Numerical Simulation of Anchorage Force and Deformation of Pile in Deep Mixed Soil Foundation Pit

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Abstract. Foundation pit support plays a pivotal role in the process of urbanization in our country. The emergence of new support forms has dramatically enriched the diversity of foundation pit support. The pile-anchor support structure is a new type of support structure that has emerged with the development of foundation pit engineering in recent years. However, the current theoretical research on the foundation pit pile-anchor support system often cannot meet the improvement of the on-site construction technology level, and many calculation models based on assumptions cannot truly reflect the relationship between the foundation pit support structure and the soil layer, and the piles The stress and deformation characteristics of the anchor support system itself[1]. With the rapid economic development and the continuous expansion of the urban construction scale, the foundation pit problem caused by high-rise buildings and underground traffic has become a hot issue in civil engineering. Foundation pit accidents often occur due to design errors. 3D numerical simulation can better simulate the whole process of foundation pit excavation and support, and provide displacement and internal force prediction data for actual construction, thereby effectively preventing foundation pit accidents. Midas finite element software performs numerical simulation analysis of deep foundation pit support. Through further analysis of vertical deformation and horizontal displacement, the deformation value of the supporting structure is extracted and compared with the measured deformation value to guide the deformation control design and engineering monitor.

Keywords: bottomless foundation pit; pile and anchor support; numerical simulation; finite element method.

1. Background and significance of numerical simulation

At the end of the 1970s, our country opened to the outside world, its economy thrived, and its comprehensive national strength jumped, becoming the second-largest economy globally. While the economy is prosperous, the urban coverage rate has also increased significantly. Many people have poured into central cities to seek more excellent development opportunities, leading to the saturation of urban space. With the continuous development of underground engineering construction, the excavation depth of the foundation pit is getting higher and higher, which requires advanced construction technology and the calculation theory that keeps pace with the times. Eventually, the discipline of foundation pit engineering was developed. Due to the complex influencing factors of foundation pit engineering, the influence of stratum conditions, surrounding buildings (structures), pit side overload, temperature and precipitation, and other factors on the foundation pit engineering should be comprehensively considered, and the appropriate enclosure structure and construction process should be selected. The "new infrastructure" is in full swing, and the construction of many engineering projects is also in full swing. This paper takes the deep miscellaneous filling foundation pit project as the research object, collects relevant information through field practice and research, and selects the appropriate support form according to the actual project[2]. The support section is checked with the design calculation software, and the selected area is numerically analyzed with the MidasGTS software. Finally, the simulation results are compared with the monitoring data to verify the reliability of the numerical simulation results to provide a reference for similar projects in the future.

2. Development of foundation pit engineering in our country

The study of foundation pit engineering has a long history, and the stress and deformation caused by excavation have always been the focus of foundation pit engineering research. In the past, the scale of foundation pits was generally small, and most of them were the foundations of houses, basements, or municipal pipe trenches. The design and construction experience of large-scale foundation pits was still lacking in engineering. After entering the 21st century, foundation pit design theory and construction technology have been further developed and improved. Real-time construction monitoring has been implemented, and information has been used to guide design and construction. At the same time, research and development of anti-analysis, environmental control, and risk prevention systems and application software. Around 2000, our country promulgated several national industry standards and local standards for foundation pit engineering, summed up the research results and practical experience of foundation pit engineering in our country in the past ten years. It provided specific guidance for future foundation pit engineering design and construction significance. The "Technical Specifications for Construction Foundation Pit Engineering Monitoring" (GB50497-2009) promulgated in 2009 comprehensively revised the industry standards for foundation pit engineering, improved the experience, achievements, and accident lessons of foundation pit engineering construction in my country, and improved the foundation pit engineering technology in my country. They reached a new higher level.

3. Characteristics and principles of bottomless foundation pit pile-anchor support structure

3.1. Analysis of the characteristics of the pile-anchor support structure

Pile-anchor support is a foundation pit support that combines slope protection piles with single anchors and multiple anchors. The pile-anchor support system uses the friction force between the anchoring section of the bolt and the soil layer and the support force provided by the support pile embedded in the soil layer to keep the entire support structure stable. The pile-anchor supporting structure is composed of supporting piles and bolts, and its characteristics are:

1) The pile-anchor support body can be excavated vertically, and the construction site conditions are relatively low. For example, when the density of buildings around the city is large, this support method can be used.

