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Study on the Impact of Shield Tunneling Side-crossing on Adjacent High-rise Building with Podium

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Abstract: Shield tunnel construction will disturb the surrounding strata and cause stress release and adjustment, resulting in uneven settlement of adjacent buildings and even collapse. According to the geological conditions of Ji'nan Railway Line 2, a three-dimensional numerical model is established. The analysis shows that the influence of tunnel excavation on existing buildings decreases with the increase of the distance from the tunnel axis. After the tunnel construction, the displacement of the building is obviously increased. The soil around the tunnel is funnel-shaped in vertical displacement. The maximum settlement is 5.57mm which appears near the tunnel invert. The uneven settlement of the building is 1.6mm. These conclusions can be used to give some reference to similar shield crossing projects in the future.

Keywords: shield tunneling, close range, side-crossing, numerical analysis, building deformation.

1. Introduction

In the construction of underground engineering such as subway, shield tunneling method has become one of the main construction methods because of its low environmental impact and fast construction speed. Although the shield construction technology has been developed, it will inevitably cause disturbance to the surrounding soil. And it will lead to varying degrees of strata displacement and deformation, resulting in uneven settlement of surrounding buildings [1]. In order to effectively prevent and reduce the adverse effects of tunnel construction on the building, the deformation and internal force of the shield tunnel should be analyzed.

In this paper, a three-dimensional numerical model is established by using finite element simulation software to analyze the influence of the impact of shield tunneling side-crossing on adjacent high-rise building with podium. It will play a certain role on the design and construction of similar projects.

2. Background

Ji'nan Railway Line 2 is from east to west, which is a rail transit backbone lines to ease the traffic pressure. According to the geological prospecting report, the interval is a landform unit of the piedmont alluvial plain, and the main stratigraphic lithology is the alluvial silty clay, clay, gravel, etc.

In this region, segment inner and outside diameter are 5.8m, 6.4m.The thickness is 300mm. Each segment is divided into 6 blocks, which are connected by 12 bending bolts. And all of the rings are connected by 16 longitudinal bending bolts. The staggered joints are assembled.

The tunnel will pass through the podium of Baihe office building at ZK17+115.203. The podium has 4 floors, while the main building has 18 floors. They are using CFG pile composite foundation, whose pile length is 14m~15m.The raft foundation thickness is 0.5m. The tunnel is located in 16-1 silty clay, 19-2 fully weathered diorite. The vertical distance between the vault and the CFG pile foundation is about 1.7m.Such close crossing certainly will affect the buildings. The relationship between the interval tunnel and the building plane is shown in Fig. 1.

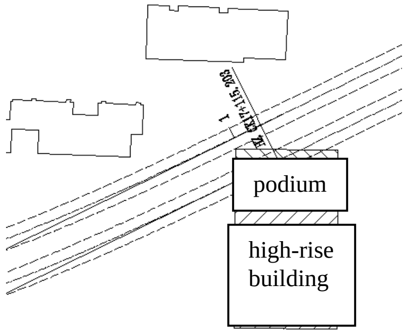

Fig. 1 The relationship between the interval tunnel and the building

3. Numerical Simulation and Analysis

3.1 Calculation Assumption

According to the actual situation and characteristics of the project, the three-dimensional finite element static analysis is considered as follows:

1) The rock soil layer is simplified as an elastic plastic material with horizontal layered distribution. And its constitutive model is based on the Mohr M-C model.

2) Assuming that the ground and soil layers are homogeneous and layered. The initial stress field considers only the deadweight.

3) The transverse and the longitudinal connection between the segments are not considered [2].

4) In the simulation analysis, the shield construction is simplified, such as the shield jacking force.

3.2 Model Establishment and Parameter Selection

According to the engineering experience and theoretical analysis, the selection of the scope is: the outer side is about 5 times the diameter of the tunnel. Therefore, the soil range is 110m×70m×65m(X×Y×Z). The whole three-dimensional finite element model is composed of 117730 elements. The calculation model is shown in Fig. 2 and Fig. 3. The physical and mechanical parameters of rock and soil are shown in Table 1.

