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Analysis of Impact of Bilateral Deep Foundation Pit Excavation on Adjacent Existing Station

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Abstract. Bilateral deep foundation pit excavation has significant influence on the structure and operations of the adjacent existing station. According to the excavation of Changsha railway station on Changsha new metro line 3 adjacent to the existing metro line 2, ABAQUS is applied to simulate dynamically the construction process of the bilateral deep foundation pit. Based on the field monitoring data, the correctness and validity of the model are verified. On this basis, the deformation characteristics of existing stations of bilateral deep foundation pit excavation are analyzed. From three aspects of excavation sequence, excavation depth and excavation width, the station deformation law is studied. The results show that (1) Symmetrical excavation is beneficial to control the horizontal displacement of the station, and asymmetric excavation is beneficial to control the vertical displacement; (2) With the increase of excavation width, the horizontal displacement and vertical displacement of the station increase.

1. Introduction

With the development of subways in cities, the number of subway lines has been increasing and new lines have been interchanged with existing lines that have already been operated. Therefore, studying the influence law of new subway construction on existing lines is of great significance for ensuring the operation of existing lines. Based on the example of foundation pit excavation, Wei [1] proposed an empirical prediction formula for the maximum ridge value of the tunnel. According to the centrifuge model experiment of foundation pit excavation, Shi [2] proposed a simple calculation method for estimating the elevation of adjacent subway tunnels using calculation charts. Based on the Winkler and Pasternak foundation models, Zhang [3] and Liang [4, 5] used a two-stage analysis method to establish a theoretical formula for the longitudinal deformation of subway tunnels under uniform geological conditions. Ng [6] carried out a series of model tests to study the influence of different relative positions of foundation pits and tunnels on tunnel deformation. The results showed that the tunnel is located below the foundation pit and is more affected by the excavation of the upper foundation pit. Huang [7, 8] and Zhang[9] studied the response of the lower tunnel to the excavation of the upper foundation pit through model test, and pointed out that the excavation of the upper



foundation pit caused obvious formation loss, resulting in the longitudinal deformation of the tunnel, which conforms to the Gaussian curve distribution. Zheng [10, 11] used numerical simulation to analyze the deformation law of soil and tunnel. It provides a reference for the reinforcement of the surrounding soil during the excavation of the foundation pit. In order to control the influence of tunnel deformation on the surrounding environment. This paper takes station of Changsha railway line 3 seamlessly docking the existing line 2 project as the background, and studies the influence law of deep foundation pit excavation on the adjacent subway station. The result is seamless for urban new subway construction. Docking existing line construction has important theoretical value and engineering practical significance.

2. Project Overview

The section headings. Changsha railway station of metro line 3 is located on the station road in front of Changsha railway station square, which is the interchange station of line 3 and line 2. The main pit of the station is divided into two foundation pits, north and south, which are located on both sides of the station where the line 2 has been built. The maximum excavation depth of the foundation pits on both sides is 24m, and the excavation width of the standard section is 23.7m. The main body of Line 2 is a box-shaped underground 3-story island station. The new station foundation pit and the existing Line 2 station are seamlessly skewed at an angle of 69.63° . The positional relationship between the foundation pit and the line 2 is shown in Figure 1.

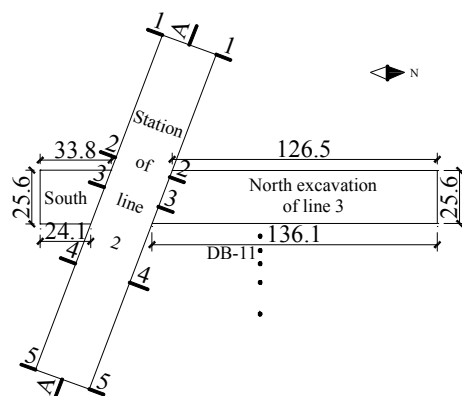


Figure 1. Plane position of foundation pit and station.

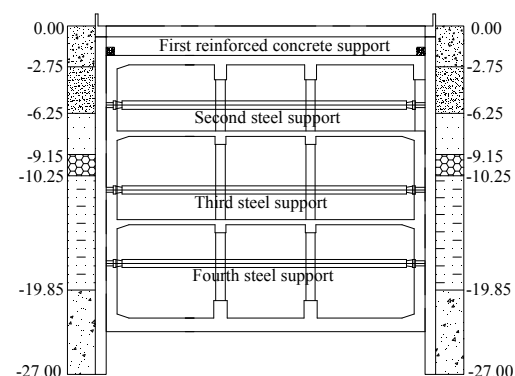


Figure 2. Surrounding soil condition.

