EJGE

# Test Study of Undisturbed Soil on Influence of Plate Space for Compressive Failure Mechanism of Concrete Plates-Expanded Pile

**Yongmei Qian[a], Zhanheng Sun[b,] Lian Zhai[c], Ruozhu Wang[d]**

*Jilin Jianzhu University, Changchun, China, 130118*
*[a]654675316@qq.com, [b]1093811058@qq.com, [c]826552602@qq.com,*
*[d]306109357@qq.com,*

## ABSTRACT

This paper presents a study of the failure mechanism of concrete plates-expanded pile under vertical compression by the method of making the undisturbed soil test with small scale half-section model. The half-section pile with different plate space will be made in this test, and through the self-made device to get the undisturbed soil samples on the site, which is loaded on the loading station, and it is observed that the destruction process of the soil around the pile. By comparing the failure state of the soil body around the pile with different plate space, it is analyzed qualitatively that the influence of plate space for the failure state and the bearing capacity of the concrete plates-expanded pile, and the reasonable range of plate space is put forward, which is applied as a foundation for the design of the concrete plates-expanded pile and the calculation of the bearing capacity of the single pile.

KEY-WORDS: The concrete plates-expanded pile, undisturbed soil, half-section piles, plate space, compressive failure mechanism

## INTRODUCTION

The concrete plates-expanded pile is a new type of pile, compared with ordinary straight pile, it has higher bearing capacity, and very big potential promotion value. The influence factors on bearing capacity of single pile of the concrete plates-expanded pile is multifaceted. The situation of force loaded on the pile is also more complex than ordinary pile[1-2]. Analyzed simply from the construction of the pile and bearing plate, the main influence factors are, the diameter of the bearing plates-expanded, slope angle, location, space and quantity, the quantitative analysis is more difficult for them, while the qualitative analysis is relatively easy[3-4]. It can be seen, from the preliminary study on the bearing capacity of single pile of the concrete plates-expanded pile, that the space of plates-expanded will produce the more influence for the failure behavior of the soil around the pile, and bearing capacity of single pile[5-6]. As one of the important factors, at present, the relative research achievements are much more limited, in this paper, through a small scale model test method, the experimental study is made on influence of plate space on the failure behavior of soil and the compressive bearing capacity of soil around the concrete plates-expanded pile, so as to provide a reliable reference for the calculation of bearing capacity of the concrete plates-expanded pile.

# SOIL PROPERTIES AND MODEL OF SPECIMENS

## The physical properties indicators of undisturbed soil

The common clay soil is selected in the test soil[7-8], which is obtained in the site through the self-developed devices for getting soil. The surveying work of the site for getting soil is done by the professional surveying company. According to "Geological Investigation Report" and the results of soil test in laboratory, they are obtained that the cohesion of soil is 59kPa, the internal friction angle 12°, the density 1.86g/cm3, the natural moisture 29.6%, the liquid limit ωL=35.1%, the plastic limit ωp=22.7%, the elastic modulus Es=2.5×104MPa[4].

## The specimens model with different plate space

In this experiment, considering the stiffness of the pile is much larger than the soil, only if pile quality has no problem, the pile body is not destroyed while only the soil is destroyed during the loading process, so the pile is made of steel, the size of the model pile is made with 1:50 scale according to the pile size of the simulation analysis in computer[9-10]. This paper focuses on the influence of plate space, according to the principle of a single variable, the plate parameters are set, the specific specimen size and pile location embedded in the soil are shown in Fig.1.

