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ANALYZING THE PERFORMANCE OF COLLAR AND SLOT IN REDUCTION OF SCOURING THE BRIDGE PIERS WITH SOFTWARE SSIIM

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Abstract: *Erosion and transporting the separated bed materials by flow is called scouring. One of the main reasons for destruction of bridges, especially in flood events, is the local scouring around the bridge piers. Depth of local scouring around the bridge piers plays an important role to design the bridges against this destructive phenomenon. Therefore, the methods of controlling and reducing this phenomenon are important. Collar and slot can be modeled by SSIIM while it is the three–dimensional software regarding time, as well as the scouring depth and its reduction can be evaluated. Finally, collar and slot have been tangible impact to reduce the scouring depth and there is no notable difference between the results of numerical modeling and the experimental model.*
Keywords: *Scouring depth, Collar, Slot, Software SSIIM*

INTRODUCTION

Flow in open channels and ducts with moving bed cause the sediment transport. Scouring is usually occurs by changes of the flow characteristics in channel or by the human activities and actions on the river system. Activities such as building structures in the channel s or removal of materials from the riverbed are defined the scouring as the riverbed sediment erosion around an obstacle in the flow field. Bridges, as key roads, are the most important and busiest river structures. Every year, many of these bridges are destroyed because of flood occurrence in the river, just when they are most needed (Tahmasby, 2009). In most cases, breaking the bridges is often occurs in condition of flood flow due to the erosion of bed materials around the pier and foundation of bridges. Erosion mechanism has sufficient potential to threaten the integrity of the hydraulic structures and bridges in which it is caused to full breakage of structures after the foundation of structures and substructures are destroyed completely.

Because of expanding the erosion pit threatens the stability of bridge structure, predicting the sunken size and adopting the necessary measures to suppress it are considered the common engineering practices in the field of river engineering, so the scientists of hydraulic and river engineering focus on it specially. Regular and smooth flow of the river is changed after hitting the bridge pier and it is created due to the diversion of flow lines and formation of boundary layer in high pressure region in the upstream pier and low pressure region in the downstream pier. This intensifies the pressure gradient and creates a kind of secondary flow around the bridge pier that is known so–called horseshoe vortex.

The phenomenon results of speed distribution and its reduction around the bed in smooth flow of upstream in which in turn leads to an imbalance in the dynamic pressure. Horseshoe vortex is another important part of flow field around the bridge pier. The torsional power flow is a three–dimensional in which the downstream flow as well as the eddy fields on the main flow (upstream smooth flow) is effective to form it.

In the figure 1, the flow field around the bridge pier is formed of three distinct regions. The upper part of flow is diverted to the down after hitting the bridge frontal and formed a downstream flow region.

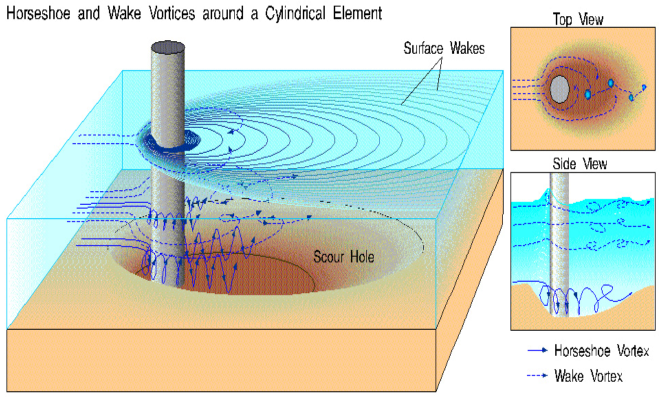

Figure 1 – Three–dimensional model of flow around the bridge pier

Flow pattern and scouring mechanism around a bridge pier and anchor is a complex phenomenon that is result of a power reaction between the three–dimensional turbulent flow around the bridge pier and the floor can be erosion. Local scouring around the bridge piers is caused by under flow and horseshoe vortex.

Radkivy Vatma (2004) has described some parameters affecting the scouring such as flow rate, flow depth, width or diameter of the pier, gravity velocity, the length of pier if the pier has an angle basis of the flow, the size of bed particle grading, flow angle to the pier, the pier shape and the effect of floating materials (ices and trashes (Alabi, 2006).

Shafai Bajestani (2005) was classified the stated parameters in four groups as follows:

1. *Hydraulic parameters: intensity and flow depth, shear velocity, mean velocity, and roughness coefficient.*
2. *Geometric parameters: the size of pier, the shape of pier, the axis angle of bridge with the flow direction, the distance of piers.*
3. *Sediment parameters: grading distribution, sediment density, particles' shape, stagnation angle of particles.*
4. *Fluid parameters: the mass per unit volume, gravity velocity, kinematic viscosity.*

Kochakzadeh et al (2002), using the available data, have examined the feasibility of using artificial neural networks to estimate the scouring depth. The results shown that there was good agreement between the network and measurements and it was even better than the linear multivariable regression. Also sensitivity analysis on the parameters affecting the phenomenon showed that the geometric standard deviation of bed particles has the greatest impact on the results and other influential factors, such as flow speed, average diameter of particles, pier diameter and the flow depth were studied in next times.

