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Flow Field and Scouring around Cylindrical Structure in Channel Bed

Sabita Madhvi Singh & P. R. Maiti

***Abstract*—Scour is the formation of scour hole around the structure mounted on and embedded in erodible channel bed due to erosion of soil by flowing water. The formation of scour hole around the structures depends on the depth of flow, shape and size of slender structure, angle of attack of flow and sediment characteristics. The flow characteristics around these structures changes due to manmade obstruction in the natural flow path which changes the kinetic energy of the flow around these structure. Excessive scour affects the stability of the foundation of the structure by the removal of the bed material. The accurate estimation of scour depth around bridge pier is very difficult. The foundation of bridge piers have to be taken deeper and to provide sufficient anchorage length required for stability of the foundation. In the present study, scour depth is estimated around circular piers by HEC-RAS for a straight channel. The flow characteristics around these structures are presented for different flow conditions. Mechanism of scouring phenomenon, formation of vortex and its consequent effect is discussed for straight channel.**

Keywords—Scour, Bridge pier, Pier shape, Horseshoe Vortex

I. Introduction

Scour at a slender pier is the formation of a hole around the pier due to erosion of soil by flowing water. It means lowering of the riverbed level by erosions as a result there is a tendency to expose the foundations of structure. Reduction of the flow area causes an increase in the average velocity for the same discharge, as well as increase in the shear stress over the stream bed. Scouring of bed material around bridge foundation is a common cause of bridge failure. Therefore, it is important to estimate the probable scour depth so that bridge foundations can be designed to support the structural load safely below the probable scour depth. The depth of scour below the riverbed level around the bridge pier in alluvial stream can vary depending on the depth of flow, shape of pier, size of the pier, angle of attack and sediment characteristics. The estimation of scour depth around piers for a bridge highly depends upon the accuracy and analysis of the hydrologic and hydraulic data.

The flow characteristic around the cylinder and its consequent effect on channel bed is important for its immense practical importance as for example flow around bridge piers. FLUENT may be used to predict the three-dimensional flow field around a circular cylinder for rigid beds. There was satisfactory agreement between the bed shear stresses predicted by FLUENT and those calculated from the experimental velocities near the bed. *Richardson et al.* simulated the flow structures around a bridge pier with and without the scour hole. They used FLOW3D with the RNG k-ε model. Comparing the simulated with the experimental results, they found that the 3D hydrodynamic model well simulates the complex flow patterns around the bridge pier.

The scour prediction methods developed based on laboratory data did not always produce reasonable results for field conditions *(Dargahi,; Jones,)*. The variability and complexity of site conditions make the development of methodology for predicting local scour at bridge piers difficult. They found only minimal agreement between the field data and laboratory-based relations. Laboratory investigations often oversimplify or ignore many of the complexities that are common in the field *(Mueller et al., 2002)*. Lots of research work has been done so far to develop equation for predicting the depth of scour. Researchers have also worked extensively to understand the mechanism of scour and the factors affecting the phenomena. Keshavarzi et at. (2014***)*** investigated the coherent turbulent flow around a single circular bridge pier and its effects on the bed scouring pattern. Pu and Lim (2014) studied for the abutment bed scour to reach its equilibrium state, a long flow time is needed. Hence, implement of usual strategy of simulating such scouring event using the 3D numerical model is very time consuming and less practical. Zhi-wen (2012) studied in order to predict the local scour hole and its evaluation around a cylindrical bridge pier, the computational fluid dynamics (CFD) and theories of sediment movement and transport were employed to carry out numerical simulations. In the numerical method, the time-averaged Reynolds Navier-Stokes equations and the standard k-ε model were first used to simulate the three-dimensional flow field around a bridge pier fixed on river bed. The transient shear stress on river bed was treated as a crucial hydrodynamic mechanism when handling sediment incipience and transport. Mousavi and Daneshfaraz (2013) studied on HEC-RAS software and found that HES-RAS software uses CSU and Froehlich (1991) equations to calculate local scour. In this study, software output and manual calculation output of CSU and Froehlich equations were compared.