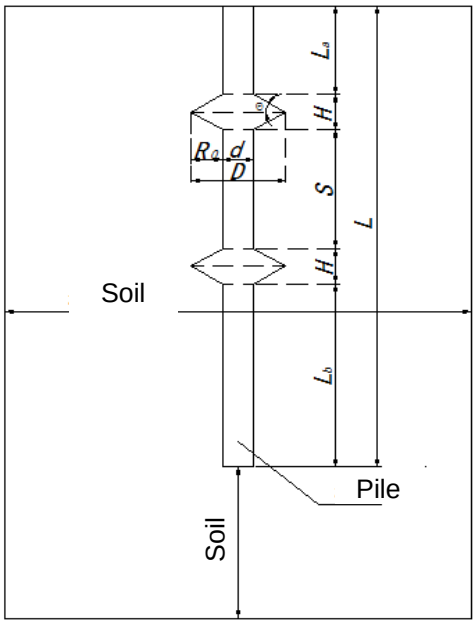



**Figure 1:** The sketch map of pile and soil

In Fig.1, $L$ is the pile length, $L_a$ is the distance between the top of pile and the top of plate, $L_b$ is the distance between the end of pile and the bottom of plate, $d$ is the diameter of main pile, $D$ is the diameter of plate, $H$ is the height of plate, $R_0$ is the cantilever diameter, $R_0$= (D-d)/2, $\theta$ is the angle of plate, $S$ is the plate space. The parameter is as follows:

Common parameters: $d$ is 10mm, $D$ is 30 mm, $H$ is 12 mm, $\theta$ is 31°, $R_0$=($D$-$d$)/2=10mm, $L$ is 210 mm, the pile length has an increase of 50mm compared with the original model, in order to give the reserved length higher the surface of soil for convenient loading.

Specific parameters: the upper bearing plate-expanded is set at location with $L_a$=80mm, other parameters remain unchanged, only by changing location of bottom plate-expanded to change the plate space. The plate space $S$ is taken in turn as n$R_0$ (n=2~7), the model piles are numbered as 5#

to 10# for six specimens. The test pile model is as shown in Fig.2, the special parameters is as shown in Table1.

**Figure 2:** The half-section test pile with different plate space

**Table 1:** Special parameters of test pile with different plate space

| Pile number | 5# | 6# | 7# | 8# | 9# | 10# |
|---|---|---|---|---|---|---|
| Quantity of the plate | 2 | 3 | 4 | 5 | 6 | 7 |
| S(mm) | 20 | 30 | 40 | 50 | 60 | 70 |

## Test apparatus and equipment

The devices name and type used in test are as shown in Table 2.

**Table 2:** Statistics of test devices

| Device name | Device mode | Number |
|---|---|---|
| Displacement sensor | YHD-100 | 2 |
| Manual hydraulic jack | ZY-2 | 1 |
| Digital camera | Canon700D | 1 |

The test device consists of three parts, which is loading system, the reaction force system and observation system [11-12].

(1) Loading system: due to the smaller specimen, bearing capacity is relatively smaller, in order to improve the accuracy of magnitude, using jack with 2000kg the maximum and manual hydraulic pressure, Hydraulic cylinder is from the reset type for the hollow, the piston stroke is 40mm, the digital pressure gauge can intuitively read the magnitude, the unit is KN, the accuracy can be up to three decimal places, which cam follow the requirements of this model test.

(2) Reaction system: to combine the dimensions of the device for getting soil, the reaction loading platform is specially produced. That is, the trestle are made through the installation of two I-column on the top of the rigid platform, with a beam as the reaction beam is set between the two I-column, as shown in Fig.3.

(3) Observation system: it is formed mainly by the displacement sensor, digital pressure gauges of jack, digital cameras, which is mainly applied for recording the change conditions of

displacement and load in the loading process, and the failure process of the soil around the pile is recorded with a digital camera.

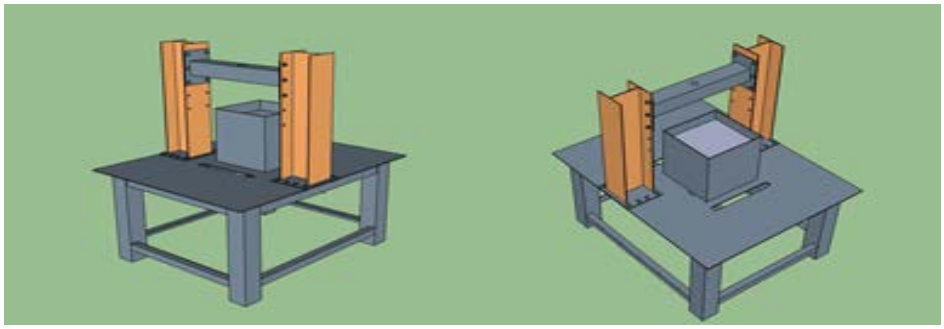


**Figure 3:** Reaction force loading platform

# THE PROCESS AND METHOD OF THE TEST

## The loading way of the test

(1) Because it is more difficult to control loading by manually hydraulic jack, so in this test load is added gradually by controlling displacement method, the magnitude of every displacement is set to 1mm, the pile-top load is recorded when every 1mm displacement is added. In accordance with the relevant provisions, when the followings occur, the load can be terminated [13-14];

