Numerical analysis of influence of deep excavations on metro tunnel

Cong Chen

Wuhan Metro Group Co., Ltd, Wuhan 430030, China

873540602@qq.com

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Abstract. As metro and urban light railway transit projects are rapidly launched in China, land exploitation projects along the railway are increasing too, and lots of new buildings' deep foundation pit work are located around metro station and tunnel protection sphere, the metro station will inevitably be influenced by those engineering constructions. Based on a deep excavation project around the metro tunnel in Wuhan, using Midas GTS software 3d numerical analysis model of deep foundation pit excavation, the simulation results show that tunnel structural maximum displacement occurs in the bottom of foundation pit excavation. It is suggested that foundation pit supporting design should be strengthened in frequency of encryption and monitoring, especially the horizontal displacement of retaining structure, supporting structure internal force and deflection.

Introduction

With the rapid construction of the urban subway and light rail in China, the development of the land along the subway and light rail line also experiences an upward trend. Therefore, a large amount of foundation pit engineering of these new buildings is located within the scope of subway protection which in turn beaks the stress state and balance of equilibrium of the station and tunnel area of subway. It leads to the redistribution of the stress which would result in the internal force change, and deformation of subway station and tunnel[1-3]. On the other hand, there exists a strict requirement of the structure deformation of the running subway. Thus, the influence of deep foundation pit unloading on subway cannot be ignored and must be evaluated precisely during the foundation pit engineering which mean that the maintenance design and the construction technology should be carefully selected and improved in order to ensure subway operating safety. In this field, 3D numerical analysis is widely accepted as the most important mean to realize the stability of the foundation pit[4-6].

The software of Midas GTS has the function of 3D modeling, auto mesh generation and professional geotechnical analysis which has been widely used in the area of geotechnical engineering. Therefore, Midas GTS is adopted in this paper to evaluate the effect of foundation pit excavation on subway.

Engineering project

Project Overview. The engineering project is located in Wuhan. The ground elevation around the foundation pit of this project is approximately 20.40 meters. The depth of the excavation is 11.75 meters with area of 13.700 m2. The area and surrounding environment as shown in figure 1, architectural details as shown in table 1.

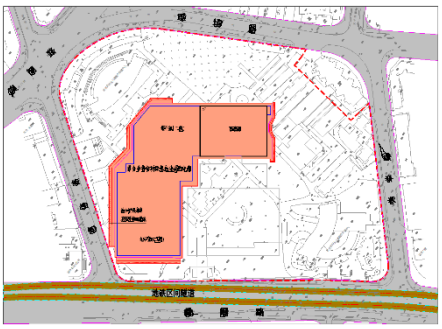


Figure 1 The general plane figure in Wuhan

Table 1 General situation of building

number	name of buildings	Struct types	Height（m）	designed elevation（m）	Embedded depth of foundation（m）	Type of base
1	superstructure	frame-shear wall structure	4/-2 layers 20.10	21.10 (±0.00)	11.75m	Pile foundation
2	basement	frame-shear wall structure	-2 layers	21.10 (±0.00)	11.75m	Pile foundation

This project is close to the subway tunnel. Considering this characteristic and the construction features of the deep foundation pit, it is suggested that during the construction of the project, the foundation pit excavation unloading would lead to negative effects on the subway structure which are mainly embodied in the following two aspects: one is subway structure displacement caused by the excavation; the other one is the stress variation of the subway structure in the excavation. To sum up, using Midas GTS calculation software, combined with the characteristics of the project, the influence of excavation on adjacent metro tunnel structure is simulated and analyzed focused on these three aspects mentioned above.

3D Data Modeling Establishment. According to the spatial relationship between foundation pit and subway, the design of its retaining and supporting structure and the features of construction, the scope of calculation model is based on foundation pit outer contour which means the outside is enlarged at least30 m (about 2 times the depth of foundation pit). The boundary conditions of finite element model are as followed: the bottom of the model constraints the vertical displacement and the horizontal displacement is constraints by the left and right sides of the model. Calculation parameters and the network model are shown in table 2 and figure 2 respectively.

