Ain Shams Engineering Journal (2015) 6, 403–411

Ain Shams University

Ain Shams Engineering Journal

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

CIVIL ENGINEERING

Investigating the effect of curved shape of bridge abutment provided with collar on local scour, experimentally and numerically

Y. Abdallah Mohamed [a,*], T. Hemdan Nasr-Allah [b], G. Mohamed Abdel-Aal [a], A. Shawky Awad [b]

[a] *Zagazig University, Faculty of Engineering, Egypt*
[b] *Benah University, Faculty of Engineering, Egypt*

Received 29 April 2014; revised 12 October 2014; accepted 17 October 2014
Available online 6 December 2014

KEYWORDS

Numerical models;
Hydraulic structure;
Abutment shape;
Bridge abutments;
Local scour;
SSIIM

Abstract Scour around bridge supports such as abutments can result in structural collapse and loss of life and property, so there is a need to control and minimize the local scour depth. In this paper, numerical and experimental studies were carried out to investigate the effect of different relative radii of the bridge abutment provided with collar on local scour depth. A 3-D numerical model is developed to simulate the scour at bridge abutment using SSIIM program. This model solves 3-D Navier–Stokes equations and a bed load conservation equation. The k–ε turbulence model is used to solve the Reynolds-stress term. It was found the curvature shape of bridge abutment provided with collar could share to reduce the local scour depth by more 95%. In addition, the results of simulation models agree well with the experimental data.

1. Introduction

Local scour at bridge foundation can cause damage or failure of bridges and result in excessive repairs, or even death. A study was produced in 1973 for the U.S. Federal Highway Administration that concluded of 383 bridge failures, 25% involved pier damage and 72% involved abutment damage [1]. There are generally three types of scours that affect the performance and safety of bridges, namely, local scour, contraction scour, and degradational scour [2]. Scour countermeasures can be generally categorized into two groups: armoring countermeasures and flow altering countermeasures. The armoring countermeasure is the addition of another layer, to resist the hydraulic shear stress and therefore provides protection to the erodible materials underneath. In the other side, the flow altering countermeasures aim to change the hydraulic properties of flows by using spur dikes, guide banks, parallel walls, collars, etc., and therefore reducing the scour effect at bridge piers and abutments [3]. A comprehensive review of different scour countermeasures for bridge piers

* Corresponding author.
E-mail addresses: Yasser_eng1997@zu.edu.eg, Yasser_eng1997@yahoo.com, ymoussa@jazanu.edu.sa (Y.A. Mohamed).
Peer review under responsibility of Ain Shams University.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.asej.2014.10.011
2090-4479

and abutments was investigated [4,5]. Spur dikes as a countermeasure to local scour at wing wall abutments was studied experimentally [6]. There are different methods for estimating local scour depth at bridge abutments [7–10]. In addition, lots of researches are carried out to minify the scour dimensions by implementing a circular collar around the pier [11–16], submerged vanes [17], a slot through the pier [18–22]. The guide wall was used to protect the scour depth at bridge abutment [23]. The effect of constructing two adjacent bridges on the flow characteristics and local scour around bridge piers was discussed [24]. Integrating approach to the estimation of local scour depth at bridge piers and abutments was presented [25]. Scour around bridge abutment is studied experimentally [26–28]. Bridge abutment was studied numerically [29,30]. Analysis of experimental data sets for local scour depth around bridge abutments using artificial neural networks was investigated [31]. Gene expression programming and artificial neural networks were used to predict the time variation of scour depth at a short abutment [32]. Previous studies [33,34] showed that different empirical equations may predict various bridge scour depths for a certain case. Hence, numerical simulation of local scour depth may be assumed as an alternative and to some extent more reliable scour depth predictor. Another important issue in the estimation of bridge scour depth deals with scale effect [35]. In fact, traditional methodologies originally developed on the basis of small-scaled laboratory experiments, while this problem will not be faced in numerical simulations. In the present study, the scour depth at bridge abutment has curved shape and provided with collar was studied numerically and experimentally. The simulated models were created by using SSIIM (sediment simulation in water intakes with multiblock option) program. This 3D CFD model was based on the finite volume method to solve the Navier–Stokes equations [36].

