Computer safety analysis and research of electrified subway deep foundation pit excavation

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Abstract. Lanzhou Metro Line 1 is the first Metro Line in Gansu Province. Before the construction of buildings along the line, it is necessary to analyze the safety of the subway tunnel to ensure the safe operation of the subway. The new project, No.23 and No.24 plots of the old plant reconstruction project of Lanshi group (Lanshi · hobska n District), is close to the Shizi tunnel between the west railway station and the West Railway Station of Lanzhou Urban Rail Transit Line 1 phase I project. The excavation and supporting construction of foundation pit may have an impact on the structural safety of Shizi tunnel between West Railway Station and West Railway Station in the first phase of Rail Transit Line 1. It is particularly important to analyze and study the structural safety of subway tunnel before the construction of this project.

Keywords: Subway, Tunnel, Safety, Foundation pit, Construction.

1. Background introduction
Lanzhou Rail Transit Line 1 starts from Donggang Station in Chengguan District in the east to Chenguanying Station in Xigu District in the west. It is the main rail transit line of Lanzhou from east to west. It has a total length of 26.78 kilometers, all underground lines, and opened for operation in June 2019. The left and right tunnels of the section are shield tunnels, the inner diameter of the tunnel structure is φ5500mm, the thickness of the tube slices is 350mm, the outer diameter of the tunnel is set to φ6200mm, and the buried depth of the tunnel vault is about 10.4-21. 6m.

No.23 and No.24 plots (Lanshi hobska n District) of Lanshi group's old plant reconstruction project are located at no.194 Xijin West Road, Qilihe district, Lanzhou city. There are two underground floors (three local floors) and three to 31 floors above the ground. The depth of the foundation pit is 13.5m. The nearest plane distance between the south side of the foundation pit and the Shizi section of line 1 West passenger station west station is about 26m, and the vertical distance between the bottom of the foundation pit and the top of the shield tunnel is about 6.5m. The clear distance between the anchor cable and the tunnel is about 6.3m.

Under this background, the influence of the construction and use of the project structure on the safety of the adjacent subway is studied and analyzed, and the construction protection measures and suggestions are put forward.
1.1. Overview of deep foundation pit support

The depth of the foundation pit of this project is 13.5m, and the total length of the foundation pit is 885m. It is mainly supported by (composite) soil nail wall, pile + prestressed anchor cable. The support design of the subway adjacent to the foundation pit is section A-B, as follows:

Prestressed anchor cable + reinforced concrete cast-in-place pile is used for support of section a-b. The current ground elevation of the site is 1534.8-1535.0m. The diameter of reinforced concrete cast-in-place column is 0.8m, the spacing between piles is 2.0m, the top elevation of crown beam is the current ground elevation, and three prestressed anchor cables are set below the crown beam.

**Figure 1.** Relationship between Location of Proposed Site and Rail Transit Line 1

**Figure 2.** Layout of Foundation Pit
1.2. Engineering Geology Overview

This project is located in the area adjacent to subway, with flat terrain and ground elevation ranging from 1533.99 m to 1535.62 m. Both sides along the line are mostly office areas and residential areas, and the overall terrain is high on both sides and low in the middle. The landform unit belongs to Grade II terrace on the south bank of the Yellow River in Lanzhou City.

Through the survey, the stratum of the proposed site is distributed from top to bottom as follows:

1. Miscellaneous fill soil layer: thickness 0.20–4.50m.
2. Loess-like silt layer: buried depth of 0.20-4.50m, thickness of 6.80-12.30m, and the elevation of the layer is between 1529.34 and 534.68m.
3. Fine sand layer: the buried depth is 10.80-14.00 m, the thickness is 0.10-1.00 m, and the layer elevation is 1521.25-1523.38 M.
4. Pebble layer: the buried depth is 10.80-14.30m, the survey thickness is 7.70-24.10m (not penetrated), and the level elevation is 1520.95-1523.49m.

