Bulgarian Chemical Communications, Volume 49, Special Issue-K1, (pp. 96 – 102) 2017

Test study on the thickness of the soil layer under the plate affecting the compression failure of the concrete expanded-plate pile

Y. Qian [1,2*], Z. Liu [1], W. Tian [1], R. Wang [1]

[1] *Jilin Jianzhu University, 130118 Changchun, China*
[2] *Jilin Structure and Earthquake Resistance Technology Innovation Center, 130118 Changchun, China*

Received, Sepember 8, 2017, Accepted, December 12, 2017

In this paper, the influence of the thickness of soil layer under the plate on the failure behavior of soil surrounding the pile and the bearing capacity of a single pile under vertical compression in the complex soil layer is studied. In the test study, the small model test method of undisturbed soil with a new half-section pile is adopted, which not only solves the question that by the original full-section pile the whole failure behavior of soil surrounding pile cannot be clearly seen, but also solves the defection that burring soil test cannot ensure soil characteristics according to the actual condition of the construction site. By comparing and analyzing the results of finite element analysis the reliability of the test results was checked. The study results will provide a reliable theoretical basis for the design and application of the concrete expanded-plate pile, promote the popularization and application of the concrete expanded-plate pile and look forward to achieve larger social and economic benefits.

Key words: Concrete expanded-plate pile (CEP pile), Thickness of soil-layer under the plate, Test of undisturbed soil, Finite element analysis, Compression failure.

INTRODUCTION

In recent years, with the rapid development of economy, the construction industry, as the leading industry in the country, which is also changing rapidly, a variety of tall buildings and special-shape buildings were built in everywhere, which put higher and higher requirements to the pile foundation. With the continuous improvement and innovation of the piles, various types of piles gradually appeared, such as multi-section-expanded piles, the bearing capacity of which is increased with the increase in side friction of pile. In the various new types of piles [1,2], concrete expanded-plate piles with high bearing capacity, small settlement, flexible position for design of plate and good benefits of social and environment, have been applied to engineering projects and praised by the society.

Traditionally for the concrete pile with constant section and simple situation of the bearing force, the bearing capacity is provided only by the side of pile and pile end. The innovative concrete expanded-plate piles with higher bearing capacity, lower settlement, good social and environmental benefits, are accepted by more and more people [3]. Although in the concrete expanded-plate pile one or multiple plate bodies are added based on the body of the ordinary concrete pile with constant section, the condition of pile bearing loads has been greatly improved, the loads are commonly afforded through the side of pile, end of pile and end of plate, thus the bearing capacity of the concrete expanded-plate is greatly increased [4]. The complex bearing characteristics of the concrete expanded-plate pile are not known enough and theoretical research of the concrete expanded-plate pile is far behind the practical engineering project.

In this paper, the effect of the different thickness of the soil layer under the plate on the performance of the concrete expanded-plate, was studied by ANSYS software with finite element analysis [5]. In the study, the test of undisturbed soil was initially adopted, which reduces the difference between laboratory soil and soil in the site, extends the new model test method with half-section pile, and the total process of failure behavior of soil can be observed, making up the disadvantage that only collecting data by the device for analysis and ratiocination in the test study, provides a new method of test study on pile foundation. Through the simulation analysis by ANSYS software to compare and analyze the results obtained by computer simulation analysis, the study on the bearing capacity of a single pile of the concrete extended-plate pile under vertical compression was improved.

EXPERIMENTAL PART

Test of undisturbed soil

Design and manufacture of test device

In this paper, the small model test with half-section pile of the concrete expanded-plate pile under compression was adopted, because traditional testing devices cannot meet the needs of the test, so a multi-functional plat for loading is suitable for the

*To whom all correspondence should be sent:
E-mail: 654675316@qq.com

test demand was specially designed [5] (as shown in Fig.1).

Fig. 1. Multi-functional plat for loading

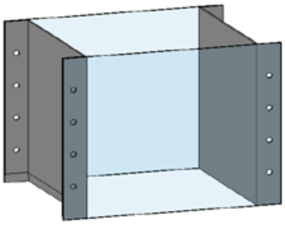

Fig. 2. Model picture of device for getting soil

Design of device for getting soil

Undisturbed soil was selected in the test. In order to get better undisturbed soil, a device for getting soil was designed. In order to keep the device unchangeable, Q235 steel and thickness of the steel plate of 4mm was adopted [5,6], the design model of the device for getting soil is shown in Fig. 2. The dimensions of the device are shown in Table 1.

