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The Undisturbed-Soil Experimental Analysis of the Destructive-State Influence of the Plate Diameter under the Vertical Tension on the CEP Pile

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In this paper the influence of different overhangs for enlarging plates on the bearing capacity of CEP piles under the vertical tension has been investigated. The destructive state of soil around the pile was also carried out through the undisturbed-soil model experiment. Furthermore, the experimental results were compared with the ANSYS simulation analysis of the finite-element software for improving the current theoretical research on calculating the uplift bearing capacity of the CEP pile.

1. Introduction

With the booming of high-rise and super high-rise buildings, many scholars home and abroad have shown great concern about the CEP pile, a new-type pile foundation, and a wealth of experimental researches have been done on it (Qian et al., 2012; 2015). Being one of the elements that affect the ultimate uplift bearing capacity of the CEP pile and the destructive state of soil, the theoretical and experimental research on the undisturbed-soil research on the damage mechanism of the plate diameter under the vertical tension on the CEP Pile is far from being perfect. Currently, there are researches on the related subject through the model test of soil burning; since there are differences between the soil sample and the real soil in the soil burying test, the reliability of study results is influenced (Qian et al., 2015).In this paper, researchers make the test model with the undisturbed soil got with the self-made geotome from the real construction site, carry out the loading experiment, observe the destructive state of the soil around the pile, compare the result with that got from the ANSYS simulation analysis of the finite-element software, and a contractive analytical research on the influence of different overhangs of enlarging plates on the bearing capacity of CEP piles and the destructive state of soil are done, so as to perfect current theories of the calculation and the design of the CEP pile and lay a good foundation for the practical engineering application (Lade, 2010).

2. The experimental research of the undisturbed soil

2.1 The specification and making of the test piece

In this experiment, the model CEP pile is designed according to the pile model of the finite-element simulation analysis. The small-scale and semi-section model pile is adopted, which is scaled down according to the proportion of 1:50. The pile model made of the round steel is processed and grinded by the fine machine (Xu, 2014).

This paper focuses on the influence of overhangs in the enlarging plate on the uplift bearing capacity of CEP piles. There are four parameter variables of the teat model. The variables are controlled by controlling the single factor; that is, in plate parameters, the value of the slope angle in the enlarging plate remains unchanged and the suspension diameter of the enlarging plate is changed.

The length of the plate suspension diameter is R0= (D-d)/2, the suspension diameter length of the enlarging plate is based on the modulus of the pile diameter, and the design lengths are 1 time, 1.5 times, 2 times and 2.5times the length of the pile diameter (Li and Gao, 2010). Since the model pile diameter of the CEP pile is

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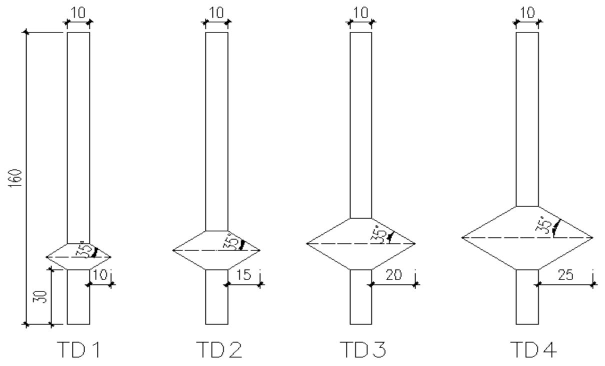
10mm, the length of the plate suspension diameter is 10mm, 15mm, 20mm and 25mm. According to the reasonable range of the design value in the slope angle of the enlarging plate, the value of the plate slope angle is set as 35º. As shown in Figure 1.



