Numerical Investigation of Local Scour Around Two Tandem Submerged Piles in Steady Current

Mingming Liu[1] and Ming Zhao[2]

[1] Research Fellow, Western Sydney University, Sydney, Australia
[2]A/Professor, Western Sydney University, Sydney, Australia
Corresponding author's E-mail: M.Liu@westernsydney.edu.au

Abstract

In this study, local scour around two vertical submerged circular piles installed on a sandy bed was investigated through numerical simulations. A three-dimensional finite element numerical model was established for simulating local scour around submerged cylinders. The Reynolds-Averaged Navier-Stokes equations are coupled with the bed morphological model to simulate the scour process. Both suspended load and bed load sediment transport rates are taken into account in the model. Efforts are made to reduce the computational time associated with parallel computing techniques. Scour around a submerged wall mounted vertical circular cylinder is simulated and the numerical results are validated against the test data. The scour depth at the upstream side of the upstream pile is found to increase with the gap ratio between the two piles. The scour mechanism around two submerged piles is investigated using the present numerical model.

Keywords: Local scour, Piles, Submerged

1. INTRODUCTION

When a vertical circular pile is placed on an erodible bed, the change of flow pattern around it increases the sediment transport. Local scour then occurs around the pile. Local scour is one of the major causes of structural failure in both bridge engineering and offshore engineering. As it is so important to engineering, many studies about local scour around a vertical pile in steady current have been carried out. For example, Raudkivi and Ettema (1983), Sumer and Fredsøe (1992), Kawata et al. (1988), Melville and Chiew (1999), Sumer and Fredsøe (2001) and Wang et al. (2016) carried out experimental study on scouring around pile. Olsen and Melaaen (1993), Olsen and Kjellesvig (1998), Roulund et al. (2005), Zhao et al. (2010) and Kim et al. (2014) applied three-dimensional numerical model to study local scour around submerged pile.

Pile groups are used in practical engineering for the consideration of low cost or safety commonly. However, few three-dimensional numerical investigations have been carried out to study local scour around piles group. Therefore, the problem of local scour around two tandem piles in steady current is investigated in this study.

2. NUMERICAL MODEL

2.1. Flow Model

The governing equation for simulating the three-dimensional flow is the Reynolds-Averaged Navier-Stokes (RANS) equations. To account for the moving seabed surface, the RANS equations are solved in the Arbitrary Lagrangian-Eulerian (ALE) scheme. Accordingly, the RANS equations can be written as

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial u_i}{\partial t} + \left(u_j - u_j^m\right)\frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\upsilon\frac{\partial u_i}{\partial x_j} + \tau_{ij}\right] \tag{2}$$

where x_i (i=1, 2 and 3) is the Cartesian coordinates, u_i denotes the velocity component in x_i direction, u_j^m is the velocity of the mesh movement, p is pressure, t is time, ρ is density of water, υ is the kinematic viscosity and τ_{ij} denotes the Reynolds stress which is defined as $\tau_{ij}=\nu_t(\partial u_i/\partial x_j+\partial u_j/\partial x_i)-(2/3)k\delta_{ij}$, k is the turbulent energy, ν_t is the turbulence viscosity.

2.2. Scour model

The movement of the sand in the water are classified into bed load and suspended load. The suspended sediment was quantified by the volume concentration (c), which was computed by solving the convection-diffusion equation:

$$\frac{\partial c}{\partial t} + \left(u_j - u_j^m\right)\frac{\partial c}{\partial x_j} - w_{sj}\frac{\partial c}{\partial x_3} = \frac{\partial}{\partial x_j}\left(\frac{\upsilon_t}{\sigma_c}\frac{\partial c}{\partial x_j}\right) \tag{3}$$

where c is the sediment concentration, σ_c=1 is the turbulent Schmidt number, and w_s is the settling velocity of sediment particle in the x_j-direction. The settling velocity$w_{s1}=w_{s2}=0$ and $w_{s3}=w_{s0}(1-c)^5$, where w_{s0} is the settling velocity without considering interaction between sand particles.

The bed load is evaluated by the bed transport rate $\mathbf{q}_b=(q_{bx}, q_{by})$, which is calculated by the semi-empirical equation proposed by,

$$\mathbf{q}_b = \frac{\pi d_{50}^3}{6}\frac{P_{EF}}{d_{50}^2}\mathbf{U}_b \tag{4}$$

where $\mathbf{U}_b$ denotes the velocity of the sediment and P_{EF} is the percentage of the particles on the sand surface that are moving on the seabed.

After the bed load and suspended sediment concentration are calculated, the seabed evolution due to the local scour is predicted based on the mass conservation equation of the sediment,

$$\frac{\partial z_b}{\partial t} = \frac{1}{1-n}\left(-\nabla\cdot q_b + D_s - E_s\right) \tag{5}$$

Where z_b denotes the bed elevation, n is t the porosity of the sediment, q_b is bed load transport rate, D_s is the deposition rate and E_s is the erosion rate.

