Original Research Article

Influence and Safety Evaluation of Underground Structure Construction on Adjacent Existing Subway Section

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Abstract: In recent years, with the rapid development of subway and underground comprehensive pipe corridor, the problem of close connection between underground structure and existing subway section structure is often encountered in engineering construction. During construction, the newly built underground structure will disturb the stratum, easily cause the additional displacement deformation and internal force change of the existing tunnel structure, and then lead to safety accidents. Therefore, it is particularly important to analyze the influence and safety evaluation of the new construction on the existing subway structure. This paper takes the construction of new underground power pipe gallery close to the existing subway section as an engineering case. The influence of adjacent construction on the existing structure is analyzed by three-dimensional finite element method, and then the safety of the existing structure is evaluated through deformation prediction, internal force analysis and bearing capacity checking calculation, and some construction safety protection suggestions are put forward. It has a certain reference for similar proximity projects.

Keywords: Underground structure; Adjacent, Influence; Subway; Safety evaluation.

1. Introduction

With the development of economy and society, the development and utilization of urban underground space are becoming more and more sufficient, and the construction of infrastructure such as underground comprehensive pipeline networks is increasing day by day. However, in recent years, the rapid development of urban underground rail transit has led to frequent occurrences of urban municipal pipe networks approaching the construction of existing subway sections[1,2]. It is particularly important to carry out new construction projects reasonably without affecting the safety conditions of existing subway structures. If there are improper measures, the consequences will be unimaginable. The excavation of a deep foundation pit near a subway in Taipei City caused damage to the wall of the adjacent tunnel, resulting in huge economic losses[4].

Therefore, it is of great practical significance to study the effects of new construction projects on the stress and deformation of adjacent subway tunnel structures[4]. This article takes the construction of a new underground power pipe gallery adjacent to a shield tunnel section of a rail transit as an engineering case, analyzes the influencing factors of adjacent construction, and uses numerical calculation methods to predict the additional displacement deformation and internal force changes of the subway section structure caused by the new construction project. Based on this, the impact on the adjacent existing subway structure is evaluated, and relevant protection suggestions are proposed, providing some reference and reference for subsequent projects.

2. Project Overview

2.1 Overview and Proximity Relationship of Newly Constructed Structures

Based on the project, a shield tunneling section of Jinan Metro has been completed. The power pipe gallery is located on the upper right slope of the section tunnel. The minimum horizontal distance between the tunnel structure and the foundation pit is about 4 meters, the vertical distance is about 5.2 meters, and the diagonal net distance is about 7.86 meters.

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The newly constructed underground power pipe gallery is a double ditch structure with a clearance size of 2.3m ∗ 2.4m ∗ 2, located on the north side of the newly constructed road. The cushion layer of the power pipe trench is made of C15 concrete with a thickness of 10cm, and the thickness of the bottom plate, side walls, and top plate is 30cm. C30 (P6) reinforced concrete is used. The design of the trench foundation pit adopts natural slope excavation, and after the pouring of the pipe gallery structure is completed, it is covered with soil and backfilled. The position relationship between the newly constructed power pipeline trench and the existing section tunnel is shown in Figures 1 and 2.

