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Study on Bearing Characteristics and Application of Variable-section Nested Pile

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Abstract. In foundation pit support, when the ground conditions are soft on the top and hard on the bottom, the "end-susupended pile" is often used.However, this support method has the problems of increasing the temporary occupation, the amount of pit excavation and backfill, etc. For this reason, this paper proposes a variable section pile. Through numerical simulation, the bearing characteristics of piles with different nesting lengths, rock-socketed depth and pile diameter ratios are investigated and applied in the field. The study shows that: the nesting length is not linearly related to the shear stress; different depths of rock embedment and different bending stiffness of the pile body will affect the location of the maximum displacement. By applying the variable section piles in the field and monitoring the horizontal displacement of the pile top, the support effect of the variable section piles is verified, which can provide reference basis for similar projects.

Keywords: pile, foundation pit, numerical simulation, support, monitoring

1. Introduction

With the acceleration of urbanisation, the shortage of construction land has become a problem in current urban construction. In order to alleviate the shortage of construction land, people gradually began to expand to the underground space, which promotes the development of foundation pit engineering.For the upper-soft and lower-hard strata, the support is mostly used by the "end-susupended pile", and a number of scholars have carried out researches on the support of the "end-susupended pile".

Xu et al. [1] have all conducted research on the end-susupended pile support. Zhao et al. [2] carried out a study on the stability effect of blasting and excavation of the lower rock layer on the supporting structure of the end-susupended pile, and established a simplified algorithm that can simulate the dynamic response of the supporting structure to the blasting load based on numerical software. Bai et al. [3] focused their study on the dynamic response of different parts of the pile body of the end-susupended pile to the moving load, which can provide a reference for the construction of similar projects in the future.Tian et al. [4] analysed the change rule of pile force and deformation with the depth of embedded rock and the width of reserved rock shoulder.

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In the construction of end-susupended piles, there are problems such as increasing the temporary occupation, the amount of pit excavation and backfilling, which bring great trouble to the pit construction. Therefore, a new type of variable section pile needs to be studied. Variable section piles are able to bear more axial force, bending moment and shear force because their shapes are very consistent with the characteristics of axial force, shear force and bending moment, and the superstructure is larger than the substructure.

Several scholars [5-7] found that variable section piles can improve the horizontal bearing capacity compared with equal section piles, and the reasonable layout of the variable section position can save the pile material and improve the horizontal resistance. Wang et al. [8] et al. used field test and theoretical derivation to investigate the horizontal bearing characteristics of large diameter variable section piles. Hu et al. [9] et al. obtained the calculation method of pile internal force and pile deformation based on linear elastic foundation reaction. Fang et al. [10] analysed the bearing performance and bearing mechanism of horizontally loaded variable section piles by using the method of indoor model test and theoretical calculations, and the results showed that the optimum variable section location of variable section piles was located between 33.3% and 46.7% of the pile length.

However, there are fewer applications of variable section piles at present, and there are no variable section supporting piles suitable for upper soft and lower hard strata yet. Therefore, this paper will use numerical simulation to study the bearing characteristics of variable-section nested pile support in soil-rock combination pits under different conditions. And the application monitoring is carried out in the field to verify the bearing mechanism.

2. Numerical modelling

In geotechnical engineering, the load structure method is often used to study the force and deformation characteristics of underground structures. In this study, the numerical simulation software GTS NX is used to investigate the bearing characteristics of variable section nested piles using the load structure method.

2.1. Establish model and mesh division

This numerical simulation mainly studies the bearing characteristics of the pile body. The length of the pile body is 21 m. The 1D element is used to model the upper concrete pile and the lower steel pipe pile. The nested part is realized by changing the parameters such as the elastic modulus of the object.In order to study the bearing characteristics of the pile body in detail, the model is divided into ten units per meter, which is divided into 210 units.

2.2. Parameters of model material

In the numerical simulation modeling, there are three main materials : concrete pile, nested pile and steel pipe pile. The basic parameters of the three materials are shown in the following table.

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Table.1 Basic parameters of different materials

	Elastic modulus(GPa)	Poisson ratio	Gravity(kg/m^3)	Diameter(m)
Concrete pile	30	0.2	2400	1
Nested pile	35	0.21	2562	1
Steel pipe pile	66	0.23	3480	0.4

2.3. Boundary conditions and loading conditions

In this study of pile bearing characteristics, the soil constraints on the inner and outer sides of the pile are simulated by curved springs, and horizontal constraints are set on the top of the pile, and horizontal and vertical constraints are set on the bottom of the pile. The load is mainly divided into soil load, self-weight load and internal support. And only the bearing characteristics of the pile are studied, so the load is applied at the same time.