3. NUMERICAL VALIDATION

The scour model was validated by comparing with the results obtained by Roulund et al.(2005) who studied the problem of scour around circular pile by both numerical and experimental method. The parameters are the same as that adopted by Roulund et al. (2005) in this validation section which are listed as the following. A pile with a D = 0.1 m diameter was placed on the bed in steady current. The water depth was h = 0.4 m, the mean flow velocity is V = 0.46 m/s and the median grain size of the sediment is d_{50}= 0.26 mm.

Tab. 1 Parameters adopted by Roulund A. et al. (2005)

Parameters	Value
Water depth h (m)	0.4
Depth mean flow velocity V (m/s)	0.46
Pile diameter D (m)	0.1
Grain diameter d_{50} (mm)	0.26

Fig. 1 shows the time history of scour depth at the upstream side of the pile. The scour depth increases quickly in the first 0.5 hour and then develops gently. The present numerical solution is in good agreement with both the experimental and numerical data obtained by Roulund et al. (2005), indicating that local scour rate is correctly predicted by the present numerical model. Fig. 2 shows the time history of scour depth at the downstream side of the pile. The equilibrium scour depth can reach about 1.2 D. Just as Fig. 1, scour depth develops fast in the first 0.5 hour and then grow up slowly. Also, the present numerical results tally well with the data from Roulund et al. (2005). However, the final scour depth at the downstream side which is about 0.8 D is smaller than that of the upstream side.

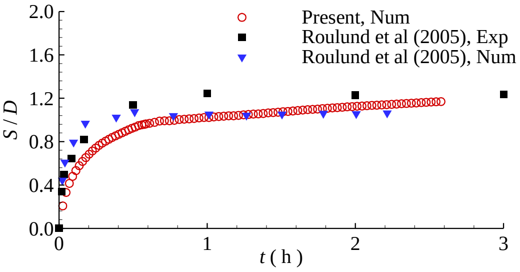

Fig. 1 Time history of scour depth at the upstream side

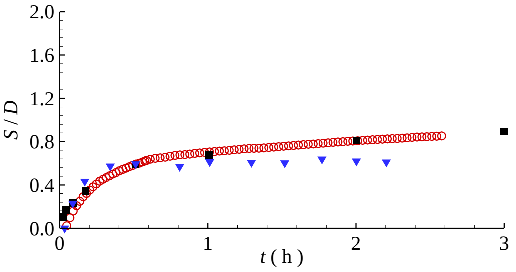

Fig. 2 Time history of scour depth at the downstream side

From the discussion above, a conclusion that the present numerical model can predict the scour process around a pile under steady current correctly can be draw.

4. RESULTS AND DISCUSSION

Fig. 3 gives the equilibrium scour depth at the upstream side of the upstream pile. In Fig. 3, S_0 denotes the equilibrium scour of single pile under the same condition. It can be seen from Fig. 3 that the equilibrium scour depth increases as the gap ratio becoming larger for G / D< 2.0. For G / D =0.5 the equilibrium scour depth at the upstream side for upstream pile is smaller than that of a single pile. However, the equilibrium scour depth changes little for *G* / *D*> 2.0. Moreover, present numerical results agree well with the experimental data from Hannah (1978) and Ataie-Ashtian and Beheshti (2006).

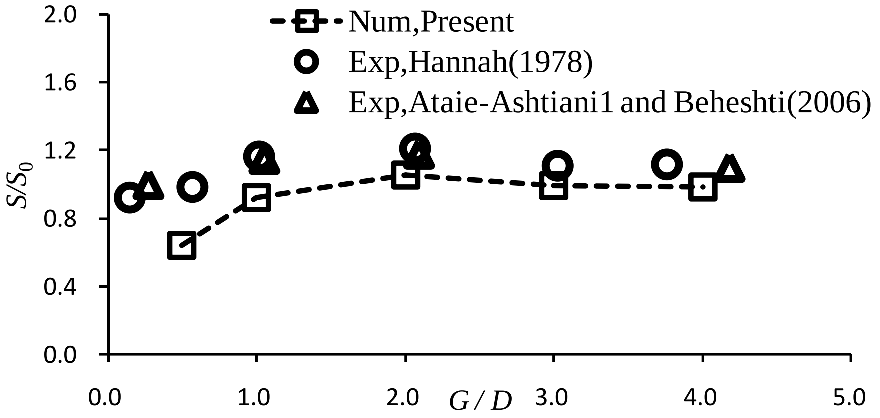

Fig. 3 Dependence of equilibrium scour depth at the upstream side of the upstream pile on *G* / *D*

Fig. 4 gives the time scale for the scour at the upstream side of the upstream pile. In Fig. 4, T_0 denotes the time scale for scour at the upstream side of a single pile at the same condition. Like the equilibrium scour depth shown in Fig. 3, time scale increases with the increase of gap ratio for *G* / *D*<2.0 and change little with the gap ratio for *G* / *D*>2.0. Time scale under *G* / *D* = 0.5 is much smaller than that of single pile.