2. Experimental work

The experimental work was carried out in a re-circulating channel with 4 m length, 20 cm depth and 40 cm width (Photo 1). Stones with different sizes were used at entrance to damp carefully disturbances. The discharge was measured using a pre-calibrated orifice meter. The median sand size (D_{50}) is 1.77 mm. The sediment is to be considered as uniform at which the geometric stander deviation of the particle size distribution is less than 1.3 ($\sigma_g = D_{84}/D_{50} = 1.29$). The experimental work was conducted under the clear-water condition. Clear water scour occurs for velocities up to the threshold for the general bed movement, i.e., $U/U_c \leqslant 1$ (U, is the approach flow velocity, and U_c, is mean approach velocity at the threshold condition [25]. In the present study the value of U/U_c equals 0.86 (i.e., clear water scour). For each test of the experimental program, the sand was leveled along the entire length of flume using a wooden screed with the same width as the flume. The sand level was checked in random points with a point gauge. The flume was slowly filled with water to the required depth. The pump was then turned on and its speed increased slowly until the desired flow rate was achieved, after that the tailgate was adjusted to get the required water depth. At the end of the test the pump was turned off and the flume was drained slowly without disturbing the scour topography. The bed topography was measured with point gauge with 0.01 mm accuracy on a grid with meshes of 3 cm × 3 cm (sometimes 1 cm × 1 cm depending on the bed topography) over an area of 2.5 m × 0.4 m spanning between 1.0 m upstream and 1.1 m downstream from the abutment. The grid pattern was dense to obtain accurate bed topography at the end of each experiment. Details of experimental models were shown in Fig. 1. Wooden edge abutments with 40 cm length (L), and 7.5 cm widths (b), were installed in the channel sides. The used protective plate (collar) in the experiments is 2 mm thickness and is made from Perspex. The collars fixed at the same level as the mobile bed. The collar width (L_1), is 6 cm, and the collar lengths (L_c), are ranged from 29 to 59 cm. The curvature radii (r) are 1.5, 3, 4.5, 6, 7.5, 9, 10.5, 18.15, 30.5 and 100 cm. The total numbers of experiments are 80. Details of the experimental conditions were summarized in Table 1. Fig. 2, presents the required time for each test, in which $d_s/d_{s\mathrm{Equilibrium}}$ was plotted against the time. It was found that 90% of maximum scour depth was achieved at 2 h.

3. The numerical model

The SSIIM program solves the Navier–Stokes equations with the k–ε on a three dimensional and general non-orthogonal co-ordinates. These equations are discretized with a control volume approach. An implicit solver is used, producing the velocity field in geometry. The velocities are used when solving the convection–diffusion equations. The Navier–Stokes equations for non-compressible and constant density flow can be modeled as follows:

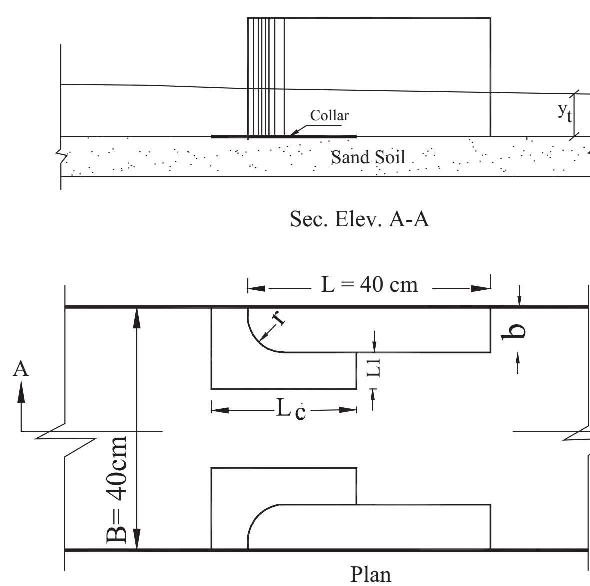

Figure 1 Sketch of experimental models.

Table 1 Details of experimental conditions.

Discharge (L/s)	3.5	Median sand size (mm)	1.77
Abutment width (b) cm	7.5	Flow depth (cm)	3–7
Collar width (L_1) cm	6	Froude number	0.20–0.55
Collar length (L_c) cm	29–58	Radius (r) cm	1.5–100