Research on Failure Mode and Ultimate Bearing Characteristics of the Single Pile Foundation in Sand Soil

Li Bin 1, 2, 3
Tianjin Port Engineering Institute Ltd.
CCCC First Harbor Engineering Company Ltd.,
Tianjin, China
Key laboratory of port geotechnical engineering, ministry of communications, PRC.
Tianjin, China
Key laboratory of port geotechnical engineering of Tianjin.
Tianjin, China

Abstract—The single pile foundation of offshore wind turbine is currently the most common form, but the huge loads and the overturning moment make characteristics of foundation is different from offshore oil platforms. Using elastic-plastic element of ABAQUS simulation of pile foundation in bearing stress and failure modes in different soil layers. The results show that the single pile foundation subjected to vertical ultimate load in different soil layers, no plastic strain. Under the horizontal ultimate load, pile shows plastic strain. Under limit bending moment load, the plastic zone in the soil is mainly distributed in the surface soil in front of pile. Use ABAQUS software to analysis characteristics and failure mode of foundation is correct and reasonable.

Keywords—Pile foundation; ultimate bearing capacity; Theoretical analysis; Finite element; mode;

I. INTRODUCTION

Offshore wind power generation technology has become a hot research and application in recent years, which is rich in wind energy resources and broad flat area [1-3]. China's offshore wind energy resources are expected to reach 750000000 kilowatts, which is 3 times than onshore wind energy resources, offshore wind power will become the focus of future development. At present, the basic structure of offshore wind power has the gravity type, the pile foundation type, the triangle type, the structure of the jacket and the floating structure. Single pile mechanism is a kind of structure which is widely used in offshore wind farms. The horizontal load and overturning moment of the offshore wind turbine foundation are much larger than the offshore oil platform, and the vertical load is less than the offshore oil platform, so the bearing form and characteristics of the foundation are different from the offshore oil platform. In particular, the pile diameter (4~7m) of single pile is far larger than the diameter of offshore oil platform (1~2m), and Bearing mechanism of single pile foundation is also one of the hot spots in the research of offshore wind turbine [4-7].

II. MODEL PARAMETERS

The finite element software ABAQUS is used to establish the finite element model of different type foundation. The calculation range of soil foundation is larger to eliminate the effect of boundary effect. In order to better simulate the interaction between piles and soil, this paper chooses Mohr-Coulomb models in the model calculation. The foundation is sand foundation, specific parameters see table 1. In this paper, the failure mode of large diameter piles in different foundation is studied by theoretical analysis, numerical simulation and model experiment[8-12]. In the calculation of the vertical ultimate bearing capacity of single pile foundation, the effect of soil arch effect on the single pile foundation is considered.

The elastic model is used for the simulation of pile foundation structure, and the concrete parameters of the pile body material are shown in Table 2.

TABLE I SOIL PARAMETERS

soil thickness (m)	unit weight (kN/m^3)	Compression modulus (MPa)	Cohesive force (kPa)	friction angle (°)
100	20.0	21.0	0	35

Normal contact and shear contact are respectively friction contact and hard contact between the pile and the soil.

TABLE II MATERIAL PARAMETERS OF PILE BODY MATERIAL

	unit weight (kN/m^3)	Poisson's ratio	Modulus of elasticity (MPa)
Steel	68.5	0.3	2.1×10^5
Concrete	24.5	0.2	3.0×10^4

Single pile foundation steel type is Q345 which using the elastic plastic model, specific material parameters are shown in Table 2, steel plastic material parameters as shown in Fig .1.

