Theoretical research on the moisture content of fine silty sand affecting the failure behavior of soil of the MEEP pile under vertical tension

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Due to its moisture content, fine silty sand has a certain influence on the failure behavior and bearing capacity of soil surrounding the MEEP pile. In this paper, using ANSYS software, an analytical model of the MEEP pile is built with the bearing plate embedded in the fine silty sand. By analyzing different models, the results for the moisture content affecting the failure behavior of soil surrounding the pile are compared in order to provide a reliable theoretical basis for the uplift bearing capacity calculation of the MEEP pile in the fine silty sand.

Keywords: Vertical tension, Fine silty sand, Moisture content, Failure behavior, Multi-Extruded-Expanded-Plates pile (MEEP pile)

INTRODUCTION

Moisture content is an important physical and mechanical index and its changes are linked to cohesive strength, internal friction angle, density and other important indices [1]. The study of the moisture content affecting the bearing capacity of the MEEP pile and the failure mechanism of soil surrounding the pile has a far-reaching significance, because the moisture content can directly affect the failure behavior and bearing capacity of soil [2]. As one of the main soils of pile foundation, the fine silty sand is different from clay and silty clay, because in dry condition and saturation, the shear strength is very small, and the cohesive force, internal friction angle and other parameters of fine silty sand are almost inexistent [3]. So, the most suitable moisture content should be studied, because the force mechanism of moisture content in extremely low and high condition is of significance. This paper selects the common moisture content under normal conditions. It is assumed that the moisture content of the analysis model can be 10%, 15%, 20%, 22.5%, 25%, 27.5%, 30%, 35%, respectively. The moisture content affects the failure behavior of the soil surrounding the MEEP pile under vertical tension.

ANALYSIS MODEL ESTABLISHED BY ANSYS SOFTWARE

Determination of material properties

In order to make the analysis results more practical, in this paper, material parameters are based on the physical and mechanical performance index of the fine silty sand from actual engineering survey reports [4]. The indices of physical and mechanical properties of fine silty sand and concrete in ANSYS model are shown in Table 1.

Determination of model dimensions

As the main research is about the effect of different moisture content on the interaction between pile and soil, and the failure mechanism of soil surrounding the MEEP pile, the analysis model of pile body must be completely placed in the same soil layer in order to reduce the influence of other factors. The vertical loads, the location of the plate of pile and the scope of surrounding soil must be considered when the model is established [5, 6].In this paper, the model pile is completely set in the fine silty sand and its thickness is 10800 mm, including the length of pile body (6800 mm) and of the soil beneath (4000 mm).

Table 1. Indices of physical and mechanical performance of various materials

Soil layer	Density (g/cm^3)	Elasticity modulus (Mpa)	Poisson's ratio	Cohesive force (Kpa)	Internal friction (°)	Dilatation angle (°)	Friction coefficient
Fine silty sand	1.95E-009	3.0E4	0.25	8	25	25	0.30
Concrete	25.0	2.5e7	0.20	-	-	-	-

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The diameter of reserve soil surrounding the pile is 4000 mm, to ensure that the pile and the bearing plate under vertical tension influencing the soil are enough. According to the change in moisture content, this paper uses 8 models, each having its own number and moisture content [7] (see Table 2). The dimensions of the model built by finite elements can be seen in Figure 1. The model diagram of piles and soil, and the model grid diagram established by ANSYS are shown in Figures 2 and 3, respectively.

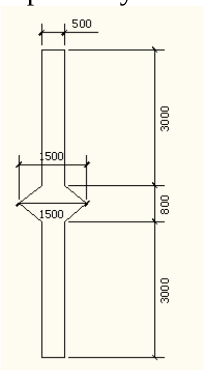


Fig. 1. Diagram of model dimension

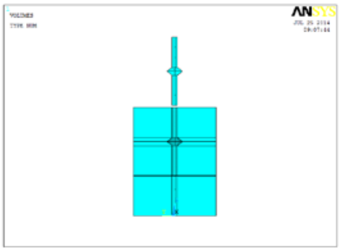


Fig. 2. Model diagram built by ANSYS

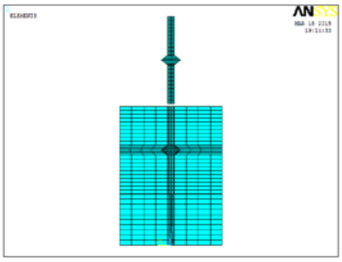


Fig. 3. Grid diagram of model

Analysis of results calculated by finite element simulation

Through the analysis of models by the above method, each of the models is loaded step by step [8, 9]. The load is divided by the area and is uniformly put on the top of the pile with half-circle section. The loading starts from 200KN (converted to load divided by area 1000 KN/m^2) and increases step by step with 200KN. All of these analyses form the nephogram and curve for parameters such as displacement, stress, strain, etc. The typical calculation results are analyzed as follows.

