Vertical Bearing Capacity of Skirted Suction Bucket Foundation Based on Elasto-plastic FEM

Ke WU *, Wen ZHANG, Haotian WU, Yajun WANG, Yalin YU

School of Civil Engineering, Shandong University, Jinan Shandong, 250061, P.R. China

***Abstract* - As one offshore foundation, suction bucket foundation is applied for marginal field oil extraction, which is mainly subjected to vertical loading from the oil extraction platform weight. However, the vertical bearing capacity of traditional suction bucket foundation easily fails by shearing along the outside of bucket foundation which leads to the decreasing of vertical bearing capacity. So, one new suction bucket foundation is presented and defined as skirted suction foundation to improving the vertical bearing capacity, which is comprised with one traditional suction bucket foundation and one circular plate foundation. The circular plate foundation is fixed at the top of bucket foundation, and the centers of circles for two foundations is the same point. The new skirted suction bucket foundation is not only holding the practicability of traditional suction bucket foundation in deep offshore, but also adding the stability of shallow offshore foundation. In order to investigate the vertical bearing capacity of new suction foundation, the elasto-plastic FEM is used to simulate two foundations in ABAQUS software. Through comparison with the vertical bearing capacity of two foundations, it can be verified that the new suction foundation is more stability than the traditional foundation and suggest the oil extraction platform to use the new skirted suction bucket foundation.**

Keywords - suction bucket foundation; numerical simulation; vertical bearing capacity; FEM

I. INTRODUCTION

With the development of offshore oil extraction in deep water, alternative types of foundations are being employed to take place traditional systems for offshore facilities, such as gravity foundation, skirt foundation, towards design in increasingly deep water and hostile loading environments [1, 2]. As one offshore foundation, the suction bucket foundation is applied for marginal field oil extraction and it is mainly subjected to vertical loading from the oil extraction platform weight. But the vertical bearing capacity of traditional suction bucket foundation easily fails by shearing along the outside of bucket foundation which leads to the decreasing of vertical bearing capacity [3-5]. So, one new suction bucket foundation is presented and defined as skirted suction foundation to improving the vertical bearing capacity, which is comprised with one traditional suction bucket foundation and one circular plate foundation. The circular plate foundation is fixed at the top of bucket foundation, and the centers of circles for two foundations is the same point. The new skirted suction bucket foundation is not only holding the practicability of traditional suction bucket foundation in deep offshore, but also adding the stability of shallow offshore foundation [6, 7]. In order to investigate the vertical bearing capacity of new suction foundation, the elasto-plastic FEM is used to simulate two foundations in ABAQUS software. Through comparison with the vertical bearing capacity of two foundations, it can be verified that the new suction foundation is more stability than the traditional foundation and suggest the oil extraction platform to use the new skirted suction bucket.

II. FINITE ELEMENT METHOD

The commercial finite element code ABAQUS/Standard has been used to numerically simulate the behavior of skirted suction bucket foundation in soft soil.

A. Finite element model

Based on elasto-plastic FEM, the three-dimensional finite element models are established respectively for suction bucket foundation and skirt suction bucket foundation in Fig. (1). Considering the symmetry of both geometrical and loading conditions, half portion of structure with foundation is used to reduce computational effort. In order to eliminate far-way boundary effect, the finite element model's length is 80m and height is 40m, the suction bucket foundation' radium is 2m and height is 4m, the skirt suction bucket foundation is the same as the former and only the circle foundation at the top of foundation's radium is 4m. The finite element models for different foundation are shown in figure 1. To estimate the initial stresses, it is assumed that after the cylinder penetrates into the soil, the contact surface between cylinder and surrounding soil is a horizontal plane. The density of bucket foundation is taken to be the same as that of surrounding soil.

