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CONTROL AND DECREASE THE SCOURING OF BRIDGE PIER BY METHOD OF NON-SUBMERGED PLATES USING SSIIM SOFTWARE

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ABSTRACT: Bridges are the vital components of each country's roads. Economic studies of the road construction show that the road bridges allocate much cost to it and due to the delicate structures of their system; they have great vulnerability as well. Therefore the detailed design of the various components of the bridge should be considered further. Erosion and transport of bed material is separated from it by a process called scouring. Occurrence of scouring around the bridge piers is one of the main reasons for the defeat and destruction of bridges and their instability. So it is important to provide methods to control and reduce this phenomenon. In the present study, the modeling of non-submerged plate's perpendicular to the water flow has been expressed in upstream of the cylindrical pier using software SSIIM. Reducing the depth of the scouring hole was observed in these pages, and has a great influence around the bridge pier.
KEYWORDS: scouring, bridge pier, non-submerged plates, software SSIIM

INTRODUCTION

Bridges are the most important and widely structures in which used in long period. In most cases the bridge structure is established on the river, in which its pier is will be in contact with the water flow. Long-term experience in establishing the bridge on river has led the engineers in the past few decades to issues to consider in the design of bridges in structural geology and the location of potential traffic is not enough, but the effect of water flow should be noted too.

Destroyed or damaged hundreds of large and small bridges in different parts of Iran in recent years due to frequent flooding demonstrate along with the proper technical knowledge of Iran's engineering society in designing the structures of bridge, the hydraulic aspects did not attention in this case. Thus due to scouring it is stressed that in most cases for lack of attention to the phenomenon, the bridge's structure has lost its efficiency and destroyed many years before overdue its useful life and this problem becomes critical when we are destroying bridges just in time (For example, in the event of flooding) that we most need to have access roads to aid victims of natural disasters. The severe flooding that comes with a lot of human and financial losses, in the last century the river engineering and flood control is particularly important in the world and in Iran.

The scouring is a phenomenon that occurs due to the bed erosion through water flow and moving the bed materials by a force that the flow exerts on the bed materials. This happens in the occurrence of flood when the use of bridge felt more. Therefore the study of scouring the bridge pier and applying methods and equipments to reduce the scouring around the piers is very important.

To the economical and reliable design for the bridge pier, it is necessary to estimate the maximum depth of scouring around the piers. At present the scientific basis for the structural design of piers is well known; although there is no specific and unique theory that estimates the scouring depth at the bridge piers with high confidence. To design the bridges, their piers should be deep enough to resist against the scouring. On the other hand, it pier should not be deep enough that cause the cost to increase. The use of methods to reduce the scouring depth around the pier, we can put foundations in higher levels that it will reduce the costs. Given the above issues, understanding the phenomenon of scouring and more importantly applying the methods to reduce the scouring around bridge piers seem necessary. Various forms of scouring may threat the stability of hydraulic structures and every year a lot of bridges around the world seriously damaged or destroyed by scouring phenomenon. In general, various types of scouring around the piers can be divided into three main categories: [1]

A. General scour: while the amount of sediment arrived to the river or a part of it, is less than the exit sediment, the erosion occurs in the floor or walls of the river. In this effect, the floor of river is dished gradually that it called Kafkani. Kafkani can enumerate as the effective factors to reduce the bed level around the bridge piers in long time period.

B. Scouring in effect of narrowing section : This type of scouring mainly occurs in the vicinity of the piers with near distances. In the scouring in the effect of narrowing flow section, the bed level and flow rate will increased and thus the potential for sediment transport will also increased from the river bed and near the bridge piers.

C. Local scouring: in general, the hydraulic structures and bridge piers may change the flow pattern and create the turbulence flows near the relevant structures and finally create a hole in the place of structures. This kind of erosion is severely in the flooding conditions and is one of main factors to occur the damaged hydraulic structures and bridges.

Numerous studies and experiments have been made by researchers to reduce scouring. To deal with this phenomenon around the bridge piers, there are three common strategies as follows: [2]

1. Put the foundation in lower levels than the depth of erosion pit.
2. Reduce the vortex pier formed around the pier
3. Creating the secure protection of revetment and or using the crack or collar or submerged plates around the pier.

