Numerical simulation of double-row pile-NPR anchor cable support based on ABAQUS

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Abstract. With the development of urban architecture, research on deep foundation ditch support is of great significance. The current anchor cables used for foundation ditch support are all traditional steel materials, which have the disadvantages of high cost and serious waste. NPR (Negative Poisson's ratio effect) anchor cables have the characteristics of high strength, high toughness, and resistance to large deformation. Currently, they are widely used in tunnel support engineering, but research on deep foundation ditch support is rarely involved. Therefore, this article uses ABAQUS software to establish a numerical model of double row pile-NPR joint support to explore the effect of NPR anchor cables on deep foundation ditch support. Research has shown that: (1) The front piles share a larger soil pressure, while the rear anchor piles play a dual role in supporting soil and pulling anchors. (2) The NPR anchor cable increases the horizontal pull-out resistance of the double row pile support structure, limits the horizontal displacement of the support structure, and enables the foundation ditch to meet its deformation requirements, indicating that it can effectively support the foundation ditch.

Keywords: Foundation ditch; NPR; ABAQUS; Double row pile.

1. Introduction

Entering the 21st century, China's new urbanization construction process continues to accelerate, construction land continues to reduce, rational use of underground space resources not only can ease traffic, but also is conducive to alleviate the tension of urban land. Therefore, the development prospects of underground engineering are broad [1]. Foundation ditch engineering has the characteristics of strong comprehensiveness and complex system. In the process of excavation and construction of the main body of the foundation ditch of high-rise buildings, under the action of unloading caused by the excavation of the soil and the gravity of the soil itself, not only the original stress distribution will change, but also will cause the uplift of the bottom of the ditch and the displacement of the side wall of the foundation ditch [2,3]. At present, an important way to analyze the excavation process and supporting structure of foundation ditch is still theoretical analysis, but thanks to the development of computer technology, simulation and analysis of foundation ditch engineering has been widely used. The foundation ditch support scheme is optimized through theoretical calculation and numerical simulation analysis, which can effectively restrain the deformation of the surrounding soil caused by foundation ditch excavation and ensure the safety of the surrounding buildings. Compared with other support schemes, the double-row pile anchor support structure has a small displacement, eliminates the need to set up and remove the internal support process, has high construction efficiency, large lateral stiffness, and the engineering cost is slightly larger than that of the single-row pile anchor structure, which is widely used in engineering practice [4]. In the mid-forties of the last century, Peck [5], a well-known British geotechnical research expert, analyzed the relationship between the displacement of the retaining wall and the internal force state of the soil by using the load response spectrum and the excavation stability record table for the internal forces generated during the excavation of the foundation ditch. In the late fifties of the last century, the geotechnical scholar Bjemun [6] had in-depth research on the deformation around the foundation ditch, the settlement and the uplift, and at the same time derived many theories and methods such as earthwork balance theory, foundation deformation theory, earth pressure calculation method and so on. In the field of rock and soil deformation and failure research, the scholar Daris [7] used the

ultimate equilibrium theory of soil at the end of the sixties of the last century to conduct in-depth failure studies on a number of rock masses that are assumed to have a certain stiffness, and obtained the basic theory of rock and soil deformation to failure. Clough [8] analyzed the relationship between rock and soil deformation and foundation ditch failure in the two-dimensional coordinates established in advance, and used the finite element calculation method to preliminarily simulate the stress-strain curve between the supporting structure and the rock-soil interface. At the same time, China's research on the analysis of endogenous forces of geotechnical engineering and its supporting structure is in its infancy, in the mid-eighties of the last century, due to the continuous increase of China's reform and opening up, urban land began to become stretched, in this context, the development of China's high-rise buildings and deep foundation ditch support engineering has gradually entered the fast lane.

In the process of geotechnical engineering support, traditional prestressed anchor cables cannot resist large deformations of soil and rock, leading to problems such as tension, failure, and failure. Therefore, it is of great significance to explore a new type of anchor cable (NPR anchor cable) with extraordinary mechanical properties, which can provide high-strength support while also stabilizing the foundation ditch.

2. Model building

2.1. Geological conditions

The geological conditions of deep foundation ditch are complex, which are divided into five types of soil layers (Table 1), and the specific geological conditions and related parameters are shown in Figure 1.