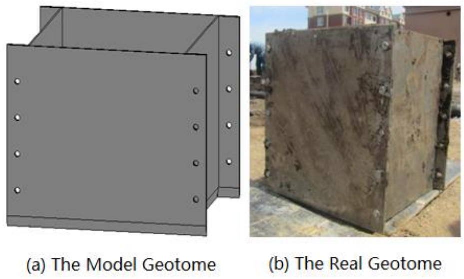


Figure 1: Design charts of the CEP pile with different diameters *Figure 2: The geotome*

According to the conclusion drawn from the previous small-scale model experimental research, the influence range of the CEP pile plate on the soil mass is 4~5 times the length of the plate overhang $R_{0,}$ so the designed geotome can ensure the successful completion of the model pile with the maximum suspension diameter in the enlarging plate (2.5 times of the pile diameter) (Bourgeois et al., 2012). The length of the test is the final size of the geotome section(H); that is, $H \geq 2\times(5R_0+d/2)$. If R_{0max}=25mm, H≥260mm. The size of the geotome is 300×300×300mm, which both satisfies the test demand and is convenient for the factory to process, is finally decided. As shown in Figure 2. The geotome is mainly made of two concave steel plates and two flat steel plates connected with bolts. When the geotome inside H=300mm, set aside the length of 30mm on four sides of the steel plate, four bolt holes with the diameter of 5mm that are used to fix the steel plate are made evenly on the front and the back. In order to prevent the geotome from the deformation when it is pressed into the soil, the steel plate is 3mm in thickness, which can ensure that its overall stiffness is large enough for being pressed into the soil. In addition, to further reduce the resistance when the geotome is pressed into the soil, the 15-mm area in the lower part of the steel plate in the geotome cross section that contacts the soil directly should be made in the shape of wedge. As shown in Figure 3(b).

2.2 The preparation process of the experiment

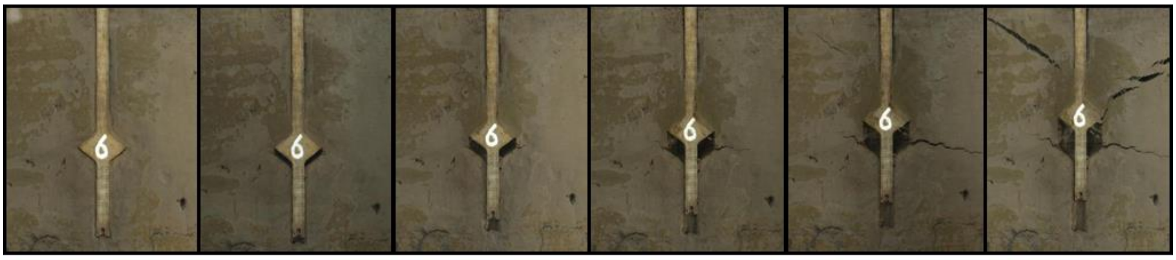
The preparation process is: extract the undisturbed soil for the test, press the experimental CEP pile, the experimental loading and data collection.
Extract the undisturbed soil: the silly clay layer with a good bearing capacity is chosen.
Press the experimental CEP pile: First, remove some soil slowly along the contour line of the pile with a graver. Then, along the contour line of the pile, press the specimen of the CEP pile into the groove resulted from removing the soil and fix it (the pile body is vertical to the upper edge). Finally, put the steel plate beside the lateral plane of the half-section CEP pile, and press the half-section model pile into soil with the vertical static. When exerting pressure, make sure that the pressure on every part of the pile (Baker and Frydman, 2009; Bourgeois et al., 2012).
The experimental loading and data collection.
(1) The collection of loading and displacement: The displacement meter is read manually and directly. When the graded load is adopted, the method of the displacement variable control is used. When the pile body has the displacement of 1mm, the loading stops and the value on the pressure meter is recorded.
(2) The image acquisition: When the displacement is 0, record the initial image with the digital camera. When every displacement of 2mm appears, record it with the camera. Until the soil around the pile is destroyed, record for the last time. The whole process of the soil is recorded.

3. Data arrangement and analysis of the cep pile experiment

3.1 The analysis of the destruction process of soil around the CEP pile

In the experimental process, the whole destruction process of soil around the pile is recorded. Take Pile TD2 as an example, soil destructions on the plate, under the plate, and around the pile are all recorded. As shown in Figure 3.

