Practices in the design of excavation engineering for Ningbo rail transit

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ABSTRACT

Ningbo is located in the southeast coast plain. There are thick, soft soil deposits lying in the sub-ground, which challenges the construction of urban rail transit in this area. A project of Ningbo Rail Transit Line 1 and the soil conditions for the construction site are firstly presented. Then, the excavation engineering designs for the project are summarized from four aspects: the design of building envelope, vertical and horizontal layout of supporting system, underground water dewatering and ground treatment. Simultaneously, the problems occurred in the design are also described. Lastly, the experiences gained from the project are summed up, so as to guide the further subway construction in the area and also provide a reference for the construction of similar project.

Keywords: rail transit; excavation engineering; soft soil; dewatering; ground treatment.

1 INTRODUCTION

In complex urban environments, the construction of rail transit has negative impact on the nearby buildings and underground pipelines (Liu 2009). There are a lot of challenges on the construction of Ningbo rail transit project as marine sedimentary soft soil, which has characteristics of high clay content, high water content, high compressibility, low permeability and high sensitivity, is widely distributed with uneven thickness in this area.

According to the planning scheme, the rail transit network is composed by 6 lines with a cover area of 2560km². In June 2009, the construction for the first stage of Line 1 is fully commenced and the whole project is completed in May 2014. So, combined domestic and international technology development in design and construction of deep foundation pit(Yang et al 2012, Zhou et al 2010, Gordon et al 2007), the key technical issues used in Ningbo's rail is elaborated in detail in this paper.

2 PROJECT OVERVIEW AND SOIL CONDITION

The project of Line 1 for Ningbo urban rail transit starts from Gaoqiao town, and it end to Tiantong village base. The full length of Line 1 is 21km. The total number of stations for Line 1 is 20, which includes 5 elevated stations and 15 underground stations. Additionally, there are 3 open-excavation sections for Line 1.

According to the geological survey report, the proposed site soil layers are Quaternary sedimentary strata. For about 80m along the depth of the ground, the soil layer contains clay, silt and sand, as shown in Tab.1. The stratigraphic distribution for soil layers is complex.

| Soil layer | Soil property           |
|------------|-------------------------|
| ①          | miscellaneous fill      |
| ②          | clay                    |
| ③          | mucky silty clay        |
| ④          | mucky clay              |
| ⑤          | silty sand              |
| ⑥          | silty clay mixed with sand |
| ⑦          | mucky silty clay        |
| ⑧          | clay                    |
| ⑨          | silty clay              |
| ⑩          | silty clay              |
| ⑪          | silty clay              |
| ⑫          | clay                    |
| ⑬          | silty clay              |
| ⑭          | silty clay              |

3 RETAINING STRUCTURE AND SUPPORTING SYSTEM

In the design of the main supporting structure for subway station excavation pit of Line 1, the limit state design method expressed with partial safety factors is applied here. Treated as a temporary structure, the influence of the carrying capacity and deformation on the safety of excavation pit and the surrounding environment is considered in the design of the supporting structure. When the supporting structure is...
used as a long-term facility, the durability is considered and the carrying capacity and limit state design is applied. Figure 1 shows the design diagram for a typical station excavation pit structure and support system.

3.1 Retaining structure

(1) Structure form selection for retaining structure

The project of rail transit Line 1 is located mainly on soft soil stratum. The subsoil water level is high. Many important risk sources as tall buildings and underground utilities distribute along the route, leading to a lot of difficulties in the design and construction for the subway station excavation. The diaphragm wall is a quite mature technology at present and has merits as big rigidity, good preventing seepage performance, less vibration, low noise and so on. The summary of the retaining structure for different subway stations is shown in Table 2.

(2) Excavation construction

After a comprehensive comparison, the "cover-excavation consequent operation" method is adopted in the excavation for most stations. Other stations as the Gulou station and Dongmenkou station, which is constrained by the construction site and traffic conditions, are constructed with the "topdown construction" method.

(3) Thickness of the retaining structure and reinforcement

For the underground stations with two floors, the excavation depth is between 14.6 m~18.7m and a thickness 0.8 m is applied for the underground continuous wall. For the underground stations with three floors, the excavation depth is between 22.4 m~25.3m and a thickness 1.0m is used for the underground continuous wall. Additionally, for Fuqing Road station, a combination of 0.6 m underground continuous wall with bored piles (diameter 900, spacing 1100) is adopted. On the other hand, a range of reinforcement ratio between 1%~1.39% is adopted for 0.8 m wall and reinforcement ratio 1.08%~1.71% is for 1.0 m wall.

