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Retrofitting of Bridge Piers against the Scour Damages: Case Study of the Marand-Soofian Route Bridge

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***Abstract*—**Bridge piers which are constructed in the track of high water rivers cause some variations in the flow patterns. This variation mostly is a result of the changes in river sections. Decreasing the river section, bridge piers significantly impress the flow patterns. Once the flow approaches the piers, the stream lines change their order, causing the appearance of different flow patterns around the bridge piers. New flow patterns are created following the geometry and the other technical characteristics of the piers. One of the most significant consequences of this event is the scour generated around the bridge piers which threatens the safety of the structure. In order to determine the properties of scour holes, to find maximum depth of the scour is an important factor. In this manuscript a numerical simulation of the scour around Marand-Soofian route bridge piers has been carried out via SSIIM 2.0 Software and the amount of maximum scour has been achieved subsequently. Eventually the methods for retrofitting of bridge piers against scours and also the methods for decreasing the amount of scour have been offered.

***Keywords*—**Scour, Bridge pier, numerical simulation, SSIIM 2.0.

I. INTRODUCTION

LOCAL scour at bridge structures has been extensively studied over the past fifty years with both experimental and numerical methods. When an obstacle is placed in a flow on an erodible bed, a scour hole forms at the footing of the obstacle. On river beds, this phenomenon typically occurs in the vicinity of bridge abutments and bridge piers, often leading to the structure collapse.

Construction of an obstacle against flow causes a difference in hydrostatic pressure at upstream and downstream of the structure which will cause a whirlpool disturbance around it. These whirlpool flows account for the main local scoring mechanism which produces large vortexes at the vicinity of pier and this phenomenon may lead to structure's failure. Local scour holes are formed around bridge pier due to the action of flow against these obstructions. Estimation of the depth of scour at the vicinity of piers has been the main concern of engineers and researchers for years.

Therefore, knowledge of the anticipated maximum depth of scour for a given discharge is a significant criterion for the proper design of a pier foundation or utilizing a method for decreasing scour around the structure. Numerous researchers like: Akib et al. (2013), Karami et al. (2012), Akib et al. (2011), Fayyadh et al. (2009), Akib et al. (2009), Hua et al. (2006), Dey (2005), Mashahir et al. (2004), Kayaturk (2004), Chiew (1992), Molinas et al. (1992), Melville (1992), and Kumar (1990) made variety of experiments in order to investigate the scour phenomenon around bridge piers and bridge abutment [1]-[15].

Beside experiment studies, variety of CFD models have been developed for computing sediment transportation and calculating bed changes in channels and around hydraulic structures or obstructions; like SSIIM, Fluent and Flow-3D.

In the present study, SSIIM 2.0 three-dimensional model was used to compute sediment transport and scouring phenomenon around bridge pier and its capability for simulation scour structures was investigated.

II. CASE STUDY

The case which is targeted to be investigated in this study is a 5 span bridge, situated in 11+406km of the Marand-Soufian route, near Payam city, which spans across the SeivanRiver. The bridge is a reinforced concrete structure in which concrete deck rests on concrete girder beams and transverse beams are used for lateral supporting. Piers are 2 meter in diameter and located on concrete foundation with a height of 1.5 meter. Fig. 1 indicates the mentioned bridge. The photos are taken in summer.

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Fig. 1 Span bridge situated in 11+406km of the Marand-Soufian route

III. Numerical Model

In this section, SSIIM 2.0, computational fluid dynamics (CFD) was used for three-dimensional numerical modeling of scour around bridge pier. SSIIM 2.0 used a finite volume approach to discrete the equations. The water flow was computed by solving the Reynolds-averaged Navier-Stokes equations using the k-ε turbulence model. The SIMPLE method was used to compute the pressure. SSIIM 2.0 computes both suspended load and bed load. The suspended sediment transport was computed by solving the transient convection-diffusion equation for sediment concentration c.

$$\frac{\partial c}{\partial t}+U_i\frac{\partial c}{\partial x_i}+w\frac{\partial c}{\partial z}=\frac{\partial}{\partial x_i}\left(\Gamma\frac{\partial c}{\partial x_i}\right) \tag{1}$$

The Reynolds-averaged water velocity is denoted by U; w= fall velocity of sediment; x= general space dimension; z= dimension in the vertical direction. And Γ is denoted as a diffusion coefficient that is set equal to the eddy viscosity taken from the k-ε model. Equation (1) describes the transport of sediments and includes the effect of turbulence on reducing the settling velocity of sediments. Equation (1) is solved using a control-volume method on all cells except the cell closest to the bed, where the concentration is specified by Van Rijn's formula [16].

$$c_{bed}=0.015\,\frac{d^{0.3}}{a}\frac{\left(\frac{\tau-\tau_c}{\tau_c}\right)^{1.5}}{\left(\frac{\rho_s-\rho}{\rho v^2}\right)^{0.1}} \tag{2}$$

