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Study on the Influence of Deep Foundation Pit Construction on the Pile Foundation of Adjacent Existing Stations

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Abstract: *In order to study the influence of deep foundation pit construction on the pile foundation of adjacent existing stations, taking the foundation pit expansion project of underground station hall of Beijing Metro Line 13 as an example, the numerical simulation method and the control variable method were used to quantitatively analyze the influence of foundation pit excavation on the pile foundation displacement of existing stations under the change of parameters such as the distance between foundation pit and pile foundation, the excavation depth of foundation pit and the stiffness of retaining structure. The results show that the decrease in the distance between the foundation pit and the pile foundation and the increase in the excavation depth can significantly increase the horizontal and vertical displacement of the pile foundation. When the distance exceeds 9m, the change rate of vertical displacement is obviously reduced. When the excavation depth exceeds 12 m, the change rate of vertical displacement increases obviously. The stiffness of the retaining structure and the displacement of the pile foundation are basically negatively correlated, and the rate of displacement decreases with the increase in stiffness.*

Keywords: *Deep foundation pit; Numerical calculation; Control variable method; Change rate; Correlation*

1. Introduction

With the rapid development of the urban rail transit industry, most subway stations are often built in the central area of the city, resulting in a complex surrounding environment. Therefore, for the construction of deep foundation pit engineering adjacent to the existing subway station, in addition to ensuring the safety and stability of the new project itself, it is also necessary to ensure the normal and safe operation of the subway station and the deformation of the surrounding buildings to meet the requirements.

At present, a large number of scholars have studied the impact of subway construction on the surrounding environment. The research results mainly focus on the impact of foundation pit excavation on the existing station structure, interval tunnel, and surrounding adjacent buildings[1-5]. Taking the expansion and reconstruction project of Huashi Station of Guangzhou Metro Line 3 as an example, An Donghui et al.[6] studied the influence of transfer reconstruction on the stress and deformation of existing stations under the condition of no reservation by establishing a three-dimensional numerical model. Based on the expansion project of Laojie Station of Shenzhen Metro Line 1, Xu Jianxuan[7] used FLAC 3D finite difference numerical software to calculate and analyze the safety impact of the construction on the existing station structure and surrounding buildings. Hu Jun[8] studied the influence of deep foundation pit excavation on the pile foundation of adjacent existing high-speed railway bridges by numerical simulation, and mainly summarized and analyzed the stress and deformation law of the main retaining structure and pile foundation of the foundation pit. Wei Limin et al.[9] used the combination of field prototype tests and numerical simulation to compare and analyze the influence of foundation pit excavation on adjacent existing bridge pile foundations. Wan Jiacheng, Jiang Jie, et al.[10-11] studied the influence of foundation pit excavation construction on adjacent pile foundations in soft soil areas by establishing a three-dimensional numerical model. Zheng Gang et al.[12] studied the influence of foundation pit excavation on the adjacent pile foundation, and further summarized and analyzed the influence of the distance between the foundation pit and the pile foundation, the stiffness of the pile foundation itself, the vertical load, and constraint conditions on the internal force and

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deformation of the pile foundation.

In this paper, the model is established by Midas GTS NX finite element software based on the foundation pit expansion project of the underground station hall of Beijing metro line 13. The influence of foundation pit dewatering and excavation on the deformation of the pile foundation of the existing subway station is studied, and then the influence of law and related experience are summarized. The research results can provide a reference for similar engineering construction.

2. Establish a three-dimensional numerical model

2.1 Fundamental assumption

(1) It is considered that the soil layer is homogeneous, layered, and isotropic, and the structures such as inner support, column, and supporting pile are regarded as linear elasticity.

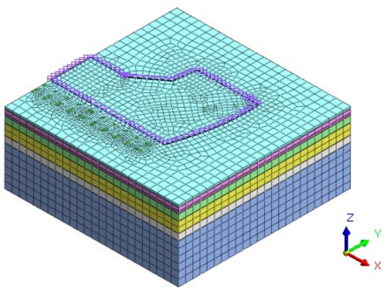
(2) Compared with foundation pit excavation, the influence of retaining structure construction and geological exploration on soil disturbance can be ignored, and only the weight of the soil is considered in modeling analysis.

(3) For the structure in the same soil layer, it is generally considered that the mass per unit volume is certain, and the mechanical properties in all directions are the same.

