Laboratory Model Test and Analysis of Excess Pore Water Pressure Dissipation of Pile Driven by Tapered - Perforated Tubular Pipe Pile

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Abstract. Through methods based on the indoor model test, the use of static pressure pile with three different hole arrangement and three different kinds of taper cone - bore log shape composite pipe pile bored into soil by static pressure,and after observing the excess pore water pressure caused by pile driving when testing, and analyzing the process of various pipe pile static pressure, the change rule of the excess pore water pressure varying with taper hole arrangement, size, radial distance, pile depth has been gotten. It is found that stellate shape has the best dissipation rate of excess pore water pressure under the condition of hole arrangement and taper 1/70, which is of certain guiding significance for promoting the engineering application of tapered - perforated tubular piles.

Keywords: pipe- pile with hole; model test; excess pore water pressure; dissipation rate.

1. Introduction
Prestressed concrete pipe pile [1] has reliable pile body quality and good pile quality. Since the end of 1990s, prestressed concrete pipe piles have been widely used in deep soft foundation treatment of expressways and railways in China.However, in the soft clay foundation with high water content, the excess pore water pressure will be produced during the construction of static pile, which will have an adverse impact on the surrounding structures.

To effectively reduce adverse influence on surrounding environment when doing the static pressure pile, based on literature [2] Tapered - Perforated Tubular Pipe Pile not only inherits the perforated pipe pile [3] - [7] reduces excess pore water pressure and acceleration time and space in a maximum way , but also inherits the conical pipe pile [8]-[9] increases rate of replacement, improves the advantages of bearing capacity of composite foundation, therefore tapered-perforated tubular pipe pile is adopted to study the rule of super pore water pressure varying with time, depth and radial distance, hole arrangement, and the size of the taper.In this paper, three kinds of tapered-perforated tubular pipe piles with different openings and three kinds of different taper sizes are used to carry out static pressure sinking pile, and the test results are of certain guiding significance for the analysis and demonstration of tapered-perforated tubular pipe technology and its application.
2. Model test design

2.1. Preparation of model box
Make a model box of 1.5m×1.5m×1.5m with angle steel and toughened glass. The specific manufacturing process is as follows: 1.5m×1.5m×1.5m angle steel frame is welded with No.5 angle steel, and the angle steel frame is welded centrally on 2m×2m×0.01m steel plate. The four sides of the model box are spliced by two type 2 tempered glass and one type 3 tempered glass respectively, which is convenient for observation. The joints of tempered glass are not sealed, which ensures that excessive free water in soil can flow out from the joints, as shown in Figure 1.

![Fig. 1 Schematic diagram of model box](image)

2.2. Preparation of soil samples
The soil samples selected in the test are all from silty clay around Nanchang, which are dried, crushed and screened indoors. According to the test requirements, water is added to the soil and stirred. The treated soil samples are filled into the model box in layers and consolidated by static pressure. Before the static pressure pile driving test, the geotechnical test is carried out to measure the relevant physical and mechanical properties of the soil samples.

| Moisture content/% | Density ρ (g/cm³) | Compression coefficient av (Mpa-1) | Compressive modulus es (Mpa) | Internal friction angle φ (°) | Cohesion c (kPa) |
|-------------------|-------------------|-----------------------------------|-----------------------------|------------------------------|-----------------|
| 42.36%            | 1.68              | 0.75                              | 2.68                        | 18.15                        | 40.10           |

2.3. Sample preparation of model pile
The purpose of this test is to study the influence of hole arrangement and taper on the generation and dissipation of excess pore water pressure. In order to make the pipe pile more easily, stainless steel material is selected for pipe pile sample preparation, considering that a little soil will enter the pipe pile cavity during pile sinking, resulting in soil plug effect. Therefore, the bottom of the model pile is sealed with steel to prevent excessive soil from entering the inner cavity of the pipe pile.

In this indoor test, there are five types of pipe piles selected, as shown in Figure 2. According to various pile type hole arrangement methods, the pile body is bored at intervals of 200mm along the pile length direction, and three layers of pile holes are respectively arranged at 200mm, 400mm and 600mm pile lengths.
Table 2 Pipe Pile Types

| Pipe diameter(mm) | Aperture(mm) | Hole arrangement mode       | Taper size |
|------------------|--------------|----------------------------|------------|
| A                | 107          | Stellate opening            | 1/70       |
| B                | 107          | Bidirectional opening       | 1/70       |
| C                | 107          | Unidirectional opening      | 1/70       |
| A1               | 107          | Stellate opening            | 1/80       |
| A2               | 107          | Stellate opening            | 1/90       |

a-1/70 star-shaped perforated pipe pile; b-1/70 bidirectional perforated pipe pile; c-1/70 unidirectional perforated pipe pile; d-1/80 star-shaped perforated pipe pile; e-1/90 star-shaped perforated pipe pile;