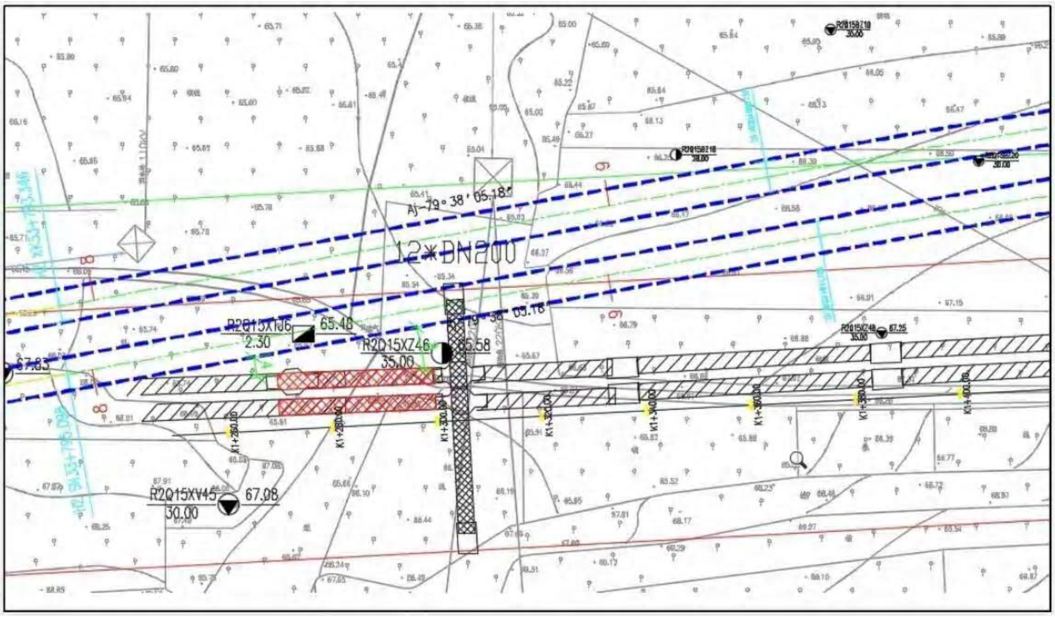

Figure 1 Plan location of new power pipe trench and existing section tunnel.

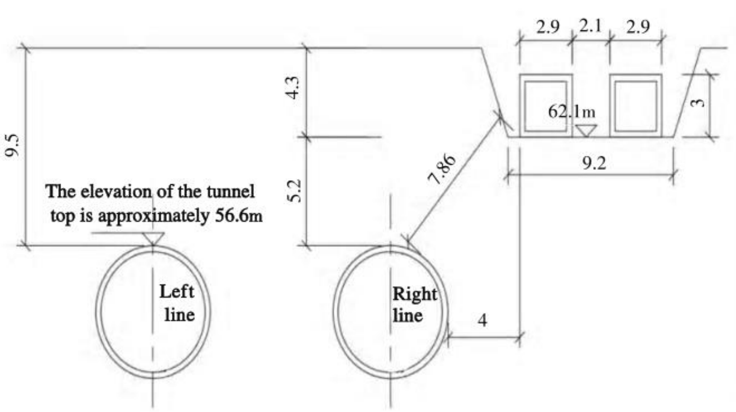

Figure 2 Section location of newly built power pipe trenches and existing section tunnels.

2.2 Geological and Hydrological Conditions

The excavation depth of the power pipe gallery is divided into three layers from top to bottom: plain fill soil and<16-1>silty clay. The water level is relatively low, and no groundwater is found within the height range of the foundation pit.

3. Investigation on the Current Situation of Tunnel Structures in Existing Sections

The buried depth of the existing subway section tunnel structure is 7-9m. The tunnel mainly passes through moderately weathered limestone, fully weathered mudstone, strongly weathered mudstone, and moderately weathered limestone. The anti floating water level elevation during operation is 30.5m, located below the bottom plate, and there is no need to consider the anti floating water pressure.

Design of existing tunnel structure: Circular shield tunnel segments are used, which are prefabricated reinforced concrete structures. The shield tunnel segments are divided into 6 pieces (1 top block+2 adjacent blocks+3 standard blocks). The outer diameter of the segment ring is 6.4m, the inner diameter is 5.8m, the segment width is 1.2m, and the segment thickness is 0.3m. High strength bending bolts are used to connect the segments and the segments ring. The strength grade of the segment concrete is C50, and the impermeability grade is P10.

After on-site inspection, the shield tunnel segments have a good appearance, with no obvious honeycomb or pitting on the surface of the concrete. There are local damages on the segments, and after repair, the appearance is good without obvious penetrating cracks. During the rainy season, there are local wet stains and leakage in the tunnel.