The buried depth of groundwater obtained from the survey is about 16.9~18.30m, and the main aquifer is pebble bed, which is located below 3.4m for earthwork excavation of foundation pit, so there is no need for precipitation during construction.

2. Analysis of the impact grade of the construction of the project on the adjacent subway structure

According to the "Technical Specifications for the Safety Protection of Urban Rail Transit Structures" (CJJ/T202-2013), the analysis of the safety protection requirements for urban rail transit structures during external operations is as follows:

1) When carrying out external operation around urban rail transit structure, safe and reliable operation scheme and protection measures shall be formulated, and external operation shall not affect the normal use of urban rail transit structure.

2) Before the implementation of external operations, the impact level of external operations shall be determined in combination with the safety protection requirements of urban rail transit structures.

3) Safety control should include: external operation impact level, external operation clearance control management index, structural safety control index.

4) The impact level of external operation should be divided according to Table 1, and the degree of proximity and engineering impact zoning of external operation should be determined according to Table 2 and Table 3.
Table 1. Classification of External Operation Impact Grade

| Engineering impact zoning of external operations | Degree of closeness | Very close | Close to | Closer | Not close |
|-------------------------------------------------|--------------------|-----------|---------|--------|----------|
| Strongly affected area (A)                       | Premium            | Premium   | First level | 2 | Level 2 |
| Significantly affected area (B)                  | Premium            | First level | 2 | Level 3 | Level 3 |
| General affected area (C)                        | First level        | Level 2   | Level 3 | Level 4 | Level 4 |

Table 2. Criteria for judging proximity

| Construction method of urban rail transit structure | Relative clear distance | Proximity |
|-----------------------------------------------------|-------------------------|-----------|
| Shield method or pipe jacking method                | <1.0D                   | Very close |
|                                                     | 1.0D~2.0D               | near      |
|                                                     | 2.0D~3.0D               | Closer    |
|                                                     | >3.0D                   | Not close |

Note: ① D is the outer diameter of tunnel. ② Relative clear distance refers to the minimum clear distance between the outer edge of external operation structure and the outer edge of rail transit structure.

5) The project affected zoning of external operations should meet the following requirements:

Table 3. Engineering impact zoning of open cut and cover cut external operation

| Engineering impact zoning | Geographic range |
|---------------------------|-------------------|
| Strong influence area (a) | Within 0.7h1 directly above and outside the structure |
| Significant influence area (B) | 0.7h1~1.0h1 range outside the structure |
| General influence area (c) | 1.0h1~2.0h1 range outside the structure |

Note: h1 is the buried depth of the bottom plate of the external work structure of the open cut and cover cut method.
6) Analysis of the influence level of the project construction on the adjacent Metro structure:

(1) The tunnel structure construction method of Shizi section from West Railway Station to West Railway Station of Metro Line 1 is shield method, with the outer diameter of the tunnel D=6.2m. The relative clear distance between the outer line of foundation pit supporting pile and the outer line of the subway tunnel is about 26m, which is greater than d = 6.2m and 3.0D=18.6m. According to Table 2, the proximity is judged as not being close.

(2) The depth of the foundation pit is h=13.5m, and the foundation pit construction adopts the open-cut method. According to Table 3, the range of 0.7h (11.9m) of the foundation pit construction operation is the strong influence area (A). The relative clear distance between the outer edge of the foundation pit supporting pile and the outer edge of the subway tunnel is about 25.9m<2h=27m. Therefore, the subway tunnel is within the general impact area (C) of the foundation pit support construction operation.

(3) According to (1) and (2) above and Table 1, the impact level of foundation pit construction is grade 4.

(4) Lanzhou Lanshi group old factory reconstruction project foundation pit construction external operation impact level is four, according to "protection code" 3.3.1, it is appropriate to evaluate the construction of the subway tunnel traffic safety impact, because the subway tunnel is an important urban traffic facilities, need to analyze the project construction and safety assessment.

