International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org Volume 2 Issue 12 ǁ December. 2013 ǁ PP.49-53

The Effect of Collar on Reducing Scour around Bridge Piers: A Numerical Study

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ABSTRACT: *Despite excessive costs spent on constructing and implementing bridges in Iran, a considerable number of these structures are destroyed because of scour and bridge pier collapse in the country annually. As a result, besides reduced useful life of bridges, life losses, and economic damages, destructed bridges will make it more difficult to reach neighboring and particularly flood-stricken regions. Using the SSIIM 3D program, this study investigates the effect of collars on reducing the dimensions of local scour holes around bridge piers. The results indicate that using rectangular collars can considerably help reduce the scour depth. Furthermore, when a collar was placed near water surface, sedimentary accumulations at rear bridge piers were transported downstream. Also, maximum sedimentation increased when a collar was placed near water surface. It was also found that the most appropriate place for installing collars is the bed level.*

Keywords: *collar, bridge piers, local scour, SSIIM numerical model.*

I. INTRODUCTION

Collars are tools installed parallel to river beds and vertically on piers and can control downflow at the upstream face of the pier, preventing the formation of scours. A collar divides the flow into two upper and lower fields. The upper collar field functions as an obstacle against downflow, moderating the force of downflow. In the lower collar field, too, the force of downflow and consequently horseshoe vortices are reduced (Chiew, 1992).

Ettema (1998) conducted extensive experimental studies on the gradual variations occurring in scour dimensions. In these experiments, two conditions of bed gradation were taken into account: uniformly graded and poorly graded. Relying on Ettema's findings (1980) as well as experiments conducted on uniform sand beds, Melville and Chiew (1999) developed a method for estimating temporal developments in the dimensions of local scour around cylindrical piers. Mia and Nago (2003), too, studied the relationship between the depth of the scour hole and hydraulic parameters (i.e. flood peak discharge).

The efficiency obtained through the use of collars was addressed in studies conducted by Kummar et al. (1999) and Zarrati et al. (2004, 2006). For instance, Zarrati et al. (2006) experimentally investigated the effect of collar (in combination with riprap) on a set of piers. The results showed that in cases in which two piers are constructed along the flow in a parallel line and in which piers are jointly supported by a collar and riprap, local scour can be reduced in the front and rear piers as much as 50-60%. Also, in constructions in which two piers are placed in a traverse arrangement, experiments suggest that using a collar will not be much effective.
The present study is an attempt to test the pattern of sedimentation and erosion around piers through a numerical study. More specifically, the effect of collars on reducing local scour will be investigated, considering the collar's place of installation in relation to bed level.

II. METHOD

2.1. Equations governing the flow field

Equations of continuity and conservation momentum are as follows:

(1)

$$\frac{D(\rho)}{Dt} = \frac{\partial(\rho)}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

(2)

$$\frac{D(\rho\, u)}{Dt} = \frac{\partial(\rho\, u)}{\partial t} + div\left(\rho\, u\vec{V}\right) = -\frac{\partial P}{\partial x} + div(\mu\; grad\; u) + \left[-\frac{\partial(\rho\overline{u'u'})}{\partial x} - \frac{\partial(\rho\overline{u'v'})}{\partial y} - \frac{\partial(\rho\overline{u'w'})}{\partial z}\right]$$

(3)

$$\frac{D(\rho v)}{Dt} = \frac{\partial(\rho v)}{\partial t} + div(\rho v\vec{V}) = -\frac{\partial P}{\partial y} + div(\mu\ grad\ v) + \left[-\frac{\partial(\rho\overline{v}'\overline{u}')}{\partial x} - \frac{\partial(\rho\overline{v}'\overline{v}')}{\partial y} - \frac{\partial(\rho\overline{v}'\overline{w}')}{\partial z} \right]$$

(4)

$$\frac{D(\rho w)}{Dt} = \frac{\partial(\rho w)}{\partial t} + div(\rho w\vec{V}) =$$

$$-\frac{\partial P}{\partial z} + div(\mu\ grad\ w) + \left[-\frac{\partial(\rho\overline{w}'\overline{u}')}{\partial x} - \frac{\partial(\rho\overline{w}'\overline{v}')}{\partial y} - \frac{\partial(\rho\overline{w}'\overline{w}')}{\partial z} \right]$$

In these relations, D/Dt is material derivation, ρ is fluid mass volume (combination of water and suspended sediments), t is time, and w, v, u are respectively the parameters of the flow velocity vector in z, y, x Cartesian coordinates.

Also, $\vec{V} = u\vec{i} + v\vec{j} + w\vec{k}$ is the flow velocity vector, P is piezometric pressure, μ is dynamic viscosity, and $\overline{w}', '\overline{v}, \overline{u}'$ are respectively the parameters of fluctuation velocity of w, v, u (as z, y, x Cartesian coordinates). It should be noted that $(\rho\overline{u}'\overline{u}'), (\rho\overline{u}'\overline{v}'), (\rho\overline{u}'\overline{w}'), (\rho\overline{v}'\overline{v}'), (\rho\overline{v}'\overline{w}'), (\rho\overline{w}'\overline{w}')$ are called Reynolds turbulence. To estimate Reynolds turbulence in this study, the $k-\varepsilon$ model was used. Also, *conservation* of *mass equation for sedimentary particles and diffusion and mass transfer equation were used.*

2.2. Modeling

In this study, SSIIM was used to analyze scour around bridge piers, considering collar effect. SSIIM uses control volume to seprate differential equations governing the flow field.