Oronghi et al (2009), using a rectangular collar at the cylinder pier, observed that the collar decreases the speed of scouring and depth of scouring hole around the bridge pier, and the collar's dimensions have an important role to decrease the scouring around the bridge pier. Collar length in upstream and downstream of the bridge pier model and the collar width has studied too. The proper values of rectangle collar length in upstream and downstream that were measured than the foundation of bridge pier model, were determined 0.92 and 1.42 by the pier diameter, respectively. Since, the proper width of collar was estimated 3 times than the bridge pier; so after 62 hours, the little scouring was observed around the bridge pier.

Oronghi et al (2008) have studied the temporal variation of scouring depth around the bridge pier in the conditions of clear water scouring. Experiments showed that more than 80% of the scouring depth was done in the first hours and then the rate of scouring is decreased sharply. There is a definition for the time of equilibrium of scouring depth, and then it was compared with the proposed definitions by researchers.

The results showed that the definitions of researchers are often express less time for the equilibrium of scouring depth. The equilibrium scouring depth was extracted in different states and compared with the proposed relations of researchers along with a good agreement. There was an experimental correlation for the temporal variation of scouring depth and also comparing the relation with the available correlations showed the acceptable results.

Radkivy Vatma (2004) has described the parameters such as flow rate, flow depth, width or diameter of the pier, gravity velocity, the length of pier (if the pier has an angle basis of the flow), the size of bed particle grading, flow angle to the pier, the pier shape and the effect of floating materials (ices and trashes on the flow.

Tayeb Zadeh et al (2005) have used the SSIIM numerical model to measure the equilibrium *scouring depth around the bridge piers with circular cross.Their research results indicated the high accuracy of the model by calculating the scouring depth in the conditions of permanent flow.*

Esmaeili et al (2009) have simulated the depth of scouring hole during the various hydrographs around the cylindrical piers by SSIIM numerical model. The results of numerical model were compared with available experimental data. However, the numerical results are in very good condition in the Ascending branch of the hydrographs but the accuracy of numerical results in the descending branch is dependent on the kind of hydrographs. This is while the major part of scouring occurs in the bridge pier in the ascending branch.

Sayyadi (2008) has provided the mathematical modeling of two–dimensional simulation to calculate the local scouring around the bridge piers. Navier – Stokes equation is used as an equation to simulate the velocity field. At first, Navier – Stokes equation was solved and then the velocity field was obtained. The velocities obtained in the horizontal plane, as input data to solve the sediment moving equation and the method of Galerkin residual weighted criterion, were used for sorting the Navier – Stokes equations. The studied scope was divided into eight group units and also the second–order functions were applied for velocities and linear pressure.

METHODS OF CONTROL AND DECREASE THE SCOURING

Researchers have provided several methods to prevent and decrease the scouring around the bridge piers in which the most important methods can be included the use of stile, submerged plates, protective candles, slot and collar.

In most studies, the methods of laboratory modeling and field observations have been used for the effect of using the collar and slot to control and decrease the scouring around the bridge pier. So the research is investigated the performance of collar and slot to decrease the scouring around the bridge pier using the numerical three–dimensional simulation. SSIIM three–dimensional software is used for modeling and analysis; and also the performance of simultaneous usage of collar and slot is investigated to decrease the scouring.

Using the Collar to Control the Scouring

Collars are the tools that are parallel to the river floor and be mounted perpendicular to the pier and they can prevent the downstream flow in the upstream cape of the pier as well as hinder the scouring pit. A collar that is mounted on the surface than a bed, divided the flow into two regions up and down. Top of the collar acts as a barrier against the downward flow and reduces the downward power by hitting the collar. At the bottom of the collar, downward power reduces by the horseshoe vortex (Chew, 1992).

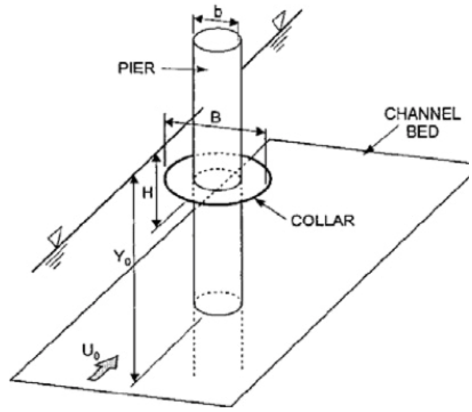

Figure 2 – Install the collar on pier

Using the Slot to Control the Scouring around Bridge Pier

Chiu (1992) at first uses the slot (hole into the pier) as one of the preventive methods and reducing the scouring. He stated that if the slot is close to the bed with a horizontal flow, the downward flow that is the main factor of horseshoe vortex and erosion around the pier would be diverted far away from the pier and reduces the scouring depth. The slot near the water surface reduces the effective depth of flow as well as the pressure gradient, thus it also reduces the downward flow and the scouring depth.