3. Analysis of results

3.1. Nesting lengths

The different nested lengths of small piles will affect the bearing characteristics of the pile body, so the research is carried out for different nested lengths. The experiment was divided into three groups : nested length 1 m, 2 m, 3 m, as shown in Fig.1.

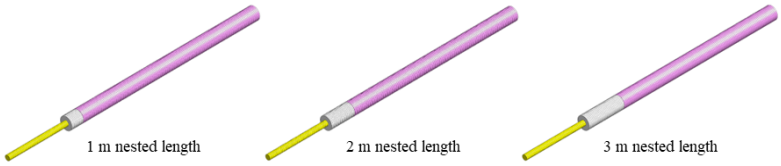

Figure 1. Different nesting lengths

The change of pile displacement under different nested lengths is shown in Fig.2. It can be seen from the diagram that the displacement trends of the three groups of tests are roughly the same, with only slight differences in the results. When the nested length is 1 m, the pile displacement is the largest, which is 4.0 cm. When the nested length is 2 m and 3 m, the pile displacement of the two is 2.5 cm and 3.1 cm, respectively, and the difference is small. Considering the actual construction, for every 1 m increase in the nested length, the construction difficulty will increase, so the nested length of 2 m should be the first choice for construction.

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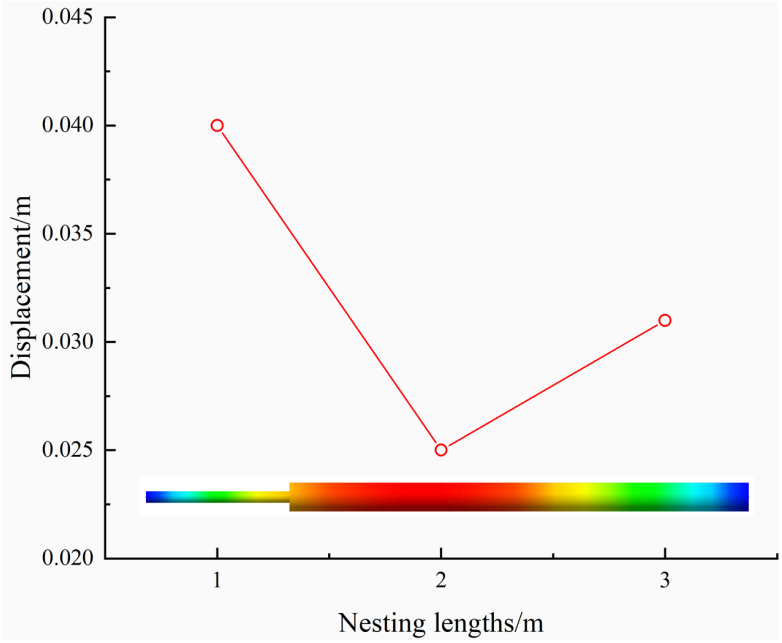

Figure 2. Numerical simulation results for different nesting lengths

3.2. Rock-socketed depth

Different rock-socketed depths of concrete piles will affect the bearing characteristics of piles, so research is carried out on different rock-socketed depths. The test was divided into three groups : rock-socketed depth of 1 m, 2 m and 3 m.

The maximum displacement of the pile under different rock-socketed depths is shown in Fig.3. The displacement difference between the three rock-socketed depths is small. When the rock-socketed depth is 1 m, the pile displacement is the largest, which is 2.51 cm ; when the rock-socketed depth is 3 m, the pile displacement is the smallest, which is 2.31 cm.

