Model Test on the Excess Pore Water Pressure of Pipe-pile with Hole during the Static-sinking Pile

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Abstract. Based on the analysis of the static sinking-pile, the pipe-pile with holes technique is put forward, which can alleviate the disadvantage effect of static sinking-pile effect. The model tests have been carried out for it, and the time-space change rule of the environmental effects of the analysis of excess pore water pressure dissipation have also been studied during the static sinking-pile of the pipe-pile with hole. The excess pore water pressure will be dissipated with the time extending during the static sinking-pile of the 3 kind of holes model of pipe-pole with hole. On the condition of the same depth, the effective radius is more bigger, i.e., the distance between the observation dot and the center of the pile is more farther, the excess pore water pressure will be more smaller; On the condition of the same effective radius, the depth of the observation dot is more bigger, the excess pore water pressure will be more bigger; On the contrast to the pipe-pole without hole, to some extent, the pipe-pile with hole can reduce the maximum of excess pore water pressure, and expedite the excess pore water pressure dissipation. This result can be provided the credible test base for the technique effect of the pipe-pole with holes expediting the excess pore water pressure dissipation and reducing the maximum of it.

Introduction

Soft soil has been widely distributed in the coastal area of China; some inland areas also contain rich lacustrine sedimentary soil. If engineering construction were performed in these area, it will be encountered the problem of soft soil foundation. The prestressed concrete pipe pile has been widely applied in soft ground treatment as a kind of rigid pile, such as railway, highway road engineering and so on. In the early 1980s, the prestressed concrete pipe pile was first applied in railway connecting engineering [1] and road widening project [2] in abroad. From the late of the 1990's of the last century, the prestressed concrete pipe pile was also beginning to be used in highway [3-5] and high-speed railway [6], and so on, in the soft soil subgrade engineering in the domestic. The engineering practice proved that the prestressed concrete pipe pile is suitable for the treatment of soft soil foundation under embankment load as a vertical reinforcement of composite foundation. It has become a widespread choice of pile type in the soft soil treatment.

As everyone knows that the damage of soil structure caused by the extrusion of pile in the process of precast pile sinking, and there will produce high excess pore water pressure around the pile body. So a series of serious impact will be brought to the surrounding environment [7]. Because of the existence of this phenomenon, the attention of the issue of environmental effects and the influence of pile sinking will be having known for a long time. But due to the complexity of this problem, so far, it is still not very clear about the adverse effects of pile sinking effect on the surrounding environment, especially, the problem of the precast pile sinking effect. There are many engineering accidents for this reason. At the same time, static pressure pile sinking technology has many advantages, such as little noise, high quality of pile, pile sinking speed, and so on. Therefore, this technology has been more and more widely used in the engineering construction. In order to avoid engineering accident of pile sinking, the new ways will be

explored to effectively reduce the adverse effects of static-sinking pile effect on the surrounding environment, further research on the environmental effects of static-sinking pile.

Technology of Pipe-pile with Hole Proposed

There are a lot of treatment measures for the excess pore water pressure of static-sinking pile at present, such as setting of stress release holes, reasonable arrangement of sequence of pile sinking, and controlling the speed of pile sinking, etc. However, these measures are carried out mostly from the viewpoint of the external environment, and not from the pile body structure to improve itself. Zhou Qian and others set many grooves around the concrete pile body, and observed the excess pore water pressure of this process of pile sinking, eventually found those grooves around the pile has accelerated dissipation of excess pore water pressure [8]. Liu Han-long and others proposed X-shaped cast-in-situ concrete pile, and a pile driving effect test was carried out. In the end, they found that the pile could well reduce the lateral displacement of soil [9]. The above phenomenon indicates that: it could effectively reduce the adverse effects of pile driving effect on the surrounding environment by changing the shape or the structure of pile.

