Research on numerical simulation technology of small and medium-sized polygonal approximate circular diaphragm wall

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ABSTRACT

In order to accurately analyse the construction process of circular shaft diaphragm wall in geotechnical engineering, based on the advancement of geotechnical engineering technology and the finite element method, we constructed a three-dimensional finite element analysis model, which comprehensively considered the factors such as groundwater seepage, soft and hard interlocking stratum conditions. The model comprehensively analysed the influence of soil layer, soil properties and support system on the project, and deeply studied the stress-strain changes of the support structure and soil body through numerical simulation. The construction complexity was accurately simulated by reasonably setting the boundary conditions, contact conditions and soil ontological relationship model. Comparison with the actual monitoring results verifies the accuracy of the model and error analysis is carried out. The study shows that the 3D finite element model provides a scientific basis for engineering design and construction.

Keywords: Numerical simulation techniques, finite element analysis, diaphragm walls, geotechnical engineering, engineering design and construction

1. INTRODUCTION

With the continuous progress of geotechnical engineering technology, the finite element method has become an important means of numerical simulation and analysis, and is widely used in various types of geotechnical engineering. This method is able to comprehensively consider the influence of multiple complex factors on the project, including the distribution of soil layers, the nature of soil, the type of support system and its setup, the excavation working conditions and the nature of the support structure. However, the traditional two-dimensional plane strain model often fails to accurately reflect the horizontal changes of the soil layer and seepage field when analysing circular shaft diaphragm walls[1], which restricts its application in some specific engineering projects. Therefore, for engineering projects that need to consider the horizontal changes of geological conditions, the use of 3D finite element analysis models has become an inevitable choice.

On the basis of academic research and analysis of typical engineering cases, we found that the 3D finite element analysis of the construction process of small and medium-sized polygonal approximate circular diaphragm walls faces a series of key technical problems[2]. Firstly, the main factors affecting the local stress concentration phenomenon of circular diaphragm walls need to be studied in depth[3] in order to optimise the structural design and improve engineering safety. Secondly, it is necessary to pay attention to the matching situation between the soil instrinsic model and the actual project[4], to ensure that the numerical simulation results can truly reflect the actual situation of the project. In addition, the setting of the contact conditions between the wall and the soil and the treatment of seepage problems are also the focus of the study[5], and the solution of these problems will help to improve the accuracy and reliability of the numerical simulation.

The purpose of this thesis is to study the stress-strain change law of the supporting structure and soil body by establishing a numerical simulation model of the construction process of vertical shaft polygonal approximate circular diaphragm wall excavation considering the groundwater seepage and the conditions of soft and hard interlayered strata. By reasonably setting the boundary conditions, contact conditions and soil ontological relationship model, we can more accurately simulate various complex situations in the construction process, providing strong support for engineering design and construction. At the same time, by comparing and analysing the results with the actual monitoring results, we

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are able to assess the accuracy of the numerical calculation results and carry out the error analysis, which will provide a useful reference for future research.

2. MAIN PROBLEMS OF NUMERICAL SIMULATION OF DIAPHRAGM WALL

2.1 Main issues explored in numerical simulation of small and medium sized circular diaphragm walls

(1) Interaction between diaphragm wall and soil body

In the finite element method of deep foundation pit ground diaphragm wall support structure analysis, because the material properties of the retaining wall of the support structure and the soil are very different, the contact surface unit is usually set up at the interface between the wall and the soil to simulate the interaction between the support structure and the soil[6]. There are two main features of the contact surface unit model:

One, it simulates the deformation on the contact surface, i.e., sliding on both sides of the contact surface;

The second one is to simulate the transfer of forces on both sides of the contact surface, including normal and shear stresses, which exist after sliding on both sides. The main contact surface units that can be chosen are Goodman unit, friction contact unit and thin layer unit.

(2) Calculation of internal force and deformation of wall and soil body

The deformation in the shaft pit includes the deformation of the diaphragm wall, the bulge at the bottom of the pit, and the surface settlement, etc. The deformation of the shaft pit will directly affect the stability of the pit and the buildings around the pit as well as the underground municipal pipelines, etc.[7]. There are many factors affecting the deformation of the ground-connected wall support structure and soil body during deep foundation pit excavation, and the factors affecting the deformation of the foundation pit can be summarized as the following main aspects[8]:

- The type and stiffness of the support system;
- The burial depth of the diaphragm wall[9];
- The magnitude of preloading and ground overloading;
- Properties of foundation soil;
- The nature, depth and construction method of excavation;

(3) Selection of soil constitutive model of finite element method

At present, there are elastic, elasto-plastic and visco-elastic-plastic models available for the selection of soil constitutive models.

