Midas /GTS Numerical Simulation Analysis on Influence of Deep Excavation to Adjacent Subway Station

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Abstracts: As metro and urban light railway transit projects are rapidly launched in China, land exploitation project along the railway are increasing too, and lots of new buildings' deep foundation pit work are located around metro station and tunnel projection sphere, the metro station will inevitably be influenced by those engineering constructions. Based on a deep excavation project around the metro station in Wuhan, using MIDAS / GTS finite element program to establish the 2D model, the simulation results show that the influence of the excavation of the foundation pit on the subway station was within the requirements of the specification, which was not affect the normal operation of the tunnel and the entrance. It should be considered to develop the high level programming for the numerical simulation analysis about metro station and tunnel near deep excavation in the future near the subway. At the same time, the superposition effect to the station caused by the operation effect of several deep foundation pits at different stages should be considered.

Introduction

As metro and urban light railway transit projects are rapidly launched in China, land exploitation project along the railway are increasing too, and lots of new buildings' deep foundation pit work are located around metro station and tunnel projection sphere, which breaks the force equilibrium of the subway station and tunnel area, at the same time, the displacement field and stress field of soil around foundation pit are changed, which cause the change of internal force and deformation of metro station and tunnel, and then influence the structure of metro tunnel [1-3]. The requirements of subway stations and tunnels on the structure deformation extremely stringent, a case of Wuhan city, according to the "Regulations of Rail Traffic in Wuhan" (2012.12), the rail transit of operation and under-construction in accordance with the following criteria set protective zone: the ground, overhead station and the outside profile of the rail transit are in 30m from outside; the entrances, ventilation shaft, substations and other construction are in 10m from outside; and the requirements of settlement on structure facilities of subway absolute cannot exceed 20 mm. Therefore, the influence of excavation and unloading on deep foundation pit cannot be ignored to the subway station, and must accurate evaluate the effect of deep foundation pit in construction process to subway station and tunnel, reasonable to select and optimize the design of deep foundation pit supporting, construction technology, and to ensure its safe operation.

In recent years, many scholars have in-depth study on this issue. In paper [4] using Midas GTS 3D numerical simulation software to analysis on Influence of deep excavation in adjacent subway station, the whole process of self-weight consolidation and foundation pit excavation are simulated and analyzed, the result of calculation and the actual monitoring data show that the method has a significance guiding to the actual project. In paper [5] using MIDAS / GTS finite element program to establish the 3D model, and studying the influence of pile foundation load to subway tunnel, considering the characteristics of force and deformation on tunnel under various factors, finally summed up stress state, deformation modes and governance measures of the tunnel under the file foundation load. Midas GTS software is mainly analyzed the structure of rock and soil tunnel, which has the fast and intuitive 3D modeling, the fast and accurate function of auto grid generating, and the professional analysis function and visual analysis results, it has been increasingly applied to the field of geotechnical engineering. So, the paper adopts the MIDAS / GTS calculation program to establish2D plane for an engineering of deep foundation pit near the Rail Transit Line 3 in Wuhan, and selecting the typical sections to establish the finite element model. To analyze the influence of the surrounding earth excavation to the structure of the tunnel portal with large scale numerical simulation.

Engineering background

Engineering situation. The deep foundation pit engineering is located in the Jianghan District of Wuhan City, and close to the construction of rail traffic No. 3, which is the 1 entry of a subway station. The main building consists of three towers, the T1 tower (h=219m), T2, T3 tower (h=149 m), and three floors basement in rectangle.

The excavation area of foundation pit is 40600.00m2, the circumference is 790.00m, and excavation depth of the tower is 23.600m, the excavation depth of the main building in exterior domain is 17.600m. The nearest distance between exterior wall of the basement and the control line of subway is about 7.0m, and about 22m to the 1 entry of the subway station.