Analysis of displacement results

From the results of finite element analysis by ANSYS, a displacement nephogram of step 8 (loading of 1600KN) was selected for all models (moisture content from 10% to 35%). The vertical direction (Z direction) displacement nephograms of piles and soil of model TSMP1-TSMP8 are shown in Figure 4.

The analysis of the nephograms in Figure 4 shows that the vertical displacement of piles and soil of models TSMP1-TSMP3 is basically the same and its change along with the moisture content is not big [10], but for the model TSMP4-TSMP7, the vertical displacement gradually increases with the increase in moisture content and the bearing capacity is gradually reduced. The maximum change of displacement of piles and soil was for TSMP7. The model TSMP8 was up to failure behavior at the third step (loading of 600KN), for the moisture content was too high, so it could not be further loaded.From the analysis results of the ANSYS model it follows that the vertical displacement value of one fixed point of pile under different loads is as shown in Table 3, and a load-displacement curve can be formed (shown in Figure 5) from the data of the table, in order to analyze the rule of vertical displacement of pile under vertical force action with the change in loads.

It can be seen from Figure 5 that with the increase in moisture content, the pile displacement of TSMP1-TSMP6 has the same change and the growth of the displacement is more stable. The pile displacement change of TSMP7-TSMP8 is bigger and suddenly undergoes an obvious change. The model TSMP8 was destroyed at a very low load.

From the analysis of the nephogram and load-displacement curve above it can be concluded that when the moisture content of fine silty sand is between 10% and 20%, the failure behavior of the soil is relatively stable and has a smaller effect on the bearing capacity.

Table 2. Name of model and moisture content

Moisture content (%)	10	15	20	22.5	25	27.5	30	35
Name of the model	TSMP1	TSMP2	TSMP3	TSMP4	TSMP5	TSMP6	TSMP7	TSMP8

