Study on the Influence of Deep Foundation Pit Excavation on Existing Tunnels

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Abstract. The three-dimensional numerical model of station, tunnel and foundation pit is established by using the formation structure method. Considering the interaction between soil and structure, the dewatering of foundation pit and the spatio-temporal effect of foundation pit excavation, the whole construction process is calculated and analyzed, and the tunnel displacement and the response results of the soil pressure of the segments are obtained. The displacement will be used as the external load in the second stage of subsequent analysis. Based on the parameter sensitivity analysis of the influence of deep pit excavation on adjacent station and tunnel structure, the influence of tunnel distance and buried depth on tunnel deformation is discussed. The results show that the finite element simulation results are basically consistent with the measured results. The maximum horizontal displacement of the tunnel is greater than the maximum vertical displacement. The horizontal displacement of the deep tunnel is slightly greater than that of the shallow tunnel, and the vertical displacement is slightly smaller than that of the shallow tunnel.

Keywords: excavation of foundation pit; stratigraphic structure method; tunnel deformation; existing tunnel

1 Introduction

In recent years, with the increase of population in our country, in order to alleviate traffic congestion, underground tunnel traffic develops rapidly. With the continuous development of underground space, external engineering construction such as foundation pit excavation and dewatering operations around the tunnel is very common. The excavation of foundation pit will lead to the unloading of rock and soil mass around the existing tunnel, resulting in the phenomenon of stress redistribution, which may

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lead to the overall large deformation of the tunnel structure, lining cracking and water leakage and many other hazards. More seriously, it will lead to the collapse of the tunnel structure and threaten people's life and property safety. Therefore, it is of great theoretical and engineering significance to study the influence of foundation pit excavation on existing tunnels. At present, relevant scholars at home and abroad have done a series of studies on this subject, mainly including laboratory tests, analytical studies, field measurement and numerical simulation [1].

For the laboratory test methods, the main focus on 1 g similar model box and centrifugal model two aspects. Although the laboratory test method has been widely used, the error between the test results and the actual results is inevitable due to the constraints of the environment and size. At present, the reasoning process of analytical research methods is relatively rigorous [2], but a large number of assumptions are adopted in the derivation process, and its accuracy cannot be fully guaranteed at present. Moreover, this method is highly theoretical and has high requirements for mechanical basis, so it is difficult to carry out practical application and promotion in engineering. In view of the field measurement method, Zhu et al. [3] studied the influence of deep foundation pit excavation on adjacent tunnels based on field monitoring data, and finally pointed out that the construction methods such as partition excavation and addition of enclosure structure can reduce the influence of foundation pit excavation on tunnel structure. Based on field monitoring data, Li et al. [4] proposed a zoning construction scheme based on spatial effect. Although this method of on-site monitoring is closer to reality, in order to obtain more accurate results, the requirements for on-site monitoring instruments are also higher, and there are some limitations. At present, the most commonly used methods of numerical simulation are load structure method and stratum structure method. Domestic and foreign scholars have used various finite element software to carry out relevant research using the above two methods [5-6]. However, most studies only consider the effect of pure foundation pit excavation on existing tunnels, and there is still a lack of studies on the synergistic effect of precipitation and excavation.

To sum up, although domestic and foreign scholars have done a lot of research on the impact of foundation pit excavation on existing tunnels, there are still many shortcomings. In this paper, the three-dimensional numerical model of station - tunnel - foundation pit is established by the method of stratum structure, and the whole process of construction is calculated and analyzed. Based on the parameter sensitivity analysis of the influence of side deep foundation pit excavation on adjacent station and tunnel structure, the influence of tunnel distance and buried depth change on tunnel deformation is discussed, in order to provide theoretical guidance for practical engineering.

2 Project Profile

The foundation pit project under construction is located near Jiubao Street, Jianggan District, Hangzhou, with a total land area of 34,106 m^2 and a total construction area of 110,887 m^2. The excavation sequence is North Zone first, then South Zone, North 2, 4, North 1, 3, 5, South 3, South 1, South 2, and the excavation division is shown in Fig.1. The buried depth of the tunnel arch is about 11 m, the double-line distance is about 6.8 m, and the interval tunnel is about 10.4 m from the outer edge of the foundation pit enclosure.

