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A Novel Method for Prevention of Scouring Around Bridge Piers

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Abstract
Bridges are one of the most expensive and important elements on transportation system. One of the most destructive phenomenon that threats bridges' stability is scouring around their piers on bed. Scouring has two essential reasons; primary one is exertion of shear stress by flow pattern around piers and secondary effect that causes developing and extending of scour pits is vertical wake vortexes that get shape in front, back and lateral sides of piers. One of common preventing method for scouring is ordinary horizontal collars, that in this paper it illustrated that these kinds of collars make flow to exert more intense shear stress to bed in compare with piers without collar. In this research for suggesting better method of prevention method, new shape of collar designed and its application validity determined by numerical analysis by Ansys-CFX ver 12.

1. Introduction

Bridges are one of the most important part of transportation system which theirs stability can be threatened by piers' instability. Many factors can cause bridge failure and the most crucial one is scouring around their piers.

When an object get place in front of normal flow, it makes the flow pattern to get shape of the obstructed object. Scouring happens in two steps, primary step happens when water flow approaches to obstructed object, in a reason of object's geometry, normal behavior of flow pattern cannot be predicted. The first effect of changed flow pattern which commence scouring is extra shear stress exertion to bed in reason of differences in flow pattern and flow velocity adjacent to bed. This fact makes the first changes in bed. In description of this fact it can be noticed that scouring will develop until exerted shear stress get equal to shear stress strength of bed materials. The secondary reason which develops the scoured pits is trailing vertical wake vortexes that get shape because of heterogeneities in bed profile and change the flow pattern again that makes the condition more critical [3].

As mentioned before vertical and horizontal wake vortexes can improve scouring in more critical condition, the most important parameters for creating and developing of vortexes is intensity of downstream flow and geometry of piers' section (Figure 1). Geometry of piers' section mainly creates and develops horizontal wake vortexes which can produce scour pits at the backside of piers [6]. Downstream flow gets shape in cause of stagnation point in front of pier. Impact of downstream flow to bed and normal flow can cause vertical trailing vortexes at back and lateral sides of piers. Strong downstream flow causes intense vortexes adjacent to bed and makes exertion of shear stress more larger (Figure 1) [4].

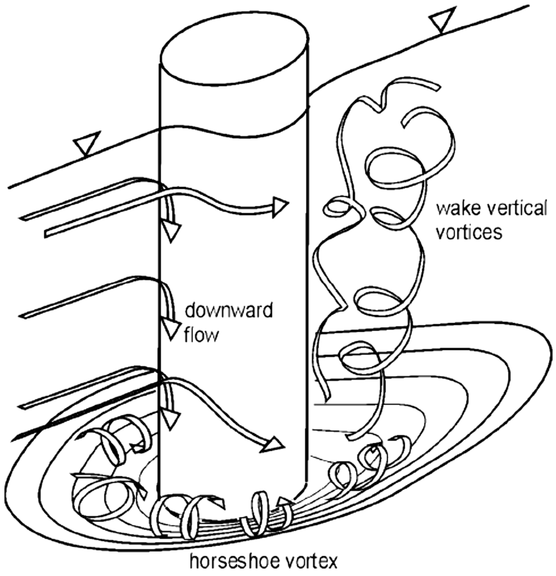

Figure 1. *Creation of downstream flow and wake vortices [R. PASIOK, E. STILGER-SZYDlO 2010]*

Many researches have been performed on this complex phenomenon and because of its importance experimental analysis are more reliable. An example of experimental analysis in this field is conducted by Ahmad and Rajaratnam that their research was focused on creation and improvement of downstream flow [2], another research like one that done by Vincenza C Santoro and coworkers who their main subject was concentrated on effect of attack angle and flow pattern on scour dept. importance and complicities of this fact put numerical analysis as a useful and common way for studying of it, and its causes and effects for finding of suitable preventive method as a solution [7,5].

Lee et al. (2007) applied the back-propagation neural network (BPN) to predict the scour depth in order to overcome the problem of exclusive and the nonlinear relationships. From the comparison with conventional experimental methods, they found that the scour depth around bridge piers can be efficiently predicted using the BPN [8]. Yang et al. studied the vortex-induced vibrations of a cylinder near a rigid plane boundary in a steady flow experimentally. Experimental results indicated the Strouhal number (St) is around 0.2 for the stationary cylinder near a plane boundary in the sub-critical flow regime [9]. Aghaee-Shalmani, and Hakimzadeh presented the experimental results of scour around semi-conical piers to show the effect of their lateral slopes on the scour depth under steady current [10].