Table 1. Size of the device for getting soil

	Length (mm)	Width (mm)	Height (mm)	Thickness (mm)
Compression capacity	400	250	130	3

Note: the side of steel plate is length, the side of I-beam is width.

Design of model pile

Due to the small-scale model test selected, and the premise that the soil is destroyed earlier than the pile itself, the material of the specimen has little effect on the test result, so steel Q235 was used as pile material [7], the dimensions of the model piles are shown in Table 2.

Collection of test soil

Undisturbed soil was applied as the test soil, which is a most important difference between this test and previous half-section pile model tests. Combining theories and practices, from aspects of device selection and operation, the way of pressing the device, the way of taking out the device, etc., were optimized to avoid soil excessive vibration in the process of taking soil, and to ensure characteristics of test soil according to actual condition. The procedure of getting soil for test is as follows: excavation of site, placing and pressing into device, taking out device, cleaning device and soil, packaging and transport.

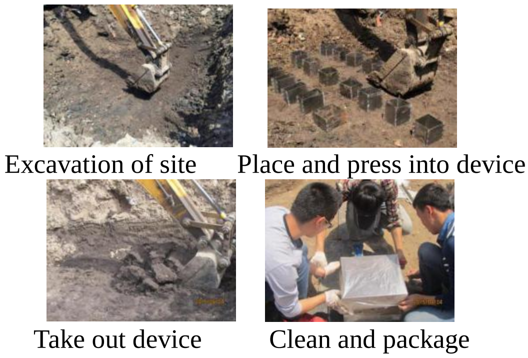

Fig. 3. The process of taking soil

The principle of model test of undisturbed soil

Undisturbed soil was selected as the test soil which is a most important difference between this test and previous half-section pile model tests, it is a premise for a successful test because the natural characteristics of soil are not destroyed as much as possible [4,8]. In addition, due to the multi-functional plat for loading (shown in Fig. 4) adopted, the test process is also different from the past.

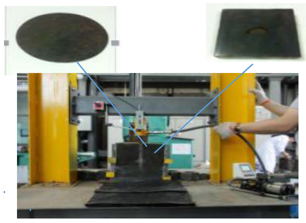

Fig. 4 The loading device of the compression test

Collection of test data

The collection of data in the test is a significant part, because the accuracy of the collection of data is directly related to the results of analysis and comparison of the test data. The collection of data mainly consists of four parts: vertical displacement of model pile, vertical bearing capacity of model pile, photos of soil surrounding the pile at different stages of loading, accuracy of physical properties around test soil.

Table 2. The size of model pile in the test

Category of Model		Specifications of Different Model Types				
Hard clay	Compression	Name	HDKY1	HDKY2	HDKY3	HDKY4
		L	0	750	1500	2250

Table 3. The models established at soil thickness different of reel up and down

Category of Model	Specifications of Different Types Model					
Hard clay	Compression	Name	HDKY1	HDKY2	HDKY3	HDKY4
		L	0	750	1500	2250

The former three data were recorded at the same time, firstly the model pile was loaded, it underwent vertical displacement, when the displacement reached 1 mm, the magnitude acting on the model pile under the load was recorded [9], every 2 mm of displacement were recorded. The test data on the failure behavior of the soil around the pile were finally recorded until the soil was up to complete failure. After the test, in order to improve the accuracy of the soil data, the test soil should be gauged in time.

RESULTS AND DISCUSSION

Under vertical compression, the thickness of the soil layer under the plate plays a significant role in bearing capacity of the concrete expanded-plate pile, therefore, as the change in the thickness of the soil layer under the plate affects the bearing capacity of the concrete expanded-plates, in the test, the thickness of the soil layer under the plate, in which the plate is embedded, was selected at four conditions as follows: 0 times the cantilever length of plate, 1.5 times, 3 times and 4.5 times (the cantilever length of the plate is the straight distance of the plate protrusion).

Analysis of data about loads-displacement

Based on the above test data, the load-displacement curve of the concrete expanded-plate pile under compression in the test, is shown in Fig. 5.

