Anura3D
MPM Research Community

Paper number: mpm2019.53
www.anura3d.com
www.mpm2019.eu

MPM simulation of uplift behaviour of piles with enlarged bases in a sand foundation

Yong-Sen Yang, Liu-Chao Qiu*, Lei Tian, Jing-Jun Li, Yu Han
Collage of Water Resources & Civil Engineering, China Agricultural University, Beijing, China

* E-mail: qiuliuchao@cau.edu.cn

ABSTRACT

Piles with enlarged bases, as an efficient foundation type, have widely appiled in the field of geotechnical engineering. In this paper, a material point method (MPM) is used to model the uplift behaviour of piles with enlarged bases in sand. The proposed MPM is a novel meshless method, which can be used for modelling large deformation and contact problems between different objects without any additional interface elements in geotechnical engineering avoiding mesh distortions. The load-displacement curves and the ultimate uplift capacity obtained from the MPM simulation are compared with the centrifugal experimental data in the available literature, and the influence of variations in angle of foundation base, embedded in loose and dense dry sand are investigated. From the results, it is observed that increasing in the sand density result in a increase in the uplift resistant and failure displacement, but decreased with the increment of angle. Moreover, MPM provides an alternative method for uplift resistance prediction.

KEY WORDS: Numerical simulation; uplift; sand foundation; piles; material point method.

INTRODUCTION

Piles with enlarged bases, as an efficient foundation type (Hamza, 1994), have commonly employed to withstand uplift forces imposed by wind and wave action or line tension in geotechnical engineering, such as transmission line towers (Hanna et al., 2015), offshore and onshore structures (Lutenegger, 2011; Byrne et al., 2015), and retaining wall (Sahoo et al., 2012). Due to numerous applications of piles with enlarged bases, many research investigations have been conducted on the uplift capacity of piles in the sand foundation in the last few decades. Test analysis and numerical simulations have been used to evaluate the behavior of anchors.

Small laboratory-scale model tests have been performed to investigate the influence of particle size, soil density, and anchor embedment depth on soil deformation (Liu et al., 2012), and to evaluate the pullout capacity of batter pile in sand (Nazir and Nasr, 2013). The influence of soil reinforcement on uplift response of anchor plates has been studied in model tests (Niroumand et al., 2013). Centrifugal model tests have been carried out to investigate the influence of foundation geometry on the uplift behaviour of piles with enlarged bases (Dickin and Leung, 1992). Wang et al. (2013) and Nazir et al. (2014) performed large-scale experimental laboratory tests to analyze the pull-out capacity. Numerical simulation, including the finite-element method (Kumar and Kouzer, 2008), discrete element method (Bai and Jian, 2004), finite difference method(Pérez et al., 2018), also have been used to study the uplift capacity. Although extensive research has been performed to understand the uplift resistance and failure patterns, there are still a lack of systematic and coherent cognition about failure mechanism, especially anchor behavior and its interaction with the surrounding soil during uplifting.

Material point method (MPM) is a novel meshless method, combines the superiority of Eulerian and Lagrangian description of motion, which can be well used for modelling large deformation and contact problems between different objects without any additional interface elements in geotechnical engineering avoiding mesh distortions (Soga et al., 2016; Lianget al., 2017), such as landslide and cone penetration problems. In this study, Anura3D software (www.anura3d.com), which implements the MPM formulation, is used to model the uplift behaviour of piles with enlarged bases in a sand foundation, and to analyze the influence of variations in angle of foundation base, embedded in loose and dense dry sand are investigated, and the results are compared to the centrifugal model tests.

NUMERICAL ANALYSIS

Numerical model

Dickin and Leung (Dickin and Leung, 1992) investigated the influence of foundation geometry on the uplift behaviour of piles with enlarged bases. Experiments were implemented in both loose and dense dry sand. The piles with enlarged bases was a belled piers, which can be described by bell angle α, shaft diameter b_s, bell diameter b_b, and embedment ratio L/b_b, as shown in the Fig.1(a). The geometry can be changed by the shaft/bell diameter and bell angle α. The model test was conducted in the geotechnical centrifuge, the model box were 570 mm × 450 mm ×230 m, and the centrifugal acceleration was 33.3g. The centrifugal tests had different bell angle(0°, 22°, 62°, 72°, 90°), but the same diameter ratio 0.17. The embedment ratios of all models were 4, and also the base diameter is 30 mm constantly. The MPM simulation is assumed to be the 2D plane strain problem. Fig. 1(b) shows the model of numerical simulation, the bottom is fixed, while constraints are imposed along the horizontal direction in the lateral surfaces. The sand was modelled with Mohr-Coulomb model, material parameters were defined as Table 1, whereas the bell bier modelled as a rigid body.

