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Analysis of Soil Characteristics Affecting Failure Behavior and Bearing Capacity of the Concrete Expanded-Plates Pile

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Abstract: By analyzing the present research results on the concrete expanded-plates pile, the article presents further preliminary studies of their influence on the bearing capacity and failure behavior when the bearing plate is put adjacent to different characteristics of soil and thickness of soil layer. The pile calculation mode for ultimate compression and uplift bearing capacity of the soil failure mechanism of the concrete expanded-plates pile under different conditions is also improved. The study results ensure the rationality and reliability of the design and the applicability of this type of pile in the actual project.

Keywords: Different characteristics soil, the concrete expanded-plates pile (the CEP pile), thickness of soil layer, uplift bearing capacity.

1. INTRODUTION

Professors Yongmei Qian and Xinsheng Yin have studied the piles, soil compression resistance, uplift resistance performance and failure mechanism when the MEEP pile is under compression and tension. They also enriched and developed the theoretical basis for studying the ultimate bearing capacity of the MEEP pile. Based on the existing theoretical research on the MEEP pile, this article analyzes the influence of the MEEP pile under the soil with different characteristics and thickness of soil layer on the pile's soil compression resistance, uplift resistance performance and failure mechanism (it mainly studied the bearing plate in clay soil and fine sand soil) [1]. Further study shows the effects of different soil thickness on bearing plate parameters and the soil failure sliding line when bearing plate is at the same soil layer. And, the theoretical basis of studying the MEEP piles is also improved, so as to make it more in line with the actual situation of the projects, to provide a better service [2, 3].

2. CURRENT SITUATION AND ANALYSIS

The MEEP pile is also named as Multi-level Expanded-Bore Pile or The Radial Multi-Section piles, referred as DX pile preliminary. The general manager of Beijing Zhongkuo Foundation Technology Co. Ltd. is the inventor of DX pile technology. DX is the abbreviation of the word DeXin. From engineering practice, it is shown that the bearing plate of the MEEP pile may be in soil with different characteristics. The bearing plates could be used widely in many kinds of soil, including plastic-hard and plastic clay soil, a little dense and dense state silt soil and sand, the soil interaction with clay soil, silt and sand, strong-weathered rock or residual soil, dense state silt and sand soil, mid-dense and dense state boulder bed and gravel layer *etc.* [4].

The recent study on the MEEP pile is done by a research group of Jilin Jianzhu University. Their study is based on the parameters, such as the diameter size, location, the slope angle of bearing plates, the bearing capacity, the soil failure criterion and the development trend of the slip failure lines. Then, it has obtained and enriched the valuable results and theoretical foundation of the MEEP pile. But these studies are hypothetical in which the soil layer of imbedded bearing plate is infinite, and it will not affect the development of sliding lines and the change of bearing capacity [5]. But in fact, the thickness of soil layer of the imbedded bearing plate is uncertain in the actual project. This will affect the development of sliding lines. Thus, to change the thickness of soil layer imbedded bearing plates could exert a significant influence on the theory of studying the MEEP pile.

The present theoretical study of the MEEP pile is basically limited to the bearing plate imbedded in only clay soil. This situation is due to fully considering the high bearing capacity of clay soil, while ignoring other soils with different characteristics. Now in the actual project the MEEP pile has been successfully applied in the fine sand. Such as, in the case of Petro- China Kunlun Energy Rudong LNG terminal project; in the pile foundation of storage tank of the receiving station in LNG project, geological conditions were very bad, but the MEEP piles were poured successfully in the silt and fine sand at the location of 60 meters below sea level, and the desired bearing capacity were achieved. But, the present theoretical study is not clear when the bearing plates are placed in the fine sand [6, 7]. Engineering practice is given priority to the immature theory. Therefore, the situation when the bearing plate is under different characteristic soils is urgently required to be researched to improve the theoretical basis of the MEEP pile.

3. THE CONTENT OF RESEARCH

Different from the past, *i.e.* unlike research on the upper and lower bearing plates in the single soil layer, the present

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study focused on the upper and lower bearing plates respectively in the different characteristics soil layers, with change of the soil thickness [8]. This study sets the model by ANSYS software for Finite Element Analysis. By changing the soil characteristics and soil thickness where the MEEP piles are imbedded in, the effects of pile-soil failure, shear failure of soil, the sliding failure character, and the influence of relevant parameters of bearing plate when the MEEP pile is under vertical loads, is determined. Strength theory and slip line theory are used for systematic analysis of the stress cloud picture and displacement contours based on ANSYS model calculation. Ultimately, the theoretical foundation of ultimate compression and uplift bearing capacity of a single pile is improved.

