THREE-DIMENSIONAL NUMERICAL MODEL OF CONSTRUCTION PROCESS FOR EMBEDDED TUNNEL OPENING OF DONGHU METRO STATION

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ABSTRACT

The Donghu station of No.6 line of Guangzhou rail transit has divided two parts, one is embedded excavation part, and the other is Open excavation part. The kilometer of embedded excavation part is from k13+462.752 to k13+519.452. The tunnel crown is located 19 m below the ground surface. Stratums are mix-filled soil, alluvial deposit to flooded alluvial deposit, eluvium and all regolith to medium regolith from the top down. The largest span of tunnel is 20 m. Its largest height is 10.349 m. Because the tunnel has large span and section, the construction is very difficult. In order to control the surface settlement and ensure the security of tunnel, the FEA method is used to analyze the construction process to find the rationality of construction method and support method. A three-dimensional numerical simulation model analyzes the construction process of the tube pre-support and center drift method in Donghu station by FLAC-3D in this paper. The results indicate that the reinforced and construction method can ensure the safety of construction, and control the surface settlement. The final conclusions are two: (1) the surface settlement and displacement are small and the tunnel is steady in the construction process. (2) The main step of influencing the surface settlement and crown settlement are step I, step IV and removing of the temporary supporter. So the supporter must be installed in time and reinforced the strength. The distance which is from working face to temporary supporter must be more than two times span of tunnel.

KEY WORDS

metro station, surface settlement, stability, FLAC-3D, numerical analysis

INTRODUCTION

The Donghu station of No.6 line of Guangzhou rail transit has divided two parts, one is embedded excavation part, and the other is Open excavation part. The kilometer of embedded excavation part is from k13+462.752 to k13+519.452. It passes through the Donghu road. The tunnel crown is located 19 m below the ground surface. Stratums are mix-filled soil, alluvial deposit to flooded alluvial deposit, eluvium and all regolith to medium regolith from the top down. The largest span of tunnel is 20 m. Its largest height

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is 10.349 m. Because the tunnel has large span and section, the construction is very difficult. But must control the surface settlement and ensure the security of tunnel. The center drift method is adopted.

In actual tunnel construction process, the tunnel support parameters, excavation method, cycle footage and the various joint of all process have the tremendous influence to the stratum disturbance as well as the surface settlement. Therefore, a three-dimensional numerical simulation model analyzes the construction process of the pipe-roof pre-support and center drift method in Donghu station by FLAC-3D.

CALCULATING MODEL

FLAC-3D (Three Dimensional Fast Lagrangian Analysis of Continua）is now popular and advanced software in the world. The software is specially used to solve the soil mechanics questions, which is a Large-scale commercial finite difference program. It was developed by Itasca Consulting Group Inc. of USA.

The scope of calculating model is: the horizontal direction is 4 times tunnel span form tunnel center to the model boundary. The vertical direction is 4 times tunnel height from tunnel bottom to base boundary. The height above tunnel is from the tunnel crown to natural ground surface. The model size (xyz) is 160m, 70.31m and 21m. The boundary conditions are as follows: ground surface is free, the left boundary and right boundary are fixed at x-axis direction, front boundary and rear boundary fixed at z-axis direction, and base boundary is fixed at y-axis direction. The uniform load of road surface is 10kpa. There are 38346 zones elements in this numerical model. An elastic-perfectly-plastic model using the Mohr-Coulomb failure criterion was adopted in this study.

Table 1: Analysis Parameters

Soils and support	**Bulk density γ （kg/m3）**	**Cohesion c （kPa）**	**Angle of friction φ （°）**	**Young's modulus E （MPa）**	**Poisson's ratio μ**
soil 1	1550	4	5	4	0.4
Soil 2	1900	5	27	15	0.33
Soil 3	1950	5	27	20	0.3
Soil 4	1900	26.4	25	70	0.31
Soil 5	2260	300	30	100	0.30
Soil 6	2420	1000	35	500	0.3
Soil 7	2560	2870	40.7	800	0.25
reinforcement circle	2500	2870	40.7	800	0.25
Support (c25)	2300			29500	0.2
Second lining (c30)	2500			31000	0.2

The pre-support of pipe-roof simulates by equivalent parameter method, namely through enhancing the parameter of pipe-roof reinforcement region to come equivalent simulation. The physics mechanics parameter of reinforcement circle enhances a rank according to the locus level. The reinforcement circle scope is pipe-roof construction region of tunnel arch; reinforcement circle thickness is 200mm.

ANALYSIS PARAMETERS

The stratum, reinforcement circle and support structure parameter are list in table 1.

