IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

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To cite this article: Changyi Yu 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **242** 062033

IOP Conf. Series: Earth and Environmental Science **242** (2019) 062033 doi:10.1088/1755-1315/242/6/062033

Numerical Analysis of Deep Foundation Pit Excavation Supported by Large Diameter Ring Beam

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Abstract. At present, there are more and more high-rise buildings and underground projects due to the shortage of land in the city, and a large number of deep foundation pits need to be built accordingly in order to study the impact on the surrounding environment in the process of foundation pit excavation. In this paper, the finite element method is proposed to simulate the excavation of foundation pit with large diameter ring beam support system. By simulating an example project, the step-by-step excavation and step-by-step support procedures in the construction steps are reproduced. The calculation results show that the ring beam support system avoids large stress concentration and has little impact on the surrounding environment. The successful simulation of this example provides an effective reference for finite element analysis of similar projects and an effective tool for engineering analysis.

1. Introduction

In the case of deep foundation pit, high underground water level, geological and environmental conditions around the pit are not allowed to be used as anchor, soil nail and soil anchor. Vertical wall support excavation is generally adopted[1-3]. The foundation pit adopts internal support, which can effectively control the displacement of the side wall and has a high degree of safety, but reduces the working surface of construction machinery, affects the efficiency of earth-moving machinery and earth-moving vehicles, and increases the construction difficulty

The depth of the foundation pit supported by the vertical wall is generally larger than that of the excavator, and it needs to be excavated in layers. In the process of construction, earthwork excavation and support construction should be carried out crosswise. Internal support is to form a supporting construction working face along with the layered and partitioned excavation of earthwork, and then to construct internal support. After the end, the excavation of the next layer of earthwork will be carried out after the internal support reaches a certain strength to form the next internal support construction working face and repeat the construction, thus gradually forming a supporting structure system[4-5]. Therefore, the earthwork excavation of foundation pit must be closely coordinated with the supporting construction. According to the working conditions of the supporting structure design, the scope of earthwork layering and zoning excavation should be determined first, and then the earthwork of foundation pit should be layered and zoning excavation. When determining the excavation scope of the foundation pit, the space-time effect of the soil, the time of supporting construction and the requirements of the mechanical working surface should also be considered[6-8].

When there is a tight inner support or in order to strictly limit the displacement of the supporting structure, the basin excavation sequence is often adopted, i.e. after digging out as much earth as possible in the lower central area of the foundation pit, cross-shaped steel pipe supports are erected and pre-tightening force is applied, or after digging out the earth in the central area of the layer, reinforced concrete supports are poured and the surrounding earth is dug out one by one to gradually form support for the retaining wall[9-10].

Therefore, under the given scheme, the key point of foundation pit safety lies in the construction steps, and the existing norms and theoretical analysis are difficult to analyze the space-time evolution law of foundation pit in the construction process. Therefore, this paper proposes to use the finite element method to reproduce the foundation pit construction process and analyze the evolution law of foundation pit with the construction progress.

2. Finite element model

A three-dimensional finite element model was established for the soil mass and its supporting system within the influence range of the excavation of the foundation pit. Due to the extremely irregular shape of the supporting structure of the foundation pit, its entire range was taken for modeling, and only some minor parts were simplified for processing. In this paper, the influence of foundation pit excavation on the surrounding environment is mainly concerned with the following aspects: horizontal displacement of the surrounding structure, surface subsidence around the foundation pit, uplift at the bottom of the pit and the stress of horizontal support.

In principle, the boundary range of the calculation model should reach the boundary where deformation and internal force will no longer occur after the foundation pit excavation structure is stressed. However, due to the limitation of calculation conditions, calculation resources and time, it is often not completely consistent with the actual requirements. Generally speaking, the stress and deformation of soil beyond the range of 3 times the actual size of foundation pit can be ignored. Therefore, the foundation site length, width and height of this engineering model are 520m, 500m and 80m respectively.

Although the retaining wall structure of cast-in-place bored piles is connected by individual piles, its stress form is similar to that of continuous underground walls. Due to the construction of the binding ring beam, which greatly enhances the integrity of the pile. In the process of modeling, pile wall is equivalent to continuous wall with uniform stiffness for analysis and calculation in order to simplify the treatment. And according to the engineering experience, the equivalent method of design is often biased towards safety and reasonable. When modeling, the wall depth is 20m and the thickness is 1.5m. The form and size of the support are given in accordance with the size of the design drawing. The width of the middle large diameter ring beam is 2.5m, the small diameter ring beam is 1.5m, the width of the support beam connected with the two ring beams is 0.8m, and the width of the rest of the beam is 0.7m.