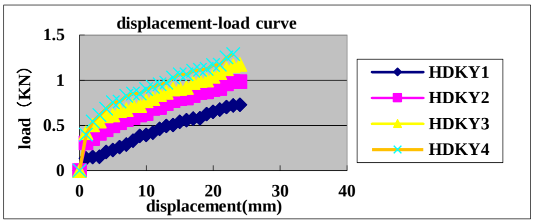

Fig. 5. The load-displacement curve of pile under compression

It can be seen from Fig. 5 that, with the increase in load, the displacement of different concrete expanded-plate pile models in compression gradually increased; for the same load, the displacement, from pile HDKY1 to pile HDYK4, gradually increased with the increase in the thickness of soil under the plate, in the early term (the top of pile displacement in 0～1mm) the load undergoes mutation, under the vertical compression the soil becomes to a dense situation due to squeezing, which improves the bearing capacity of soil, and the increase in vertical load in unit displacement is very fast, which complies with the result of the gradient of the curve being biggest; in the middle stage (the top of pile displacement in 1～10 mm) with the gradual increase in vertical compression, the trend of vertical load with the displacement increase was gradually flattened, subtle cracks on the soil of plate edge developed, integrity of soil was destroyed and bearing of capacity decreased, the gradient of displacement-load curve slowed down; in the final stage (the top of pile displacement in 10～24 mm) the increased trend of vertical load of the top pile gradually decreased, which means that the soil reaches the failure behavior, while the vertical displacement remains unchanged with the increase in vertical compression.

According to the comparison and analysis of the displacement-load curve of the concrete expanded-plate pile model, it was concluded that:

(1) For the model piles from HDKY1 to HDKY4, the bearing capacity of the concrete expanded-plate pile increased with the increase in load, and the trend of the load-displacement curves remained similar.

(2) The thickness of soil under the plate of model pile HDKY1 was 0 times the cantilever length of the plate, the curve is located at the bottom of the figure. As we can see from Fig. 5 the ultimate bearing capacity of the pile is greater than 0.5KN, when the load reaches 0.5KN, the trend of the load-displacement curve gradually flattened but it was still increasing, the displacement of the pile body reached 24 mm and failure happened due to excessive displacement. The load-displacement curves of the model piles from HDKY2 to HDKY4 were close, the thickness of soil under the plate was 1.5 times, 3 times and 4.5 times the cantilever length of the plate, respectively, the ultimate bearing capacity of the pile was greater than 0.7KN in HDKY2, greater than 0.9KN in HDKY3 and greater than 1.2KN in HDKY4, while the trend of the load-displacement curves of the three types of pile remained unchanged. This indicates that the regulation in the process of soil failure is similar, so the thickness of soil under the plat of the concrete expanded-plate pile is greater than at least 1.5 times the cantilever length of the plate.

(3) When the initial displacement of the model pile reaches 1 mm, the gradient of the load-displacement curve rises in turn, that is, when the displacement of the pile body reaches 1 mm, the load successively increases, but the trend of load does not directly increase with the increase in the thickness of soil under the plat of concrete expanded-plate pile. It can be seen from Fig. 5 that the load of HDKY1 has the smallest increasing range, the loads of HDKY2～HDKY4 have a similar increasing range, which compares with that of HDKY1. This illustrates that when the thickness of soil under the plat of the concrete expanded-plate pile is smaller than 1.5 times the cantilever length of the plate, the effect of the bearing capacity of the pile is not significantly improved; otherwise the effect is very obvious, it also shows that the actual thickness of soil under the plate of the concrete expanded-plate should be greater than 1.5 times the cantilever diameter in order to sufficiently play a role in the bearing capacity of the concrete expanded-plate pile.

Failure behavior of the soil surrounding the pile

The main task of the test was to observe the failure situation of soil surrounding the pile. The behavior before and after the failure of each pile was compared with the failure shapes of soil surrounding the pile and above the plate of four half-sections of the test pile with the increase in the cantilever length of the plate. In the test, half-section pile and test device were specially designed, which provides conditions for observing the failure of pile and soil. The failure process of pile and soil is shown in Fig. 6 (example of pile No.2.)