To evaluate the precision of the numerical model employed in this study and to verify the results, the experimental data provided by Khodashenas et al. (2009) were drawn on. The canal under study had a length of 10m, a width of 30cm, and a height of 10cm. Also, the thickness of sediments in the experimental sample was 16cm. To fully develop the flow, the length of the experimental sample was chosen to be 1.5m and it was positioned at a 5-m distance. Also, the diameter of the cylindrical pier was 25cm, the average size of sedimentary particles was 0.8 mm, and relative density of sedimentary particles in the bed was 2.64.

The mesh used in the study is illustrated in Figure 1. Of course, the strands of the net were more densely woven than other areas in the vicinity of bed sediments, the bridge pier, and the collar.

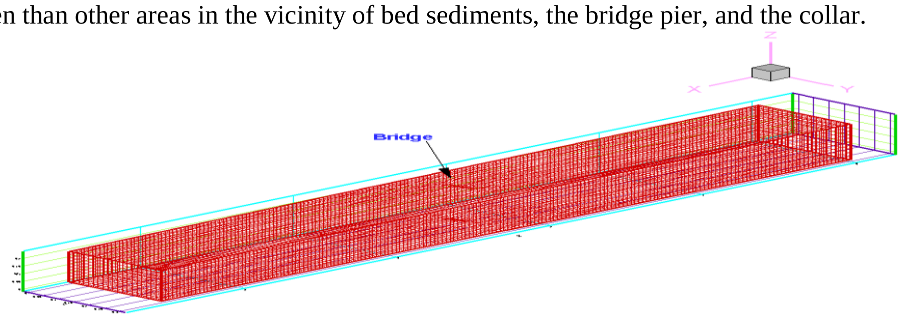

Figure 1. The final calculation mesh of the canal encapsulating the pier.

III. RESULTS AND DISCUSSION

3.1. Results of scour without collar installed

In all of the numerical calculations, the depth and flow rate were considered 10.5cm and 10l/s respectively. The model was simulated for 7 hours. The duration of scour equilibrium of pier samples with collar was also 7 hours.

Figure 2 illustrates the results of the simulation. Clearly, scour started right in front of the pier in a relatively asymmetric pattern relative to the pier's axis, while sedimentary materials were washed from the front and sides of the pier and were accumulated into a heap at the back of the pier. These heaps were gradually transported downstream.

Considering the typography of the scour hole formed around the pier, maximum scour depth in the numerical model was found to be 61mm, whereas this value was 53mm in the experimental model. Therefore, the results indicated the conformity of the SSIIM findings after calibration with experimental data. To perform the calibration of the numerical model in this study, thickness coefficient and time step were modified in sediment-related calculations, and they were adjusted so that they would maximize the conformity of the findings of the numerical model with those of experimental modeling. As a result, the values of thickness coefficient and time step for the collar-less bridged pier were 0.0153 and 60s respectively.

Figure 3 shows velocity vectors around the bridge pier. Figure 3 also illustrates the spiral pattern of flow around the pier and the formation of the low-pressure zone as a result of backflow at the back of the pier.

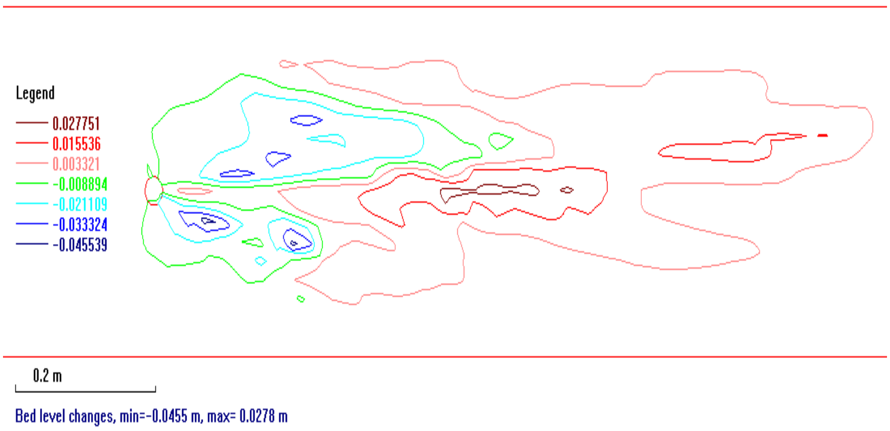

Figure 2. Scour around the pier after 7 hours in the calibrated SSIIM model.