The prestressed concrete piles used in highway, railway and other soft soil subgrade project, its main purpose is used to control the subgrade settlement deformation , but it is much more to control the amount of subgrade settlement after construction. In the process of construction of static pressure pile sinking, the water are moved into most of the inner cavity of pipe pile, especially in soft soil engineering of some large water content, much water are moving into the inner cavity of pipe pile. The reason for this phenomenon is mainly due to the excess pore water generated during the process of pile sinking. The phenomenon of excess pore water moving into the inner cavity of pipe pile can accelerate the excess pore water pressure time-space dissipation and reduce its maximum, increase the settlement of roadbed during the construction, reduce the settlement of roadbed after construction, and other factors can play a positive role. In other words, it is to reduce the negative impact of static pressure pile sinking which affect on the surrounding environment and enhance the treatment effect of prestressed pipe pile in soft soil foundation, as much as possible to exhaust the soil pore water during the construction of static pressure pile sinking. In order to let excess pore water which is generated in the process of pile sinking much actively flow into the inner cavity of pipe pile, at that time, considering the embankment load is generally not too high and the difference between pile and soil in rigidity by a large, so the shape and structure of existing conventional prestressed concrete pipe pile can be reconstructed. The technology of the pipe pile with hole is put forward by making some hole in the pipe pile wall, a number of patents related to the aspects of design and production of pipe-pile with hole have been obtained [10-13].

The sand soil is almost always used for model test of static pressure pile sinking nowadays[14,15],so, this will cause the fact that the model test results cannot truly reflect the change of the actual situation of time-space dissipation of excess pore water pressure when static pressure pile sinking in soft soil foundation. Moreover, whether the pipe-pile with hole or not is also directly related to the effects of static pressure pile sinking on the surrounding environment. In fact, opening holes in the pipe-pile body would be able to effectively reduce the adverse effects of static pressure pile sinking which affects on the surrounding environment. However, it’s not clear how the effectiveness of the reducing. Therefore, this paper will be carried out the research of model test on the excess pore water pressure of pipe-pile with hole during the static-sinking pile in order to explore accelerating the excess pore water pressure dissipation during the process of the static-sinking pipe pile with hole. All of these model test research have provided a reliable testing foundation for its theoretical research and engineering application.

Model Test

Test Equipment and Apparatus

Model Box. Angle steel and tempered glass is used to make a box model which size is 1m×1m×1m. The specific production process is: using the angle iron which model is 5 welded to be an angle iron bracket which size is 1m×1m×1.4m. The angle iron bracket be welded on the central of a steel plate which size is 2m×2m×0.01m. Each surface of the model box which was spliced up by 2 toughened glasses

whose size is 0.5m×0.5m×0.01m, and those toughened glass can be put into the angle iron bracket just right. In order to ensure the free water of soil can flow from the seams, those seams of toughened glass was not sealed. As shown in figure 1 and figure 2.

Fig. 1 Model Box Device

Fig. 2 The Place of Steel Glass Seams

Model of Pile. Considering that the test-pile-sinking model effect of pipe-pile with hole is mainly to study the influence of pile body shape on the dissipation of excess pore water pressure and the material of pile, the material of pile is not the mainly influencing factors. PVC-conduit was chosen to make the model of pile in this paper. Geometric proportion of pile model is n=6, length of pile model is 800mm, diameter of pile model is 75mm, and diameter of hole is 10mm. In order to prevent excessive soil into the cavity of pipe-pile model, scotch tape used to seal the bottom of the pile model in this paper. As shown in figure 3. There are three kinds of arranging hole of pipe-pile with hole, such as single direction-perforated pipe-pile with hole, double direction-perforated pipe-pile with hole, radial direction-perforated pipe-pile with hole, and pipe-pile without hole. The spacing of arranging hole of pipe-pile is 200mm (in the longitudinal direction). The concrete way of arranging hole of pipe-pile is shown in figure 4.

Fig. 3 Model of Pipe-pile with Hole Made by PVC-conduit

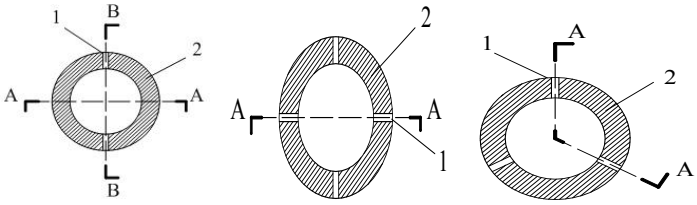

Fig. 4 Three Kinds of Pipe-pile with Hole (Note: 1-hole; 2-pile cliff)

Selection and Preparation of the Soft Soil Foundation. Soil of this model test was taken from soft soil area of Nanchang. And these soils have been carried on a series of processing:

(1) Air-dried soil

These soils have been put to a wide range of tile in the test chamber after soil been retrieved. At the same time, ensure that the indoor air circulation to make the soil to dry naturally.