Table 2 The soil parameter

number	soil	The compression modulus（MPa）	Poisson's ratio	Bulk density（kN/m^3）	Cohesive force（kPa）	Angle of internal friction（°）
1	Grain filling	3.5	0.34	18.0	10	8.0
2	Silt clay	3.0	0.35	17.0	8.6	5.3
3	Silt and silty clay	6.5	0.33	18.1	14.6	8.4
4	silt	16.0	0.30	18.5	0	32.8

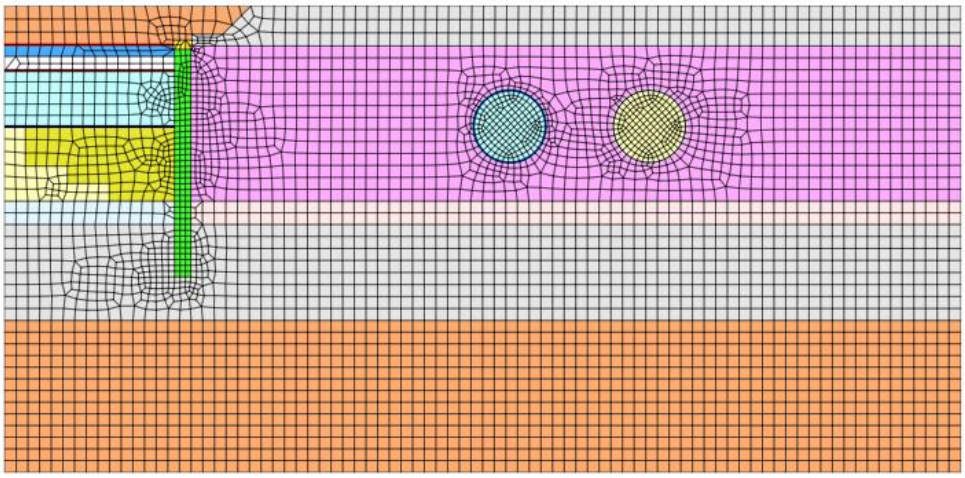
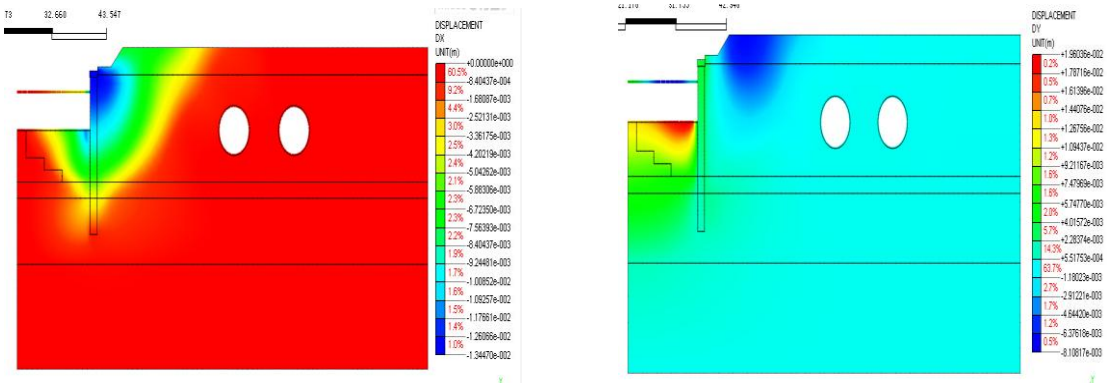


Figure 2 The model of calculation

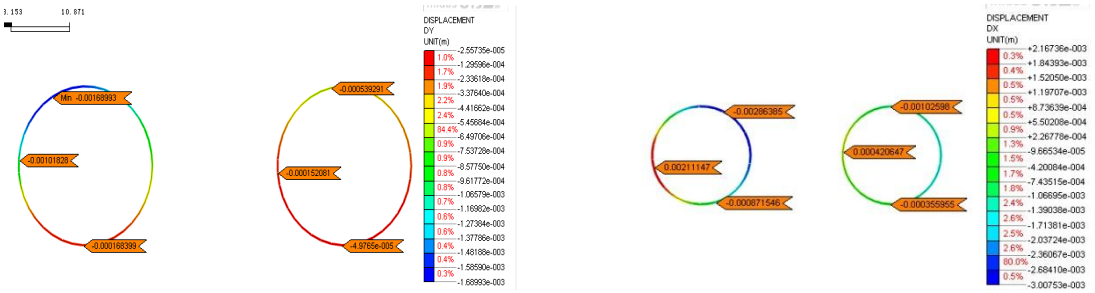
The Analysis About the Influence of Proposed Project on Metro Tunnel

The Displacement Analysis About the Influence of Proposed Project on Metro Tunnel. According to numerical calculation, it is concluded that the overall model and the subway interval of horizontal and vertical displacement, as shown in figure 3 and figure 4.