(4) The insertion ratio for the retaining structure

Too small of the penetration depth for the underground continuous wall, the stability coefficient Ks is small, increasing the possibility of engineering accident. The oversized excavation depth has less contribution to the security index of deformation, resulting in the waste. The statistical analysis conclusion is as follows: the insertion ratios for station pits of Line 1 are centralized in 1:0.8~1:1.2; the biggest one is 1:1.472.

| Subway station name | length and width of excavation (m) | excavation depth (m) | protection level | Retaining structure and its size | Insertion ratio | Amount of supporting structures |
|---------------------|----------------------------------|----------------------|-----------------|---------------------------------|----------------|------------------------------|
| Wangchun Bridge Station | 458.6,19.7 | 14.6 | II | CH,800 | 1:1.05 | 4 |
| Zemin Station | 178.2,17.3 | 15.9~16.2 | I | CH,800 | 1:1 | 5 |
| Daqin Bridge Station | 172.6,20.7 | 16.31 | II | CH,800 | 1:1.05 | 5 |
| Ximenkou Station | 149.6,18.7 | 16.48 | I | CH,800 | 1:1.1 | 5 |
| Gulou Station(1) | 168.6,20.5 | 23.768 | II | CH,1000 | 1:0.935 | 6 |
| Gulou Station(2) | 300.5,20.1 | 16.716 | II | CH,800 | 1:0.914 | 5 |
| Dongmenkou Station | 185.0,21.0 | 22.4 | I | CH,1000 | 1:0.79 | 6 |
| Jiangxia Bridge station | 150.0,18.7 | 16.81 | I | CH,800 | 1:0.904 | 5 |
3.2 Supporting system arrangement

Concrete support and steel support (diameter 609mm, wall thickness 16 mm) are mostly used in Ningbo Metro Line 1 project. Appropriate relationship between the numbers of support with the excavation depth: 4 to 5 supports for the depth less than 16 m; 5 supports for the depth between 16 m to 20 m; 6 supports for depth between 20 m to 26 m; and 7 supports for 26m to 28m deep. The vertical spacing for the first support can be enlarged so as to facilitate the construction since the earth pressure for the shallow soil of Ningbo Metro pit is small; and generally a 3 m spacing is adopted for the bottom support to meet the requirement for normal operation of small-scale excavator.

4 FOUNDATION PIT DEWATERING

The hydrology geology of Ningbo is complex. Generally, the special study of the pump experiment based on the scene geology situation and the requirement of dewatering is needed before the pit excavation. Then, according to the test result, each content as the arrangement of the well pint, quantity, the structure, the dewatering target and monitoring requirement and so on will be determined after the joint research by the owner, supervisor and designer, so as to realize the targets of guaranteeing the security of the excavation and the peripheral constructions and pipelines.

The excavation depth of Ningbo subway pit is mainly at 15-25 m, where is rich for the ground water and confined water. The ground water is generally buried in the shallow clayey soil. The water level (typically between 0.5 m to 1.0 m) changes slightly and the supply of the ground water is the river system. The confined water mainly occurs in the central sandy silt and the deep silty fine sand layer. Both the ground water and the confined water are non-aggressive to the concrete materials.

According to the hydrogeological conditions, the tube well point and the light well point are most commonly applied in Ningbo and the spacing of the dewatering wells is between 15m~20m.

Ningbo groundwater is buried in the shallow of the project site. The depth of the groundwater level is generally below the surface with 0.4 m to 2.0 m. The confined water issue displays prominent, which challenges the excavation of subway station for varying degrees. The cost for the excavation of subway pit usually accounts for a small proportion of the total cost of the pit (generally 2% to 5%). However, the procedure of dewatering is very important. The treatment of the confined water is directly related to the construction of the pit excavation. The dewatering for the confined water should be solved once for all in the pre-construction of the excavation. Or else it will be very unfavorable for the later construction.