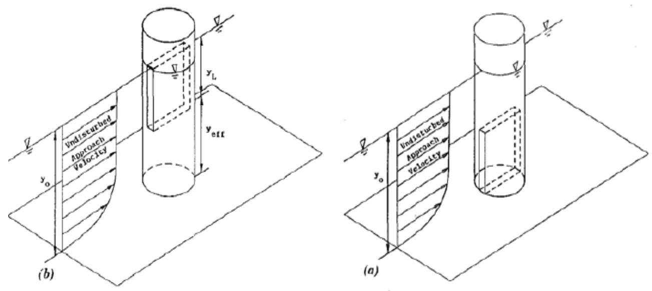

Figure 3 – (a) slot near the bed, (b) slot near the water surface (Chiu, 1992)

MATERIALS AND METHODS

The large number of parameters influencing the scouring effect can increase its complexity. Thus, a numerical model is needed that the use of discrete equations governing the flow field and sediment equations and applying some simplifying assumptions, has changed the complex relationships in this phenomenon into the solvable and simple equations. SSIIM three–dimensional numerical code can satisfy most of the requirements in various fields such as hydraulic scouring around the bridge piers.

Three–dimensional flow pattern and scouring under clear water conditions around a pile group were simulated using the SSIIM numerical model. Numerical model can solve the three–dimensional Navier – Stokes equations for the flow along with k–ε turbulence model.

Shear stress in the bed was used to calculate the near–bed sediment concentration and to solve the equation of transport – distribution of sediments. There are changes in the bed by solving the continuity equation for cells near the bed. By considering the state of convection flow and simultaneous solving the flow and sediment calculations, we can model the scouring around the pile group. Modeling is done for both fixed and moving state around the pile group. In the first case, the flow pattern clearly showed the dominant mechanisms on the scouring around the pile group. In the latter, the changes of bed, scouring and maximum depth of scouring can be modeled and the results were compared with experimental values. There was a good agreement between the shape and depth of scouring by the numerical model with the laboratory results. (Beheshti and Ataee Ashtiani, 2008).

Sayyadi (2008) has provided the two–dimensional mathematical simulation to calculate the local scouring around the bridge pier. Navier – Stokes equation was used as an equation that simulated the velocity field. At first, Navier – Stokes equation is solved and the velocity field is also obtained. Then the velocities obtained in the horizontal plane were used as input data to solve the sediment transport equation and the method of Galerkin residual weighted criterion for sorting the changes of Navier – Stokes equations. The studied scope was divided into eight group units and also the second–order functions were applied for velocities and linear pressure.

After solving the sediment transport equation with initial and final concentrations, the scouring depth and similar responses were compared with the laboratory measured values based on simulations that obtained by solving the Laplace equation with the finite difference method. In practice, the results showed a good agreement with the measured values. Finally, the effect of various factors such as flow depth, riverbed slope, and mean particle size on the depth of scouring was investigated. Graphs for investigating the effect of various factors with the scouring depth on the flow depth and their compare with the results obtained by the above equation using the finite difference method and the determined values have shown a good agreement.

In most studies, the methods of laboratory modeling and field observations have been used for the effect of a collar and slot to control and decrease the scouring around the bridge pier, therefore, this study examines the performance of collar and slot to reduce the scouring of bridge pier using three–dimensional numerical simulation. SSIIM three–dimensional software is used for modeling and analyzing, also the performance of synchronous usage of collar and slot was investigated to decrease the scouring. In this study, the phenomenon of local scouring and its reduction by helping the collar and slot will be investigated using a computer model, and the combination of collar and slot is used to reduce the local scouring depth. This project shows that what a performance is by reducing or increasing the collar and for reduction of scouring.

In the present study, a series of relevant data was provided using the principles of hydraulic scouring around the bridge pier and the studies by other researchers in the field of use of collar and slot in scouring and then the synchronous performance of two methods will be analyzed using SSIIM three–dimensional model. The accuracy of model will be examined by analyzing the modeling results using the statistical indicators such as Correlation Coefficient, Sensitivity Coefficient, Root Mean Square Error and Absolute Error and then they analyzed the results by the graphical tests. The statistical indicators used in the study include the correlation coefficient (R2):

$$R=\frac{\left(\sum_{i=1}^{n}(O_i-\overline{O})(P_i-\overline{P})\right)^2}{\left[\sum_{i=1}^{n}(O_i-\overline{O})\right]\left[\sum_{i=1}^{n}(P_i-\overline{P})\right]} \quad (1)$$

To calculate the root mean square error (RMSE), the following formula is used:

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(O_i-P_i\right)^2} \quad (2)$$

Also, to calculate the mean absolute percent error (MAPE), the following formula is used:

$$MAPRE=\frac{1}{n}\sum_{i=1}^{n}\left(\frac{|O_i-P_i|}{O_i}\right)100 \quad (3)$$

where O(i) is the observed value and P(i) is the estimated value, $\overline{O}$ and $\overline{P}$ are the observed and estimated values, respectively, and n is the used data. RMSE indicator is a unit equal to the variable unit and also is a criterion to measure the output error values of model than the observed values. RMSE index represents the square errors, as a result it has more sensitive to the error distribution and the gross errors affect more on the indices and the optimal values of this index is equal zero. MAPE index represents the percentage relative error and mean relative error and its optimum value is zero.

RESEARCH MATHEMATICAL MODEL

In this study, SSIIM model will be used to simulate the flow field that is a three–dimensional model for simulating the flow field and sediment transport using the various turbulence models. Evaluation of model results will be done using the measured data.