2)The pile-anchor support structure is composed of anchor rods and support piles. The top of the piles is set with crown beams. The middle waist beams are set to control the deformation of the pile body jointly; the anchor rods actively control the deformation and displacement of the support structure by applying to prestress. That reduces the embedded depth of the supporting piles, makes the force of the row piles and the anchor rods more reasonable, and satisfies a broader range of support requirements.

3)Anchor rods are used instead of inner supports, the underground construction site is comprehensive, the construction is convenient, and the anchor rods are set up and constructed in parallel with the excavation of the foundation pit to improve the construction efficiency[3].

3.2. Research on the principle of pile-anchor support system

The study believes that the force on the free end of the anchor rod is transmitted to the anchoring section through the anchor rod. Due to the friction between the anchoring section and the soil layer, the anchoring section can transmit the external force to the surrounding soil layer through the friction force between the anchoring sections. To achieve the purpose of reducing stress. Natural soil has formed a stable state under long-term weathering and gravity. During manual or mechanical excavation, the original mechanical balance is destroyed. To not affect human beings' average production and construction activities, support and reinforcement measures must be taken to form a new stable state of mechanical balance. During the excavation process, the soil tends to slide

downward, and the deformation of the soil is controlled under the action of the support system. At the same time, the support system is affected by the release pressure of the soil; that is, the support system is deformed. After being adjusted by the mechanical model, the support system generates different forms of force to control the deformation of the soil, thereby forming a relationship between the soil, and the support structure interaction the interaction, between soil and the supporting structure, is essentially the process of mechanical equilibrium when the soil is in a stable state.

3.3. Numerical Simulation of Pile Anchor Supporting Structure in Deep Foundation Pit

The depth of the foundation pit to be analyzed is 10 m, and the inclination angle of the foundation pit is at a right angle. The excavation is divided into five steps, and the excavation depth of each step is 2 m. The length, width, and height of the model used in the study are 60 cm, 20 cm, and 30 cm, respectively, and then the plane strain model is used for calculation, and the Mohr-Coulomb criterion is used as the soil failure criterion. This model has no pile-anchor elements, only pile and anchor elements. Therefore, in order to better realize the combination of these two methods, we must first determine the intersection point of the two, then delete the node, and then establish a new node according to the boundary conditions of the node so that the changes in force and displacement are respectively transmitted to Anchor elements and pile elements[4].

The safety of the foundation pit increases with the length of the bolt. When the inclination angle of the anchor rod is kept at 30°, the effective length of the anchorage will appear; beyond this length, continue to increase the length of the anchor rod, and the safety factor of the foundation pit will not increase accordingly. In other bolt inclination calculations, there is no concept of bolt length. Unlike single bolt reinforcement, in the actual pile-anchor reinforcement process, in addition to the role of the anchor, it will also be reinforced by the supporting pile. Compared with other curves, the slope of 20° is the largest, indicating that under the condition of this inclination angle, the change of the bolt length has the most significant influence on the stability coefficient of the foundation pit. When the length of the anchor rod is 2-6 m, the slope of the formed curve is the largest, and the slope of the curve is gentle at 6-12 m, indicating that the correlation between the safety factor of the foundation pit and the length of the anchor rod is small.

4. The basic idea of the finite element method

The finite element method provides a more reasonable and effective method for theoretical calculation. The numerical solution has specific difficulties for a continuum composed of numerous elements. The finite element method is to discretize the structure or continuum and then use the structure matrix to solve it. First, the continuum is discretized into finite elements, the W nodes between each element are connected, and the actual force is equivalent to the force on the nodes. Secondly, according to the similarity between elements, a simple function relationship is selected to approximate the displacement component law, and the relationship between the nodal element force and displacement is established; finally, the special relationship between the nodal force and displacement of each element is synthesized to obtain W Equations with unknown nodal displacements are then solved by W to obtain the nodal displacement components. The finite element method simplifies the infinite freedom continuum into a finite degree of freedom element set so that the complex problem W can be numerically solved. Of course, with the refinement of the unit and the increase in the number of units, the manual calculation becomes very difficult and must be done with the aid of a computer.

