Experiment on Soil Squeezing Effect During Penetration of PHC Pipe Pile Static Pressure Pile in Deep Silt Site

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Abstract. This paper takes the construction of a foundation pile project in Wenzhou as an example. Through indoor experiments, the law of squeezing soil stress with time and space and the dissipation of pore water pressure during the process of pile driving are studied. The test results show that (1) the static pressure of pipe pile driving has a good exponential increase relationship with the pile penetration depth; (2) the pile bottom pressure and radial squeezing soil pressure have a linear relationship with the pile penetration depth; (3) the radial earth pressure increases with the static pressure on the top of the pile during pile sinking, while decreases during unloading; the increment of radial earth pressure decreases with the increase of the distance between the pile and the measuring point, and the radial squeezing range can be determined according to the increase ratio of the radial earth pressure; (4) the ratio of the excess pore water pressure to the distance from the measuring point to the pile diameter decreases exponentially.

Keywords: Pipe pile, static pressure, pore pressure dissipation, radial earth pressure.

1. Introduction

Prestressed high strength concrete pipe pile has the advantages of high bearing capacity, good bending performance, stable quality and strong adaptability. Static pressure PHC pipe pile is widely used in soft soil area and densely populated cities. How to correctly predict the compaction effect and load transfer in the process of pile sinking is the guidance for the reasonable selection of jacked pile machine, and the impact on the surrounding environment has become the focus of research on jacked pile in recent years. At present, the experimental research on soil compaction effect of pile driving mainly includes two aspects: field test and indoor model test. Compared with field test, indoor model test can reduce the interference of many external factors, ensure the accuracy of test data, and can be verified repeatedly, so it is widely used by scholars at home and abroad.

Li Jingpei and Li Yunong [1-4] carried out the indoor model test of static pile driving in layered soil, and explored the displacement field of soil near the pile body during the pile driving process, and the variation law of the pile force, pile dynamic end resistance and pile dynamic side resistance with pile penetration depth in the whole pile driving process. Chen Wen and Xu Jianping [5,6] analyzed the spatial distribution of soil displacement and excess pore pressure caused by pile driving in saturated clay through indoor model test. Qian Feng et al. [7] carried out the model test of open-end pipe pile, and analyzed the variation law of soil lateral pressure, pore pressure and surface vertical displacement. Zhang Jianxin et al. [8] analyzed the variation law of soil deformation near the pile body, excess pore pressure inside the soil body around the pile body with the pile sinking depth through the indoor...
model test of pile group. Through the penetration test of static pressure single pile and row pile, Li Furong et al. [9] explored the variation law of soil deformation and pore water pressure. Jinhua Xia[10] studied the influence of drainage plate spacing on the dissipation of excess pore pressure during the construction of pipe pile in soft soil foundation, and its success can provide reference for pile construction in soft soil area.

Although there is some research on the soil compaction effect of pipe pile, the soil compaction effect caused by large-area pipe pile construction in deep silt field still needs further study. In this paper, it is significant to study the variation of static pressure and pore pressure with the time of pile construction in Wenzhou.

2. General Situation of Model Test

2.1. Model Test Box and Test Soil

The model box is made of steel plate with length, width and height of 100cm × 100cm × 100cm, the thickness of steel plate is 10mm, and the corners are riveted with angle steel. The 30 cm thick sand is placed at the bottom of the test box, which is used for drainage and consolidation of the soil layer after the test layer is set.

The test soil is taken from the soft soil of Wenzhou Economic and Technological Development Zone. There are 27.20m ~ 33.60m thick. The gravity of soft soil layer is 17.4kN/m$^3$ ~ 18.3kN/m$^3$. The weighted average value of water content is greater than 45.6%, less than 59%, and liquid index is greater than 1.50. According to the situation of field test, the test soil in the form of soft soil is configured. Mix a certain amount of water and experimental water evenly, pack them in three layers, 20 cm in each layer, and let each layer stand for 24 hours. After 4 weeks of self weight consolidation, the soil compaction experiment was carried out. The average value of weight is 17.7kN/m$^3$, and the average value of water content is 54.2%.