This study examines and compares the performance of non-submerged plates to reduce scouring around the bridge pier. One of the most useful software in modeling and analysis of scouring phenomena is software SSIIM; the modeling and analysis of scouring phenomenon and also its reduction using the non-submerged plates will be discussed on the results obtained using the software and laboratory data.

The bridges at their construction site may cause to scouring in the rivers for several reasons. First to shorten the length of the bridge, the cross of the bridge is considered too narrow than the river level that it causes to increase the flow rate and cut-off tension in the bed and finally the scouring occurs (the scouring due to narrowing). Second because of pier and abutment, a three-dimensional eddy of vortex flow produces around that separates the grains from the bed and local scouring. This scouring is very important due to the complexity of formed flows. If there is a scouring in the river flow, it also added to the scouring of bridge. The bridge pier acts as a barrier against the flow of the river and affects its hydraulic properties. The geometry shape and location of pier for the flow length and also the number and distance of piers and amount of narrowing are the effective factors to change the flow location of river and its results. [2]

Many researchers due to the laboratory or field data and wide studies on the mechanism of scouring have provided many relationships to estimate and predict scouring depth. Each of these relationships is based on a number of parameters affecting the scouring. Some of the researchers consider the effect of one or two parameters in their relations and others use more parameters in their relations.

Inglis (1938) and Laursen. EM (1958) and Issard & Bradley (1959) and Hassounizadeh (1990) [3] and Dietz (1972) and Melville (1974) [4], have done numerous studies and tests to estimate the scouring. Garde & Raju (1977) [2] and Lauchlan (1999) and Chabert & Engeldinger (1956) [5] and Thomas (1967) and Ettema (1980) and Dargahi (1987) and Zaraty and Azizi (1997) [6] and Thomas (1967), Tanaka and Yanno (1967), Neill (1973) and Ettema (2001) [7] have conducted researches and experiments to control and reduce scouring. Asghar Azizian et al (2010) evaluated the scouring of bridge pier using the experimental results and using the numerical model HEC-RAS4.0 [8] and Masoumeh Rostam Abadi and Seyed Ali Akbar Neishabouri (2006) began a simulation of flow pattern around a plate over the bed of a rectangular channel using software FLUENT [9].

An extensive study has been carried to calculate the scouring using the numerical models of the actual flows on the river adjacent the channel by Lanca motta et al (2007) [11] and Tanana and also 524 bridge piers on Tanana river with respect to the proposed process HEC-18 (Richardson and Davis, 1994) in discharge condition of 100 and 500 years and the bridge of Tanana river in Parkers highway in Nenana region by Langley (2006) [13].

Using the flow field and sediment transport equations around the bridge piers, Sayadi (1996) calculated the depth of local scouring to use the finite element method. The study uses the Navier-Stokes equation as the equation that models the velocity field. Firstly the equation of Navier-Stokes to solve and the velocity field is achieved. Then the velocity in the horizontal plane uses ad the input data in the sediment transport equation [4].

Almasi (1999) using a physical model studied the scouring of rectangular piers in various modes and compared the obtained results with the results of theoretical relations. He tested the square and rectangular shaped piers and different angles to the prevailing rate in the channel [4].

Mohammad Pour and Rakhshanddeh Ru (2002) have studied the scouring around the cylindrical and non-cylindrical shaped uniform piers in the river structures. The scouring experiments have done in a flume on the basis of the surface area of a circle, square, triangle, rhombus and then the relationship between the measured data has been proposed to determine the changes of scouring depth [4].

Tayeb Zadeh et al (1384) used the SSIIM numerical model to measure the equilibrium scouring depth around bridge piers with circular cross.Their research results indicated the high accuracy of the SSIIM numerical model by calculating the scouring depth [10].