Table 1 Physical and mechanical parameters of soil layer

Stratum No	Stratum name	Internal friction angle/(°)	Mass Density(kg/m³)	Poisson's ratio
1	Coarse sand	30	2000	0.3
2	Silty soil	11.76	1930	0.25
3	Fine sand 1	28	1900	0.25
4	Fine sand 2	32	2070	0.25
5	Plain soil	10	1650	0.38

2.2. Supporting structure arrangement

The front row of piles is made of Φ1200@1600 bored piles, the pile length is 32.8m, the pile diameter is 0.8m, and the pile spacing is 2.0m, and the rear piles are made of Φ1200@3200 bored piles, the pile length is 22.8m, the pile diameter is 0.8m, the pile spacing is 2.0m, and the concrete material grade is C35. NPR anchor cables are set up behind the front row of piles, one pile and one anchor, the anchor cable is set to 6Φ15.2@1000, the inclination angle is 22.5 degrees, 7 anchor cables are arranged, the elastic modulus of NPR anchor cable is 2.05×11Pa, and the Poisson's ratio is -0.126, as shown in Figure 1.

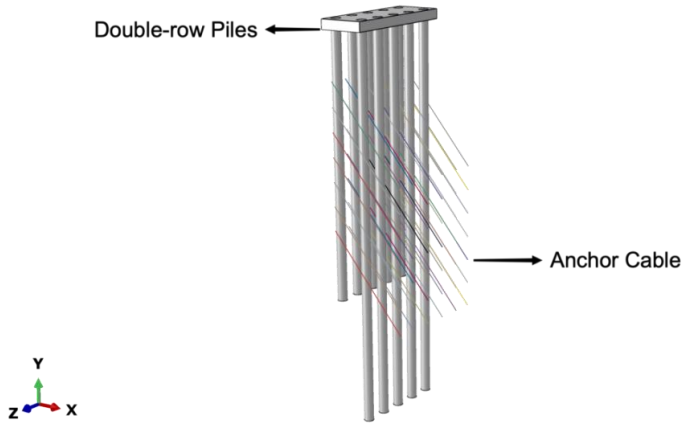


Figure 1 Model diagram of prestressed anchor cable for double row piles

2.3. NPR Anchor Cable Composition and Mechanical Properties

NPR anchor cable is a combination structure of NPR structure and PR anchor cable [9]. During the tensile process, NPR anchor cable has excellent deformation force and high energy absorption (Figure 2).

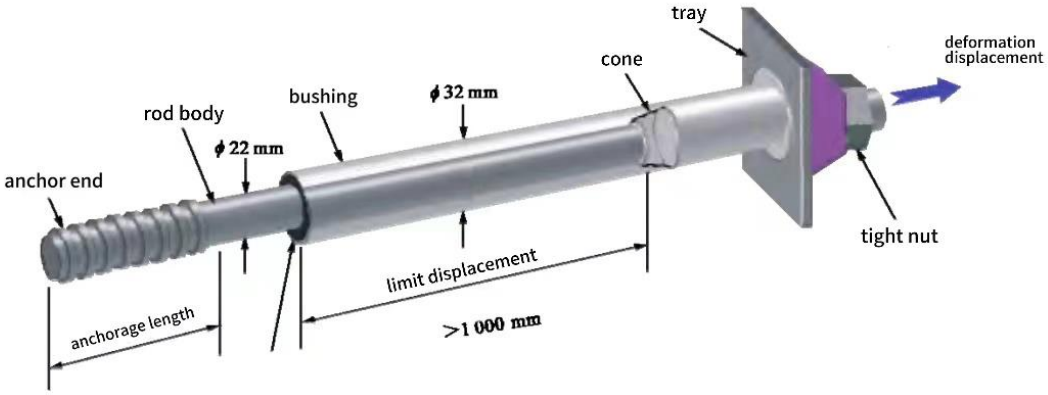


Figure 2 NPR Anchor Principle [9]

The mechanical properties of NPR anchor cables were explored by using the NPR anchor cable static tensile experimental system [10-11], which provided a scientific basis for the optimization of the performance of NPR anchor cables (Figure 3).

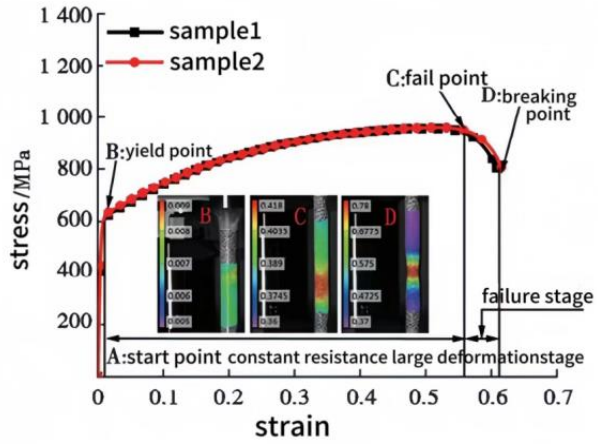


Figure 3 Static tensile test curve of NPR anchor cable [11]

