Response Analysis of Excavation of Deep Foundation Pit in Metro Station of Soft Soil

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Abstract. Based on a deep foundation pit engineering of subway station in Ningbo soft soil area, the whole process of excavation of deep foundation pit engineering is carried out by PLAXIS finite element software and comparative analysis with field monitoring data based on HS soil hardening model. The analytical results indicate that the numerical simulation results can be well fitted to the field monitoring data. It is proved that the PLAXIS HS model can well complete the numerical simulation analysis of complex foundation pit excavation in soft soil area. From the monitoring data and calculated values, the horizontal displacement of the grounding wall and surface settlement caused by the excavation of the auxiliary foundation pit are small, which has little effect on the main foundation pit. It is proved that the foundation pit support mode and construction method used in this project can well control the influence of the excavation of the auxiliary foundation pit on the main foundation pit.

1. Introduction

With the continuous development of urban rail transit construction, a large number of deep foundation pit projects have appeared. The southeast coastal area is a region with developed economy in China, and the number of deep and large foundation pits in this area is high. Moreover, the soil in the southeast coastal areas is soft soil, the soft soil is poor in soil quality, the creep is large, the permeability coefficient is large, and the water content is high. Therefore, it is necessary to study the deep foundation pit of the metro station in the soft soil area.

At present, the numerical calculation method has been well applied in deep foundation pit engineering. Such as, Xiaola Feng [1] used finite element software to carry out numerical simulation analysis of the whole process of foundation pit excavation for the deep foundation pit of Wuhan Laopu film commercial and residential project, Lianxiang Li [2] used PLAXIS3D software to study the pit engineering of a foundation pit in the West Railway Station area of Jinan, Siwei Li [3] and other on-site monitoring data for excavation analysis of a subway deep foundation pit project in Beijing, Youhai Yang [4] used finite element software to analyze the structural characteristics of the foundation pit support of the Qutao Road Station of Hangzhou Metro, Liqiao Cao [5] used ABAQUS finite element software to establish a model, and summarized the basic law of foundation pit bulge during foundation pit excavation and precipitation.

Nowadays, there are more and more connected foundation pits in deep foundation pit engineering, but less research on connected foundation pits. Therefore, this paper will use the PLAXIS2D finite...
element software to analyze the excavation process of the sluice project with a certain pit project of a subway station on Ningbo No.3 line. Therefore, it provides reference for the design and construction of deep foundation pit engineering in soft soil areas.

2. Project overview

The deep foundation pit of the subway is a two-story single-column reinforced concrete box structure with a clear excavation method. Figure 1 shows the schematic diagram of the foundation pit. The deep foundation pit is divided into two foundation pits for construction. The standard section of the main pit of the station is 21.7m wide and the excavation depth of the standard section is 17.76m. Foundation pit A is provided with 5 supports along the depth of the foundation pit, the first of which is reinforced concrete support; the second to fifth are steel supports. The foundation pit B is provided with 5 supports along the depth of the foundation pit, wherein the first track is reinforced concrete support and the second to fifth tracks are steel supports. The soil at the bottom of the pit is reinforced with foundation, and the reinforcement depth is 3m below the bottom of the pit. It can be seen that the deep foundation pit of this subway is poor in geology, the surrounding environment is complex, and the construction has high risk and high difficulty.

![Figure 1 Foundation pit plan](image1)

The foundation pit is located in the Ningbo fault basin, and the terrain is flat. The stratum is rich in water and weak in mechanical properties, and the mechanical properties are poor.

![Figure 2 Cross section of Foundation pit standard section](image2)

3. Finite element simulation of foundation pit excavation process

In order to deeply study the deformation of the foundation pit retaining structure and the ground settlement during the foundation pit excavation process, the numerical simulation model was established by using PLAXIS finite element software. PLAXIS can effectively analyze the problems of deformation, stability, consolidation and groundwater seepage in geotechnical engineering, and is widely used in deep foundation pit engineering.

The two most important factors in finite element calculation are the establishment of the model and the selection of soil parameters. Since the shape of the foundation pit is a regular "long strip", the
standard section of the foundation pit is selected for 2D simulation. The construction process of the foundation pit excavation includes the construction of the retaining structure, the excavation of the soil, and the installation of the support. These processes are simplified by the “activation” and “freezing” of the unit body.

The selection of soil constitutive model and the determination of parameters are particularly important in the model. The HS model (soil hardening model) is a constitutive model that can simulate the behavior of different types of soils in various soil layers. This model can consider the hardening characteristics of soft clay and adopt different loading/unloading modulus. It simulates the influence of stress history and stress path on soil deformation, and is suitable for numerical simulation of excavation of foundation pit under sensitive conditions. Combined with the engineering survey report and Wang et al [6], Song et al [7] Yang et al [8], the soil parameters are shown in Table 1. The calculation model of the foundation pit is shown in Figure 3.