Taimaz Esmaeili (2009) with regard to the time factor was calculated the maximum scouring depth corresponding flood hydrograph using software SSIIM. The effect of changes for the geometry parameter of pier diameter as well as the change of pier shape were simulated by creating a gap in the cylindrical pier using software SSIIM. As expected, the diameter of cylindrical was correlated with the equilibrium *scouring depth but with a 2-fold increase, the pier diameter of equilibrium scouring depth around the pier increased by less than 60% [10].*

MATERIALS AND METHODS - INTRODUCING A NUMERICAL MODEL [14,15]

The SSIM model is three-dimensional software for simulation of water and sediment movements and it was developed by Nilz Oulsen in the Hydraulic Engineering department and Environment of Norway Science and Technology University. The three-dimensional CFD model is based on the finite volume method and solves Navier - Stokes turbulence model based on the standard turbulence model $K-\varepsilon$.

SSIIM model is the numerical software with applications in the field of river engineering, environmental hydraulics and sediment that the primary purpose of this software structure is to simulate the movement of sediment in the river and channel geometry. Then the application of this software was developed in other hydraulic issues such as spillovers modeling, drop in tunnels, relation between depth and discharge in rivers. The main advantage of SSIIM model comparing CFD software is an ability to analyze complex geometries to model sediment transport in live bed. During the years, SSIIM software has been used to model the crossing Salmon and algae as the calculation of water quality. However, most attention has been focused on sediment transport calculations.

SSIIM software solves Navier-Stokes equations with the standard model $K-\varepsilon$ on a non- orthogonal three-dimensional grid. For detached implementation, a control volume method can be used with Power-Law scheme or Second Order Upwind algorithm. SIMPLE method also uses as a default to correct pressure. This method is invoked by the set of information K 9 in the Control File. SIMPLE method is used to relate pressure and velocity terms.Using an implicit solution, the velocity field is calculated in geometry and the velocities use when Convection-diffusion equations have been solved for various sizes of sediment. SSIIM software uses to facilitate Input file from the dialog boxes.

□ ***Turbulence Model*** $K-\varepsilon$

Model $K-\varepsilon$ *is calculated vortex viscosity as follows:*

$$\mathrm{v}_{\mathrm{T}}=\mathrm{C}_{\mu}\frac{\mathrm{k}}{\varepsilon^{2}} \quad (1)$$

K is the kinetic energy of turbulence and defined as follows:

$$\mathrm{K}=\frac{1}{2}\overline{\mathrm{u}_{\mathrm{i}}\mathrm{u}_{\mathrm{i}}} \quad (2)$$

*Differential equation for **k** is expressed as follows:*

$$\frac{\partial \mathrm{k}}{\partial \mathrm{t}}+\mathrm{u}_{\mathrm{j}}\frac{\partial \mathrm{k}}{\partial \mathrm{x}_{\mathrm{j}}}=\frac{\partial}{\partial \mathrm{x}_{\mathrm{j}}}(\frac{\mathrm{v}_{\mathrm{T}}}{\sigma_{\mathrm{K}}}\frac{\partial \mathrm{k}}{\partial \mathrm{x}_{\mathrm{j}}})+\mathrm{p}_{\mathrm{k}}-\varepsilon \quad (3)$$

In the above relationship, p_k *is defined in the following form:*

$$p_k=v_T\frac{\partial u_j}{\partial x_i}(\frac{\partial u_j}{\partial x_i}+\frac{\partial u_i}{\partial x_j}) \quad (4)$$

ε *represents the rate of dissipation of k and is specified as follows:*

$$\frac{\partial\varepsilon}{\partial t}+u_j\frac{\partial\varepsilon}{\partial x_j}=\frac{\partial}{\partial x_j}(\frac{v_T}{\sigma k}\frac{\partial k}{\partial x_j}) + C_{\varepsilon 1}\frac{\varepsilon}{k}P_k+C_{\varepsilon 2}\frac{\varepsilon^2}{k} \quad (5)$$

*In equation (1) to (5), **C** is constant coefficients that cannot be changed by the user. As described,* $k-\varepsilon$ *turbulence model is the default turbulence model in SSIIM.*

