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Numerical Analysis of the Influence of Foundation Pit Excavation on the Deformation of an Existing Tunnel

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Abstract: ***In this paper, taking a new hotel project near the existing tunnel as an example, the deformation effect of the existing tunnel during the excavation process is simulated by using the MIDAS GTS NX numerical simulation finite element software, and it is concluded that the excavation and unloading of the foundation pit will cause the vertical settlement displacement and horizontal displacement of the tunnel. Among them, the maximum vertical settlement displacement is 0.47mm, and the maximum horizontal displacement is 0.41mm, which are in line with the local control and early warning values, and the entire foundation pit excavation process is within a safe and controllable range.***

Keywords: Foundation pit excavation, Numerical analysis, Existing tunnels, Deformation**.**

1. Preface

Since entering the 21st century, with the construction of new buildings in the city, the density of buildings has been increasing, and the available space has gradually shrunk. At present, the construction of foundation pit engineering often surrounds buildings, subway lines, pipeline facilities, etc., and the scale of foundation pit excavation is also more and more large and complex, and the excavation depth and area are larger, if the construction site is close to the existing subway line, it will have a greater adverse impact on the subway line.

Whittle et al. [1] used finite element analysis to model top-down construction of a seven-story underground parking lot in Boston Post Office Square. The difference between predicting and measuring wall motion is primarily attributed to post-construction shrinkage of roof and floor systems, while settlement is influenced by pressure elevation modeling in the underlying rock. J.S Sharma et al. [2] established a three-dimensional model based on a deep and large foundation pit to analyze the displacement and internal force changes of the tunnel during the excavation process. Zhou Jiankun et al. [3] established a three-dimensional model based on an example of a project in Shanghai, analyzed the deformation law of the tunnel at different distances between the foundation pit and the adjacent tunnel, and analyzed the inverse relationship between the tunnel deformation and the distance of the foundation pit. Sun Min [4] used the three-dimensional finite element method to simulate the deformation law of the tunnel in the adjacent section of the foundation pit excavation in order to protect the construction of high-rise buildings in Shanghai.

In this paper, taking a new hotel project near the existing tunnel as an example, the MIDAS GTS NX numerical simulation finite element software is used to numerically simulate the deformation effect of the existing tunnel during the excavation of the foundation pit, and the displacement of the two shield tunnels in the X and Y directions during the whole excavation process is analyzed, and the corresponding code values are judged after consulting the specifications, so as to provide some reference experience for similar projects in Changchun in the future.

2. Project Overview

2.1 Overview of the Foundation Pit of the New Project

The new hotel is located on the northeast side of the intersection of Taiyuan East Street and Southeast Lake Road, Nanguan, Changchun. The project is consist of four floors above ground and one basement. The depth of the foundation pit of the proposed project is 4.95m, the slope excavation and steel pipe pile support are adopted, and the precipitation wells are set around the edge of the foundation pit excavation, and the plane size of the foundation pit is 121m×70.86m, and the depth is 4.95m. The excavation of the foundation pit adopts slope excavation and steel pipe pile support (laid along the perimeter of the existing building); Along the perimeter of the foundation pit, there is an inner diameter of 300mm tube well precipitation, with a depth of 12m and a spacing of about 5~6m, which mainly involves the excavation of the soil layer as miscellaneous fill soil and silty clay; The slope hanging net spraying is 80 thick, and the anchor plum blossom arrangement spacing is 1.5m, a total of 3 lines. Reserve 1m working face width at the bottom of the pit.

2.2 Overview of Existing Tunnels

Overview of the project related to the rail transit section: the section is constructed by the shield method, which affects the mileage of the section K36+728.000~K36+966.000, a total of 238m. This section is in the R=336/350m circular curve section, with a connecting channel and a line spacing of about 13~13.4m. Overview of the rail transit section project: the slope of the line is 28‰ and 6‰ respectively, the covering soil of this section is 17.89~22.4m, the water level is buried deep of about 3m, and the interval is mainly in the weathered sandstone and weathered mudstone. Overview of the project of the rail section: the width of the segment ring is 1.2m. The seam connection of the lining ring comprises 16 annular seam connecting bolts (M30) and 12 longitudinal seam connecting bolts (M30); Lining concrete strength class C50, impermeability class P12.