Main subject of this paper is application of collars' shape on prevention of scouring and for results suggestion of new kinds of collars will be offered for better prevention method. Efficiency of suggested collar shape will be compared with older kinds. This research is based on numerical analysis by Ansys-CFX ver 12, geometry and mesh of model generated by Ansys workbench's components (Figure 2).

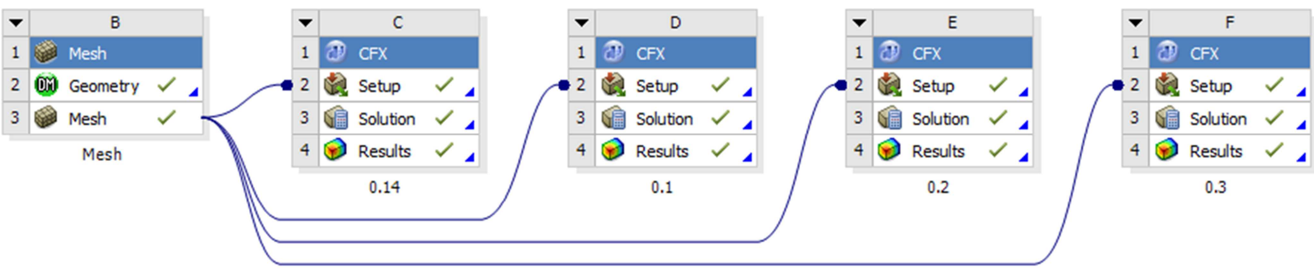

Figure 2. *Ansys-Workbench flow chart with components*

2. Software Simulating Logic

Transport equation:

$$\frac{\partial(\rho\phi)}{\partial t} + \nabla.(\rho U\phi) = \nabla.(\rho D_\Phi \nabla\phi) + S_\phi \qquad (1)$$

Which ρ is the mixture density, mass per unit volume, ρ is the mixture density, mass per unit volume, $\phi=\Phi / \rho$ is the conserved quantity per unit mass, S_ϕ is a volumetric source term, with units of conserved quantity per unit volume per unit time, $D\Phi$ is the kinematic diffusivity for the scalar (Ansys-CFX ver 12 Theory Guide) [1].

For turbulent flow, this equation is Reynolds-averaged [1]:

$$\frac{\partial(\rho\phi)}{\partial t} + \nabla.(\rho U\phi) = \nabla.\left((\rho D_\Phi + \frac{\mu_t}{Sc_t})\nabla\phi\right) + S_\phi \qquad (2)$$

Which Sc_t is the turbulence Schmidt number, μ_t is the turbulence viscosity (Ansys-CFX ver 12 Theory Guide).

Turbulent function for K-epsilon and rough surface expresses in term of turbulent viscosity [1].

$$\frac{\partial\rho U}{\partial t} + \nabla.(\rho U \otimes U) = -\nabla P' + \nabla.\left(\mu_{eff}(\nabla U + (\nabla U)^T)\right) + S_M \qquad (3)$$

Where S_M is the sum of the body forces and μ_{eff} is the Effective Viscosity defined by (Ansys-CFX ver 12 Theory

Guide) [1]:

$$\mu_{eff} = \mu + \mu_t \quad (4)$$

Where μ_t is the turbulence viscosity. The k-ε model assumes that the turbulence viscosity is linked to the turbulence kinetic energy (Ansys-CFX ver 12 Theory Guide) [1].

3. Modeling

Geometry of simulated model has been derived from common hydraulic laboratory flume. Modeled sections are square, circle and rhomboid with and without common collar type and for prevention method of scouring, new geometry of collar will be suggested and for its application validity numerical analysis has been performed.

Software that used is Ansys-CFX ver 12 and for solving 2 steps of mesh refinement considered on basis of volume fraction 0.5 that means surface profile of water in touch of air above open channel. Geometry of open channel that modeled is 1m upstream and 2m downstream of pier with width of 0.6m and height of 1m (Figure 3), Froude number of flow is 0.2 for all models, mesh of air and flow are generated in same condition that this fact helps simulating of multiphase condition better and lets free surface profile to change due to obstructed object. Modeling conducted in steady state situation with considering of K-epsilon for turbulent modeler.