Fig. 2 Schematic diagram of tapered-perforated tubulaire pipe pile structure with various layout control methods and conicity

2.4. Burying of pore pressure gauge

The location of the buried hole pressure gauge is very important to the data acquisition and research analysis, therefore, nine LY - 350 pore water pressure gauge were used in this test, with numbers for U1 - U9 respectively, buried in the soil of different position, horizontal distance respectively pile body 3 D, 6 D, 9 D (D is model of pipe pile diameter is 107 mm), vertical buried three layer respectively 400 mm distance from the soil surface, 600 mm, 800 mm, the concrete layout diagram as shown in figure 3. Fill in the first model to the embedded depth, according to the scheme using the tape measure, measure, determine the pile pile body position, use prepared fine sand for leveling, hole pressure gauge is placed, the wire side toward the DH - 3818-2, set with a side of porous stone level up, surface covered with fine sand, wire embedded in the soil is S type, buried pore water pressure gauge and continue to fill on the surface, and when filling, don't produce too much disturbance to its, guarantee the stability of pore pressure meter level, lest affect testing accuracy, to reset test equipment before the test, to ensure that the test data is relatively accurate, which is advantageous to the result analysis.
2.5. Test steps
The main route of the test: determining the position of the pile sinking → determining the scale of the pile body → determining the direction of the hole opening of the pile body → data collection during the piling process (leveling the data before collection) → keeping the soil moisture content stable (covering the soil surface of the model box with impermeable film during the test) → data collection after the piling is completed. The test process was carried out in strict accordance with the Pore Water Pressure Test Procedure [10] (CECS55:93), and the test process was designed for 60h.

3. Analysis of the change law of excess pore water pressure dissipation in time and space

3.1. Analysis of changes with time
Based on the whole test, the variation law of excess pore water pressure with time during pile sinking of different types of pipe piles is analyzed, as shown in Figure 4, which is the relationship curve of excess pore water pressure in soil around the pile with time caused by five different types of pipe piles during static pressure pile sinking.
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b

c

d
Fig. 4 Relationship curve of pore water pressure with time for various types of pipe piles

A- star-shaped pipe pile with 1/70 taper; B- pipe pile with bidirectional opening and taper of 1/70; C- pipe pile with one-way opening and taper of 1/70; D- star-shaped pipe pile with 1/80 taper; E- pipe pile with star-shaped opening and taper of 1/90;

From each curve it can be found in figure 4 the change tendency is roughly similar, which can be concluded that in the process of static pressure sinking pile, as the pile sinks, the soil around the pile is subjected to the compressive action during the pile sinking process, and the pore water pressure in the soil cannot be dissipated in time, so a large pore water pressure is generated instantly, that is the excess pore water pressure is accelerating (0 to 3 h) time (relation curve of the slope increases gradually, the shaking increase type), at the end of the pile driving process, piled pore water pressure within 4-60 (h) gradually dissipate over time (curve slope gradually decreases, and in a slow type)

3.2. The relationship with depth

From a local point of view, the variation of pore water pressure in various types of pipe piles with depth is analyzed. According to the observation and analysis in fig. 5, when the radial distance R is constant, the excess pore water pressure increases with the increase of depth H, and the dissipation rate becomes smaller and smaller (the tangent slope of the curve decreases gradually).

Fig. 5 Variation law of excess pore water pressure with depth
3.3. The relationship with radial distance

It can be concluded from the observation and analysis in Figure 6 that at the same time, when the depth $H$ remains unchanged, the size of excess pore water decreases with the increase of radial distance, and the dissipation rate becomes smaller and smaller (the tangent slope of the curve decreases gradually).

![Variation law of excess pore water pressure with radial distance](image)

**Fig. 6** Variation law of excess pore water pressure with radial distance

3.4. Analysis of excess pore water pressure dissipation rate

Excess pore water pressure dissipation rate refers to the difference between the peak value of excess pore water pressure and the value of excess pore water pressure at a certain time point in dissipation stage after the peak value occurs. That is,

$$\text{Dissipation rate} = \frac{\Delta p}{p_{\max}} = \frac{|p_{\max} - p|}{p_{\max}}$$

In which $\Delta p$ represents the difference between the peak value of excess pore water pressure and the peak value of excess pore water pressure at a certain time point in the dissipation stage after the peak value appears; $p_{\max}$ represents the peak value of excess pore water pressure; $p$, represents the value of excess pore water pressure in static pile driving for $t$ hours.