The sediment particle diameter is denoted d; a = reference level that is set equal to the maximum value of half the bed-form and grain roughness of the bed; τ = bed shear stress; τ_{cr}= critical bedshear stress for movement of sediment particles according to Shields' curve; ρ_w and ρ_s= density of water and sediment; ν= viscosity of water and g = acceleration of gravity. In addition to the suspended load, the bed load q_b is computed by Van Rijn's formula [17].

$$\frac{q_b}{d^{1.5}\sqrt{\frac{\rho_s-\rho}{\rho}g}}=0.053\,\frac{\left(\frac{\tau-\tau_c}{\tau_c}\right)^{1.5}}{d^{0.3}\left(\frac{(\rho_s-\rho)g}{\rho v^2}\right)^{0.1}} \tag{3}$$

In the present study bed changes around pier of Marand – Soofianrout bridge was simulated. Boundary conditions were as follows: One inlet was needed to define the water inflow and one outlet was needed to define the water outflow to satisfy the actual velocity around pier. Both inflow and outflow were specified as inflow and outflow discharge value at discharge editor. To estimate the effect of a wall on the flow, empirical wall function known as standard wall function was used [17].

$$\frac{U}{u_x}=\frac{1}{\kappa}\ln\left(\frac{30h}{k_s}\right) \tag{4}$$

The bed roughness is denoted k_s; κ = Prandtl constant that is equal to 0.4 and h = distance from the wall.

A. Verification

Before employing the numerical model to study the scour around bridge pier, it was necessary to ensure the accuracy of the numerical model. For this purpose, the results which were obtained by Basser et al. were used [18], [19]. In the mentioned studies in order to numerical simulation, various sensitivity analysis on bed roughness, turbulence models and sediment transport formulas were carried out for the best state that had the best agreement with observed measurements. Based on sensitivity analysis on bed roughness, it was achieved that the amount of $5d_{90}$ was the best value for simulating the scour depth. According to various studies, the amount of bed roughness can differ from d_{50} to $100d_{50}$ [17].

Based on a sensitivity analysis of effect of two k-ε standard and k-ε with some RNG extensions turbulence models, the k-ε turbulence model with some RNG extensions had showed the best agreement with experiment measurements. And based on a sensitivity analysis of effect of various sediment transport formulas on the local scour, the results that had been achieved from Van Rijn's formula [16] have been showed the best agreement with measured topography. A computer with 2.2 MHz processor was used to run the numerical models.

B. Simulation

In continue in order to simulate the geometry of river and bridge pier, an unstructured mesh were made. Fig. 2 indicates the mentioned mesh. The area around the pier used a finer mesh than the other regions because of more intense velocity gradients and also in order to decrease the time of computation. The gird size was 110×31×9. (The numbers indicate the number of grids at x, y and z directions respectively). The distortion ratio around the pier was 2.5 while it was 1 in other regions. A computer with 2.2 MHz processor was used to run the numerical models. The bridge had 4 pier and 5 span. The whole width of river around bridge was 90 meter, then the effective span for one pier was 1.8 meter. The discharge for the effective span was 0.459m^3/s.