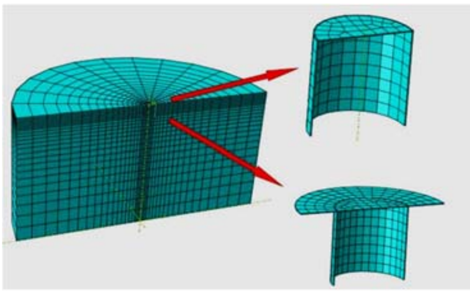


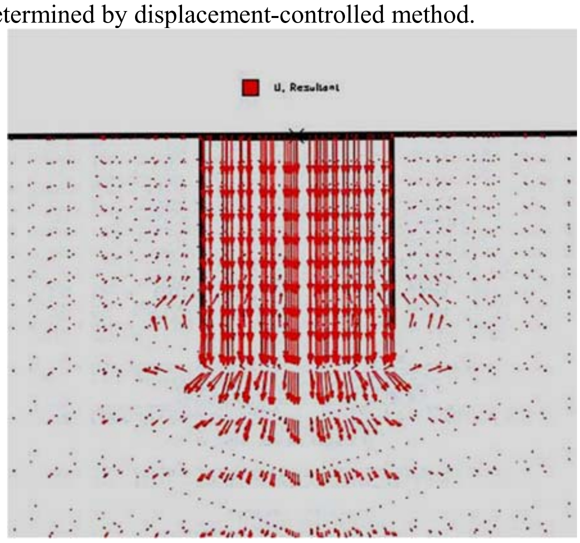
Figure 1. Finite element model

B. Geometry and material parameters

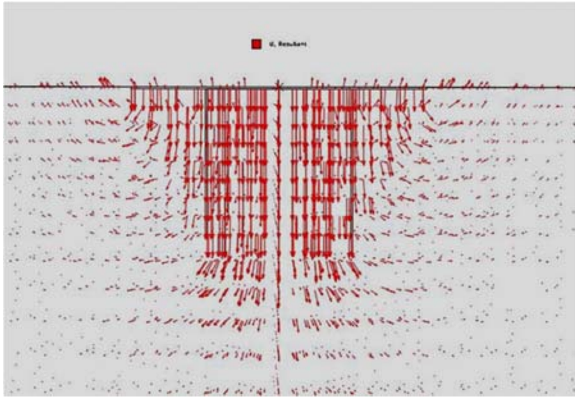
The bucket foundation of width D and depth L used for the analysis is assumed to be rigid, interacting with the surrounding of the foundation soil. The contact between the footing and the foundation soil is assumed to be rough 16. Used for bucket structure is a linear elastic constitutive model with a modulus of elasticity of E=210GPa and Poisson's ratio of ν =0.125. For subsoil, the linearly elasto-perfectly plastic constitutive model obeying to Mises' yield criterion is employed. The Poisson's ratio of soft soil is taken as ν =0.49 and the deformation modulus is assumed to maintain a constant modulus ratio, Eu/su, of 500. Under the undrained condition, soft soil is assumed to obey to Mises' yield. Coulomb's friction law is used to estimate tangential ultimate frictional resistance. When shear stress on the contact surface is less than the ultimate frictional resistance, both are stuck together and no slip happens. On the contrary, when shear stress on the contact surface exceeds the ultimate frictional resistance, slip happens along the contact surface. Contact in normal direction of the interface is considered the hard contact or it is assumed that under the undrained condition, the separation of normally consolidated clay from the bucket wall is not allowed.

C. Displacement controlled method

Being different from the load controlled method, the displacement controlled method can simulate the post-failure response. From the load displacement response of footing, it may be concluded that the soil foundation has attained its limit equilibrium state. In this state, the slope of load-displacement curve tends to vanish, so that the bucket foundation displacement continually increases without additional increment of the applied load. Therefore, in this paper, the ultimate bearing capacity of suction bucket foundation founded in the homogeneous soil strata under the undrained conditions subjected to vertical (V) loading is determined by displacement-controlled method.



(a) Suction bucket foundation



(b) Skirt suction bucket foundation

Figure 2. Vertical displacement vectors for different foundations

III. VERTICAL BEARING CAPACITY

A. Vertical displacement

Figure 2 is showing the vertical displacement vectors of different foundations. It can be observed that: (1) the skirt suction bucket foundation is downward displacement under the vertical loading, which is the same as that of suction bucket foundation. (2) Because of the circle skirt foundation slowing down the displacement, the bottom of skirt bucket foundation is pressed more little than that of suction bucket foundation. (3) The vertical displacement vector of suction bucket foundation is entirely vertical downward. But that of skirt foundation is inverted triangle.