3. Selection of safety evaluation standards and methods

3.1. Analysis of engineering risk points

Because the excavation and support of foundation pit in this project is close to the Shizi tunnel between West Railway Station and West Railway Station of Metro Line 1, the following risks may exist:

1) Excavation and unloading of large-scale foundation pits leads to the uplift and lateral deformation of the base, which leads to deformation of the adjacent subway structure. If the limit is exceeded, the safety of the subway will be affected.

2) Excavation and unloading of large-scale foundation pits leads to the uplift and lateral deformation of the base, which leads to deformation of the adjacent subway structure. If the limit is exceeded, the safety of the subway will be affected.

3) The excavation of the foundation pit causes stratum deformation, resulting in the deformation of the adjacent subway structure. If the limit is exceeded, the safety of the subway will be affected.
4) The deformation of the subway structure will cause the deformation of the track. If it exceeds the limit value, it will lead to the local deformation of the subway track, which will produce adverse effects such as vibration and turbulence in the operation process.

5) After foundation pit excavation and backfill construction, the distribution of earth pressure around the subway structure changes, and the internal force of the subway structure may exceed the limit.

6) Because of the differential deformation of the tunnel structure, it will cause the opening of the deformation joints and water leakage.

3.2. Evaluation standard

3.2.1. The control indicators of the "Technical Specification for the Safety Protection of Urban Rail Transit Structures" (CJJ/T202-2013) are as follows:

| Table 4. statistics of deformation indexes of existing structures |
|---------------------------------------------------------------|
| **Seria number** | **Standard** | **Control standards** |
| 1 | Technical code for structural safety protection of urban rail transit (CJJ / t202-2013) | Track safety: the vertical deformation of the track is 4mm, the transverse height difference between the two tracks is < 4mm, the height difference between the horizontal and horizontal triangular pits is < 4mm/10m, and the gauge is+6mm and-4mm. Structural safety: the settlement, horizontal displacement and radial convergence of the tunnel are less than <20mm. The control value of curvature radius of tunnel longitudinal deformation curve is r > 15000m. The relative buckling control value of the tunnel is less than 1/2500: the control value of additional load on the outer wall of the tunnel is ≤20kPa(≤2t/m2); Peak velocity control value caused by vibration tunnel ≤2.50cm/s .. Segment joint opening control value < 2mm. The width of structural cracks is less than 0.2mm on the water front and less than 0.3mm on the water back. |

3.2.2. Control indicators of the proposed project. Combining the specific conditions of this project and comprehensively considering the current status of the subway structure, it is determined that the impact of the excavation of the foundation pits of the Lanshihaobuska plots 23 and 24 on the structure of the subway line 1 must meet the following standards:

Subway structure: ① the vertical displacement of the subway structure is less than 10 mm, and the horizontal displacement is less than 10 mm. ② The radial convergence is less than 10 mm. ③ The differential settlement of subway structure is less than 0.04% Li (Li is the distance between the two monitoring points). ④ The additional load to the subway structure caused by construction is less than 20KPa.

Track structure: ① the vertical deformation of the track is less than 4mm, the transverse height difference between the two tracks is less than 4mm, and the rail height difference (vector value) is less than 4mm; ② -4mm < rail spacing < +6mm. ③ the vertical deformation of roadbed is less than 4mm/10m.

3.2.3. Foundation pit deformation and control standards. The safety level of this foundation pit is level 1, and the monitoring level of this foundation pit is level 1, and the corresponding support structure deformation control standards are as follows:
Table 5. Monitoring alarm value of foundation pit and supporting structure

| Serial number | Monitoring items | Vlass a | Support structure type | Cumulative value |
|---------------|------------------|--------|------------------------|------------------|
|               |                  |        | Absoloute value / mm   | Relative depth of foundation pit (H) mm · D-1 | Change rate / mm · D-1 |
| 1             | Deep horizontal displacement of retaining wall | 30     | Slope, soil nailing wall and shotcrete anchor support | 0.3%             | 5 |
|               | Vertical displacement of ground surface around foundation pit | 25     | Cast in place pile | 0.2% | 2 |
| 2             | Monitoring items | 30     | Slope, soil nailing wall and shotcrete anchor support | 0.3% | 3 |
|               | Horizontal displacement of top of wall (slope) | 15     | Cast in place pile | 0.1% | 2 |
| 3             | Vertical displacement of top of wall (slope) | 45     | Cast in place pile | 0.5% | 2 |
| 4             | Deep horizontal displacement of retaining wall | 30     |                        |                  | 2 |