(2) Soil been pounded

In order to ensure the uniformity of the final soil, soil was mashed into clods by a particle size less than 2cm.

(3) Stirring the soil

Clods were put into an iron pan and particle size of clods is less than 2cm, adding water and stirring well. In order to satisfy the test requirements, "Technical Specification for Construction of Highway Subgrade (JTG F10-2006)" division of moisture content of natural soft soil is greater than 35% for the standard, soil moisture content was controlled at 50%.

(4) Filling soil

Iron plate was placed on soil surface, and then placed the rated weight of concrete blocks on the iron plate, compacting those soils for 24 hours. These are carried out in the process of soil filled in the model box. Fill model box with soil in three days.

(5) Consolidation of the soil

Iron plate was placed on soil surface, and then placed the rated weight of concrete blocks on the iron plate after the model box was filled with soil. Until the soil surface is smooth. Its purpose is to let the soil consolidation, and to maintain the stability of pore water pressure. It could be believed that the soil consolidation effect is good after 7 days.

(6) Soil resilience

The concrete test block and iron plate were taken down, and waterproof plastic film was used to seal on the soil surface inside the model box after completion of soil consolidation. This is to ensure the stability of the soil moisture content. In order to take soil which had been compressed into a state of over-consolidated rebound to a stable state, let these soils without load standing for 7 days. Then a test of the static pressure pile sinking can be performed.

Pore Water Pressure Gauge Buried and Its Data Collection

Data acquired by pore water pressure type KYJ-30D and vibrating wire readings instrument type 609A.

In order to ensure the smooth flow of the intake of the instrument and prevent mud clogged intake, producing a good permeable bag as the artificial percolation layer whose diameter is 8cm. After sieving the obtained sand, take the above 1mm sieve layer and the below 2mm sieve layer of sand particles into the bag. As shown in figure 5.

Fig. 5 Measurement Equipment for Excess Pore Water Pressure (including percolation layer)

Put the pore water pressure gauge with percolation layer into clear water soak for 24 hours to the saturated state in order to make the front cover of the pore water pressure gauge is filled with water without air bubbles before laying the instrument. It's to make fine sand of the filter layer is fully saturated.

In the radial symmetry position around the model of pile layout 12 pore water pressure gauge type KYJ-30D when the soil in the model box landfill to a predetermined height. Those positions from U1 to U12. As shown in figure 6.

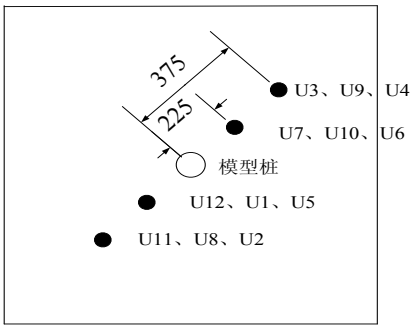

Fig. 6 The Layout for Measurement Equipment for Excess Pore Water Pressure

In order to prevent water in the cavity overflow, the intake of pore water pressure gauge was putted upwards. The specific location of pore water pressure gauge such as shown in Table 1.

Tab.1 The Place of Excess Pore Water Pressure

	H=200mm	H=400mm	H=600mm
L=225mm	U7、U12	U10、U1	U6、U5
L=375mm	U3、U11	U9、U8	U4、U2

(Note: *L* represents the effective radius of a measurement point to the axis of the pile model in this table)

Test Procedure

(1) Determining the position of the pile

In order to determine the center position of the soil surface as the predetermined center position of pile sinking, the waterproof plastic film was removed.

(2) Setting scales on the pile

In order to control the speed of pile sinking and monitoring the process of pile sinking, inscribing a marker on the model of pile each 10cm. The data of excess pore water pressure was collected when the pile sank to a predetermined position.

(3) Determining the original frequency module

A set of data collected by reading instrument type 609A within half an hour before the pile sinking, the data come from those 12 pore water pressure gauge, as the original frequency module F0.