(2) When the pile-top displacement increases but the load does not change or the load increases the displacement appears to increase sharply, to award up to the limit load, unable to continue load;

(3) When the abrupt change of the ultimate bearing capacity can be decided in the displacement-load curve, or the curve is no obvious mutation due to slow type development, but the total settlement of the pile-top exceeds 40mm of the stroke of the jack;

(3) The other situation of not suitable to continue to load cause, while the test cannot continue.

## The collection of data

The process of collection of data is as follows:

(4) The magnitude of displacement meter is recorded by manual or digital display device connected, through displacement controlling, each 1mm displacement develops, and the magnitude of a jack gauge is read one time.

(5) From the beginning of loading, every 2mm displacement, to record the failure behavior of soil around the pile by a digital camera.

(6) When the ultimate failure is reached, the failure behavior of the soil around the pile is taken a final picture.

(7) In the process of getting soil and testing, soil moisture content and other property may occur smaller changes, on the basis of the geological investigation data, in order to improve the accuracy of the data, after the experiment has been done, the soil is immediately sampled with a ring cutter, the soil properties are measured by soil tests in the laboratory.

# THE ANALYSIS OF TEST RESULTS

## Failure behavior of soil around pile

To observe the failure situation of soil around the pile is the key to the test, they are mainly observed that the failure process of the soil around the pile with the increase of the load, and the similarities and differences of failure behavior of the soil between the plates-expanded piles with different plate space when reaching the ultimate failure. In the test, the half-section pile and test equipment designed specially provides conditions for observing the failure behavior of pile and soil [15-16].

(1) The failure process of soil around pile

The displacement of each 2 mm is generated when each load is applied to the top of pile, a digital camera is used to record the failure of soil around the pile, and the failure process of soil around pile is described on the basis of the 7 # pile, as shown in Fig.4.