The site geomorphology unit of Changsha railway station is the third-order terrace of Xiangjiang River and the floodplain and secondary terrace of Liuyang River, which belongs to the huaxia system. The site is a typical river erosion and accumulation landform. The terrain is relatively flat. It is located on the main road of the city. The ground is distributed in the north, low and south, and there is no liquefiable stratum in the site. It is a general site for construction. The stratum is divided into 6 layers from top to bottom, which are mixed filling, silty clay, round gravel, residual silty clay, strong weathered siltstone, middle weathered siltstone which are showed in fig.2. The main mechanical parameters are shown in Table 1.

Table 1. Mechanical parameters of soils and rocks

Soil name	Bottom depth(m)	$\rho(\text{kg}\cdot\text{m}^{-3})$	$E(\text{MPa})$	ν	$\phi(^{\circ})$	$c(\text{kPa})$
Miscellaneous fill	2.75	1900	5	0.35	10	12
Silty clay	6.25	2000	8	0.3	13	34
Boulder	9.15	2300	35	0.25	40	3
Residual silty clay	10.25	2000	8	0.35	16	40
Strong weathered siltstone	19.85	2300	60	0.28	25	25
Middle weathered siltstone	50.00	2430	6500	0.25	40	100

3. Numerical model and verification

The ABAQUS finite element software was used to establish a numerical model for the influence of foundation pit excavation on both sides of Metro Line 2 on the structure of existing metro stations. In order to minimize the influence of the model boundary conditions on the calculation results, the model size is determined to be 284m long and 189m wide, 50m height, the displacement constraint of X, Y and Z directions is applied to the bottom surface of the soil, and the displacement constraint is applied to the normal direction of the surrounding side to simulate the semi-wireless region of the soil. Line 2 station, retaining wall and the first support adopt reinforced concrete structure whose material adopts the linear elastic material model. The parameters are density $\rho=2400\text{kg/m}^3$, elastic modulus $E=30\text{GPa}$, poisson's ratio $\nu=0.2$. The second, third and fourth supports are steel supports, the support center height are -6m, -12m, -18m. The steel pipe diameter $\phi=609\text{mm}$, the wall thickness $\delta=12\text{mm}$, using the linear elastic model, the material parameter $\rho=7800\text{kg/m}^3$, $E=210\text{GPa}$, $\nu=0.3$. The soil is divided into 6 layers from top to bottom, and the Mohr-Coulomb material model is used whose parameters are shown in Table 1. The reinforced concrete and soil body adopt C3D8 solid element, and the steel support adopts B31 linear beam unit. The contacts between soil and station, between soil and retaining wall, and between station and retaining wall are in contact with each other. The binding constraint between the support and the wall is adopted. In the calculation, the life and death method of each unit is used to simulate the excavation process of the foundation pit. The relationship between the new foundation pit and the existing station is shown in Figure 3. The overall numerical model is shown in Figure 4.

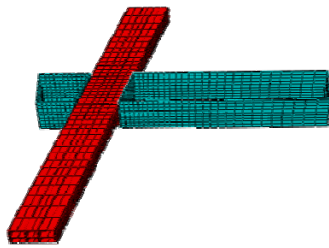


Figure 3. Position of foundation pit and station.

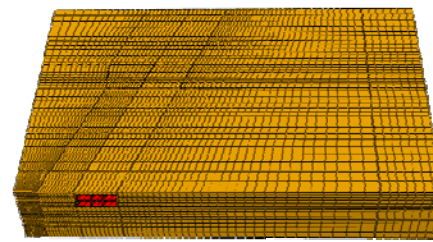


Figure 4. Numerical model.

In order to verify the validity of the numerical model and the correctness of the material parameter selection, the numerical simulation of the excavation scheme 1 shown in Table 2, the numerical simulation results of the ground settlement and the structural deformation of the line 2 during excavation and on-site monitoring the results [12] were compared. Figure 4 is a comparison of the numerical simulation results of the surface settlement of the monitoring section DB-11 and the monitoring results when the excavation depth H is 12m and 24m respectively.

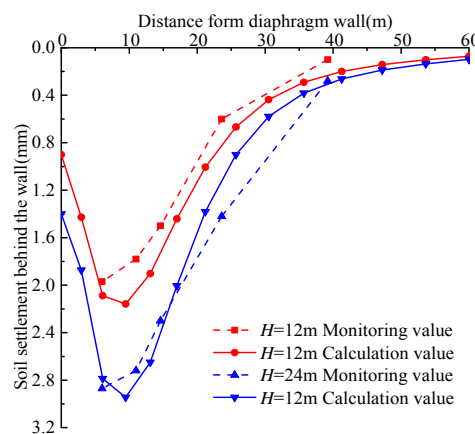


Figure 5. Comparison of calculated value and monitored value of ground settlement behind the wall.