(4) Determining the direction of opening in pile model

As much as possible to make the opening direction of the pipe-pile with hole is consistent to the layout direction of the pore water pressure gauge. The pile tip was putted on the center of model box and keeping the pile end just touched the soil surface, so it could be ready for sinking.

(5) Data acquisition in the process of pile sinking

Applying certain load on pile head and keeping the pile at the speed of 5 cm/min for static pressure pile sinking. Collected once excess pore water pressure data Fi when pile sank down 10cm every time. Test piles will be divided into eight times to completely sink in the soil.

(6) Maintain the stability of the soil moisture content

In order to ensure the stability of the soil moisture content, using waterproof plastic film sealed on the soil surface inside of the model box after completing pile-sinking. This is to prevent the soil moisture in the rapid loss by evaporation.

(7) The data collection after pile sinking completed

In the early stage of the completed pile-sinking, variation of the excess pore water pressure in the soil is obvious. Therefore, excess pore water pressure data Fi collected once every 10 minutes at the first hour after pile-sinking completed. After that, excess pore water pressure data Fi collected once every 20 minutes within 2 to 7 hours after pile-sinking completed. Due to start at 8 hours after pile-sinking completed, the change of excess pore water pressure in soil tends to slow. So, data collected once every two hours until the first 60 hours after pile sinking complete.

Time-space Analysis of Dissipation of Excess Pore Water Pressure

Analysis of the Rule of Excess Pore Water Pressure Generation and Dissipation

This test had measured the change of excess pore water pressure of four kinds of piles in the process of pile driving and a period of time after pile-sinking completed. Those four kinds of piles including the following pile types: pipe-pile without hole, single direction-perforated pipe-pile with hole, double direction-perforated pipe-pile with hole, radial direction-perforated pipe-pile with hole. The curve of each measuring point of the creation and dissipation of excess pore water pressure u and time t are as shown in figure 9 to figure 12.