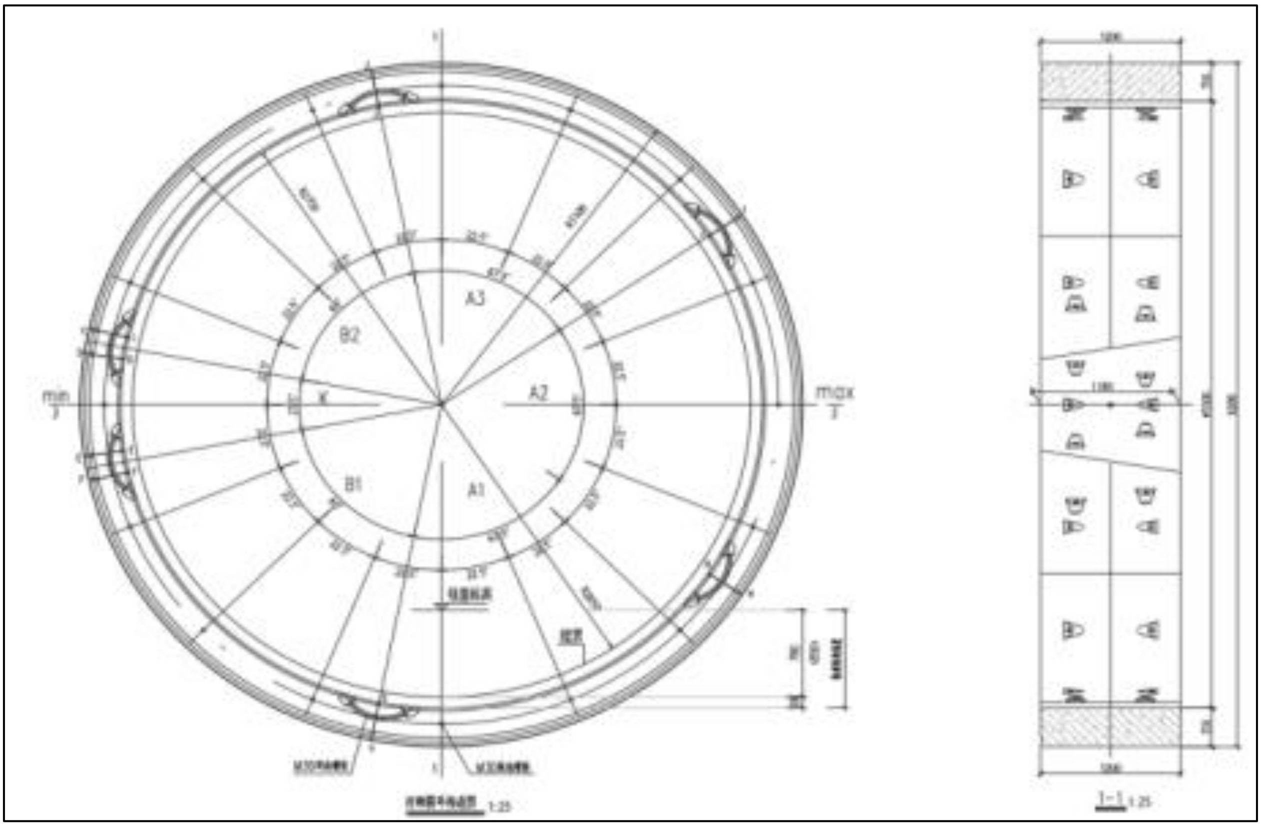

Figure 1: Cross-sectional view of the tunnel section

2.3 The Location Relationship between the Foundation Pit and the Existing Tunnel

Below the proposed project is the section of the first phase of Changchun Rail Transit Line 7 Huizhan Street Station ~ Liberty Road Station during the construction period (track laying has been completed). Will ~ from the interval for a single hole single-line tunnel, the use of shield construction, the affected section of the covering soil of about 17.89~22.4m, the interval where the soil layer is mainly weathered sandstone, the proposed structure across the exhibition street station ~ freedom road station section structure, vertical structure net distance of about 15~16m. The position relationship is shown in the following figure:

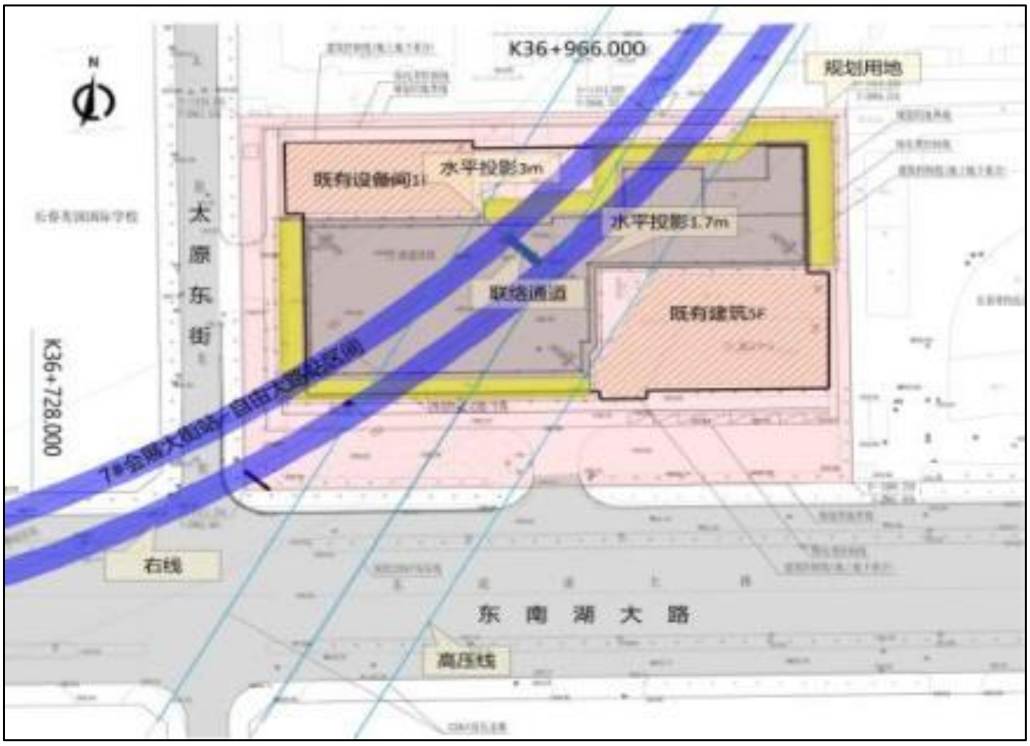

Figure 2: Floor plan

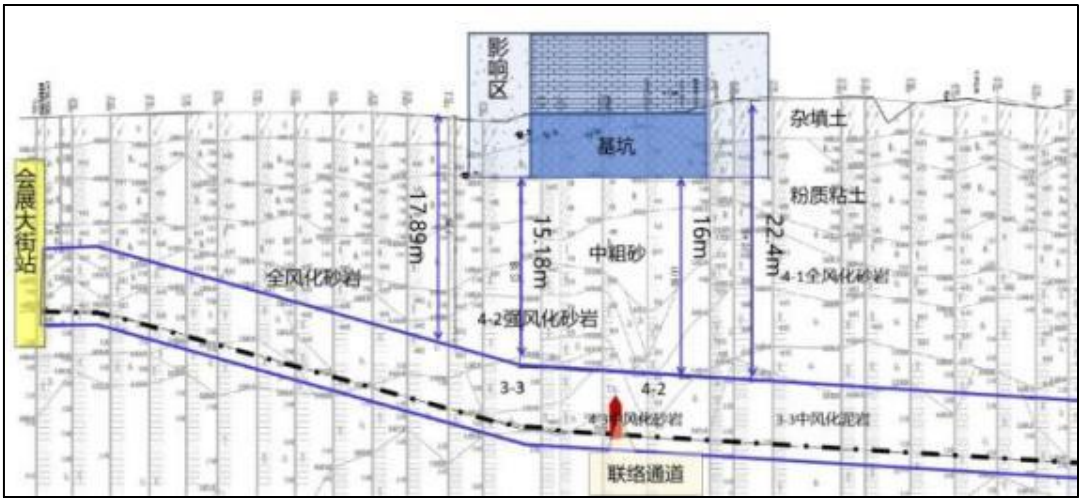

Figure 3: Profile location diagram

2.4 Hydrogeological Overview

According to the drilling data and the results of indoor geotechnical tests, according to the sedimentary age and genesis type of the strata, the soil layers within the exploration scope of the project site are divided into three categories: artificial accumulation layer (Q4ml), Quaternary Holocene alluvial layer (Q4al+pl) and Cretaceous mudstone layer (K). It is further divided into 10 sublayers according to the lithology and physical and mechanical properties of the strata, and the specific mechanical properties and physical indexes of each soil layer are shown in Table 1 below.