Sabita Madhvi Singh, Research Scholar

Department of Civil Engineering, Indian Institute of Technology (Banaras Hindu University) Varanasi-221005, India

P R Maiti , Assistant Professor

Department of Civil Engineering, Indian Institute of Technology (Banaras Hindu University) Varanasi-221005, India

The present paper is concerned with the numerical simulations for the local scour around a bridge pier. The flow field around cylindrical pier is found by using ANSYS Fluent. The effect of pressure and turbulent kinetic energy is presented.

II. Governing Equations

The momentum equation for the incompressible viscous fluid flow is

$$\frac{\partial u}{\partial t}+(u.\nabla)u=-\frac{1}{\rho}\nabla p+\nu\nabla^2 u \qquad (1)$$

Where, **u** = Velocity Vector, ***p***= Pressure, **ρ**= Density of fluid, **ν**=Kinematic viscosity.

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{dx}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho_f}\frac{\partial p}{\partial x}+\nu\left[\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right]$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{dx}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho_f}\frac{\partial p}{\partial x}+\nu\left[\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right]$$

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{dx}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho_f}\frac{\partial p}{\partial x}+\nu\left[\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right] \qquad (2)$$

The continuity equation

$$\nabla.\vec{u}=0$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \qquad (3)$$

The flow behavior around slender structure can be found by solving the governing equation (1) with flow boundary conditions. The equation (1) is solved by using ANSYS software. The flow characteristics influence the bed shear and shear along the slender structure. The erosion and deposition characteristic of soil particles in channel section depends on the flow characteristics. The scouring around slender structure depends on the discharge, velocity, and particle characteristics of the channel bed. The scour is determined using HEC RAS software.

III. Results and Discussions

The flow field around a circular cylinder of diameter 0.3m is determined for a free stream velocity 2 m/s. The slender structure is kept vertical in an impervious bed and there is no influence of boundary wall.

The velocity vector, streamline and variation of pressure around the slender structure is analyzed using ANSY Fluent. The variation of different flow parameters are presented in the Figure 1 to Figure 6. The velocity contour and velocity surface stream line and stream line are found at a section 0.2m from the bed. Vortex motion is observed in the wake zone of the cylinder.

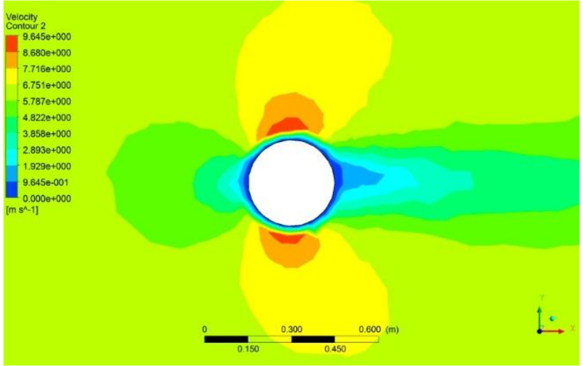

Figure 1: Velocity contour

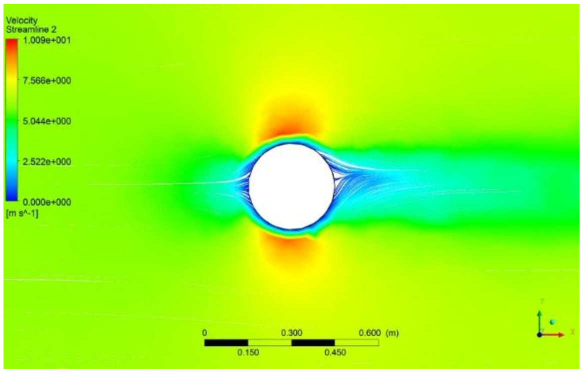

Figure 2: Velocity surface streamline

The turbulent kinetic energy, pressure contour and eddy viscosity contours are plotted at a horizontal surface 0.2m from bottom and presented in Figure 4 to Figure 6.