4. Results

As it have been illustrated in Figure-4 it can be found that flow around rhomboid section has exerted less shear stress on bed than other ordinary sections. Flow around square section has exerted the most shear stress but in Figure-5 it can be seen that wake vortexes get shape stronger at lateral and behind side of pier.

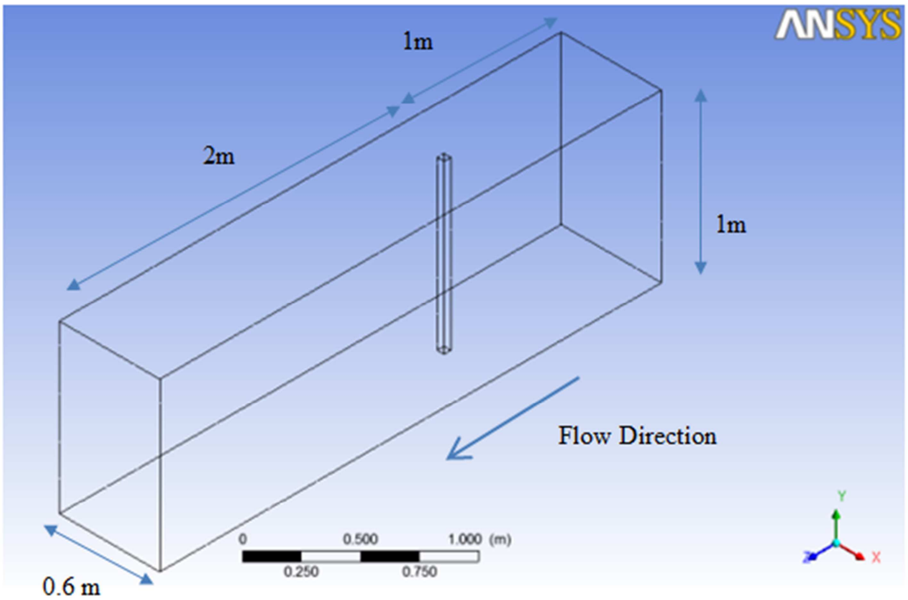

Figure 3. *Geometry of simulated flume*

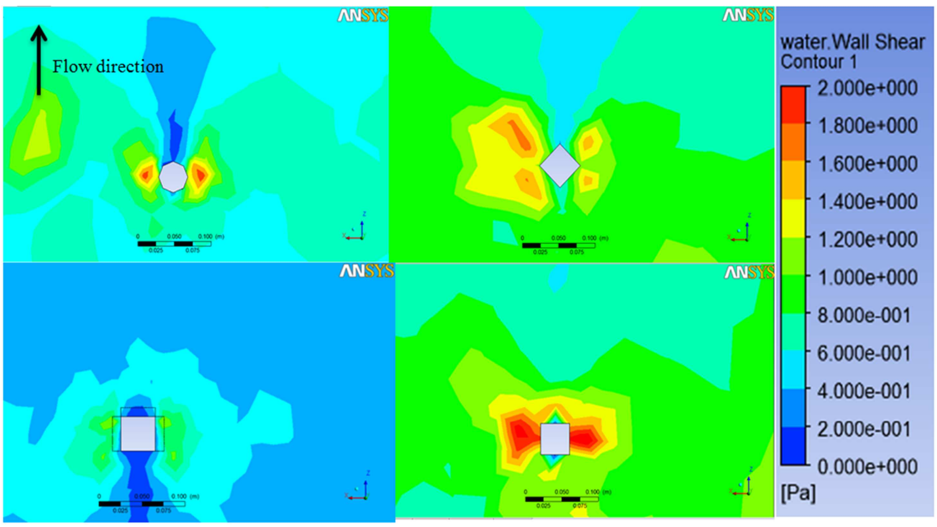

Figure 4. *Shear contour around pier with the same flow condition(bottom left: square with suggested collar shape)*

Application of common piers' collar make situation more critical (Figure 6) because horizontal collars is designed to block downstream flow in front side of pier but in cases that collar didn't used, in lateral section of flow pattern it can be seen that when downstream flow approaches to bed it finds horizontal component in opposite direction of flow which decreases flow velocity adjacent to bed, in addition less shear stress will be exerted to bed in conditions that piers doesn't have collar (Figure 1).