The rail transit line 3 is a subway line under construction in Wuhan, the whole line is under ground, which is the backbone connecting the Hankow and Hanyang. The line starts at the Public Center station and ends at Tunyang Road station. The whole line is 28km with 24 stations, and all are underground stations and underground lines with 11 transfer stations. The relationship between foundation pit and metro station is shown in figure 1.

Geological condition of engineering. Wuhan city is located in the mid latitude, which belongs to the subtropical monsoon zone, the regional water system is developed. According to the water physical properties of each layer of rock and soil in the engineering field, water-bearing property and groundwater burial conditions, we can divide the groundwater of site into perched water, pore confined water and bedrock fissure water. According to the depth of excavation, the influence of soil layer to the stability and deformation of the foundation pit consists 7 layers: ①Miscellaneous fill soil, ②1 Clay layer, ②2 Silty clay layer, ③Silty clay layer, ④Silty sand and clay interbeded , ⑤1 Silty sand, ⑤2 Fine sand, ⑥Gravel sand, ⑦1 Pelitic siltstone , ⑦2 Pelitic siltstone, the main physical and mechanical parameters are shown in table 1:

Table 1 Physical and mechanical parameters of soils

Formation code	Name of rock and soil	Density and state	Soil test		Standard penetration test			Static cone penetration test			Comprehensive value	
			f_{ak}(f_a) (kPa)	$E_{s1\text{-}2}$ (Mpa)	N_k (N_{635k})	f_{ak} (kPa)	$E_{s1\text{-}2}$ (MP_a)	P_{Sk} (MP_a)	f_{ak} (kPa)	$E_{s1\text{-}2}$ (MP_a)	f_{ak}(f_a) (kPa)	E_{s1-2}(E_0) (MP_a)
②	Clay	Plastic	123.9	6.4	5.7	134.0	6.7	1.17	118.0	5.9	120	6.0
②1	Silty clay	Soft plastic	101.9	4.2							90	4.5
③	Silty clay	Soft plastic	100.2	4.3	2.5	<85		0.71	81.0	4.1	80	4.0

④	Silty sand and clay interbeded	Slightly dense silty sand			8.9			4.81	146.2	12.8	115	5.0
		Soft plastic silty clay	112.5	4.4				0.73	83.0	4.2		
⑤1	Silty sand	Medium dense			21.3	207.8	18.8	8.45	219.0	19.9	210	19.0
⑤2	Fine sand	Dense			36.3	276.4	25.6	13.90	328.0	31.7	280	26.0
⑥	Gravel sand	Dense			43.7	376.0					360	36.0
⑦1	Pelitic siltstone	Strong weathered	500								500	(46.0)
⑦2	Pelitic siltstone	Medium weathering	(2019)								(2000)	

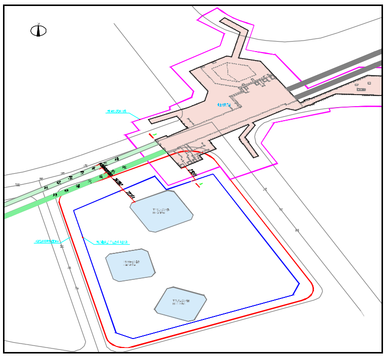


Fig.1 Locations of the foundation pits and calculated section plan

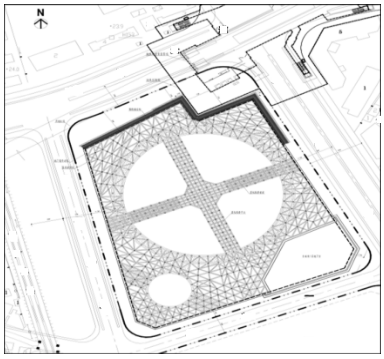


Fig.2 General layout of foundation pit supporting

Supporting schemes of foundation pits. Foundation ditch of the third basement using the continuous wall of reinforced concrete and the internal bearing beam of reinforced concrete as supporting system of foundation pit, meanwhile, the thickness of waterproof curtain on underground continuous wall is 1m, the bottom of the wall enters into medium weathered rock about 5.0m. The groove joint of continuous concrete wall installs grouting pipe, and arranges triaxial mixing pil on the outside, sets high pressure spraying pile outside the joint, and combined with dewatering well as a comprehensive treatment measures of dewatering and waterproof. The general layout of foundation pit supporting as shown in figure 2.