In this section, three–dimensional equations of flow and sediment transport will be presented that they solve in a three–dimensional numerical model as well as their numerical solutions are presented. Three–dimensional mathematical model used in this study is SSIIM model. Preliminary version of the model has been prepared by Melaaen Olsen in the Norwegian Institute of Technology in 1990 – 91 and has been developed in different years (Olsen, 2010). Navier–Stokes equations and turbulence models can be solved using a non–orthogonal three–dimensional grid. The control volume method is used for discretization. SIMPLE method is applied for relation of velocity and pressure term. The velocity field is calculated using the method of implicit solving, and also the velocity components are used to solve transmission and distribution equations for different sizes of sediment. SSIIM is used both structured grid in SSIIM1 model and unstructured grid in SSIIM2 model to solve the equations that is formed by two infrastructures of numerical solution and graphical schema. The flow equations in the software are the Navier– Stokes averaged temporal equations called Reynolds equations (RANS). The whole form of this equation is a continuity equation and three momentum equations in three directions that they will be presented after introduction of governing assumptions the model.

Governing Equations and their Numerical Solution in Three–Dimensional Model

Due to the above assumptions, the governing equations used in a three–dimensional model are written as follows (Olsen, 2010):

Correlation:

$$\frac{\partial U_i}{\partial x_i}=0 \qquad i=1,2,3 \quad (4)$$

Momentum:

$$\frac{\partial U_i}{\partial t}+U_j\frac{\partial U_i}{\partial x_j}=\frac{1}{\rho}\frac{\partial}{\partial x_j}(-P\delta_{ij}-\rho\overline{u_iu_j}) \qquad i,j=1,2,3 \quad (5)$$

In these equations, Ui is the temporal average of flow velocity in three directions, x coordinate position, t the time, P the pressure, δ Kronecker delta (Kronecker delta is 1 when i = j and otherwise zero), u velocity fluctuation than the time during a time frame Δt. The first term on the left momentum equation is a non–permanent term; the second term on the left is the convection term, the first term on the right is the pressure term and the second term on the right is the turbulence term that is capable to model using various turbulence models such as $\kappa-\varepsilon$ and $\kappa-\omega$. In the present numerical model, the method of solving equations based on the finite volume method is an implicit method and SIMPLC and SIMPLE methods are used for coupling the pressure and velocity fields. Convection terms can be modeled using the second order upstream difference methods or potential pattern, and Rhie and Chow pattern is used for interpolation. Reynolds turbulence stress term is *determined using the concept of eddy viscosity and Bosinski hypothesis.*

Turbulence Modeling

Laminar flow can be simulated using the correlation and Navier – Stokes equations completely. But if the Reynolds number of flow is high so the flow becomes turbulent in which the velocity and pressure will constantly and randomly changed over time, and the velocity fluctuations will increase the stress on the fluid. In this case, the irregular and stochastic behavior of the flow causes a non–permanent and three–dimensional flow. Such flows can be analyzed by entering the temporal fluctuations of the turbulent flow profile into the Navier – Stokes and correlation equations in which in this case, in addition to the four unknown components of velocity and pressure, the other six unknowns called Reynolds stress are also enter the system of equations. The number of equations is less than the number of variables, and closing the system of equations and calculating the unknowns needed to additional equations for Reynolds stress. The additional equations are known as turbulence models. $\overline{u_i u_j}$ *term in momentum equation (Equation 3–4) shows the fluctuation of turbulent flow and transfers the turbulent momentum called Reynolds stresses, and additional equations needed for calculating the unknowns in which Bosinski hypothesis is used for the reason. In this theory, like Newton's Second Law, the turbulent stresses are assumed proportional to the velocity gradient (Olsen, 2010):*

$$-\overline{u_i u_j} = \nu_t \left(\frac{\partial U_j}{\partial x_i} + \frac{\partial U_i}{\partial x_j}\right) + \frac{2}{3}\kappa\delta_{ij} \qquad (6)$$

In this equation, the eddy viscosity ν_t *(x, y, z, t) is not constant property of fluid, but the function of time and position of flow field, it is necessary to determine* ν_t *distribution throughout the flow field in all calculations. Turbulence models are used to determine the eddy viscosity. Turbulence models are calculated the Reynolds stresses based on the concept of eddy viscosity (Bosinski hypothesis) or directly to calculate the Reynolds stresses. Turbulence models based on the eddy viscosity are divided into the zero–equation, one–equation and two–equation models. The most important models are presented below.*

Law of the Wall and Bed Form Roughness

The public law of the wall is used for strong velocity gradient adjacent to the boundaries in the numerical model as follows (Olsen, 2009):

$$\frac{u}{u_*} = \frac{1}{\kappa}\ln\left(\frac{30y}{k_s}\right) \qquad (7)$$

Where k_s *is the roughness of wall or bed and assumes a coefficient of particle size or bed form dimensions. Van Rijn relationship (1993) is used to determine the default dimensions of bed form in the model:*

$$k_s = 3.0d_{90} + 1.1\Delta\left(1.0 - e^{\left(\frac{-25\Delta}{7.3y}\right)}\right) \qquad (8)$$

$$\frac{\Delta}{y} = 0.11\left(\frac{d_{50}}{y}\right)^{0.3}\left(1 - e^{-0.5\left(\frac{\tau-\tau_{c,s}}{\tau_{c,s}}\right)}\right)\left(25 - \left(\frac{\tau-\tau_{c,s}}{\tau_{c,s}}\right)\right)$$

Δ is the bed form height, t_c*, s is the critical shear stress for s particle size.*

Three–Dimensional Sediment Transport Equations

Sediment transport is calculated as suspended load and bed load and separately in SSIIM numerical model and then the changes in bed level are simulated using the whole transmitted sediments, (Olsen, 2009).