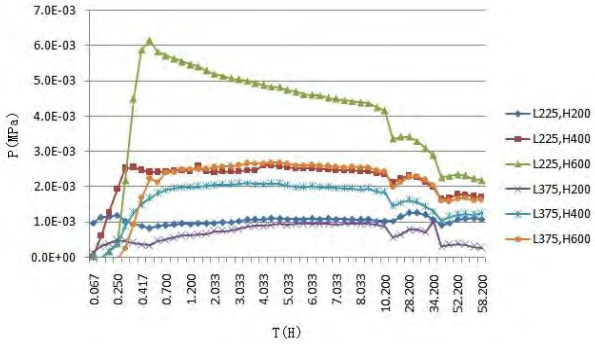

Fig. 9 u-t Curves of Pipe-pile without Hole

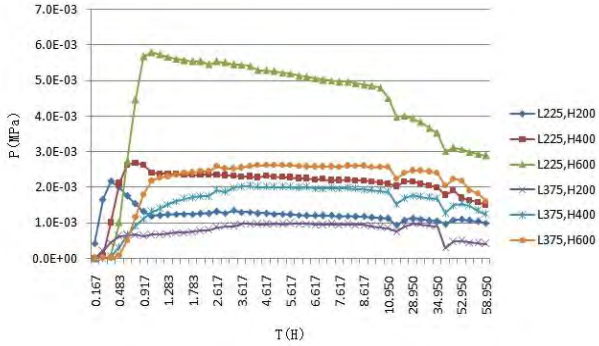

Fig. 10 u-t Curves of Single Direction-perforated Pipe-pile

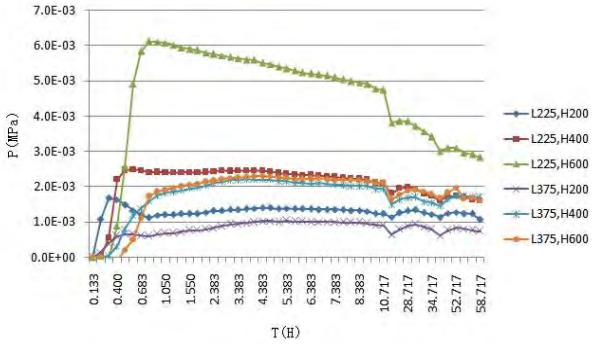

Fig.11 u-t Curves of Double Direction-perforated Pipe-pile with Hole

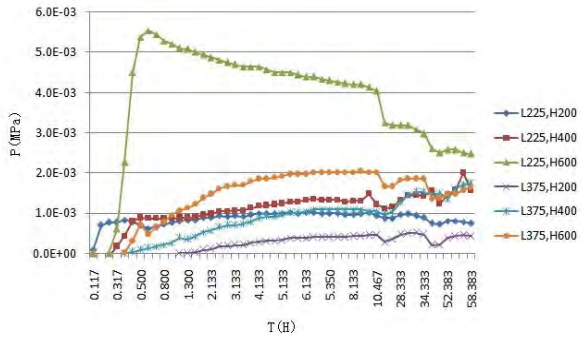

Fig.12 u-t Curves of Radial Direction-perforated Pipe-pile with Hole

These above figures show that: In the process of model pile into the soil, each measuring point measured those relationship curves of excess pore water pressure and time can basically reflect the general process of excess pore water pressure generation and dissipation.

Specific process is as follows: In the early stages of pile-sinking, as along with the process of pile-sinking, the soil around the pile was squeezed tight, pore water in the soil can't get dissipation in time, resulting in excess pore water pressure generated in the soil, so that the relation curves of excess pore water pressure and time rises. After finishing the process of pile-sinking, as along with the gradual dissipation of excess pore water pressure in the soil, making the relation curves of excess pore water pressure and time declined gradually.

The Relationship between the Excess Pore Water Pressure and Effective Radius

The relationship curves of excess pore water pressure and time of three different depth position of single direction-perforated pipe-pile with hole. Those positions are in depth 200mm, 400mm and 600mm, and the distance of each position from the pile axis is not the same. As shown in figure 13 to figure 15.

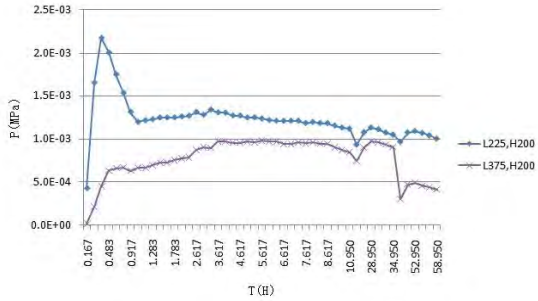

Fig.13 u-t Curves of Single Direction-perforated Pipe-pile with Hole(H=200mm)

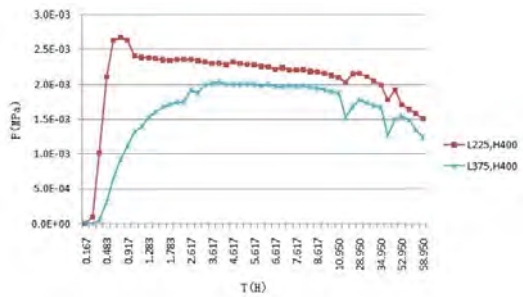

Fig.14 u-t Curves of Single Direction-perforated Pipe-pile with Hole(H=400mm)

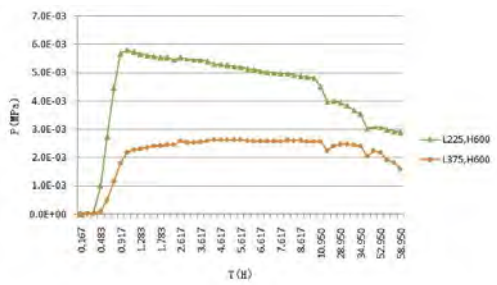

Fig. 15 u-t Curves of Single Direction-perforated Pipe-pile with Hole(H=600mm)

These above figures show that: On the condition of the same depth, the effective radius is much bigger, i.e., the distance between the observation dot and the center of the pile is much farther, the excess pore water pressure will be smaller. When the depth is 200mm, the excess pore water pressure peak is 1.267E-03MPa and 9.956E-04MPa of those points which in the effective radius for 225mm and 375mm respectively. When the depth is 400mm, the excess pore water pressure peak is 5.793E-03MPa and 2.039E-03MPa of those points which is in the effective radius for 225mm and 375mm respectively. When the depth is 600mm, the excess pore water pressure peak is 5.793E-03MPa and 2.631E-03MPa of those points which is in the effective radius for 225mm and 375mm respectively.

