Geotechnical Aspects of Underground Construction in Soft Ground – Ng, Huang & Liu (eds)
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Excavation entirely on subway tunnels in the central area of the People's Square

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ABSTRACT: The Open and Go-down square is located at the center of the city where the constructional surroundings are very complex. It's a great challenge to the excavation because metro line 1 and 2 tunnels just underlie the pit forming a shape of double crossing "#". The detailed excavation process and many technical measures are stated in the paper which may be referred by coming similar projects.

1 INTRODUCTION

With the rapid development of the state economy and acceleration of urbanization, many domestic big cities are facing problems such as land limitation, population expansion, traffic jam, environment pollution et al. which restrict the continuable development of the cities. To exploit the underground space can find new space for the continuable development of the city, and to develop the rail traffic is an effective way for solving the problem of traffic jam.

With the large-scale exploitation of the underground space and formation of the city rail traffic network, more and more deep excavations will be very close to the existing rail traffic facilities, including 1) sharing the same retaining wall with existing subway stations, 2) excavation at the side of running subway tunnels, 3) excavation above running subway tunnels, 4) excavation between the columns of the elevated light-rail, and all these cases are challenges to the new excavation engineering.

2 GENERAL CONDITION OF THE CASE PROJECT

The Open and Go-down square is located at the crossing point of West Nanjing Road and Middle Xizang Road, neighboring New World Mansion and World Trade Building, and it's one part of the key project – the pivotal rail traffic project of the People's Square. The area of the excavation is about 3300 square meter with depth about 4 meter. The tunnels of running metro line 1 and line 2 underlie the pit forming a shape of double crossing "#", and the minimum distance from the bottom of the pit to the top of existing tunnels of metro line 1 is only 3.3 meter. The features of this project are mainly as follows:

1. The site is at the center area of the city, so the surrounding traffic is very busy, and the organization of constructional vehicles is difficult.
2. Environment protection is very strict for the control of the noise, vibration, dust, and wastewater caused by construction activities.
3. Time limitation is critical because many construction activities can not be carried out before the underground rail traffic stopped running at midnight.
4. For the safety of the running metro lines, the deformation of the underlying subway tunnels should be controlled within certain scope, which makes it very difficult for the construction.
5. The deformation of the nearby roads and underground pipelines should be strictly controlled.
6 Many concrete obstructions underlie and should be demolished first.

3 GEOLOGICAL CONDITION

As well-known, Shanghai is one of the classical areas that have deep soft soil which has poor mechanical characteristics such as high compression, large deformation and obvious rheology. Therefore, the soft soil is easily disturbed and excavations shall display sharp "Time and Space Effect".

According to the geotechnical report, within the scope that excavation affects, the soil layers are mainly

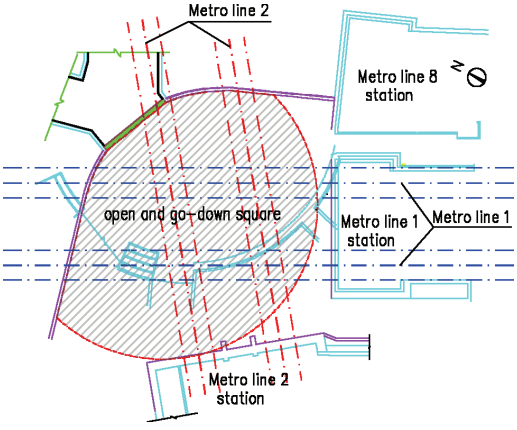

Figure 1. Location of Open and Go-down square.

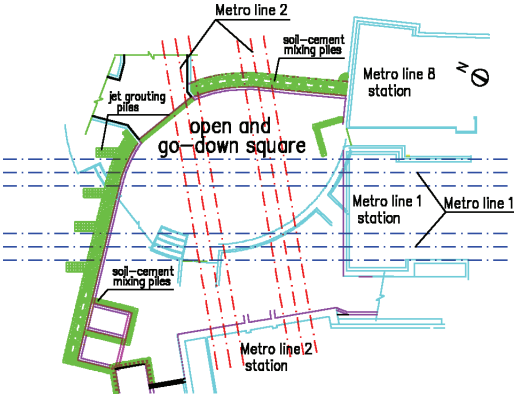

Figure 2. Plan of retaining structures.

Table 1. Soil layers.

