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Experimental and numerical investigation of scour around inclined pier group with sacrificial pile and collar

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ABSTRACT: The scour has been studied in hydraulic science for many years; due to its complexity, it has been the attention of hydraulic scientists. Hydraulic structures are situated as an obstacle in front of water flow that changed the flow pattern in their vicinity and causing the local scour around the structure. There are various methods to reduce local scour around the pier. In this research, sacrificial pile and collar were used to reduce the local scour around the inclined pier group. The results show that using the sacrificial pile in front of the inclined pier group, the effect of the inclined pier angle on the reduction of the scour is lower. So the difference between the percentage of scour reduction for the first and second inclined piers with the angle of 5 and 15 degrees is zero and in vertical pier is 1.4%. The use of three collars with a diameter of 4b in pier group with the distance of 4b between piers and presence of sacrificial pile in front of the first inclined pier in the distance of 3b compared to 2b show a greater scour depth reduction in front of the piers. In the numerical model, the use of an inclined pier group with the distance of 3b between piers and sacrificial pile with the distance of 2b shows lower turbulence intensity compared to distances of b and 3b. .

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1- Introduction

The use of the pier group, due to geotechnical and economic reasons, in the design of the bridge piers has increased Bozkus and Çeşme (2010) experimentally studied the reduction of the local scour depth around the inclination of the dual pier with diameters of 25, 50 and 70 mm and for the pier with angles of 0, 5, 10 and 15 degree under clear water conditions. The results showed that the sediment behind the second was greater. Bozkus and Yildiz (2004) have proposed Eq. (1) to determine the scour depth at the inclined pier with a uniform grading

$$\frac{d_s}{b} = 0.455\left(\frac{y}{b}\right)^{0.202}\left(\frac{u}{u_c}\right)^{0.591}\alpha^{1.725} \quad , \quad R^2 = 0.98 \quad (1)$$

In this equation, y is the depth of flow, b the pier diameter, ds the depth of scour, u the flow velocity, uc the velocity threshold and α=90-β which is the angle of the inclination pier with the vertical direction. Mahmoudi and Heidar Pour (2016) have used the sacrificial pile to control local scour around the pier. The sacrificial piles had a triangular arrangement. The results showed that the performance of the sacrificed pile increased as the angle and distance of piles decreased. In this research, the collars and nanostructures were used to reduce scouring around the inclined pier group. The effect of the collar and nanoclay around the inclined pier group and the change angle of inclination of the pier was investigated. Using the numerical model, the flow pattern between the sacrificial pile and the inclined pier was investigated.

2- Material and methods

2- 1- Experimental model

Experiments were carried out in the hydraulic laboratory of the Water Engineering Department in a canal with 6 m length, 80 cm width and 50 cm height. The flow rate was measured by a rectangular weir calibrated at the end of the channel. The water depth was measured by a depth gauge mounted on the channel with an accuracy of 1 mm. The sedimentary bed contains non-cohesive materials and a density of 2.52. According to Raudkivi and Ettema (1983) criteria, to prevent the formation of bed form, the average particle size (d50) should be more than 0.7 mm. In this study, the average particle size was 0.8 mm. Chang et al. (2004) suggested the geometric deviation of sediment uniformity 1.1 to 1.4. In this study, the standard deviation of the sediments was 1.25. Piers model was placed in the middle of the mobile bed. According to Chiew and Melville (1987), for the ratio of flow depth to pier diameter, Mellvile and Chiew (1999) criteria for the ratio of particle size to pier diameter, Arvanaghi et al. (2006) criteria for the ratio of