ANALYSIS BEHAVIOUR

The pre-support is pipe-roof. The excavation method is centre drift method with bench method. The distance between top heading and bench is 3m. The abstract parameters are as follows: the pipe-roof is φ108mm seamless steel pipe, which install in tunnel arch with 0.4m circumferential spacing interval. Spacing interval of steel grid is 0.5m. The excavation footage is 1m. The construction procedure which has eight steps is shown in figure 1.

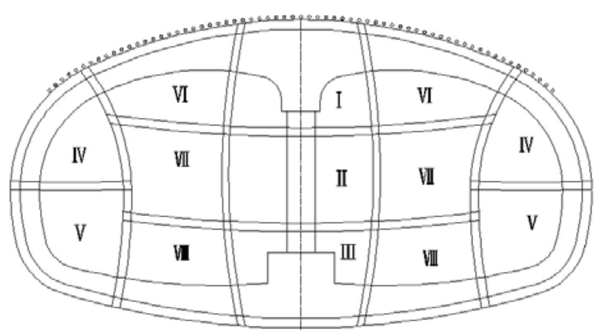

Figure 1: Construction Procedure

Table 2: The Inner Displacement and Ground Surface Settlement of Centre Drift

behavior	Maximum crown displacement(mm)	Maximum step waist displacement（mm）			Maximum ground settlement (mm)
		Step Ⅰ	Step Ⅱ	Step Ⅲ	
Step Ⅰ: opening and support finished	3.02	1.7			0.85
Step Ⅱ: opening and support finished	3.18	1.84	0.9		0.98
Step Ⅲ: opening and support finished	3.22	1.87	0.93	0.26	1.02
finished main structure of step Ⅰ,Step Ⅱ and Step Ⅲ	0.086	1.93	1.07	0.44	1.05

ANALYSIS RESULTS

THE INNER DISPLACEMENT AND GROUND SURFACE SETTLEMENT OF CENTRE DRIFT

The inner displacement and ground surface settlement of centre drift is listed in table 2.

THE INNER DISPLACEMENT AND GROUND SURFACE SETTLEMENT OF OTHER STEPS

The inner displacement and ground surface settlement of other steps are listed in table 3

Table 3: The Inner Displacement and Ground Surface Settlement of Other Steps

behavior	Maximum crown displacement (mm)	Maximum arch waist displacement (mm)	Maximum arch foot displacement (mm)	Maximum spring displacement (mm)	Maximum ground settlement (mm)
Step □: opening and support finished	0.6		1.83		1.86
Step □:opening and support finished	0.59		1.91		1.91
From Step □ to step□: lining finished	0.75		0.53	1.05	1.96
Step □: opening and support finished	0.88	0.96	0.64	1.06	2.52
Step □: opening and support finished	0.89	0.97	0.64	1.01	2.53
Step □: opening and support finished	0.885	0.94	0.62	0.99	2.51
finished Main structure	2.21	1.55	1.1	0.96	3.36

THE GROUND SURFACE SETTLEMENT OF FINISHED MAIN STRUCTURE

The ground surface settlement of finished main structure is shown in figure 2.

THE STRESS OF FINISHED MAIN STRUCTURE

The contour of minimum principal stress is shown in figure 3. The contour of maximum principal stress is shown in figure 4.