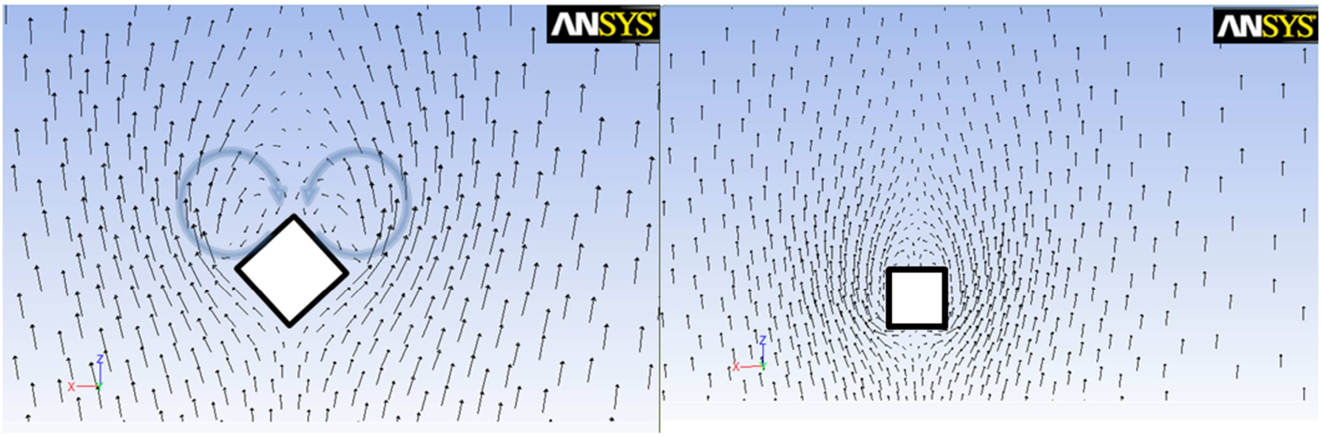

Figure 5. *Plan of velocity vector in bed around rhomboid and square section*

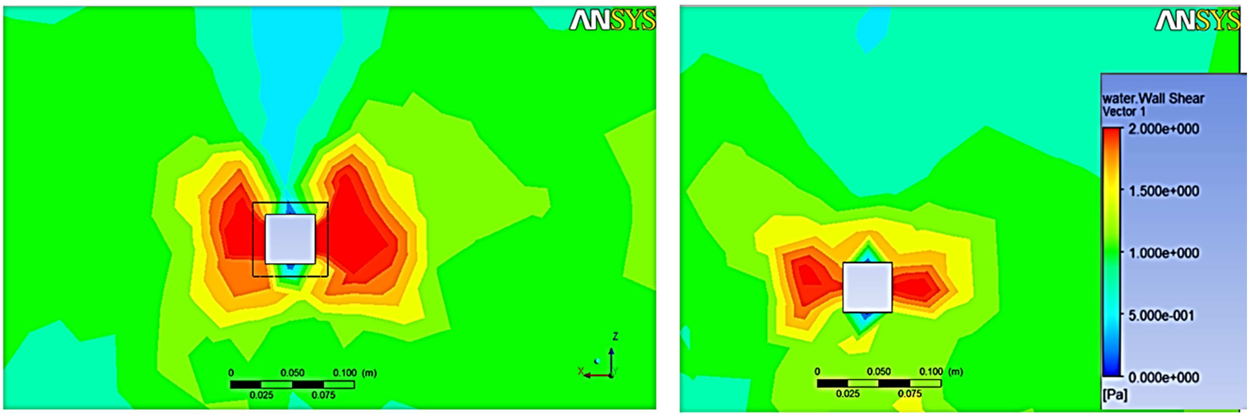

Figure 6. *Shear stress contour on bed (Left: pier with ordinary collar, Right: pier without collar)*

In suggested collar shape because of inclined shape (Figure 8) of collar it blocks downstream flow in front side due to make wake vortexes weaker and because of upward shape of collar in lateral side, vortexes' center get shape in upper elevation related to bed that results less shear stress exertion on bed (Figure 7).