3.3. Selection of analytical methods
In this paper, a stratum-structure model is established by using the finite element software of geotechnical analysis, and the dynamic simulation analysis of the foundation pit construction process is carried out. The deformation and stress change process of subway structure during the whole foundation pit construction process are studied, and the maximum deformation of subway structure during the foundation pit construction process is obtained, and its safety is judged according to the deformation control standard of subway structure. In this paper, Midas GTS NX finite element software is used to establish a three-dimensional model, and the whole foundation pit construction process is simulated, and the most unfavorable deformation value of subway structure in the whole foundation pit construction process is obtained, and its safety is quantitatively judged according to the control standard.

4. Security analysis and research
4.1. Analysis of influence of foundation pit excavation process on subway tunnel
4.1.1. Model building. The finite element model is established according to the size of the subway tunnel structure and the spatial geometric position of the foundation pit, as shown in Figures 6 and 8. The length of the model in the X, Y, and Z directions is 300m and 200m, respectively. 80m. From top to bottom, the stratum is plain soil, loess-like soil, silt soil and pebble. The Mohr Coulomb elastic-plastic constitutive model is used in the simulation, and the element type is tetrahedral and hexahedral mixed element. The tunnel lining structure adopts plate element, and the element type is quadrilateral and triangular mixed element. The equivalent rigidity conversion principle of retaining pile is adopted,
and the diaphragm wall is simulated as plate element. The embedded truss element is used for anchor cable, and the element type is ID line element.

![Figure 6. Finite Element Model of Foundation Pit Excavation Construction](image1)

![Figure 7. Spatial Position Relationship between Foundation Pit and Subway Tunnel](image2)

![Figure 8. Model Diagram of Anchor Cable and Retaining Pile (Underground Continuous Wall)](image3)

4.1.2. Basic assumptions. The soil, the lining structure of the section tunnel, etc. are calculated in accordance with the isotropy.

The constitutive model of rock and soil adopts Mohr-Coulomb elastoplastic constitutive model, and the structure adopts linear elastic constitutive model.

Without considering the relative displacement of soil and retaining structure, the joint displacement of soil and retaining structure is coupled.

The Newton Raphson method is used in the iterative calculation.

The convergence standard adopts double convergence standards of force and displacement.

In the simulation analysis of this construction stage, the foundation pit is excavated by layers only, and the influence of sectional excavation on the calculation results is not considered.

4.1.3. Model material parameters. According to the geological survey report, the parameters of the rock and soil mass and structure in the simulation are shown in Table 6.
Table 6. Numerical simulation parameter table

| Stratum name | Severe (kN/m³) | Cohesion (kPa) | Internal friction angle (°) | Poisson's ratio | Modulus of elasticity (kN/m²) | Constitutive model |
|--------------|----------------|---------------|-----------------------------|----------------|------------------------------|-------------------|
| Plain fill   | 18.0           | 8.0           | 23.0                        | 0.38           | 15000                        | Moore Cullen      |
| Loess        | 15.8           | 13.6          | 24.3                        | 0.31           | 30000                        | Moore Cullen      |
| Pebble       | 21.0           | 2.0           | 40.0                        | 0.30           | 100000                       | Moore Cullen      |
| C20 concrete | 24.0           | —             | —                           | 0.30           | 2550000                      | Elasticity        |
| C40 concrete | 24.0           | —             | —                           | 0.30           | 3250000                      | Elasticity        |
| Steel        | 78.0           | —             | —                           | 0.30           | 210000                       | Elasticity        |

4.1.4. Simulation of construction phase. The excavation of foundation pit is carried out in layers and four times. The excavation depth of the first layer is 3 m, and the excavation depth of the second, third and fourth layers is 3.5 m. When the construction reaches the design elevation, the excavation is completed in time, and the shotcrete is used to protect the surface. Meanwhile, the second, third and fourth layers are installed with anchor bolts in time.

