CHEMICAL ENGINEERING TRANSACTIONS

VOL. 66, 2018

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Songying Zhao, Yougang Sun, Ye Zhou

ISBN 978-88-95608-63-1; **ISSN** 2283-9216

DOI: 10.3303/CET1866189

Experimental Study on the Influence of Moisture Content of Fine Silty Sand on Compressive Failure of Concrete Expanded-plate Pile

Yongmei Qian*, Guanqun Zhang, Xinsheng Yin, Yujie Jin

Jilin Jianzhu University, Changchun 130118, China
654675316@qq.com

This paper mainly studies the influence of moisture content of fine silty sand on the compressive failure state of soil around the bearing plate and the compression bearing capacity of the expanded-plate piles. In the research, the indoor half-section pile small model test and ANSYS finite element simulation are mainly used, and the two types of analysis results are compared to ensure the reliability of the failure mechanism and the bearing theory. The innovative point of this paper is mainly the test method, which uses the form of half-section pile to better observe the entire experiment process from the loading of the concrete expanded-plate (CEP) piles to the failure of the soil; the test soil adopts fine silty sand and uses a self-made soil loader which can be disassembled, taking into account the influence of moisture content, an important influencing factor on the bearing capacity. The test method is more feasible and the test results are more reliable.

1. Introduction

In modern construction industry, as high-rise buildings continue to rise, the bearing capacity of some soft soils such as sand, water, and marshes is very low. Ordinary concrete cast-in-place piles can hardly meet the requirements, even by lengthening the piles, enlarging the diameter of piles or other method, it still cannot make the bearing capacity meet the requirements (Qian et al., 2006), and the engineering cost is higher. Therefore, in the early 20th century, a variety of non-uniform piles appeared in the country, among which the concrete extended-plate (CEP) pile is a relatively new type of pile, it has the advantages of high bearing capacity, small settlement amount, and simple pile forming process, and has been widely used both at home and abroad (Finno et al., 2005). At present, there are many researches on the failure modes and bearing capacity of soil under the vertical force of CEP piles. However, most of the researches at home and abroad are focused on the undisturbed soil, and rarely consider the influence of the soil to the CEP piles. For this research gap, this paper mainly studies the bearing capacity of CEP piles and the state of soil failure around the piles in the fine silty sand soil layer, taking into account the influence of moisture content on the bearing capacity of the expanded-plate piles. In this paper, through the half-section pile small model test, the influence of the moisture content of fine silty sand on the failure of the soil around the pile and the bearing capacity of the expanded-plate piles is studied under the effect of vertical pressure. Combining the ANSYS finite element software simulation analysis and the slip line theory as the background, it provides a theoretical basis for the calculation formula of the bearing capacity of original single expanded-plate pile.

2. Experiment preparation and process

2.1 Specimen specifications and production

The main content of this study is the influence of the moisture content of fine silty sand on the compressive failure of CEP piles. The focus of attention is on the effect of changes in the moisture content of fine silty sand on the compressive failure of fine silty sand, so we only need to design one group of reasonable pile type, and the model piles use steel piles, as shown in Figure 1, the detail size parameters are shown in Table 1.

Please cite this article as: Qian Y., Zhang G., Yin X., Jin Y., 2018, Experimental study on the influence of moisture content of fine silty sand on compressive failure of concrete expanded-plate pile, Chemical Engineering Transactions, 66, 1129-1134 DOI:10.3303/CET1866189

Table 1: Model pile size parameters

	Main pile diameter (mm)	Pile length L (mm)	Plate diameter D (mm)	Plate height H (mm)	Plate slope angle θ (°)	Overhang diameter R_0 (mm)
Test parameters	20	220	80	32	28°	30
Simulation parameters	500	6700	2000	800	28°	750

