Model test and analysis of soil displacement of cone-perforated column composite pipe pile under static pressure

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Abstract. In view of the fact that there is relatively little research on soil squeezing effect of conical-perforated column composite pipe pile, the lateral displacement and surface uplift of conical-perforated column composite pipe pile after single pile is pressed into soil are observed by static pressure pile sinking method, and the change law of soil lateral displacement and surface uplift during pile sinking is analyzed. It is found that the lateral displacement increases with the increase of pipe pile driving depth, and when the pipe pile is fully penetrated, the soil lateral displacement ends, and the influence range of soil lateral displacement is 2 days.

1. Introduction

When the prestressed concrete pipe pile [1] is sunk in saturated cohesive soil, it is easy to cause the pile body to lift up, which leads to the increase of pile foundation settlement, the decrease of bearing capacity, the vertical displacement and radial displacement of the soil in the process of static pressure pile sinking, and the large pore water pressure has adverse effects on the surrounding structures.

In order to effectively reduce the adverse impact on the surrounding environment caused by static pressure pile driving, the tapered-perforated column composite pipe pile proposed according to the literature [2] not only inherits the wedge-shaped pipe pile, but also changes the cross-sectional size of the pile body, improves the side friction of the pile and increases the area replacement rate, so as to reduce the damage to the surrounding caused by the displacement of the soil during static pressure pile driving, and also solves the problems that the wedge-shaped pipe pile has limited treatment depth, more molds for processing and inconvenient pile connection. However, there is still a lack of relevant experimental observation and analysis on the influence of soil displacement and surface uplift of conical-perforated column composite pipe pile, and only theoretical derivation is made for the soil displacement of wedge-shaped pipe pile and perforated pipe pile [8-12]. Therefore, in this paper, the soil displacement and surface uplift caused by static pressure sinking of conical-perforated column composite pipe pile are observed and analyzed by model test method, and the test results have certain guiding significance for analyzing and demonstrating conical-perforated column composite pipe pile 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.

![Figure 1. Model box schematic.](image)

1-2m×2m×0.01m steel plate; 2-1.5m×0.5m×0.01m tempered glass; Tempered glass 3-1.5m×0.4m×0.01m; 4-1.5mx1.5mx2m angle steel frame.

2.2. Soil sample preparation
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/water content/% | Density ρ (g/cm³) | Coefficient of compressibility a_v (Mpa⁻¹) | Modulus of compressibility E_s (Mpa) | Internal friction angleφ (°) | Cohesive force 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 pile sinking depth, radial distance and pipe pile style on soil displacement. In order to make the pipe pile convenient, 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, the selected pipe pile is shown in Figure 2. The pile body is bored every 200mm along the pile length direction, and three layers of pile holes are arranged at 200mm, 400mm and 600mm respectively.

![Table 2. Pipe pile type.](image)

| Pipe diameter (mm) | Aperture (mm) | Hole arrangement mode            | Taper size |
|-------------------|--------------|----------------------------------|------------|
| A                 | 107          | Unidirectional opening           | 1/70       |
2.4. Testing program
Due to the limited laboratory equipment, in order to measure the displacement of soil in the process of static pressure piling of conical-perforated cylindrical pipe piles, a layer of lime is laid every 10cm soft clay in the process of filling the model box, and the inside of tempered glass is wiped clean during the laying of lime. 1.5m×1.5m plastic film engraved with 1cm square grid is stuck on the outside of toughened glass, and the displacement change of lime around pile is observed through transparent toughened glass. And the camera is used to photograph the change of soil around the pile every 10cm after static pressure sinking. Finally, using the image ranging technology, taking the grid depicted on tempered glass as a reference, the displacement information of lime on the photographed picture is read, and the displacement data of soil at a certain depth around the pile is obtained.

Steel nails with a height of about 10mm and a diameter of 1mm are arranged every 50mm in the pile diameter direction to observe the uplift height of soil surface during static pressure pile driving.

3. Analysis of variation law of soil displacement
3.1. Relationship with radial distance
As shown in fig. 4, the lateral displacement of conical-perforated column composite pipe pile under three different pile sinking depths is observed. It is found from the observation of figs. (a)-(c) that the lateral displacement decays with the increase of radial distance under the condition of constant depth, and the farther the radial distance from the pile edge is, the faster the decay rate is, showing a logarithmic relationship.
Figure 4. (a) (b) (c) Data diagram of soil displacement and lateral displacement of cone-perforated column composite pipe pile driven by static pressure.
3.2. Relationship with depth
From the observation and analysis in Figure 5, it can be found that the lateral displacement of soil increases with the increase of depth, and the horizontal displacement is also small due to the small influence range of penetration at the pile tip, so the influence range at 0-1.5D is neglected, so the influence range of lateral displacement is from 2d to 6d.

![Figure 5. Soil displacement varying with depth.](image)

4. Height of surface uplift
From the analysis and observation in Figure 6, it can be found that when observing the surface uplift, it is found that the soil around the pile moves down vertically during the static pressure of the pile, and starts to uplift at 0.5D beside the pile. With the increasing depth of pile sinking, the uplift amount also increases. When the depth of pile sinking remains constant, with the increase of radial distance, the uplift of soil surface decreases continuously until it reaches 0, the influence range is about 6 days, and the maximum uplift is about 2.3D days.

![Figure 6. Displacement and uplift of soil with depth variation.](image)
5. Conclusions
1) With the increase of penetration depth, the static pressure sinking of conical-perforated column composite pipe pile increases, and the lateral soil displacement ends when the pile body is fully penetrated.

2) The lateral displacement of tapered-perforated column composite pipe pile decays according to logarithmic law, and the farther the radial distance from the pile edge, the faster the decay rate.

3) Because the horizontal displacement at the pile tip is somewhat different, the impact of penetration in this range is small, resulting in small horizontal displacement, so the influence range at 0-1.5D is ignored, and the influence range of lateral displacement is from 2d to 6d.

4) In the process of static pressure pile driving, the amount of soil uplift increases with the increase of depth, but decreases with the increase of radial distance when the depth is constant, until it reaches 0, and the soil surface uplift ranges from 0.5d to 6d in the pile diameter direction.

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