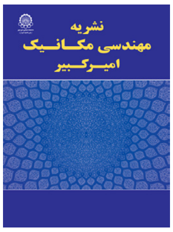

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Numerical Investigation of Scour Around a Cylindrical Pier in Laboratory Scale Using Euler-Lagrange Approach

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ABSTRACT: The placement of a pier in flow causes a three-dimensional complex flow pattern around the pier, which leads to a scouring hole around the pier. In this research, modeling of scouring around piers was performed both experimentally and numerically. In the first section of this study, two different scenarios were used to simulate the scouring process. In the two numerical models, the effect of phase coupling and drag models on the scoured bed was investigated. One-way coupling with the sphere drag model was implemented in the first scenario and four-way coupling with a nonsphere drag model in the second one. According to the results, the first model was not satisfying, but the result of the second model was in good agreement with experimental results. The maximum depth of scour at the cross-section in numerical and experimental results was equal (6 percent error). In the second section of this research, in order to study the effect of a collar on the reduction of scouring, a simple cylinder without a collar and then with the presence of a collar at two different levels were performed. The result shows that as the collar goes up, both the maximum depth and the radius of the scour hole increases.

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1. INTRODUCTION

It is obvious that bridges play an important role in transportation. Many bridges fail every year, most of them because of scouring around their piers. The failure of bridges causes serious damage. Therefore, research on the control and reduction of scouring at piers is necessary. The mechanism of scouring around a pier is very complex. The decrease in velocity at the upstream face of the pier causes an increase in pressure. Also, the dynamic pressure on the pier reduces downwards. This pressure gradient forces the flow down the pier. When this downflow touches the streambed, it makes a hole in front of the pier [1].

A review of previous studies shows that most of the simulations carried out to study scouring around piers are based on the Eulerian-Eulerian approach, in which both the fluid and particle phases are assumed to be continuous. In this investigation, in order to take into account the discrete property of sediment, simulations are performed using the Eulerian-Lagrangian approach with $k-\omega\_SST$ turbulence model in OpenFOAM. In the first part of the simulation, the modeling results are evaluated by changing the coupling and drag model and then are compared to experimental results. Later, in the second part of the simulation, the effect of collar presence on scouring reduction around a cylindrical pier is investigated.

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2. METHODOLOGY

The numerical model we have developed consists of two modules. The first one is the hydrodynamic module which simulates the flow field and solves Navier-Stokes equations. The second one is a morphological module which calculates the sediment transport and solves Newton's second law of motion. In this study, the sediment-laden flow is treated as a two-phase flow, which includes the water phase and the sediment phase. In Euler-Euler two-phase models, both the water and sediment phases are treated as a continuum. In the simulations to better represent the discrete property of sediment, Euler-Lagrange two-phase models are being used [2, 3]. In this investigation, the soft sphere model is applied to model collision or contact between particles. The soft sphere model is modeled by using mechanical elements such as a spring and a dash-pot. This model is also called the Discrete Element Method (DEM) [4].

Fig. 1 represents a schematic view of geometry and mesh in the numerical computational domain. The lower part of the domain is filled with particles and the upper 4 cm is filled with fluid passing over the sediment.

The boundary condition for the inlet velocity is set to be a fixed value of 0.3 m/s for the first part and 0.5 m/s for the second part of simulations. In the first part, a simple pier is modeled to validate the numerical model with the experimental results. In the second part, the pier is simulated with the presence of a collar at different levels.

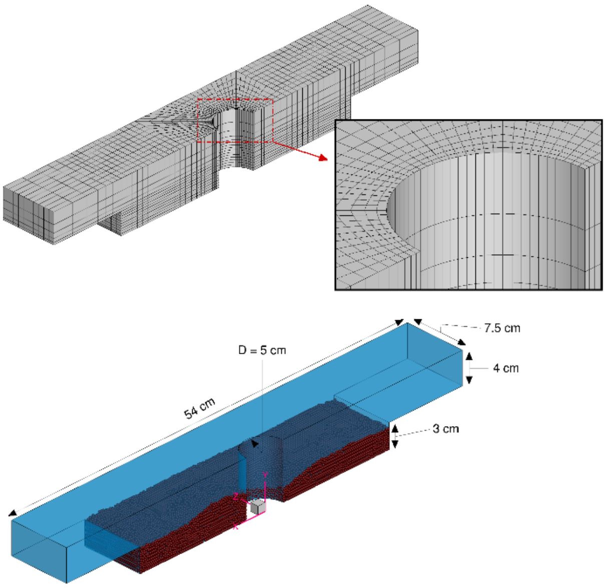

Fig. 1. The geometry and mesh of the numerical computational domain

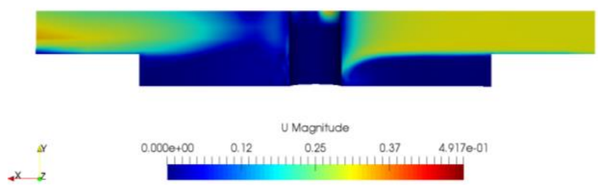

Fig. 2. The contour of velocity in the coupled approach on the plane of *z*=0 (m/s)