According to the formula, the excess pore water pressure dissipation rate of each group of pipe piles at 20h, 40h and 60h is obtained. By comparing and analyzing the excess pore water pressure dissipation rate of five groups of pipe piles at each time point, the difference of excess pore water pressure dissipation of each pipe pile is obtained.

| Pore water pressure dissipation rate of each group (%) | Time    | Pile type                          | 20h  | 40h  | 60h  |
|-----------------------------------------------------|---------|------------------------------------|------|------|------|
|                                                     | 20h    | 40h    | 60h    |
| Star hole, taper 1/70                               | 25.52% | 43.31% | 64.27% |
| Cross hole, taper 1/70                              | 32.81% | 45.03% | 62.97% |
| Unidirectional opening, taper 1/70                  | 29.54% | 43.47% | 61.76% |
| Star hole, taper 1/80                               | 25.16% | 40.11% | 59.60% |
| Star hole, taper 1/90                               | 25.93% | 45.28% | 61.95% |

It can be seen from the data in Table 3 that the dissipation rate of excess pore water pressure of all kinds of perforated pipe piles increases continuously in (20-60h), and then the area is stable. Observed
that under the condition of the same pile diameter and taper, the dissipation effect of excess pore water pressure in the star-shaped cross-over mode is the best, while under the condition of the same pile diameter and hole arrangement mode, the dissipation effect of excess pore water pressure in time and space of 1/70 pipe piles is the best.

4. Concluding remarks
1) Five different types of pipe piles will have certain excess pore water pressure around the pile in the process of static pressure sinking. Excess pore water pressure rises sharply within 0-3h and decline slowing in 4-60h.

2) When the radial distance remains constant, the excess pore water pressure will increase with the increase of depth, and its dissipation rate will gradually decrease. When the depth remains constant, the excess pore water pressure decreases with the increase of radial distance, and the dissipation rate becomes slower and slower.

3) By comparing three hole arrangement modes, i.e., one-way piercing, two-way piercing and star-shaped piercing, it is found that the dissipation rate from large to small is star-shaped piercing, two-way piercing and one-way piercing. However, in the case of star-shaped piercing, 1/70 taper is the best, followed by 1/90 and 1/80 is the worst. The average dissipation rate of five kinds of conical-perforated column composite pipe piles is more than 60% on average, which indicates that conical-perforated column composite pipe piles can effectively improve the dissipation rate of excess pore water pressure in the process of static pressure pile sinking.

References
[1] Zhongmiao ZHANG. Pile Foundation Engineering [M]. Beijing: China Building Industry Press, 2007
[2] Jinyou YANG, Jinbo LEI, Yongqiang ZOU, Zhuangzhuang LI. A kind of bamboo-shaped two-way perforated cone-column composite pipe pile [P]. Jiangxi: CN 208056052 U, November 6, 2018.
[3] Kelin CHNE, Jinbo LEI, Tengsheng YUE, Xing ZHOU. Thoughts of Alleviating the Disadvantage Effect of Static Sinking-Pile [J]. Applied Mechanics and Materials, 2015, 4075.
[4] Tengsheng LEI, Jinbo LEI, Xing ZHOU, Fei YI, Yousun LIAO, Kelin CHEN, Jun LIU, Kang YANG. Laboratory model test analysis of excess pore water pressure dissipation of bored pipe pile driven by static pressure [J]. Industrial Architecture, 2016, 46(04):83-87.
[5] Jinbo LEI, Menghua WAN, Fei YI, Jinyou YANG. Analysis of excess pore water pressure dissipation of bored pipe pile driven by static pressure [J]. Industrial Architecture, 2016, 46(11):111-116+121.
[6] Menghua WAN, Jinbo LEI, Jun LIU. Analysis of influencing factors of excess pore water pressure dissipation of static pressure bored pipe pile [J]. Chinese Journal of Underground Space and Engineering, 2019, 15(02):465-472.
[7] Kelin CHEN, Jinbo LEI, Tengsheng YUE, Xing ZHOU, Thoughts of Alleviating the Disadvantage Effect of Static Sinking-Pile [J]. Applied Mechanics and Materials, 2015, 4075.
[8] Tianhui ZHOU, Qiang CONG. Analysis of technical points of concrete tapered pipe pile [J]. Low Temperature Building Technology, 2005(03):93-94.
[9] Aiqun GONG. Application and Practice of Prestressed Concrete Pipe Pile [D]. Harbin Engineering University, 2007.
[10] Cecs55: 93 test regulations for pore water pressure.