Two-dimensional numerical simulation

Numerical simulation scheme. The soil of the engineering uses a modified Mohr-Coulomb constitutive model. The main load in calculation process includes unit weight, soil pressure, and over loading during the construction etc.. The plane strain element is used to simulate the formation and building envelope, and the beam element is used to simulate the tunnel structure and the importing and exporting structure. The scope of the calculation model is based on the outer contour of the foundation pit which is not less than 30m (it's about 2 times depth of foundation pit). The vertical displacement of the model is bound at the bottom of the model, and the model of the horizontal displacement on the left and right sides is restricted.

According to the spatial relationship of the foundation pit, adjacent metro and main structure of the station, as well as the design and construction characteristics of retaining structure of foundation pit to select the typical section of the subway station entrances and exits for finite element calculation. The upper boundary of the model is the free surface of the ground; the self-weight is taken to acceleration of gravity, and the uniform load of the 20kPa is applied to the model. The profile of the section and mesh generation are shown in figure 3.

According to the characteristics of the construction in project, analyzing the excavation of foundation pit, the construction of the basement structure to determine the project that was used 14 construction steps for simulation after appropriate optimization (12 construction conditions). Condition 1: The original formation condition, the initial gravity stress field; Condition 2: The completion of the new ventilation pavilion; Condition 3: Displacement reset to zero; Condition 4: Construction of retaining structure on foundation pit; Condition 5: Excavation of the first layer of earthwork, and construction of the first support; Condition 6: Excavation of the second layer of earthwork, and construction of the second support; Condition 7: Excavation of the third layer of earthwork, and construction of the third support; Condition 8: Excavation of the fourth layer of earthwork, and excavation to the bottom; Condition 9: Construction the floor and backfill the floor to support side ; Condition 10: Remove the support of the third layer, and construction negative third floor; Condition 11: Remove the support of the second layer, and construction negative floor; Condition12: Remove the support of the first layer, and precipitation remained in the basement.

The analysis of computing result. This paper focuses on the influence of the surrounding earth excavation to the structure of the station entrance. In the calculation and analysis, because the foundation pit in the construction of the excavation and the basement are a stress release process, after the completion of the excavation in the construction process of the basement, the displacement will continue to increase. The calculation results are as follows:

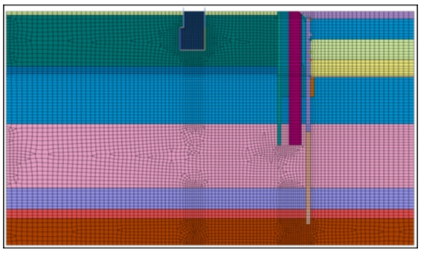
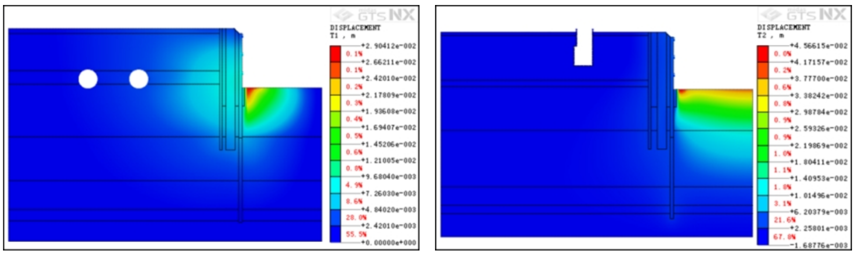
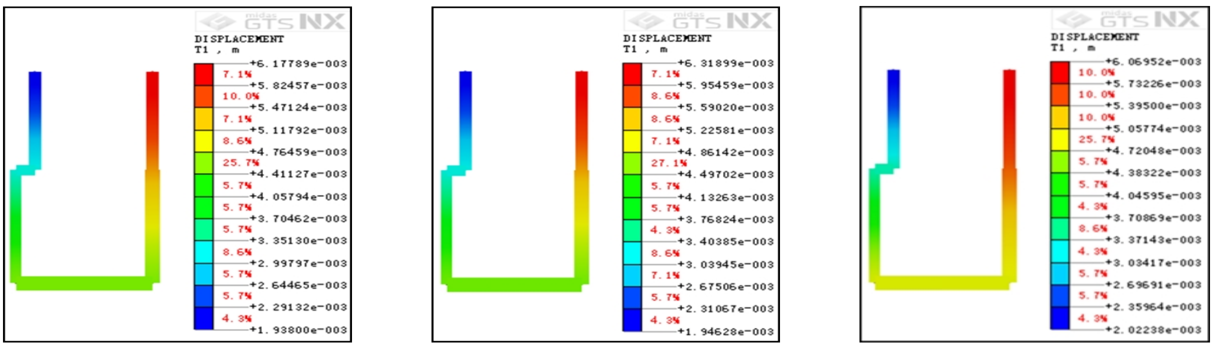


Fig.3 Typical calculated section



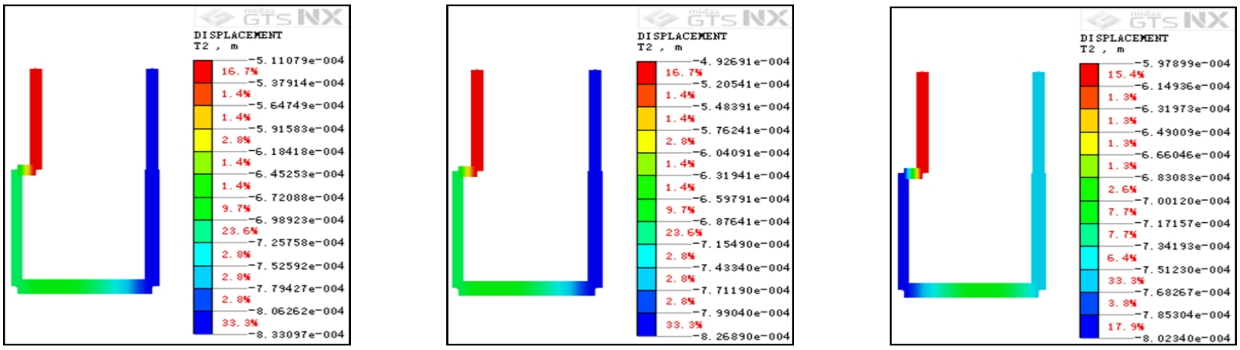
(a) Horizontal displacement (b) Vertical displacement

Fig.4 The whole horizontal and vertical displacement of excavation to basement



(a) Remove the support of the third layer, construction negative third floor (b) Remove the support of the second layer, construction negative floor (c) Remove the support of the first layer