From Figure 5, it can be clearly seen that the oil construction around the pile is the slip failure. Firstly, because of small loading, the vertical displacement of the pile body is small, which is mainly the compression deformation of the local soil above the plate; the soil under the pile is separated from the plate. Then, with the increase of the vertical tension on the pile top, the displacement of the pile increases; the soil above the plate gradually increases and reaches the elastic deformation limit of the soil of mass, the slip failure of the soil mass begins. With the further increase of the loading displacement, the range of the soil slip around the pile increases gradually and reaches the limit state. Finally, in order to research the ultimate state, the displacement increases and meanwhile the soil around the pile plate is completely destroyed. Since there is only a short distance between the soil mass above the plate and the soil surface, the punching failure of the soil above the plate appears that is along the direction of 45°; finally, the soil mass above the plate is separated from the whole and loses the bearing capacity.



(a) (b) (c) (d) (e) (f)

Figure 3: The whole process of soil destruction of Pile TD2

3.2 The destruction analysis of soil around model piles with different suspension diameters in the enlarging plate

The experimental research in this paper focuses on the destructive form of soil mass when the pile soil functions. Destructive forms of soil masses both around the pile and on the pile are observed, compared and analyzed. The situation before and after the destruction of soil around Piles TD1~TD4 are shown in Figure 4~7.

Figure 4: Model pile TD1 *Figure 5: Model pile TD2* *Figure 6: Model pile TD3* *Figure 7: Model pile TD4*

The soil destructive form can be clearly seen from Figure 4~7, and the following conclusions can be drawn:
(1) When the pile and the soil interact, the destructive form of the soil has something to do with the maximum bearing capacity of the CEP pile. When the plate position remains the same, the suspension length of the plate is relatively small and there is enough distance between the plate and the soil top, the destructive form of the soil above the plate is the slip failure. (As shown in Figure 4 and 5) This conclusion conforms to the conclusion got from the anti-uplift experiment of small disturbed-soil model pile; when the plate overhang increases, the distance between the plate and the soil top gradually decreases; after a certain slip, the soil above the plate is not destroyed and then there appears the punching failure of the soil above the plate. As shown in Figure 6 and 7.
(2) When there appears the soil slip of the model pile, the soil slip on the model pile plate is similar. Measure the horizontal distance between the outermost edge of the slip line and the symmetrical shaft of the CEP pile; that is, the influence range of the enlarging plate under pulling on the soil above the plate, which is about 3~5 times the length of the suspension diameter in the enlarging plate. This conclusion conforms to previous conclusions got from the anti-uplift experiment of the small disturbed-soil model pile.

3.3 Arrangements of raw displacement-loading data of model piles with different suspension diameters of the enlarging plate

The loading-displacement curve got from the experiment is shown in Figure 8.
Compare and analyze S-Q curves of Model CEP piles TD1, TD2, TD3 and TD4, follow in conclusions can be drawn:
For Model piles TD1~TD4, trends of S-Q curves are similar; basically, it gradually increases in the early stage and slowly increases in the later stage.
The bearing capacity of the CEP pile increases with the increased of the suspension diameter of the enlarging plate. S-Q curves of Piles TD1 and TD2 are similar, and their pension diameters of the enlarging plate are 1.5 times and 2.5 times of the pile diameter, which means that rules of the soil destruction are similar.