4.1. Establish a finite element model

A three-dimensional model was established by using P1AXIS3D finite element software. The calculation results showed that: (1) the stress-strain relationship of the soil conformed to the hardened soil constitutive theory, and the profiled steel supporting piles, beams, and wooden panels conformed to the linear elastic constitutive relationship; (2) the profiled steel supporting piles and The elastic

constitutive relation of the plank is ideal; ③ This paper does not consider the time effect of excavation of the foundation pit. According to the construction conditions, the flexible wood panel is installed after the excavation of the first floor is completed. Since the foundation pit adopts an asymmetrical support structure, only half of the foundation pit needs to be modeled and analyzed, as shown in Fig. 1.

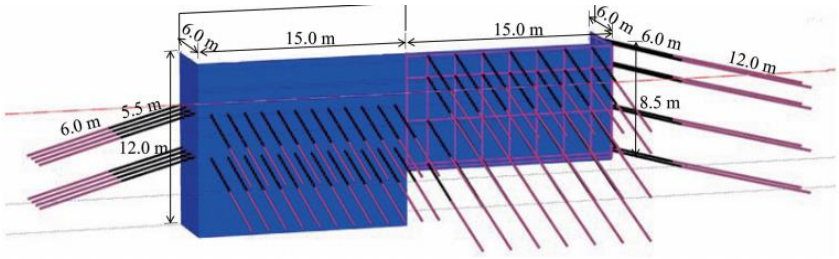


Figure 1. Foundation pit model

In the example, the point-to-point anchor rod is used to simulate the free section of the three-dimensional solid element anchor rod, the anchor section is simulated with the embedded beam element, the concrete supporting pile equivalent plate element of the pile-anchor support structure, and the prefabricated returnable support The steel pipe piles, crown beams, and waist beams of the structure adopt embedded beam elements, the wooden panels are simulated with plate elements, and the soil layer parameter settings are calculated according to the method of the previous section. According to the experience of numerical simulation of foundation pit excavation, in order to eliminate the influence of boundary conditions on the simulation results, according to the experience of researchers, the excavation depth is 3 to 4 times, and the model is determined to be 110 meters long and 50 meters wide. The meshing is done with medium and local refinement, and Fig. 2 shows the meshing diagram of the model.

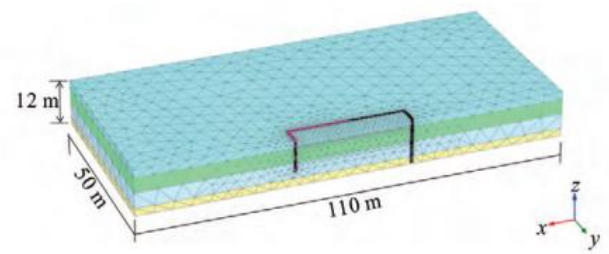


Figure 2. Model meshing diagram

4.2. Combined with the construction sequence of foundation pit excavation.

The excavation process of the foundation pit is divided into seven stages, and the specific simulation steps are shown in Table 1.

Table 1. Construction Conditions

Working condition	Excavation depth/m	Construction steps
1	0	Activating slab and interface elements for pile anchor support, vertical beams for fabricated support structures
2	-0.5	Activate the first layer of beams and the first layer of anchor rods of the fabricated support structure
3	-1.8	Activate the second layer of beams, the second layer of anchor rods and the first layer of planks of the fabricated support structure
4	-3.5	Activate the first layer of anchor rods for pile anchor support
5	-4.7	Activate the third layer of beams, the third layer of anchor rods and the second layer of planks of the fabricated support structure
6	-6.5	Activate the second layer of anchors for pile anchor support
7	-8	Activate the fourth layer of beams, the fourth layer of anchor rods and the third layer of planks of the fabricated support structure

5. 3D Numerical Analysis

5.1. Building the model

According to the geological conditions of the foundation pit and the support design scheme, using MidasGTS finite element numerical analysis software, combined with the model size effect, a three-dimensional numerical model of the bottomless foundation pit was established, as shown in Figure 3.