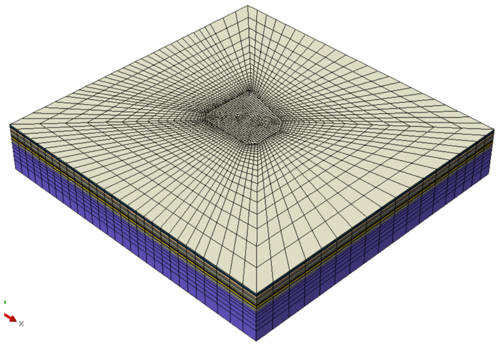

Figure 1. Soil mesh.

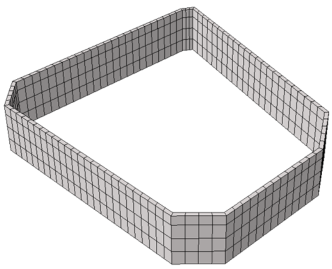

Figure 2. Diaphragm wall mesh.

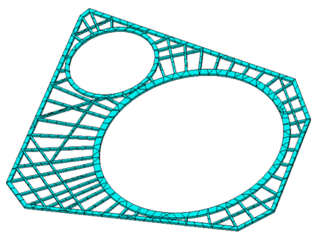

Figure 3. Horizontal support mesh.

Figure 1 shows the finite element model of soil within the calculation range, figure 2 shows the finite element model of surrounding wall, and figure 3 shows the finite element model of ring beam support. The mesh division of the soil body inside the foundation pit and around its surrounding wall is relatively thin. With the increase of the distance from the foundation pit edge, the mesh division is relatively sparse. The element type is a space 8-node hexahedron element. Since it is a three-dimensional stress analysis, the mesh type adopts 3D stress analysis. The grid forms of soil mass, surrounding wall and support are shown in figure 1-3.

Foundation pit excavation involves the interaction of wall - soil and wall - support. According to the actual construction experience, the binding constraint is between the connecting wall and the horizontal support, while the friction is between the connecting wall and the soil. The constraint around the soil body adopts axial constraint, and the constraint on the bottom surface adopts three-dimensional fixed constraint. Fixed constraints are also used at the bottom of the retaining wall.

ABAQUS provides a series of constitutive models for simulating rock and soil. The model soil established in this chapter adopts Cambridge model. Cambridge model, also known as critical state plastic model, is a representative elastic-plastic model of soil established by Roscoe et al. of Cambridge University in England. The model has been widely accepted and applied internationally by adopting elliptical yield surface and corresponding flow criteria and taking plastic body strain as hardening parameter. ABAQUS extended the Cambridge model proposed by Roscoe et al., but it was essentially the same.

According to the soil distribution of the site in the survey report, various parameters required for finite element calculation can be obtained, as shown in Table 1.

Table 1. Calculation parameters of soil layer selected by finite element method

Solum	Thickness (m)	Severe (kN/m^3)	φ(°)	c(kPa)	Elastic modulus (MPa)	Poisson's ratio
Miscellaneous fill	1.5	18.5	5	5	500	6
Grain filling	3.5	19.4	10.48	13.63	2511.61	8
Silty clay with silty soil	3.5	18.9	18.3	12.8	6147.8	16
Silty clay	8.5	17.9	6.87	9.29	1185.94	3
Silty clay	2	20.3	23.37	12.61	8000	10
clay	2.5	19.2	14.89	17.59	4704.24	13
Silty clay	3	20.2	17.19	14.76	5666.92	12
silt	2	20.6	25.2	9.4	9000	18
Silty clay	2.5	19.8	18.45	16.9	6653.05	15
silt	2.5	20.8	28.47	9.92	9000	19
silt	23	20.4	30.74	0	9000	24

The reinforced concrete is assumed to be linear elastic material, and the grade is calculated according to C30. The diaphragm wall and horizontal support are modeled using a fully elastic model.

The calculation of the model is carried out in three steps. The first step is to calculate the initial stress field before foundation pit excavation. Since the soil has experienced long-term consolidation in history and has reached a stable state, the displacement field in the first step of calculation is zero. The second step is to calculate the displacement field caused by the first step of foundation pit excavation. The third step is to calculate the displacement field after the horizontal support is applied and the second step of excavation of the foundation pit.