4. Impact Analysis and Safety Evaluation of Adjacent Existing Tunnels

4.1 Analysis of the Impact Mechanism and Factors of Proximal Construction

During the construction of adjacent existing tunnels, the excavation of the existing tunnel causes disturbance to the original geological stress field, leading to a redistribution of the stress field and the formation of the first stress equilibrium. With the excavation of new underground structures, the stress field in the surrounding strata of the tunnel is disturbed again, and the stress is redistributed again. The evolution process is similar to the first disturbance, and finally the stress field forms a second new equilibrium[3]. This evolutionary process deteriorates the existing tunnel structure and surrounding rock, which may cause structural deformation or damage to the interval tunnel structure, thereby affecting the safety and operation of the existing tunnel.

Figure 3 Existing shield tunnel structure.

The main factors affecting the construction of the new power pipeline gallery on the existing section are: excavation of the new foundation pit damages the original strata, and the self weight load of the new structure; Causing bias voltage differences on existing structures.

Mainly manifested in the following aspects:

Excavation of upper foundation pit and unloading of soil. The newly constructed underground structure is located in the upper right corner of the existing tunnel. During the excavation and construction of the upper foundation pit, the foundation and pit wall soil are simultaneously unloaded, causing stress redistribution around the tunnel and upward tensile deformation and displacement of the strata. At the same time, due to the unloading of the soil, the burial depth of the upper covering layer decreases, which may affect the arching effect around the tunnel, leading to an increase in the load on the tunnel lining.

The load impact of building structures after completion. After the completion of the new construction, additional compressive stress is generated around the tunnel, causing an increase in the overlying load on the tunnel lining. Moreover, due to the new construction being located above the tunnel side, it exerts a biased pressure on the tunnel, affecting the internal forces of the structure, resulting in compression deformation and displacement of the lining.

4.2 Safety Assessment Methods for Adjacent Structures

At present, domestic and foreign scholars have also conducted some research on the calculation and analysis methods related to the construction of adjacent subway tunnels, mainly in two categories.

The first type is finite element numerical simulation method (FCFEM). The characteristic of this method is to analyze the surrounding soil and subway tunnel as a whole while simulating the construction of new structures. The killing element technique is used to simulate the excavation of the foundation pit, and then the excavation boundary node force is applied in reverse to simulate the release of soil stress. FCFEM can simulate the complex interaction between tunnels and soil, as well as the elastic-plastic behavior of soil[4-6]. This method is also currently the main analytical method in China, with strong applicability and wide application, which can better simulate the actual engineering situation. Usually, large-scale commercial finite element software such as Ansys, Flac, Midas, etc. are used for calculations.

The second type is a two-stage analysis method. The characteristic of this method is to first calculate the additional stress or soil deformation caused by the construction of the new project on the adjacent existing tunnel, then apply the additional stress or soil deformation to the tunnel, and then analyze the longitudinal deformation and internal force changes of the existing tunnel. However, this calculation method has the drawback of not considering the influence of existing tunnels on additional stress, and can be used as a simplified calculation.

4.3 Analysis of the Impact of Close Proximity Construction

This analysis uses MIDAS-GTS geotechnical and tunnel simulation software for three-dimensional numerical simulation analysis, aiming to more realistically reflect the impact of construction of new underground power pipe gallery structures on the internal forces and deformations of adjacent existing tunnel structures through simulation.

4.3.1 Calculation Principles

(1) Assuming that each layer of the surrounding rock is an isotropic continuous medium, the soil adopts a Mohr Coulomb constitutive model;

(2) Assuming that the surface and various soil layers are uniformly distributed horizontally in layers;

(3) The stress and strain of the strata and materials vary within the elastic-plastic range;

(4) The initial equilibrium is automatically obtained by the program by adding the gravitational acceleration to the model.