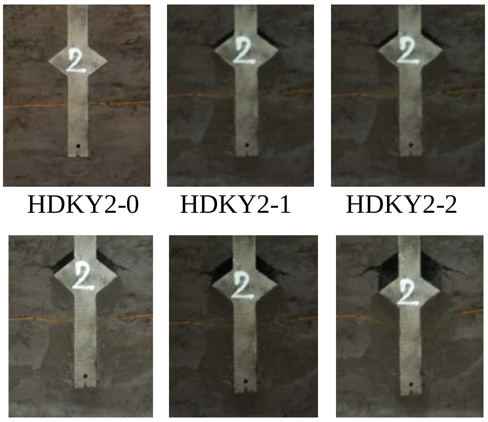

Fig. 6 The failure process of pile and soil with the increasing of vertical compression

Failure behavior and whole process of failure is clearly seen from Fig. 6, which is combined with the above data of load-displacement curve. In the test, the failure process of soil surrounding the half section expanded-plate under compression is divided in three stages.

First stage - elastic compaction stage. This is the early stage of model test being loaded, load effect is small, the triangular zone compressed under the plate is formed, at this time, the load-displacement curve is linear, with the increasing of load, the soil under the plate and the end of pile are gradually compacted.

Second stage - plastic deformation stage. This is the middle stage of the model test, the load at the top of pile is gradually increased, subtle cracks firstly develop at the soil of plate edge; to compare with the common pile, as the concrete expanded-plate is added to the bearing plate, which increases the interactivity between pile and soil and decreases the vertical displacement of pile body. With the increasing of load, shear failure at the end of the plate is gradually increased, the stress of soil under the plate is gradually increased and settlement displacement of pile also gradually increases, the cracks of the soil surrounding the edge of plate are further extended.

Third stage - failure stage. This is the last stage of the model test, the developing trend of load-displacement curve is gradually flattened, that is, in the situation of larger load increment, the changes of pile displacement are small, the model pile loses the bearing capacity, the failure behavior of the soil surrounding the plate is more serious, the load reaches the ultimate condition. Larger cracks develop at the end of the plate, the compactness of the soil under the plate increases, the sliding failure of soil under the plate finally occurs.

Given all this, as can be seen from the figure of test process under compression, with the increase in vertical compression on the concrete expanded-plate pile, through the watermark under the plate and in the soil surrounding the pile it is obtained that the compactness of the soil under the plate and soil surrounding the pile is increased. In other words, with the increase in vertical compression, the stress under the plate and bottom of pile increases, which is concentrated on the position under the plate. In the undisturbed soil test, the thickness of the soil layer under the plate affects the failure of soil surrounding the concrete plate-expanded pile, as shown in Figs.7 and 8.

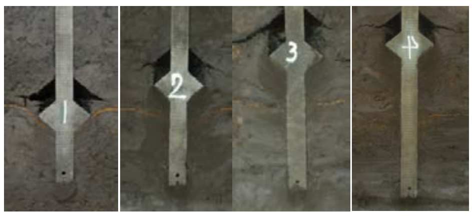

Fig. 7. Failure behavior of the soil for different model piles

Fig. 8 Failure behavior after the pile being taken

The summary of the results is as follows:

(1) As the soil itself has a certain degree of elasticiy-plasticity, under the initial stage of vertical compression loaded, the soil under the bearing plate of model piles HDKY1 to HDKY4 is compacted; with the increasing of load, in the range of elasticity-plasticity of the ultimate deformation of undisturbed soil, the soil under the the bearing plate is gradually compacted with the increasing of the displacement of pile body. In the process of the soil being compressed, shearing failure firstly develops at the soil of plate edge. As can be seen from Figs. 7 and 8, after the soil is destroyed, the soil in the edge of the bearing plate displays an obvious shearing failure, the effect of degree of shearing failure on the subsoil is decreased on increasing the thickness of the soil under the bearing plate. HDKY1 pile is biggest, HDKY4 pile is the smallest. On the one hand, because of the existence of a bearing plate, the displacement of the test model pile is very small in the early stage. On the other hand, the soil is compacted what is also beneficial to improve the bearing capacity of soil.

(2) For the soil above the plate, at the initial stage of vertical tension loaded for the model pile in the test, the top surface of the plate of the concrete expanded-plate pile does not immediately separate from the soil, and does not destroy the soil above the plate.