2.2 Mechanical model of circular diaphragm wall excavation

Circular diaphragm wall support structure has good symmetry, and its geometric conditions, boundary conditions and loads are basically symmetrical, which can be simplified into semi-structural model, 1/4 structural model or even two-dimensional axisymmetric structural model. The group used three-dimensional 1/4 structural model structure for the analysis of the spatial effect of circular diaphragm wall and the study of the thickness of circular diaphragm wall and liner, and two-dimensional axisymmetric structure for the effect of groundwater seepage on the structural stability of the wall[10].

3. CASE OF NANTANSEA SHIELD THROUGH SHAFT PROJECT

3.1 Establishment of finite element model

In order to simulate the spatial effect of the circular diaphragm wall, we use the soil layered axisymmetric two-dimensional finite element model, which means that the diaphragm wall support structure and the surrounding soil strata are simulated as a whole for excavation.

3.2 Materials and parameters

The supporting structure materials (including diaphragm wall and internal support) in this project are assumed to be linear-elastic. The concrete strength grade is considered as C30, and the material model is taken as linear elasticity, concrete elasticity model, considering the influence of the construction process, the modulus of elasticity of both diaphragm wall and inner liner is taken as 3×107 kPa, and Poisson's ratio is taken as 0.2. The geological materials (including soil and rock) are also assumed to be linear elastic, and the mechanical properties of each soil layer are as follows (Table 1):

Table 1. Mechanical parameters of soil layers.

Ground level parametric	Modulus of elasticity KPa	Poisson's ratio	Capacity	Cohesion	Angle of internal friction	Layer thickness (m)
Shallow clay	3000	0.45	18.5	12	10	1
Clays	2800	0.45	19	8	8	4
Pebble layer	9000	0.42	19	3	19	4
Strongly weathered sand	600000	0.40	20	20	32	20

3.3 Load and boundary conditions

The earth pressure acting on the wall support structure is greatly affected by the soil conditions and construction conditions, and the theoretical prediction is very difficult because the distribution and size of earth pressure are closely related to the size of the pit, the nature of the foundation, the depth of excavation, the stiffness of the retaining wall, the depth of the retaining wall's embedment, and the number and location of the horizontal support. This paper adopts the axisymmetric finite element model of the joint action of the retaining wall and the soil, selects the appropriate ontological relationship of the soil, adopts the principle of water-soil integration, selects the appropriate Poisson's ratio, and automatically loads the lateral pressure of the soil on the retaining wall according to the geostress generated by the model. Take the uniform additional load 20 KPa within 50 m of the bottom of the shaft pit to simulate the uniform load of the ground outside the shaft. The boundary conditions of the model are calculated, all nodes on the bottom surface of the model are constrained to be fixed, the nodes on the outermost arc surface of the model are released from vertical degrees of freedom, and the top surface of the shaft is a free boundary.

3.4 Calculation realization steps

(1) We need to establish a comprehensive model for the soil and its supporting structure across the entire site.

(2) All liner structure units should be deactivated, and the ground wall units should be substituted with their corresponding soil bodies. Subsequently, the weight load of these soil bodies should be applied to the model in order to generate the initial self-gravity stress within the strata.

(3) The model, which has been influenced by the weight stress, should be exported as a file for further use.

(4) Another identical model should be created, and the previously generated self-gravitating stress file should be imported into it. This model should then be recalculated to eliminate any residual initial strain and displacement.

(5) The diaphragm wall units should be activated by altering their material properties. Specifically, the soil material occupying the original diaphragm wall locations should be replaced with concrete material, thereby simulating the construction of a circular diaphragm wall.

(6) A ground overload should be applied to the soil surface surrounding the foundation pit, and the first layer of soil units scheduled for excavation should be deactivated. This marks the initiation of the first load step for calculation.

(7) Upon the completion of the first load step, the second layer of soil intended for excavation should be deactivated, and the first layer of liner units should be activated. This constitutes the second load step calculation.

(8) The process of deactivating soil units and activating corresponding liner units should be sequentially repeated, layer by layer, in order to simulate the ongoing excavation of soil and the construction of lining.

(9) These steps should be continually repeated as needed.

(10) The excavation process should proceed until the bottom of the pit is reached.

