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Research on the moisture content of adjacent soil layer affecting the failure behavior of soil and the uplift bearing capacity of the MEEP pile

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Using ANSYS software, an analysis model is established for a Multi-Extruded-Expanded-Plates pile (MEEP pile) in different soil layers under vertical tension. The effect of the moisture content of the adjacent soil layer (sandy soil) below and above the bearing plate on the failure behavior of soil surrounding the piles and the uplift bearing capacity of the single pile at the same time is studied. The model improved the calculation mode of uplift bearing capacity of the single pile, which provides a theoretical basis for engineering design of a MEEP pile.

Keywords: Adjacent soil layer, Moisture content, Failure behavior, Uplift bearing capacity, Multi-Extruded-Expanded-Plates pile (MEEP pile)

INTRODUCTION

Under vertical tension, the uplift bearing capacity of a MEEP pile is closely related to the thickness and character of the soil above the bearing plate. Especially for a sandy soil layer, it is a very important mechanical performance index, whose change will affect important physical indices of soil, such as soil adhesion stress, angle of internal friction, density, etc. [1]. So, when the upper soil of the buried MEEP pile is sandy soil, the change in moisture content will have a significant influence on the failure behavior and bearing capacity of the soil. In this paper, the effect of different moisture contents affecting the failure mechanism and bearing capacity of the soil surrounding the MEEP pile was studied through the finite element method and the calculating mode of uplift bearing capacity of the MEEP pile was improved. Due to the too weak shear strength of sandy soil under drying and saturation regime the adhesion stress, angle of internal friction and other parameters are almost zero, thus it makes no sense to study the moisture contents under two conditions - high or low [2-3]. So the present research focuses on the common moisture content of 10%, 15%, 20%, 25%, and 30%, which affects the failure behavior and bearing capacity of the soil surrounding the pile.

ANSYS ANALYSIS

The paper establishes a half-circle section pile model by ANSYS software. The effect of different moisture contents on the bearing capacity of the MEEP pile and the failure mechanism of the soil surrounding the pile was studied [3]. To establish a MEEP pile model buried in a multilayer soil, different models were formed by changing the moisture content of the model. The results of the comparative analysis were obtained by loading step by step in the course of calculating [4-5].

Determination of material properties

In order to conform to the engineering practice, the physical and mechanical performance index in every soil layer is provided mainly according to practical engineering survey reports. The physical and mechanical performance indices of the concrete pile and every soil layer in the ANSYS modeling, are shown in Table 1.

The MEEP pile is buried in soil with three layers, the top-layer is sandy soil, the middle-layer is silty clay, the sub-layer is clay, the thickness of the three soil layers is 2000 mm, 2500 mm and 3000 mm, respectively.

In order to ensure that the model pile is buried in three layers of soil, the top of the pile is at same level with the surface of the top-layer soil, the bearing plate is set at the middle level of the silty clay layer, the end of pile stretches into the sub-layer soil for 1500 mm, which maintains a certain distance from the end of the pile to the bottom of the sub-layer soil, so the total length of the pile is 6000 mm, the reserved distance of soil surrounding the pile is 3000 mm, which meets the influence range of the soil when the pile and the bearing plate are under load. The size diagram of the model is shown in Figure 1 [6-7]. The five model specifications of the changed moisture content of the sandy soil are shown in Table 2.

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Table 1. Physical and mechanical performance indices of pile and soil-layer

Soil layer	Density (g/cm³)	Elasticity modulus (Mpa)	Poisson Ratio	Cohesion (Kpa)	Friction Angle (°)	Dilation Angle (°)	Coefficient of Friction of Piles
Sandy Soil	1.85E-009	2.0e4	0.25	10.5	38.0	38.0	0.35
Silty Clay	1.9E-009	2.5E4	0.35	17.4	18.29	18.29	0.45
Clay	2.1E-009	3.7E4	0.42	27.8	17.33	17.33	0.5
Concrete Pile	2.5E-009	2.5e7	0.20	-	-	-	-