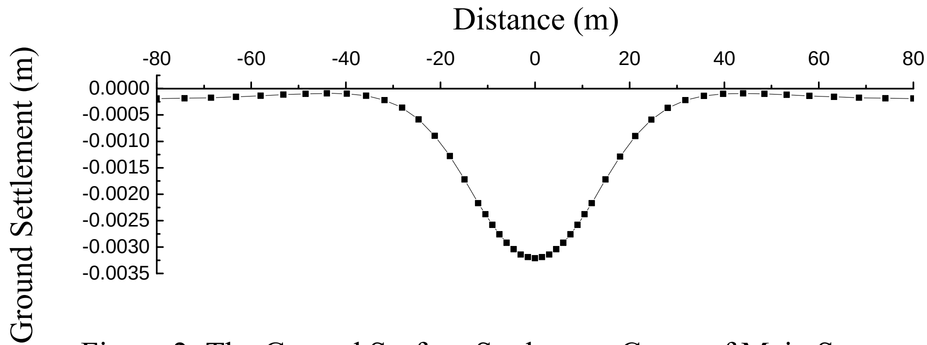

Figure 2: The Ground Surface Settlement Curve of Main Structure Finished

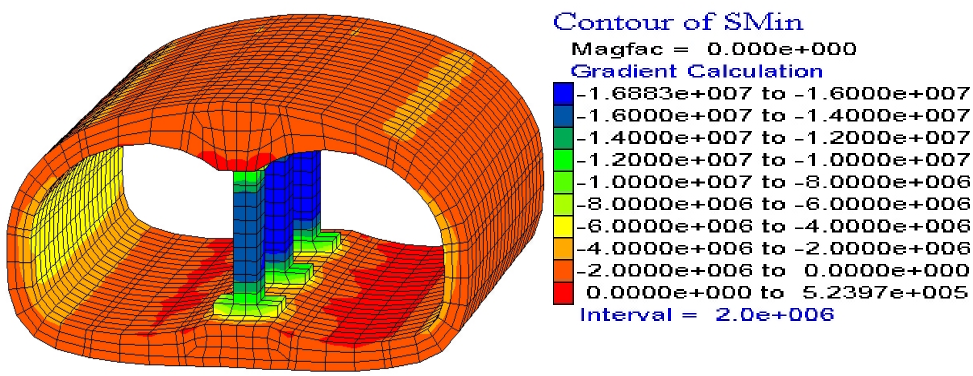

Figure 3: The Contour of Minimum Principal Stress

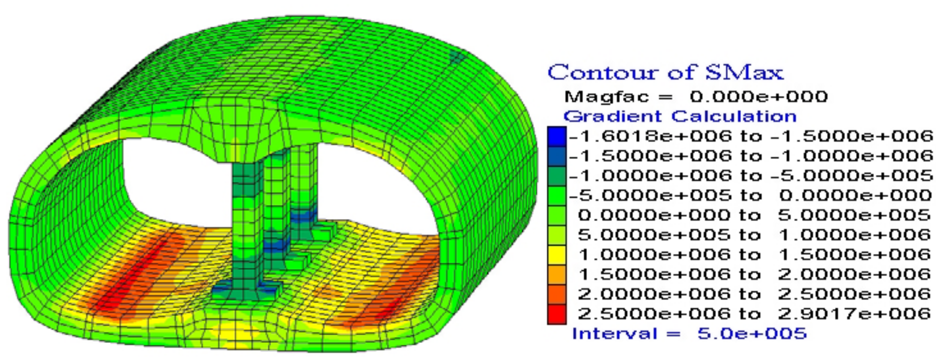

Figure 4: The Contour of Maximum Principal Stress

The maximum compression stress located in centre pillar of main structure. The maximum value is 16.88MPa. The maximum tensile stress is 2.5MPa, which lies right tunnel center and left tunnel bottom.