It can be seen from Fig. 5 that the calculated value agrees well with the monitored value. The settlement of the soil after the underground continuous wall is a concave settlement section: the surface settlement gradually increases away from the underground continuous wall and reaches about 10m away from the underground continuous wall. The maximum value decreases as the distance increases. The maximum settlement of the calculated value when the excavation depth is 24m is 2.94mm, and the maximum settlement of the monitored value is 2.87mm, which is 2.44%. When the excavation depth is 12m, the maximum settlement of the calculated value is 2.15mm, and the maximum settlement of the monitored value is 1.97mm, which is 9.14%. Through the above comparative analysis, it can be seen that the calculated values are basically consistent with the on-site monitoring values, indicating the validity of the numerical simulation method and the accuracy of the calculation model and parameters. Therefore, the numerical simulation method can be used to study the excavation of both sides of the deep foundation pit. There are rules of influence of the station.

4. Influence of excavation on both sides of existing pits on existing stations

4.1. Influence of excavation timing on existing stations.

Adjacent to the excavation of the existing subway station, it is necessary to ensure the safe operation of the existing Metro Line 2 station. In order to explore the influence of the foundation pits on both sides of the north and south of the subway station position under different excavation schemes, another two sets of numerical simulation tests were carried out according to scheme 2 and scheme 3 shown in Table 2, and three different excavation schemes were studied. The influence of the subway station on Line 2 is affected.

Table 2. Geotechnical parameters

Scheme	1	2	3
Excavation sequence	Excavation at both sides at the same time	Firstly excavate the south, then excavate the north	Firstly excavate the north, then excavate the south

The positive value of the horizontal displacement indicates that the horizontal displacement of the station is biased toward the north side of the foundation pit, and the negative value indicates that the horizontal displacement of the station is biased toward the south side of the foundation pit.

As shown in Figure 1, the center section A-A of the station roof is selected and the length is section 1-1 to section 5-5. The vertical displacement of the station under three excavation schemes is shown in Figure 6(a). The vertical displacement of the station under the three excavation schemes shows a curve with approximate normal distribution, and the vertical displacement appears as a bulge and the maximum position is located near the middle of the foundation pit. The vertical displacement of the station under the symmetrical excavation scheme is 1.29mm, and the maximum displacements of the firstly south excavation and firstly north excavation are respectively 1.19mm and 1.16mm. The vertical displacement under symmetrical excavation is the largest, which is due to the fact that the excavation stress generated by each layer of soil excavation is greater when the two sides are simultaneously excavated, resulting in greater upward displacement of the soil and the station. For the excavation of the foundation pit on the side of the non-symmetric excavation scheme, taking the excavation of the foundation pit on the north side as an example, the interception of the station blocks the displacement of the soil to the south side. At this time, the station and the unexcavated foundation pit of the soil body together resisted the excavation and weakened the uplift of the station. When excavating the south side foundation pit, since the retaining structure of the north side foundation pit has been formed, it has a certain overall rigidity, and the station resists the uplift caused by the excavation of the south. The vertical displacement of unsymmetrical excavation is smaller than that of the symmetrical excavation.

It can be seen from Figure 6(b) that the positive horizontal displacement is the largest under the first north and south excavation scheme, and the negative horizontal displacement is the largest under

the first south and north excavation schemes. Therefore, the two asymmetric excavation schemes are not conducive to the horizontal displacement of the station. Symmetrical excavation scheme is beneficial to the control of horizontal displacement.