4.3.2 Computation Model

The calculation model has a length of 70m, a width of 70m, and a height direction (z-direction) of 32.7m. The rock and soil are solid elements, using the Mohr Coulomb constitutive model. The tunnel segments and electric lining are simulated using shell structural elements. The overall calculation model generates a total of 20180 elements and 11352 nodes. The mesh division of the overall model is shown in Figure 4.

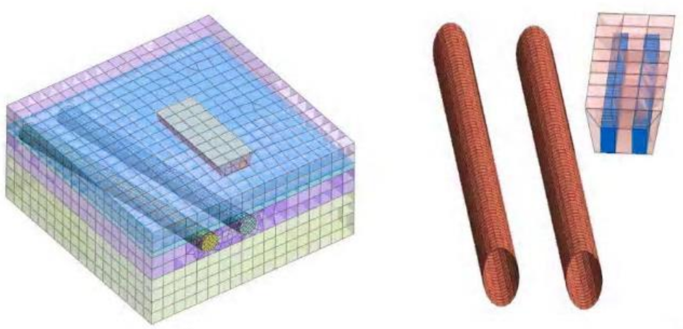

Figure 4 Schematic diagram of calculation model and proximity spatial position relationship.

4.3.3 Calculation Parameters

Selecting geological information from boreholes around the project as model calculation parameters, the basic physical and mechanical properties parameters of each soil layer are shown in Table 1.

Table 1 Physical and mechanical parameters of rock and soil layers.

Name of Rock and Soil	Bulk density Kn/m³	Cohesive force kPa	Friction angle ∅（∘）	Elastic modulus MPa	Poisson's ratio υ
Silty clay	18.6	42.3	20.6	21	0.34
Fully weathered marl limestone	21.3	22.6	16.5	26	0.25
Strongly weathered marl limestone	22	38	15	135	0.24
Moderately weathered limestone	24	80	26	450	0.28
Shield tunnel segments	25	/	45	34500	0.2
Power pipe trench structure	25	/	/	30000	0.2

4.3.4 Computational Procedure

The excavation of rock and soil is carried out on the basis of the stress distribution obtained in the previous calculation step, which is a process of stress redistribution and rebalancing. During numerical calculation, the actual excavation method is applied to release the load from the stratum, and the stress field changes after excavation are calculated. In order to better reflect the actual construction sequence of existing tunnels and new construction projects, the original ground stress field is calculated first, and the construction of existing tunnels is simulated. After completing the first initial ground stress balance, the displacement is reset to zero as the initial condition for the new construction project. Then, the excavation, structural construction, covering and backfilling of the new power pipeline trench foundation pit are simulated, and the close impact of the two is analyzed.

4.3.5 Analysis of Displacement and Deformation Calculation Results

(1) Working condition 1: Excavation of power pipe trench foundation pit

After working condition one is completed, the displacement and deformation of the foundation pit and tunnel structure are as follows:

The excavation of the new foundation pit caused a displacement of about 20mm in the base uplift, as shown in Figure 5; The lower tunnel structure deforms outward at the right arch shoulder position due to the unloading of the foundation pit soil, with a horizontal deformation of 0.6mm and a vertical deformation of 1.26mm, as shown in Figures 6 and 7.

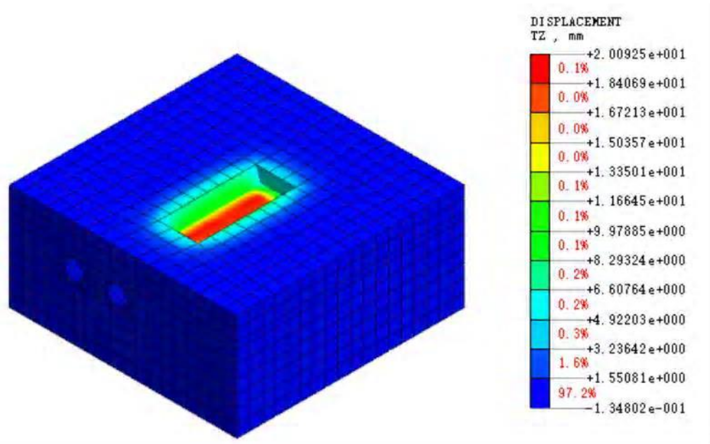

Figure 5 Cloud map of vertical uplift displacement at the bottom of foundation pit under working condition one.