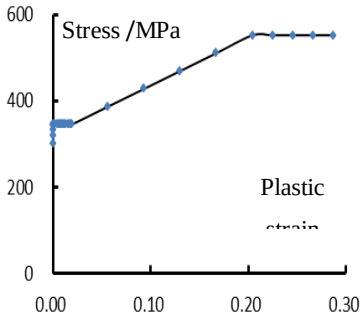

Figure 1. Q345 Relationship of stress and strain

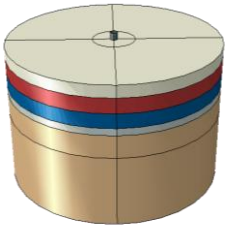

Figure 2. finite element model diagrams

III. FOUNDATION FAILURE MODE

The failure mode and load bearing characteristics of single pile foundation are analyzed based on the finite element software ABAQUS. The finite element model is shown in Fig .2.

A. Foundation failure mode under vertical load

When the pile body under the ultimate vertical load , different diameter of pile equivalent plastic strain cloud chart and the plastic region distribution in soil respectively as in Fig .3, Fig .4.

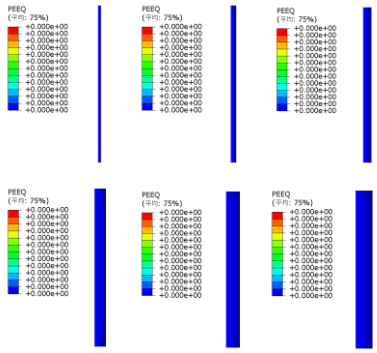

Figure 3. equivalent plastic strain cloud chart of pile body

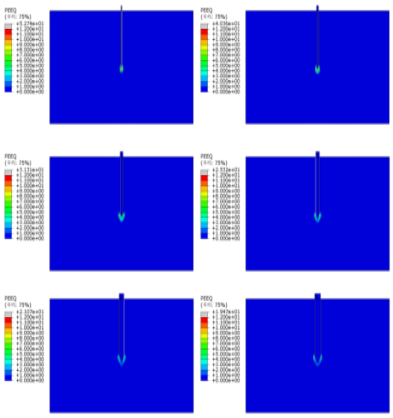

Figure 4. distribution of plastic zone in soil

From Fig .3. it is known that the equivalent plastic strain of piles in different diameters is 0, which has no plastic strain. Because of the large axial rigidity of steel pipe piles, the vertical load of the steel pipe piles will not appear the plastic strain, and it is in the elastic working stage. Therefore, The ultimate failure of single pile foundation under vertical load is the bearing failure of the soil.

Fig . 4 show that with the change of the pile diameter, the plastic zone distribution in the soil gradually increases. The pile length is longer, the foundation depth is larger, and the fracture surface is not extended to the foundation surface, the failure of the soil is manifested by local shear failure. With the change of the pile diameter, the distribution of plastic zone in the soil increases gradually, but the shape is basically the same. In the sand soil foundation, the plastic point of the soil is first appeared below soil mass at the side wall in the bottom of the pile foundation, and then gradually spread to the bottom of the pile soil, and ultimately formed through the slip surface in the bottom of the pile.

B. Foundation failure mode under horizontal loading

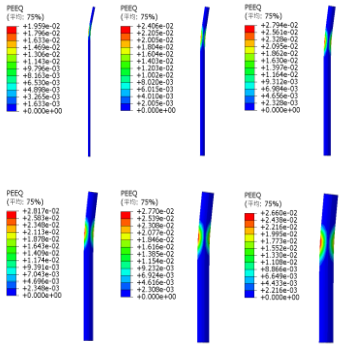

Figure 5. equivalent plastic strain contour of pile body

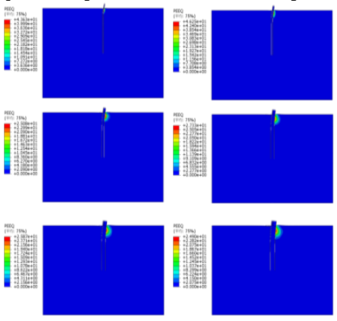

Figure 6. distribution of plastic zone in soil

In sand soil foundation, when the pile body under horizontal load , different diameter of pile equivalent plastic strain cloud chart and plastic region distribution in soil and the displacement vector diagram in soil are shown as Fig .5. and Fig .6. and Fig .7.