3. Numerical Simulation Calculation of Foundation Pit Excavation on Existing Tunnels

3.1 Selection of Calculation Parameters

In this paper, GTS-NX finite element analysis software is used to establish a three-dimensional model of subway tunnel and deep foundation pit. According to the local geological conditions of Changchun, it can be seen from reading the literature that in the process of model calculation, the side walls, enclosure structures and tunnel structures of buildings are all linear elastic models, and the soil are modified Moore Coulomb models, according to the geotechnical engineering investigation report (detailed investigation stage) between Huizhan Street Station ~ Liberty Road Station of the first phase of Changchun Urban Rail Transit Line 7, the properties of each soil layer and the parameters of the tunnel structure are shown in the following table:

Table 1: Numerical simulation calculates the soil parameters of the foundation

The name of the rock and soil layer	γ（kN/m3）	Ccu（kPa）	φcu（°）	E50ref（MPa）	Eoedref（MPa）	Eurref（MPa）	Constitutive
miscellaneous fill 1	17.5	5	8	4.4	4.4	35.2	HSS
Silty clay 2A2	19.2	29	16	4.9	4.9	39.2	HSS
Medium coarse sand 2a7	21	0	28	20	20	160	HSS
Full bloom sandstone 4-1	20.3	35	22	9	9	72	HSS
Strongly weathered sandstone 4-2	21	40	28	35	35	280	HSS
Moderately weathered sandstone4-3	22	100	35	120	120	960	HSS

Table 2: Structural parameters used for numerical simulation

material	Elastic modulus（GPa）	Poisson's ratio（v）	density（ρkg/m3）
C20	25.5	0.2	2450
C30	30.0	0.2	2450
C50	34.5	0.2	2450
HRB400	300	0.3	7850

3.2 Basic Assumptions of the Model

In the simulation analysis, the following assumptions are made: the ideal elastoplastic body of the same soil layer is homogeneous and isotropic, and the Mohr-Coulomb yield criterion and isotropic hardening law are adopted; The assumption that the deformation of the tunnel lining structure is consistent with the deformation of the soil; Before the excavation of the foundation pit, the soil has been consolidated; The soil deformation caused by tunnel excavation has been stabilized; The disturbance caused by the construction process of the diaphragm wall to the surrounding soil and tunnel is not considered.

3.3 Build a Model

The displacement constraints of the calculated model are as follows: the top surface of the model is taken as a free boundary, the side horizontal direction is set as a fixed boundary, and the bottom is also set as a fixed boundary. The loads applied in the model include the self-weight of the material and the uniform load, and the three-dimensional model of 120m×80 m×50m is established considering the disturbance of the excavation of the foundation pit to the surrounding soil and the subway tunnel. The upper boundary of the calculation model is the free boundary, the bottom is fully constrained, and the sides are constrained by the displacement in the vertical plane direction. The finite element type of the whole is an eight-node linear hexahedral element.