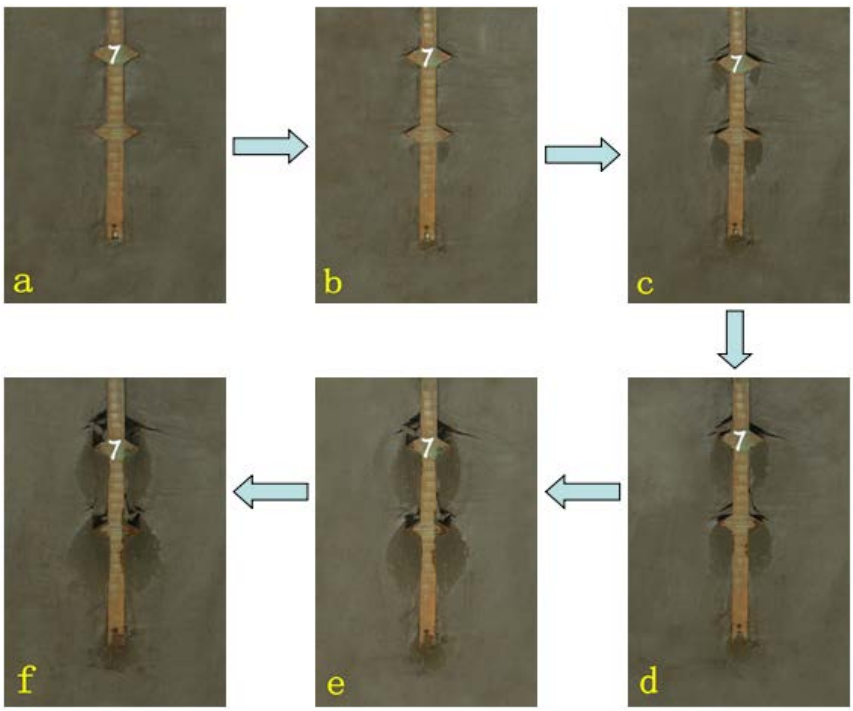
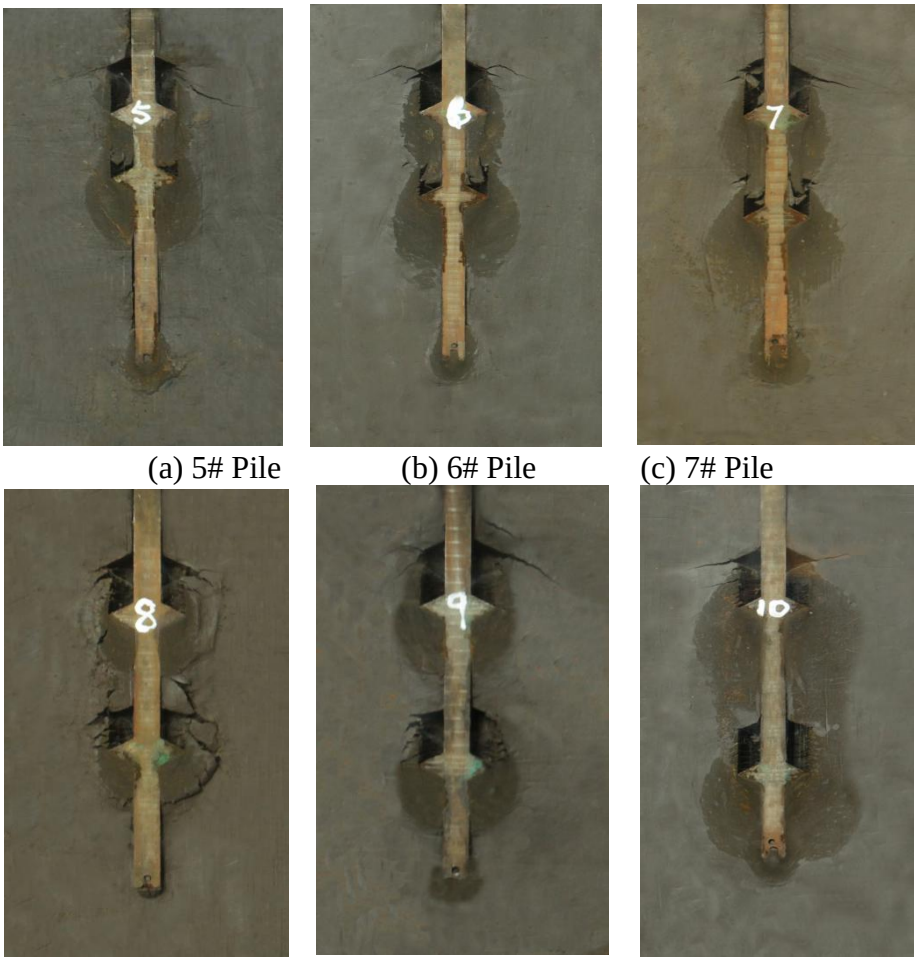



**Figure 4:** The failure process of soil around the pile of 7# pile

In the Fig.4, the pictures of a to f are the failure process of the soil around the pile with the increase of load at the top of pile, from the picture a unloaded, it can be seen that the combination between the upper of the plate-expanded and soil is closely, no effect squeezed of the soil under plate. After the load reaches a certain level as in picture b, the soil upper the plate begins to separate from the pile and the crack develops, watermark appears under the plate, indicating the soil under plate to be pressured, watermark is developed due to the extrusion of the soil under the plate, it can be observed the influence range of soil under the plate-expanded by the the change of watermark . From the picture c to d, it can be seen that with increasing of the load , the crack upper the plate becomes larger and the watermark gradually spreads downward. As shown in picture e, with the load continues to increase, the shear failure occurs at the end of the plate, and a larger crack appears upper the plate, at which the tensile stress zone develops, so that in the area of length along the pile the side friction should be ignored[2]. The length of ignoring the side friction at the top of plate is approximately equal to the top displacement of pile subtracts the compression value of the pile body, at the same time, as the soil under the plate is compressed,

the friction coefficient of the pile side should be increased corresponding. In the picture f, the load reaches the ultimate magnitude, the watermark upper and lower plate has been connected together, shear failure develops in soil between the two plates, the influence range of the soil underneath the plate is approximately elliptically closed from the end of the plate to the pile side along 45o, which is consistent with the theory of soil failure along slipping line[3].