Fig.5 Horizontal displacement of the new ventilation pavilion

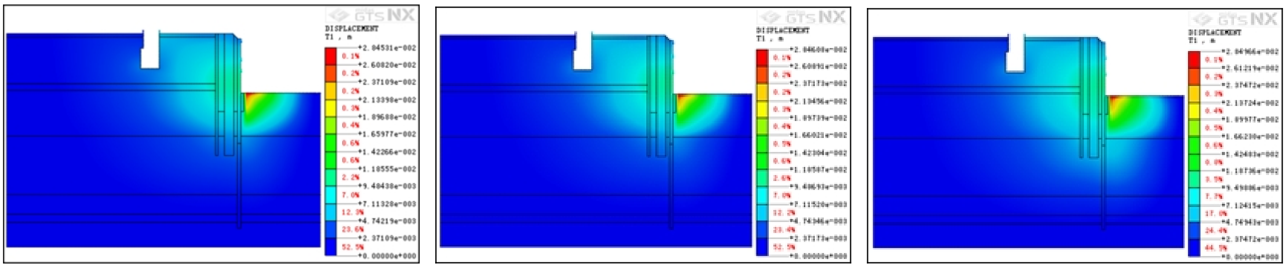


(a) Remove the support of the third layer, construction negative third floor

(b) Remove the support of the second layer, construction negative floor

(c) Remove the support of the first layer

Fig.6 Vertical displacement of the new ventilation pavilion



(a) Remove the support of the third layer, construction negative third floor

(b) Remove the support of the second layer, construction negative floor

(c) Remove the support of the first layer

Fig.7 The whole horizontal displacement

From the results calculated above, when the third reinforced concrete support was removed, the horizontal displacement of the new ventilation pavilion near the pit was 4.41mm, and the maximum vertical displacement was 0.833mm; when the second reinforced concrete support was removed, the horizontal displacement of the new ventilation pavilion near the pit was 4.49mm, and the maximum vertical displacement was 0.827mm; when the first reinforced concrete support was removed, the horizontal displacement of the new ventilation pavilion near the pit most was 4.72mm, and the maximum vertical displacement was 0.80mm; when the first reinforced concrete support was removed, the horizontal displacement of the new ventilation pavilion was the maximum, which was the most dangerous conditions. But the displacement values were within the controllable scope, which had little effect on the entrance of the tunnel structure in safe operation, but taking into account of a certain risk, it is suggested that we should strengthen the change of support measures when supporting the foundation pit in the design, such as the change of support plate and strip.

Considering the risk in the implementation process of the project, the foundation pit near the tunnel and subway station should be encrypted monitoring points and monitoring frequency, especially the horizontal displacement, force and transformation of the supporting structure; at the same time, the additional load above the main structure of track traffic shall not be greater than 20KPa; the excavation of foundation pit should follow the principles of partition, block, hierarchical, symmetric and limit.

Conclusion

Taking the deep excavation engineering close to the 1 entry of a subway station that was the construction of rail traffic No. 3 as the example. In accordance with the construction scheme of the practical engineering, establishing a two-dimension numerical analysis model with MIDAS / GTS software, and using multi-threading technology to massively parallel computing. Through a complete simulation of numerical simulation to the engineering construction of deep foundation pit, obtaining the following conclusions:

(1) When the third reinforced concrete support was removed, the horizontal displacement of the new ventilation pavilion near the pit was 4.41mm, and the maximum vertical displacement was 0.833mm; when the second reinforced concrete support was removed, the horizontal displacement of the new ventilation pavilion near the pit was 4.49mm, and the maximum vertical displacement was 0.827mm; when the first reinforced concrete support was removed, the horizontal displacement of the new ventilation pavilion near the pit most was 4.72mm, and the maximum vertical displacement was 0.80mm; when the first reinforced concrete support was removed, the horizontal displacement of the new ventilation pavilion was the maximum, which was the most dangerous conditions.

(2) According to the numerical simulation of excavation to foundation pit, the influence of the excavation of the foundation pit on the subway station was within the requirements of the specification, which was not affect the normal operation of the tunnel and the entrance.

(3) The numerical simulation analysis carried out in this paper, only considering the short-term impact of the construction in a single deep foundation pit to the subway station. From the long-term safety operation of the subway station, it should consider to develop the high level programming in the future near the subway. The operation effect of several deep foundation pits may cause the superposition effect to the station at different stages. Therefore, it is suggested that in addition to strengthening the monitoring of subway station and tunnel during construction, it should be considered in the engineering design, and made the corresponding control measures.

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