Study on the Influence of Large-Span Open-Cut Foundation Pits over Existing Intercity Railway

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Abstract. As an important way to solve the problems of urban public transportation, urban rail transit has been comprehensively developed in urban construction. However, the subsequent construction of municipal engineering will affect the deformation of the underlying subway tunnel due to excavation and unloading. Aiming at the excavation of the foundation pit of the upper-span intercity railway tunnel section, by optimizing the construction technology, it is proposed to excavate in stages, small pits and small silos, and Midas GTS is used to establish a finite element model of foundation pit construction. The deformation and force influence of the existing tunnel structure underneath have been analyzed in detail. The method of excavation by stages, small pits and small silos can be used. And the technical methods adopted can reduce the impact of soil unloading on the underlying tunnel and ensure the safety and quality of foundation pit excavation. The project provides a reference basis.

1. Introduction

As an important way to solve the problems of urban public transportation, urban rail transit has been comprehensively developed in urban construction. However, the subsequent construction of municipal engineering will affect the deformation of the underlying subway tunnel due to excavation and unloading [1-4].

Through on-site monitoring and measurement, Li Donghai proved that the excavation unloading resulted in different temporal and spatial distributions of the longitudinal deformation of the existing primary tunnel underneath. He also pointed out that the effect of time and space on the longitudinal deformation of the underlying primary tunnel cannot be ignored. Moreover, the speed and method of unloading of foundation pit excavation are one of the key factors that directly affect the longitudinal deformation of the existing tunnel [5]. Zhang Chengping conducted deformation monitoring on the construction process of the subway station constructed by the undercut method under the existing subway tunnel, and found that the structural deformation of the existing subway tunnel caused by the construction was mainly settlement, which mainly occurred in the pilot tunnel construction stage; the tunnel structure was present Rigid body characteristics, the settlement curve is approximately linear, the maximum settlement of the tunnel structure at the deformation joint is 31.26 mm, and the maximum differential settlement on both sides of the deformation joint is 14.0 mm; the track bed shows a certain flexibility, and the settlement curve is nonlinear; uncoordinated settlement causes the track bed and the tunnel The structure has disengaged, the maximum disengagement value is 12.7 mm, and the maximum disengagement range is 7.0 m [6]. Zhang Zhiguo [7] used the elastic layered half space foundation model to establish the continuous elastic analysis method of the influence of tunnel excavation on adjacent existing tunnels in multi-layer foundation, which changed the situation that the
simplified analysis method could only solve such engineering problems in homogeneous foundation in the past. The results can provide certain basis for reasonably formulating the protection measures for the adjacent existing tunnels in the underground engineering construction. He Meide [8] takes the construction of large section pedestrian passage crossing the shield tunnel of subway in Beijing as the background, and according to the field measured data, the vertical displacement, horizontal convergence displacement and vertical displacement of track bed structure of subway east and West lines are analyzed. Based on the comparative analysis of the typical monitoring sections of the East and west line tunnels, the influence relationship between the two indexes of the covering span ratio and the thickness of the intercalated soil layer on the deformation is obtained. Based on the foundation pit engineering of Tianhe Road node box tunnel over the existing metro tunnel in the north extension project of Liede Bridge, Huang Haibin designs and analyzes the supporting structure and foundation pit excavation method of the project, and points out that the rebound of the foundation soil and the deformation of the existing subway tunnel can be effectively controlled by using manual strip drawing slope excavation and plate anchor support [9]. In order to improve the disaster prevention and mitigation ability of subway shield tunnel, Yao Aijun, based on a typical subway shield tunnel in Beijing and its adjacent foundation pit, applied the method of similar material model test and numerical simulation to study the deformation characteristics and surrounding earth pressure distribution law of subway shield tunnel under the unloading loading of excavation above the foundation pit, and analyzed the deformation characteristics and surrounding soil pressure distribution law of the subway shield tunnel under the unloading loading and unloading of the upper foundation pit. The influence of clear distance and loading strength of foundation pit is analyzed [10]. The disturbance of the soil above the existing structure will cause changes in the local stress field and displacement field, which will affect the structure. How to smoothly excavate and unload without affecting the safety and quality of the structure is the focus and difficulty of the work. This paper studies the safety protection scheme for the upper intercity railway section of a certain tunnel project in Zhuhai. Based on the geological survey data, the soil layers are classified according to their types and characteristics. Midas GTS is used to model the portal reinforced structure and existing tunnels. The construction steps are established in accordance with the actual construction in stages, and the foundation pit is dewatered or not. Establish construction conditions for the two conditions of precipitation. Analyze the displacement and stress results and evaluate the safety and stability of the existing intercity railway during the construction process.

