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Study on deformation characteristics of the tunnel during construction crossing the existing metro line

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Abstract. With the rapid development of urban rail transit networks, it produced an inevitable problem that the new subway lines through the existing subway lines. Because the interaction of the close-spaced construction is very complex, it's important to solve the problem that ensuring the safety of the normal operation of the existed line under the premise of the smooth construction of the new structure. This shows that the research on deformation and stability of existed subway line is an important research topic in the development of urban subway network. This paper take the typical shallow tunnel engineering of International Airport Line of Beijing Urban Rail Transit under (upward) crossing the behind-station turn back line of existing metro line, urban rail 13th as an example, with its geological condition, construction environment as the research background, this paper has made an overall and systemic analytical study on influence of urban metro tunnel construction by shallow excavation upon the overlying existed structure, by theoretical analysis, long-distance automation monitors and numerically simulated.

Key words. shallow excavation technique, under (upward) crossing projects, existed lines, structure settlement, numerical simulation FLAC3D.

1. Introduction

With the rapid development of urban rail transit, the world has been suggested that "the 21st century as the development and utilization of underground space of the era" , Japan also put forward "full use of underground space, the territorial

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area expanded several times the idea" . Many of the underground track in the construction of the track in succession, then more and more in the vicinity of the existing line through the tunnel construction is inevitable, so how to ensure the smooth opening of the existing line to make the new Line security, this research topic has become the urban rapid rail transit network must be resolved in one of the most important problems.

Many scholars at home and abroad have carried on the related research to this difficult problem. R.Selman and J.R. Standing studied the extension of the London subway Jubilee through five subway lines and ten tunnels at the beginning of the 21st century [1]. B.P. Kassap (1992-2000) et al. Analyzed and reported the engineering overview of crossing the subway Redline South Station under the northbound tunnel section of the I-93 Interstate in Boston, USA [2-6]. SBchang studied the variation of the stress and displacement of the surrounding rock lining of a three-arch and two-column metro station in South Korea during the construction [7]. GCASSANI and P. LWARDI reported and analyzed the suburbs of Italy Highway Bologna under the existing ground rail line project overview [8]. Liu Hongzhou, Sun Jun, Shen Peiliang, Zhang Haibo, Yin Zongze and others in the early 21st century explored the upper and lower line of Shanghai Pearl Transit Pearl Line project in a close range of overlapping tunnel.

Based on extensive analysis of relevant domestic and foreign literatures, this paper will draw lessons from the past successful engineering experience and existing relevant theories, and refine and summarize the analysis results, and take the shallow subsoil excavation project Beijing Subway Airport Line Dongzhimen Station The deformation and stability of the tunnel passing through the existing metro line are studied in the case of Dongzhimen station. By using the FLAC3D simulation software, the results of field measurement are analyzed, and the results are compared and analyzed. The simulation results are representative and practical.

2. Numerical simulation research

2.1. Project overview

Dongzhimen Station of Beijing International Airport Line is on the east side of East Second Ring Road and the northeast corner of Dongzhimen Overpass. It is located on the north side of Dongzhimenwai Street, showing the east-west direction. Airport Line Dongzhimen Station on the west side is the Dongzhimen overpass and Metro Line 2 Dongzhimen Station, the north side of the Dongzhimen important underground transportation hub, namely the subway line 13 Dongzhimen station. As the first stop of Capital International Airport Line Project, Dongzhimen Station is a double-spanning station with four floors underground. The structure of the station is complicated. The main structure of the station consists of five independent structures. According to the different construction methods, can be divided into safety lines, A, B, C and D and other five parts. The single-arch structure is adopted in the A-section, and the double-arch structure is adopted in the B-zone. C area is mainly used in the form of double-layer structure, respectively, under the open-cut and dug through the line under the 13th line of the foldback two parts, D area is mainly used in the open and cut five-story three-span double column box structure type.

2.2. Model building and parameter selection

Numerical simulation of the calculation of the assumption that the following points, namely:

First, the surface and the soil layers are in a uniform horizontal distribution.

Second, the surrounding rock is a continuous elastic-plastic material. Its plastic yield criterion is calculated by the Mohr-Coulomb yield criterion according to the isotropy and large strain deformation model. In addition, the structure of the existing station the linear elastic model is used in the support, and the elastic material is used in the concrete structure to simulate.

Thirdly, only the gravity stress of rock and soil is taken into account in calculating the effect of initial geostress, and the tectonic stress of rock and soil is neglected, and the influence of groundwater is not considered at the same time. Of the self-gravity effect, the occurrence of consolidation settlement until it reaches a certain equilibrium state, and then excavation construction simulation. The strain and strain of the formation and the material are within the elastic - plastic range;

Fourthly, the geotechnical investigation report (detailed investigation stage) of Dongzhimen station of Beijing Capital International Airport Line has been completed when the surrounding soil parameters of the construction are affected to some extent by the construction disturbance.

