A Study on the Influence of Soil Thickness on Calculating Bearing Capacity of CEP Pile under Vertical Compression and Tension

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Abstract — **In this paper we study the effects of soil thickness to calculate the bearing capacity of Concrete Expanded-Plates (CEP) piles under vertical compression and tension. Through the ANSYS software, a finite element analysis model is established. Then by analyzing the bearing capacity of different soil thickness under vertical compression and tension, the bearing capacity of the pile is determined, and the influence of soil thickness on bearing capacity is calculated. Under vertical load, the calculation model of compression and uplift capacity of single pile is derived. This study provides the theoretical foundations for the engineering calculation of bearing capacity of CEP piles.**

Keywords - soil thickness, the CEP pile, compressive bearing capacity, uplift bearing capacity

I. INTRODUCTION

Due to the special structure of CEP pile, it is different from the common pile. Although the current theoretical study on the CEP pile has made some progress, most of the studies don't pay attention on the effects of soil characteristics on the bearing capacity and the damage state of the surrounding soil, such as the soil thickness and moisture content. Hence, these would affect the calculation accuracy. In order to solve the existing problems in the current research and improve the theoretical research of the CEP piles, this paper based on the finite element method, set up analysis model and analyzed the influence of different soil thicknesses for the CEP single pile under the vertical load by the ANSYS software program. Finally, the calculation model of the compression bearing and uplift bearing capacity of the single CEP has been modified through determining the adjustment coefficient.

II. MODIFICATION OF THE UPLIFT BEARING CAPACITY CALCULATION MODEL WITH THE DIFFERENT SOIL THICKNESS

A. *The Calculation Model of the Uplift Bearing Capacity of the Single CEP Pile*

According to calculation formula of the single CEP pile uplift bearing capacity, the schematic diagram is shown in Fig. (1) Under the condition of the bearing plate depth, the punching damage was not happened, and bearing capacity according to the sliding failure to consider. The calculation model of the bearing capacity of single CEP pile can be expressed as follows [1]:

$$F_t = F_{ed} + F_{sp} + G_p \quad (1)$$

where,

F_t ---the uplift bearing capacity;

F_{ed} ---the bearing capacity at end of the disc;

F_{sp} ---the friction resistance in side of the CEP pile;

G_p ---the CEP pile body weight.

(1) Calculation formula of the bearing capacity at the end of disc:

$$F_{ed} = p\frac{D+d}{2}c\cot f\, R_0(e^{2q\tan f} - 1) \quad (2)$$

where,

D ---the diameter of bearing expanded-plates;

d ---the diameter of the main pile;

c ---soil cohesive force;

Φ ---soil internal friction angle.

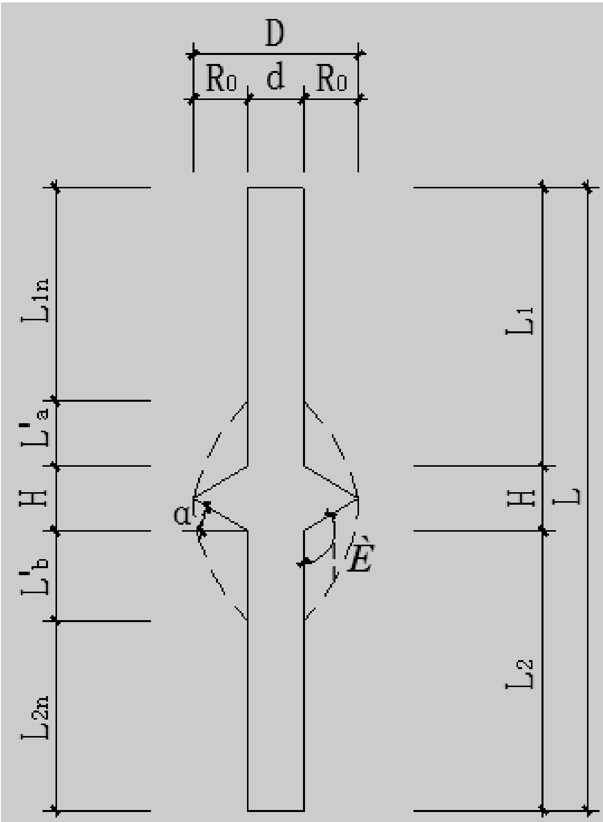

Figure 1. The diagram of pile under vertical tension

(2) Calculation formula of friction resistance in side of CEP pile

$$F_{sp} = f_s pdL_0 = f_s pd(L - H - L'_b + g'L'_a) \quad (3)$$

where,

L ---the length of the pile; H is the height of the plate;

L'_a ---horizontal pressure stress range around the main pile above the plate;

L'_b ---horizontal tension stress increases around the main pile under the plate;

γ' ---an increasing coefficient(γ'= 1.1~1.2).