2. Project Overview and Hydrogeology

2.1. Project Overview
The open-cut tunnel to be excavated is located on the intercity railway that has been laid and opened to traffic, and orthogonal to the intersection, as shown in figure 1. The intercity railway tunnel adopts a shield tunnel with a buried depth of about 18.2 m, an outer diameter of 8.5 m, and an inner diameter of 7.7 m. The length of the intersection between the main line of the open-cut tunnel and the intercity railway tunnel is 40 m, and the clear distance between the bottom of the open-cut tunnel structure and the intercity railway tunnel is 7.83~8.89 m, as shown in figure 2. The width of the foundation pit of the open-cut tunnel to be excavated is about 17.1 m, and the depth is about 8.38~10.3 m. According to the wave speed test conducted by the borehole, the soil type of the site is judged. The artificial fill, silt, and silty soil distributed along the tunnel are all soft and weak soil; the plastic silty clay, coarse sand, and gravel sand are medium-soft soil; Hard plastic residual soil and fully weathered soil are medium-hard soil; strongly weathered rock and medium weathered rock are hard soil or soft rock. Among them, the artificial fill is mainly plain fill, which is distributed on the surface, and locally contains a lot of granite boulders and gravel. Its compactness is uneven, the structure is loose, and the self-stability is poor, which is easy to produce in the tunnel excavation section. Instability and collapse; the silt and silty soil generally distributed in this section are buried deep and thick (average 10.21 m and 7.55 m respectively), which has a great impact on the construction of the tunnel.
2.2. Model Building
The numerical modeling of this project is based on the Midas GTS finite element calculation software. The horizontal geometric dimension of the foundation pit is 3~5 times or more of the excavation depth of the foundation pit, and the vertical direction is 2~4 times or more. The dimensions x, y, and z are 150m, 150m, and 70m, respectively, as shown in figure 3. Horizontal and vertical constraints are added to the side and bottom of the model, and no constraints are added to the top surface. In the analysis, the vertical displacement of the bottom of the finite element model and the normal displacement of each side of the model are constrained, and the deformation, bending moment and shear force of each supporting structure in the model are calculated, as shown in figure 4.

2.3. Parameters
According to the geological age, genetic type, lithological characteristics, weathering degree and other engineering characteristics and regional stratigraphic data of the stratum exposed in the site, the rock and soil layers in the site are divided into eight layers: artificial origin \((Q_{me})\) plain fill 1-1, alluvial fill 1-2; Mud 2-1, coarse sand 2-2, silty clay 2-3, silty soil 2-4 and gravel sand 2-5 layers of sea-land alternate sedimentary origin \((Q_{ms})\); residual origin \((Q^{r})\) Sandy clay soil 3; Yanshanian (γ) fully weathered granite 4-1, strongly weathered granite 4-2, moderately weathered granite 4-3; the detailed physical calculation parameters of each layer are shown in table 1:
Table 1. Soil parameter and constitutive relationship.