(4) When the modified Mohr-Coulomb elastoplastic constitutive model is used to simulate the soil, the sliding phenomenon of the retaining structure and the soil under the load is not considered. In addition, the change of soil stress state is not considered in the construction process of the retaining structure.

2.2 Model establishment and boundary conditions

A reasonable analysis range needs to be determined when planning the size of the model. Because the influence area caused by foundation pit excavation construction is limited, when establishing the model, the influence area of the deep foundation pit can be determined according to the influence partition of foundation pit engineering. The influence depth range of foundation pit excavation is generally 2-4 times the excavation depth, and the influence width range is 2-3 times the excavation depth. In this paper, the deep foundation pit of the underground station hall expansion of the station is taken as the research background. The actual length of the deep foundation pit is about 147.23 m, the width is 26.35 ~ 54.88 m, the excavation depth is 8 m, and the depth of the local pit is 21.8 m. Considering the shape and size of the foundation pit, the excavation depth, the engineering hydrogeological conditions, and the surrounding environment of the foundation pit, the size of the simplified model is determined to be 120m × 120m × 50m, and the finite element model is shown in Figure 1. The distance between the retaining pile and the center of the pile foundation of the existing station is 4.4 m, and the position relationship between the foundation pit and the pile foundation is shown in Fig.2. The pile is numbered and sequenced.



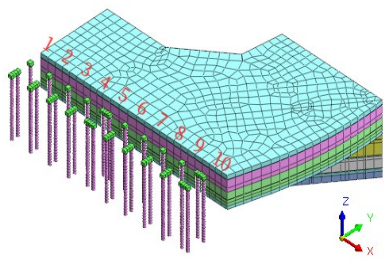


Figure 1: Three-dimensional finite element model. (Left)

Figure 2: Location relationship diagram of foundation pit-existing pile foundation.(Right)

In this paper, the model is established and analyzed by Midas GTS NX finite element software, and the rock and soil mass is simulated by a modified Mohr-Coulomb constitutive model. The retaining pile of the foundation pit is simplified to a 0.6 m thick underground continuous wall according to the principle of equivalent stiffness. When determining the structural unit of the model, the soil of each layer is defined as a 3D solid element, the underground continuous wall is defined as a 2D plate

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element, and the existing pile foundation, column, concrete support, and steel support are defined as 1D beam element for simulation.

The boundary conditions of the model: the uniform load of 200KN / m^2 is applied to the upper surface of the pile cap, and the displacement of the bottom and surroundings of the model is completely constrained.

2.3 Material parameter

The soil layer within the site of the foundation pit is divided into an artificial accumulation layer and a quaternary alluvial layer, a total of 2 layers. According to the lithology and physical and mechanical properties of the soil layer, it is further divided into seven sub-layers. The lithology of the stratum in which the foundation pit is located is mainly clay, silt, sand, and gravel. The groundwater is 4.2 m below the ground, and precipitation should be considered. There is no sand liquefaction problem in the proposed site. The detailed parameters of the soil layer are shown in Table 1.

Table 1: Indicators of soil physical and mechanical properties.

Name of soil layer	thickness/ m	elastic modulus/ (kN/m^2)	permeability coefficient/ (m/d)	poisson ratio	gravity /(kN·m^{-3})	angle of internal friction/(°)	force of cohesion/kPa
miscellaneous fill	1.5	5000	0.2	0.3	17.5	18	12
Silty clay 1	4	9000	0.02	0.3	19.5	25	23
Silty clay 2	4.5	10000	0.02	0.35	19.5	17	24
clayey silt	7.5	20000	0.1	0.35	19.8	25	23
silty fine sand	4.5	7000	6	0.3	18.5	30	30
pebble	28	1500000	60	0.2	20	40	40

2.4 Simulated conditions

The details of the simulated construction process are shown in Table 2.

Table 2: Simulated calculation conditions in construction stage.

Condition number	Working condition content	remark
1	Analysis of initial seepage field	All soil elements and rigidly connected grids are activated, and the boundary conditions activate the initial water level and the total water level in the pit.
2	Analysis of initial stress field	Activate displacement constraints, torsional constraints of existing pile foundations, self-weight and superstructure loads
3	the construction of underground continuous wall	Activate the diaphragm wall, column pile, cut-off curtain, passivation rigid connection grid
4	First excavation	Activation of the crown beam and first internal support, first excavation to -1.5 m
5	First precipitation	Activate the first precipitation, the first precipitation to − 9m.
6	Second excavation	Activate the first waist beam and the second inner support, the second excavation to -8m
7	Second precipitation	Activate the second precipitation, the second precipitation to − 13.6 m.
8	The third excavation	Activation of the second waist beam and the third internal support, excavation to -12.6 m
9	The third precipitation	Activate the third precipitation, the third precipitation to − 18.8 m.
10	The fourth excavation	Activate the third waist beam and the fourth internal support, the fourth excavation to-17.8 m
11	The fourth precipitation	Activate the fourth precipitation, the fourth precipitation to − 22.8 m.
12	The fifth excavation	The fifth excavation to the bottom of the foundation pit-21.8 m, the end of the excavation