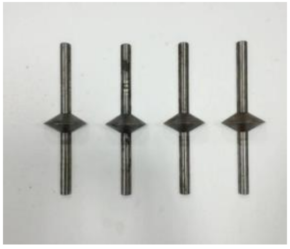


Figure 1: Image of model piles in kind

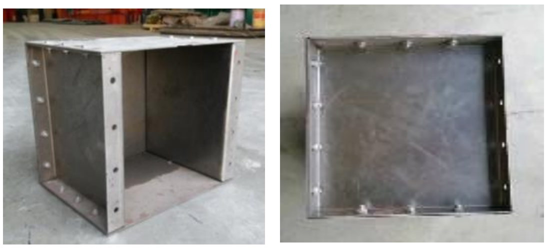


Figure 2: Image of soil loader design in kind

The design principle of the soil loader is: satisfy the impact range of the compressive failure of CEP piles, satisfy the convenience of movement during the test, economic and reasonable production cost, the stiffness should meet the test requirements, and the boundary effect and other factors also needs to be taken into consideration. Therefore, according to the existing soil loader used in the undisturbed soil small model test, improvement was conducted to the soil loader, the surrounding side panels are concave for easy removal of the steel plates, the design of the soil loader is shown in Figure 2 (Bourgeois et al., 2012, Li and Gao, 2010).
The soil loader is mainly assembled by grooved iron plates and flat iron plates with screws. According to the previous theoretical calculations and finite element simulations to analyze and calculate the impact range of CEP piles, therefore, the size of designed soil loader is 280×320×320mm.The soil loader needs to withstand the lateral pressure during the compaction process of fine silty sand, and the lateral pressure generated during the loading process. Therefore, the thickness of the groove-shaped side steel plate and the flat steel plate is designed to be 3mm; the steel plate on the top has a semi-circular cut-out, so that during the test, the pile can be 3-4cm higher than the top plate; the steel plate protruding from the side of the soil loader is used to bolt the glass plate.

2.2 Test preparations

Prepare sand soil samples for the test. Quartz sand with corresponding particle size is used instead of fine silty sand. To ensure the particle size and proportion of quartz sand to conform to the test requirements and the accuracy of test data, the electric screen is used for screening. The electric screening machine is equipped with screens with different mesh numbers. The screens can be stacked on top of a vibrating screen. The top layer of the electric screen selects 100 meshes, which is used to remove larger particles in the fine silty sand. The number of screen meshes is gradually increased from top to bottom. Determine the moisture content of fine silty sand. According to the geotechnical test instruction book, based on the calculation formula for soil moisture content (Lade P. 2010), it can be concluded that the moisture content of fine silty sand is the ratio of the mass of water to the mass of dry sand, so controlling the mass of fine silty sand and the mass of water is the key to controlling the moisture content. According to the calculation formula of moisture content, the design of the test controlled the moisture content of fine silty sand to be 10%, 12.5%, 15%, and 17.5%. The mass of water calculated based on the mass of sand.
Soil loader sand loading and pile positioning and burying. In the process of sand loading, at first the time should be controlled well in order to avoid the loss of moisture in the fine silty sand. Using lumps of wood to compact the fine silty sand layers to ensure that the compaction degree of each group in the experiment is the same. After the sand loading is completed, the surface of the soil is leveled and the floating soil is cleared to determine the position of the buried model piles. In the pile burying process, vertical pressure is applied to the upper and lower ends of the pile at the same time to make the force of each part of the pile uniform, make sure that the plane of the buried model piles, the surface of the soil layer and the edge of the steel plate of the soil loader are in the same plane.

2.3 Experiment process and data collection

The loading station provides reaction forces in this test and is an integral part of the loading system. The test adopts a counter force loading device independently designed and developed by Prof. Qian Yongmei of Jilin

Architectural University. It consists of a working platform, an I-shaped column, a square beam, and 4 square columns, as shown in Figure 3.

The prepared pile-soil model was moved to the test loading station, move the soil loader so that the top of the pile was aligned with the loading beam, the glass was fixed on the surface of the buried pile, the displacement meter and the loading device were installed, start loading and collect relevant data (Qian et al. 2015; Qian, 2002).