Suspended Load Transport Equation

The suspended load is calculated using the three–dimensional equation numerical solution of transport – distribution (Olsen, 2010):

$$\frac{\partial c}{\partial t} + U_j\frac{\partial c}{\partial x_j} + w\frac{\partial c}{\partial z} = \frac{\partial}{\partial x_j}\left(\Gamma_t \frac{\partial c}{\partial x_j}\right) \qquad (9)$$

Where c is the concentration of suspended sediment; w the fall velocity; x_j *the coordinate position; z the vertical position;* U_j *the velocity of* x_j *direction and* Γt *the distribution coefficient that is called dispersion coefficient in the one–dimensional models. A transport phenomenon occurs by the effect of flow velocity and the diffusion phenomenon occurs also in the effect of density gradient and turbulent mixing. The boundary condition is needed for solving the equation that is done at the inlet boundary of a given concentration, and the symmetry boundary conditions (zero gradient) is used in downstream* *borders, outlet and sides, and the concentration of water surface equals to zero. There is two ways to introduce the bed boundary condition in diffusion–transport equation: one, a source term adds for the bed's cells in which the removal rate of sediments is determined according to it and the other, the Fan Rhine equilibrium concentration relation is used for the model. According to the Fan Rhine equilibrium relation, the following equation is satisfied in the volume controls adjacent to the bed (Ruther, 2006):*

$$c_{b,suspendedload,i} = 0.015\frac{d_i\left[\dfrac{\tau-\tau_{c,i}}{\tau_{c,i}}\right]^{1.5}}{aD_i^{0.3}\left[\dfrac{(\rho_s-\rho)g}{\rho v^2}\right]^{0.1}} \qquad (10)$$

In the equation, di is the sediment size, υ the fluid cinematic viscosity, ρ_s the specific weight of sediments, ρ the special density of water, $\tau_{c,i}$ the particle shear stress per sediment size based on Shields curve and τ the shear stress. a is the base height and equals to the roughness height. Sediment concentrations calculated from the above equation is used for volume control adjacent to the bed, and the concentration is calculated to solve the three–dimensional numerical equation (3–21) for the upper level of control volume.

Bed Load Calculations

In most methods for calculating the bed load, the flow is uniform and the flow depth is showed as one of the parameters. The secondary flow in three–dimensional flows is effective and due to the lack of credit in logarithmic distribution of velocity, most equations of bed load are not usable and the equations of bed load included the relevant parameters to the bed: sediment characteristics, shear stresses of bed and turbulence. However, Fan Rhine offered the equation of dimensionless bed load with Shields parameters and particle size. The calculation process of sediments in the field of three–dimensional numerical model is based on figure 1–3. The volume of white and shaded controls (two upper layers) represents the real computational field. The suspended sediment transport and bed load transport occur in the volume of white and shaded control respectively. The volume of shaded controls is divided into two sediment transport layers of active and passive, and then formed a virtual computational field together (Ruther, 2006).

The bed load transport occurs in the shaded area where cells are adjacent to the bed, in which the volume of bed load in the layer is calculated using the Fan Rhine equation in the three–dimensional model. In computational model of bed load, qb is calculated for each particle size using the Fan Rhine equation as follows (Ruther, 2006):

$$\frac{q_{b,i}}{d_i^{1.5}\sqrt{\dfrac{(\rho_s-\rho)g}{\rho}}} = 0.053\frac{\left[\dfrac{\tau-\tau_{c,i}}{\tau_{c,i}}\right]^{2.1}}{d_i^{0.3}\left[\dfrac{(\rho_s-\rho)g}{\rho v^2}\right]^{0.1}} \qquad (11)$$

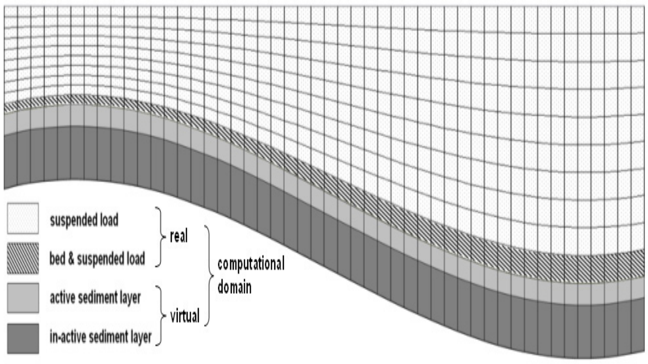

Figure 4 – Longitudinal view of computational field for sediments (Ruther, 2006)

The model is used the Fan Rhine equation to calculate the effective height of the bed form and roughness. The critical shear stress and shear stress are determined according to the Shields critical shear rate and shear rate respectively (Olsen, 2009):

$$\tau = u_*'^2, \qquad \tau_{c,i} = u_{c,i}^2 \qquad (12)$$

Once the model using the above equation can be calculated any size of bed load, it is converted to concentration using the following equation (Olsen, 2009):

$$c_{bed,bedload,i} = \frac{q_{b,i}}{aU_b} \qquad (13)$$

Where a is the base height and equals to the half of height in the first control volume, and U_b is the velocity in the first control volume adjacent to the bed.