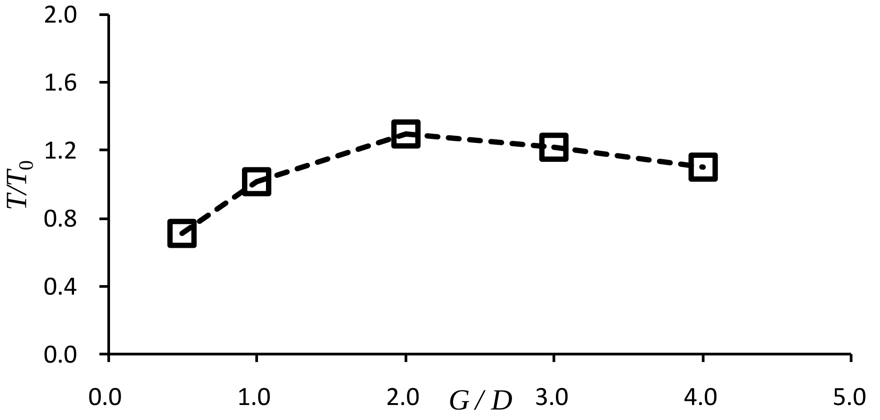

Fig. 4 Dependence of time scale for scour at the upstream side of the upstream pile on *G* / *D*

5. CONCLUSION

A three-dimensional finite element numerical model was developed to investigate local scour around two submerged piles in steady current. The numerical model was firstly validated with published experimental data. Good agreement was obtained. Then the numerical model was used to study the problem of local scour around two piles. The following conclusions can be draw within the present study scope.

(1) The equilibrium scour depth increases as the gap ratio becoming larger for $G / D< 2.0$. For $G / D =0.5$ the equilibrium scour depth at the upstream side for upstream pile is smaller than that of a single pile. However, the equilibrium scour depth changes little for $G / D> 2.0$.

(2) Time scale increases with the increase of gap ratio for $G / D<2.0$ and change little with the gap ratio for $G / D>2.0$. Time scale under $G / D = 0.5$ is much smaller than that of single pile.

REFERENCES

Raudkivi AG, Ettema R (1983). Clear-water scour at cylindrical piers. J. Hydraul. Eng., 109(3), 338-350.

Sumer BM, Christiansen N, Fredsøe J (1992). Time scale of scour around avertical pile. Proceedings of the Second International Offshore and Polar Engineering Conference. San Francisco, USA, 14-19.

Kawata Y, Tsuchiya Y (1988). Local scour around cylindrical piles due to waves and currents combined. Proceedings of 21st Conference on Coastal Engineering, Torremolinos, Spain, 1310-1322.

Melville BW, Chiew YM (1999).Time scale for local scour at bridge piers. J. Hydraul. Eng., 125(1), 59-65.

Sumer BM, Fredsøe J (2001). Scour around pile in combined waves and current. J. Hydraul. Eng., 127(5): 403-411.

Zhao M, Cheng L, Zang ZP (2010). Experimental and numerical investigation of local scour around a submerged vertical circular cylinder in steady currents.Coast. Eng., 57,709-721.

Wang H, Tang HW, Liu QS, Wang Y (2016). Local scouring around twin bridge piers in open-channel flows. J. Hydraul. Eng., (06016008), 1-8.

Olsen NRB, Melaaen MC (1993).Three-dimensional calculation of scour around cylinders. J. Hydraul. Eng., 119(9), 1048-1054.

Olsen NRB, Kjellesvig HM (1998). Three-dimensional numerical flow modeling for estimation of maximum local scour depth.J Hydraul Res, 36(4),579-590.

Roulund A, Sumer BM, Fredsøe J, Michelsen J (2005). Numerical and experimental investigation of flow and scour around a circular pile. J. Fluid Mech.,(534), 351-401.

Kim HS, Nabi M, Kimura I, Shimizu Y (2014). Numerical investigation of local scour at two adjacent cylinders.Adv Water Resour., 70, 131-147.

Hannah CR (1978). Scour at pile groups. Research Rep. No. 28-3, Civil Engineering Dept., Univ. of Canterbury, Christchurch, NewZealand.

Ataie-Ashtiani B and Beheshti AA (2006). Experimental Investigation of Clear-Water Local Scour at Pile Groups. J. Hydraul. Eng., 132 (10) , 1100-1104