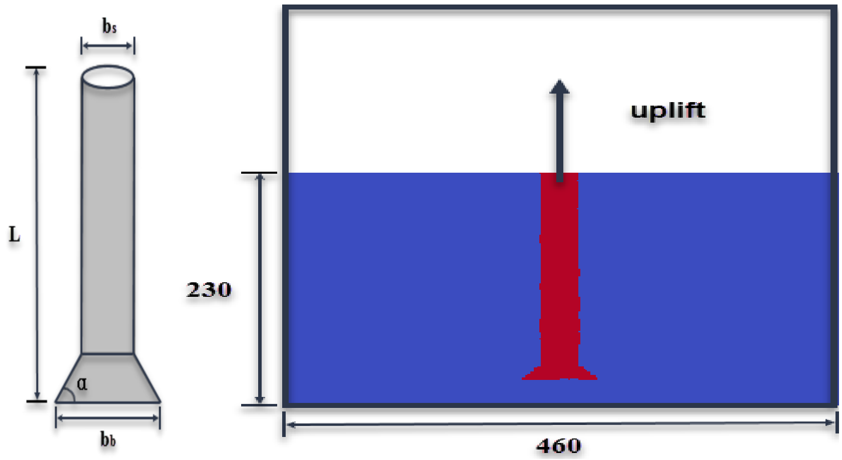


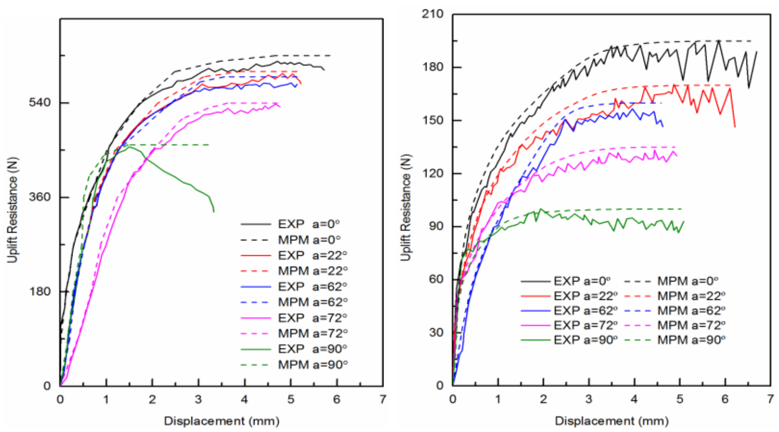
Figure 1 (a) Basic geometric properties of a belled pier; (b) The model of MPM simulation

Table 1 Material parameters of numerical simulations

Description	Loose sand	Dense sand
Young's modulus	15.8MPa	52.1MPa
Poisson's ratio	0.22	0.31
Unit weight	14.2kN/m^3	16kN/m^3
Friction angle	27°	38°
Cohesion	0	0

Results

The uplift resistance with displacement for models and experiments of series 1 are showed in Figure 2, and the Figure 2(a) and Figure 2(b) are for dense sand and loose sand respectively.