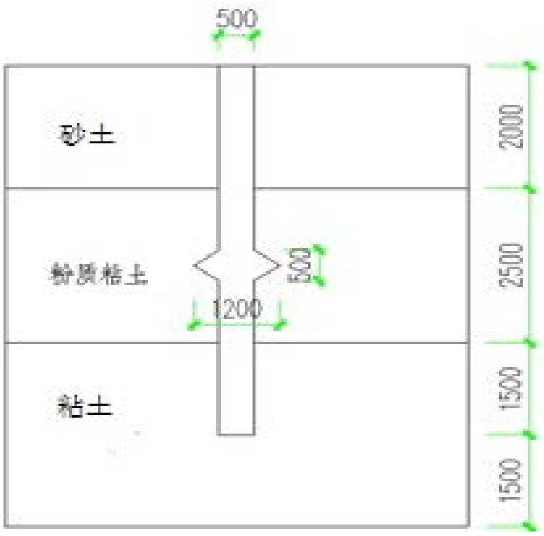


Fig. 1. The model diagram

Table 2. Specification and name of model

Model name	Moisture content（%）
STS1	10
STS2	15
STS3	20
STS4	25
STS5	30

In order to observe the changes in the soil surrounding the pile, a half-circle section pile was designed, the ANSYS model was divided into element grids according to the needs of analysis, and considering the demand of calculating, refinement of the grids was done for the buried plate of pile, pile body and soil cross-section. To consider the actual load situation, a gap of 1 mm is set between the soil model and the pile below the bearing plate, to ensure that the soil is separated from the pile after the pile is loaded. The specific model diagram and grid division are shown in Figures 2 and 3.

ANALYSIS OF THE SIMULATION CALCULATION RESULTS

Analysis of displacement

In the ANSYS analysis, the load is added by an area which is evenly added at the top surface of the half-circle section pile. The load is added from 100KN (which is converted to surface load and

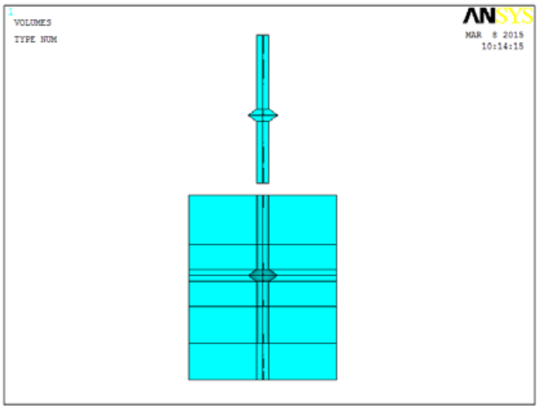


Fig. 2. Model diagram

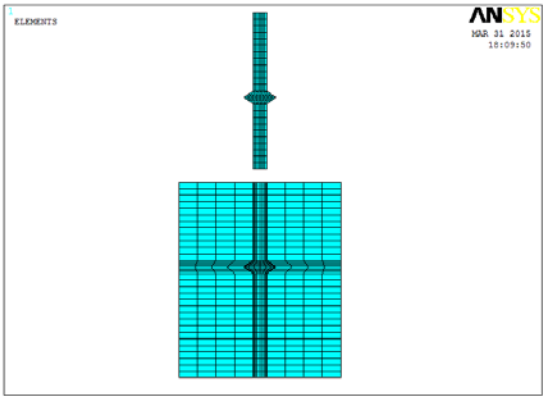
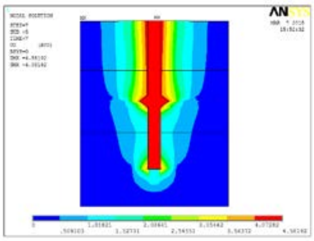


Fig. 3. Grid division of model

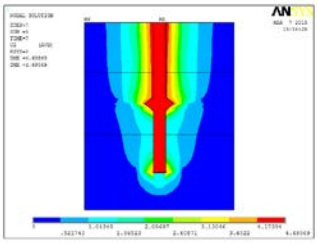
load of 500KN/m^2) [8-9]; the load is added step by step according to the 100KN. When the results are analyzed, the displacement nephogram of the 7th step (up to 700KN load) of each model is taken, as shown in Figure 4.

From Figure 4 it can be seen that the vertical displacement from STS1 to STS4 is generally the same, and it is obvious that the displacement of STS5 is much larger, the change in soil failure behavior is larger, so the bearing capacity will be lower when the moisture content of soil exceeds 30%.