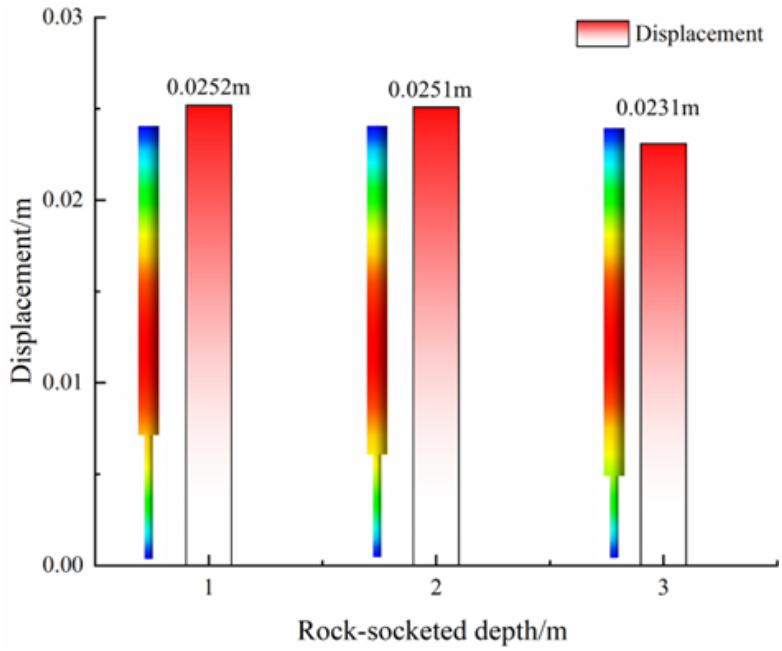

Figure 3. Different rock-socketed depth

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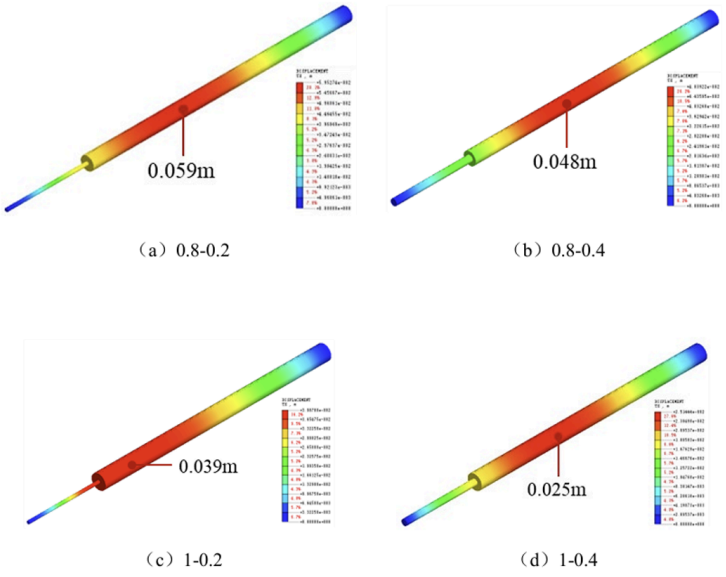
3.3. Pile diameter ratio

The pile diameter ratio of variable section nested pile will affect the bearing characteristics of pile body, so the research is carried out for different pile diameter ratios. The experiment was divided into three groups :

Table 2. Different pile diameter ratio dimensions

No.	Concrete pile diameter	Steel pipe pile diameter
1	0.8m	0.2m
2		0.4m
3	1m	0.2m
4		0.4m

The displacement deformation of different pile diameter ratios is shown in Fig.4. Under different pile diameters, the bending stiffness of concrete piles and steel pipe piles is different, so the displacement of piles is different. When the diameter of the concrete pile is 1 m and the diameter of the steel pipe pile is 0.2 m, due to the large difference in stiffness between the two, the maximum displacement occurs at the nesting, which is 3.9 cm. When the diameter of the concrete pile is 0.8 m and the diameter of the pipe piles pile is 0.2 m, the overall stiffness is the smallest, so the displacement is the largest, which is 5.9 cm. When the diameter of the concrete pile is 1 m and the diameter of the steel pipe pile is 0.4 m, the overall stiffness is the largest, so the displacement is the smallest, which is 2.5 cm.



（a）0.8-0.2　（b）0.8-0.4

（c）1-0.2　（d）1-0.4

Figure 4. Variation of pile displacement under different pile diameter ratios

4. Field application and monitoring

4.1. Overview of the test site

Hanchuan Road Station is the fourth station of the second phase of Qingdao Metro Line 2. It is connected to Hechuan Road Station in the west and Dongchuan Road Station in the east, with a total

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length of 267 m. The strata in the field area where Hanchuan Road Station is located are plain fill, silty clay, gravel sand, cohesive soil gravel sand, strongly weathered granite, moderately weathered granite and slightly weathered granite from top to bottom, and the rock surface of the left and right lines fluctuates greatly. The base plate of the station is basically located in the strongly weathered and slightly weathered granite layer. The excavation range of the main body of the station contains thick fill layer, gravel sand and cohesive soil gravel sand layer.