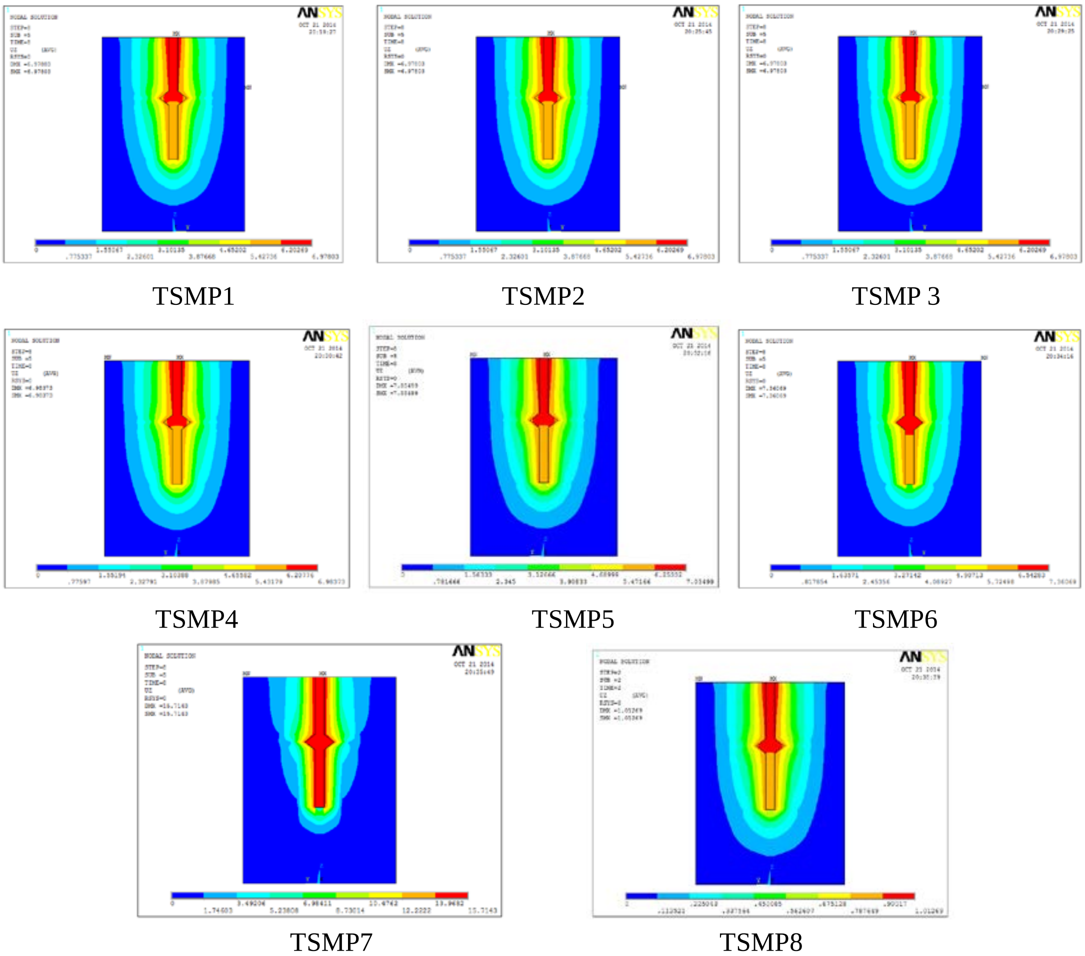


Fig. 4. Z direction displacements of piles and soil of different models in fine silty sand

Table 3. Data of vertical displacement at one fixed point of the pile under different loads

	200KN	400KN	600KN	800KN	1000KN	1200KN	1400KN	1600KN
TSMP1	-0.83E-29	0.99571	1.9914	2.9872	3.9830	4.9788	5.9747	6.9705
TSMP2	-0.83E-29	0.99571	1.9914	2.9872	3.9830	4.9788	5.9747	6.9705
TSMP3	-8.30E-30	0.99571	1.9914	2.9872	3.983	4.9788	5.9747	6.9705
TSMP4	3.88E-30	0.99578	1.9916	2.9874	3.9833	4.9792	5.9751	6.9762
TSMP5	4.18E-30	0.99578	1.9916	2.9874	3.9833	4.9792	5.98	7.0274
TSMP6	2.39E-29	0.99578	1.9916	2.9875	4.0074	5.0562	6.1652	7.3529
TSMP7	3.72E-30	0.99578	1.9916	3.0153	4.0933	5.3457	8.6161	15.706
TSMP8	0.37E-29	1.0116	19.53	-	-	-	-	-

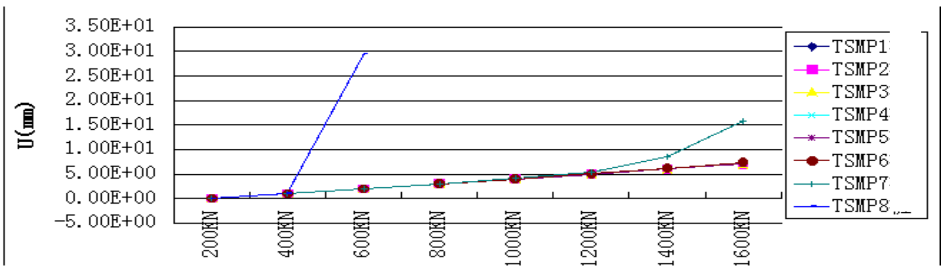
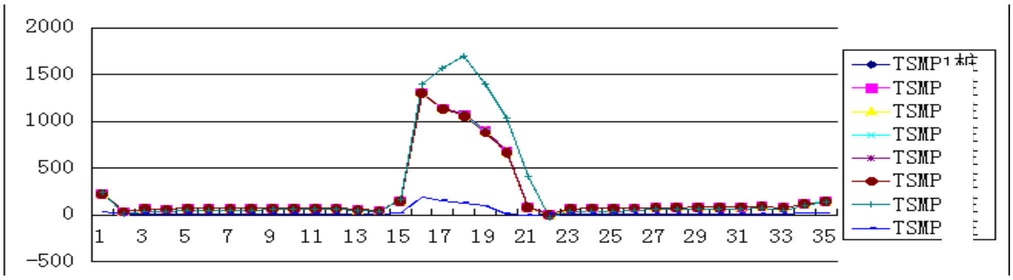
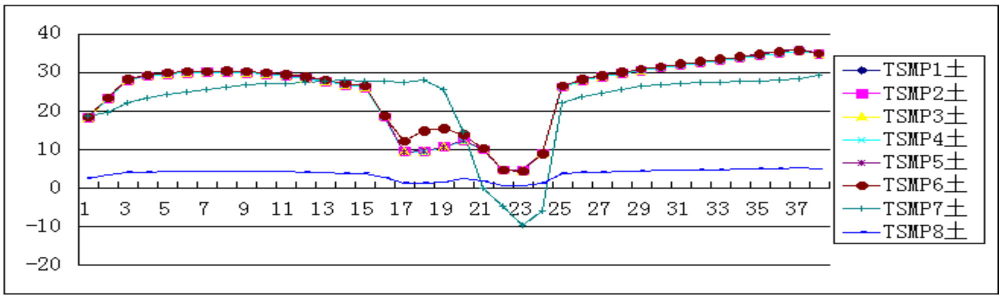


Fig. 5. Displacement-load curve of different model piles with different moisture content in the fine silty sand



Note: the location of change is at the location of the bearing plate in the curve shape

Fig. 6. Shear stress curve of pile body under the same load for different models



Note：the location of 16-20-24 is the location of the bearing plate

Fig. 7. Shear stress curve of soil surrounding pile under the same load for different models

When it is between 20% and 30%, the failure behavior of the soil changes, and the displacement increases stably, showing that the bearing capacity gradually decreases to a lower extent. When it is between 30% and 35%, the displacement suddenly changes at a larger load, showing that the bearing capacity decreases more; when it is above 35%, the model is destroyed under a lower load, showing that the bearing capacity is extremely low.