![Figure 3 FEM model of foundation](image)

| Soil type          | $E_{\text{ref}}^{\text{ref}}$/MPa | $E_{50}^{\text{ref}}$/MPa | $E_{\text{ur}}^{\text{ref}}$/MPa | $C_{\text{ref}}^{\text{ref}}$/KPa | $\phi$° | $R_f$ |
|--------------------|----------------------------------|---------------------------|----------------------------------|----------------------------------|--------|-------|
| ① 填充            | 5.00                             | 5.00                      | 20.00                            | 10.0                             | 28.0   | 0.50  |
| ② 黏土            | 4.63                             | 4.63                      | 23.15                            | 5.6                              | 26.7   | 0.76  |
| ③ 泥状土          | 2.40                             | 3.60                      | 19.20                            | 6.7                              | 24.7   | 0.83  |
| ① 二组中粒土      | 2.07                             | 3.10                      | 16.56                            | 5.9                              | 23.8   | 0.83  |
| ② 二组泥状土      | 2.23                             | 3.35                      | 17.84                            | 6.9                              | 23.7   | 0.83  |
| ③ 二组黏土        | 2.92                             | 2.92                      | 14.60                            | 5.3                              | 23.4   | 0.76  |
| ⑤ 三组黏土        | 6.52                             | 6.52                      | 32.60                            | 24.1                             | 24.9   | 0.76  |
| ⑥ 三组粉土        | 5.95                             | 5.95                      | 29.75                            | 21.8                             | 25.1   | 0.66  |
| ⑦ 三组粘土        | 7.22                             | 7.22                      | 21.66                            | 4.4                              | 28.5   | 0.50  |
| Reinforced soil    | 65                               | 65                        | 195                              | 60.0                             | 25.0   | 0.90  |

4. Comparative analysis of finite element calculation results and monitoring data

4.1. Monitoring point layout
In order to fully understand the deformation and deformation behavior of the deep foundation pit during construction, a number of monitoring work was carried out during the construction of the foundation pit, mainly including: The vertical displacement of the wall of the retaining wall, the horizontal displacement of the retaining wall (the inclined hole), the support axial force, the surface settlement, the settlement of the building, the settlement of the pipeline, the settlement of the column, and the groundwater level. Figure 4 shows the layout of the monitoring points of the foundation pit A, and Figure 5 shows the layout of the monitoring points of the foundation pit B.
4.2. Horizontal displacement curve of diaphragm wall

Compare the calculated value of the numerical simulation with the horizontal displacement value of the ground wall monitored in the field. Figure 6 is a schematic diagram showing the horizontal displacement of the wall of the main foundation pit. Figure 7 is a schematic diagram of the horizontal displacement of the adjacent foundation pit. The monitoring values of the main foundation pit and the auxiliary foundation pits are based on the excavation to the bottom of the foundation pit. It can be seen from Fig. 6 and Fig. 7 that the calculated value and the monitored value are well fitted. The depth monitoring value of the ground wall above 10 m in Fig. 6 almost coincides with the calculated value. The maximum excavation monitoring value of the main foundation pit is 66.66 mm, the calculated value is 62.46 mm, the error is 6.3%; the maximum excavation monitoring value of the attached foundation pit is 22.70 mm, the calculated value is 18.72 mm, the error is 17.5%. It can be seen that the calculated value of the excavation of the auxiliary foundation pit is larger than the calculation value of the excavation of the main foundation pit. Because the disturbance of the auxiliary foundation pit is larger than that of the main foundation pit, the 2D plane model is difficult to completely reflect the engineering conditions.
4.3. Surface subsidence

As shown in Fig. 8 and Fig. 9, the settlement monitoring map of the foundation pit and the numerical simulation results are compared, and the data of the foundation pit excavation to the bottom are selected. It can be seen that the numerical simulation calculation value can be well fitted with the monitoring data, and the curve of the surface settlement is two small and large in the middle. When the main foundation pit is excavated to the bottom, the maximum surface settlement of the monitoring data is -48.60mm, and the calculated maximum surface settlement is 40.28mm with an error of 17.1%. When the auxiliary foundation pit is excavated to the bottom, the maximum surface settlement of the monitoring data is -11.30mm, and the calculated maximum surface settlement is -10.38mm with an error of 8.1%.

5. Conclusion

(1) The finite element numerical simulation results of the horizontal displacement and surface settlement of the ground wall are well fitted with the monitoring data. The finite element numerical simulation based on HS model can be used to simulate the simulation of foundation pit excavation under complex conditions. The simulation results are reasonable and reliable.

(2) It can be seen from the test data and numerical simulation results that the position of the maximum horizontal displacement of the ground wall when the foundation pit is excavated is about 5m above the excavation surface of the foundation pit. Therefore, the data of this project can be used as a reference for design and construction during the excavation of deep foundation pits in similar soft soil layers.

(3) From the monitoring data of the site and the results of finite element numerical simulation, it can be seen that the deformation of the side of the auxiliary foundation pit adjacent to the main pit is relatively small. The maximum horizontal wall displacement of the monitoring data is 34.05% of the main excavation, and the maximum surface settlement is only 23.25% of the main foundation pit
excavation, which proves that the construction method adopted in this project can well control the deformation of the foundation pit.

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