| Stratum name        | Shear strength (fast cut) φ (°) | Density γ (kN/m³) | Compression modulus Es (MPa) | Deformation modulus E₀(MPa) | Poisson’s ratio | Constitutive relationship |
|---------------------|--------------------------------|-------------------|-------------------------------|-----------------------------|----------------|--------------------------|
| Artificial fill     | 10                             | 18.0              | -                            | -                           | 0.35           | Elasticity               |
| Silt                | 3                               | 16.6              | 1.53                         | -                           | 0.4            | Elasticity               |
| Coarse sand         | 30                              | 19.5              | 1.8                          | 35                          | 0.26           | Elasticity               |
| Silty clay          | 4.6                             | 17.8              | 2.5                          | -                           | 0.39           | Elasticity               |
| Sandy clay          | 20.1                            | 19.0              | 4.8                          | 49                          | 0.25           | Elasticity               |
| Fully weathered granite | 24                          | 19.0              | 5.1                          | 89                          | 0.30           | Elasticity               |
| Fully weathered granite | 25                          | 20                | -                            | 160                         | 0.23           | Elasticity               |
| Moderately Weathered Granite | *33                      | 25.5              | -                            | 2000                        | 0.15           | Elasticity               |

Model the foundation pit support parameters provided by the design instructions. The support structure parameters and constitutive relationships used in the simulation process are shown in the table 2:

Table 2. Supporting parameters and constitutive relationship.

| Name                          | Material               | Modulus of elasticity (kPa) | Bulk density (g/cm³) | Poisson’s ratio | Constitutive relationship |
|-------------------------------|------------------------|----------------------------|----------------------|----------------|---------------------------|
| Reinforced concrete crown beam | C35 Concrete          | 3.15×10⁷                   | 25                   | 0.3            | Elasticity                |
| Reinforced concrete support   | C30 Concrete           | 3.00×10⁷                   | 25                   | 0.3            | Elasticity                |
| I-beam purlin                 | Steel                  | 2.06×10⁸                   | 78.5                 | 0.25           | Elasticity                |

3. Working Condition and Result Analysis

3.1. Working Condition
This analysis is mainly divided into two working conditions, setting precipitation and no precipitation, as shown in table 3. The working conditions include 13 construction steps. The main loads in the calculation process include dead weight and construction machinery load of 20 kPa.

Table 3. Working condition design.

| Working condition | Content                                                                                           |
|-------------------|---------------------------------------------------------------------------------------------------|
| 1                 | Before the excavation of the foundation pit, the water will be lowered to 0.5 m below the bottom. |
| 2                 | No precipitation.                                                                                 |

The excavation process is divided into 13 steps, and as follows: Initial stress analysis; Urban rail tunnel construction; Reinforcement of soil around foundation pit and construction of H-shaped pile wall; Excavation of the first layer of the first stage foundation pit; Excavation of the second layer of the first stage foundation pit; Excavation of the third layer of the first stage foundation pit; Excavation of the fourth layer of the first stage foundation pit; Demolition of the second and third steel pipe braces of the first-stage foundation pit, construction of the first-stage tunnel structure; Excavation of the first layer of the second stage foundation pit; Excavation of the second layer of the second stage foundation pit; Excavation of the third layer of the second stage foundation pit. Excavation of the fourth layer of the second stage foundation pit; Demolition of the second and third steel pipe braces of the second-stage foundation pit, construction of the second-stage tunnel structure, as shown in figure 5.
Figure 5. Stage excavation process.
3.2. Results and Analysis
In the construction process of the foundation pit dewatering (i.e. working condition 1), the most unfavorable situation is selected-in the case of construction step 7 (stage 1 foundation pit excavation 4), calculate the right-line tunnel in the y and z directions Maximum displacement; and construction step 12 (Phase 2 foundation pit excavation 4), calculate the maximum displacement of the left tunnel in the y and z directions, as shown in figures 6-9.

Figure 6. The first-stage foundation pit excavation 4 right line tunnel Y direction displacement.

Figure 7. The first-stage foundation pit excavation 4 right line tunnel Z direction displacement.