(3) For the soil under the plate, in the middle stage of the test, under the effect of vertical compression load, after the soil contacting with the end of plate in the test model pile reaches the soil elastic-plastic limit of deformation, sliding failure develops; a sliding line is first seen at the edge of the plate and along a certain angle θ (the acute angle between the direction of the tangent line and the horizontal line) is developed symmetrically to the outside of the pile. When the vertical compression increases to some degree, the sliding line will be withdrawn.

The following differences were observed:

(1) When there is interaction between pile and soil, the influence of soil thickness under the plate on the bearing capacity of the concrete expanded-plate pile is different. It can be clearly seen from the dividing line of soil in two layers in the figure under vertical compression that the boundary of HDKY1 is obviously concave, the boundaries of HDKY2 and HDKY3 are not obvious, while the boundary of HDKY4 does not change. This shows that the influence of the soil under the plate of the concrete expanded-plate pile is getting smaller and smaller from HDKY1 to HDKY4, when the thickness of the soil-layer under the bearing plate is greater than 1.5 times the cantilever length of the plate at least. The result is consistent with that of theoretical calculation.

(2) When the soil under the plate of the bearing plate comes to sliding failure, the soil around the edge of the expanded-plate will produce a sliding crack. The angle θ (acute angle) formed along the tangent line of the sliding crack to the horizontal line is known as the sliding angle. It can be seen from the figure that the sliding angle of HDKY1 is small and the sliding curve has the trend of horizontal development, while the development of sliding curves for HDKY2 to HDKY4 is consistent with theory.

Size and specification of model

In this paper, the establishment of a pile model under compression is as follows: length of concrete pile is 5750 mm, diameter of pile is 500 mm, diameter of bearing plate is 1500 mm, height of bearing plate is 750 mm, slope angle of plate is 37°, which is in accordance with the reasonable range found in the previous study [10]. The pile has centrosymmetric structure. In order to directly observe the images such as displacement cloud picture and stress cloud picture of the pile and soil, in the study, the half-section pile model was adopted. The soil layer was silty clay and hard clay, the thickness of both soil layers was 3250 mm.

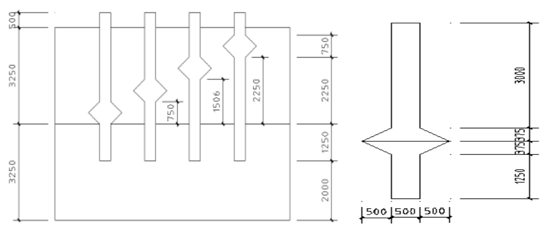

Fig. 9. Diagram of different soil thickness models under the action of vertical compression

Analysis of results by finite element simulation

As can be seen from the curves in Fig.10, when the load is 0～150KN, the displacement of pile is almost not changed; when the load is 200～450KN, the displacement of the pile increases with the increasing of load, which becomes a linear relationship in a certain range; after the load is greater than 450KN, the rate of change of displacement gradually increases with the increasing of load. At the action of the same load, the displacement of pile gradually decreases. With the increase in the thickness under the plate, the displacement of HDKY4 is the smallest, that of HDKY1 is the largest, and the load-displacement curves of HDKB2 to HDKB4 are basically the same with little change. When the thickness of the soil under plate is less than 1.5 times the cantilever length of the plate, the displacement change is largest in the situation of the same load; when the thickness of the soil under the plate is smaller than 1.5 times the cantilever length of the plate, the displacement gradually decreases in the same load. When the thickness of soil under the plate is 1.5 times, 3 times and 4.5 times the cantilever length of the plate, respectively, the displacement of pile body is not significant. So, it is reasonable that the thickness of the soil under the plate of the concrete expanded-plate pile should be greater than 1.5 times the cantilever diameter.

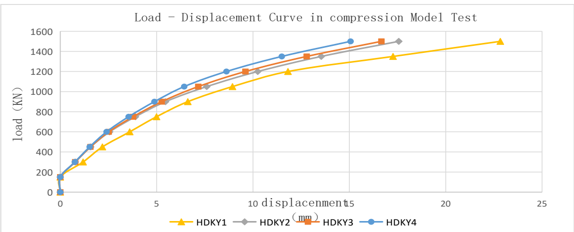

Fig. 10. Load-displacement curves of model pile in the silty clay for finite element analysis

Comparative analysis of model test and simulation result

The following is an example of HDKY2, which shows the trend of the load-displacement curve for model test and simulation test, as shown in Fig.11.