B. Vertical ultimate bearing capacity

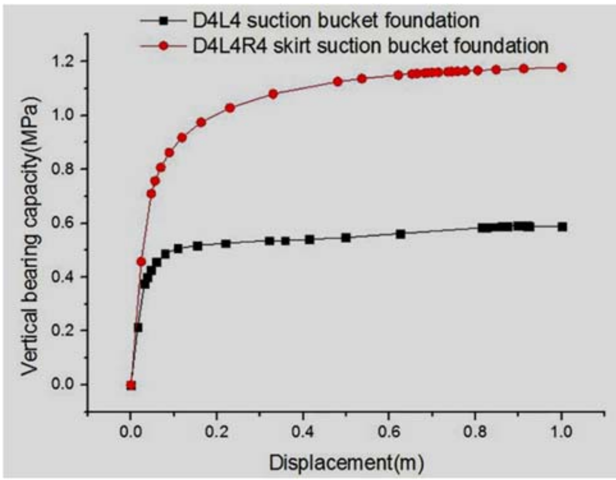


Figure 3. Vertical bearing capacity of different foundation

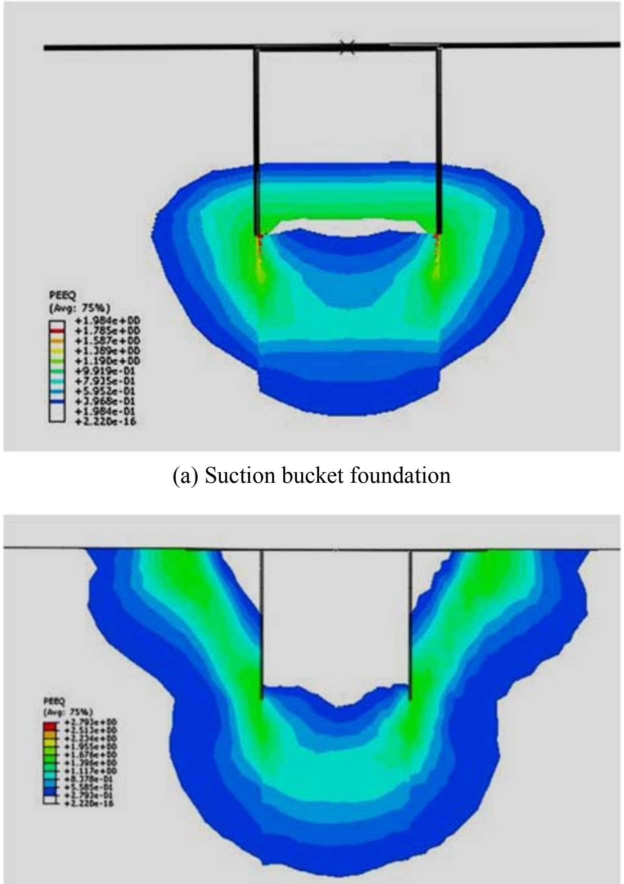
Figure 3 is giving the vertical ultimate bearing capacity of different foundations. It can be observed that: (1) the curves of vertical bearing capacity and displacement for different foundations are similar and increasing as line before displacement is 0.2m, then the curves are proximity level when the displacement is exceeding 0.2m. So, the

DOI 10.5013/IJSSST.a.17.43.24

ISSN: 1473-804x online, 1473-8031 print

vertical bearing capacity corresponding to the displacement 0.2m is defined the ultimate bearing capacity, which are 0.52MPa and 1.2MPa respectively. (2) The curve of skirt bucket foundation is larger than that of suction bucket foundation.

C. Failure mechanism



(a) Suction bucket foundation

(b) Skirt suction bucket foundation

Figure 4. Failure mechanisms for different foundations

The failure mechanisms of different foundation subjected to vertical ultimate loading is shown in figure 4. It can be founded that: (1) the soil at the bottom of foundations is extrusion failure and the failure area are similar to the semi circle. (2) The soil at the bottom of circle skirt foundation also fails and the failure area are similar to inverted triangle, which is the same as the vertical displacement vector of skirt bucket foundation. So, more vertical loading should bring to bear on the skirt bucket foundation than that of suction bucket foundation, which leads to foundation failure and instability. The results is same as the ultimate bearing capacity.

IV. CONCLUSIONS

A series of 3D elasto-plastic FEM has been preformed to investigate the vertical ultimate bearing capacity of skirt suction bucket foundation subjected to vertical loading. It can be obtained from the simulation results: (1) The vertical displacement vector of suction bucket foundation is entirely vertical downward. But that of skirt foundation is inverted triangle. (2) The vertical bearing capacity corresponding to the displacement 0.2m is defined the ultimate bearing capacity, which are 0.52MPa and 1.2MPa respectively. (3) The soil at the bottom of circle skirt foundation also fails and the failure area are similar to inverted triangle, which is the same as the vertical displacement vector of skirt bucket foundation. From these results, the skirt suction bucket foundation is more stability and ultimate bearing capacity than that of traditional suction bucket foundation.

ACKNOWLEDGMENTS

This work was financially supported by National Natural Science Fund(51308323).

REFERENCES

[1] Ivan Depina, Thi Minh Hue Le, Gudmund Eiksund and Thomas Benz. "Behavior of cyclically loaded monopile foundations for offshore wind turbines in heterogeneous sands", Computers and Geotechnics, pp. 266-277, April. 2015.

[2] M. M. LIU, J. J. LIAN, M. YANG and H. J. WANG. "Vertical bearing capacity of wide-shallow bucket foundation", Chinese Journal of Geotechnical Engineering, vol. 37, pp. 379-384, Feb. 2015.

[3] Klaus Thieken, Martin Achmus and Christian Schroder. " On the behavior of suction buckets in sand under tensile loads". Computers and Geotchnics, pp. 88-100, April. 2014.

[4] M. M. LIU, M. YANG and H. J. WANG. "Bearing behavior of wide-shallow bucket foundation for offshore wind turbines in drained silty sand", Ocean Engineering, vol. 82, pp. 169-179, May. 2014.

[5] Aligi Foglia, Guido Gottardi, Laura Govoni and Lars Bo Ibsen. "Modelling the drained response of bucket foundations for offshore wind turbines under general monotonic and cyclic loading", Applied Ocean Research, vol. 52, pp. 80-91, October. 2015.

[6] D. Y. LI, Y. X. GUO, Y. F. GAO and Y. K. ZHANG. "Earth pressure distribution of skirted suction caissions embedded in saturated fine sand under monotonic lateral loading", China Civil Engineering Journal, vol. 48, pp. 112-119, Jan. 2015.

[7] Q. L. FAN and J. ZHENG. "Bearing capacity of skirted foundations subjected to cyclic combined loading", Industrial Construction, vol. 45, pp. 109-112, Jan. 2015.