The data that need to be collected in the experiment includes pile displacement value, vertical pressure load value, and pile-soil interaction images. The displacement value is manually read by the displacement meter, the load value on the hydraulic jack display is recorded every 1mm, and a camera is used to record the image every 2mm to record the change in the displacement and pile-soil interaction caused by the increase of the load. In the test, the camera is used to clearly and intuitively record the state of pile-soil interaction under the vertical pressure. After the test is completed, the soil after the destruction is timely tested for soil traits to ensure the accuracy of the data.

Figure 3: Test loading system

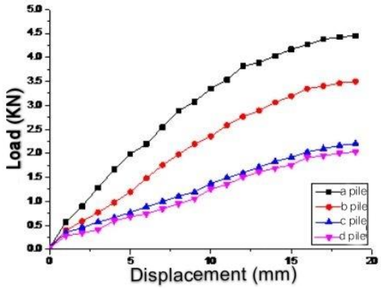


Figure 4: Comparison of s-Q curves of a,b,c,d model piles

3. Experiment data sorting and analysis

3.1 Displacement-load data collation and analysis of fine silty sand with different moisture content

Collect data through the test, the displacement-load data of model piles under different moisture content were collected and analyzed. The corresponding relationship between the CEP piles and the moisture content of the soil layer where the pile is placed is shown in Table 2. By collecting the test data, the load-displacement comparison curve for No. a-d piles is obtained, as shown in Figure 4.

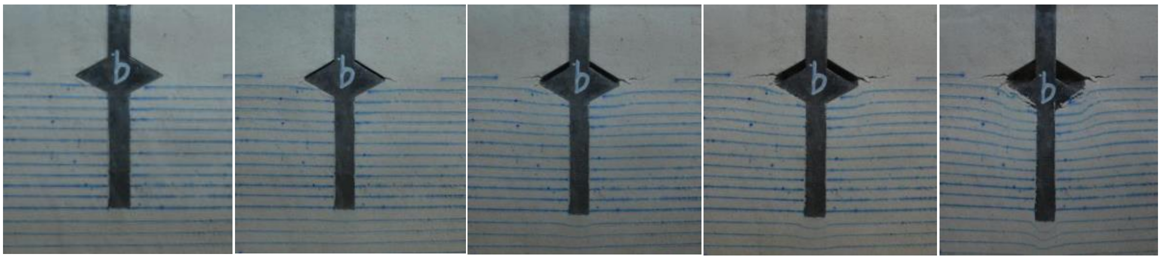
Table 2: Correspondence between pile and the moisture content of soil layer where the pile is placed

Pile No.	a	b	c	d
Moisture content (%)	10.47	12.05	13.60	15.13

From the load-displacement curves of a-d piles, it can be seen that all four curves increase with the increase of displacement. However, with the change of displacement, the rate of change of the curve corresponding to different model piles are different. Among them, the vertical bearing capacity of pile a is the largest, and the changing trend of the corresponding curves of pile a and pile b is similar. Although the moisture content of the fine silty sand in the two model piles is only 2.5% different, their vertical bearing capacities have a big difference. The ultimate bearing capacity of pile a is 4.45kN, and the ultimate bearing capacity of pile b is 3.496kN. The difference between the two is 0.954kN. According to the analysis of the curves corresponding to pile c and pile d, it is found that the displacement-load curves of pile c and pile d are quite similar, and the difference in the ultimate bearing capacity of the two is also small. However, comparing the displacement-load curves of pile c and pile d, the difference in moisture content between the two is also 2.5%, and there is a clear difference between the changing trend of load and the ultimate bearing capacity of piles, indicating that when the theoretical moisture content of fine silty sand is more than 14%,the bearing capacity of CEP piles changes little with the change of the moisture content, and when the theoretical moisture content of the fine silty sand is less than 14%, with the change of moisture content, the bearing capacity of CEP piles has changed significantly. Therefore, based on the above data analysis, when the CEP pile is constructed in a fine silty sand environment, if the moisture content of the fine silty sand is not uniform, the estimated bearing capacity of the expanded-plate pile should be multiplied by a corresponding adjustment coefficient. The coefficient is also related to the moisture content, and the specific value of the coefficient needs further study.