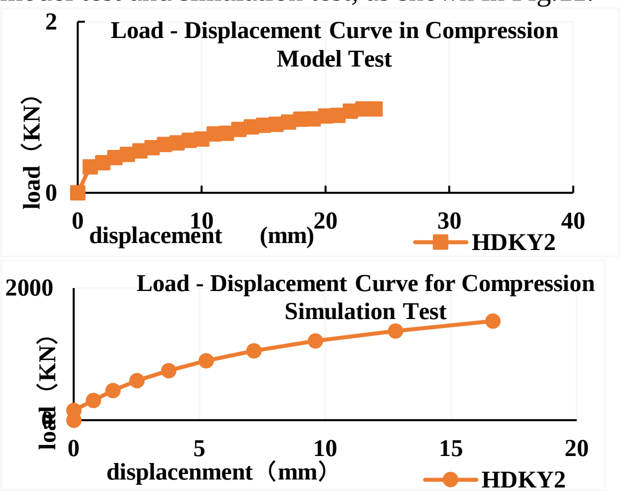

Fig. 11 Test and simulation displacement-load curve contrast

It is known that by comparing the load-displacement curves of the test and simulation analysis, the load of simulation pile model and test model of HDKY2 under compression are all increased with the increasing of the displacement, the load also exhibits a convex line change with respect to the displacement.

The difference is that the model test at the beginning (displacement 0 ~ 1 mm) the load has mutation, while the simulation analysis, the load has a mutation but little change in the displacement, which is due to the fact that the increasing of displacement is controlled to record the load during the test, while the simulation analysis is to control the increasing of load to derive the displacement, the difference is better able to verify each other. In summary, the study results of model test and simulation analysis are basically the same.

CONCLUSIONS

The study is about the test of undisturbed soil of the concrete expanded-plate pile, of which the innovation point is to break the traditional test laboratory method. The test is carried by taking undisturbed soil from the construction site, and a multi-functional loading platform is designed to ensure the smooth conduct of the test; then, to analyze the initial data and picture the information obtained in the model test. The initial data include collected vertical compression load in the process of loading of test, and corresponding displacement of pile body, picture information is process picture about interactivity of the pile and soil. In the paper, it is adopted that the method of comparison and analysis by the combination of data and picture, and analyze the whole failure behavior of soil surrounding plate in the different stages. The test results obtained from the analysis method are more reliable and persuasive than those obtained from the test data. The important conclusion is as follows: with the increase in vertical compression, the displacement of pile increases, the stress under the plate and bottom of pile also increases, which is focused on the soil under the plate; in order to better improve the bearing capacity of pile, the thickness of the soil under the plate should be at least 1.5 times the cantilever length of the plate.

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

REFERENCES

1. S.Bao-han, H.De-xin, L.Zhen-liang, *J.Ind. Bldg.*, **34** (3), 1 (2004).
2. Q.Yong-mei, *J. JL Archit. Civ. Eng. Inst.*, **21** (2), 14 (2004).
3. Q.Yong-mei, Y.Xin-sheng, W.Ruo-zhu, *J. JL Archit.*

Civ. Eng. Inst., **27** (3), 4 (2010).
4. C.Hai-ming, B.Feng-qi,L.Xiao-wei, *J. HF. Univ. Technol.*, **29** (6), 736 (2006).
5. Q.Yong-mei, Z.Da-peng, X.Xue-wei, *J. Adv. Mater. Res.*, **578-579,** 232 (2014).
6. Q.Yong-mei, X.Guang-han, *J. Open Cons. Bldg. Technol* ., **41** (11), 22 (2014).
7. Z.Yan-qing.Y.Hui, *J. BJ. Univ. Technol.*, **32** (10), 879 (2006).
8. W. Ruo-zhu, Q.Yong-mei, Y.Xin-sheng, *J. Cons. Bldg. Technol.*, **38** (1), 5 (2011).
9. Q.De-ling, *J. Geotech. Eng.*, **24** (3), 371 (2002).
10. X.Xue-wen, *Jilin Jianzhu University*, *Changchun*, 2015.