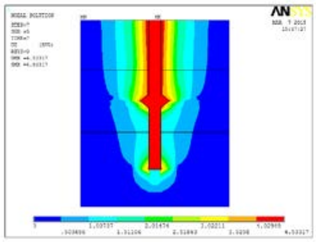
From the ANSYS analysis, the vertical displacement data extracted of a fixed point on the pile under different load are shown in Table 3. According to these data, a curve of displacement *vs* load can be drawn, as shown in Figure 5.



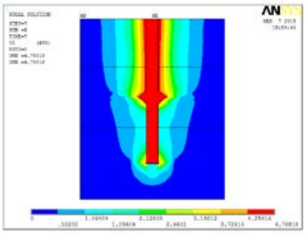
STS1 Displacement



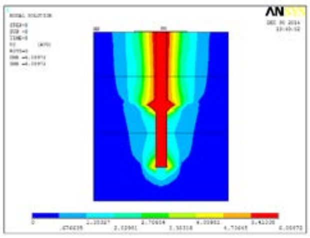
STS2 Displacement



STS3 Displacement



STS4 Displacement



STS5 Displacement

Fig. 4. Displacement nephograms of direction Z

Table 3. The vertical displacement data of a fixed point on the pile under different load

	100KN	200KN	300KN	400KN	500KN	600KN	700KN
STS1 Pile	5.23E-15	0.51539	1.0308	1.5905	2.3495	3.2686	4.4876
STS2 Pile	5.23E-15	0.51539	1.0308	1.5906	2.3598	3.2895	4.5325
STS3 Pile	5.23E-15	0.51539	1.0308	1.591	2.3723	3.3133	4.5812
STS4 Pile	5.23E-15	0.51539	1.0308	1.5922	2.4006	3.3612	4.695
STS5 Pile	5.23E-15	0.51539	1.0308	1.594	2.4238	3.4228	5.0874

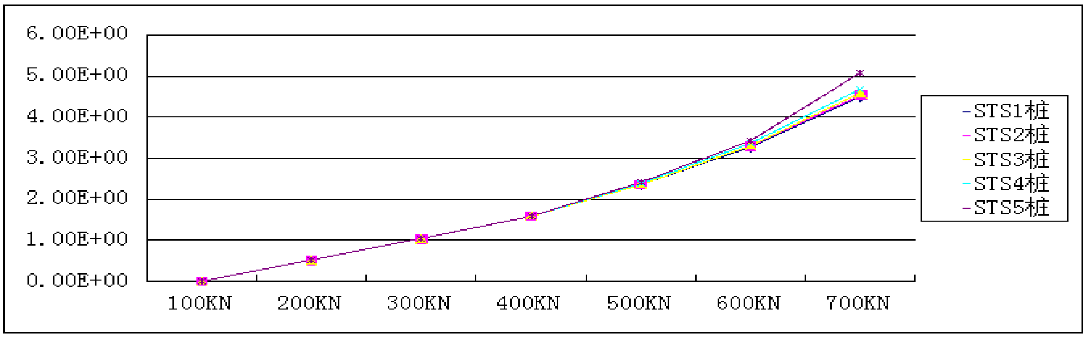
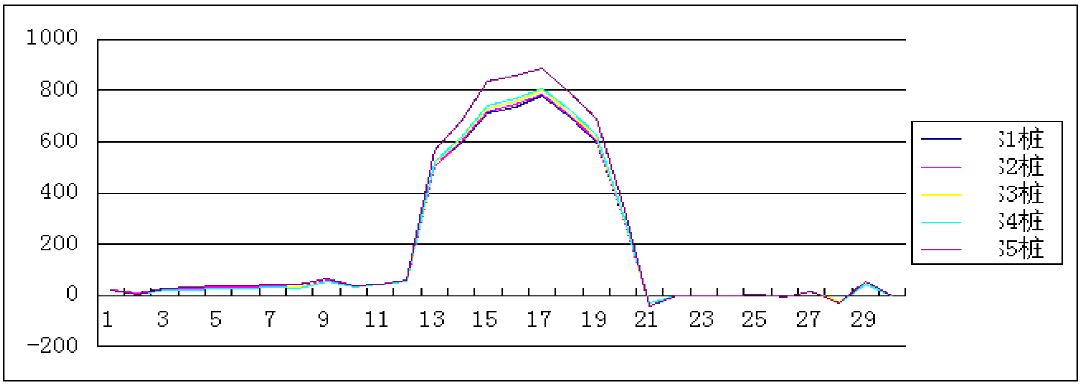


Fig. 5. The displacement-load curve of pile in different moisture content

From figure 5 it can be seen that the displacement changes of the pile with the increase in moisture content from STS1-STS4 are basically the same, the displacement steadily increases with the increase in moisture content. The displacement of STS5 has an obvious twist when load is added to step 6 and step 7, and when load is up to the 8th step (800KN), the bearing capacity cannot meet the requirements and the curve does not converge, so it can be considered that the failure behavior change and the bearing capacity will be lower when the moisture content exceeds 30%.