Fifth, because the modeling is relatively difficult, the author simplified the section of the horseshoe-shaped double arch of the reentrant line structure into a single-layer box-shaped structure, so as to achieve unity with the open-cut section of the folding line;

Sixth, in order to simplify the analysis and save time, the calculation will oblique intersection to vertical intersection, the model of this simplification is actually a more unfavorable situation, the results are relatively conservative.

According to the engineering geology and hydrogeological conditions of the site, the physical properties of the surrounding rock are mainly referred to the "Geotechnical Investigation Report of Dongzhimen Station of Beijing Capital Airport Line Project". And then through the weighted average method, and then determine the use of Table 1 as shown in the formation parameters, the region is divided into six different soil layers for simulation analysis. The parameters of the lining and the envelope are shown in Table 2, and the input parameters of the beam element and the pile element are shown in Table 3 below.

Table 1.Generalized formation parameters

No.	Soil layer	Thickness (m)	Natural density (g/cm3)	Cohesion C (kPa)	Internal friction angle $\varphi(1)$	Poisson's ratio μ
1	Fill layer	9.04	1.92	25	11	0.36
2	Sand layer	7.52	2.06	0	32	0.23
3	Cohesive soil	4.63	1.97	32	26	0.31
4	Fine sand layer	6.6	2.02	0	30	0.23
5	Silty clay	5.7	2.03	39	16	0.31
6	Sand layer	10.51	2.07	0	33	0.2

Table 2.Calculation parameters of lining and envelope

No.	name	Elastic Modulus E0 (MPa)	Poisson's ratio μ	Density (kg/m3)
1	Primary support concrete C20	25500	0.20	2300
2	The main structure of concrete C30	30000	0.20	2500
3	Joist, pile, continuous wall concrete C25	28000	0.20	2400
4	Filled concrete C15	22000	0.20	2200

Table 3.Beam element and pile element input parameters

Unit type	Elastic Modulus E(GPa)	Poisson's ratio μ	Density (kg/m3)	Simulate an object
Beam(D=0.15(m))	200	0.20	7850	Pit support, jack
pile(D=0.8(m))	28	0.25	2400	Digging hole in the guide hole
pile(D=1.2(m))	28	0.25	2400	Excavated pile in guide hole No.1 and No.3

In this paper, the finite difference program of FLAC 3D is mainly used in the calculation and analysis, while the boundary condition of the model is strictly according to the analysis result of tunnel mechanics. In this paper, the three-dimensional finite element model of interaction between the stratum and the structure is selected. In this paper, the calculation error caused by the size effect is mainly considered in the scope of modeling, in which the boundary of calculation is about 3 times of the width of the structure of the left and right border, and 1.5 times of the lower boundary The height of the foldback line structure, the height of the upper boundary is selected until the surface. The width of the whole model is 44 meters and the width is 100 meters. The length is 32 meters according to the actual excavation length of C area. The total model is 32 meters in length. Including 62976 units and 67914 nodes. The meshes in the scope of the construction of the underfloor structure have adopted a finer grid.

Y = the boundary of 16m, constraining its displacement in the Y direction; Z = -22m boundary, restrain its Z direction displacement; The top surface of the model is the boundary of the model, X = ± 50m; Free surface. Finite difference calculation model and the grid division as shown in Figure 1 below.

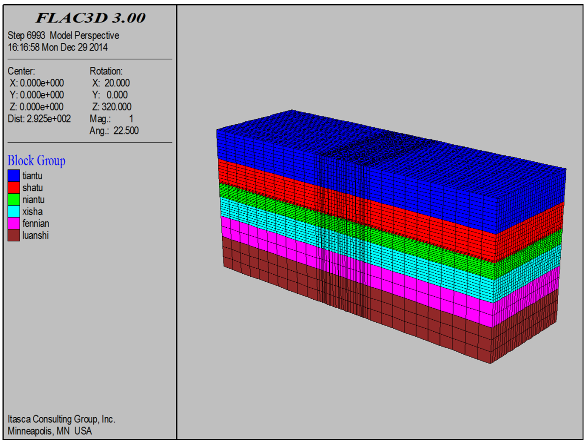

Fig. 1. Global Mesh Model

2.3. Construction process simulation and calculation result analysis

(1) Simulation of stage excavation

Under the cross-section through the reentry line, the structure of the application of the pile pile underpinning construction scheme, the program first through the pile-beam system to support the entire reentry line structure, and then structural dug construction work, which can be effective of the fold line to ensure the safety. Among the construction schemes designed in this paper, the main construction steps of the upper span crossing the existing reentrant line structure are shown in Fig.2.