5 GROUND TREATMENT IN THE BOTTOM OF THE FOUNDATION PIT

Ningbo soft soil characteristics: high natural water content, a minimum of 30% to 40%, and a maximum up to 200%; large void ratio, a minimum of 0.8 to 1.2, and a maximum up to 5; high compression; low permeability; and high sensitivity, in a range of 2 to 10, and the strength will be remarkably reduced with disturbance. To improve the foundation conditions, cement mixing method is mainly used in the project. Table 3 shows the statistics of the ground treatment for the subway station excavation. The measured value of lateral displacement of diaphragm wall is approximately 1.3 to 5.9 times of the calculated results considering the ground treatment and approximately 1.1 to 4.7 times of the calculated results without reinforcement. For similar geological conditions, the arrangement pattern for skirt border improvement is better than the pattern of strip reinforcement, which can be gotten from a comparison for lateral displacement of Daqin Bridge station and Ximenkou Station. The method of strip reinforcement...
with small spacing is better than skirt border improvement with big spacing strip reinforcement, which can be gotten from a comparison for lateral displacement of Gulou station and Dongmenkou station. Quantities of different reinforcement methods: the quantity for 3m spacing strip reinforcement is 6221m³; the quantity for 3m skirt border improvement adding with 6m spacing strip reinforcement is 6605m³; and, the quantity for 3m skirt border improvement adding with 9m spacing strip reinforcement is 6148m³. It can be obtained that the quantity for the three arrangement patterns are similar, whereas the reinforcing effect of the second method works best in these three kinds of reinforcement type.

Tab.3 Statistics of the ground treatment and measured maximum lateral displacement of diaphragm wall

| Subway station name | excavation depth (m) | Soil layer at the bottom of the pit | Ground treatment method and arrangement pattern | H₁ (m) | Sₘ(m) (mm) |
|---------------------|----------------------|-----------------------------------|-----------------------------------------------|--------|------------|
| Wangchun Bridge Station | 16.3 | 2_1 | Triple-tube high-pressure jet pile, strip reinforcement | 16.5 | 71.52 |
| Zemin Station | 15.91 | 1 | Cement-mixed pile, strip reinforcement | 18.0 | 54.37 |
| Daqin Bridge Station | 16.31 | 3 | Cement-mixed pile, strip reinforcement | 21.0 | 43.71 |
| Ximenkou Station | 16.41 | 3 | Three-axis mixing pile, skirt border improvement, strip reinforcement with a spacing of 3 m | 11.0 | 26.86 |
| Gulou Station | 23.77 | 3 | Jet grouting pile, skirt border improvement, strip reinforcement with a spacing of 12.5 m | 24.5 | 106.75 |
| Dongmenkou Station | 22.4 | 3 | Jet grouting pile, strip reinforcement | 16.5 | 52.40 |
| Jiangxia Bridge Station | 16.81 | 3 | Three-axis mixing pile, strip reinforcement | 13.0 | 27.10 |
| Zhoumen Road Station | 16.41 | 3 | Three-axis mixing pile, strip reinforcement | 16.5 | 40.51 |
| Yinhua Park Station | 16.31 | 3 | Three-axis mixing pile, strip reinforcement with a spacing of 9 m | 9.5 | 42.67 |
| Fuming Road Station | 16.31 | 3 | Three-axis mixing pile, strip reinforcement with a spacing of 6 m | 18.5 | 63.6 |
| Shiji Road Station | 16.61 | 3 | Three-axis mixing pile, strip reinforcement with a spacing of 3 m | 21.0 | 74.80 |
| Haiyan Road Station | 16.31 | 3 | Three-axis mixing pile, strip reinforcement | 18.5 | 80.00 |
| Haiyan Road West Station | 16.31 | 3 | Three-axis mixing pile, strip reinforcement with a spacing of 9 m | 21.0 | 84.20 |
| Shengmo Road Station | 16.48 | 2_2 | Mixing pile, strip reinforcement | 21.0 | 67.45 |
| Donghuan Road Station | 16.9 | 2_2 | Three-axis mixing pile, strip reinforcement with a spacing of 6 m | 21.0 | 142.59 |

Notes: H₁ is the depth where the maximum horizontal deformation occurs; Sₘ is the measured maximum horizontal deformation.

6 CONCLUSIONS

The applicable insertion ratio of underground diaphragm wall for Ningbo Rail Transit Line 1 is from 1.08 to 1.12. When the excavation depth is between 14.6 m-18.7 m, a thickness 0.8 m is suitable for the diaphragm wall, and 1.0 m is feasible for the case of 22.4 m-25.3m. According to the monitoring data, the lateral displacements of foundation pit are within a reasonable range. The majority of pit’s maximum horizontal displacement occurs in the bottom of the pit to the bottom of the pit for 4 m range, which indicating that the displacement control effects of passive zone improvement are significant. For similar geological conditions, the reinforcement method of 3m skirt border improvement adding with 6m spacing strip reinforcement is the best one.

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