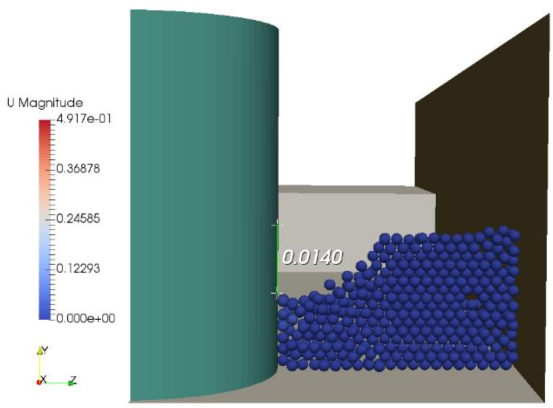

Fig. 3. Scoured bed profile and particle velocity on the cross-section (the plane of *x*=0) (m/s)

3. RESULTS AND DISCUSSION

In the first part of the simulation, the modified model is done using a four-way coupling and nonsphere drag model. Fig. 2 represents the contour of flow velocity on the plane of *z*=0. As the Figure shows, the flow velocity reaches zero in the zone of particles due to the coupling effect.

Fig. 3 represents the bed cross-section in a steady state. It shows that the maximum scour depth is 14 mm. Fig. 4 shows the comparison between numerical and experimental bed

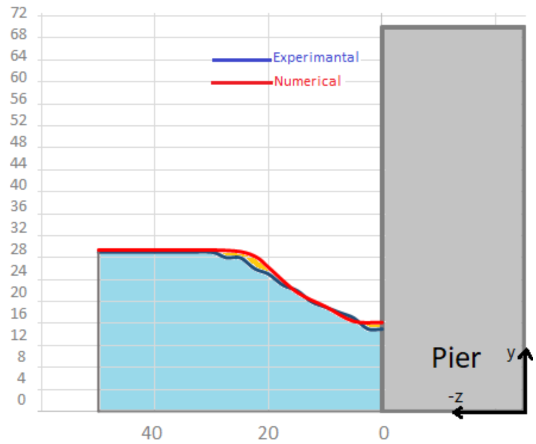

Fig. 4. The comparison of scoured bed profile in a coupled numerical model with the experimental model on the plane of *x*=0 (mm)

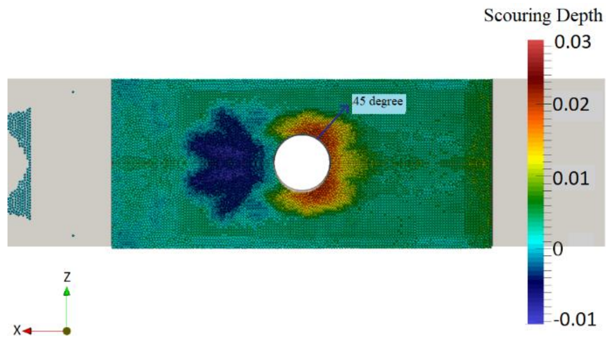

Fig. 5. The contour of particle distance from the bed surface (m)

cross-section in a steady state. The maximum scour depth in numerical and experimental results are almost equal. Finally, Fig. 5 represents the particle distance from the bed surface. It also shows the scouring hole and backfilling downstream of the pier.

In the second part of the simulation, in order to investigate the effect of the collar on scouring reduction, the scour depth is compared between a simple pier and pier with a collar. The numerical results show that the presence of a collar decreases the maximum depth of scouring. As a result, the collar at lower levels has a better performance in reducing scour.

4. CONCLUSIONS

In this study, a three-dimensional solver called pimpleLPTdenseFoam is used to simulate scouring around a vertical cylindrical pier. In this research, the $k-\omega\_SST$ model has been selected as the turbulence model because of its better performance in the case of flows with a strong adverse pressure gradient. The experimental model was developed in the hydraulic laboratory of the Babol Noshirvani University of Technology. In order to obtain a suitable model for simulating scour around a cylindrical pier in the first part of the model, two scenarios were evaluated using the Eulerian-Lagrangian approach. In the first scenario, the discrete phase has no effect on the continuous phase and sphere drag was being used but the results were not in good agreement with the experimental results. Therefore, in the second scenario, to improve the accuracy of the simulation, a four-way coupling and a nonsphere drag model were used as a modified model. The numerical results were in good agreement with the experimental results. The second part of this study has been done to investigate the effect of the collar on scouring reduction around a cylindrical pier. The result shows that as the collar goes up, both the maximum depth and the radius of the scour hole increases.

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