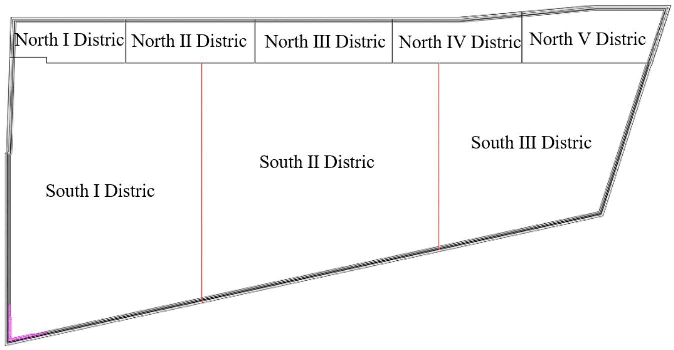


Fig. 1. Pit zoning map

3 Model Establishment and Validity Verification

3.1 Foundation Pit and Station Tunnel Integral Finite Element Model

The whole model basically restores the construction site, in which the subway station, tunnel, foundation pit envelope, horizontal steel support and other structures are set according to the actual scale. The numerical model was established by PLAXIS software. In order to eliminate the boundary effect, the overall modeling size is 350 m × 230 m × 50 m, with a total of 309668 cells and 495,870 nodes. Fig. 2 shows the overall 3D finite element model of the project.

This model considers the dewatering factor of foundation pit excavation, and the water level is 2.3m below the ground elevation. With the progress of foundation pit engineering, the water level of the excavated part in the model is set as dry, and the water level of the soil layer below the excavation is set as interpolated at the elevation of the enclosure structure. This method can simulate the hydrostatic pressure at different depths caused by the change of water level during foundation pit construction.

In finite element calculation, the construction of station and tunnel structure, the construction of envelope structure, and the partition excavation of foundation pit are all set by the activation or not of the unit. The ground stress balance will be carried out in working condition 1. Condition 2 defines the initial state and generates the tunnel structure and station structure. Condition 3 simulates the construction of foundation pit retaining structure, and at the same time, the displacement is reset. Working conditions 4-18 are the excavation process of the foundation pit, the excavation of the foundation pit adopts the partition excavation method, the steel support will be constructed after each stage of excavation, and the water level is 2.3m below the surface.

3.2 Material Parameter Determination

The beam element is used to simulate the steel support, the foundation pit envelope structure, the main structure of the station and the tunnel structure are simulated by the plate element, and the tunnel stiffness is reduced to 0.7 times and 0.2 times along the longitudinal and transverse respectively. The interface element is used to simulate the relationship between the structure and the soil. The Coulomb friction is used as the failure criterion of the interface strength, and the parameters are related to the adjacent soil. The elastic modulus of the section steel bracing, bored pile, Interpolated H-shaped steel and the tunnel is 206 GPa, 31.5 GPa, 206 GPa, and 34.5 GPa.

In order to improve the calculation efficiency and ensure the accuracy of the calculation results, the shallow soft clay is simulated by the small strain soil hardening model (HSS model), and the deep boulder is simulated by the soil hardening model (HS model). The soil model parameters are shown in Table 1.