We can summarize the equations governing the flow field in turbulent mode as the continuity equation and momentum equation. If it is assumed that the flow is constant $(\frac{\partial}{\partial_t}=0)$ *and the special density fluctuations are zero (* $p'=0$ *), then continuity and Momentum equations are expressed as follows:*

$$\frac{\partial}{\partial \mathrm{x}_{\mathrm{j}}}(\mathrm{pu}_{\mathrm{j}})=0 \quad (6)$$

$$\frac{\partial}{\partial x_j}(pu_iu_j)=-\frac{\partial p}{\partial x_j}\delta_{ij} + \frac{\partial}{\partial x_j}\mu(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i})+\frac{\partial}{\partial x_j}(-p\overrightarrow{u_i}\,\overrightarrow{u_j}) \quad (7)$$

In relations (6) and (7), U is velocity component, p the fluid density and P the total pressure. $-p\overrightarrow{u_i}\,\overrightarrow{u_j}$ *Term is the Reynolds stress term. According to the equations (6) and (7) , we can write three momentum equations and one continuity equations in which there are 10 unknowns (velocity in three directions of w, v, u and p pressure and six components of Reynolds stress) that means the field of equations governing the flow is not closed and Reynolds stresses are modeled by using mathematical methods. Thus, the turbulence equations will use to close the governing equation field.*

□ ***Equations Governing the Sediment Flow***

The process of calculations for SSIIM numerical model is that at first - sediment concentration is calculated by solving the Convection-diffusion equation of sediment in distance between the water level and the base level (a). The base level is considered in order to the equivalent roughness height. Sediment transport is traditionally divided into the bed load and suspended load. Suspended load can be determined using Convection-diffusion equations by calculating the sediment concentration.

$$\frac{\partial \mathrm{c}}{\partial \mathrm{t}}+\mathrm{u}_{\mathrm{j}}\frac{\partial \mathrm{c}}{\partial \mathrm{x}_{\mathrm{j}}}+\mathrm{w}\frac{\partial \mathrm{c}}{\partial \mathrm{z}}=\frac{\partial}{\partial \mathrm{x}_{\mathrm{j}}}(\Gamma_{\mathrm{T}}\frac{\partial \mathrm{c}}{\partial \mathrm{x}_{\mathrm{j}}}) \quad (8)$$

In above relation, the fall velocity of particle was determined by W and Γ_T *is distribution coefficient which is derived from standard equation* $k-\varepsilon$ *.*

$$\Gamma_T=\frac{u_T}{S_c} \quad (9)$$

S_c *is the Schmidt number which by default is equal to 1.*

Van Rijn has offered a formula for determining sediment concentration near the bed in 1978, which is as follows:

$$C_{bed} = 0.015\frac{d^{0.3}}{a}\frac{\left[\frac{\tau-\tau_c}{\tau_c}\right]^{1.5}}{\left[\frac{(p_s-p_w)g}{p_w u^2}\right]^{0.1}} \quad (10)$$

In the above relation, d is the sediment particle diameter, a is reference level of the roughness height, τ is bed shear stress, τ_c is critical shear stress of bed for replacing the sediment particles according to the Shields diagram, p_s, p_w are the sediment and water density, u is the viscosity of water, g is the acceleration of gravity. In SSIIM model, a reduction coefficient of critical shear stress use for sedimentation in sloping bed by Brooks (1963).

$$K = -\frac{Sin\phi Sin\alpha}{\tan\theta} + \sqrt{\left(\frac{Sin\phi Sin\alpha}{\tan\theta}\right) - Cos^2\phi\left[1-\left(\frac{\tan\phi}{\tan\theta}\right)^2\right]} \quad (11)$$

In this relation, α is an angle between the flow and a line perpendicular to the bed, φ is the slope angle and θ is the slope parameter. K factor is calculated by multiplying the horizontal plane at critical shear stress. The SSIIM numerical model is used the following equation to calculate the bed load in distance from the bed load to baseline level.

$$\frac{q_b}{D_{50}^{1.5}\sqrt{\frac{(p_s-p_w)g}{p_w}}} = 0.053\frac{\left[\frac{\tau-\tau_c}{\tau_c}\right]^{1.5}}{D_{50}^{0.3}\left[\left(\frac{(p_s-p_w)g}{p_w U^2}\right)\right]^{0.1}} \quad (12)$$

Experimental value of 53 0/0 is changeable in F 83 data set in the control file.