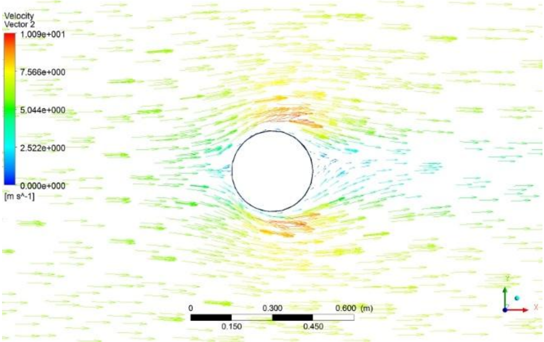

Figure 3: Velocity vector

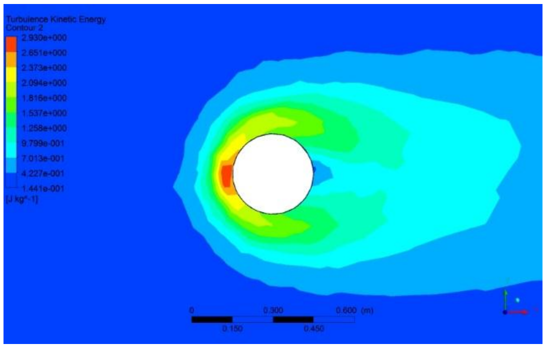

Figure 4: Turbulent Kinetic Energy

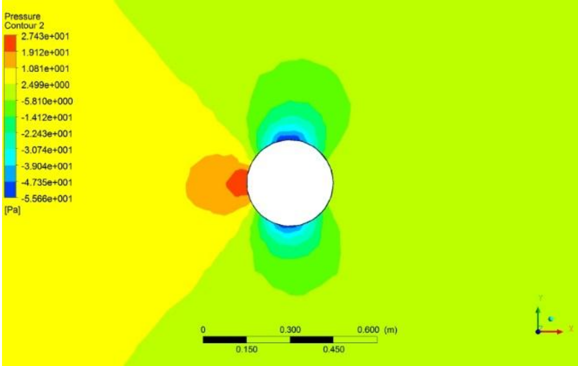

Figure 5: Pressure contour

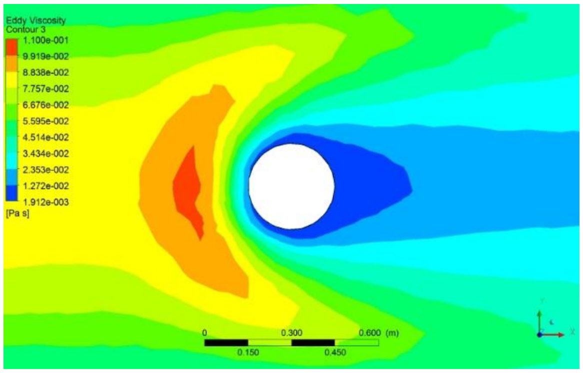

Figure 6: Eddy viscosity contour

The velocity contour, velocity surface streamline and velocity vector is determined and plotted in the vertical section in Figure 6 to Figure 9 and the variation are observed along the slender structure. The