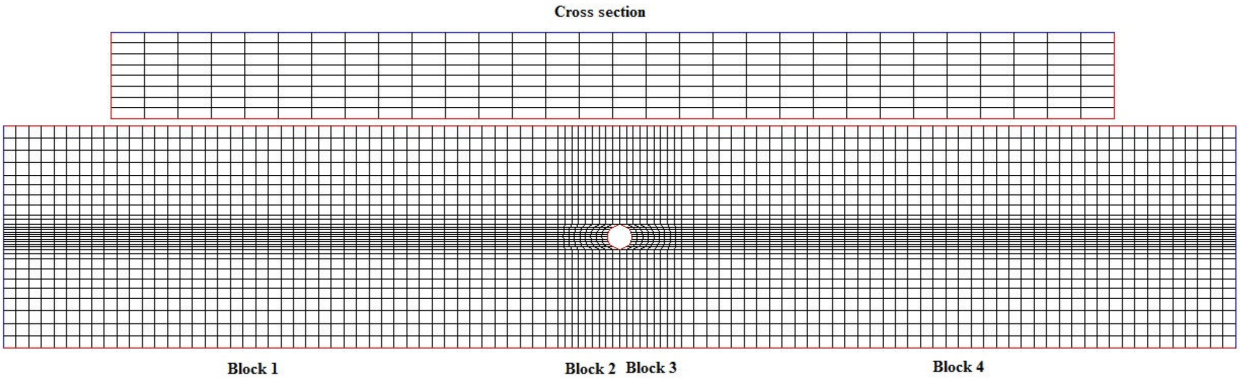


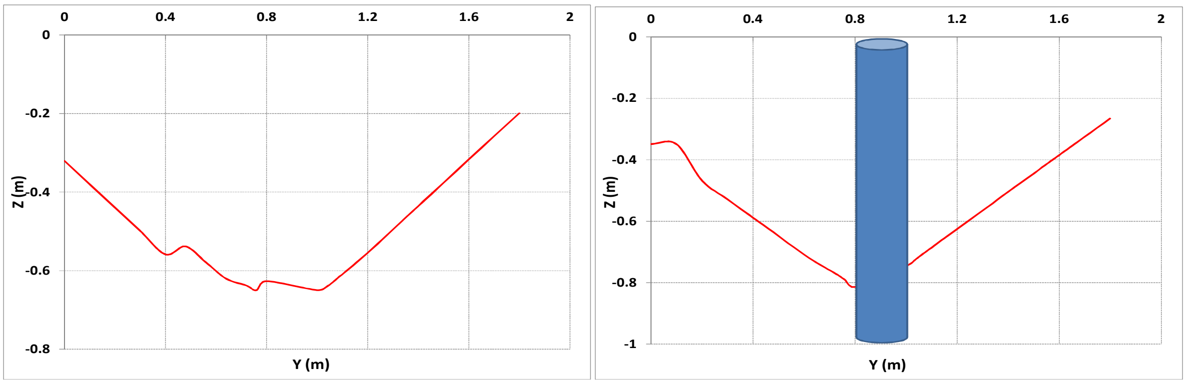
Fig. 2 Developed mesh with one bridge pier

Table I shows the characteristics of flow and properties of the river and the bridge pier.

TABLE I
CHARACTERISTICS OF FLOW AND PROPERTIES OF THE RIVER AND THE BRIDGE PIER

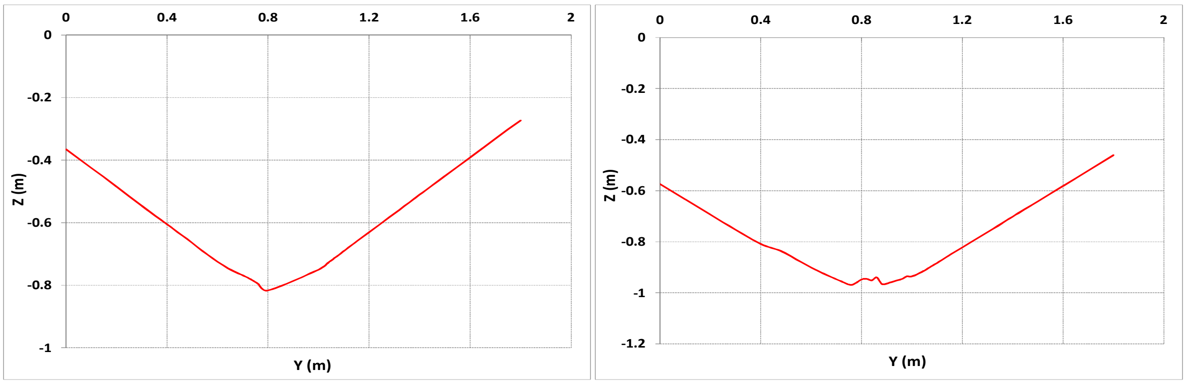
Pier shape	Pier diameter (m)	Effective span (m)	D_{90} (m)	Sediment size (D_{50}) (m)	Discharge (m^3/s)	Mean velocity (m/s)
Cylindrical	2	1.8	0.01	0.0083	0.459	1.5

Fig. 3 shows four cross sections of scour around pier, (a) shows scour cross section at the beginning of pier and (b) shows the scour cross section at the middle of the pier, (c) shows the scour cross section at the downstream edge of the pier, and (d) shows the scour cross section at x = 5.5m. From this figure it can be seen that maximum scour depth is about 1 meter. While the designed foundation's height is 1.5 meter, then the foundation is designed well against scour phenomenon.



(a)

(b)



(c) (d)

Fig. 3 Scour cross sections around bridge pier a) X = 4.9 m b) X = 5 m c) X= 5.1 d) X= 5.5 m

Fig. 4 indicates the scour contours throughout the channel. The results showed that the maximum scour depth occurs at the downstream side of the pier and X = 7.5 m.