Table 1. Parameters of physical and mechanical properties of soil

Soil layer number	Name	γ (kN/m^3)	c' (kN/m^2)	ϕ (°)	E_{oed}^{ref} (MPa)	E_{50}^{ref} (MPa)	E_{ur}^{ref} (MPa)
1	Miscellaneous fill	18	2	26	3	3	12
2	Clayey silt	18.4	5	28	8.5	8.5	51
3	Sandy silt	19	6	29	10	10	50
4	Silt inclusion	19.2	6	30	11	11	55
5	Silty clay with silty soil	17.4	2	23	3	3	27
6	Sandy silt type (silty) Silty clay	18.4	4	26	5.5	5.5	33
7	Mucky silty clay	17.4	2	23	3	3	27
8	Sandy silt with silty clay	18.6	4	26	5.5	5.5	33
9	Silty clay	18.2	5	24	4.2	4.2	29.4
10	Sandy silty clay	19	6	24	5	5	30
11	Boulder	20	1	33	25	25	75

3.3 Model Validity Verification

The monitoring data of 0-144m tunnel mileage were selected for comparative analysis. It can be seen from Fig. 3 that the variation trend of the measured horizontal displacement of the tunnel is consistent with that of the calculated results. The maximum value of the measured results is 24.2mm, and the maximum value of the calculated results is 21.2mm, and the overall displacement is within the allowable error range. Due to the construction disturbance and other unstable factors in the actual construction process, the calculated results are less than the measured ones.

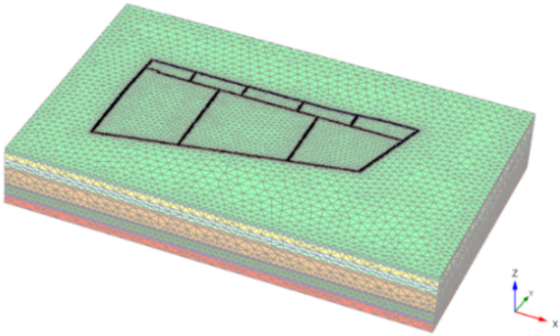


Fig. 2. Pit and tunnel location

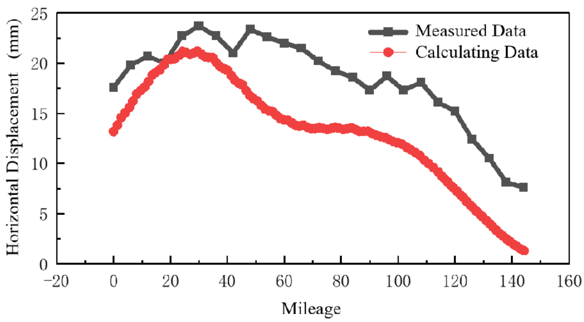
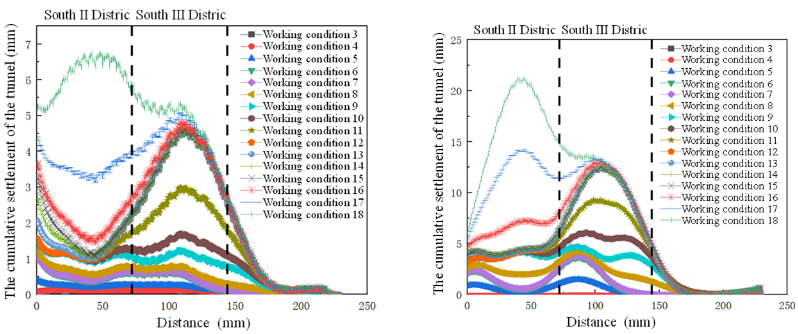


Fig. 3. Comparison between simulation and measured data

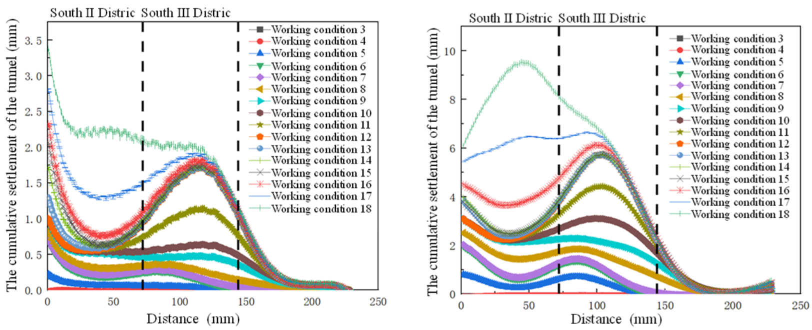
4 Study on the Influence of Tunnel Structure Deformation