3.1. The Kinds of ANSYS Models

Several kinds of ANSYS models are included as follows:

1. The research is about soil failure behavior and bearing capacity of a single pile when the MEEP pile is under vertical compression. The content of research includes two aspects: first is based on a pile with single expanded-plate (as shown in Fig. (**1**)), through the method of finite element, a model of the bearing plate in soil with different characteristics is established, when the pile is under the vertical compression. It is a model of a bearing plate respectively in the clay soil and fine sand under the same vertical compression. Second, based on a pile with single expanded-plate, a model in the same characteristic soil (clay soil or fine sand) is established, but thickness of soil layer is different when the MEEP pile is under vertical compression. It is a model based on changing thickness of soil layer in order to analyze the situation when the MEEP pile is under the same vertical compression.

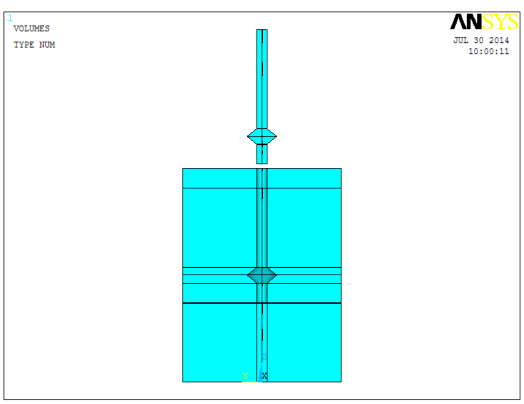

Fig. (1). The model of ANSYS.

2. The content of research is the same as above, but the direction of the load is changed. Here, the load is a vertical tension, so the research is mainly focused on the uplift bearing capacity of the MEEP pile. Thus, the research is mainly focused on soil failure behavior and bearing capacity of single pile when the MEEP pile is under vertical compression. The content of research includes two aspects: first is based on a pile with single expanded-plate. Through the method of finite element, a model of the bearing plate in soil with different characteristics is established, when the pile is under the vertical compression. It is a model of a bearing plate respectively in the clay soil and fine sand under the same vertical compression. Second, based on a pile with single expanded-plate, a model in the same characteristic soil (clay soil or fine sand) is established, but thickness of soil layer is different when the MEEP pile is under vertical compression. It is a model based on changing thickness of soil layer in order to analyze the situation when the MEEP pile is under the same vertical compression.

3.2. The Models with Different Soil Properties and Thickness

The paper preliminarily studies the influence of different soil properties and thickness of the soil on the bearing capacity of the MEEP pile and the mechanism of failure of pile and soil. In this article, the main soil layer includes: the backfill soil, silty clay, fine silt soil, and hard clay. According to the actual engineering survey report and the previous literature, the physical and mechanical performance index of different soil is concluded. The physical and mechanical performance index of soil and concrete used in the ANSYS is shown in Table **1**.

While studying the influence of different soil thickness on the bearing capacity of the MEEP piles, and the effect of piles and soil on the failure mechanism, the establishment of a research model is achieved, which is consistent with the actual situation. The soil in this model includes backfill soil, silty clay (or fine silt soil) and hard clay. The models established with the bearing plate in the soil layer are shown in Table **2**.

The surface between pile and soil is avoided by applying a flexible and rigid body at the interface; the interface between two surfaces should be simulated for slide or frictional distortion, the simulation is followed by the practical interface application.

When the piles are pulled (or compressed), the ANSYS is used to analyze the models that consist of different soil properties and soil thickness under the plate (or on the plate), and drawn the follow conclusions:

When the soil thickness under the plate (or on the plate) is different, the displacement of the piles and the soil in the fine silt soil or in the silty clay is gradually decreased as the soil thickness on the plate is increased, and the capacity of the piles is gradually increased. When the soil thickness on the plate is two times of the plate height, the capacity of piles is higher. When the soil thickness on the plate is four times and five times of the plate height, the capacity is basically the same. So, it is reasonable to set a bearing plate when the soil thickness on the plate is between two and four times of the plate height; it is shown in Figs. (**2** and **3**).

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Table 1. The physical and mechanical performance index of soil and concrete.