(2) The failure behavior of soil for pile with different plate space




(a) 5# Pile (b) 6# Pile (c) 7# Pile

(d) 8# Pile (e) 9# Pile (f) 10# Pile

**Figure 5:** The ultimate failure state of soil around the pile with different plate space

In Fig.5, compared picture(a) with picture(c), it can be seen, when the plate space is less than $4R_0$, ($R_0$=($D$-$d$)/2), namely the distance between the two plates is closer, the soil under the upper plate and the soil at the top of bottom plate will produce effect each other[4], resulting the phenomenon of stress superposition, the plate-expanded cannot fully take the action to bear, resulting in bear capacity reduced, the final form of soil failure are shear failure of soil between the plates. In the picture(d), due to the plate space lager, although the result is failure of soil under plate of upper plate and bottom plate separately develops belong to the failure along slipping line, but due to the soil undisturbed between the two plate smaller, which tend to produce shear failure. When the plate space is greater than $5R_0$, as shown in picture (e) and picture (f), the soil failure under the plate, for the upper plate and bottom plate, is all failure along the slip line, and with no the stress superposition between the soil under the upper plate and the soil at the top of bottom plate, and it shows that the bearing capacity of the plate can be fully given play to. The forms of ultimate destruction are based on the soil under plate for the sliding failure. From the above

analysis of soil failure the failure along the slip line can be drawn from the critical plate space is about $5R_0$. [17-18]

It can be seen from the test results that the larger of the plate space, the smaller influence each other for soil between the plates, the higher the bearing capacity of the single pile, the horizontal compression stress enhancement zone under the plate should be increased accordingly [3]. But that is not the more better more the plate space. From the picture(e) and picture(f), it can be seen that the range of watermark of picture(f) is lager than the picture(e), but the color of watermark in the picture(e) is deep, indicating that up to the ultimate failure, the stress level under the plate of 10# pile is lower than it of 9# pile, so if the plate space is enlarge unlimited, the length of pile will be increase with the increase of bear capacity is limited, resulting in waste of materials. In order to not only improve the bearing capacity, but also to save costs, the plate space of the plate-expanded pile should not exceed $6R_0$.

## The analysis of displacement-load curve

The displacement-load curve is plotted from the displacement and load values collected as shown in Fig.6, where the load at zero displacement is the weight of the jack, pile cap and gasket.

