Optimization Design of Large-Area Foundation Pit Support System Based on Finite Element Method

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Abstract. With the acceleration of urbanization, more and more large-scale deep foundation pit projects are being carried out in the city. Due to the requirements of site and construction technology, it is necessary to design a supporting form that can be used as a supporting system without affecting the construction. In this paper, the large open ring beam structure is proposed as the supporting system, and the direct beam supporting system and the proposed ring beam supporting system are analyzed by finite element method. The structure shows that the ring beam structure proposed in this paper has better effect. The support form proposed in this paper provides an effective reference for design and optimization of foundation pit support form.

1. Introduction
As a structural system, foundation pit support should meet the requirements of stability and deformation: the two limit states mentioned in the general specification, i.e. the bearing capacity limit state and the normal use limit state[1-2]. The displacement control of general support structure is mainly based on horizontal displacement, which is more intuitive and easy to monitor. Horizontal displacement control is related to the requirements of the surrounding environment. If there are important structures around the foundation pit that need to be protected, small deformation should be controlled[3]. Usually, when the site around the foundation pit is limited, it is required that the supporting structure should not interfere with the construction excavation, which requires that the supporting structure have enough space for machinery and personnel to work, and that it should meet the requirements of deformation control[4-5]. The large - opening ring beam structure is a newly-emerged support form in recent years, which facilitates the lifting of materials and the outward transportation of earthwork in the construction process[6-7]. In order to further study the influence of different support forms on the excavation deformation of foundation pit, the excavation model of foundation pit with regular shape is established in this paper. Under the same other conditions, the support forms of ring beam and straight beam are adopted respectively to compare their support effects.
2. Finite element model
The three-dimensional finite element model is established, and the simulated working condition is that the excavation depth of the foundation pit is 7m, and the excavation is divided into two layers, with the first excavation depth of 4m. The depth of the second excavation is 3m. The size of the foundation pit is a square with a length of 30m on one side. The length, width and height of foundation soil are 100m, 100m and 30m respectively. The depth of the underground continuous wall is 15m and the thickness is 1m. Support forms are divided into ring beam support and straight beam support. The interface area between the main beam and the secondary beam of the two supports is the same. The construction procedure is to first excavate the foundation soil 4m, then immediately join the support, and finally continue to excavate the foundation soil 3m deep. The finite element model of soil is shown in Figure 1 below.

In order to calculate quickly, the grid division of the soil inside and around the foundation pit is relatively thin. With the increase of distance from the foundation pit edge, the grid division is relatively sparse. Because it is a three-dimensional model, the element type is a spatial 8-node hexahedron element, and the mesh type is 3D stress analysis. The grid form of enclosure wall and support is shown in figure 1 - 3 above.

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.

3. Calculation result
Due to the excavation of the foundation pit, the inherent balance state of the soil body is destroyed, and the soil body at the bottom of the foundation pit rebounds upward and bulges. At the same time, due to the lateral unloading of the soil body, the supporting wall body moves towards the foundation pit, and the soil body behind the wall moves, causing the surface settlement. Therefore, the
deformation of foundation pit excavation mainly includes wall deformation and surface settlement behind the wall.

Figure 4. Soil deformation.

Figure 5. Horizontal support stress.

Figure 4 is the calculation result of vertical displacement of foundation pit, from which it can be seen that the soil mass within a certain depth at the bottom of foundation pit has produced upward displacement, and the maximum displacement is located in the center of the bottom of foundation pit, i.e. the center of the bottom of foundation pit has the largest uplift. The soil outside the retaining wall structure will move downward, i.e. the surface settlement around the foundation pit will be uneven, and the maximum settlement value will be located near the retaining wall outside the retaining wall.

As shown in Figure 5, the calculation results of the internal force of horizontal supports show that the internal force values of the four corner supports of the support structure are larger, the stress concentration phenomenon is obvious, and the internal force of other positions is smaller.

Figure 6. Deformation and vector diagram of enclosure structure.

Figure 7. Deformation and vector diagram of horizontal support of ring beam
Figure 6 shows the calculation results of the horizontal displacement of the retaining wall. It can be seen from the figure that the retaining wall has horizontal displacement to the inside of the foundation pit. For each side wall, the displacement of the middle part near the ground surface is the largest and the corner is smaller. For a single supporting pile, the displacement of the pile top is larger and the bottom is smaller, that is, the horizontal displacement of the pile body gradually decreases with the depth.