Calculate the Shear Stress for Bed

Given the rate of bed cell, height of bed cell and roughness; the shear stress for bed is determined using the law of wall (Olsen, 2000):

$$\tau_{bed} = \rho U_*^2 = \frac{\kappa U_{bed}}{\ln(\frac{30\delta n}{k_s})} \qquad (14)$$

Where δ_n is the vertical distance between the wall and center of boundary cell, and k is the Carmen constant. If k_e turbulence model is used, assuming that the production and dissipation of turbulence is in equilibrium state near the wall, the amount of shear stress is determined due to the given κ in the first center of control volume adjacent to the bed as follows (Khosronejad, 2005; Olsen, 2000):

$$\tau_{bed} = \sqrt{c_\rho}\,\rho\kappa = 300\kappa \qquad (15)$$

Note that T_{bed} is special density of water and equals to 1000, Cp is a constant quals to 0/09 and k is the turbulent kinetic energy in the first center of cell adjacent to the bed where the turbulence model has been calculated, and the above equation can be obtained where the placement of values in the boundary conditions represents the turbulent kinetic energy in the first control volume adjacent to the bed (Khosronejad, 2005).

Calculate the Critical Shear Stress

The critical shear stress for sediment particle movement is determined basis on the Shields curve as follows (Olsen, 2000):

$$\text{For} \quad R_* > 500 \quad \tau_{*c}$$
$$\text{For} \quad R_* < 500 \quad \log(\tau_{*c}) = a\log R_* + b(\log R_*)^2 + c(\log R_*)^3 + d(\log R_*)^4$$
$$a = -0.9986312 \quad b = -0.92539586 \quad c = 0.5428363\,1d = -0.0848406 \qquad (16)$$
$$R_* = \frac{U_* d_s}{\nu} \quad \tau_* = \frac{\tau_c}{g(\rho_s - \rho_w)d_s}$$

Experimental Data Set Used in the Study

The experimental channel has length 10 m, width 30 cm and height 50 cm. The Flow can be seen from the wall of glass channel while its floor made of metal. Maximum capacity for the supply source of a pump is 24 liters per second. The closed–circuit system of flow can provide a long opportunity to continue the experiments. The Flow control is done by a valve on the drift tube of pumping system. Flow rate was measured by an overflow edge.

Since the sediments have about 16 cm height in experimental range, the part of upstream and downstream of the experimental range due to the materials thickness was brought up about 16 cm using the Plexiglas plates. The floor aquarium glue was used for sealing plates mounted with the walls of channel and thus the floor height was brought up 16 cm in channel length. The height of the new channel in downstream reduces with a medium gradient to the outlet area and behind the control valve on lower level and then upper level of upstream and downstream regions was coarse by the used particles in the experimental range. In order to complete development, the flow of experimental range is considered with 5/1 m length at 5 m distance.

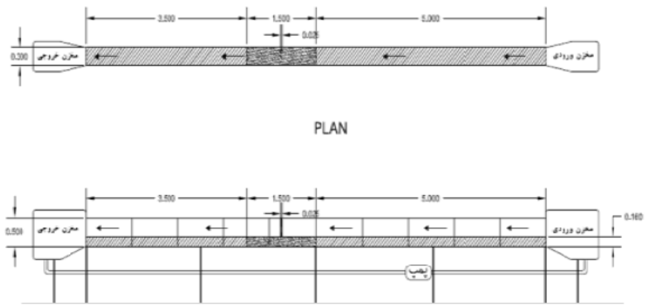

Figure 5 – Plan and view of the laboratory flume

ANALYSIS OF RESULTS

The first and most important step in preparing the input data required for SSIIIM model is the building of computational network. The size and direction of the computational cells have a significant effect on the accuracy of the model results and also the convergence and computational time for the model is built as a function of network characteristics. It is necessary that the computational network around and adjacent to the bridge pier should be finer than farther regions in order to achieve the desired accuracy and better results. Therefore, in this study, the upstream and downstream regions are simulated with coarse mesh to 5/3 m length and 2 m length, respectively. The region near the bridge pier (two sides of the bridge pier with 5/1 m length) is simulated using the finer mesh; also the region around the bridge pier with 5/1 m length and 16 cm in thickness where there are sediments is modeled with smaller mesh.

Mesh dimensions in upstream and downstream regions of the bridge pier are 10 cm in longitudinal direction and 1 cm in transverse direction. The finer mesh is used with 5 cm in longitudinal direction and 1 cm in transverse direction around the regions adjacent to the bridge pier, and the mesh dimensions is 5/2 × 5/0 cm around the bridge.

Finally, the computational mesh for total regions is obtained by connection the three computational meshes shown in previous figures together and along the downstream end of the flume that is obtained in the face.

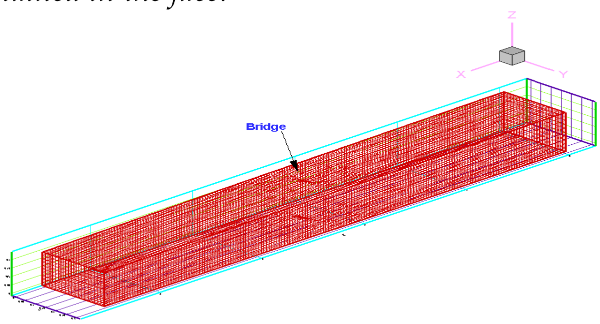

Figure 6 – The generated mesh around the bridge pier

Results of Scouring the Bridge Pier without Collar and Slot

This section is provided the results of scouring around the bridge pier and in the absence of collar and slot. The experimental range is considered with 1/5 m length far away 5 m from the top of the channel in order to complete the development for the flow.