3. Calculation Results and Analysis

3.1 Numerical simulation analysis of surface subsidence outside the pit

As shown in Figure 3: Two lines are selected along the edge of the deep foundation pit as the surface settlement measuring points, which are located in two different directions of the deep foundation pit. By extracting the relevant data, the surface settlement curve outside the pit after the excavation of the foundation pit to the base is obtained, as shown in Figure 4. The surface settlement curve outside the pit is consistent with the changing trend of the settlement curve proposed by Peck, showing a groove-shaped distribution. The maximum settlement value of the ground surface outside

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the foundation pit observation point 1 is 4.84mm, and the maximum settlement value of observation point 2 on the right side of the foundation pit is 4.42mm, and both occur about 9m from the edge of the foundation pit.

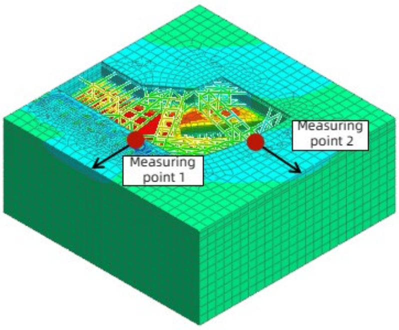


Figure 3: Settlement observation points.

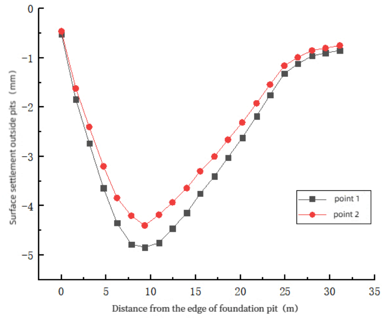
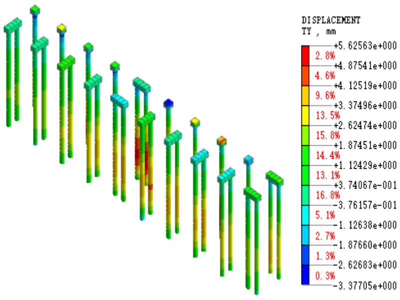


Figure 4: The surface subsidence curve outside the pit.

3.2 Displacement analysis of existing pile foundation

As shown in Fig.5, it can be seen that the pile foundation as a whole has a lateral displacement to the inside of the foundation pit, and the horizontal deformation of the pile foundation on the side closer to the foundation pit is generally greater than the horizontal displacement deformation of the pile foundation on the side farther from the foundation pit. In addition, due to the constraint effect of the cap foundation on the deformation of the top of the pile foundation, the horizontal displacement of the top of the pile foundation is relatively small.

As shown in Fig.6, along the depth direction of the pile foundation, the horizontal displacement of the pile foundation shows a trend of increasing first and then decreasing, and the shape of the change is similar to the side ' U ' type. The horizontal displacement value of the upper part of the pile foundation is greater than that of the lower part of the pile foundation because the soil under the pile foundation is less affected by the disturbance and is almost in a stable state. In terms of specific values, the maximum displacement of the pile foundation caused by each excavation condition is 6.68 mm, which is still within the control range. This also shows that the foundation pit retaining structure system effectively constrains the deformation of the foundation pit.



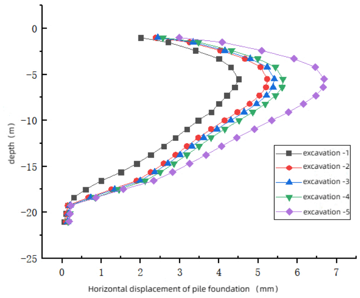


Figure 5: Horizontal displacement diagram of existing pile foundation. (Left)

Figure 6: Horizontal displacement curve of existing pile foundation. (Right)

4. The influence of various parameters on the displacement of pile foundation

In order to further explore the influence of different excavation parameters on the displacement of the existing pile foundation, this chapter, on the basis of the above model, by changing the distance between the foundation pit and the pile foundation, the excavation depth, the size and stiffness of the retaining structure and other conditions, uses the control variable method to further explore the influence of the foundation pit on the deformation of the adjacent existing station pile foundation under different excavation parameters.