It shows that the excess pore water pressure decreases with the increase of the effective radius from the pile axis. This phenomenon is consistent with the general rule of excess pore pressure generation and dissipation.

The Relationship between the Excess Pore Water Pressure and the Depth

These will be discussed the relationship curves between excess pore water pressure and three different depth position of single direction-perforated pipe-pile with hole. These positions are in depth 225mm, 375mm and 600mm, and the distance of each position from the pile axis is not the same. As shown in figure 16 and figure 17.

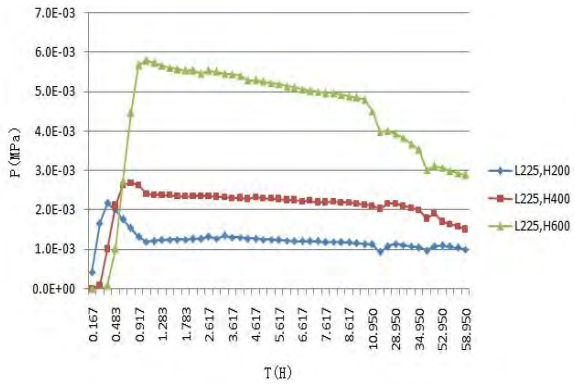

Fig. 16 u-t Curves of Single Direction-perforated Pipe-pile with Hole(L=225mm)

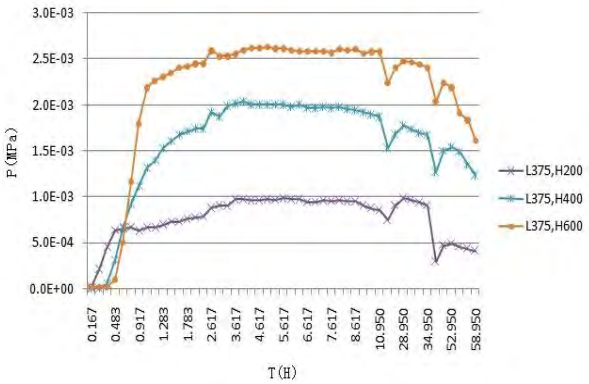

Fig. 17 u-t Curves of Single Direction-perforated Pipe-pile with Hole(L=375mm)

These above figures show that: On the condition of the same effective radius, the depth of the observation dot is much bigger, the excess pore water pressure will be bigger. When the effective radius is 225mm, the excess pore water pressure peak is 2.174E-03MPa and 2.674E-03MPa and 5.793E-03MPa of those points which in the depth for 200mm and 400mm and 600mm respectively. When the effective radius is 375mm, the excess pore water pressure peak is 9.838E-04MPa and 2.039E-03MPa and 2.631E-03MPa of those points which in the depth for 200mm and 400mm and 600mm respectively.

It shows the rules of the excess pore water pressure increases with the increase of the depth. This phenomenon is consistent with the general rule of excess pore pressure generation and dissipation.

The variation regularity of the curve *u-t* of other two kinds of pipe-pile with hole is similar to the single direction-perforated pipe-pile with hole. And it would be no more repeat.

Analysis of the Characteristics Values of Excess Pore Water Pressure of Different Pile Types

The peak value of excess pore water pressure of measuring points after four kinds of model of pile had been pressed into the soil is as shown in table 2. The degree of reduction for the peak value of excess pore water pressure of measuring points is as shown in table 3, which is based on the peak value of excess pore water pressure of pipe-pile without hole. The data of excess pore water pressure dissipation after 58 hours as shown in table 4. In those tables, the effective radius of a measurement point to the axis of the pile model represented as *L*, and the depth of each point represented as *H*.