Fig.4 and Fig.5 respectively show the longitudinal horizontal deformation and settlement characteristic curves of the tunnel under different conditions. It can be found that with the influence of excavation and unloading effect of the foundation pit in the adjacent zone, the tunnel mainly appears horizontal deformation, which indicates that the unloading effect of the side foundation pit is mainly lateral unloading. The vertical and transverse deformation changes of the tunnel under working conditions 3 to 10 are not large. The reason is that the excavation of the foundation pit in the north zone is carried out in different zones, which reduces the stress release of soil unloading to a certain extent. In addition, the excavation area and depth of each zone are relatively small, and the enclosure structure bears most of the earth pressure. The deformation of the tunnel is wavy. Because the station structure has a certain constraint effect on the deformation of the tunnel, and the corresponding tunnel in the South 3 zone is far away from the foundation pit, the peak value of the wave appears in the corresponding South 2 zone. Working condition 17~18 is foundation pit construction in South 2 Zone, the peak value appears in South 2 zone, and the tunnel deformation reaches the peak value, which is about 35 m away from the station.



(a) Settlement (b) Horizontal displacement

Fig. 4. Longitudinal displacement of upstream line



(a) Settlement (b) Horizontal displacement

Fig. 5. Longitudinal displacement of downstream line

5 Influence of Optimum Design of Tunnel Distance on Tunnel Structure Deformation

The diameter of the subway tunnel is 6.2 meters, and the depth of the upper and lower lines is 14.4 meters. Based on the relationship between the buried depth and twice the tunnel diameter, it can be determined that the whole subway tunnel is in a deep buried state. For ease of calculation, the structure is simplified as shown in Fig.6. The original tunnel is a deep buried tunnel. Assuming that the buried depth of the shallow tunnel is 10.4m, the ideal situation is that the buried depth has an influence on the tunnel. The nearest distance between the outer perimeter of the original foundation pit retaining structure and the tunnel structure is x=10.4 m. In order to explore the influence of different clear distance between foundation pit and tunnel, the clear distance x is: x=10.4, x=9.4, x=8.4, x=7.4. The specific relative position relationship between tunnel and foundation pit is shown in Table 2.