CHARACTERISTICS OF LABORATORY CHANNEL [16]

A set of long experiments using the cylindrical piers in channel have done with uniform bed under the limpid water in the hydraulic library of Okayama University. The tests have done in channel with 1600cm length, 60cm width and 40cm depth.

Water from a reservoir by a pipe is transmitted into the channel from a channel opening when discharge is measured by a sharp edged overflow. The flow rate in channel is set using a valve (tap water). The water depth was adjusted by a valve in downstream. Head on the sharp edged overflow and water levels were measured with a point gauge having 0.1mm sensitivity. A region with the moving bed with 100cm length and 60cm width and 57cm depth is embedded in 800cm distance in downstream of the beginning of channel and was filled with sediments having medium diameter of particles $d_{50} = 1.28mm$ and standard geometric deviation $\sigma_g = 1.29$. A vertical circular base with diameter $D = 6cm$ is inserted in the center of the moving bed that is created before the experiment. The water tap is smoothly adjusted without any turbulence in the bed materials until the expected discharge created. Steady stream is fully created under the limpid water for the required discharge. The whole process to complete the steady stream was stabilized under the limpid water in less than three minutes for each case. Experiments were stopped in a period when the scouring is created less than 1mm area or no scouring. The depths of scouring at different times were connected by a connected index. In this experiment, the water level is 200mm, cylindrical pier diameter is 6cm, average diameter of particles is $d_{50} = 1.28mm$, discharge is $Q = 0.4\,m^3/s$, time of scouring is 140min and scouring depth is 78mm.

NUMERICAL MODELING

In the present study, SSIIM numerical model (2007 Olsen) was used for the purpose of networking and solution of flow and scouring around the bridge pier. As part of the field networking is seen in figure (1), the smaller network near the pier but the larger network in longer distance.

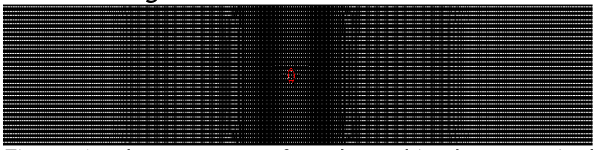

Figure 1 - the structure of mesh used in the numerical simulation and schematic view for smaller cells by approaching the pier

In order to verify the feasibility of the numerical model results from the lab results, discharge and water level of flume downstream are given to the numerical model as boundary conditions, then the numerical model or time steps 4s were calibrated with the roughness coefficient equal to 0.012.

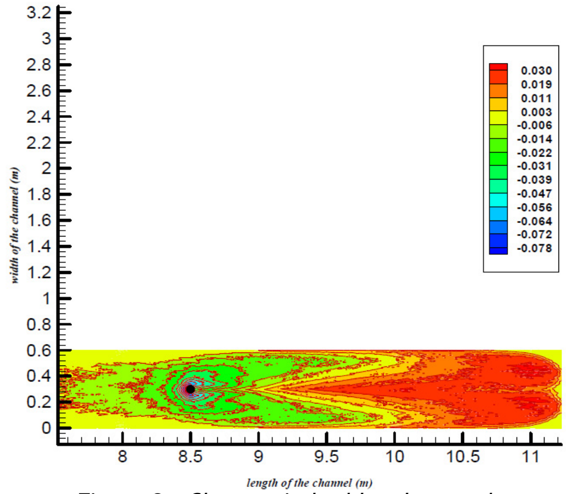

Figure 2 - Changes in bed level around the cylindrical pier

CONCLUSIONS

In the present study suggested that non-submerged plates which are designed as shear edged overflows to be used. These plates are modeled with different configurations and finally using the results obtained from the numerical model, they are selected the most optimum mode among different configurations. Then the plates are used in front of the bridge pier and the obtained results shows the reduced amount of scouring can be calculated using the plates.