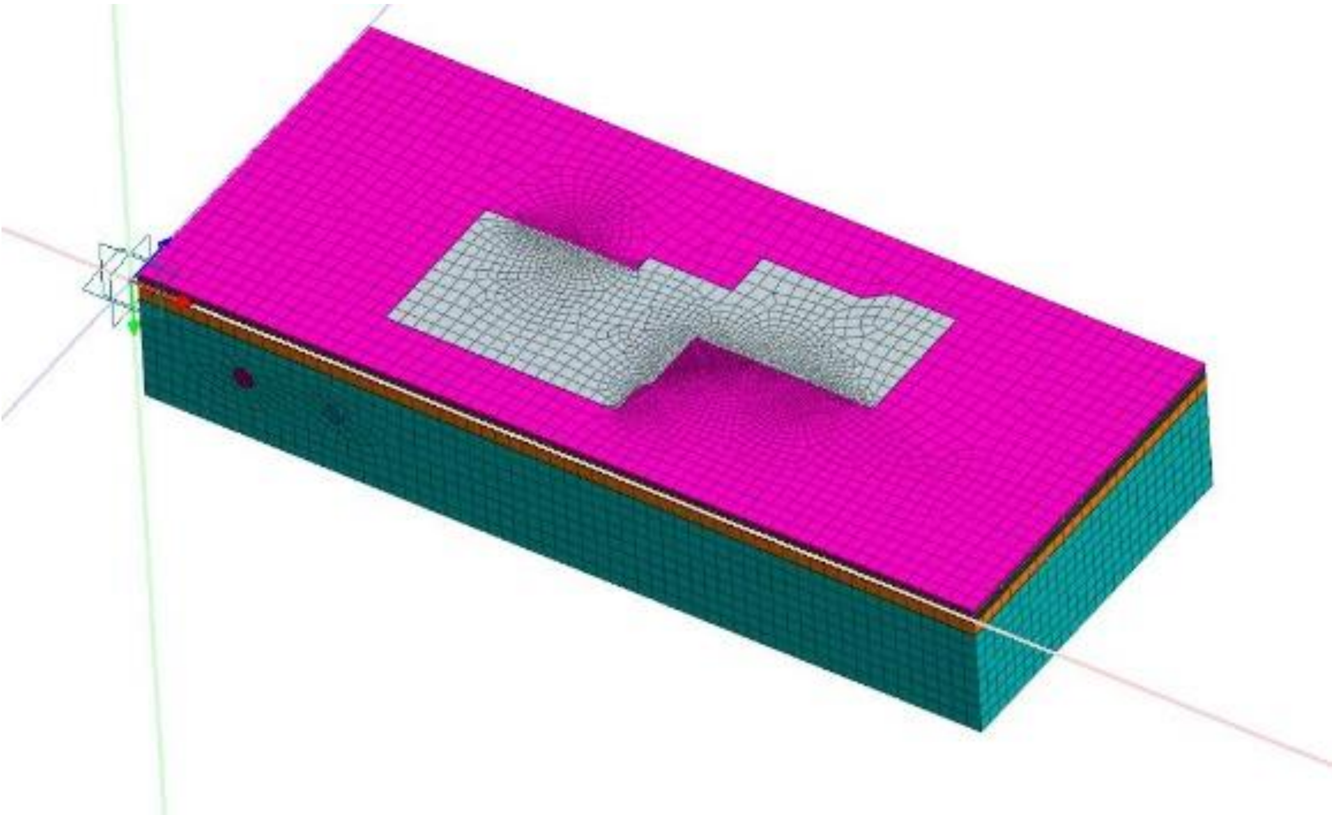

Figure 4: Excavation model diagram

3.4 Simulation Calculations

Before carrying out foundation pit excavation, the initial in-situ stress balance is carried out, and then the spraying and cast-in-place pile construction is carried out to eliminate the displacement, the foundation pit excavation is carried out, the first layer of internal support is laid when the excavation reaches the first layer, and then the second and third excavation is carried out, etc., and finally the bottom plate is poured after excavation to the bottom layer.

Working condition 0: Initial in-situ stress equilibrium;

Working condition 1: Tunnel excavation, the displacement generated during tunnel excavation is not calculated.

Working condition 2: Shotcrete and steel pipe pile support excavation are carried out, and the displacement generated by this condition is not calculated.

Working condition 3: Carry out foundation pit excavation, and when the foundation pit is excavated to 1m, lay the first layer of internal support.

Working condition 4: When the foundation pit is excavated for 2.5m, the second layer of internal support is laid.

Working condition 5: when the foundation pit is excavated for 4m, the third layer of internal support is laid.

Working condition 6: excavate the foundation pit to the bottom, and carry out cushion and bottom plate construction.

4. Simulation Results and Analysis

Through the MIDAS GTS NX numerical simulation finite element software, the horizontal displacement and vertical displacement contours of the subway tunnel under each working condition under the following excavation and unloading of foundation pit excavation are obtained, as shown in the following figure:

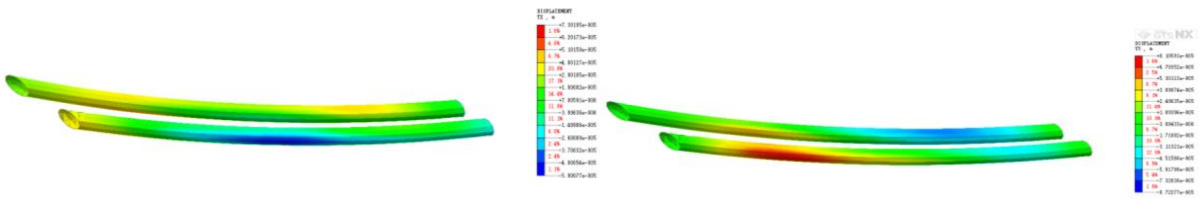

Figure 5: Contour diagram of horizontal displacement and vertical displacement of tunnel section under condition 3

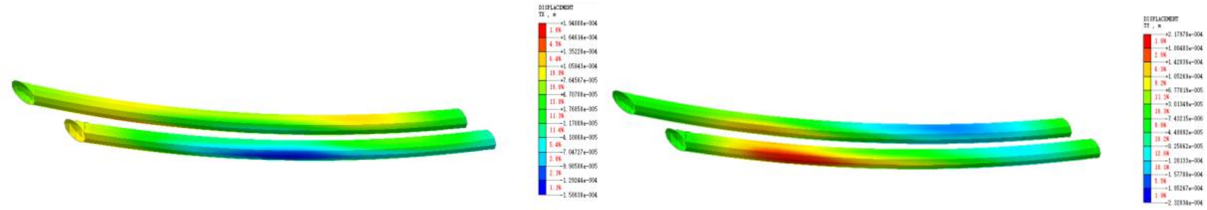

Figure 6: Contour diagram of horizontal displacement and vertical displacement of tunnel section under condition 4

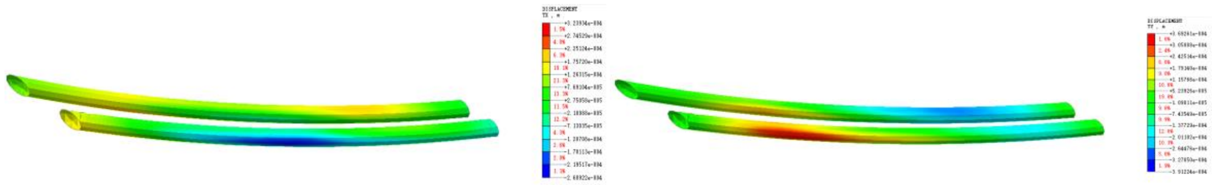

Figure 7: Contour diagram of horizontal displacement and vertical displacement of tunnel section under condition 5

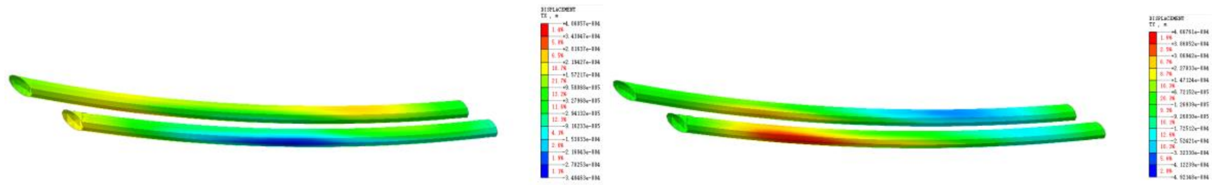

Figure 8: Contour diagram of horizontal displacement and vertical displacement of tunnel section under condition 6

In the excavation and unloading stage of foundation pit, the horizontal displacement to the direction of the foundation pit and the settlement along the direction of the soil depth will occur in the tunnel section. As can be seen from the figure, the maximum horizontal displacement of the tunnel interval is 0.41mm, the maximum settlement displacement is 0.47mm, and the maximum settlement displacement is 0.06mm larger than the maximum horizontal displacement.

5. Conclusion

Through the numerical simulation analysis of the deformation of the existing tunnel caused by the excavation and unloading of the foundation pit of a new project, it is known that the excavation of the foundation pit will cause the vertical settlement and horizontal displacement of the existing tunnel. The characteristics of the overall displacement are summarized as the greater the horizontal distance from the foundation pit, the greater the displacement. According to the final results, the maximum vertical settlement value of the tunnel is 0.47 mm, and the maximum horizontal displacement is 0.41 mm.

To sum up, the deformation value of the existing tunnel caused by the excavation of the foundation pit of the project is within a safe and controllable range.

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