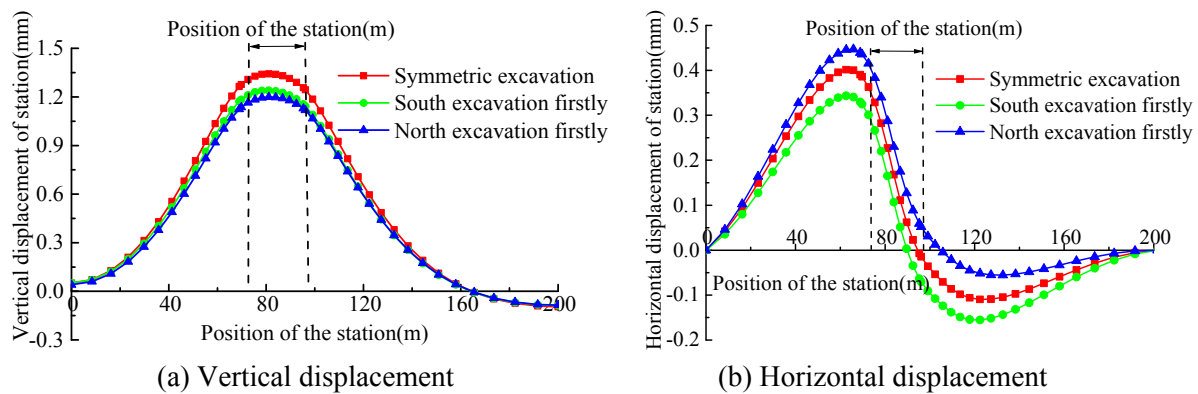


Figure 6. Displacement of the station after the excavation.

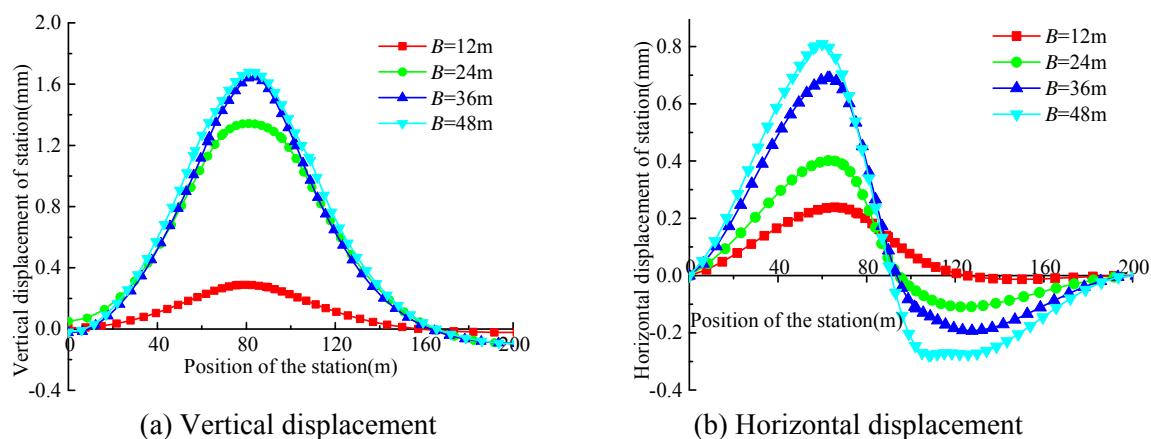


Figure 7. Displacement of the station under different lateral sizes.

4.2. Influence of excavation depth on existing stations

In order to study the influence of the width of the foundation pit on the displacement of the station, the simulation analysis is carried out under the conditions of the foundation pit width B of 12m, 24m, 36m and 48m respectively. The displacement diagram of the station under the four working conditions is shown in Figure 7(a) and 7(b).

As shown in Figure 7(a), it is a comparison of vertical displacement of stations at different widths. The above figure shows that as the width of the foundation pit increases, the vertical displacement of the station increases. The width of the foundation pit is between 12 and 24 m, the vertical displacement of the station increases the most, the increase of 24 to 36 m is the second, and there is almost no increase between 36 and 48 m. This indicates that the vertical position of the foundation pit is increased after reaching a certain range. The influence of the displacement is gradually reduced, which is consistent with the conclusions reached. Therefore, when the width of the foundation pit is between 12 and 36 m, the actual construction should pay attention to the influence of the foundation pit width on the vertical displacement of the station, and measures such as soil reinforcement measures and block construction are adopted to control the vertical displacement of the station.

As shown in Figure 7(b), the horizontal displacement comparison chart of the station at different widths, the maximum forward and maximum negative horizontal displacement of the station gradually increase with the increase of the foundation pit width. And the horizontal displacement of the station

increases the maximum between the width of the foundation pit of 24~36m, and the increase of 12~24m and 36~48m is small. Therefore, when the width of the foundation pit is 24-36m, the control of the horizontal displacement of the station should be strengthened to ensure the safety and operation of the station structure.

5. Conclusion

(1) In the excavation of the foundation pit adjacent to the existing metro station, the symmetric excavation of the foundation pits on both sides is beneficial to the balance of horizontal unloading stress on both sides of the station, and it is easy to control the horizontal displacement of the station; however, the vertical unloading stress generated by symmetric excavation is larger. (2) As the width of the foundation pit increases, the horizontal displacement and vertical displacement of the station will increase accordingly. When the width of the foundation pit is between 12 and 24 m, the vertical displacement of the station increases the most. (3) The width of the foundation pit is between 24 and 36 m, the horizontal displacement of the station increases the most.

Acknowledgments

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