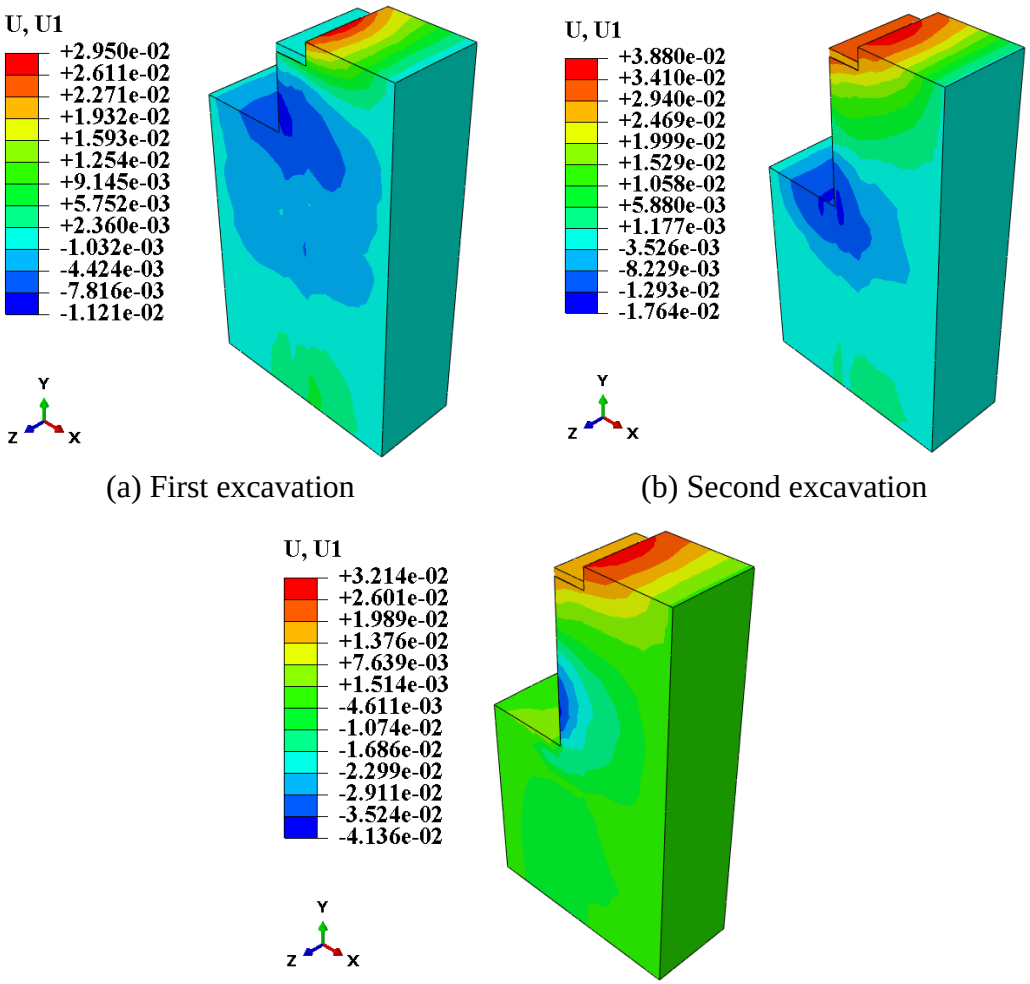
It can be seen from the whole experimental process that the NPR anchor cable shows ideal constant resistance characteristics in the 2m range, the constant resistance slip distance is 1830mm, which fully proves that the anchor cable can have the characteristics of large deformation, constant resistance and large absorption energy in the static stretching process, and also indirectly proves that when the landslide body is slowly deformed, the static tensile energy acting on the anchor cable can be fully absorbed by the anchor cable and converted into its deformation energy, so that the soil can develop in a balanced manner.

3. Analysis of results

In the process of numerical simulation, the first step to perform initial geostress balance is to apply gravity load to the soil, and then define the density of the soil layer to apply soil gravity through gravity acceleration; The second step is to define the displacement and stress boundary conditions of the model, and submit the work under gravity load. The third step is to apply the obtained initial stress field and gravity load together to the soil model, so as to obtain an initial geostress equilibrium that does not violate the yield criterion. Secondly, use the unit deletion algorithm for soil excavation.