Soil layer	Description	Thickness m
①$_1$	Fill	1.2
①$_2$	Fill	0.6
②	Silty clay	1.1
③	Muddy and silty clay	3.2
④	Muddy clay	7.4
⑤1	Clay	8.5
⑤3	Silty clay	10.0
⑤4	Silty clay	1.9
⑦2	Fine sand	12.3

composed by muddy silty clay and muddy clay with thin layer of fine sand between them. Because of some certain geological reasons, the soil layers ⑥ and ⑦$_1$ are absent. The soil layers from top to down are listed in table 1.

The groundwater belongs to phreatic water type and is supplied mainly by rainfall. The water table varies from 0.5 m to 1.2 m below the ground surface.

4 RETAINING SYSTEM AND REQUIREMENT OF DEFORMATION CONTROL

The area of Open and Go-down square is about 3300 square meter with length of 66 m, 55 m in longitudinal and latitudinal direction respectively. The slab of Open and Go-down square ramps from ground surface to 3.8 m below in west-east direction.

For the excavation is not deep, a dam formed by soil-cement mixing piles is adopted as temporary retaining structure which has a perimeter of 137 m, width of 3.2 m. The length of soil-cement mixing piles varies from 6 m to 11 m, and its strength should be no less than 1.2 MPa. To reduce the impact on the subway tunnels, high pressure jet grouting piles with same parameters are used to substitute for soil-cement piles above and between metro line 1 tunnels. The jet grouting piles have diameter of 800 mm, overlapped by 150 mm.

The life of subway facilities is 100 years for its essentiality, and its safety during excavation is the key point of this project. The deformation requirements of station structures and tunnels are regulated as below by metro-managing unit.

1. Differential deformation of subway rails in transversal direction should be less than 2 mm,
2. Differential deformation of subway rails in longitudinal direction should be less than 2 mm per 10 m,
3. The radius of deformation curvature of subway structures should be greater than 15000 m,
4. The relative deformation curvature of subway structures should be less than 1/2500,
5. The final absolute settlement and displacement of subway structures should be less than 10 mm,
6. The rate of structures' deformation caused by excavation should be less than 0.5 mm per day,
7. The width of newly generated crack should be less than 0.2 mm,
8. The final accumulated settlement of station and tunnels should be less than ±10 mm,
9. The final accumulated displacement of station retaining walls should be less than ±2.5 mm,
10. The accumulated settlement of structures in longitudinal direction should be less than ±4 mm per 10 m,
11. The distance change between subway rails should be limited within the scope of −2 mm to +6 mm.

For the particularity of this project, although the excavation depth is not large, the pit engineering is still designated to the highest grade, so the control of

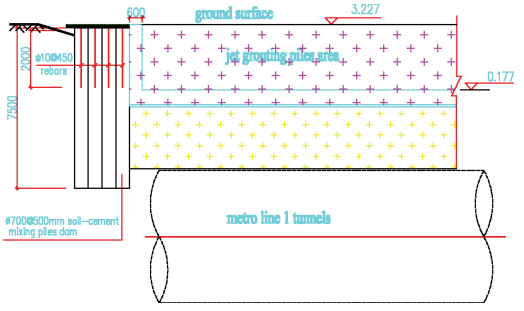

Figure 3. Section of retaining structure.

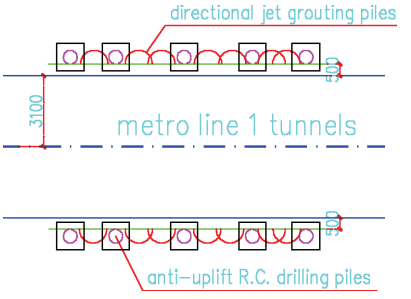

Figure 4. Plan of directional jet grouting piles.

deformation indices are rather strict than before which are listed below,

1 The accumulated horizontal displacement of temporary retaining structure should be less than 0.1%H (H is excavation depth),
2 The settlement of ground nearby the pit should be less than 0.14%H.

5 TECHNICAL MEASURES OF EXCAVATION

5.1 *Treatment of soft soil*

Because of its poor mechanical characteristics, Shanghai soft soil makes it rather more difficult in underground engineering than in other areas. For the soft soil is easily disturbed and easily deforms, usually certain ways are adopted to improve its poor mechanical characteristics. To reduce the lateral deformation of retaining structure during excavation, jet grouting piles with diameter of 1200 mm at spacing of 800 mm are used for soil treatment. Nearly the soft soil in the pit are all treated from the ground surface to 3 m below the bottom, and the total area reaches 2880 m^2. Over the metro 1 tunnels, the jet grouting piles extend from the ground to 500 mm to the top of tunnels. For the treated soil is hard to remove, so the requirements below and above the pit bottom are different. The strength of treated soil below and above the bottom should reach 1.2 MPa and 0.6 MPa respectively.