4.1.5. Result analysis. (1) analysis of settlement and deformation of surface and foundation pit

![Figure 9. Cloud picture of surface settlement after excavation of the first layer of soil](image1)

![Figure 10. Cloud image of surface settlement after excavation of the second layer soil](image2)

![Figure 11. The third layer of soil is excavated to complete the surface settlement cloud map](image3)

![Figure 12. The fourth layer of soil is excavated to complete the surface settlement cloud map](image4)

The settlement deformation of the ground surface during the excavation of foundation pit is analyzed, and the results are shown in Figure 9 to Figure 12. In the process of foundation pit
excavation, with the increase of foundation pit excavation depth, the ground settlement increases continuously, and the maximum value of ground settlement is -6.18m, which meets the requirement of 15mm deformation control standard of foundation pit support structure. The maximum ground settlement of foundation pit excavation is 6.18m, which is not obvious.

1) The soil quality of foundation pit excavation is mainly loess, which has great cohesion and good self-stability, so the ground settlement is not obvious.

2) The design of foundation pit support is reasonable, and measures such as pile arrangement and anchor cable have little disturbance to the stratum.

(2) Analysis of vertical displacement and deformation of subway tunnel

Figure 13. The vertical displacement of the tunnel is completed by the excavation of the first layer of soil

Figure 14. The vertical displacement of the tunnel is completed by the excavation of the second layer of soil

Figure 15. Vertical displacement of tunnel after excavation of the third soil layer

Figure 16. Vertical displacement of tunnel after excavation of the fourth soil layer

Figures 13 to 16 show the vertical displacement nephogram of subway tunnel during foundation pit excavation. According to the figure, with the increasing depth of foundation pit excavation, the influence of foundation pit excavation on the left line of the tunnel is greater than that on the right line of the tunnel, and the vertical displacement of the tunnel generally shows an upward trend, with the maximum vertical displacement of the inverted arch of the tunnel. After the excavation of the first layer of soil, the vertical displacement of the inverted arch of the tunnel lining is about 1.10mm, and the arch bottom has a slight downward displacement. After the excavation of the third layer of soil is completed, the overall tunnel lining floats up obviously, the maximum vertical displacement of the vault is 0.51mm, and the maximum vertical displacement of the invert is 2.46mm. The fourth layer of soil has been excavated, and the maximum vertical displacement of the tunnel is 3.72mm.

(3) Analysis of horizontal displacement and deformation of subway tunnel.
Figures 17 to 20 show the horizontal displacement nephogram of subway tunnel in the process of foundation pit excavation. According to the figure, with the increasing depth of foundation pit excavation, the influence of foundation pit excavation on the left line of tunnel is greater than that on the right line of tunnel. After the first soil excavation, the horizontal displacement of the left tunnel side wall is 0.84 mm. With the increase of foundation pit excavation depth, the maximum horizontal displacement of the tunnel side wall is 1.04 mm, which has little change on the whole and is not obviously affected by the depth of foundation pit excavation.

4.2. Analysis of the impact of the construction of the foundation pit on the adjacent subway tunnel

4.2.1. Construction phase simulation. This stage mainly analyzes the impact of the construction of the Lanshi-Haobska project on the adjacent subway tunnel structure. The calculation at this stage is carried out after the simulation and analysis of the influence of the excavation of the foundation pit on the structure of the adjacent subway tunnel, so the finite element model is used to establish the model. The difference is that at this stage, the foundation pit has been backfilled and the building has been built. Considering that the building of this project adopts a raft foundation, the total weight of the building is evenly distributed on the bottom of the raft foundation in the finite element model, which is applied as a surface load on the bottom of the raft foundation. The bottom of the foundation pit. In the finite element model, the soil in the pit is activated to simulate the backfill of the foundation pit and the basement. However, when the parameters of this part of the soil are set, the soil weight should be removed due to the consideration of the basement.
4.2.2. Calculation results

4.2.2.1 Analysis of surface settlement and deformation after construction

It can be seen from figure 22 that the maximum surface settlement after construction is 14.6 mm, which meets the requirement of 30 mm control standard for surface settlement and deformation around the foundation pit.