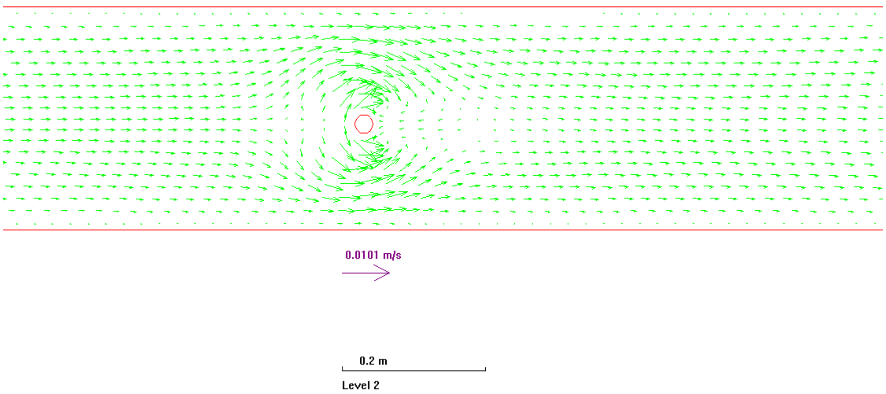

Figure 3. Magnified velocity vectors of the flow field around the pier in the bed after simulation (no collar installed).

3.2. Modeling the effect of collar on scour

At this stage, three different levels were used to install the 6.25cm rectangular collar on the bridge pier. As Figures 4-6 show, as collar's place of installation was below the bed, maximum local scour decreased. When the collar was installed above the bed, maximum erosion was 40mm, whereas when the collar was placed at the bed level, maximum scour was found to be 36mm. Yet, when the collar was installed below that bed level, local scour was found to be 36mm; this value did not show any difference from the time when the collar was installed at the bed level. As a result, the best place to install collars seems to be bed level.

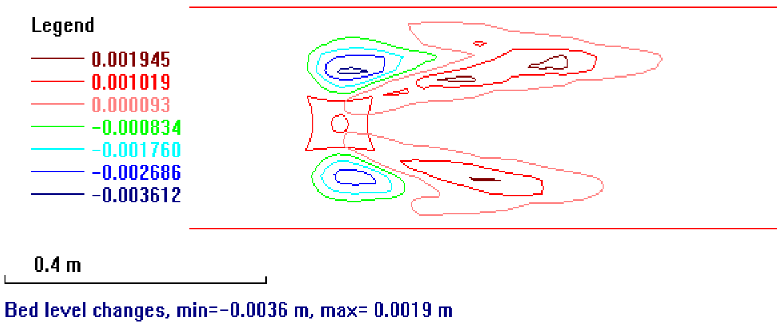

Figure 4. Contours of bed level around the bridge pier with the collar precisely installed at bed level.

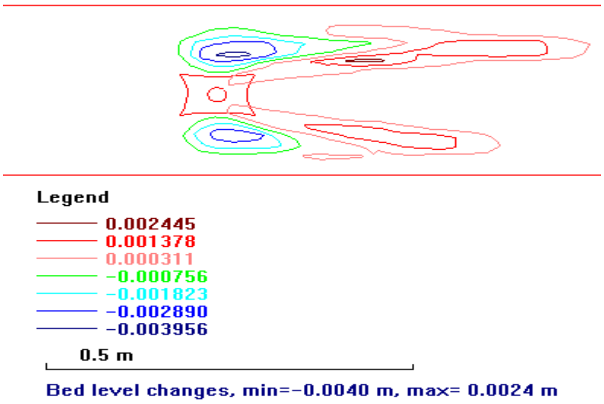

Figure 5. Contours of bed level around the bridge pier with a collar in place above bed level 0.2 times the water depth.

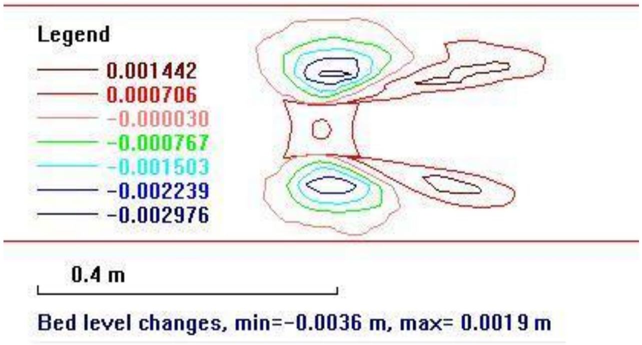

Figure 6. Contours of bed level around the bridge pier with a collar bed level 0.2 times the water depth.

According to the figures, as the collar's place of installation gets closer to water surface, scour hole around the bridge pier is developed and expanded, while sedimentary accumulations at the back of the pier are transported downstream. Also, maximum sedimentation increases as collar's place of installation gets closer to water surface.

IV. CONCLUSION

The findings show that the SSIIM numerical model predicted acceptable values in flow simulation and calculations of typographical changes of the bed. Furthermore, using collar around the pier can control downflow and horseshoe turbulence, thus reducing the depth of local scour. As collar's place of installation gets closer to water surface, scour hole in the vicinity of the bridge pier is developed and expanded, while sedimentary accumulations at the back of the pier are transported downstream. . Also, maximum sedimentation increases as collar's place of installation gets closer to water surface.

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