Figure 8. The second-stage foundation pit excavation 4 right line tunnel Y direction displacement.
Figure 9. The second-stage foundation pit excavation 4 right line tunnel Z direction displacement direction displacement.

For condition 1 (dewatering), during the construction process, the maximum displacement in the y direction of the right tunnel is 3.19mm, when the first phase of the foundation pit is excavated to the bottom of the pit; the right tunnel has a maximum displacement of 8.08mm in the Z direction during the first phase of the foundation When the pit is excavated to the bottom of the pit; the maximum displacement in the Y direction of the left-line tunnel is 3.97 mm, when the second-stage foundation pit is excavated to the bottom of the pit; the left-line tunnel’s maximum displacement in the Z direction is 8.62 mm, which is reached in the second-stage foundation pit at the bottom of the pit, as shown in table 4.

Table 4. Summary of the maximum displacement of the Zhujiang machine tunnel under various working conditions.

| Step | Working condition | Displacement-y (mm) | Displacement-z (mm) |
|------|-------------------|---------------------|---------------------|
| 4    | First-stage foundation pit construction (Above the right tunnel) | 1 | 0.44 | 1.41 |
|      | 2                  |                     |                     |
| 5    | 1                  | 0.73                | 1.94                |
|      | 2                  | 1.39                | 3.34                |
| 6    | 1                  | 1.64                | 3.86                |
|      | 2                  | 2.43                | 5.73                |
| 7    | 1                  | 2.81                | 6.27                |
|      | 2                  | 3.19                | 8.08                |
| 8    | 1                  | 3.56                | 9.75                |
|      | 2                  | 1.58                | 3.47                |
| 9    | 1                  | 1.92                | 4.02                |
|      | 2                  | 0.61                | 1.68                |
| 10   | 1                  | 1.04                | 2.12                |
|      | 2                  | 1.46                | 3.69                |
| 11   | Second-stage foundation pit construction (Above the left tunnel) | 1 | 1.91 | 4.03 |
|      | 2                  |                     |                     |
| 12   | 1                  | 2.64                | 5.91                |
|      | 2                  | 3.11                | 6.79                |
| 13   | 1                  | 3.97                | 8.62                |
|      | 2                  | 4.43                | 9.83                |
|      | 1                  | 1.81                | 3.75                |
|      | 2                  | 2.35                | 3.96                |

For condition two, during the construction process, the maximum displacement in the Y direction of the right tunnel is 3.56 mm, when the first phase of the foundation pit is excavated to the bottom;
the right tunnel has a maximum displacement of 9.75 mm in the Z direction, and the first phase of the foundation pit is excavated. When reaching the bottom of the pit; the maximum displacement in the y-direction of the left tunnel is 4.43 mm, when the second-stage foundation pit is excavated to the bottom of the pit; the maximum displacement in the z-direction of the left tunnel is 9.83 mm, when the second-stage foundation pit is excavated to the bottom of the pit.

The displacement of the intercity railway tunnel structure in all directions increases with the increase of the excavation depth of the foundation pit. The z-direction displacement of the intercity railway tunnel structure under the condition of working condition 2 (no precipitation) changes significantly from that of the condition of working condition 1 (precipitation). It can be seen that precipitation has an impact on the structural displacement of the intercity railway tunnel.

According to the CJJ/T202-2013 specification of “Technical Specification for Safety Protection of Urban Rail Transit Structures”, the vertical and horizontal displacements of the intercity railway tunnel caused by each construction process should be less than the limit of 20mm, so there are left and right tunnels of the intercity railway. The structure is in a safe state.

4. Conclusion
The finite element model of foundation pit construction is established through Midas GTS, and the influence of foundation pit excavation on the deformation and force of the existing tunnel structure underneath is analyzed in detail. The method of excavation by stages, small pits and small silos can be used. Reduce the impact of soil unloading on the underlying tunnel and ensure the safety and quality of foundation pit excavation.

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