From Fig .5. Plastic deformation of piles appears in different diameter piles under horizontal ultimate load. When the diameter is smaller, the range of the plastic zone is distributed in the upper part of the pile; when the diameter is increased, the plastic zone is distributed in the middle part of the pile. Single pile foundation appears the plastic damage under the horizontal limit load, the pile body bears limited stress.

As shown in Fig .6. in sand soil foundation, plastic zone are mainly distributed in the surface of the soil mass which in the front side of the pile body; when the pile diameter increasing, the shape of plastic zone is always same, the range is gradually increasing, the final destruction is the destroy of soil mass where is the front side of the pile body.

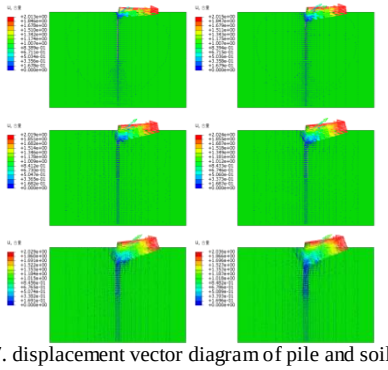

Figure 7. displacement vector diagram of pile and soil

As shown in Fig .7. when the pile diameter is smaller, lower pile is blocking in the soil, The upper part of the pile body moves along the direction of horizontal loads, displacement of pile top is the biggest, the front side soil is uplifting and the soil of the back side moves to the pile body direction. When the pile diameter increases, the resistance of the foundation is larger, and the lower part of the pile is embedded in the soil, the situation is same as smaller diameter.

C. Foundation failure mode under the bending moment.

When the pile body bear bending moment limit load in the sand soil, different diameter of pile equivalent plastic strain cloud chart and plastic region distribution in soil and the displacement vector diagram of pile and the soil as shown in figure 8 and Fig .9. and Fig .10.

From Fig .8. the plastic deformation of piles appears in different diameters of piles under the ultimate load, the plastic zone is distributed in the area which near the top of the pile, different from the horizontal load. The foundation of single pile under ultimate load of the bending moment appears the plastic damage; stress of pile body is overrun.

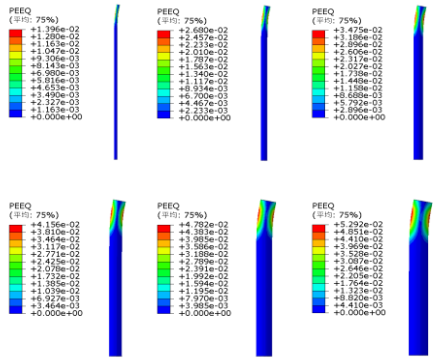

Figure 8. equivalent plastic strain contour of pile body

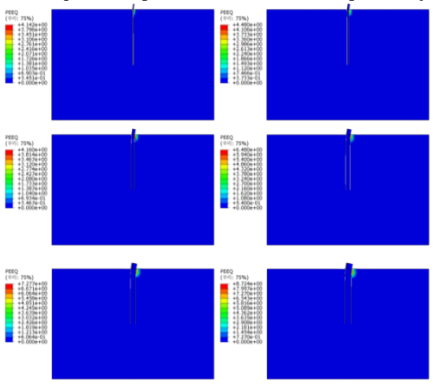

Figure 9. distribution of plastic zone in soil

From Fig .9 it is known that the plastic zone of the soil is mainly distributed in the upper part of the pile body when the pile body bear bending moment load , Plastic zone is relatively smaller than horizontal load condition. the plastic zone is increased when the diameter is increased, The ultimate destruction of the soil mass is the upper surface of the pile.