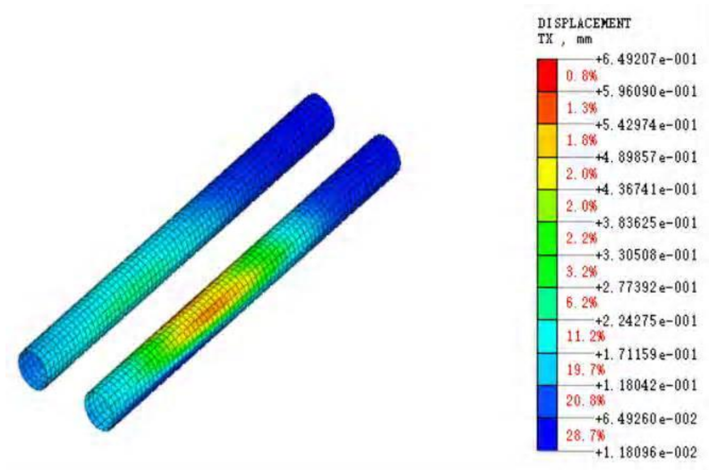

Figure 6 Horizontal deformation of tunnel structure under working condition 1.

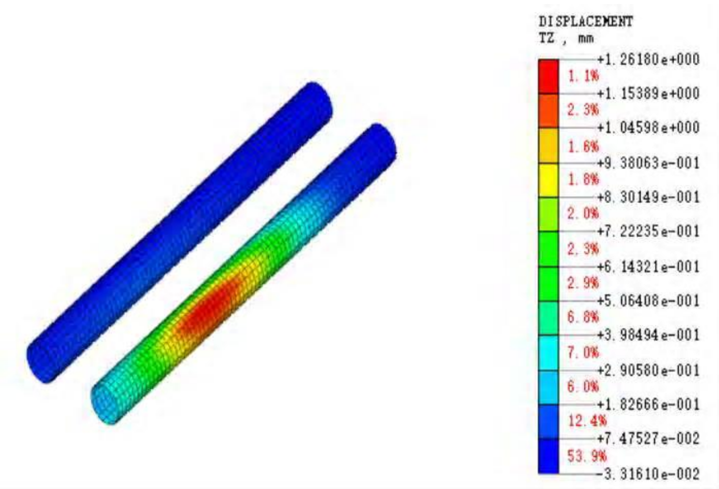

Figure 7 Vertical deformation of tunnel structure under working condition 1.

(2) Working condition 2: Construction of power pipe gallery structure

The excavation of the foundation pit for the power pipe trench was carried out to the base, and the main structure of the power pipe trench was constructed. The deformation results of the tunnel structure are as follows:

After the completion of the construction of the power pipe gallery structure, due to the back pressure of the bottom cushion layer of the foundation pit and the self weight load of the main structure, the horizontal and vertical deformation at the arch shoulder of the right line structure decreased to 0.57mm and 1.07mm, respectively, as shown in Figures 8 and 9.