The deformation result of horizontal support is shown in figure 7. It can be seen from the figure that the ring beam near the enclosure wall will move into the pit with the maximum displacement at the middle position and the smaller displacement at the ring beam and corner support.

4 Calculation results of straight beam support

Figure 8 shows the calculation results of the lateral deformation of the foundation pit. It can be seen from the figure that obvious horizontal displacements have taken place in the soil inside and outside the foundation pit. The maximum displacement is located inside the foundation pit near the retaining wall. The soil mass within a certain depth range at the bottom of the foundation pit has an upward displacement, and the maximum displacement is located in the center of the bottom of the foundation pit, i.e. the center of the bottom of the foundation pit has the largest uplift. The soil outside the retaining wall structure will move downward, i.e. the surface settlement around the foundation pit will be uneven, and the maximum settlement value will be located near the retaining wall outside the retaining wall. The calculation result of the internal force of the horizontal support is shown in figure 9. It can be seen from the figure that the internal force value of the corner support part of the support structure is larger.

Figure 10 shows the calculation results of the horizontal displacement of the retaining wall. It can be seen from the figure that the retaining wall has horizontal displacement to the inside of the foundation pit. For each side wall, the displacement of the middle part near the ground surface is the largest and the corner is smaller. For a single supporting pile, the displacement of the pile top is larger and the bottom is smaller, that is, the horizontal displacement of the pile body gradually decreases with the depth.
Figure 11. Deformation and vector diagram of horizontal support of straight beam

The deformation result of horizontal support is shown in figure 11. It can be seen from the figure that the upward displacement occurs at the intersection of the two main beams, and the ring beam near the enclosure wall protrudes into the pit, with the displacement value at the middle position being the largest and the displacement at other positions being smaller.

Because the model is highly symmetrical, only one quarter of it is selected for analysis. First, a path is established on a straight line perpendicular to the enclosure wall, and the settlement of soil around the foundation pit on the path is analyzed. Secondly, a path is established on the supporting pile located in the middle of the retaining wall, and the horizontal displacement of the pile body on the path is analyzed. Thirdly, a path is established on the soil surface located in the middle of the pit bottom, and the pit bottom uplift on the path is analyzed.

Figure 12. Settlement curve of soil outside pit under two support forms

In figure 12, the central point is the position where the outer edge of the retaining wall of the foundation pit contacts the soil. Contrast curve of surface settlement around foundation pit on the built path. Through the comparison and analysis of the calculation results, it can be seen that the settlement value of the soil outside the pit under the ring beam support is smaller than that under the straight beam support. When using ring beam support, the maximum surface settlement around the foundation pit is 0.9cm, while when using straight beam support, the maximum surface settlement around the foundation pit is 1.7cm, which indicates that using ring beam support can better control the settlement deformation of soil outside the pit.

Figure 13. Deformation curve of retaining structure under two support forms

In Figure 13, the central point is the bottom of the enclosure wall. Comparison curve of horizontal displacement value of foundation pit retaining structure pile body on the built path. Through the comparative analysis of the calculation results, it can be seen that the horizontal displacement value of the pile body under the ring beam support is smaller than the horizontal displacement value of the pile body under the straight beam support at this position. When using ring beam support, the maximum horizontal displacement of foundation pit pile body is 4.1cm, while when using straight beam support,
the maximum horizontal displacement drop of pile body is 4.7cm, which indicates that using ring beam support can better control the horizontal displacement of pile body of enclosure structure.

Figure 14. Comparison curve of pit bottom uplift values under two support forms

Figure 14 is a comparison curve of the uplift values at the bottom of the foundation pit on the built path. Through the comparison and analysis of the calculation results, it can be seen that the uplift value at the bottom of the foundation pit under the ring beam support is smaller than that under the straight beam support. When using ring beam support, the maximum uplift at the bottom of the foundation pit is 3.3cm, while when using straight beam support, the maximum uplift at the bottom of the foundation pit is 2.9cm, which indicates that ring beam support can better control the uplift at the bottom of the foundation pit.

4. Conclusion
Under the same working condition, the internal force distribution of the ring beam support itself is reasonable without obvious stress concentration. After the foundation pit excavation is completed, the surface settlement around the foundation pit is small, the horizontal displacement of the retaining structure is small, and the uplift at the bottom of the pit is also small. To sum up, according to the comparison results, the effect of ring beam support structure in foundation pit excavation support is obviously better than that of straight beam support structure. Therefore, this form of ring beam support is worthy of reference and promotion.

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