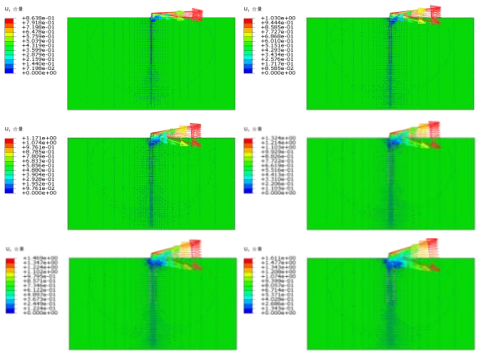

Figure 10. displacement vector diagram of pile and soil

From Fig .10. the lower pile embedded in solid when pile body bear the load moment, upper pile rotation, soil in front of pile body is heaved. when pile diameter is smaller, a smaller range of soil uplift ,pile diameter is larger when soil to uplift range is larger, soil surface of pile body back side moves to the pile body direction.

IV. CONCLUSION

In this paper, the bearing characteristics and failure modes of the single pile foundation in different soil layers are analyzed by using the large finite element software ABAQUS.

(1) Single pile foundation in soil l under the vertical ultimate load, no plastic strain, in the elastic working stage, single pile foundation under the vertical load appears

failure is the destruction of the soil. The distribution of plastic zone in the soil is closely related to the soil layer of the single pile foundation.

(2) Single pile foundation in soil under the horizontal limit load, the pile body has plastic strain. The single pile foundation bearing layer for sand soil, soil surface in front of pile side appear plastic zone distribution.

(3) The position of the plastic strain of the pile is always the top of the pile and the soil is not the same but the position is same, when single pile foundation in different soil layers under the bending moment limit load. Soil in the plastic zone is mainly distributed in the soil surface of pile body's front side; plastic zone is smaller when comparing with the horizontal load condition.

REFERENCE

[1] Global wind report. Global Wind Energy Council. 2010.

[2] European Environment Agency (EEA). Europe's onshore and offshore wind energy potential. 2009.

[3] Lian J J, Sun L Q, Zhang J F, et al."Study on bearing characteristics and technology advantages of the composite bucket foundation of offshore wind turbines. " Journal of Tianjin University. 2011, vol. 2, pp. 55-60.

[4] Chang, Kun Tan, and D. S. Jeng."Numerical study for wave-induced seabed response around offshore wind turbine foundation in Donghai offshore wind farm, Shanghai, China. " Ocean Engineering, vol. 5, 2014, pp32–43.

[5] Fan, Lijia, et al. "The Finite Element Analysis of Interaction among Raft Foundation-Soil and Superstructure." Soil Engineering Foundation. vol. 33, 2013, pp35–46.

[6] Nim, Erik.Wind turbine with floating foundation. US, US7156586 B2. 2007.

[7] Huan Choi. "Offshore pile type fan foundation structure design and research of " . Dalian University of Technology, 2009.

[8] Chen Guangsi, Liu Run, Liu Yuchen, et al. "Analysis of the bending characteristics of the wide and shallow cylindrical foundation with offshore wind power". vol. 46, 2013, pp. 393-400.

[9] Le Cong Huan, Ding Hongyan, Pu Yang Zhang. "The deck concrete bucket foundation of offshore wind turbine bearing model. Engineering mechanics, "vol. 30, 2013, pp. 429-434.

[10] Chen Fei, Yang Xu, et al. "Numerical analysis and experimental verification of the soil compaction effect of tube type foundation." Rock and soil mechanics, vol. 35, 2014, pp. 3587-3591.

[11] Hu Caiqing, Ding Hongyan, et al. "Analysis of horizontal load bearing capacity of single pile foundation in a single layer of clay." Marine engineering, vol. 32, 2014, pp. 820-826.

[12] Wang Haijun. "Under cyclic loading composite barrel type foundation of pore water pressure changes and liquefaction analysis. Rock and soil mechanics, " vol. 35, 2014, pp. 30-37.