The Model Change function in ABAQUS can “kill" the specified cell structure. When establishing the interaction, the first step is to " kill" all the supporting structural units, the second step is to " kill" the first layer of soil units in foundation pit excavation to simulate the first step of soil excavation, the third step is to " activate" the underground continuous wall units to simulate the construction of ground connecting walls, and the third step is to " activate" the ring beam supporting units to simulate the construction of horizontal supports. “Kill" the soil unit of the second excavation.

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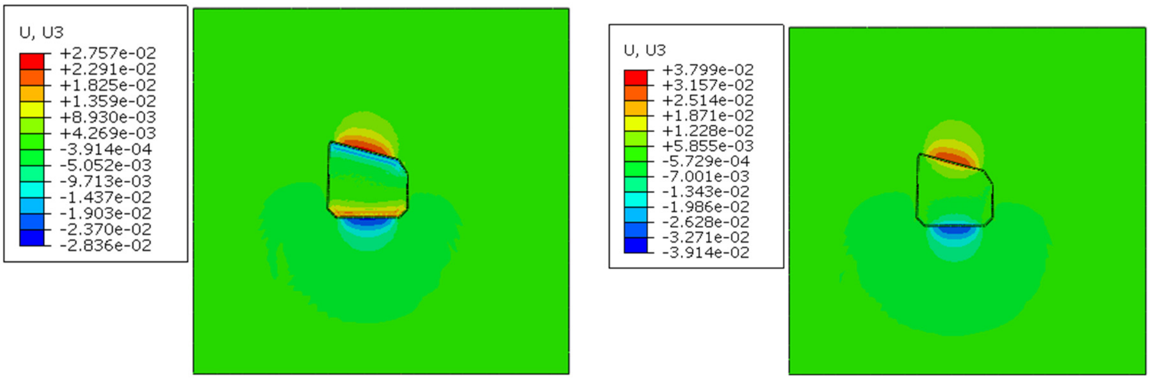
3. Calculation result

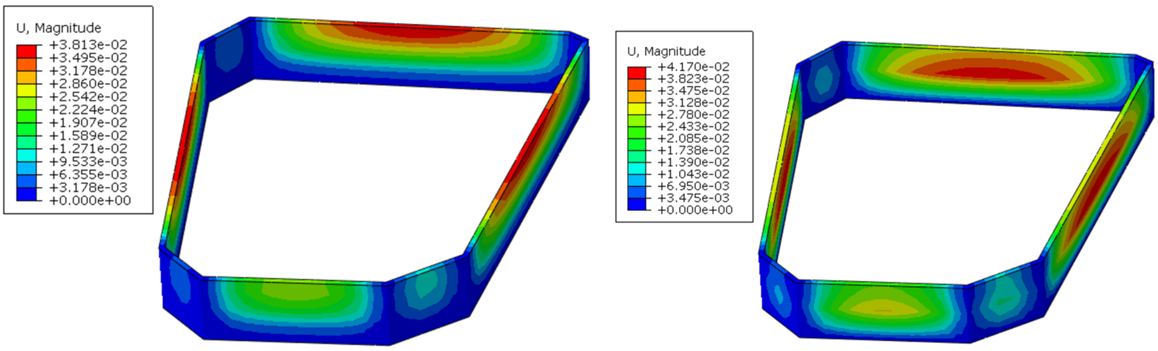
Surface subsidence is due to excavation of foundation pit and strata movement, which appears in the vertical deformation form of the ground around the foundation pit. Foundation pit excavation is the process of unloading the soil on the excavation surface at the bottom of the foundation pit. After unloading, the soil at the bottom of the pit rebounds and produces upward displacement. At the same time, the earth pressure on both sides of the retaining wall varies, and the earth outside the foundation pit will move horizontally inward under the influence of the earth pressure difference.



(a) Excavation first step level U_3. (b) Excavation second step level U_3.

Figure 4. Horizontal displacement of different excavation steps

The rebound of the soil under the pit is caused by the self-weight stress of the soil being removed during the excavation of the foundation pit and the insufficient depth of wall insertion, and the soil outside the pit moves from the bottom to the inside of the pit, resulting in the uplift of the pit bottom. After unloading, the soil mass at the bottom of the pit bulges vertically, with the amount of uplift at the bottom of the pit being large in the middle and small on both sides.