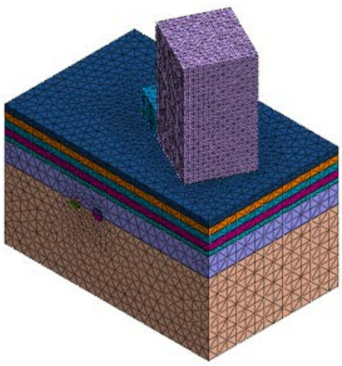

Fig. 2 Vertical view

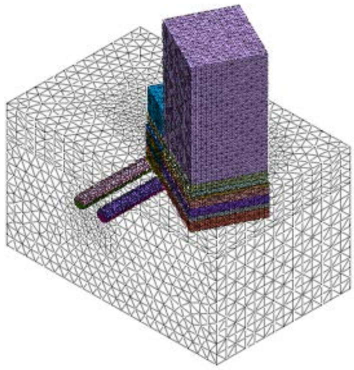

Fig. 3 Perspective

Table 1 Design parameters of physical and mechanical parameters of rock and soil mass

Number	Name	Density ρ (g/cm^3)	I_L	I_P	Direct shear consolidation		K0	Coefficient of subgrade reaction	
					Cc (kPa)	Φc (°)		Kv（MPa/m）	Kh（MPa/m）
1-1	Miscellaneous fill	1.94	-	-	(10)	(15)	-	-	-
7	Clay	1.88	20.1	0.38	35	19	0.54	25	23
7-1	Silty clay	1.93	13.4	0.42	24	17	0.45	35	22
10-1	Silty clay	1.96	13.5	0.40	30	19	0.43	58	27
10-2	Clay	1.95	19.2	0.13	45	22	0.38	56	43
16-1	Silty clay	1.87	13.4	0.52	35	19	0.40	59	36
19-1	Completely weathered diorite	1.96	11.8	0.29	-	-	-	—	—

3.3 Simulation Results and Analysis

(1)Analysis of soil deformation and stress field in shield tunnel

The displacement field of shield tunnel after excavation is shown in Fig. 4, Fig. 5, the stress field is shown in Fig. 6, Fig. 7.

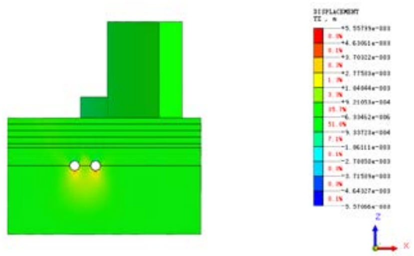

Fig. 4 Vertical displacement

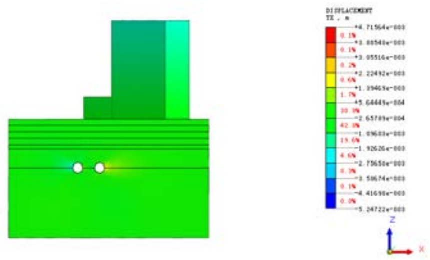

Fig. 5 Horizontal displacement

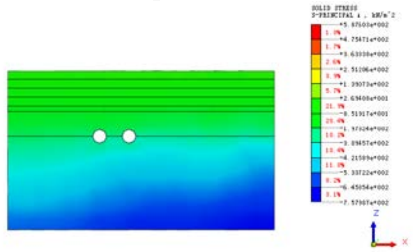

Fig. 6 The maximum principal stress

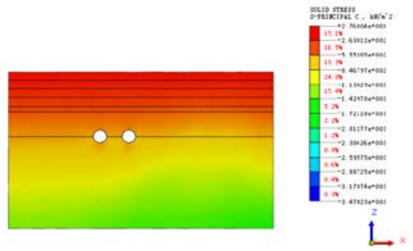

Fig. 7 The minimum principal stress

Seen from the results, the soil around the tunnel is funnel-shaped in vertical displacement of shield segment after construction. The maximum settlement is 5.57mm which appears near the tunnel invert. The scope of the impact is 12m, about 2 times the diameter of the tunnel.

The vertical and horizontal displacement of the building also occurred with the excavation of the tunnel. When the double shield tunnel passes through, the maximum settlement is 0.97mm. It appears at the top of the left tunnel, the surface subsidence surface is roughly "V" shape.