2.2. Model Pile

The model of engineering pile is PCA 500 (100), pile diameter is 500mm, static pressure and final value of static pressure is 1620kN. This test mainly simulates the compaction effect of foundation pile in deep soft soil foundation, so the length of model pile is 55cm, and the pile diameter is 25mm and 50mm respectively. The relationship between pile static pressure and penetration depth is shown in Figure 1. The relationship between pile static pressure and pile penetration depth shows a good exponential relationship, and R-square is greater than 0.98.

![Figure 1](image-url)

**Figure 1.** The relationship between model pile static pressure and foundation pile penetration depth.

2.3. Measuring Equipment and Test Elements

The optical fiber pore water pressure sensor is HC-25, and the acquisition instrument is HCSC-32. The earth pressure sensor at the pile side is of pressure sensing type, with the pressure measuring range of 0-30kPa, and the static strain gauge of Youtai is used. As shown in Figure 3, four optical fiber pore water pressure sensors are arranged in the soil layer of the model box, with the buried depth of 55cm;
and four earth pressure sensors are respectively arranged at the position of $z=25\text{cm}$ and $50\text{cm}$. For the convenience of analysis, the coordinate origin is set at K1.

![Schematic diagram of measuring point layout.](image)

**Figure 2.** Schematic diagram of measuring point layout.

### 3. Test Results and Analysis

#### 3.1. Earth Squeezing Pressure During Pile Driving

Figure 3 shows the variation law of radial earth pressure and pile bottom pressure with time when the model pile diameter $d = 50\text{ mm}$. It can be seen that the pile bottom pressure and radial earth compaction pressure increase with time, and reach the maximum value after pile sinking, and the ratio is 4.26; during unloading, the soil at the pile bottom rebounds, and the pile bottom pressure decreases rapidly, and the two are almost the same as time goes on. Figure 4 shows the variation of pile bottom pressure and radial earth compaction pressure with pile penetration depth during pile driving. With the increase of penetration depth, the pile bottom pressure and radial compaction pressure have linear relationship with penetration depth, R-square is 0.955 and 0.906 respectively.

![The law of squeezing earth pressure-time variation during pile driving.](image)

**Figure 3.** The law of squeezing earth pressure-time variation during pile driving.
Figure 4. Variation law of squeezing earth pressure-depth during pile driving.

Figure 5 shows the variation law of radial earth pressure with time at different positions and depths in the process of pile construction. 0s ~ 3800 s is the radial earth pressure produced by 4 piles with d = 50 mm, and 3800 s ~ 12000s is the radial earth pressure produced by 6 piles with d = 25 mm. It can be seen that the radial earth pressure increases with the depth of pile sinking, and reaches the maximum value when the pile reaches the final position; when the pile top is unloaded, the radial earth squeezing pressure recovers. After the completion of each pile sinking, the radial earth pressure recovers more than 80% after standing for 30 minutes. The results show that the radial pressure of T10 and T5 has the greatest influence on the 4 piles nearest 2.0D, and the maximum radial pressure ratio is 2.22, and the distance between the pile at other locations is greater than 5D, which has less influence; the radial compaction pressure of T8 and T9 is the largest at the distance of 10cm (4D) 10 piles, and the maximum radial pressure ratio is 3.05; When the distance from the measuring point T1 and T2 is 10.3cm (4.12d), the maximum value of 9 piles and the maximum ratio of radial pressure is 1.85.

Figure 5. Changes of radial squeeze pressure at different positions and depths with time.
Figure 6. The cloud chart of Pile5-10 peak radial earth pressure \((x=0,y=37.5cm,z=50cm)\).

Figure 6 shows the cloud chart of the increment peak value of radial earth pressure at different positions and depths. The incremental ratio of radial pressure \(\frac{\Delta p_x}{p_s}\) \(\Delta p_x\) is the increment of radial earth pressure; \(p_s\) is the static earth pressure at the same position and depth of foundation pile.

When the increment ratio of radial earth pressure is equal to a certain limit value, the corresponding range is the influence range of pile driving. When \(\frac{\Delta p_x}{p_s} = 5\%\), the influence range of pile driving was 7 times of pile diameter.