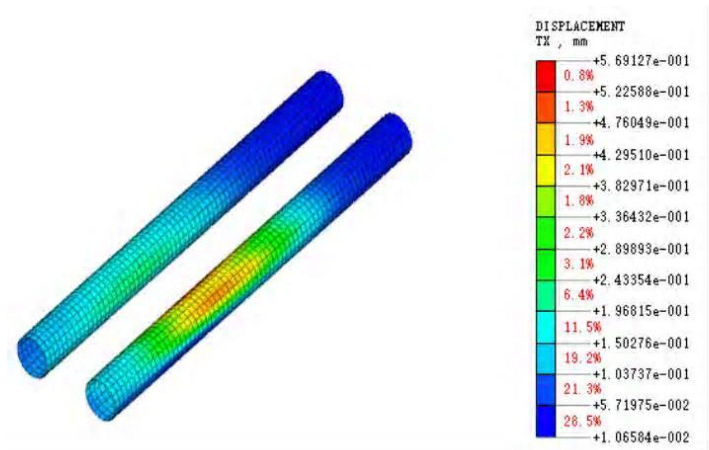

Figure 8 Horizontal deformation of tunnel structure under working condition 2.

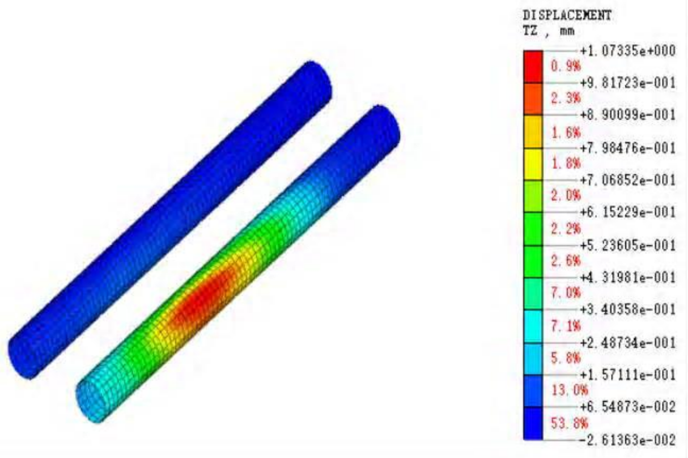

Figure 9 Vertical deformation of tunnel structure under working condition 2.

(3) Working condition 3: backfilling of power pipe trench foundation pit

After backfilling with soil, the deformation calculation results of the tunnel structure are as follows:

After the backfilling construction of the power pipe trench foundation pit is completed, the deformation at the arch shoulder of the right line tunnel structure continues to decrease due to the continued back pressure of the upper load, which is 0.13mm and 0.12mm respectively. As shown in Figures 10 and 11.

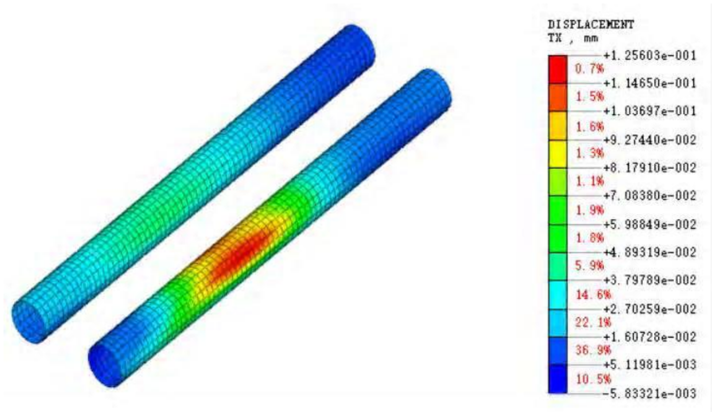

Figure 10 Horizontal deformation of tunnel structure under working condition 3.

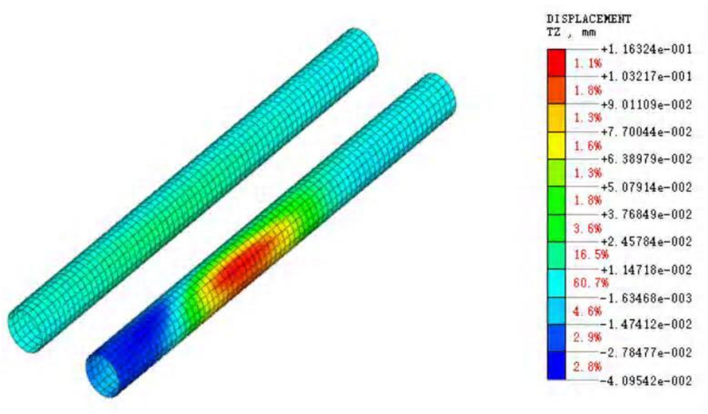

Figure 11 Vertical deformation of tunnel structure under working condition 3.