Usually, when the jet grouting piles is being processed, there is fairly high pressure acting on the very close soils, thus those soils would be compressed and disturbed. To avoid the high pressure acting on the subway tunnels, semicircular other than circular jet grouting piles are used adjoining the metro line 1 tunnels (see fig. 4). The semicircular piles are formed by jet grouting only at opposite side of tunnels which is called directional jet grouting technology, and this technology is developed during the past years in Shanghai.

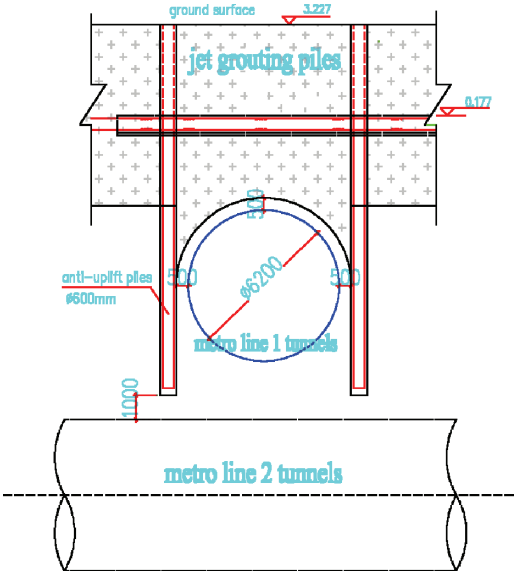

Figure 5. Special anti-uplift structure.

5.2 *Special anti-uplift structure*

The existing running subway tunnels are in balance by the soil below and over them. If part of the soil over them is removed, then the balance state will be broken, and there seems to have a force dragging the tunnels upward, so the tunnels may uplift. To prevent the tunnels from uplifting, new balance must be established. In this project, a new kind of anti-uplift structure is invented which is indicted in figure 5. At each side of tunnel, reinforced concrete (abbreviated as R.C. hereafter) bored piles with diameter of 600 mm are set up close to the tunnel by 500 mm. The end of drilling pile is only 1 m from the underlying metro line 2 tunnels at crossing point. When a small area of soil over the tunnel is removed, the R.C. slab in same area will be constructed quickly. At the same time, rebars of bored piles are anchored into slab and welded together with its rebars. Thus, the uplift capacity of bored piles can

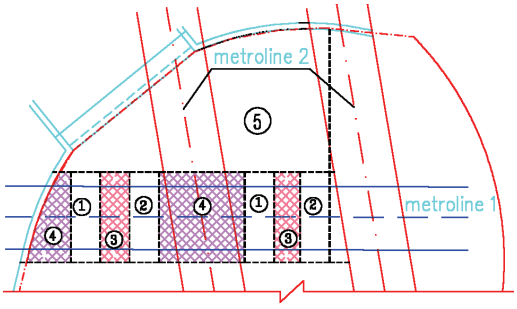

Figure 6. Excavation step 1.

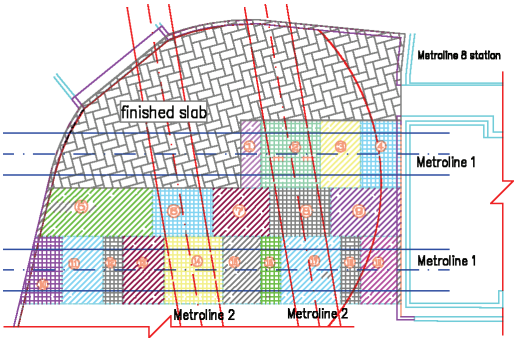

Figure 7. Excavation step 2.

balance the uplifting force acting on tunnels which equals the weight of removed soil.

5.3 *Dividing excavation into pieces*

It is not difficult to be understood that more soil are removed from the top of the tunnels at one time, the uplifting displacement will be larger. To control the uplifting displacement within certain scope, the pit is divided into three parts which are divided into pieces either, so the procedure of excavation is fairly complex. The whole excavation includes tree steps corresponding to the tree parts. The numbers in figure 6 indicate the sequence of excavation in step 1. Excavation over the metro 1 tunnels is relatively shallower which is arranged to be carried out first. Usually, the width of each excavation piece is 3 m which is determined by experience. After the soil is excavated to the bottom, the bedding cushion layer and R.C. slab will be constructed on time. The main rebars in the slab of different pieces would be connected by mechanical connector pre-embedded in the concrete. Figure 7 and figure 8 demonstrate excavation in step 2 and 3, and the numbers do not indicate the excavation sequence.