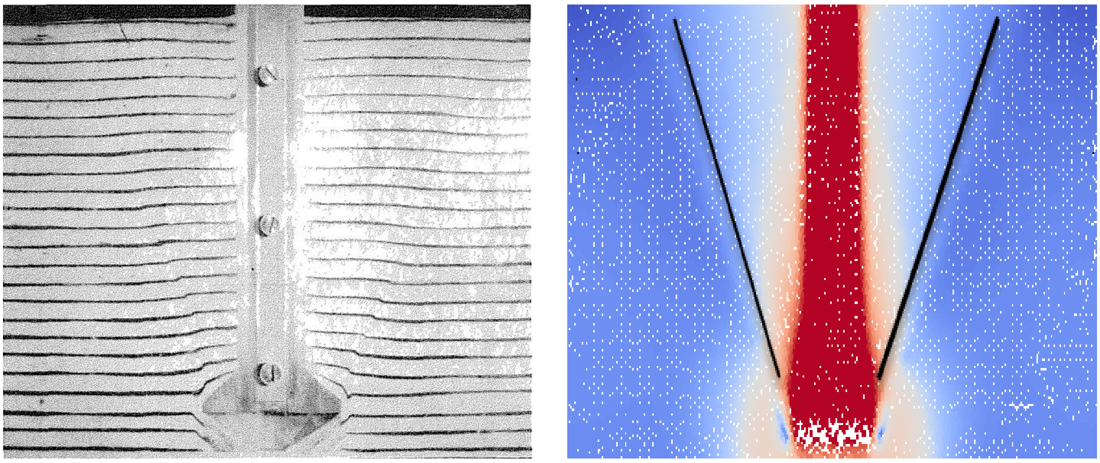


(a) dense sand (b) loose sand

Figure 2 Variation of uplift resistance with displacement for models

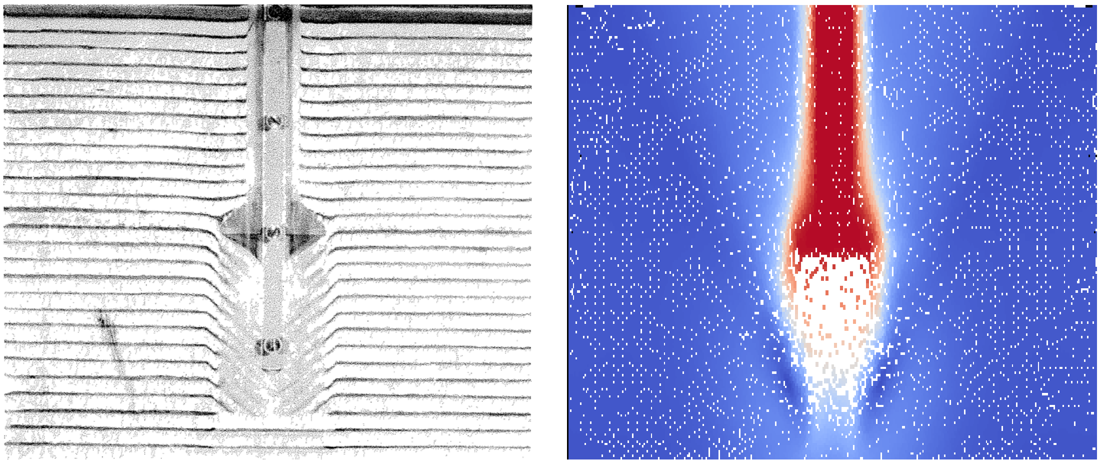
Compared to the experiments, the numerical results indicate a relatively good agreement although some deviation occurs, which maybe result of the effect of edges in the 2D models. The dense sand provides a higher uplift resistance than the loose sand. When the bell angle is 0°, the pile was just like a disc anchor, and that with 90° was a purely conventional pile. The disc anchor can bear stronger uplift load in both loose and dense sand, while the conventional pile uplift resistance is not satisfactory, with a sharp postpeak reduction in resistance in dense sand. It is indicated that the residual uplift resistance is very small. The influence of bell angle is significant in general in both loose and dense sand, decreased with the increment of angle in the uplift resistant and failure displacement. However, the influence with the bell angle from 0° to 62° in the dense sand is respectively little, the loose sand don't has the phenomenon.

The experiment studied the failure mechanism around belled piers was in a perspex-sided tank with a perspex pier, which had a 75mm base and 37mm shaft. Figures 3~4 show the failure mechanism around a belled pier subject to uplift in the dense sand and loose sand, the difference between experiments and simulation results is not very apparent. In addition, from the Figures 3-4, it is indicate that the density is a significant factor of the soil deformation. Hence, the MPM replicate the centrifugal model tests, and the result is basically consistent between numerical simulations and experiments. Once the pile begin to be uplifted, it appears a gap in the bottom of the pile base, and the sand of two sides on the pile base flow down to fill the gap. The gap of the simulation is smaller than the experiment, it is maybe related with the grains size and composition, which is the reason of the higher uplift resistance obtained by the simulation. With the uplifting, it forms an active area and a passive area. In the dense sand, the failure surface tends to develop to be a rupture plane like a trapezoid, and the angle between the black line in the Figure 3(b) and the vertical is closed to half of the internal fictional angle of the sand, the uplift resistance come into the peak value, and then the failure surface gradually reduces until pulled out of the pile. This is the same with the conclusions from Meyerhof (Al-Mhaidib et al., 1998) and Georgiannou (Georgiannou, 2008).