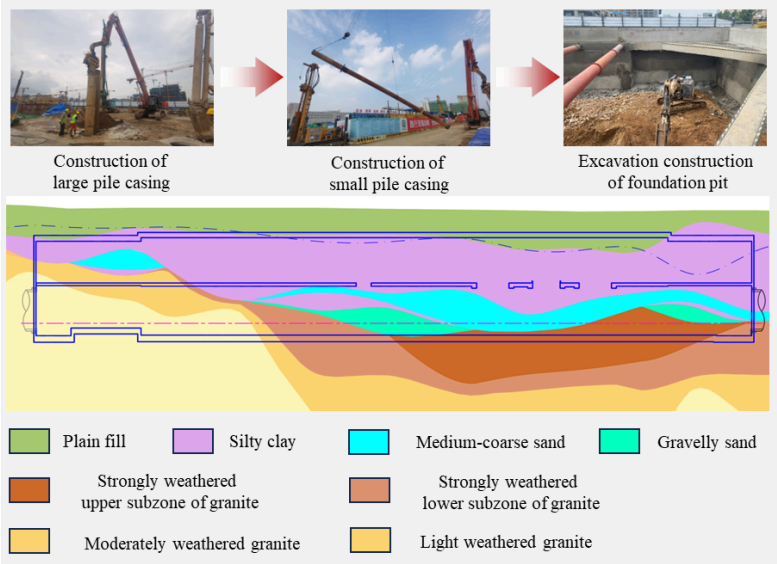

Figure 5. Variable cross-section nested pile site geology

The thickness of the soil layer of the test section is about 8m.Combined with the above numerical simulation results, the size of the variable cross-section pile is : the length of the concrete pile is 10m, the diameter is 1m, the length of the steel pipe pile is 10m, and the diameter is 0.4m.Among them, the steel pipe pile is embedded in the concrete pile for 2m, and the steel pipe pile is embedded in the rock layer for 2m.

Horizontal displacement measuring points are set on the top of 4 variable cross-section piles, and the horizontal displacement of pile top under different excavation stages is monitored by total station.

4.2. Analysis of monitoring results

The horizontal displacements of the four measuring points in different excavation stages are shown in Fig.6. It can be seen from the diagram that in the early stage of excavation, with the increase of excavation depth, the horizontal displacement of pile top increases continuously ; when the excavation reaches 4m, the horizontal displacement gradually tends to be gentle.

When excavating from the soil layer to the rock layer, because the stiffness of the steel pipe pile is small, the overall stability is affected, so the overall displacement will suddenly increase, but it is still within the safe range. When the excavation is deep in the rock stratum, the displacement of the pile top tends to converge, and the final maximum displacement is stable at about 20 mm.

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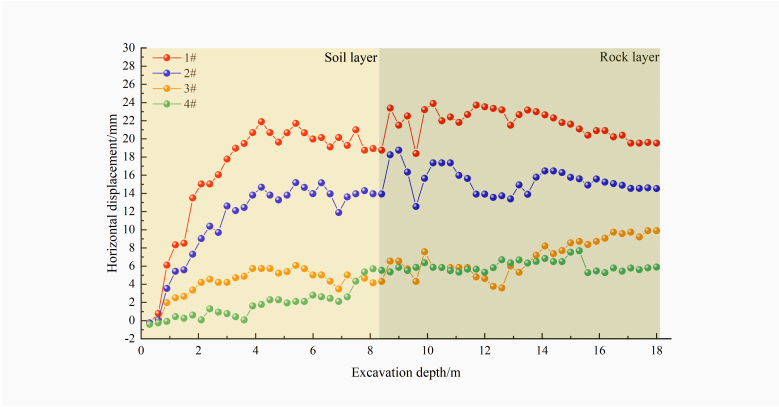

Figure 6. Change in horizontal displacement of pile top

5. Conclusion

In this paper, a variable section nested pile is proposed, and the bearing characteristics of the variable cross-section pile are studied by numerical simulation. Finally, it is applied in the field. The main conclusions are as follows :

(1) The embedded length of a variable cross-section pile will affect the deformation of the pile body. When the embedded length is 2 meters, it can ensure both safety and construction convenience.

(2) Different rock-socketed depths lead to different areas of the maximum displacement acting on the pile. When the rock-socketed depth is small, the maximum displacement will affect the nesting place. As the rock-socketed depth increases, the maximum displacement gradually shifts to the concrete pile part.

(3) Under different pile diameter, the bending stiffness of large pile and small pile is different, so the pile displacement is different. When the stiffness difference between the two is large, the maximum displacement occurs at the nesting ; the size of the overall stiffness affects the size of the displacement.

(4) The variable cross-section pile is applied in the field, and the horizontal displacement of the pile top is monitored. The monitoring results show that the displacement of the variable cross-section pile top is within the safe range, and the stability of the foundation pit is good.

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