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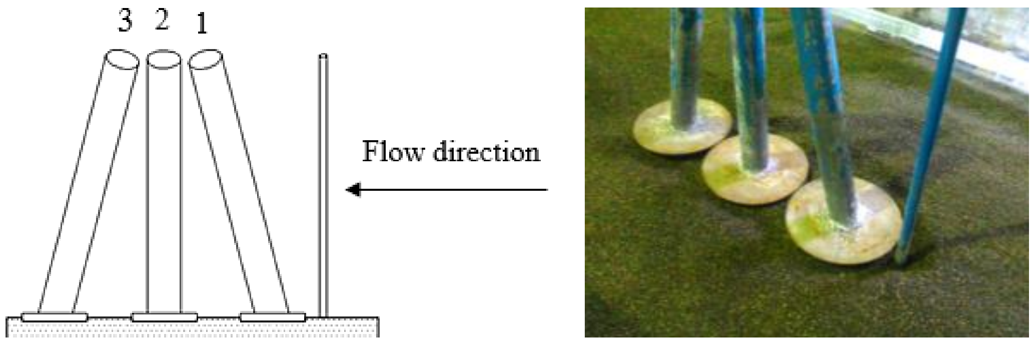

Fig. 1. Experimental photo of inclined pier group with sacrificial pile b) Inclined pier group with collar and sacrificial pile

Table 1. characteristics of Nano clay materials used in this research

Nano Clay	Particle size	Density	origin
Montmorilonite	1-3 (nanometer)	600 (gr/cm^3)	China

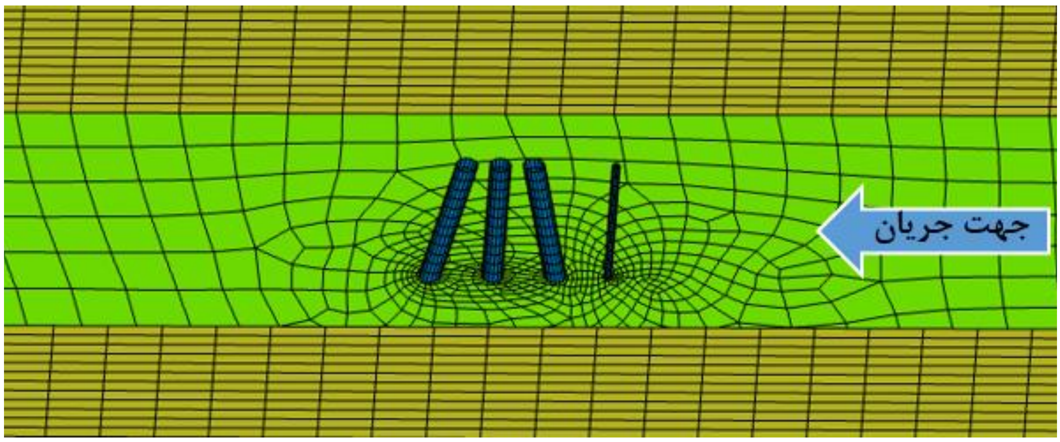

Fig. 2. Meshing around inclined pier group with presence of sacrificial pile

width channel to pier diameter, the pier diameter was selected 3.4 cm. In Figure 1, the model of inclined piers (pier group) showed that the first pier was inclined to the downstream, the second pier was vertical and the third pier was inclined to upstream. The angles of inclination (θ) were 5, 10 and 15 degrees. The distance between piers was 3 and 4 times pier diameter. .

Laser meter with an accuracy of 1 mm was used to the topography of the bed around the pier and area of scour. In experiments of sediment with nano-clay materials, one type of nano-clay was used, referred to as CLOISITE 15A; its characteristics according to the information on the package were shown in Table 1. The color of the powder nano-clay was yellow .