In addition to create more sediments, the plates should be designed as reduce the scouring. To study *different configurations and determining the most optimum mode, various forms are modeled by the layout of plates as follows. According to the test specifications, since the diameter of the cylindrical pier is 6cm, the length of the plates' coverage in front of the pier is considered 12cm.*

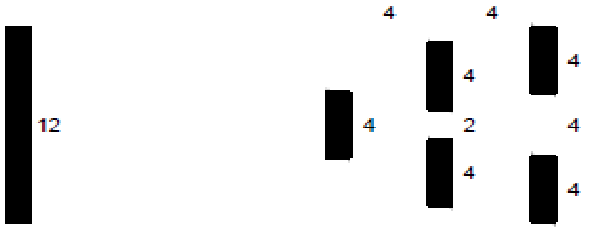

Figure 3 - Different configurations of plates

Now the results obtained from the above models are shown in various forms respectively.

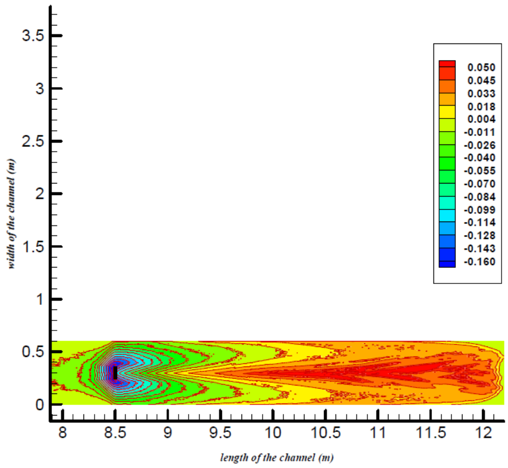

Figure 4 - Changes in bed level for a single plate model

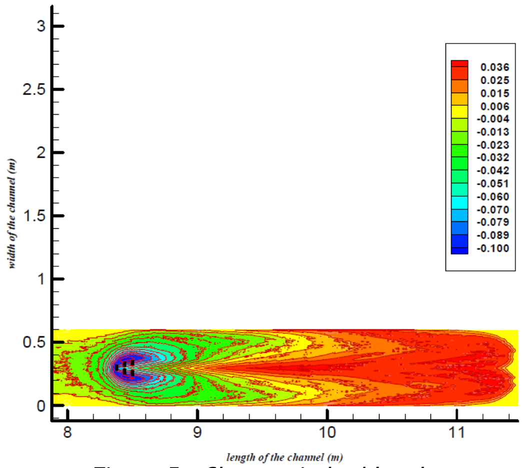

Figure 5 - Changes in bed level for the five plates model

Due to the sediment rate and scouring depth, we should consider a state that more sediment appears due to low scouring depth. According to the results obtained from the above figures, in five plates model, the scoruing depth is equal to 100.2mm and sediment rate is equal to 36mm, which is better than the other modes. As a result, the second model will use to examine the effect of sub-merged plates for reduction of scouring of cylindrical pier.

According to figure (6) observed that the area of deposited sediment is considered in range of 9m to 11.4m in channel and can determine that the range of maximum sediment is in 11m.

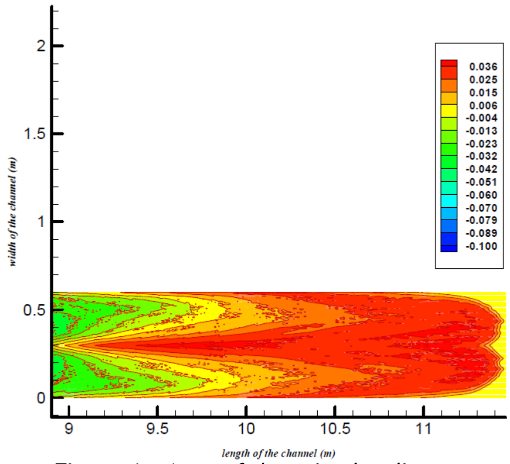

Figure 6 - Area of deposited sediment on the bed in Model 3

According to figure (6), the best points of the plates have been detected at 2.5m intervals in center of cylindrical pier and in upstream. The results of modeling, while the plates are embedded in the mentioned distances and cylindrical pier of upstream, are shown in figures (7), (8) and (9).