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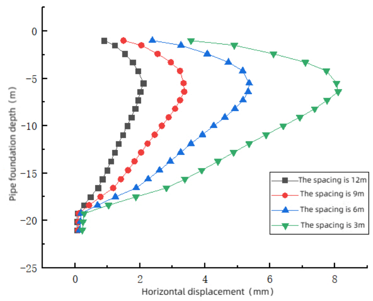
4.1 The influence of the distance between foundation pit and pile foundation on the displacement of pile foundation

The distance between the foundation pit and the pile foundation is set to 3m, 6m, 9m, and 12m respectively for parameter analysis. Under the condition of excavation-5, the influence of the No.6 pile foundation on its displacement at different distances from the foundation pit is selected.

From Figure 7, it can be seen that with the increase of pile foundation and foundation pit, the horizontal displacement of the pile foundation under different working conditions decreases gradually, and each working condition reaches its corresponding horizontal displacement extreme value at about one-third of the upper part of the pile foundation. The maximum horizontal displacement of the pile foundation is 2.1mm, 3.35mm, 5.36mm, and 8.1mm respectively when the distance between the foundation pit and pile foundation is 12m, 9m, 6m, and 3m. When the spacing exceeds 9m, the change rate of the maximum vertical displacement at the top of the existing pile foundation is obviously reduced. It can be seen from Fig.8 that with the increase in the distance between the foundation pit and the pile foundation, the maximum vertical displacement at the top of the pile foundation gradually decreases, and the two are negatively correlated. This is because the farther the distance, the smaller the disturbance effect of foundation pit excavation on the surrounding soil.



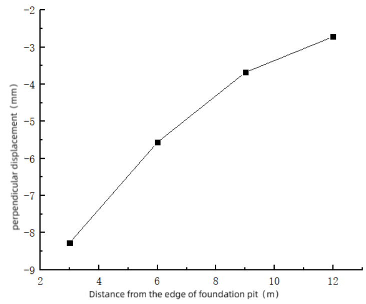


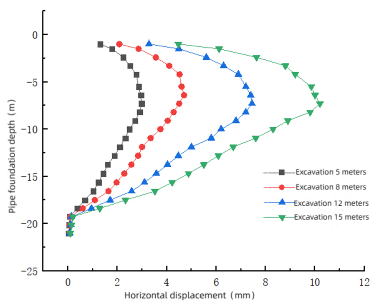
Figure 7: Horizontal displacement curve of pile foundation under different spacing. (Left)

Figure 8: Vertical displacement curve of pile top under different spacing. (Right)

4.2 Influence of excavation depth of foundation pit on displacement of pile foundation

The excavation depth of the foundation pit is set to 5m, 8m, 12m, and 15m respectively for analysis. Under the condition of excavation-5, the influence of different depths of foundation pit excavation on the displacement of the No.6 pile foundation is selected.

It can be seen from Fig.9 and Fig.10 that with the increase of excavation depth, the horizontal displacement and settlement of pile foundations increase gradually, and there is a positive correlation between them. The maximum horizontal displacement of the pile foundation is 2.98mm, 4.5mm, 7.45mm, and 10.2mm respectively when the excavation depth of the foundation pit is 5m, 8m, 12m, and 15m. The corresponding vertical displacement of the pile top is 3.25 mm, 4.96 mm, 7.41 mm, and 10.42 mm. It can be seen that the deeper the excavation, the faster the growth rate of vertical displacement. When the excavation depth of the foundation pit is deeper, effective measures must be taken to strengthen the support, and the displacement deformation and surface settlement of the foundation pit should be monitored in real-time to avoid adverse effects on the surrounding buildings.