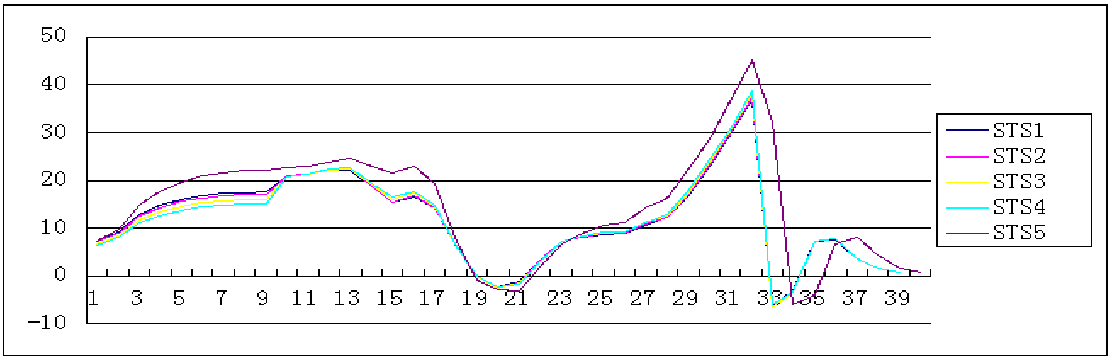
Analysis of stress and strain results

The variation curves of shear stress extracted from the ANSYS results calculated for all kinds of piles and soil surrounding the pile under the same load, are shown in Figures 6 and 7 [10].



Note: The mutated position in curve is the position of the bearing plate

Fig. 6. The curve of shear stress of pile in model with different moisture content



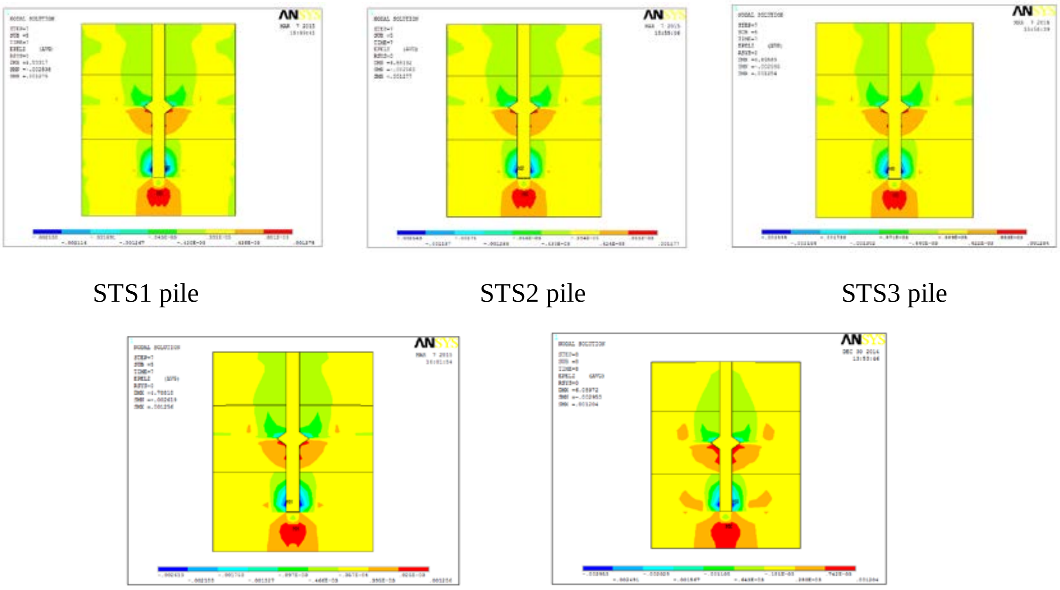
Note: Points 15-21-27 is the position of the bearing plate, points 31-33 is the location of bottom of pile