According to the comparative analysis of the calculations of working conditions 1, 2, and 3 mentioned above, working condition 1 is the most unfavorable condition. After the excavation of the foundation pit is completed, the lateral deformation of the arch shoulder of the existing tunnel structure is the greatest.

4.3.6 Analysis of Internal Force Changes

After the completion of working condition 3, the internal force changes of the existing tunnel structure are shown in Figures 12 to 14.

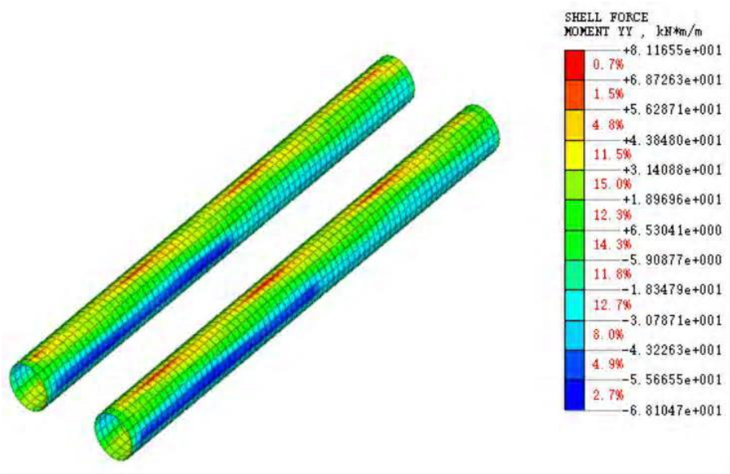

Figure 12 Cloud diagram of tunnel structure bending moment.

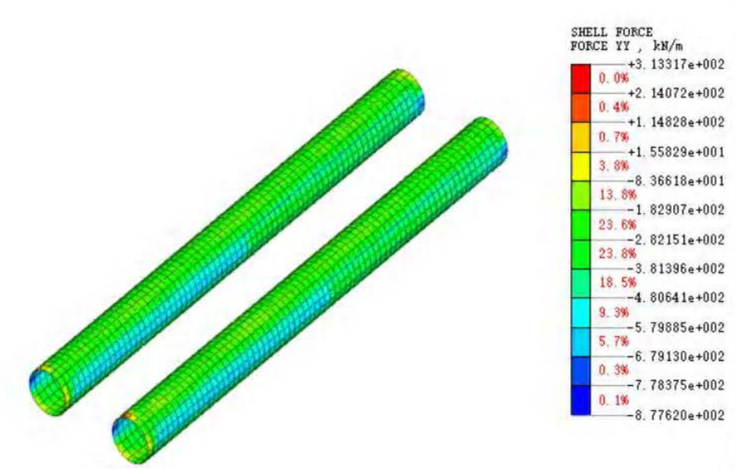

Figure 13 Axial force cloud map of tunnel structure.