4. VISUALISATION AND ANALYSIS OF CALCULATION RESULTS

Figure 1 shows the model diagram of the shaft before excavation of the shaft, Figure 2 shows the model diagram of the shaft before excavation of the shaft, Figure 3 shows the distribution of the total stress after the completion of one excavation, Figure 4 shows the horizontal stress distribution after completion of one excavation, Figure 5 shows the distribution of the vertical stress after the completion of one excavation, and Figure 6 shows the distribution of the vertical displacement after the completion of one excavation, the inner support is processed by the unit substitution technique, and the whole finite element computational model modelling and calculation is carried out in the ABQUS6-10. The project is carried out by the five-step excavation+internal support in a smooth way, and the excavation depth of each sequence is 4 m. From the figure, it can be seen that the excavation is easy to cause the uplift of the bottom of the shaft and the subsidence of the soil behind the shaft wall, and the influence of the ground heap load on the shallow soil pressure is still relatively large, and the influence range is about 4 m below the ground surface, and the deformation of the retaining wall from the deformation of the wall and the distribution of stress diagrams can be seen: the bottom position of the pit of each excavation is the horizontal stress of the largest place. large place, at the same time in the whole construction process, the end of the circular diaphragm wall is also the stress concentration site. The stress concentration part is also the vulnerable area of diaphragm wall, because it is a segmental excavation, so the stress concentration position keeps moving down with the excavation, and the degree of stress concentration is getting bigger and bigger, which may be one of the drawbacks of the segmental excavation support, because he greatly increased the range and duration of the wall where the stress concentration occurs, and a one-time excavation of the bottom of the pit, and then do the support, it will only occur in the bottom of the pit stress concentration. It can also be seen from the figure that both the soil behind the wall and the wall, the horizontal displacement is very small, are within a few mm, which is basically consistent with the field monitoring data. For the circular diaphragm wall, during the whole construction process, both vertical stress and horizontal stress, the whole shows the nature of compression, which is also basically consistent with the site monitoring data.

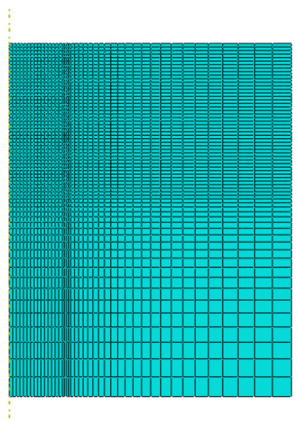

Figure 1. Shaft model before shaft excavation.

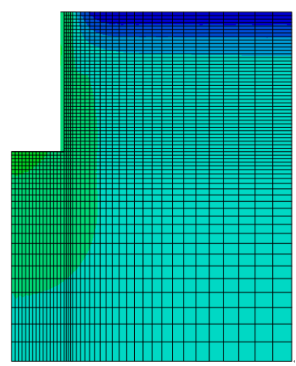

Figure 2. Shaft model before shaft excavation.

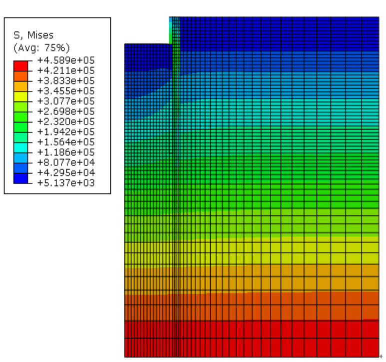

Figure 3. Total stress distribution after completion of one excavation.

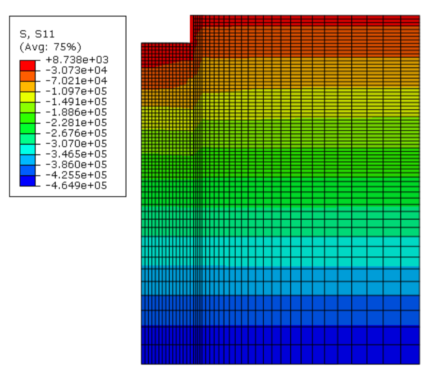

Figure 4. Horizontal stress distribution after completion of one excavation.

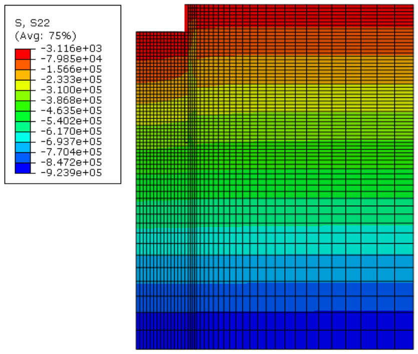

Figure 5. Vertical stress distribution after completion of one excavation.

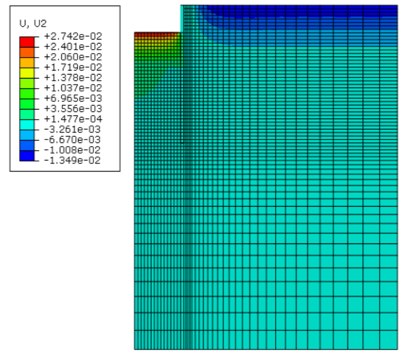

Figure 6. Vertical displacement distribution after completion of one excavation.

5. CONCLUSION

(1) Excavation caused the uplift of the bottom of the shaft and the subsidence of the soil behind the shaft wall, and the influence of the ground stacking load on the soil pressure in the shallow layer was large, and the influence range was about 4 m below the ground surface.

(2) The location of the bottom of each excavation pit is the place with the largest horizontal stress, and also the end of the circular diaphragm wall is the part with concentrated stress during the whole construction process. Because of the segmental excavation, the location of stress concentration moves down with the excavation, and the degree of stress concentration is getting bigger and bigger.

(3) The horizontal displacements of both the soil behind the wall and the wall are small, both within 5 mm. For the circular diaphragm wall, the wall as a whole presents a compressed nature during the whole construction process.

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