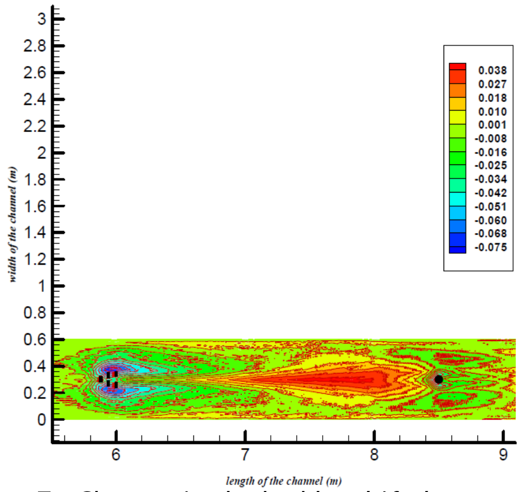

Figure 7 - Changes in the bed level if plates settled at 2.5m distance from the center of cylindrical pier and in its upstream

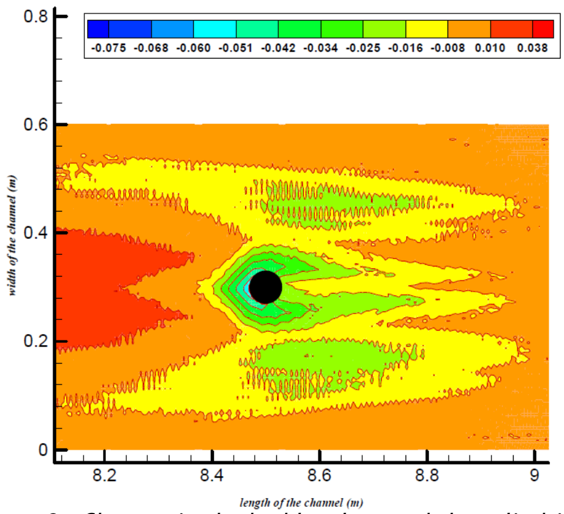

Figure 8 - Changes in the bed level around the cylindrical pier if plates settled at 2.5m distance from the center of pier and in its upstream

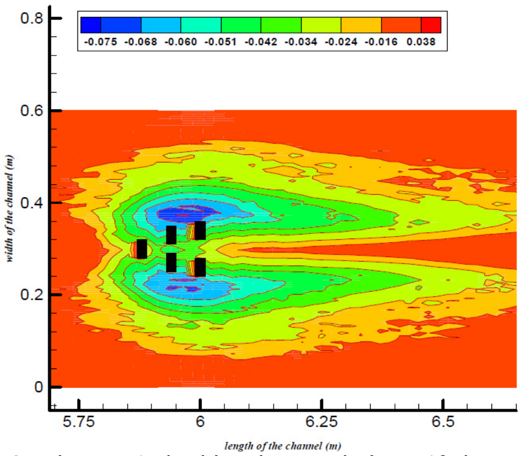

Figure 9 - changes in bed level around plates if they settled at 2.5m distance from the center of pier and in its upstream

As observed in figure (8) the maximum scouring around the cylindrical pier at 2.5m distance from the downstream of plates is equal to 0.051m and according to (9) we see that the scouring depth around the plates is equal to 0.068m. Finally the scoruing of cylindrical pier is reduced about 35% compared to the initial state.

RESULTS

1. In this research, using a laboratory model and SSIM models, it was attempted to offer the proper procedure to confront the scouring phenomenon. According to the represented results, the use of non-submerged plates with different spatial arrangements is a proper procedure to control the scouring phenomena.
2. The dimensions and the place of plates on the piers are considered as the important parameters in reducing scouring, in a way that between the two conditions that were analyzed the second modle (five-plates non-submerged plates) was shown better function in regards to scouring and its sediment area.
3. The scouring depth reduces considerably by changing the place of cylinderical pier in the sediment area of non-submerged plates.
4. SSIM software is a three-dimensioanl software and can model the expand of hole depth of scouring in a mode dependent to time. The software can be a good option for calculation of sediment and scouring depth around the bridge pier.

Parameters

K: kinetic energy of turbulence
ε : loss of kinetic energy of turbulence
U: Velocity components
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
S_c : 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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