The deposits fallen in experimental range was 16 cm in thickness. Therefore, the floor level of channel was brought up about 16 cm in the upstream and downstream regions. To avoid the wall effects on the rate of scouring as Chiu and Melville told, the maximum pier diameter should be 10% of the channel width, and according to a theory by Radkivy Vatma, the ratio of channel width to the pier diameter should be larger than 6/25. Thus, a Teflon plastic cylinder with 25 mm in diameter was used to model the pier.

To prevent the formation of bed form (Ripple), the average diameter of particles should be larger than 0/7 mm. Also, D/d_{50}> 20–25 needed to removal of the effect of the sediments on scouring depth. D is the pier diameter and d50 is an average particle size of sediment. Therefore, the deposits with d_{50} =0/8 mm is used. On the other hand, there is no effect on the scouring volume if the flow depth is larger 3/5 times than the pier diameter.

The topography of scouring hole created around the pier is shown that the scouring pattern is almost symmetric, and maximum scouring depth is equal to the obtained value in numerical model in which the value is 53 mm in laboratory model, and similar results is obtained with SSIIM model after calibration with the experimental data. Note that for calibrating the numerical model in study, the roughness coefficient and time pace are changed in deposit calculations and adjusted as there was the highest correlation between the results of numerical modeling and experimental modeling in which These values for the bridge pier without a collar and slot can obtained with the roughness coefficient 015296/0 and time pace 60 seconds

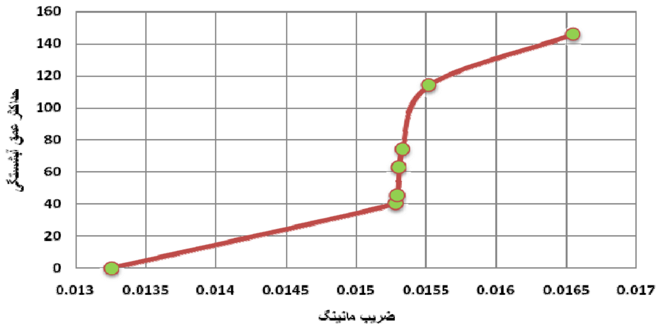

Figure 7 – Maximum changes for scouring depth around the bridge pier against the roughness coefficient in calibration stage of SSIIM model

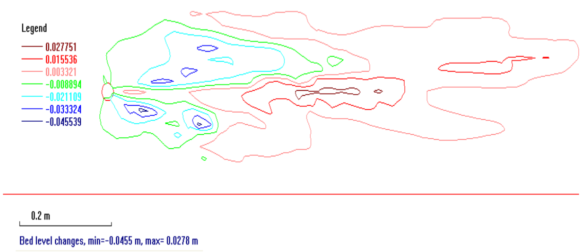

Figure 8 – Scouring around the bridge pier after seven hours in SSIIM calibrated model

Three–Dimensional Modeling for the Effect of Collar on Scouring the Bridge Pier

Geometry schema of channel, dimensions of pier, sediment characteristics and flow field is the same as previous state, and the square collar around the pier is just introduced in this part and the scouring is re–modeled. The square collar around the pier has 25/6 cm length as the results are presented in following figures. The collar is placed on the bed.

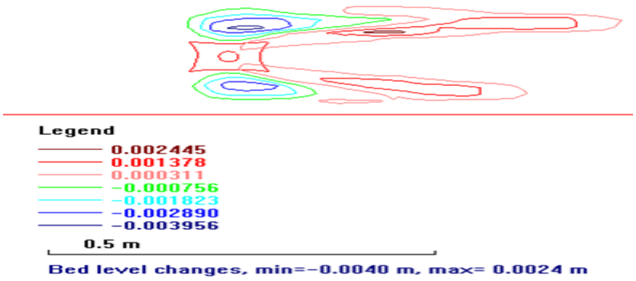

Figure 9 – Erosion of bridge pier after seven hours (Square collar 25/6 cm)

Three–Dimensional Modeling for the Effect of Slot on Scouring the Bridge Pier

A slot was added to the pier and its impact was simulated for reduction of the scouring around the pier using the three–dimensional numerical model. The slot is created with a width by a quarter in diameter of pier (25/ mm) and a length twice the diameter of pier (50 mm) on the model. Once the slot is the adjacent to the bed, and once is near the water surface, and its effect on the pier scouring is investigated too.

