the approaching flow from the abutment. Design guidelines for some of these mitigation techniques can be found in Lagasse et al. [10], Lauchlan [11], Cardosa and Fael [12], Melville et al. [13], Melville et al. [14], Radice and Lauva [15], and Radice and Davari [16].

Johnson et al. [17] conducted tests to investigate the effect of the location, number, and non-submerged vane angle on the reduction of scour at a bridge abutment. The abutment located in the flood plain and the vanes to be tested were installed in the main channel. Their conclusion was that vanes could effectively force the streamlines 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. Thereby, the abutment scour was moved away from the bank and abutment toward the middle of the channel. Barkdoll [18] reanalyzed the experimental data of Johnson et al. [17] and stated that although the use of non-submerged vanes attached to the bank could shift the scour hole from the bank, the maximum scour depth tripled at the tip of the vane because of the contraction of the channel. The non-submerged vane could also accumulate debris during flood season, when floating logs are more commonly transported.

Despite the design guidelines and many studies in the literature, there are still unanswered questions concerning abutment scour mitigation for certain types of bridges in certain locations, which lead to further research in hope of finding efficient measures for existing bridges. For practical purposes, new pier or abutment scour countermeasures should not (1) accumulate debris (Tafarojnoruz and Gaudio [19]), (2) cause aesthetic problems (e.g., sacrificial piles or guide panels, Tafarojnoruz et al. [20]), or (3) interfere with the bridge structure (e.g., by drilling a slot through an abutment or a pier, Gaudio et al. [21]).

The application of a submerged vane as a countermeasure against abutment scour, which has not been studied so far, at least to the best of the authors' knowledge, was therefore the main goal of this study. The hypothesis behind the present study is that by installing a submerged vane, secondary currents will be generated due to the vertical pressure gradient on the two sides of the vane. These vertical velocity components form vortices at the trailing edge of the submerged vane. The resulting vortices roll up to form a large vortex (tip vortex) springing from a position that is somewhat below the top elevation of the vane. This vortex moves downstream with the flow, while it circulates transversely. It gives rise to a helical motion that causes changes in the bed-shear stress and bed-sediment transverse distribution (Odgaard, [22]). Because of this vortex, a vertical shear layer is developed along the channel at the position where the vanes are installed. Thus, the flow velocity within the channel between the bank and vanes is reduced, causing a weakening pressure gradient and downflow vortex upstream of the abutment, with a reduction in the abutment scour expected. Thus, the aim of the present study was to experimentally determine the positioning criteria and angle of a submerged vane as a countermeasure to abutment scour.

2. Experimental set-up

In this research, a laboratory recirculation flume was used. It was 9.0 m in length, 1.0 m in width, and 0.6 m in height, with a constant slope of 0.0003, and side walls of transparent Plexiglas. A 2.0-m-long reach of the flume bottom was covered with sand with a relative density of 2.65, having a median grain size D_{50} of 0.5 mm and standard deviation of 1.22. The depth of the sediment bed layer of the test reach was fixed at 30 cm. The length and width of the rectangular abutment were 20 and 15 cm, respectively. Fig. 1 shows the sectional view of the flume.

A centrifugal pump discharged water from an underground reservoir into the stilling tank at the entrance of the flume. A tail gate was used to adjust the flow depth (d) of the water to 15 cm within the entire flume. The flow discharge was measured and adjusted using a standard 53° triangular weir, which was installed at the outlet system of the flume. Each test started after the bed sediment was leveled using a spirit level, and water flow was introduced to the flume very slowly by closing the tail gate so that no scouring occurred around the abutment before the flow conditions reached the desired conditions. Once the flow discharge and flow depth were fixed, the scour and flow characteristics were obtained at intervals. The flow conditions (Froude number) were maintained within an acceptable range so that a clear water condition existed in all the tests (the velocity ratio V/V_c was equal to 0.67, 0.76, 0.86, and 0.95, where V is the flow velocity equal to 0.19,