3.1. Horizontal displacement

After excavation of the soil, the foundation ditch and piles experience horizontal displacement, with opposite directions of displacement. After the excavation of the first layer of soil, the horizontal displacement value of the pile is 29.50mm, and the horizontal displacement of the foundation ditch is 11.21mm. After the excavation of the second layer of soil, the horizontal displacement value of the pile increased to 38.80mm, and the horizontal displacement of the foundation ditch increased to 17.64mm. After applying NPR anchor cables, continue to excavate the third layer of soil. The horizontal displacement value of the pile is 32.14mm, and the horizontal displacement value of the foundation ditch is 41.36mm. It can be seen that there is a positive correlation between the excavation depth and the horizontal displacement of the foundation ditch and piles. The effective application of anchor cables hinders the displacement of piles and controls the horizontal displacement of the foundation ditch. During the construction process, real-time monitoring of the horizontal displacement of the foundation ditch should be carried out to ensure construction safety (Figure 4).



(a) First excavation (b) Second excavation

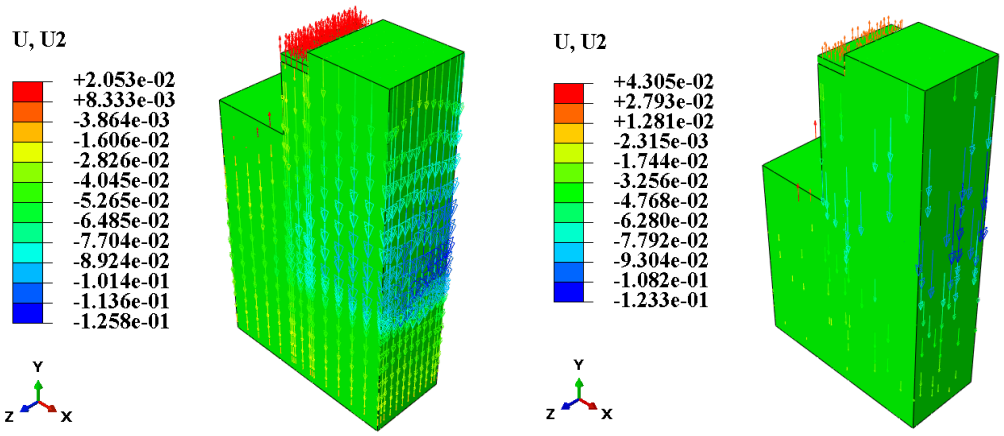
(c) Third excavation

Figure 4 Horizontal displacement

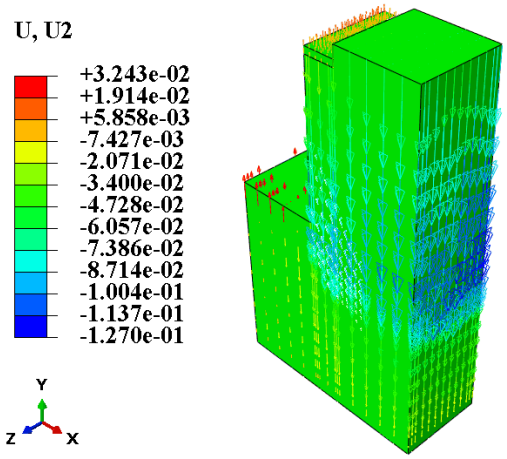
3.2. Vertical displacement

Figure 5 shows the vertical displacement cloud map of the soil. It can be seen from the figure that after excavation, the displacement direction between the pile and the foundation is upward, and the soil around the foundation ditch sinks. After the excavation of the first layer of soil, the pile displacement was 20.53mm, the base rebound was 8.33mm, and the settlement value of the soil around the foundation ditch was 12.58mm. After the excavation of the second layer of soil, the displacement of the pile increased to 43.05mm, and the base rebounded by 27.93mm. Afterwards,

NPR anchor cables were applied, and after excavation of the third layer of soil, the pile displacement decreased to 32.43mm, and the rebound amount of the foundation ditch was 19.58mm. It can be seen that after applying NPR anchor cables, the displacement areas of the pile and foundation remain stable.



(a) First excavation (b) Second excavation



(c) Third excavation

Figure 5 Vertical displacement

4. Conclusion

This article proposes a new deep excavation support method using double row piles combined with NPR anchor cables, and conducts numerical simulation research on a certain deep excavation project. The research results indicate that:

(1) During the excavation process of the foundation ditch, both the foundation ditch and the piles experience displacement. The vertical displacement direction is the same, while the horizontal displacement direction is opposite. In addition, settlement of the soil around the foundation ditch requires displacement monitoring of adjacent buildings during construction.

(2) After applying NPR anchor cables, the vertical displacement of the foundation ditch and piles tends to stabilize. This indicates that NPR anchor cables can effectively improve the stability of foundation ditchs.

(3) As the excavation depth increases, the horizontal displacement between the foundation ditch and piles increases. It is necessary to strengthen monitoring during construction to ensure construction safety.

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