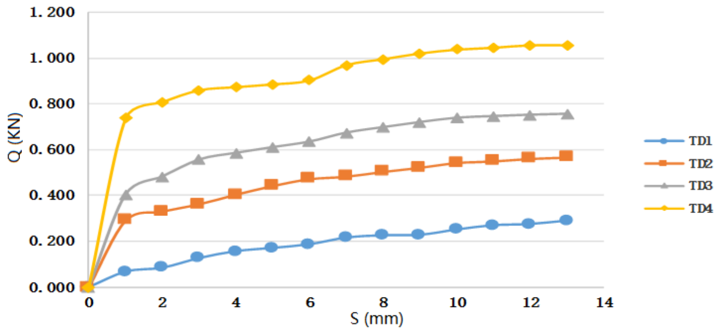


Figure 8: The contrastive S-Q curves of Model piles TD1, TD2, TD3, TD4

The pension diameter of the enlarging plate for Model pile TD4 is 2.5 times of the pile diameter. From the S-Q curve, it can be seen that after the bearing capacity researches 0.9KN, the curve trend is gentle and close to the level. But when the pile displacement researches 6mm, the curve rise absolutely and then tends to be gentle. Combined with previous experiment observations, reasons are that the influence range of the soil above the TD4 plate is beyond the range of the theoretical research (5 times the length of the suspension diameter). The squeeze phenomenon between the soil above the plate and the upper pressure beam appears when the soil above the plate moves upwards, and thus the reverse pressure appears. The loading value increases, so there are differences between the loading value of Pile TD4 got after the displacement of 6mm and the actual value.

4. The ansys finite-element simulation analysis of the cep pile

In this paper, four types of model piles with different suspension diameters are named respectively as MTD1, MTD2, MTD3 and MTD4. In the ANSYS finite-element analysis, data from the tenth-level load (1400 KN) is analyzed. The maximum value of the simulated load for MTD1~MTD4 is 1400KN. The load begins from 14ooKN and is divided into 10 levels; and 140KN is added step by step in every level. In the ANSYS finite-element model test, the concentrated load needs to be converted into the load on the top surface of the pile; that is, the load begins from 1.4MPa, and in every level an additional 1.4MPa is applied; when the load reaches 14MPa, the load ends.

4.1 The displacement image analysis

When the load on the top surface of the pile is 1400 KN (the load reaches Level 10), the displacement contour is shown in Figure 9. Based on Figure 9, the following conclusion can be drawn:
(1) When CEP piles are under the same vertical tensile load, with the increase of the suspension diameter length of the enlarging plate, the influence range of Model piles MTD1 ~ MTD4 on the whole soil mass gradually increases.
(2) The maximum influence range of model piles on the whole soil is 3~4 times the length of the suspension diameter of the enlarging plate. This conclusion conforms to the conclusion drawn from the anti-uplift test of the small-proportion and undisturbed-soil model CEP piles.
(3) When under the same vertical tensile load, the biggest displacement appears on the pile top and the relative maximum displacement region decreases with the increases of the suspension diameter length of Model piles MTD1~MTD4.

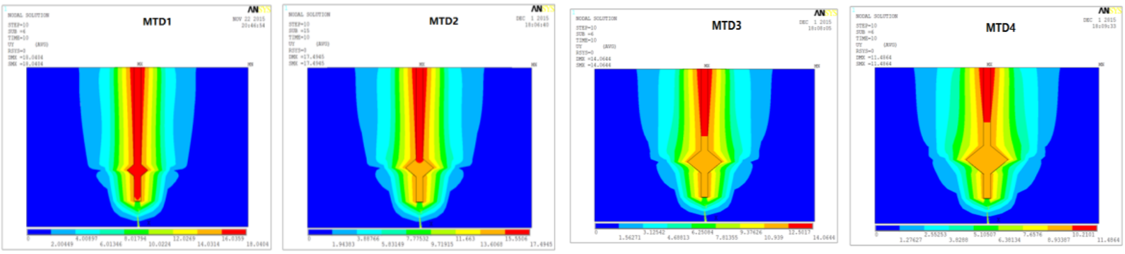


Figure 9: The Y-direction soil displacement of model piles with different suspension plate diameters

4.2 Data analysis of the displacement

In this simulation test, being the representative value of the pile displacement in the ANSYS model, the displacement value at a fixed point on the pile top is chosen to be analyzed. When the fixed point on the pile top is under different vertical tensile loads, the vertical displacement rules of the pile are shown in Figure 10. From the curve in Figure 12, the displacement of the CEP pile increases with the increases of the load. At the beginning, the change rate of the displacement is small; the change rate of the displacement gradually increases with the increase of the load. From Figure 10, it can also be seen that when under the same load, the pile displacement decreases with the increase of the suspension diameter length of the enlarging plate. (MTD1 the biggest, and MTD4 the smallest) With the increase of the vertical tensile load, the interval among Piles MTD1, MTD2, MTD3 and MTD4 gradually increase. Trends of MTD1 and MTD2 in the whole process are basically the same, but change rates of the displacement for MTD 3 and MTD4 in the later stage are obviously lower than those of MTD 1 and MTD 2. Consequently, when the length of the suspension diameter of the enlarging plate is at least 2 times the length of the pile diameter, the bearing capacity of the pile improves obviously; when the length of the suspension diameter of the enlarging plate is less than 2 times of the pile diameter, bearing capacities are basically the same. Consequently, it is reasonable that the length of the suspension diameter of the enlarging plate should be at least 2 times of the pile diameter.