3.2 Analysis of failure process of soil around the model pile with different moisture content

In the following, we take No. b compressive pile as an example to observe the failure situation of the soil on the CEP pile, under the CEP pile and surround the CEP pile, the whole process of the soil failure is shown in Figure 5.



(1) (2) (3) (4) (5)

Figure 5: whole process of soil failure under pile b

According to the test process and combined with the load-displacement curve of the pile, the whole test can be divided into three stages.

First stage: Figure 5 (1) is the unloaded state; the pile bottom and the expanded-plate are tightly integrated with the fine silty sand. The horizontal grid lines around the expanded-plate piled are not bent. Figure (2) shows that at the initial stage of loading, cracks appear at the horizontal position of the plate top, and the fine silty sand on the plate is separated from the plate. Only the grid lines near the expanded-plate appear slight bending, and the soil under the plate does not change significantly.

Second stage: Figure (3) shows the middle period of loading. As the load increases, the cracks on the plate increase, reaching the state of Figure (4), when the soil on top of the plate starts to show shear failure, and the horizontal grid lines below the plate and at the end of the pile show obvious bending, indicating that the soil under the plate and at the top of the pile began to be squeezed, suffering bigger shear force, the soil cracks continue to expand, changing from the curved state of grid lines into heart-shaped squeezed under-plate soil.

Third stage: Figure (5) is the end stage of loading, the load continues to increase, the unit vertical displacement load changes very little shows that the ultimate failure state has been reached, the horizontal grid lines under the plate bending along the vertical direction is obvious, grid lines that are near the plate and at the end of the pile have been interrupted, indicating that the soil around the plate has occurred slip failure.

3.3 Comparative analysis of compression resistance and uplifting resistance in fine silty sand with same moisture content

Figure 6 shows the displacement-load curve of a CEP pile subjected to compression and pull-out tests when the theoretical moisture content is 15%. It can be seen from the figure that when the CEP pile is in fine silty sand and the top displacement of the pile is small, the uplifting bearing capacity of the pile is slightly larger than the compression bearing capacity of the pile.

There are primarily three reasons for the large initial bearing capacity of the uplifting pile: first, due to the different pile types of the compressive piles and the uplifting piles, the expanded-plate of the uplifting pile is farther from the top of the pile; second, due to the limitation of test conditions, in order to increase the stroke of the pile top, the depth of the uplifting pile is larger; third, the compressive pile is dominated by slip failure, while the uplifting pile is dominated by shear failure. The main reason for the higher bearing capacity of the compressive piles in the later period is that: with the increase of pile displacement, the sand under the plate and at the end of the pile is compacted, and the compressive effect of the expanded-plate pile is obvious at this time.

3.4 Comparison of pile-surrounding soil failure status

In order to further study the failure state of CEP piles in fine silty sand, the failure state of the soil around the pile in this test is compared with the results of the pull-out test. Figure 7 shows pile-surrounding soil failure status of in the compression and pull-out tests when the theoretical moisture content is 15%.

By Comparing and analyzing the failure state of the pile-surrounding soil of compressive pile and uplifting pile, it can be seen that: under the load of the pile top, the soil on (under) the bearing plate of the compressive pile and uplifting pile is separated from the plate. At the initial stage of the loading, shear failure occurred at the plate end of the compressive pile and the uplifting pile, and the displacement at the plate side of the uplifting pile was small. Both of them showed horizontal cracks at the tip of the plate. When the loading continues, both compressive pile uplifting pile are subject to slip failure, but the displacement of the compressive pile during slip failure is bigger than the displacement of the uplifting pile.