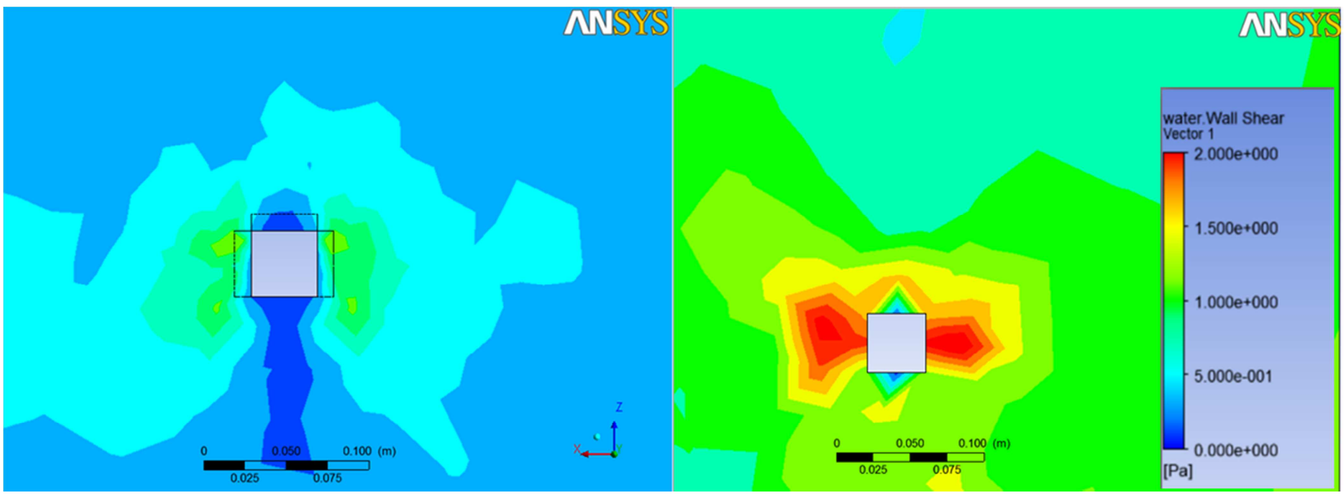

Figure 7. *Shear stress contour on bed (Left: Suggested collar shape, Right: without collar)*

Figure 9 illustrates exerted shear stress by flow on bed in distance of 12.5% of bridge's width. Curves show that section with ordinary (horizontal) collar makes flow to exert larger shear stress, comparing to section without collar, and modified collar that suggested in this research make condition better and it makes flow to exert the lowest shear stress (Figure 9).