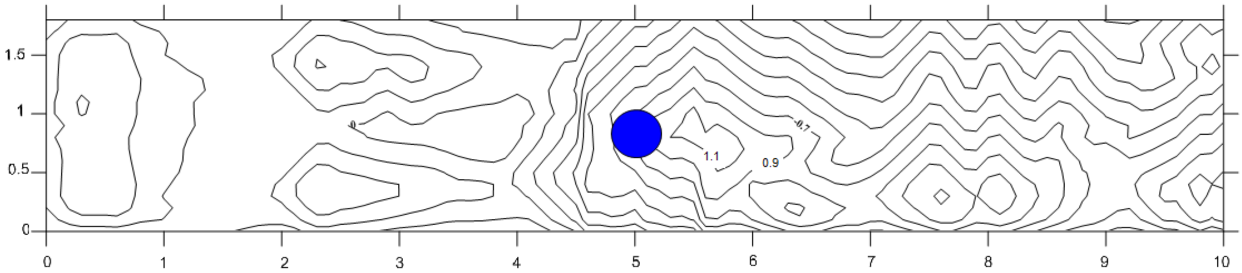
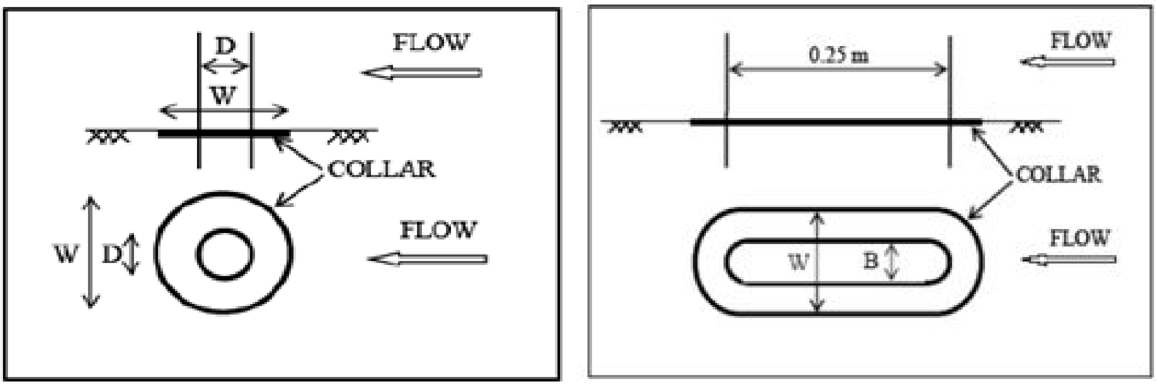


Fig. 4 Scour contours throughout the channel

IV. RETROFITTING METHODS

A. Collar

Collar is a prevalent method for preventing scour, which is often used for bridge piers and abutments. Collar is a thin steel plate which is connected to bridge pier or abutment. It may be installed in different levels from the bed. This protective disc is a thin plate to prevent proceeding of the scour. Being installed to the exterior part of the abutment or pier, collar acts as an obstacle against downward flow, by preventing direct contact of the flow and the bed. The main function of the collar is to bear the compression force and reducing them and also to alter the local scour mechanism and reducing the scour. Fig. 5 indicates collar installation to circular and rectangular pier [8].



(a) (b)

Fig. 5 Collar installation on a) circular pier b) rectangular pier [8]

B. Parallel Wall

Constructing guidance walls made of stone or embankment beside bridge pier causes the scour to be conducted to a further area from the bridge pier, by adjusting flow development. The main application of this method has been reported in USA. The guidance wall prevents the erosion caused by eddies effects in the time of flood when it is moving at upstream direction. Length shape, size and downstream area are the effective factors in reducing scour. Guidance wall provides a flat pathway to the main channel at the time of flood and conducts the flow at the channel route [14].

C. Spur Dike

Using spur dikes as an indirect technique for erosion protection is one of the common and economic methods. A spur dike is a structure that projects from a stream bank into the river channel and causes a redirection of flow away from the bank toward the tip of the spur dike. These structures are usually preferred to be built in group. Spur dikes benefit the stream by reducing velocities near the banks and create still water areas that encourage deposition and channeling flow to reduce the width and create a defined channel [12].

D. Direct Protection

Due to the fact that protectors usually are subjected to destruction and fracture, the direct protecting methods are useful for short time protection against the scour. For long time protection, in order to respond to the natural flow of the river, factors such as maintenance, reconstruction and installation of additional protectors, must be taken into account. Among direct techniques Rip rap and CTB are common in usage [15].

V. CONCLUSION

In this research, bed changes around cylindrical bridge pier were studied with numerical method. By investigating the local scour depth and scour cross sections the following main results were found in this research:

- Scouring is an important phenomenon which can lead to the structure collapse.
- The amount of scour depth should be calculated before the foundation design. And the foundation height should be more than scour depth.
- The SSIIM 2.0 three dimensional numerical modeling can simulate the scour phenomenon around cylindrical pier well.
- The maximum scour depth occurred at the downstream side of the pier and at $X = 7.5$ m.
- The results showed that the maximum scour depth is lower than the designed foundation height, and then the foundation is well designed against scour phenomenon.

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