5.4 *Loading on the finished slab*

Another measure is taken to assure the safety of subway tunnels during excavation. That is, one piece of

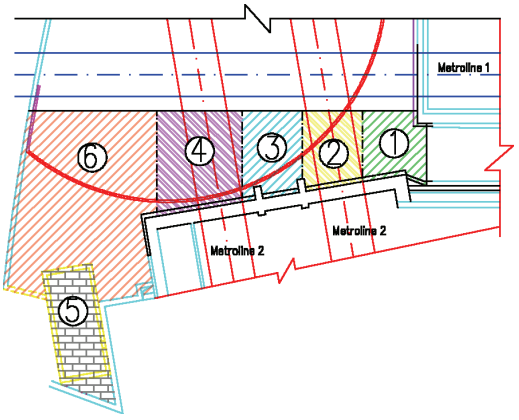

Figure 8. Excavation step 3.

Figure 9. Loading on slab.

slab will be loaded with heavy materials soon after being finished and reaching certain strength. The loading must be equivalent to the weight of soil removed from the tunnels' top.

6 INFORMATION-BASED MONITORING

It is well-known that information-based monitoring is necessary during the construction in underground engineering. Due to vagueness and variability of mechanical characteristics of soft soil, it is impossible to predict the deformation of retaining structure accurately during excavation, so monitoring is the only measure that can see the state of safety. Figure 10 shows the layout of monitoring points of metro line 1 tunnels.

Figure 11 demonstrates the deformation curve of metro line 1 tunnel (upper one) during the first excavation step. The accumulated maximum uplifting displacement of underlying tunnel is 3.05 mm after the complement of excavation in step 1. It is obvious that

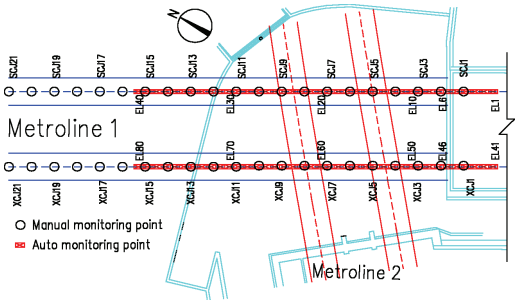

Figure 10. Monitoring points of subway tunnels.

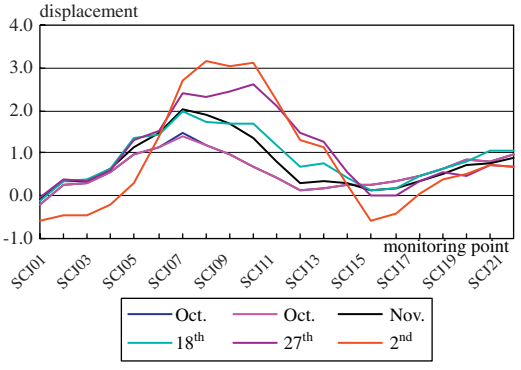

Figure 11. Uplifting displacement of subway tunnels during excavation step 1.

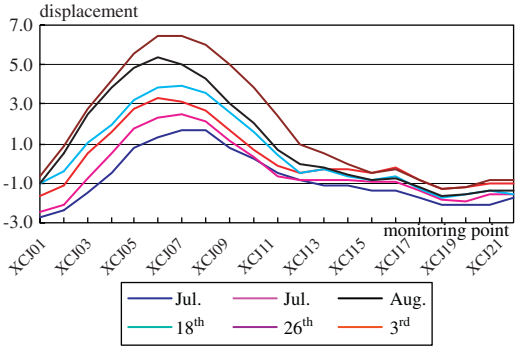

Figure 12. Uplifting displacement of subway tunnels during excavation step 2.

the deformation is fairly small and the safety of running tunnel is guaranteed. Figure 12 demonstrates the deformation curve of metro line 1 tunnel (lower one) during the second excavation step. The accumulated maximum uplifting displacement of underlying tunnel is 6.47 mm in step 2 which includes displacement generated in step 1. Generally speaking, the accumulated deformation is fairly small during the construction of underground engineering.

7 CONCLUSION

With the rapid development of the urban rail traffic, more and more excavations are to be restricted by existing underground subway facilities such as excavation under, above or between subway tunnels et al. One case excavation completely on the running subway tunnels is introduced in detail in this paper. The technical measures employed during the process of excavation and the successful experience can be referred by similar projects in future.

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