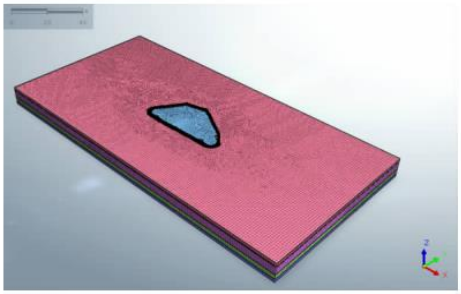


Figure 3. 3D deep foundation pit engineering numerical model

5.2. Segmented excavation and analysis of simulation results

5.2.1 Analysis of vertical deformation at the bottom of foundation pit

After the first step of excavation, the maximum deformation of the pit bottom uplift is 12.0 mm, and the maximum settlement is 2.3 mm; after the second step of excavation, the pit bottom uplift reaches 14.0 mm, and the maximum settlement reaches 2.5 mm; after the third step of excavation In the pit, the maximum uplift of the pit bottom is 19.0 mm, and the maximum settlement value is 3.5 mm. The uplift deformation at the bottom of the foundation pit gradually increased, and the range where the displacement exceeded 10.0 mm was further expanded. However, the settlement change around the foundation pit was not noticeable, and there was an increasing trend[5].

5.2.2 Horizontal deformation analysis of foundation pit sidewall

After the excavation in the first stage, the maximum lateral displacement of the FG side is 4.5 mm, and the AB side is 3.9 mm; after further construction, the horizontal displacement of the FG and AB sides both reaches 6.3 mm; after the excavation and support are completed, the FG side The maximum horizontal displacement is 11.7 mm, and the AB side increases to 12.2 mm. After the excavation of the first step, due to the shallow excavation depth of the foundation pit and the supporting effect of the first prestressed anchor cable, the unloading effect of the excavation is not apparent. The displacement is effectively limited, and the amount of displacement is minimal.

5.2.3 Internal force analysis of support structure

After excavating the foundation pit, each prestressed anchor cable is in tension, and the uppermost prestressed anchor cable has minor axial tension due to its low earth pressure. After the third step of excavation is completed, the bottom anchor cable on the right side of the foundation pit will bear the maximum tensile force.

Numerical simulation of foundation pit excavation was carried out by MidasGTS technology, and the horizontal displacement of soil and the axial internal force of anchor cable after grouting reinforcement were analyzed. The deformation law of the pit is similar. The displacement of the top of the foundation pit is significantly reduced, the maximum displacement no longer appears at the top of the foundation pit, and the maximum displacement appears at a depth of 0.75 H of the foundation pit. The analysis found that the stress loss of the anchorage section of the prestressed anchor cable is significantly reduced after grouting reinforcement, which shows that grouting reinforcement plays a good role in the safety of the foundation pit[6].

The three-dimensional finite element simulation analysis of the bottomless mixed soil foundation pit was carried out using Midas finite element software. The results show that the total stress method

calculates the pile-anchor supporting structure according to the equivalent stiffness. It is feasible to some extent. The maximum vertical settlement of the foundation pit occurs at a certain distance behind the edge of the foundation pit. Necessary protective measures should be taken, and a control point should be set at this position for real-time monitoring and timely feedback. In all supporting structures, the performance of the first row of bolts directly affects the change of the foundation pit's displacement, so the bolts' performance must be strengthened. The axial force of the bolt is evenly distributed in the free section, and the anchoring section is gradually reduced; in this project, the length of the anchoring section is too long, resulting in economic waste, which is consistent with the measured results of the bolt deformation measured on-site, which once again proves that the numerical analysis method is used in the foundation pit project. Application is feasible. Increasing the anchor bolt prestress can reduce the foundation pit's horizontal displacement and reduce the foundation pit's horizontal displacement. However, with the increase of the prestressing degree, the decreasing effect is weakened.

6. Ending part

Deep miscellaneous fill is soil with poor performance in geotechnical engineering, especially when the backfill time is short and the soil is soft. It has a tremendously adverse effect on the support design and construction. Under the premise of fully considering the engineering geology of the foundation pit and the surrounding environment, a proposal to increase the grouting reinforcement in the active area and the grouting reinforcement in the passive area based on the traditional pile-anchor support design is proposed for successful completion of the request. In the process of foundation pit support design and construction, in addition to meeting the overall stability requirements of the slope, the displacement of the support structure should also be strictly controlled to avoid excessive deformation of the surrounding soil and affecting the surrounding environment. Applying the numerical simulation of the anchoring force and deformation of the pile pit in the bottomless mixed soil foundation pit is effective.

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