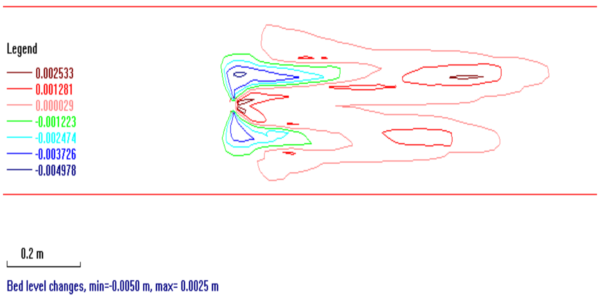

Figure 10 – Erosion of bridge pier after seven hours (slot adjacent to the water surface)

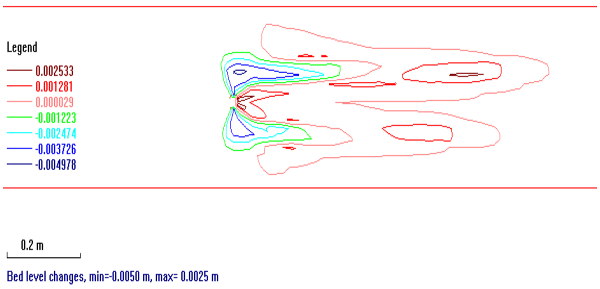

Figure 11 – Erosion of bridge pier after seven hours (slot adjacent the water surface)

Using the slot near the water surface, the scouring and erosion volume is much less than where the slot is in the vicinity of bed, and the slot efficiency near the water surface is better than the slot near the bed. So the next part will reviewed the effect of synchronous usage of collar and slot on the flow pattern and scouring around the pier, and their effectiveness has been analyzed to decrease and control the scouring.

Results of Three–Dimensional Modeling for the Effect of Synchronous Usage of Collar and Slot on the Pier Scouring

The effect of synchronous placement of collar around the pier and slot near the water surface on the results of flow pattern and scouring have been reviewed in this part, and also their performance has been evaluated to decrease the scouring depth.

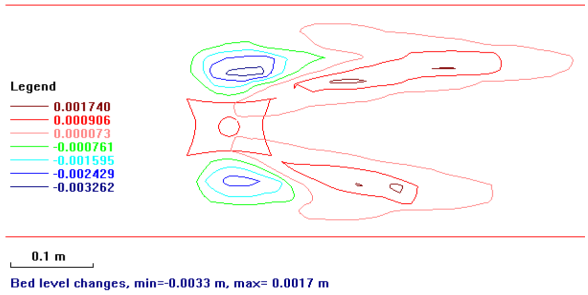

Figure 12 – Erosion of bridge pier after seven hours (collar and slot)

According to the results of numerical models, a dramatic reduction will be observed in scouring the pier at the first use of collar and slot. Finally, comparing the results obtained from the numerical model and laboratory model is shown a maximum difference 20 to 25% in different states.

CONCLUSION

The study of scouring phenomena and erosion of piers and foundations is one of the important considerations for designing the bridge pier of rivers. In past chapters, the erosion mechanism and methods to reduce and controlling this phenomenon was studied and the results of numerical modeling were presented graphically. Overall the obtained analyses and results are listed and finally suggestions are made to complement and enhance the design. Due to the limitations of physical models, it is inevitable to use the three–dimensional numerical model in complex problems of river engineering. However, the performance of three–dimensional numerical model is needed to consider the accuracy for calculations and approximations on different issues due to the existent assumptions and the required time to perform and non–convergence possibility. This thesis has been used the SSIIM three–dimensional numerical models of flow and sediment transport for a number of complex problems of river engineering.

- √ *The results of this thesis show that the used numerical models, one of the available three–dimensional models for engineers, can be predicted the acceptable values by simulating the flow and calculating the free level and changes of bed topography in rivers, and the acceleration error can be high in some points where there are strong rotational flows, but the model is capable to model the rotational flows and acceleration distribution.*

- √ *Applying the collar around the bridge pier can reduce the depth of local scouring by weakening the downward flow and horseshoe vortex.*
- √ *The results showed that the use of a square collar plays a significant role to reduce the scouring depth.*
- √ *The slot with creating the horizontal flow can divert the downward flows in front of the pier farther away and reduces the scouring depth.*
- √ *The combination of both collar and slot on the pier can further reduce the scouring depth.*

According to the mentioned notes, we can say that the accuracy of three–dimensional numerical models such the used model in the thesis is acceptable due to the required accuracy in engineering works, and in most cases it can be used to solve the issues of the river engineering.

SUGGESTIONS

- √ *Analysis of experimental results for the effect of collar and slot in various states and its modeling using SSIIM software*
- √ *Other methods of numerical modeling for reduction of scouring depth and its performance*
- √ *Further study and research is done in order to find new ways to reduce the scouring depth.*
- √ *Further study and modeling should be done to evaluate the effect of collar and slot on a single–pier and multiple–piers with different forms of pier.*
- √ *Other mixing methods should be done to reduce the scouring depth and also their performance to reduce the scouring depth should be examined using different study and modeling.*

Parameters

K: kinetic energy of turbulence
ε: loss of kinetic energy of turbulence
U: velocity component
p: fluid density
P: total pressure
$-p\overrightarrow{u_i}\,\overrightarrow{u_j}$ *: Reynolds stress term*
W: fall velocity of particle
Γ_T *: Distribution Coefficient*
Sc: Schmitt Number
d: diameter of sediment particles
a: reference level due to the roughness height
τ: shear stress of bed
τ_c*: Critical shear stress of bed for replacing the sediment particles due to the Shields diagram*
p_w*: water density*
p_s*: sediment density*
u: viscosity of water
g: acceleration of gravity
α: Angle between the flow direction and a line perpendicular to bed
φ: Angle of bed slope
θ: Slope Parameter

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