The left and right lateral displacements of the tunnel are 2.76mm, 1.39mm. Because of the disturbance superposition effect, the soil in the middle of the shield tunnel is more serious. But it is within the scope of security risk control (<10mm).

In the process of tunnel excavation, the original stress field of soil is destroyed, and then a new balance is formed. During excavation, the maximum principal stress is 0.76MPa.

(2)Analysis of deformation and stress field of buildings

Fig. 8 is the vertical displacement of Baihe office building caused by shield tunneling.

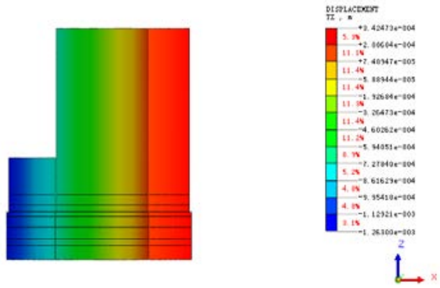

Fig. 8 Vertical displacement of buildings

It is not difficult to see from the simulation results, the largest vertical displacement of Baihe office building is 1.26mm which occurs on the left side of the building. It is mainly caused by the excavation of the shield tunnel in the lower part of the building. The uneven settlement is 1.6mm, which meets the requirements of specification. It can be concluded that the influence of tunnel excavation on existing buildings decreases with the increase of the distance between the building and the tunnel axis. After the tunnel construction, the displacement of the building is obviously increased. At the same time, the superposition effect caused by the two line shield construction is not obvious.

Fig. 9 and Fig. 10 are the vertical stress and the maximum shear stress of the buildings.

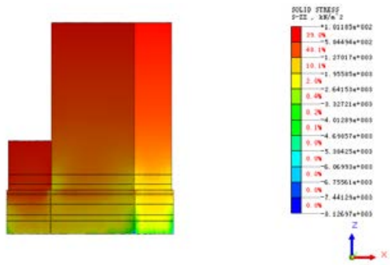

Fig. 9 Vertical stress of buildings

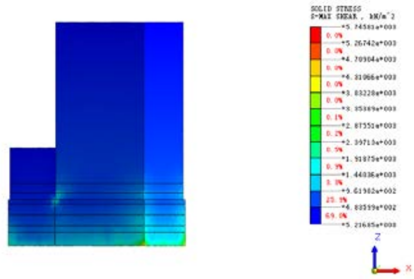

Fig. 10 The maximum shear stress of buildings

As it can be seen from the figure, the maximum compressive stress increment value is 8.1MPa，which meets the compressive strength of C30 concrete in Code for design of concrete structures；

The maximum shear stress increment of the building is 5.7MPa, which meets the shear requirements of C30 concrete.

Through analysis, the largest deformation value of the office building is 1.26mm. Uneven settlement is 1.6mm, within the design specifications related to the control standards.

4. Conclusions

The following conclusions can be obtained by simulation calculation:

(1)The influence of tunnel excavation on existing buildings decreases with the increase of the distance between the building and the tunnel axis. After the tunnel construction, the displacement of the building is obviously increased. The vertical displacement of the soil around the shield tunnel is a funnel shape whose maximum value appears near the tunnel invert. The maximum settlement is 5.57mm, the uneven settlement between podium and the main building is 1.6mm. The maximum settlement of shield tunnel is 5.57mm, which occurs in the tunnel location just below the podium. The overall deformation of the tunnel is compressed, which is caused by the top settlement and the bottom heave of the tunnel excavation.

(2)The numerical simulation results show that the building displacement, uneven settlement and tunnel deformation are smaller. However, in the actual construction process, due to the instability of the dynamic control of shield construction parameters and the construction of auxiliary means such as the construction is not timely, it may bring instability to the construction safety factors. Therefore, the protective measures should be taken to protect the soil around the buildings.

(3)Under the influence of shield tunneling parameters and stratum parameters during construction, the settlement can be further reduced by strengthening the twice grouting, optimizing the parameters of shield tunneling and enhancing the monitoring.

Acknowledgments

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