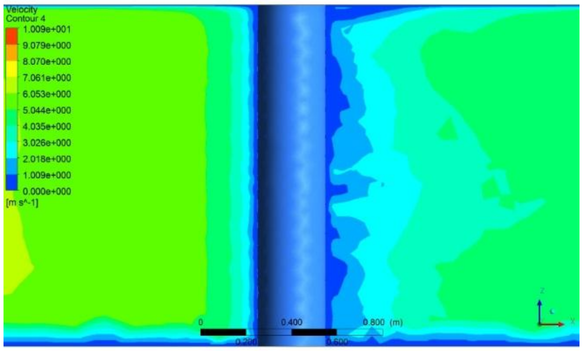

Figure 7: Velocity contour in vertical plane

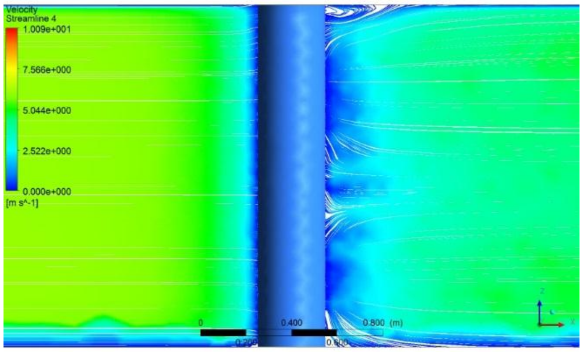

Figure 8: Velocity surface streamline in vertical plane

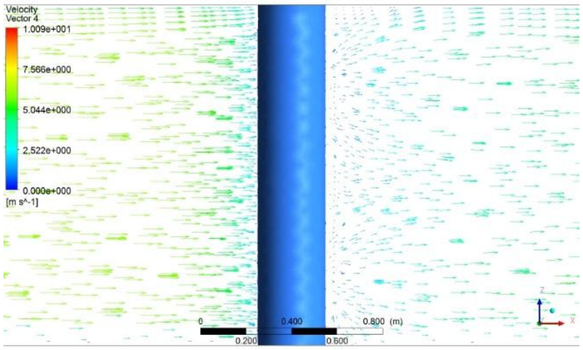

Figure 9: Velocity vector in vertical plane

The turbulent kinetic energy, pressure contour and eddy viscosity contour is plotted in Figure 10 to Figure 12. The shear stress along the vertical plane of the cylinder is plotted in the Figure 13.