Fig. 7. The curve of shear stress of soil surrounding pile in model with different moisture content

From Figure 6 it can be seen that the shear stress of the pile body in the different models is the largest at positions of the bearing plate from STS1 to STS4. With the increase in the moisture content of sandy soil, the variations of shear stress at the plate of pile are basically the same. The maximum shear stress of STS5 has a larger variation, which illustrates that when the moisture content of the soil is 30%, the bearing capacity is far less than for the four moisture contents of the sandy soil, so the shear afforded by the bearing plate is the biggest. So it is considered that under vertical tension, if the adjacent layer above the plate of the MEEP pile is sandy soil with moisture content is below 30%, the failure behavior of the soil surrounding the pile is relatively stable and the bearing capacity is relatively better.

From Figure 7 it can be seen that under the same load, the shear stress of the soil surrounding the pile from model STS1 to STS5 creates mutation at the position of the bearing plate, and the same is at the end of the pile. The shear stress of soil surrounding the pile is minimal at the bearing plate in the different models, but the end of the pile is rarely affected by the shear force under vertical tension, thus the shear stress of the soil at the end of pile is insignificant too. It is the same increase in the shear stress at the upper bearing plate from STS1 to STS4. For the model STS5 whose moisture content is 30%, the shear stress of the soil surrounding the pile at the bearing plate is obviously bigger than for the other piles, that is to say, the cohesive force of sandy soil with moisture content 30% is less than for other moisture contents, which has a significant influence on the uplift bearing capacity. Thus, if the adjacent soil layer above the plate of pile is sandy soil with moisture content below 30%, the bearing capacity is basically stable.

In addition, the elastic strain nephograms of direction Z obtained through the model analysis are shown in Figure 8:



STS1 pile STS2 pile STS3 pile

STS4 pile STS5 pile

Fig. 8. The elastic strain graph of direction Z in different model

From Figure 8 it can be seen that if the moisture content of sandy soil is different, the maximum elastic strain of direction Z arises near the plate and the end of the pile for models STS1 to STS5 while the value of elastic strain gradually increases for models STS1 to STS3 and decreases for STS3 to STS5. The value distributes symmetry along the pile axis, the maximum of STS1 to STS4 is basically the same, the reduction rate of maximum value of STS5 is accelerated.

By other nephograms and data extracted from simulation calculations [4], relevant conclusions can be drawn: it can be seen from the stress diagram of direction Z that the stress of direction Z is largest at the top of the pile in models STS1 to STS5, and it reduces gradually along the pile body. The stress of the pile body above the bearing plate changes obviously, it is basically the same as below the bearing plate; the stress changes of direction Z are basically equal for STS1 to STS4 and significantly bigger for STS5.

It can be seen from the first principal stress diagram that with the increase in moisture content, the changes of the first principal stress are basically the same for STS1 to STS5. It decreases along the pile body downward the first principal stress, which changes obviously above the bearing plate, but does not change below the plate. The maximum of STS1 to STS4 is basically the same and bigger for STS5.

It can be seen from the total strain figure of direction Z that as the moisture content increases the change of the maximum total strain of direction Z is basically the same for STS1 and STS2, slightly bigger for STS3. The maximum of total strain of direction Z changes distinctly from STS4 to STS5, the maximum of STS5 is much larger than STS4.

CONCLUSION

It can be concluded that under vertical tension, the moisture content of the adjacent soil layer above the plate of the MEEP pile affects the failure behavior and the bearing capacity of the soil surrounding the pile. From the results of ANSYS analysis, including the displacement nephogram, the curve of displacement *vs* load, the shear stress of the pile body and soil surrounding the pile, the stress of direction Z, the first principal stress, and the total strain figure of direction Z, and so on, the same conclusion can be drawn: if the adjacent soil layer above the plate is sandy soil with a moisture content between 10% and 30%, the failure behavior of the soil surrounding the pile is basically stable, the bearing capacity is relatively better. By the model the bearing capacity can be calculated when the moisture content is equal to or greater than 30%, and different data such as displacement, stress and strain will undergo great changes, and the bearing capacity will decrease. The formula for calculating the bearing capacity should be adjusted before using.

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