(a) Experiment (b) MPM

Figure 3 Failure mechanism around a belled pier subject to uplift in dense sand



(a) Experiment (b) MPM

Figure 4 Failure mechanism around a belled pier subject to uplift in loose sand

CONCLUSIONS

In this work, the uplift behaviour of piles with enlarged bases in sand was reproduced by MPM, and two series of tests from the experiments of literature was carried out to investigate the influence of variations in angle of foundation base, embedded in loose and dense dry sand, base diameter ratio. The load-displacement curves and the ultimate uplift capacity obtained from the numerical simulations were compared with the centrifugal experimental data, it was observed that MPM simulated results agrees well with the experimental data in both loose and dense sand. MPM can model the uplift problems with large displacements and deformation, and describe the sand deformation which is difficulty for FEM. Moreover, MPM provides an alternative method for uplift resistance prediction.

ACKNOWLEDGMENTS

The authors are grateful for the financial support from the National Natural Science Foundation of China (Grant No. 11772351) and the National Key Technology R&D Program (Grant No. 2018YFC0406604).

REFERENCES

Hamza, Abdel Salam H. A. (1994). Transmission line tower representation and its effect on the tower surge response calculation. Energy Conversion & Management, 35(12), 1087-1096.

Hanna, A., Foriero, A. & Ayadat, T. (2015). Pullout Capacity of Inclined Shallow Single Anchor Plate in Sand. Indian Geotechnical Journal, 45(1):110-120.

Lutenegger, A. J. (2011). Historical development of iron screw-pile foundations: 1836-1900. International Journal for the History of Engineering & Technology 81(1):108-128.

Byrne, B. W. & Houlsby, G. T. (2015). Helical piles: an innovative foundation design option for offshore wind turbines. Philosophical Transactions, 373(2035).

Sahoo, J. P. & Kumar, J. (2012) Horizontal Pullout Resistance for a Group of Two Vertical Plate Anchors in Clays. Geotechnical and Geological Engineering, 30(5):1279–1287.

Jinyuan Liu, Mingliang Liu & Zhende Zhu. (2012) Sand Deformation around an Uplift Plate Anchor. Journal of Geotechnical and Geoenvironmental Engineering, 138(6):728-737.

Nazir A. & Nasr A. (2013) Pullout capacity of batter pile in sand. Journal of Advanced Research, 4(2):147-154.

Niroumand, H., Kassim, K. A., & Nazir, R. (2013). The influence of soil reinforcement on the uplift response of symmetrical anchor plate embedded in sand. Measurement, 46(8), 2608-2629.

Dickin, E. A., & Leung, C. F. (1992). The influence of foundation geometry on the uplift behaviour of piles. Canadian Geotechnical Journal, 29(3): 498-505.

Wang D., Merifieldr., S., & Gaudin C. (2013) Uplift behaviour of helical anchors in clay. Canadian Geotechnical Journal, 50(6): 575-584.

Nazir, R., Moayedi, H., Pratikso, A., & Mosallanezhad, M. (2014). The uplift load capacity of an enlarged base pier embedded in dry sand. Arabian Journal of Geosciences, 8(9):1-12.

Kumar, J., & Kouzer, K. M. (2008). Vertical uplift capacity of horizontal anchors using upper bound limit analysis and finite elements. Canadian Geotechnical Journal, 45(5): 698-704.

Bai, L. W., & Jian, Z. (2004). Particle flow code numerical simulation of extended foundation under the action of uplift loading. Journal of Hydraulic Engineering, 12(12): 69-76.

Pérez, Z. A., Schiavon, J. A., Dias, D., & Thorel, L. (2018). Numerical and experimental study on influence of installation effects on behaviour of helical anchors in very dense sand. Revue Canadienne De Géotechnique, 55(1).

Soga, K., Alonso, E., Yerro, A., Kumar, K., & Bandara, S. (2016). Trends in large-deformation analysis of landslide mass movements with particular emphasis on the material point method. Géotechnique, 66(3): 248-273.

Liang, D., Zhao, X., & Martinelli, M. (2017). Mpm simulations of the interaction between water jet and soil bed. Procedia Engineering, 175: 242-249.

Al-Mhaidib, A. I., & Edil, T. B. (1998). Model tests for uplift resistance of piles in sand. Geotechnical Testing Journal, 21(3): 213-221.

Georgiannou, V. N. (2008). Unstable behaviour of model jamuna micaceous sand. Géotechnique, 58(10): 825-829.