Indicators	Severe (g/cm³)	Modulus of elasticity (kPa)	Poisson's rate (υ)	Cohesive force(C) (kPa)	Friction angle (φ)/ expansion angle(β)(°)	The friction coefficient of piles and soil
Backfill soil	1.8E-009	5.5e4	0.30	15.0	12.0	0.25
Silty clay	1.9E-009	2.5e4	0.35	17.4	18.29	0.40
Fine silt soil	1.95E-009	3.0e4	0.25	8.0	25.0	0.30
Hard clay	1.9E-009	10.0e4	0.25	6.0	24.0	0.45
Concrete pile	2.5E-009	2.5e7	0.20	-	-	-

Table 2. The models established with soil thickness different.

Classification model		Different types of model specifications						
Silty clay	Pulling	The model name	TCTP0	TCTP1	TCTP2	TCTP3	TCTP4	TCTP5
		L	4000	3200	2400	1600	800	0
	Compressive	The model name	CCTP0	CCTP1	CCTP2	CCTP3	CCTP4	CCTP5
		L	0	800	1600	2400	3200	4000
Fine silt soil	Pulling	The model name	TSTP0	TSTP1	TSTP2	TSTP3	TSTP4	TSTP5
		L	4000	3200	2400	1600	800	0
	Compressive	The model name	CSTP0	CSTP1	CSTP2	CSTP3	CSTP4	CSTP5
		L	0	800	1600	2400	3200	4000

Note: L is a plate placed vertically on the top of hard clay.

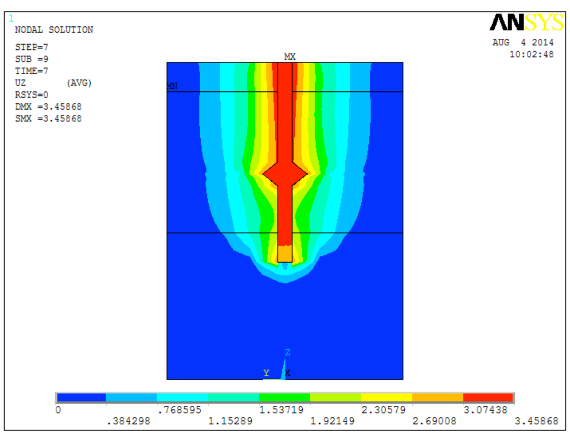

Fig. (2). The displacement in silty clay soil.

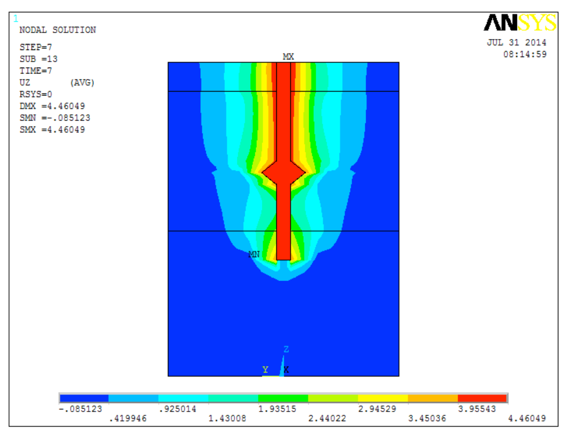

Fig. (3). The displacement in fine silt soil.

When the soil thickness under the plate (or on the plate) is different, the soil shear stress is mutated in two kind of soil: the silty clay and fine silt sand. Both the sliding failure curve of soil and the soil shear stress are changed at the bearing plate.

CONCLUSION

By analysis of this study results, it is shown that the results obtained for the MEEP pile based on the simulation model are the same as actual project situation, which is in line with the actual situation. The study conclusion will further enrich the theoretical basis of compression and uplift bearing capacity when the MEEP pile is under vertical loads, and it makes up for research status of the MEEP pile uplift and compression resistance when the MEEP piles are placed in the soils with different characteristics and thickness of soil layer. The article also provides guidelines for a further research on the effect of pile-soil and soil failure characteristics of the MEEP pile under vertical loads. By changing the relevant factors, sliding failure behavior of the soil surrounding the pile and the effect of pile-soil can be studied. Through modeling analysis, the theoretical basis of compression and uplift bearing capacity of the single pile can be further improved. Further, the formulas of compression and uplift bearing capacity of a single pile under vertical loads are improved in order to give more accurate calculations for piles in different characteristic soils.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

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