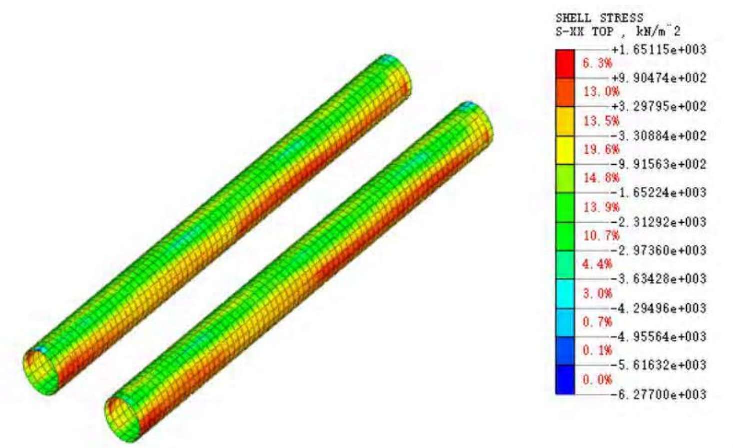

Figure 14 Cloud map of maximum principal stress in tunnel structure.

4.3.7 Safety Evaluation

According to the Technical Specification for Structural Safety Protection of Urban Rail Transit (CJJ202-2013), the control indicators and discrimination are shown in Table 2.

Table 2 Safety control index values for urban rail transit structures.

Safety control indicators	Warning value	Control value	Calculated value max	Does it meet the requirements
	mm	mm	mm	
Horizontal displacement	<10	<20	0.6	Correct
Vertical displacement	<10	<20	1.27	Correct

(1) From the table, it can be seen that the maximum vertical and horizontal deformation of the tunnel structure during the construction of the power pipe trench is less than 10mm, which meets the requirements of the specifications.

(2) After the completion of the new construction project, as shown in Figure 14, the maximum tensile stress of the tunnel structure is about 1.6MPa and 1.89MPa, which meets the structural stress safety requirements.

(3) After the construction of the new pipe gallery project in the upper part is completed, as shown in Figures 12 and 13, the maximum bending moment of the tunnel structure is about 81kN* m/m, and the axial force is 480kN/m. After calculation, the original structural reinforcement design meets the requirements of structural bearing capacity and crack control.

In summary, the construction of new underground power structures has a relatively small impact on the safety of existing subway section structures. After theoretical deformation prediction, internal force analysis, and bearing capacity verification, the existing subway structure is safe.

5. Conclusion and Suggestions

This article takes the construction of a new underground power pipe gallery in a city adjacent to an existing subway section tunnel as the engineering background. The three-dimensional finite element numerical method is used to analyze the impact of the new project on the pre-built tunnel during the construction process. The full process working condition analysis and safety evaluation are carried out, and certain rules are summarized. This can provide reference and guidance for similar projects, and some safety protection suggestions are proposed as follows:

(1) When a newly constructed structure is adjacent to an existing subway tunnel, the construction of the follow-up project will cause additional deformation and internal force changes in the existing subway structure. The safety of the existing structure should be fully evaluated.

(2) When excavating the foundation pit in the vicinity of the existing subway structure, the uplift at the bottom of the foundation pit causes local deformation of the existing subway section structure, resulting in tensile stress. In poor geological conditions, it is recommended to take reinforcement and improvement measures for the soil between the two, which can help reduce the deformation of the soil around the tunnel. If necessary, isolation piles can be installed to protect the existing subway structure from the impact of foundation pit excavation.

(3) Due to the low groundwater content, the anti-floating effect of groundwater was not considered in this article. Excavation of the soil above the subway is equivalent to unloading, which will increase the risk of upward floating in the subway section. In areas with high groundwater levels or rich water layers, it is advisable to install anti pull anchor rods or other anti-floating measures around the subway section to resist the structural uplift caused by soil unloading and reduce the deformation of the existing subway section.

(4) During the construction of the new upper structure, it is recommended to strengthen the monitoring and measurement of underground and underground dynamics, especially focusing on the areas where the numerical calculation results in the text show significant internal forces and deformations.

(5) The maximum displacement deformation of existing subway structures occurs during the excavation of the upper foundation pit, and the later construction of new structures and backfilling with soil can help improve

the displacement deformation of subway structures. Therefore, during foundation pit construction, the exposure time of the foundation should be reduced, and underground new structures should be constructed and backfilled as early as possible.

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