(3) Calculation formula of CEP pile body weight

$$G_p = \frac{pg_G}{12}[3d(L - H) + H(D^2 + Dd + d^2)] \quad (4)$$

B. Correction Coefficient of Different Soil Thickness

Through the finite element analysis, it is found that the integrity of the sliding damage curve of the soil is affected under the vertical tension because of the difference of soil thickness above the plate, the bearing capacity is also affected at the same time[2]. Silty clay and fine silty sand, which are the different properties were studied. Above the plate, soil thickness layer was 0~5 times higher than plate high of the model，and the analysis results and the calculation model bearing capacity of the single CEP pile was calculated according to the above. The results are shown in table Ⅰ.

TABLE □. THE COMPARISON OF RESULTS OF THE THEORETICAL EQUATION AND THE FINITE ELEMENT ANALYSIS UNDER VERTICAL TENSION

Model (soil thickness above the plate)	Silty clay bearing capacity(KN)			Fine silty sand bearing capacity(KN)		
	Theoretical equation	*Finite element analysis*	λ	*Theoretical equation*	*Finite element analysis*	λ
0 times	922	700	0.76	764	500	0.65
1times	1002	900	0.90	827	700	0.85
2 times	1073	1000	0.93	886	800	0.93
3 times	1088	1100	1.01	998	1000	1.01
4 times	1088	1200	1.10	998	1200	1.20
5 times	1137	1400	1.23	935	1200	1.28

From table Ⅰ, it can be seen that the uplift bearing capacity according to the single CEP plate uplift ultimate bearing capacity calculation equations is different from that of ANSYS finite element analysis. According to the previous research [2], the slip line is complete and the bearing capacity increased when the soil thickness layer above the plate is at least 2 times higher than the plate high，otherwise the bearing capacity will be affected. Therefore, the results obtained from the theoretical formula should be corrected. According to the comparison between the results obtained from the finite element analysis and the theoretical formula, the coefficient λ is the correction factor of the theoretical formula.

From table Ⅰ, it can be seen that whether silty clay or fine powder sand, λ is less than 1 when the soil thickness is not greater 2 times higher than the plate high; λ is greater than 1 when the soil thickness is more than 2 times higher than the plate high. It illuminates that the impact of punching shear damage when the soil thickness is not greater 2 times higher than the plate high, and the results of finite element is less than that of the theoretical calculation formula. Also it can be seen that when the soil thickness is 3 times higher than the plate high, the result of the finite element calculation is greater than that of the theoretical calculation formula. After the soil thickness is more than 2 times higher than the plate high, the influence coefficient is linear distribution, and gradually increased.

According to the results of the linear statistical, the calculation formula of uplift bearing capacity will introduce adjustment coefficient modification. When the soil thickness is 2 times higher than the plate high, λ is 1.2; when the soil thickness is 5 times higher than the plate high, λ is 0.9, intermediate by interpolation method. It should ensure that the soil thickness on the plate is greater than the plate high as possible when set expanded-plate.

III. Modification of The Compressive Bearing Capacity Calculation Model with the Different Soil Thickness

A. The Calculation Model of the Compressive Bearing Capacity of the Single CEP Pile

According to the previous studies and the theory of slip line, soil damage region strain field curve under the plate is composed of two radial rays θ=Θ, θ=0 and $r = R_0 e^{q \tan f}$ (as shown in Fig.(2)), when the concrete expanded-plates pile under the vertical compression [3]. Currently, the calculation model of the compressive bearing capacity of single CEP pile can be expressed as follows:

$$F_c = F_{ep} + F_{ed} + F_{sp} \qquad (5)$$

Where,

F_c ---the compressive bearing capacity;

F_{ep} ---the bearing capacity at end of the CEP pile;

F_{ed} ---the bearing capacity at end of the disc;

F_{sp} ---the friction resistance in side of the CEP pile.

(1) Calculation formula of bearing capacity at the end of disc:

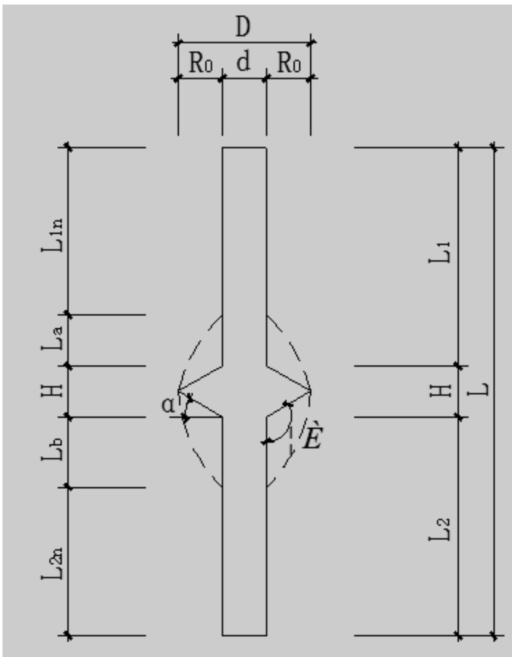

Figure 2. The diagram of pile under vertical compression

Because of the damage of the soil under the bearing plate and the slip line theory (the schematic diagram is shown in Fig. 2), the calculation can be expressed as:

$$F_{ed} = p\frac{D+d}{2}c\cot f\,R_0(e^{2q\tan f} - 1) \qquad (6)$$

All symbols in the formula are the same as mentioned before.