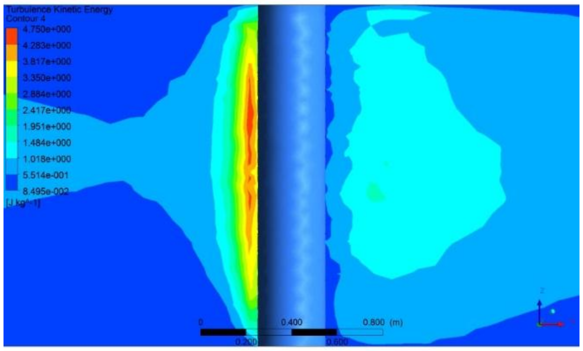

Figure 10: Turbulent Kinetic Energy

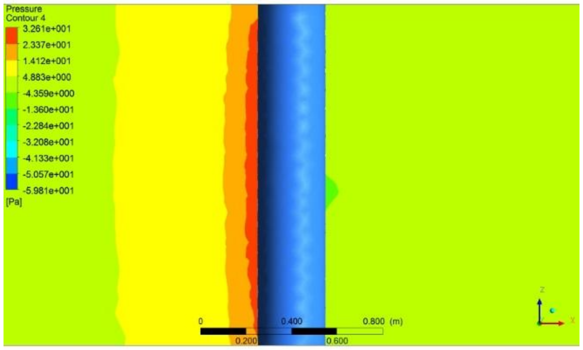

Figure 11 : Pressure contour

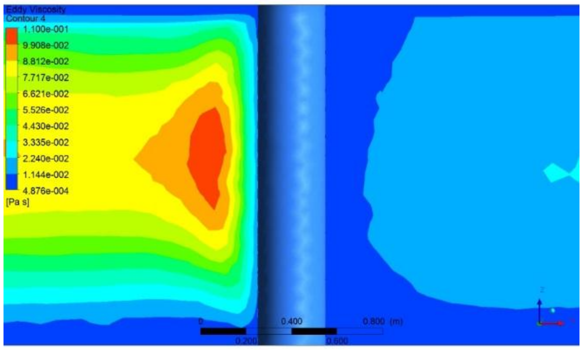

Figure 12 : Eddy Viscosity contour

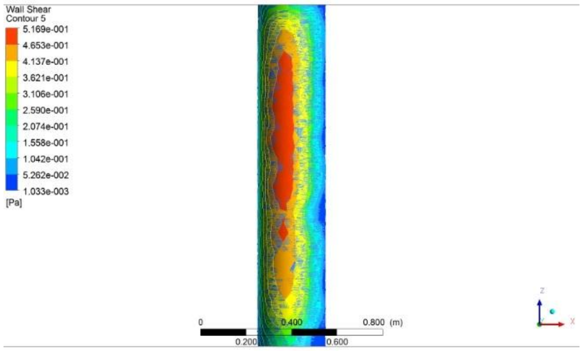

Figure 13 : Wall Shear Contour

The scour depth around the circular cylinder is found by using HEC RAS software and the results are as below. The pier and the channel section is shown in the Figure 14.

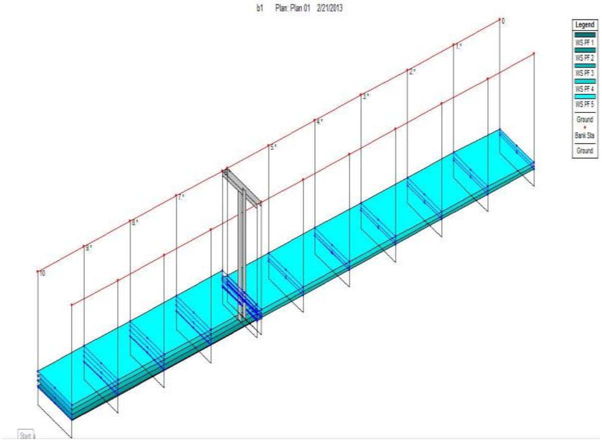

Figure 14: Cylidrical Pier inside the Channel

The analysis is carried out for the followng input data given in Table 1

Table 1: Input Parameters

Input Parameters	Values
K1 Nose Shape	1.0
Pier Angle	0
K2 Angle Coefficient	1.0
K3 Bed Cond Coefficient	1.1
Grain Size D_{90} (mm)	0.33
Grain Size D_{50} (mm)	0.10
K4 Armouring Coefficient	1

The results obtained as presented in Table 2

Table 2: Output Parameters

Discharge (m^3/s)	0.25	1.00
Depth of flow Upstream (m)	0.040	0.650
Velocity Upstream (m/s)	0.62	1.54
Froude Number	0.31	0.61
Scour depth (m) around upstream and downstream of piers	0.22	0.34

The Scour depth around the pier is found for the input data as given in Table 1 and the maximum scour depth at a station is shown in Figure 15.

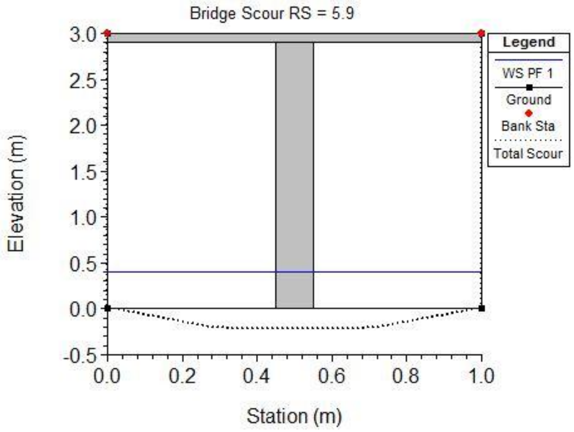

Figure 15: scour depth around the pier

IV. Conclusions

When an obstruction comes in between flow path, the flow field changes and consequently the changes occurs in the channel bed. If the channel bed is erodible one, then erosion takes place. The eddy current produces around the structure depending upon the fluid velocity. The vortex motion enhances the scouring process. At the point of contact, eddy currents or vortex are formed alternately on either side of the object. This creates a local increase in pressure and a local decrease in velocity on one side of the obstruction. The scour hole extends in the downstream. Exact scour depth varies with the kinematics and dynamic boundary condition hence estimating the exact values of scour depth is difficult and complex.

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