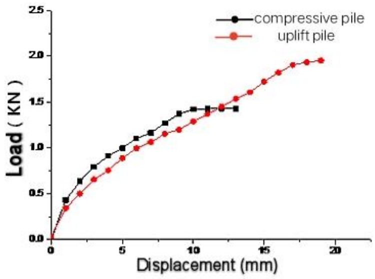
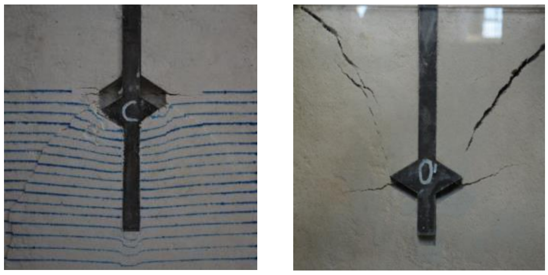


Figure 6: Comparison of s-Q curves



(a) Compressive failure *(b) Uplifting failure*

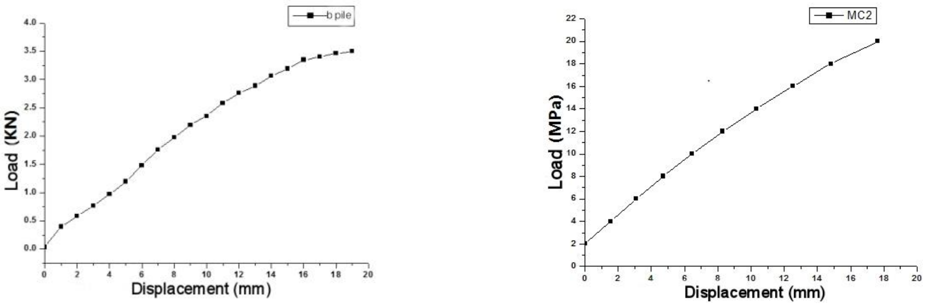
Figure 7: failure state of compressive pile and uplifting pile

Since this test is an indoor small model test, the thickness of the fine silty sand on the expanded-plate pile is limited, and no constraint is set on the top surface of the fine silty sand, so the uplifting pile will occur shear failure first compared with the compressive pile, forming an oblique crack of 45° from the top down, and the fine silty sand under the compressive pile gradually squeezed and compacted, and no obvious failure occurred. With the increase of load, the compressive pile occurs slip failure along the "heart-shaped" affected range, and the compressive pile move upward with the fine silty sand together, the load value shown by the jack no longer changes. Due to the failure status of the two and the difference in pile type, the ultimate bearing capacity of compressive piles in the fine silty sand with the same moisture content is much bigger than the ultimate bearing capacity of the uplifting piles. Combining with previous experiments and theoretical research, the main reason that affects the compression and uplifting bearing capacity is the different failure mechanism.

4. ANSYS finite element analysis of CEP piles

4.1 Displacement result analysis

Since the theoretical analysis is less affected by the objective conditions, in order to analyze the influence of the soil moisture content on the performance of CEP piles, the performance of several groups of soil layers under different moisture content was investigated. The moisture content of MC1 to MC6 is seperately 10.47,12.05,13.6,15.13,16.5 and 18. From the ANSYS postprocessor, the vertical displacement value of a fixed point on the top of the MC1 to MC6 model piles under different loads was extracted.



a. Model b displacement-load curve. *b. Model MC2 displacement-load curve*

Figure 8: Comparison of test and simulated displacement-load curves

As shown in Figure 8, the load-displacement curve of the MC1-MC3 model remains basically the same and almost linear, while the curves of the MC3 and MC4 models are relatively close. The load-displacement curve change rate of the MC6 model increases significantly when loaded to 10 MPa. Therefore, it can be concluded that the compression bearing capacity of CEP piles in fine silty sand decreases with the increase of moisture content. When the actual moisture content is higher than 14%, the bearing capacity drops significantly.