Analysis of stress and strain results

From the results calculated by ANSYS, it can be extracted that the shear stress data of variety of model pile body and soil surrounding the pile under the same load action, from which the curves are formed as shown in Figure 6 and Figure 7.

It can be seen from Figure 6 that the shear stress of different model pile bodies has a maximum value at the location of the bearing plate. From TSMP1 to TSMP6, the shear stress in the bearing plate has the same change with the increase of moisture content. The maximum change rate of shear stress can reach the top point for TSMP7-TSMP8, so the model TSMP8 is destroyed at a smaller load when the moisture content is 35% and the shear stress of the pile body is small. Therefore, the stress condition of the pile body is more stable when the moisture content is between 10% and 27.5%.

It can be seen from Figure 7 that the shear stress of the soil surrounding the pile in the different models has the minimum value at the location of the bearing plate, and the model TSMP8 is destroyed under a smaller load when the moisture content is 35% and the shear stress of the pile body is extremely small. The shear stress of the soil surrounding the pile of TSMP1-TSMP6 has the same increase rate at the location of the bearing plate, and the shear stress of the model TSMP7 is bigger than that of the others. In general, the shear stress at the location of plate is bigger than under the plate. The shear stress of model TSMP7 is smaller than that of the others, and the shear stress under the bearing plate is bigger than that of the soil surrounding the bearing plate. The shear stress surrounding the pile of TSMP8 is extremely small.

The following conclusions can be drawn from the stress-strain nephogram and respective curve:

From the Z direction stress figure it follows that the stress can reach the maximum value at the top of the pile of model TSMP1-TSMP8, and decreases gradually from the top to the end of the pile body. The stress of the pile body obviously changes at the location of the bearing plate, but it is basically the same under the plate. The Z direction stress of TSMP1-TSMP6 pile is mostly the same, but the change for model TSMP7 is obvious, especially for the stress of the soil surrounding the pile. The stress of TSMP8 is only in the Z direction under the second step load, and it is destroyed with increasing load.

From the first main stress figure it can be concluded that from TSMP1 to TSMP6 the change of the first main stress is the same with increasing moisture content, and it decreases from top to end of the pile body. It strongly changes above the bearing plate, but not under the bearing plate. The maximum of the first main stress from TSMP1-TSMP6 is mostly the same. The nephogram of TSMP8 is at the second step load and has a lower capacity.

From the total strain figure of Z direction it can be concluded that the maximum total strain in Z direction is mostly the same from TSMP1 to TSMP3 with the increase in moisture content and is slightly larger for TSMP1 than for TSMP2 and TSMP3. The maximum total strain in Z direction gradually increases with the same rate for TSMP4 to TSMP7; the maximum for TSMP7 is higher than for TSMP6; TSMP8 is destroyed at the third step load, and from the figure it can be seen that the moisture content is not higher than 27.5%, but less than 20% is most appropriate.

From the elastic strain diagram of Z direction it can be gained that the maximum value of all models appears near the location under the plate, and it gradually decreases from TSMP1 to TSMP7 and distributes symmetrically along the pile axis. The maxima of models TSMP1-TSMP3 are mostly the same, but their decrease rate increases from TSMP4 to TSMP7. The model TSMP8 is destroyed at the third step.

CONCLUSION

It is concluded that the moisture content in the fine silty sand has a certain effect on the failure behavior of soil surrounding the pile when the MEEP pile is under vertical load. Through the analysis of various parameters it is shown that for a moisture content of the fine silty sand between 10% and 20%, the failure behavior of the soil is relatively stable ad has a lower impact on the bearing capacity; when it is between 20% and 30%, the failure behavior of soil changes, and the displacement stably increases, showing that the bearing capacity gradually decreases, but the extent is not high; when it is between 30% and 35%, the displacement suddenly changes at a larger load, showing that the bearing capacity further decreases; when it is above 35%, the model is destroyed under a lower load, showing that the bearing capacity is extremely low. Therefore, the effect of moisture content on the bearing capacity should be considered and properly modified in the process of design and capacity calculation of the MEEP pile ad.

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