(2) Calculation formula of friction resistance in side of the CEP pile

$$F_{sp} = f_s pdL_0 = f_s pd(L - H - L_a + gL_b) \qquad (7)$$

(3) Calculation of bearing capacity at end of the CEP pile

$$F_{ep} = f_e\frac{pd^2}{4} \qquad (8)$$

All symbols in the formula are the same as mentioned before.

B. *Correction Coefficient of Different Soil Thickness*

Through the finite element analysis, it is found that [2] the integrity of the sliding damage curve of the soil is affected under the vertical compression because of the difference of soil thickness above the plate, the bearing capacity is also affected at the same time. Silty clay and fine silty sand, which are different properties were studied. Under the plate, soil thickness layer was 0~5 times higher than plate high of the model，and the analysis results and the calculation model bearing capacity of the single CEP pile was calculated according to the above. The results are shown in table Ⅱ.

TABLE Ⅱ. THE COMPARISON OF RESULTS OF THE THEORETICAL EQUATION AND THE FINITE ELEMENT ANALYSIS UNDER VERTICAL COMPRESSION

Model (soil thickness under the plate)	**Silty clay bearing capacity(KN)**			**Fine silty sand bearing capacity(KN)**		
	Theoretical equation	***Finite element analysis***	***λ***	***Theoretical equation***	***Finite element analysis***	***λ***
0 times	1450	1600	1.10	1273	1400	1.10
1times	1523	1600	1.05	1349	1400	1.04
2 times	1601	1800	1.12	1411	1600	1.13
3 times	1601	2000	1.25	1411	1800	1.28
4 times	1601	2000	1.25	1411	1800	1.28
5 times	1645	2000	1.22	1443	1800	1.25

From table □, it can be seen that the compressive bearing capacity according to the single CEP plate uplift ultimate bearing capacity calculation equations is different from that of ANSYS finite element analysis. According to the previous research [2], the slip line is complete and the bearing capacity when the soil thickness layer under the plate is at least 3 times higher than the plate high..When 0 times higher, the damage of the lower soil has a relatively complete slip line, bearing capacity will be affected by the nature of the lower soil. When 1 times higher, slip line exists in the two soil layer. So the bearing capacity increased. Therefore, the results obtained from should be corrected. According to the comparison between the results obtained from the finite element analysis and the theoretical formula, coefficient λ is the correction factor of the theoretical formula.

From table Ⅱ, it can be seen that whether silty clay or fine powder sand, λ is less than 1.1,when the soil thickness is not greater than 2 times of the plate high. When the soil thickness is more than 3 times of the plate high, λ is greater than 1.25.When the soil thickness is more than 5 times of the plate high, λ would decrease.

According to the results of the linear statistical, the calculation formula of compressive bearing capacity will introduce adjustment coefficient modification. When the soil thickness is 2 times higher than the plate high, λ is 1.1; when the soil thickness is 3 times higher than the plate high, λ is 1.2,and intermediate by interpolation method. It should ensure that the soil thickness under the plate is greater than 2 times higher as possible, when set expanded-plate.

IV. Conclusion

The conclusion can be conducted from this paper: the results obtained from the calculation formula of the single CEP pile compression and uplift bearing capacity is different from that of the finite element method. Meanwhile, different soil thickness has different influence coefficients. Different soil thickness affects the integrity of the slip line when soil up and down the CEP pile is damaged. Therefore, the bearing capacity has been affected. The influence coefficient of the compressive and uplift bearing capacity of the CEP pile under the different soil layer thickness was obtained. The theoretical calculation model of compression and uplift bearing capacity of the single CEP pile is fixed, which provides the theoretical basis for the pile design and calculation.

Acknowledgments

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REFERENCES

[1] Yongmei Qian, Jiajia Ren, Nan Mu, "The Research on the Calculation Model of the Uplift Bearing Capacity of the Concret Expended-Plates Pile", building technology[J], vol.46, no.6, pp 503-503, 2015.

[2] Yongmei Qian, Xuewen Xie, Xiaolong Liu, "Analysis of influence on damage state and bearing capacity of the Concret Expended-Plates Pile by soil properties", Building Technique Development[J], vol.41, no.5, P31-33,2014.

[3] Yongmei Qian, Dapeng Zhang, Xuewen Xie, "The Research on the Ultimate Bearing Capacity of Soil around the Push-extend Multi-under-reamed Pile at Sliding Failure State",Advances in Civil Structures IV[C], Trans Tech Publications, Vol.21, no.3,pp 232-235. 2014.