(2) The analysis of computing result

A record point is set up at the center point of the floor through the existing foldback line structure and used as the simulation value of the settlement of the existing foldback line structure. The excavation simulation calculation is carried out according to the reasonable steps, and the existing line in the construction process Settlement characteristics of a certain analysis and summary. Among them, each excavation stage has the structural settlement displacement cloud chart as shown in Figure 3:

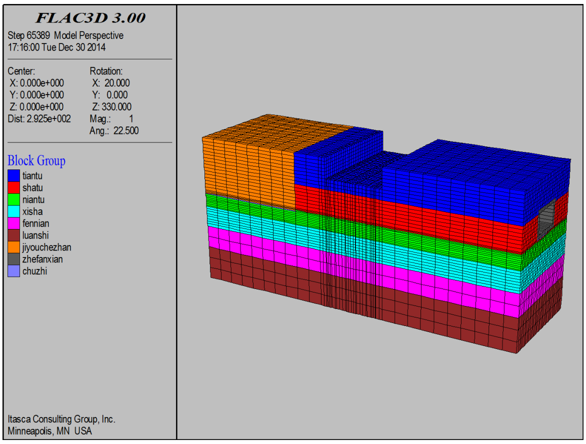

Fig. 2. Simulation of stage excavation

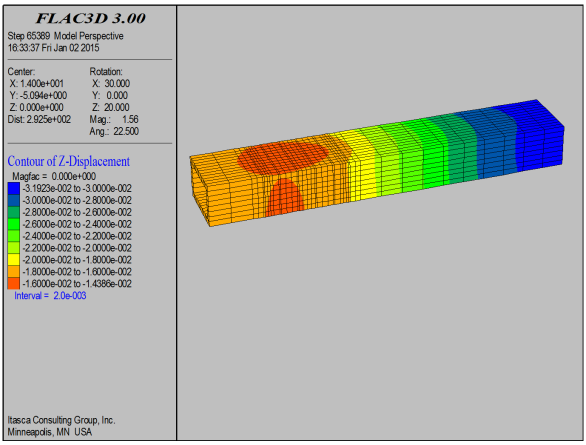

Fig. 3. The vertical displacement nephogram of existing metro Line after excavation

3. Construction monitoring and data analysis

The Dongzhimen station of the Capital Airport Line crossed through the post-war reentry line structure project of No. 13 line. From the first step of excavation to the last step, the excavation construction work was completed. Based on the remote automatic monitoring record data, The characteristics of the subsidence of the existing line structures and the reasons of its subsidence are compared and analyzed respectively in each stage of construction.

Based on the data of Dongzhimen station, the settlement data of the existing structures are completely completed from the excavation to the dismantling of the Dongzhimen station. The central monitoring points are plotted as settlement time curves corresponding to the crossing points of the simulated points crossing the line, Smooth out the settlement in each stage of the displacement diagram, the simulation results and monitoring data comparison analysis is drawn as shown in Figure 4:

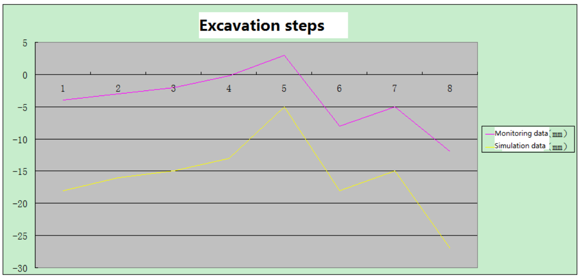

Fig. 4. Contrasting calculation result and monitoring data

In general, the curves of numerical simulation are similar to those of monitoring and measuring curves in shape and trend, but the settlement of numerical simulation is about half larger than that of the actual monitoring. This is because the numerical simulation the physical and mechanical properties of the soil, the construction excavation method and the structural model of the existing line are all simplified. In the actual situation, the real situation of the soil exists Very large uncertainties, and in the construction process, the construction method can be changed at any time, for example, in each step of the excavation of the soil immediately after the addition of a temporary support, etc., which will cause the numerical simulation of the results and the results of the actual monitoring there are some differences in the numerical.

4. Analysis of influencing factors

4.1. Construction process simulation and calculation result analysis

Compared with the actual parameters of the surrounding rock, the parameters of the actual rock mass are compared with those of the practical parameters, and the settlement curve of the existing line is compared with the practical one under the condition of other conditions being invariable. The influence of different surrounding rock parameters on the characteristics of the shallow tunnel and the settlement law of the existing line structure is obtained.

Compared with the simulation results of the actual parameters, the influence of the parameters of the surrounding rock on the settlement of the existing station structure is shown in Fig.5.