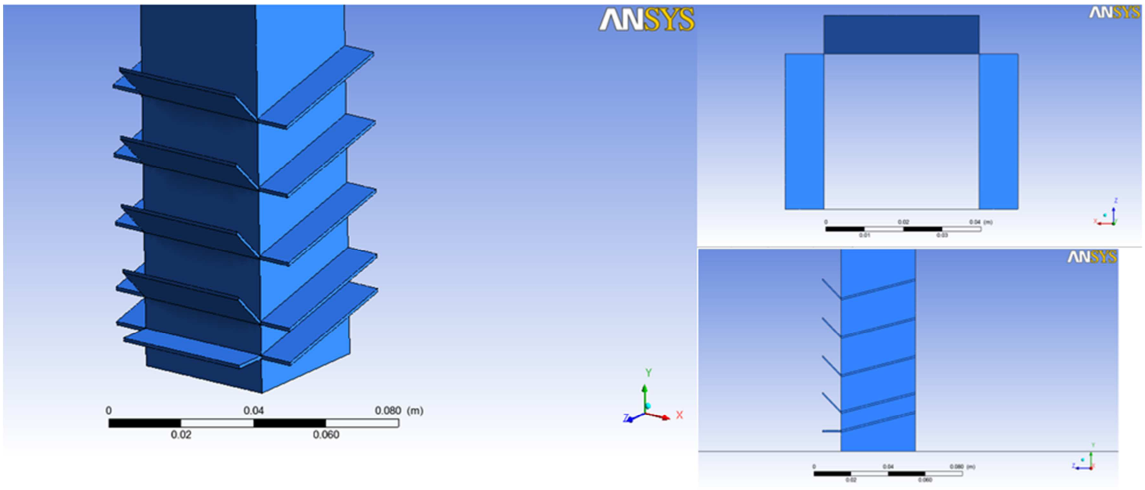

Figure 8. *Sugguested collar in different view*

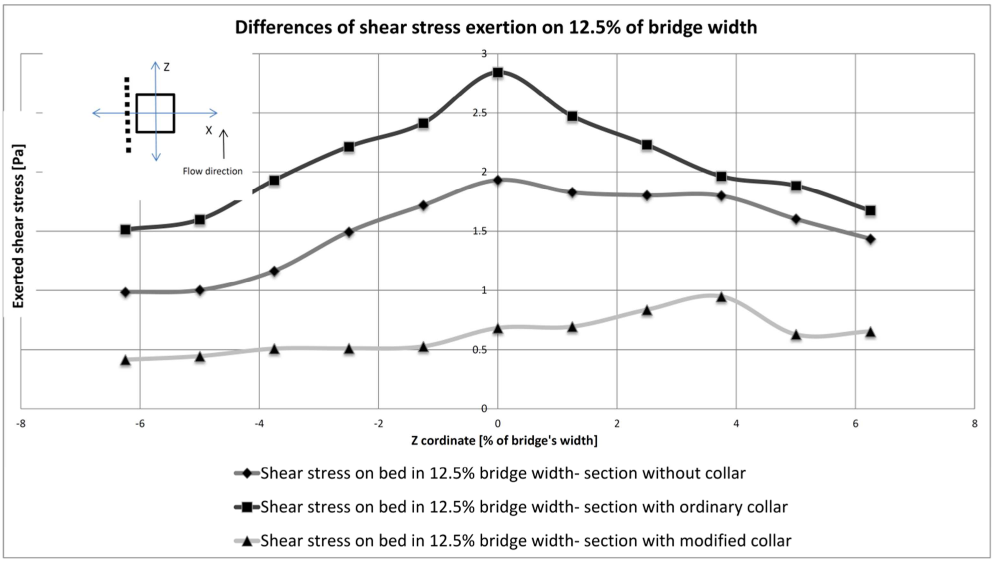

Figure 9. *Differences of shear stress exertion on 12.5% of bridge width*

5. Conclusion

As mentioned before to prevent scouring 2 factors must be controlled. First, shear stress around pier, second, wake-vortexes in behind side. 5 kinds of sections compared to each other, circle, square, rhomboid, square with ordinary collar and square with modified collar. Ordinary collar puts flow in more critical condition. Square has both problem of strong vortexes and intense shear around pier. Circle has fewer vortexes but intensive shear stress around it. Rhomboid has the least shear stress around but strong vortexes happen in back side. Modified collar because of its geometry and inclined shape, in square sections, make vortexes to get shape in upper elevation therefore less shear stress will be exerted on bed. Proper design of pier cannot be achieved without optimization of effects related to piers conditions.

References

[1] Ansys-CFX solver theory guide.

[2] Ahmed, F, and Rajaratnam, N "*Flow around bridge piers*", ASCE, 124(3), 288-300, (1998)

[3] Kirkil, G., Constantinescu, S. G., and Ettema, R "*Coherent structures in the flow field around a circular cylinder with scour hole.*" J. Hydraul. Eng., 572–587, .(2008)

[4] Graf, W. H., and Istiarto, "*Flow pattern in the scour hole around a cylinder*" Journal of Hydraulic Research, 40(1), 13-19, (2002)

[5] T. A. Heinrichs, D. E. Langley, R. L. Burrows and J. S. Conaway, "*Hydraulic survey and scour assessment of bridge 524, Tanana River at Big Delta, Alaska*" U.S. Geological Survey Water-Resources Investigations Report 2006-5282, 66p., (2007)

[6] Pasiok R., Popow A.: *"A numerical free surface flow model in the analysis of a bed stability at piers"*, Proceedings of XXIV International School of Hydraulics, Gdańsk, (2004)

[7] Santoro, V.C., P.Y. Julien, E.V. Richardson, and S.R, "*Velocity profiles and scour depth measurements around bridge piers*", Proc. Annual Meeting, Transportation Research Board, FHWA, paper # 910874, (1991)

[8] Lee, T.L., Jeng, D.S., Zhang, G.H. and Hong, J.H., *Neural network modeling for estimation of scour depth around bridge piers*. J Hydrodynamics, Ser. B, 19(3): 378-386 (2007)

[9] Yang, B., Gao, F., Jeng, D.S., and Wu, Y., *Experimental study of vortex-induced vibrations of a cylinder near a rigid plane boundary in steady flow*. ACTA MECH SINICA, 25(1), 51-63, (2009)

[10] Aghaee-Shalmani, Y. and Hakimzadeh, H., *Experimental investigation of scour around semi-conical piers under steady current action*. EUR J ENV CIVIL ENG, (ahead-of-print), 1-16, (2014)