4.2.3. Analysis of vertical deformation of tunnel after construction

Figure 22. vertical deformation cloud map of tunnel after construction

Figure 23. Cloud map of vertical deformation of tunnel after completion of construction
It can be seen from figure 23 that the maximum vertical displacement of tunnel lining after construction is 4.01mm, which meets the requirement that the maximum settlement of control standard should not exceed 10mm.

4.2.4. Analysis of the horizontal deformation of the tunnel after construction

![Figure 24](image_url)

Figure 24. The horizontal deformation cloud map of the tunnel after the construction is completed.

It can be seen from Figure 24 that the maximum horizontal displacement of the tunnel lining after the construction is completed is 1.09mm, which meets the requirements of the control standard that the maximum horizontal displacement does not exceed the limit of 10mm.

4.2.5. Analysis on radial convergence of tunnel after construction. The horizontal deformation of the left and right sides of the tunnel is extracted, and the difference between them is regarded as the radial convergence value of the tunnel. After the completion of the construction, the maximum radial convergence value of the tunnel near the foundation pit side is 0.21mm, and the maximum radial convergence value of the tunnel far away from the foundation pit side is 0.13MM, which meets the requirement that the radial convergence of the control index is less than 10mm.

4.2.6. Analysis of differential settlement of tunnel after construction. The settlement data of the tunnel is extracted, and the difference between the maximum and minimum settlement values of the tunnel is taken as the differential settlement value. The maximum differential settlement value of the tunnel near the foundation pit side is 1.83mm, and the maximum differential settlement value of the tunnel far away from the foundation pit side is 0.32mm, both of which meet the requirement that the control index is less than 0.04% Li = 55mm.

4.2.7. Analysis of Vertical Deformation of Track after Construction. Extract the vertical deformation data of a total of four tracks in two tunnels. The maximum vertical deformations of track A, track B, track C and track D are 2.39mm, 2.16mm, 0.11mm, 0.05mm, respectively, which all meet the control index. The vertical deformation of the track is less than 4mm.

The maximum lateral height difference between track a and track B is 0.23mm. The maximum lateral height difference of track C and track D is 0.06mm, which meets the requirements of the control index that the lateral height difference of the two tracks is less than 4mm.

The maximum rail height difference of track a, track b, track c and track d is 2.39mm, 2.16mm, 0.11mm and 0.05mm respectively, all of which meet the requirement that the rail height difference of control index is less than 4mm.

4.2.8. Analysis of the horizontal deformation of the track after the construction is completed. The horizontal deformation data of a total of four tracks in two tunnels are extracted. The maximum values
of horizontal deformation of track A, track B, track C and track D are 1.09mm, 1.09mm, 0.33mm, 0.33mm, respectively. The difference between the horizontal deformations of the track A and the track B is taken as the track pitch deformation of the track A and the track B, and the difference between the horizontal deformations of the track C and the track D is taken as the track pitch deformation of the track C and the track D. The maximum value of track pitch deformation of track A and track B is 0 mm, and the maximum value of track pitch deformation of track C and track D is 0 mm. All meet the requirements of the control index -4mm<track spacing deformation <+6mm.

4.2.9. Analysis on vertical deformation of track bed after construction. The vertical deformation data of track bed is extracted. The maximum vertical deformation of track bed is near the middle of foundation pit. The vertical deformation of the track bed near the foundation pit side is 3.89mm, and that far away from the foundation pit side is 0.11mm, which meets the requirements of the control index that the vertical deformation of the track bed is less than 4mm / 10m.