3- Numerical model

ANSYS FLUENT was used to simulate the flow pattern in the inclined pier. The geometry of the canal was designed in the Design Modeler of ANSYS. The meshing of the model geometry was generated in work bench meshing. Then boundary condition was defined in FLUENT. The computational region for simulated models had a width of 80 cm, a height of 17.8 cm and a length of 3 m for a single cylindrical pier. In order to determine the effect of different hydraulic conditions on the inclined pier group, the hydraulic conditions of flow in a numerical model were different from the hydraulic conditions of the flow in the laboratory. The boundary conditions were considered for inlet, velocity inlet, for an outlet as outflow, wall for the bed and bridge, piers, and for the top plane as symmetry. Figure 2 showed the meshing around three piers with inclined angles of 15 degrees and a sacrificial pile. The number of meshes created in the simulated models was about 13000

4- Results and discussion

To evaluate the numerical model results, the data of Mahjoob et al. (2014) were used. In Figure 3, Mahjoob et al. (2014) showed an increase of 26% in front of the first pier; a scour reduction of 43% in the second pier and a reduction of 50% in the third pier compared to a single pier. In this study, the scour

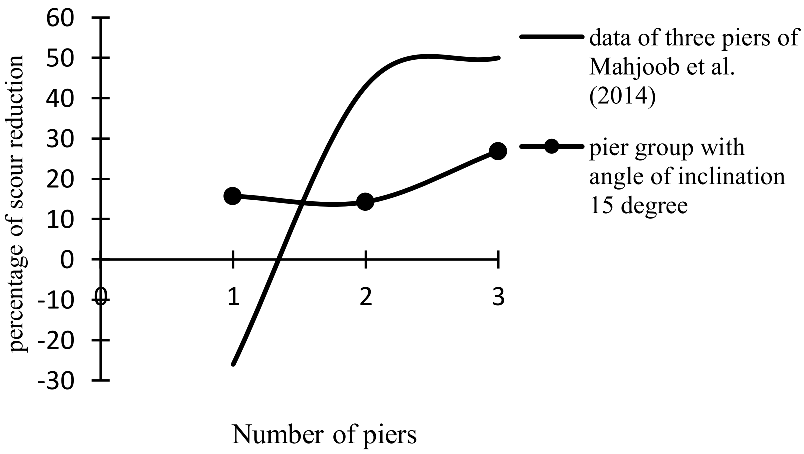

Fig. 3. Comparison of scour reduction percentage for inclined pier group (15 degrees) with data of Mahjoob et al. (2014)

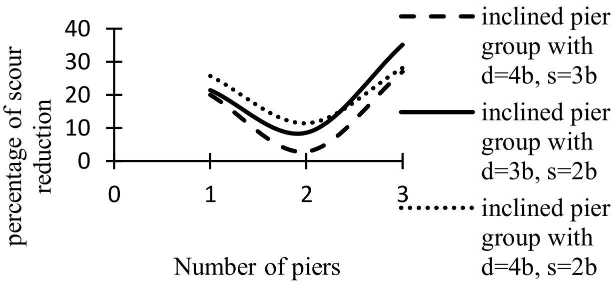

Fig. 4. the effect of the sacrificial pile and inclined pier group distance changes on the scour reduction percentage

reduction percentages in front of the inclined piers with angel of θ = 15 degrees were 15.7, 14.3 and 26.9%, respectively

The effect of the sacrificial pile and pier group distances change for s = 2b, 3b and d = 3b, 4b (θ =15) was shown in Figure 4. The results showed that with increasing the sacrificial pile distance, the effect of the reinforcement phenomenon decreased. It can be seen that in a sacrificial pile with the distance of s = 2b and the group piers distance of d = 4b, the pile caused more reduction of the local scour compared to the pile distance of s =2b, 3b and the pier group distances of d = 3b, 4b. Also, for the sacrificial pile with the distance of 2b and pier group distance of 4b, the scour reduced more around all three piers due to the protection phenomenon of the pile and sediment transfer to the front of the piers.

5- Conclusions

- Inclined pier group with distances of d=4b and the presence of the sacrificial pile in front of the first inclined pier with the distance of s=2b reduced the scour more compared to pier group and pile with distances of 4b, s=3b and d=3b, s=2b.
- The numerical studies showed the turbulence intensity in the depth of flow had a little change for different distances between the pier group. The turbulence intensity was less for the pier group with distances of d=3b and the presence of the sacrificial pile with a distance of s=2b compared to the other distances of s=b, 3b.

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