The above figure can be seen: the elastic modulus of the surrounding rock E, the cohesion of the surrounding rock C and the angle of internal friction across the construction of a significant impact on the increase in these three parameters of the same construction sequence after the obvious structural settlement reduce. Therefore, in similar projects encountered later, these parameters is the engineering design and construction and other aspects need to focus on one of the important factors to consider.

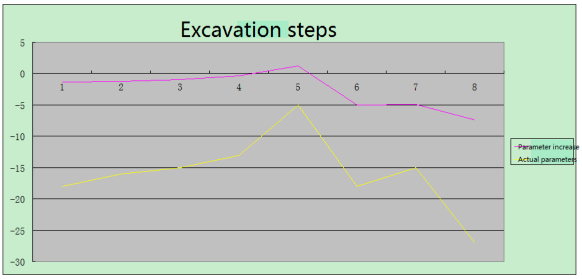

Fig. 5. The Contrasting calculation result of historical settlement curve of center points of different parameters of surrounding rock

4.2. The influence of excavation sequence

There are two different construction schemes for the construction of the upper and lower crossing works:

(1)The first program is to dig out the top of the fold line excavation pit, and then under the reentry line through the excavation construction.

(2)The second program is to complete the construction of the first line through the undercutting tunneling, and then across the excavation pit excavation.

In the actual tunnel construction process, the third scheme is adopted, that is, for the project of crossing the existing line, it is necessary to actively control and reasonably adjust the stratified excavation quantity of the soil above the existing line, and , So that the upper part of the excavation of the excavation and undercutting the construction of the excavation step by step, the use of the top of the existing excavation of the existing line uplift deformation to the appropriate "offset" below the construction part of the existing line Of the settlement, can effectively reduce the existing line structure settlement. At the same time you can adjust the excavation of small guide hole sequence.

The comparison of the existing settlement values of the three excavation schemes is shown in Figure 6:

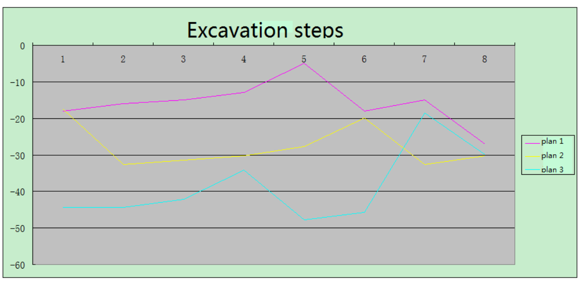

Fig. 6. The contrasting calculation result of historical settlement curve of center points of different excavation sequence

In the above figure, we can see that when the upper span crosses the existing line, the third scheme is adopted to ensure the minimum settlement of the existing structure. In these three different construction plans, if the second program for construction, the settlement of existing structures will be the largest. Therefore, if a similar project in the future, should try to avoid the construction of the lower part of the structure and then the construction of the upper part of the structure. The upper and lower structures shall be constructed simultaneously.

5. Conclusions

(1) It is very significant to implement monitoring system for the construction of existing lines, when the monitoring data has a large subsidence, we can keep the construction methods reasonable adjustment in time, it plays an important role for ensuring the safety of existing lines structure and the safety of the normal operation of the subway station.

(2) although the simulation results are larger than the actual monitoring results, they have the same variation trend. The simulation results accurately reflect the construction process of displacement trends. Therefore, simulation results for the new line construction still has a certain guiding role.

(3) it is concluded that the existing line's settlement is small when the soil parameters of surrounding rock are large, and the existing line's settlement constructed simultaneously is less than the independent construction.

References

[1] J.B. Burland, J.R. Standing, F.M. Jardine: *Building Response to Tunneling, case studies from construction of the Jubilee Line Extension, London Volume 1: PROJECT AND METHODS. London.* Thomas Telford Publishing (2001), 509–545.

[2] Brenner, B, Neff, T: *Design and management for underground uncertainty on the Central Artery/Tunnel Project.* North American tunneling (2000), 13–21.

[3] Burton, R&KassaP: *An underpinning scheme for the red line subway at south station.* Civil engineering practice *18* (1992), 67–86.

[4] Grynkewicz.F, Robert. B: *Instrumentation controls for chemical grouting during tunneling operation. Boston.* North American tunneling (2000), 465–474.

[5] Kassap,B.P,Goyal,B.B: *Redline underpinning-lessons learned.* North American tunneling (2000), 485–496.

[6] B.B. Goyal: *Underpinning of red line south station.* North American tunneling (2000) 83–88.

[7] S.B. Chang, S.J. Moon: *A case study on instrumentations of a large section tunnel crossing under the existing subway structure.* Proceeding of the KGS 2000 Spring Conference (2000), 56–59.

[8] G.Cassani: *Construction of an underpass at the Ravone railway yard in the city of Bologna:aspects of the design and construction.* Progress In Tunneling After2000 (1960).

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