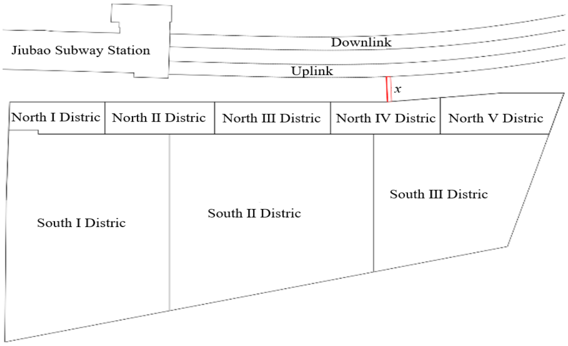


Fig. 6. Simplified model floor plan

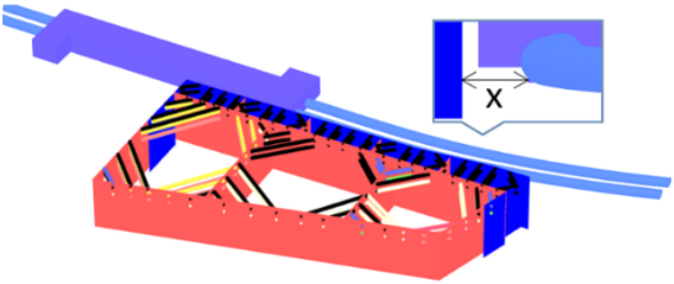


Fig. 7. Simplified model floor plan

Table 2. Relative position of tunnel and foundation pit

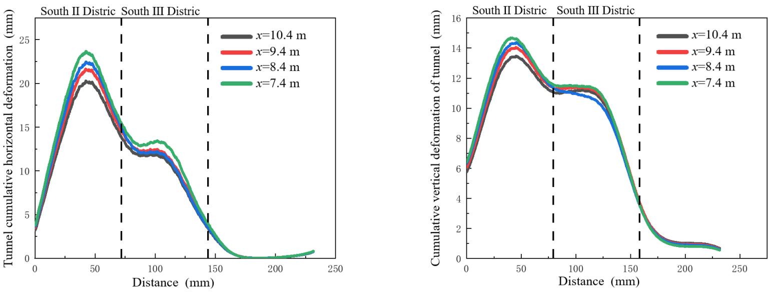
Serial number	burial depth /(m)	Pit tunnel distance（m）	Serial number	burial depth /(m)	Pit tunnel distance（m）
1	10.4	10.4	5	14.4	10.4
2	10.4	9.4	6	14.4	9.4
3	10.4	8.4	7	14.4	8.4
4	10.4	7.4	8	14.4	7.4

5.1 Finite Element Model and Parameter Change of Tunnel Distance of Foundation Pit

The model structure is shown in Fig.7. The material parameters and calculation conditions of the model are consistent with those in Chapter 2.

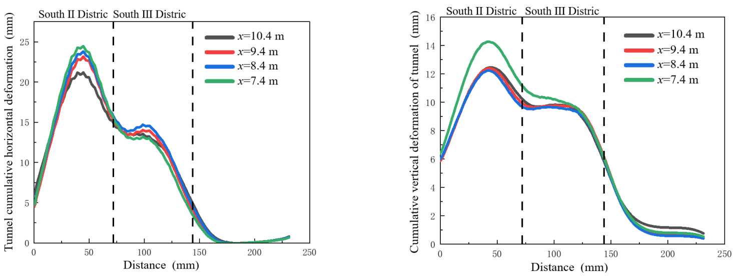
5.2 Finite Element Model and Parameter Change of Tunnel Distance of Foundation Pit

The extraction deformation curves of shallow and deep tunnels with the change of tunnel distance are shown in Fig. 8 and Fig. 9. It can be observed from the longitudinal displacement of the tunnel in the figure that the maximum horizontal displacement of the tunnel is larger than the maximum vertical displacement under different pit and tunnel distances. This means that the excavation of the side foundation pit will have a greater impact on the horizontal deformation of the tunnel. The horizontal deformation of deep buried tunnel is slightly larger than that of shallow buried tunnel, and the vertical deformation is slightly smaller than that of shallow buried tunnel.



(a)Horizontal displacement (b)Vertical displacement

Fig. 8. Shallow buried tunnel displacement with pit-tunnel distance



(a)Horizontal displacement (b)Vertical displacement

Fig. 9. Deeply buried tunnel displacement with pit-tunnel distance variation

6 Conclusions

In this paper, the three-dimensional numerical model of station - tunnel - foundation pit is established by using stratum structure method, and the whole construction process of support engineering is calculated. The main conclusions are as follows:

(1) Under the action of foundation pit excavation in each zone, the maximum deformation of the tunnel appears in the corresponding tunnel range in the north 3 zone. After the completion of foundation pit construction, the maximum horizontal deformation of the tunnel upstream line is 21.2 mm, which is beyond the scope of safety control.

(2) The excavation of side foundation pit will have a greater impact on the horizontal deformation of the tunnel. Horizontal deformation deep buried tunnel is larger than

shallow buried tunnel, vertical deformation deep buried tunnel is smaller than shallow buried tunnel.

(3) Under the influence of unloading effect of excavation, soil pressure in both the upper and lower tunnel shows a downward trend, and is located near the arch waist of one side of the foundation pit. The soil pressure changes most significantly in the horizontal direction, indicating that the unloading effect of excavation of side foundation pit is mainly embodied in horizontal unloading.

Due to the complexity of geotechnical environment, the change of stress and displacement field around tunnel structure during foundation pit excavation is actually a continuous and complex process, which is not fully considered in this paper. Therefore, how to consider this continuous and complex change process needs further study.

Acknowledgments

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