4.3. Load-calculation structural model analysis

4.3.1. Calculation model and method. The "load-structure model" is used to analyze the stress of segment structure, and the modified conventional method is used to calculate. By introducing ring stiffness reduction coefficient and segment bending moment adjustment coefficient, the influence of segment stiffness reduction and segment staggered joint assembly caused by multiple segments joints is simulated, and the values of parameters are usually determined according to segment structure test and stratum conditions. Considering the influence of segment joint, the stiffness is reduced and calculated as homogeneous ring. The calculation results are adjusted by considering the effect of staggered joints between segments and rings. Combined with the paper "Research on the Effectiveness of Modified Segment Ring Bending Stiffness and the Increase Rate of Bending Moment" written by Huang Zhengrong, Zhu Wei and Liang Jinghua, the paper written by Guo Deping "Comparison of Modified Conventional Use and Elastic Foundation Beam Method" and shield tunnels Based on the design experience, the stiffness reduction \( \eta = 0.8 \), and the bending moment increase coefficient \( \xi = 0.3 \). The ground spring is used to simulate the resistance of the ground, and when the water and soil pressures are considered, the water and soil calculations are used. Midas gts is used to calculate the internal force of the lining segment, and the reinforcement bearing capacity and crack width are checked according to the "Specification for Design of Concrete Structures".
Figure 25. load structure model of shield tunnel

Tunnel structure inner diameter $\phi$ 5500mm, segment thickness 350mm, tunnel outer diameter $\phi$ 6200mm. See figure 26 for the layout of segment lining ring.

Figure 26. Structure of Lining Ring

4.3.2. Calculation section and working condition. The principle of selecting the calculation section is "the most unfavorable principle", that is, the section with the most unfavorable relationship with the position of the project is selected for calculation, and the poor drilling holes in the adjacent geological drilling holes are selected for calculation and analysis. The first working condition to be calculated is the original design normal working condition of subway structure, and the second working condition is the calculation of subway internal force after foundation pit excavation.
4.3.3. Calculation results. The tube slices adopt staggered flat tube slices, the calculation model adopts the beam-spring analytical method model, and the rotating spring is used between the tube slices to simulate the radial joint of the tube slices.

![Figure 27. calculation diagram of segment elastic support](image)

1) Case 1 (original design normal condition of Metro structure)

![Figure 28. bending moment](image)

![Figure 29. axial force](image)

![Figure 30. stress of segment under working condition 1](image)

2) Case 2 (internal force calculation of subway after foundation pit excavation)

![Figure 31. Bending Moment](image)

![Figure 32. Axial Force](image)

![Figure 33. Forces on the second segment of the operating condition](image)

Through the comparison of the two calculation methods, the calculation result of working condition one is safe before excavation, so the calculation result of working condition one is used to calculate the segment reinforcement.
(1) Vault reinforcement:
Known: \( M = 66.9 \times 1.1 = 73.6 \text{kn} \), \( M, n = 1060 \times 1.1 = 1166 \text{kn} \), \( B = 1000 \text{mm} \) (segment width 1500mm), \( H = 300 \text{mm} \), \( H0 = h-40-10-0.5d \), C50 concrete.

Checking calculation of eccentric compression bearing capacity of rectangular section:
\( h0=H-40-10-0.5d=241\text{mm} \)
\( x=44<2as=118\text{mm} \).
\( As = 888 \text{ mm}^2 \sim 2, \)
\( As = 3318\text{mm}^2 \) (reinforcement of shield section) / 1.5 = 2212\text{mm}^2
\( e0= \frac{M}{\lambda T}=115.4<0.55h0= 132.6\text{mm} \), Therefore, there is no need to check the cracks.

(2) Arch waist reinforcement:
It is known that \( m base = 74.3 \times 1.1 = 81.7 \text{ kN m} \), \( N=1237*1.1=1361\text{KN} \), \( B=1000\text{m} \) (segment width: 1500m), \( h = 300 \text{ m} \), \( H0 = 50-10-0.5 d \), C50 concrete.