4.2 Comparison analysis of model tests and simulation studies

Taking the compressive CEP piles with soil moisture content of 12.05% as an example, the trend graph of displacement-load curve of model test and simulation analysis is formed. In which No. b compression test pile corresponds to the No. MC2 compressive pile, as shown in Figure 8. In Figure 8, from the comparative analysis of the displacement-load curve obtained from the test and simulation analysis of the compressive expanded-plate pile we can know that: both the impact range and the failure state of the two piles are basically the same; by analyzing the load-displacement curve from the test and simulation analysis, the changing trend of the two is the same; the difference in the change rate of the curve is mainly due to the experimental conditions and the pure ideal state of the simulation analysis. But on the whole, the conclusions from the test research and simulation analysis are consistent.

5. Conclusion

Through the small model test of indoor half-section piles, it is found that when the moisture content of fine silty sand is less than 14%, the compression bearing capacity is obviously improved, and the compression bearing capacity decreases with the increase of the moisture content. Therefore, in engineering practice, when the moisture content of fine silty sand is not uniform, the estimated bearing capacity of the expanded-plate pile should be multiplied by a corresponding adjustment coefficient, and the adjustment coefficient varies with the moisture content.

Comparing the model test with the simulation results, we can obtain that, in the case that the fine silty sand has the same moisture content, the impact range and the failure state of the two piles are basically the same, both convergence into a "heart shape" toward the body of the pile along the direction of 45° down from the end of the plate; from load-displacement curve analysis of the test and simulation analysis, the load-displacement curve of the test and simulation analysis shows the same trend of change.

From comparative analysis of compression and pull-out tests in fine silty sand, it can be concluded that the change rate of the displacement-load curve is greater in the initial stage of loading than in the later stage of loading, with the increase of load, the uplifting pile reaches the ultimate failure state first. At this time, the load value of the compressive pile continues to increase, and the bearing capacity of the compressive pile when it breaks is far greater than that of the uplifting pile. In terms of the failure state of the soil surrounding the pile, the compressive pile occurs slip failure with the sand in the area under the influence of the plate, as for the uplifting pile, it occurs shear failure along the horizontal upward direction of 45° from the tip of the expanded-plate.

Through ANSYS finite element software simulation analysis, when the moisture content of fine silty sand is less than 14%, the change of moisture content has a great influence on the soil around the pile, and it has less influence on the bearing capacity and maximum displacement of the expanded-plate pile. When the moisture content of fine silty sand is higher than 14%, the effect of moisture content on the soil around the pile varies little, and the bearing capacity and maximum displacement of the expanded-plate pile are greatly affected. And the results of the simulation agree with the test results.

Acknowledgments

This work was financially supported by National Natural Science Foundation of China (51678275 and 51278224).

Reference

Bourgeois E., Buhan P., Hassen G., 2012, Settlement analysis of piled-raft foundations by means of a multiphase model accounting for soil-pile interactions, Computers and Geotechnics, 26-32.

Finno R.J., Asce M., Chao H., 2005, Guided Waves in Embedded Concrete Piles, Journal of Geo technical and Geo environmental Engineering,131, 11-19, DOI: 10.1061/(ASCE)1090-0241(2005)131:1(11)

Lade P. (2010). The mechanics of surgical failure in soil slopes, Engineering Geology, 57-63.

Li Y., Gao X. (2010). Extruded-Expanded-Plate pile and ordinary pile uplift bearing capacity contrast test research, Journal of Henan University of Technology (natural science edition), 543-546, DOI: 10.3969/j.issn.1673-9787.2010.03.020

Qian D., Sun C., Wang D., 2006, Study on the Interaction Law Between Squeezed Branch Pile and Soil, Foundation Analysis and Design, 218-225

Qian D.L., 2002, The Load Transfer Law about the Squeezed Branch and Plates Pile Extrusion Expansion and FEM, Simulation-Journal of Geotechnical Engineering, 24(3), 371-375.

Qian Y.M., Wang J., Wang R.Z., 2015, The Analysis of the Vertical Uplift Bearing Capacity of Single the CEP Pile, The Open Civil Engineering Journal, 598-601.