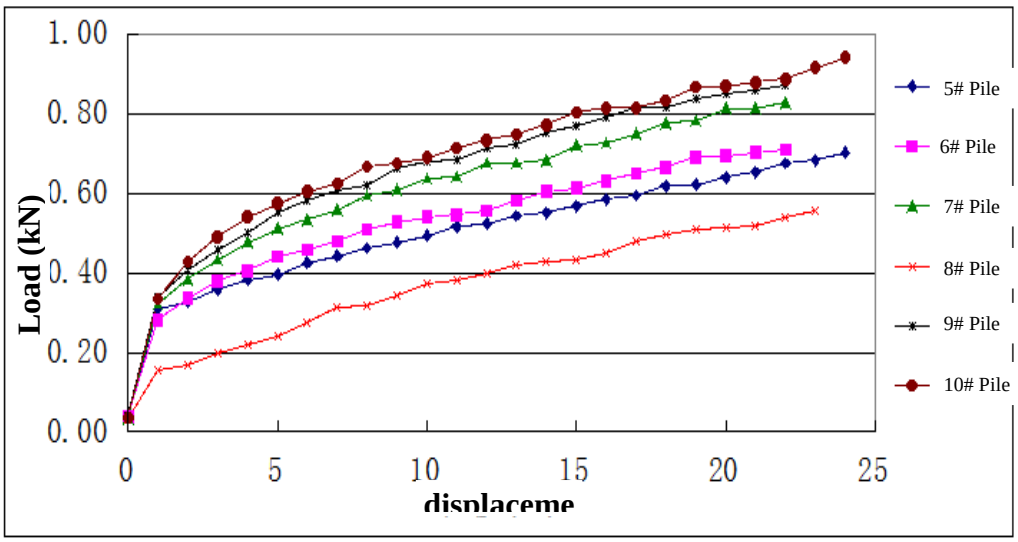



**Figure 6:** The displacement-load curve comparison chart of testing pile with different plate space

Compared different piles in Fig.6, from the load displacement curve of model with different plate space, it can be seen that displacement is same, larger plate space, larger load on top of pile means greater capacity. Among them, the load value of 8# pile occurs abnormal, because the soil and pile are not tightly connected with glass during the test, there is a gap between the pile and the glass. When loaded the pile is outward, the bearing capacity reduces, so when the data analyzed the test results of 8# pile is to be ignore. The plate space of 5# pile is the smallest, after the displacement reaches 1mm, the curve is almost close to the oblique line, that is, the growth of the displacement and loads come to linear. The displacement-load curve of 6# ~ 10 #piles has phenomenon as step-up: such as the displacement of 7# pile close to 14 mm, the slope of curve suddenly becomes bigger, which may be due to stress redistribution produced by rearrange of soil particles [5]. It can be clearly seen that the bearing capacity of 7# pile is better than 6# pile, this shows when the plate space S is greater than five times $R_0$, where $R_0=(D-d)/2$, the bearing function of each plate of the plate-expanded pile can be fully achieved. But the larger plate space means the length of pile grows bigger and bigger, which indirectly increases the cost of the project. In the case of without taking into account the geological conditions, the reasonable plate

space proposed is (5-6) $R_0$, which not only to make every plate do the bearing function, but also save cost.

## CONCLUSIONS

It can be seen from the soil failure process of the plate-extended pile that, at the beginning of loading, subtle cracks began to develop at the top of plate, with the load increasing, crack becomes bigger, then a larger gap appears on the top of plate, tensile stress area develops in the soil upper the plate, in this area, the side friction of pile should be ignored. The length of ignoring the side friction at the top of plate is approximately equal to the top displacement of pile subtracts the compression value of the pile body, at the same time, as the soil under the plate is compressed, the friction coefficient of the pile side should be increased corresponding. The load reaches the ultimate magnitude, shear failure develops in soil between the two plates, and the influence range of the soil underneath the plate is approximately elliptically closed from the end of the plate to the pile side along $45^o$, which is consistent with the theory of soil failure along slipping line.

From soil failure it can be drawn, when the plate space is less than $4R_0$, ($R_0$= ($D$-$d$)/2), because the distance between the two plates is closer, the soil under the upper plate and the soil at the top of bottom plate will produce effect each other, the plate-expanded cannot fully take the action to bear, the final form of soil failure are shear failure of soil between the plates. When the plate space is greater than $5R_0$, the soil failure under the plate is all failure along the slip line, and with no the stress superposition between the soil under the upper plate and the soil at the top of bottom plate, and the bearing capacity of the plate can be fully given play to. The forms of ultimate destruction are based on the soil under plate for the sliding failure.

It can be seen from the load-displacement curve of model with different plate space, when displacement is same, larger plate space, larger load on top of pile means greater capacity. When the plate space is $4R_0$, the bearing capacity is significantly improved to compare with the bearing capacity of plate space is $3R_0$. However, the larger plate space, the slower growth of curve, which indicates that the increasing of plate space has smaller contribution for the displacement. Considering the reason, it is suggested that the reasonable plate space is (5~6) $R_0$, which can make each plate do the bearing function, but also save cost.