GROUND SURFACE SETTLEMENT OF EXCAVATION STEPS

Ground surface settlement of excavation steps at z=0m is shown in figure 5

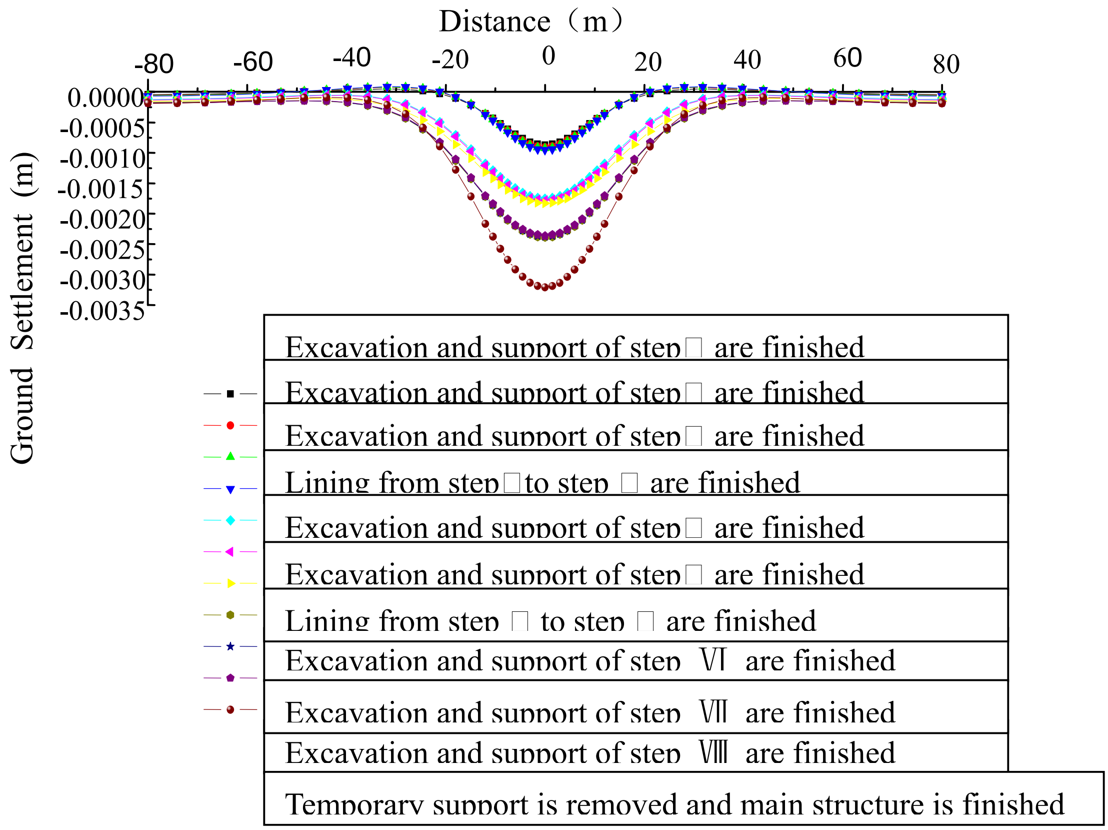

Figure 5: Ground Settlement after Finishing Every Construction Procedure

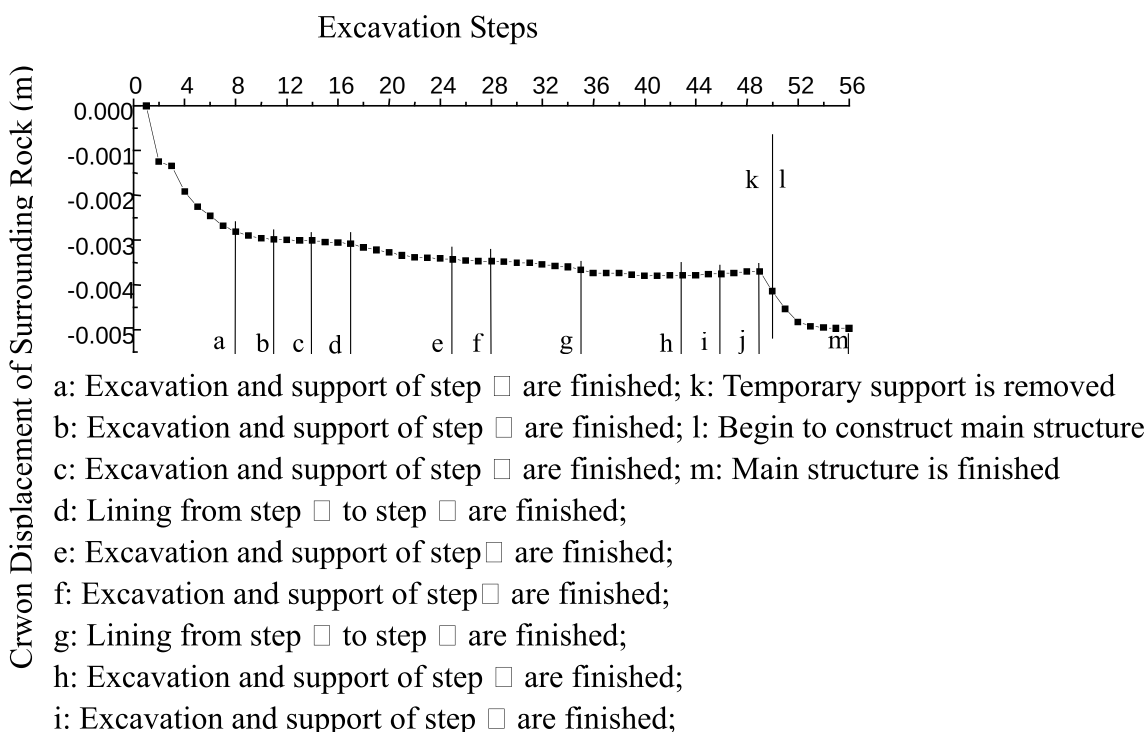

Figure 6: Vertical Crown Displacement of Surrounding Rock versus Excavation Steps

ROCK CROWN DISPLACEMENT OF EXCAVATION STEPS

In order to know rock crown displacement of excavation steps, the rock vertical displacement of excavation steps at z=0m is shown in figure 6. It was get that after excavation step □, the vertical crown displacement of surrounding rock varies smaller before removing the support, but after removing support, it begins to increase fast. After main structure is finished, the crown vertical displacement of surrounding rock has increased 34 percent.

CONCLUSION

The final conclusions are as follows:

(1) Surface settlement and displacement are small and the tunnel is steady in the construction process.

(2) The main step of influencing the surface settlement and crown settlement are step I, step IV and removing of the temporary supporter. So the supporter must be installed in time and reinforced the strength. The distance which is from working face to temporary supporter must be more than two times span of tunnel.

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