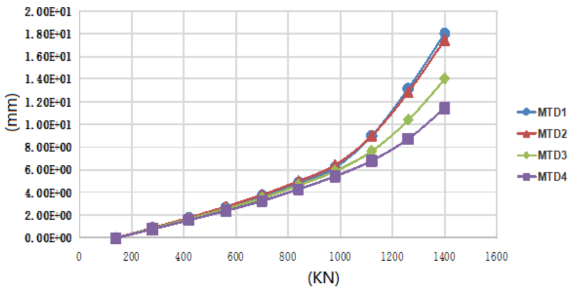
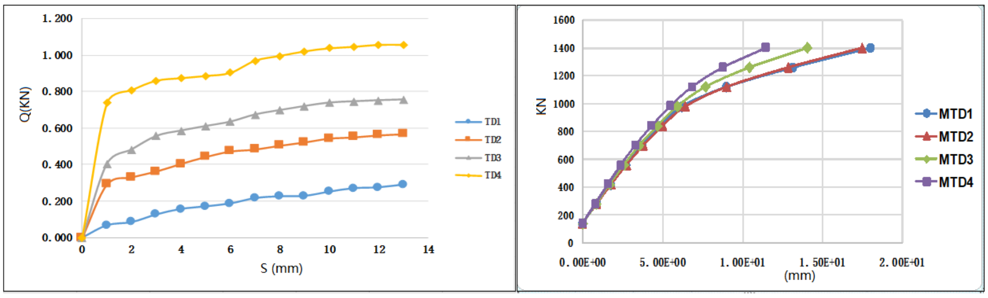


Figure 10: The L-D curve of a fixed point on the pile top under different vertical loads

4.3 The contrastive analysis of simulation test and the simulation result

The ANSYS finite-element simulates the anti-uplift state of the CEP pile under the original proportion, but the model test is carried on according to the proportion of 1:50 shrink. Data results got from them are not completely the same, but trends of the L-D curves are roughly the same; test results conform to each other. From Figure 11, it can be seen that trends of L-D curves in the model test and the ANSYS simulation are the same, the bearing capacity of the CEP pile increases with the increase of the suspension diameter of the enlarging plate; when the length of the suspension diameter of the enlarging plate is more than 2 times of the pile diameter, the bearing capacity of the pile improves significantly.



(a) The load-displacement curve of TD1～TD4 (b)The load-displacement curve of MTD1～MTD4

Figure 11: L-d curves in the model test and the simulation with different suspension diameters of the enlarging plate

5. Conclusion

Based on the above analysis, when under the vertical tensile load, the destructive mechanism effect of the diameter of the enlarging plate on the soil mass around the pile are as following:

(1) To the soil under the plate, in the early stage when the CEP pile is under the vertical tensile load, the lower surface of the enlarging plate immediately separates from the soil and does not destroy the soil under the plate.

(2) The influence range of the soil slip failure above the enlarging plate is 3~5 times the length of the suspension diameter of the enlarging plate. Such conclusion conforms to that gained from the previous anti-uplift study of the CEP pile with small models and the undisturbed soil.

(3) When suspension diameters of the enlarging plate are different, the bearing capacity of the CEP pile increases with the increase of the suspension diameter of the enlarging plate. When the length of the suspension diameter of the enlarging plate is more than 2 times of the pile diameter, the bearing capacity of the CEP pile increases fast. In order to make the enlarging plate fully function, the length of the suspension diameter of the enlarging plate hold be more than 2 times of the pile diameter; however, the too much increase will cause the increase of the pile length and the increase of the disturbing range of the soil mass.

Acknowledgments

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