3.2. Excess Pore Water Pressure and Dissipation Law during Pile Driving

Figure 7 shows the variation of pore water pressure with time at the depth of 55cm during pile driving. Figure 8 shows the cloud chart of excess pore water pressure of 6 piles with \(d = 25mm\) at \(z = 55cm\) at K3. It can be seen that the pore water pressure dissipates due to the destruction of soft soil structure during pile driving (manifested as the decrease of pore water pressure), and then the pore water pressure rises. After pile sinking (unloading), the pore water pressure dissipates, and the influence range of excess pore water pressure caused by pile driving is more than 11 times of pile diameter. The construction time of 10 piles is 5.2 hours, and the pore water pressure of the four measuring points is still 2.86kPa, 1.98kpa, 1.61kPa and 0.732kPa higher than the initial value of 2.6h after construction.

The excess pore water pressure \(\Delta u_a\) decreases with the distance from the measuring point. The influence of other 9 piles is very small. Figure 9 shows the change of excess pore water pressure decreases exponentially with the change of pile position during pile driving, and R-square is greater than 0.97.
Through the indoor model test, this paper analyzes the variation law of radial earth pressure and excess pore water pressure with time during the construction of pipe pile in deep soft soil site.

(a) The results of field pile driving and indoor model test show that the static pressure has a good exponential increasing relationship with the pile penetration depth, and the R-square is greater than 0.94.

(b) There is a linear relationship between the pile bottom pressure and the radial earth pressure in the process of pile driving. The pile bottom pressure is greater than the radial earth compaction pressure. The ratio of the two is 4.26 after the construction, and they are almost the same after unloading.

(c) The radial earth pressure increases with time in the process of pile driving, and decreases obviously with the increase of the distance between the foundation pile and the measuring point in the process of pile driving. The increment ratio of radial earth pressure is defined to determine the influence range of pile driving construction.

(d) Due to the destruction of soft soil structure during pile driving, the pore water pressure dissipates, and then the pore water pressure rises. After the pile sinking (unloading), the pore water pressure dissipates. The ratio of the excess pore water pressure to the distance from the measuring point to the pile diameter decreases exponentially.

Figure 8. Incremental cloud diagram during pile driving.

Figure 9. Change law (K1) of $\Delta u_a \sim r / D$.
Reference

[1] Li Jingpei, Li Yunong, Zhang Shutao. Experiment on soil squeezing effect of single static pressure pile in layered foundation[J]. Journal of Tongji University (Natural Science Edition), 2011, 39(06): 824-829.

[2] Wang Changming, Chang Gaoqi, Wu Qian, et al. Static pressure pipe pile-soil interaction mechanism and determination method of vertical bearing capacity[J]. Journal of Jilin University (Earth Science Edition), 2016, 46(03):805-813.

[3] Li Yunong, Lehane B M. Model test of pile sinking characteristics in double-layer kaolin clay[J]. Journal of Jilin University (Earth Science Edition), 2018, 48(06): 1778-1784.

[4] Zhang Shutao, Li Jingpei, Li Yunong. Model test study on soil squeezing effect of static pressure piles in layered soil[J]. Chinese Journal of Underground Space and Engineering, 2009, 5(S2): 1557-1561.

[5] Chen Wen, Shi Jianyong, Gong Youping, et al. Centrifugal model test study on soil squeezing effect of static pressure pile in saturated clay[J]. Journal of Hohai University (Natural Science Edition), 1999(06): 103-109.

[6] Xu Jianping, Zhou Jian, Xu Chaoyang, et al. Model test study on soil squeezing effect of pile driving[J]. Rock and Soil Mechanics, 2000(03): 235-238.

[7] Qian Feng, Liu Ganbin, Qi Changguang, et al. Model test and numerical simulation of static pressure pile driving in saturated clay[J]. Hydrogeology and Engineering Geology, 2016, 43(05): 56-61+69.

[8] Zhang Jianxin, Lu Qun, Wu Dongyun, et al. Analysis of soil deformation caused by static pressure pile group based on model test[J]. Rock and Soil Mechanics, 2010, 31(04): 1243-1246+1252.

[9] Li Furong, Zhang Yanmei, Wang Zhaoyu. Model test study on the squeezing effect of static pressure piles in soft soil[J]. Building Science, 2013, 29(01): 52-54+19.

[10] Jinhua X, Guanghui J, Zhongliang L. Experimental Study on Soil Squeezing Effect of Pipe Pile in Soft Soil Subgrade[J]. Construction Technology, 2015.