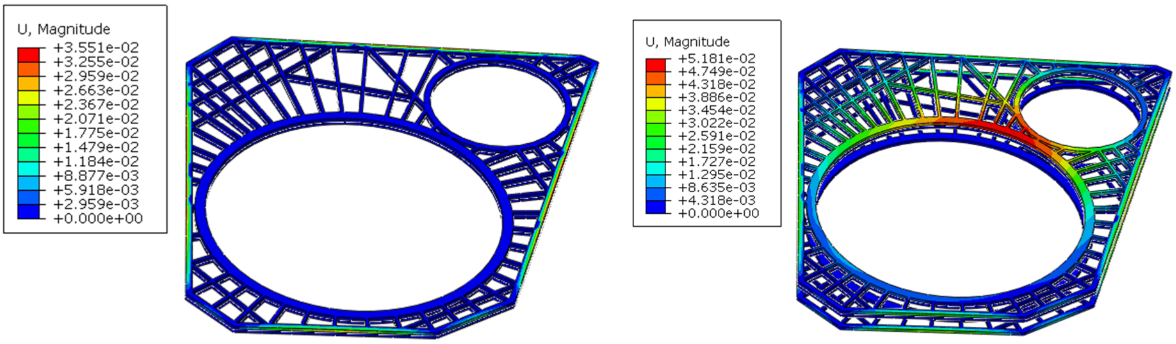
(a) The first step of excavation. (b) The second step of excavation.

Figure 5. Displacement of different excavation steps

From the above calculation results of soil deformation, it can be seen that after the excavation of the foundation pit, the surrounding soil has significantly settled, and the maximum settlement is located in the middle of the contact between the retaining structure and the soil outside the pit. The bottom of the foundation pit is uplifted, and the maximum uplift amount is approximately in the middle of the pit bottom. The calculated results are in good agreement with the actual situation.

When the foundation pit is excavated, the original earth pressure is removed from the inside of the retaining wall, while the outside of the foundation pit is subjected to active earth pressure, while the inside of the bottom wall is subjected to all or part of passive earth pressure, and unbalanced earth pressure causes deformation and displacement of the wall. When the foundation pit excavation is shallow, the displacement of the top of the wall is the largest. However, with the increase of the excavation depth of the foundation pit, after the completion of the horizontal support construction, the displacement of the top of the wall remains the same or even moves outside the foundation pit, with the middle of the wall protruding into the pit and the displacement being the largest.

With the excavation of foundation pit, under the action of active earth pressure, the wall will be deformed and displaced. When the support has not been poured, the displacement of the wall decreases linearly along the depth direction. After that, due to the completion of the erection of the horizontal ring beam support, the horizontal displacement curve of the retaining wall pile body becomes a bow shape with large middle and small two ends. For each side wall, the middle deformation is larger and the corners are smaller.



(a) The first step of excavation. (b) The second step of excavation

Figure 6. Displacement of beams at different excavation steps

From the above calculation results, it can be seen that after foundation pit excavation, the wall will deform and the wall will move horizontally into the pit. The displacement of the middle part of the wall is the largest and the displacement of the corner is smaller. For a single supporting pile, the displacement of the pile top and the pile foot is small, and the displacement of the middle part of the pile body is the largest. The stress is the largest in the corner of the wall, with a certain degree of stress concentration and a small internal force in the middle of the wall. The calculated results are in good agreement with the actual situation.

From the calculation results of the above horizontal supports, it can be seen that the supports have obviously shifted in both horizontal and vertical directions. The vertical displacement at the tangent position of the ring beam is the largest, and the four long sides of the ring beam are all deformed inward. This is consistent with the measured results. The stress of the ring beam support is in good condition and there is no place where excessive stress concentration occurs. It shows the superiority of ring beam support in foundation pit support application.

4. Conclusion

This project involves layered excavation, multiple support and irregular shape. This paper uses 3D finite element method to analyze the impact of the excavation process on the surrounding environment. This not only can calculate the stress and deformation of each node of the supporting structure system at each time analysis step in the foundation pit excavation process, and more accurately analyze the internal force of the ring beam support, but also can dynamically simulate the construction process according to the actual situation of the foundation pit project, considering the working conditions of soil excavation and support erection step by step. Through calculation and analysis, the numerical model can better simulate the support form of large-diameter ring beam and the layered excavation condition of foundation pit.

Acknowledgments

I would like to thank CCCC-Tianjin Port Engineering Institute, Ltd. for their support of this work and for the technical guidance provided by my colleagues, Zhifa Yu and Bin Li.

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