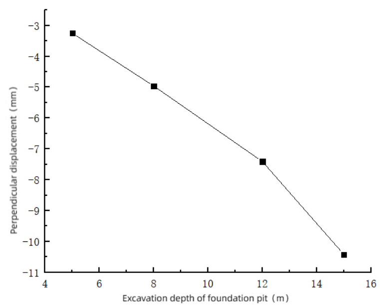


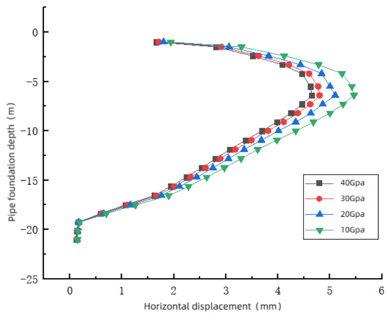
Figure 9: Horizontal displacement curve of pile foundation under different excavation depths. (Left)

Figure 10: Vertical displacement curve of pile top under different excavation depths. (Right)

4.3 The influence of retaining structure stiffness on pile foundation displacement

The stiffness of the retaining structure is set to 10 GPa, 20 GPa, 30 GPa and 40 GPa respectively. Four working conditions are analyzed, and the influence of the No.6 pile foundation on its displacement under different retaining structure stiffness is selected under the condition of excavation-5.

As shown in Figs.11 and 12, the pile foundation is deformed to the side of the foundation pit as a whole. With the increase in the stiffness of the retaining structure, the horizontal displacement of the pile foundation shows a decreasing trend, but the overall change is not large. When the stiffness of the retaining structure is 10 GPa, 20 GPa, 30 GPa and 40 GPa, the maximum horizontal displacement of the pile foundation is 5.46 mm, 5.1 mm, 4.8 mm, and 4.65 mm respectively, and the corresponding vertical displacement of pile top is 6.27 mm, 4.75 mm, 3.52 mm, and 2.89 mm respectively. There is a negative correlation between the stiffness of the retaining structure and the displacement of the pile foundation, and the rate of displacement reduction decreases with the increase in stiffness. When the stiffness reaches a certain critical value, the control effect of increasing the stiffness is not significant. Therefore, in the case of strictly limiting the deformation of the pile foundation, it is necessary to reasonably select the stiffness of the retaining structure and use it in conjunction with other deformation control measures, such as setting up a separation wall, strengthening the soil around the pile foundation, and adjusting the horizontal and vertical spacing of the internal support.



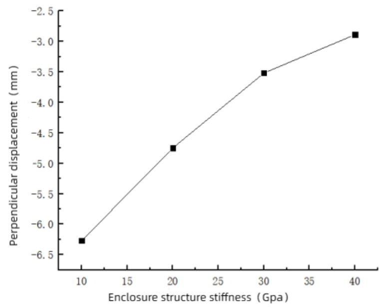


Figure 11: Horizontal displacement curve of pile foundation under different retaining structure stiffness. (Left)

Figure 12: Vertical displacement curve of pile top under different retaining structure stiffness. (Right)

5. Conclusion

In this paper, the influence of foundation pit excavation on the deformation of the pile foundation of the existing station is studied by numerical simulation, taking the foundation pit expansion project of the underground station hall of Dazhongsi Station of Beijing Metro Line 13 as an example. The existing research conclusions are as follows :

(1)The surface settlement curve outside the pit is roughly distributed in a groove shape. The maximum settlement value of the surface outside the pit is 4.42 mm. After that, with the increase of the distance from the foundation pit, the surface settlement value gradually decreases and finally tends to be stable.

(2)The horizontal displacement of the existing pile foundation gradually increases with the advancement of the excavation conditions. On the whole, the horizontal displacement of the pile foundation shows a trend of large in the middle and small on both sides along the depth direction, and the horizontal displacement at the top of the pile foundation is larger than the horizontal displacement at the bottom of the pile foundation. The closer the pile foundation is to the foundation pit, the greater the overall horizontal displacement change, but on the whole, the horizontal displacement value of the existing pile foundation is not large, which is within the safe range.

(3)In this paper, the variation of the displacement of the existing pile foundation under different excavation parameters is studied. By changing the distance between the foundation pit and the pile foundation, the excavation depth of the foundation pit, the size and stiffness of the retaining structure, and the influence of the excavation of the foundation pit on the pile foundation of the adjacent existing station are quantitatively analyzed. The results show that the horizontal displacement growth rate of the pile decreases with the increase of the distance between the foundation pit and the pile foundation, and the displacement change rate of the existing pile foundation is the most obvious at 9 meters. With the increase of excavation depth, the horizontal and vertical displacements of pile foundations increase rapidly. Effective measures must be taken to strengthen the support when the excavation depth of the foundation pit is deep. The stiffness of the retaining structure and the displacement of the pile foundation show a negative correlation with the decrease of the displacement with the increase of the stiffness. When selecting the stiffness, the cost and the actual effect can be considered.

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