Tab.2 The Maximum of Excess Pore Water Pressure (MPa)

Measuring point/ Category	L225mm/ H200mm	L225mm/ H400mm	L225mm/ H600mm	L375mm/ H200mm	L375mm/ H400mm	L375mm/ H600mm
No hole	1.267E-03	2.600E-03	6.146E-03	9.956E-04	2.108E-03	2.682E-03
Single direction	2.174E-03	2.674E-03	5.793E-03	9.838E-04	2.039E-03	2.631E-03
Double direction	1.674E-03	2.493E-03	6.120E-03	1.038E-03	2.217E-03	2.301E-03
Radial direction	1.024E-03	2.005E-03	5.541E-03	5.165E-04	1.748E-03	2.045E-03

Tab.3 The Reducing of the Maximum of Excess Pore Water pressure (MPa)

Measuring point/ Category	L225mm/ H200mm	L225mm/ H400mm	L225mm/ H600mm	L375mm/ H200mm	L375mm/ H400mm	L375mm/ H600mm
Single direction	71.62%	2.86%	-5.74%	-1.18%	-3.29%	-1.93%
Double direction	32.15%	-4.11%	-0.42%	4.26%	5.15%	-14.22%
Radial direction	-19.19%	-22.88%	-9.83%	-48.12%	-17.10%	-23.77%

Tab.4 The Number of Excess Pore Water Pressure after 58 Hours (MPa)

Measuring point/ Category	L225mm/ H200mm	L225mm/ H400mm	L225mm/ H600mm	L375mm/ H200mm	L375mm/ H400mm	L375mm/ H600mm
No hole	1.083E-03	1.700E-03	2.179E-03	2.662E-04	1.244E-03	1.636E-03
Single direction	1.002E-03	1.503E-03	2.882E-03	4.112E-04	1.231E-03	1.612E-03
Double direction	1.062E-03	1.599E-03	2.839E-03	7.407E-04	1.708E-03	1.594E-03
Radial direction	7.455E-04	1.569E-03	2.475E-03	4.254E-04	1.748E-03	1.636E-03

These above tables show that: The peak value of excess pore water pressure of measuring points and the data of excess pore water pressure dissipation after 60 hours of those three pipe-pile with hole both smaller than the pipe-pile without hole. Take an example of single direction-perforated pipe-pile with hole. The peak value of excess pore water pressure of those four points reduced 5.74%, 1.18%, 3.29% and 1.93% respectively relative to the pipe-pile without hole. Those four points are in the location of L225mm/H600mm, L375mm/H200mm, L375mm/H400mm and L375mm/H600mm respectively.

This suggests that the pipe-pile with hole would reduce the peak value of excess pore water pressure of the soil which around the pile in a certain extent, and expediting the excess pore water pressure dissipation. Individual measured data of the pipe-pile with hole increased relative to the pipe-pile without hole. Investigate its reason, it may be caused by uneven distribution of the soil and some parts of the soil is not dense.

Table 2 and table 3 show that: Although the number of hole is different for three pipe-pile without hole type, but the corresponding point of excess pore water pressure data are very similar under a variety of conditions. Investigating its reason, there are two possible reasons:

1) Opening hole in the pile body has an effect on the dissipation of excess pore water pressure of the soil near the hole on one side, because the position of the measuring point is fixed, and the number of holes of

three pipe-pile with hole type near the measuring point is fixed too. Therefore, the measured data results in relatively close.

2) The diameter of hole is too small, and the number of hole is not enough.

The diameter of hole is too small relative to the size of pile body. Leading to the influence of hole for excess pore water pressure is not big enough. Therefore, the measured data results in relatively close.

Conclusion

(1) The relationship curve of measured excess pore water pressure u and time t of pipe-pile with hole is basically consistent with the curve of pipe-pile without hole. This phenomenon is consistent with the general rule of excess pore pressure generation and dissipation. On the contrast to the pipe-pole without hole, to some extent, the pipe-pile with hole can reduce the maximum of excess pore water pressure, and expediting the excess pore water pressure dissipation.

(2) When the pipe-pile with hole sinking, and on the condition of the same depth, the effective radius is much bigger, i.e., the distance between the observation dot and the center of the pile is much farther, the excess pore water pressure will be smaller, On the condition of the same effective radius, the depth of the observation dot is much bigger, the excess pore water pressure will be bigger.

(3) Under the experimental conditions in this paper, the ability of these three pipe-pile with hole type is relatively close in the aspect of reducing the maximum of excess pore water pressure and expediting the excess pore water pressure dissipation. But it is still need further study on the way of arranging hole.

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