(a) Transverse displacement nephogram (b) Longitudinal displacement nephogram

Figure 3 The whole model displacement nephogram after the demolition of support



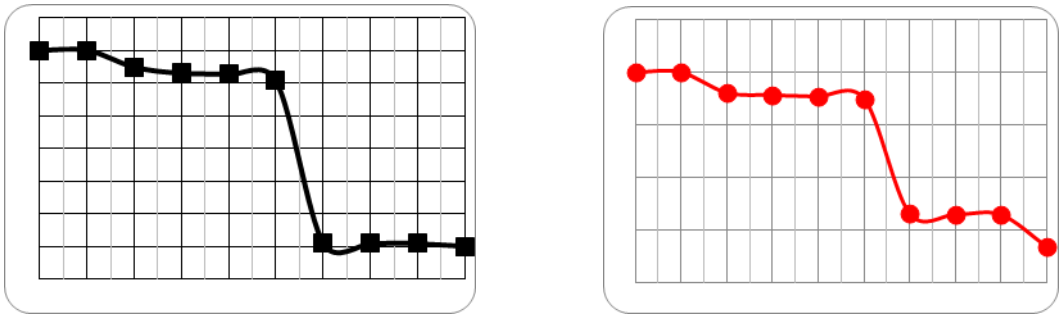
(a) Transverse displacement nephogram (b) Longitudinal displacement nephogram

Figure 4 The metro tunnel's model displacement nephogram after the demolition of support

In the different cases, the change of tunnel's displacement is shown in table 3 and figure 5.

Table 3 The change of tunnel's displacement

model	Horizontal sedimentation （mm）	Vertica sedimentation （mm）
Case 1	0	0
Case 2	0	0
Case 3	-0.26	-0.2
Case 4	-0.35	-0.22
Case 5	-0.37	-0.23
Case 6	-0.46	-0.26
Case 7	-2.95	-1.35
Case 8	-2.95	-1.36
Case 9	-2.95	-1.36
Case 10	-3	-1.69

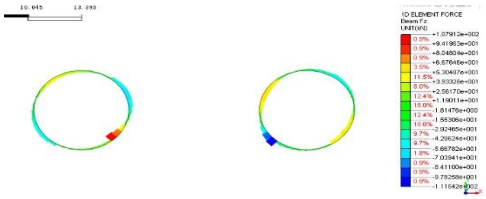


(a) Transverse displacement x axis-case, y axis-displacement(mm) (b) Longitudinal displacement x axis-case, y axis-displacement(mm)

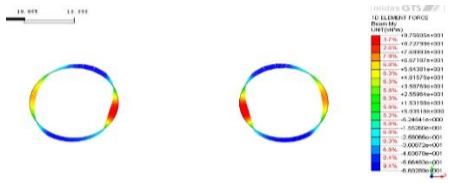
Figure 5 The displacement of tunnel

According to the results of numerical simulation, the influence scope of proposed project on metro tunnel are safety. The structural deformation caused by foundation pit construction meet the requirements

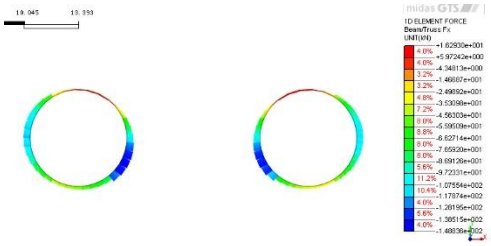
The Internal Force Analysis About the Influence of Proposed Project on Metro Tunnel. According to numerical calculation, it is concluded that the metro tunnel's internal force, as shown in figure 6 and table 4.



(a) Bending moment diagram



(b) Shear diagram



(c) Axial force diagram

Figure 6 The internal force of structure after excavation

Table 4 The calculation result of tunnel

program	model		Reinforcement calculation
	Before the excavation	after the excavation	
Bending moment（kN·m）	94.31	97.56	meet requirement
Shear（kN）	109.54	111.54	meet requirement
Axial force（kN）	148.37	148.84	meet requirement

According to the results of numerical simulation, the influence of internal force about proposed project on metro tunnel are safety. The change of structural internal force caused by foundation pit construction meet the requirements

Conclusion

Taking the construction of the foundation pit near Wuhan urban rail transit line 6 as an example, Midas GTS is used to make the 3D data analysis model based on the real construction project and various situations. According to the data from the model, it is concluded as below.

1) The project of the Integrated Service Building of Wuhan Women and Children Medical and Health Center dose not conflict with the subway tunnel in terms of spatial position. According to the construction sequence, the construction of this project is earlier than the subway tunnel. Therefore, this project has the construction feasibility with necessary engineering safety protection.

2) According to the calculation using finite element method, the structural displacement of the tunnel always happens at the final stage of excavation or the moment

of foundation pit supporting replacement. As a result, some methods of supporting replacement such as plate and strip should be carefully considered in the design of foundation pit support.

3) With consideration of the risks existing in the construction, it is suggested that foundation pit supporting design should be strengthened in frequency of encryption and monitoring, especially the horizontal displacement of retaining structure, supporting structure internal force and deflection. Special operation monitoring plan should be made at the same time.

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