Checking calculation of eccentric compression bearing capacity of rectangular section;
\( h0=H-50-10-0.5d=231\text{mm} \)
\( x=50<2as=138\text{m} \).
The as calculated in the table \( As=976\text{mm}^2 \).
Therefore, \( As=3318\text{mm}^2(8C20+4C16) \) (reinforcement of shield section of this project)
/1.5=2212\text{mm}^2
\( e. =\frac{M}{\lambda T}=82.3<0.55h0=127.1\text{mm} \), so there is no need to check the cracks.

(3) Shear calculation:
\( V base =154*1.1=169\text{KN} \), C50 concrete, \( B=1000\text{mm} \)
\( H=300\text{mm},h0=H-50-10-0.5d=231\text{mm}, fc=23.1\text{N/mm}^2, ft=1.89\text{N/mm}^2 \).
Calculated:
The structural reinforcement (8C20+4C16) can meet the requirements.
According to the calculation, the reinforcement of shield section of this project meets the requirements after foundation pit excavation.

4.3.4. Summarize. According to the calculation results, the bending moment, axial force and shear force of subway structure have little change from working condition one to working condition two, and still meet the requirements of normal service limit state and bearing capacity limit state, so the construction of this project will not have a significant impact on the safety of existing subway structure.

5. Main conclusions and recommendations

5.1. Main conclusion
1) Before the construction of the neighboring subway, it is necessary to analyze whether the construction is within the protection control range of the rail transit structure according to the "Urban Rail Transit Structure Safety Protection Technical Code" (CJJ/T202-2013) and determine the level of impact on the neighboring subway.
2) During the construction of the adjacent subway building, it will have a certain impact on the subway tunnel structure. From the excavation of the foundation pit to the completion of the superstructure, the ground subsidence and the deformation of the subway tunnel gradually increase until the deformation is maximized.
3) The impact level of the project on the adjacent subway structure is grade 4. Through the standardized construction operation, the subway tunnel structure is relatively safe.
4) The maximum settlement of tunnel lining, the maximum settlement of ground surface, the maximum convergence of tunnel, the maximum differential settlement of tunnel, the maximum vertical deformation of track and the maximum deformation of rail spacing are all within the control index after the completion of the construction of the adjacent subway tunnel of the project, which will not have a great impact on the subway structure.
6. Suggestion
Considering the influence of engineering geology and unpredictable conditions during construction, in order to further protect the safety of subway structure, the following measures are suggested:

1) Prepare special monitoring plan for subway structure and foundation pit, and monitor the subway structure and foundation pit. Through the analysis of monitoring data, we can judge whether the current construction situation is scientific and reasonable, find out the problems in the project in time, provide basic information for taking effective preventive measures, and guide the safe and smooth construction. The monitoring content includes: vertical displacement of subway structure, horizontal displacement of subway structure, relative convergence of tunnel, opening of shield segment joints, tunnel section size, displacement of track bed and track, horizontal displacement of the top of the envelope, and vertical top of the envelope. Displacement and deep horizontal displacement of rock and soil, horizontal displacement of foundation pit slope top, vertical displacement of foundation pit slope top, deep horizontal displacement, supporting axial force, vertical displacement of column, anchor cable internal force, and surrounding construction (structure) of foundation pit Settlement of buildings and roads.

2) Within 20m away from the side line of the existing structure of the subway, punching, squeezing pile and blasting construction are not allowed. Static crushing or other operation methods are adopted when the distance is beyond 20m from the side line of the existing structure of the subway.

3) It is strictly forbidden to damage the supporting structure of foundation pit before backfilling.

4) Metro Line 1 has been put into operation, and there are certain risks in the construction of prestressed anchor cable in the south of foundation pit. Therefore, before construction, the anchor cable position elevation and tunnel elevation should be checked to ensure that the position and elevation of each structure are correct, then the anchor cable construction should be carried out, and the disturbance to the tunnel structure should be avoided as much as possible during construction.

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