## ACKNOWLEDGMENT

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

## REFERENCES

1. Zhijun Xu, Technology Development and Engineering Application of the Multi-Extruded-Plates Pile[M], Beijing, China Architecture and Building Press, 2014.3;
2. Yongmei Qian, Jie Wang, Ruozhu Wang,The Analysis of the Vertical uplift bearing capacity of Single the CEP Pile, The Open Civil Engineering Journal, Vols.9,2015.9, pp598-601;
3. Dexin He; Baohan Shen; Zhenliang Liu; Guixia Guo; Junping Sun.The generation and features of DX the Multi-Extruded-Expanded-Plates pile Industrial Buildings 2004-03-18
4. Deling Qian, Soil mechanics[M], Beijing, China Architecture and Building Press, 2009;

5. Yongmei Qian, Rongzheng Zhai, Ruozhu Wang, Analysis of Soil Characteristics Affecting Failure Behavior and Bearing Capacity of the Concrete Expanded-Plates Pile, The Open Construction and Building Technology Journal, Vols.9, 2015.9, pp188-191;
6. Weijin Wang. Bottom-expanded pile uplift bearing capacity analysis. Master degree theses of master of Henan University. May 2010. P8 - P9.
7. Yongmei Qian, Rongzheng Zhai, "Analysis of the influence of plate spacing on the uplift bearing capacity of the concrete plates-expanded pile", 《Journal of Jilin Jianzhu University》, 2015 (Volume 32) No. 4, pp. 5-8;
8. Yuehui Li, Xiaojuan Gao.Extruded-Expanded-Plate pile and ordinary pile uplift bearing capacity contrast test research. Journal of Henan University of Technology (natural science edition) in June 2010。
9. Yongmei Qian, Xu Wang, Ruozhu Wang, Preliminary Study on Effect of Water Content of Fine Silty Soil on Compression Failure of Concrete Expanded Pile,《Industrial building》(Chinese core), 2016.6.20, 2016 (Vol. 46) Supplement, pp 542-545;
10. W.J. Wang, "Bottom-expanded pile uplift bearing capacity analysis", Henan University. 2010
11. Yongmei Qian, Qingyu Cheng, Ruozhu Wang, Research on the Test Method of the concrete plates-expanded pile, 《Advanced in Engineering Research》, Vols.39, pp1065-1070.
12. Y.H. Li, X. J. Gao, "The research of contrast test on uplift bearing capacity between squeezed branch piles and common piles", Henan University of Technology, vol. 29, pp.391-395, Jun,2010
13. Dexin He; Baohan Shen.The Multi-Extruded- Expanded-Plates device and DX pile of multi-section application,Industrial Buildings 2001, 31( 1):27- 31
14. H. Yuan, Y.Q. Zhang, ZH. Qu, H.D. Gao, "The experimental research of expansion pull-out performance on squeezed branch piles", The 16th national conference on structural engineering , China: Chengdu, 2008, pp378-380.
15. Zhang Jie, Shang Yuequan and Lin Xuwu, " The analyze of considering pulling force position effects the deformation of tension pile," journal of civil engineering, vol. 38, pp102-106, July, 2005.
16. J.S. Jin, "Structure of Concrete", China: Wuhan, 2009, pp287-312
17. Ma Fei and Zhang Yong Xing: "Experiments and Analysis of the Acoustics Properties of Concrete Tunnel" *Electronic Journal of Geotechnical Engineering*, 2009 (14.A) pp 1-17. Available at ejge.com.
18. Frédéric V. Donzé, Vincent Richefeu, and Sophie-Adélaïde Magnier "Advances in Discrete Element Method Applied to Soil, Rock and Concrete Mechanics" Special volume of Electronic Journal of Geotechnical Engineering, Bouquet 08, 2008: pp 1-44. Available at ejge.com.

© 2017 ejge

***Editor's note.***
This paper may be referred to, in other articles, as:

Yongmei Qian, Zhanheng Sun, Lian Zhai, and Ruozhu Wang: "Test Study of Undisturbed Soil on Influence of Plate Space for Compressive Failure Mechanism of Concrete Plates-Expanded Pile" *Electronic Journal of Geotechnical Engineering*, 2017 (22.01), pp 365-374. Available at ejge.com.