Integrated Monitoring and Control of Deformation of Metro under Construction effected by the Construction of Foundation Pit

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Abstract: In view of the influence of Metro under construction on the foundation pit excavation of the new commercial service project in the city and in order to ensure the safety of subway in the process of foundation pit excavation, combined with the geographical location and geological conditions of the project in this paper, the corresponding monitoring points were set up to protect and monitor the Metro near the project, so as to ensure the minimum impact on the Metro under the premise of normal construction of the foundation pit. The monitoring results were in line with the requirements of the specification, providing guarantee for the subsequent construction.

1. Introduction
There are more and more subways under construction\cite{1} in the current large cities, and there are also high-rise structures under construction near the subways under construction. How much influence will the substructure construction of the high-rise structure have on the subway? This requires the integrated monitoring and control of the whole process of the subway in the construction process\cite{2-10}, so as to ensure that the impact of the subway construction during the foundation pit construction is within the safety control range.

2. Project overview

2.1. General situation of foundation pit engineering
Xiaozhengchu commercial service project is located in the northwest corner of Shixin North Road and Guangchang Road, Qianjiang Century City, Hangzhou. The project consists of two 22 storey towers and four storey podium, all of which are frame shear structures, with three overall underground floors and bored pile foundation.

The shape of basement foundation pit is about rectangle, and the size of foundation pit is about 151 m × 75 m (see Fig. 1 Relative position of foundation pit, subway and adjacent construction site). The foundation pit shall be maintained by bored cast-in-place pile + one or two steel concrete internal supports, 3 ∅ 850@600 Cement mixing pile water stop curtain. The ± 0.000 design elevation of the project is equivalent to the absolute elevation of 7.200m; the absolute elevation of the design natural floor is taken as 6.000 (relative elevation - 1.200). After calculation to the bottom of basement floor or cushion cap, the actual excavation depth of basement foundation pit is 12.6m-13.7m, and the excavation depth of partial elevator shaft is 16.0m and 17.0m. According to the relevant regulations of Zhejiang Province standard "technical standard for building foundation pit engineering" (db33 / t1008-2000) and
the characteristics of the surrounding environment, the safety level of the foundation pit engineering is grade I.

2.2. Surrounding environment

The East and south sides of the project are Plaza Road and Shixin North Road respectively. The location of the red line of the land on both sides is the site fence. The distance between the inner boundary of the East Square Road enclosure and the red line of the land is 7-13m, and the distance is gradually reduced from south to north. The nearest distance between the enclosure boundary of Shixin North Road on the south side and the red line of the land is about 8.2m.

The northwest corner of the foundation pit is the h-05 & h-08 business complex, and the basement has been completed; the large slope retaining form is adopted at the connection position with the project. A circle of closed triaxial retaining form is used as the water stop curtain. Throughout the surrounding environment of the project, the surrounding environment is relatively complex. There are a lot of municipal pipelines buried under the roads in the South and East; especially in the South Shixin Road, there are not only gas stations, but also metro shield tunnels; the deformation control requirements of the retaining structure are high. The section relationship between the foundation pit and the metro shield tunnel is shown in Figure 2.

2.3. engineering geological conditions

According to the comprehensive analysis of the data of field drilling, standard penetration test, heavy dynamic penetration test and indoor geotechnical test, the stratum of the site is divided into 9 major layers and 16 geological sub layers from top to bottom, and the physical and mechanical properties of each layer are shown in Table 1.

2.4. hydrogeological conditions

During the survey, the measured buried depth of the stable groundwater level is 1.80m-2.40m, which is equivalent to the Yellow Sea elevation of 3.30m-4.42m. The surface phreatic water is mainly supplied by atmospheric precipitation with an annual variation range of 0.5m-1.0m. The 6-2 layer, 8-1 layer and 8-2 layer contain confined water, and the confined water level is -1.0 to -4.0m (Yellow Sea elevation), which has little impact on the project. The ground water of the site is slightly corrosive to the concrete structure and the steel bars in the reinforced concrete structure. According to the regional experience, the site soil is slightly corrosive to the concrete structure and the steel bars in the reinforced concrete structure.
### Table 1. Physical and mechanical properties of each soil layer

| Stratum No | Soil layer name | Water content (w) (%) | Density (r) (KN/m³) | Consolidated direct-quick compression modulus (E_s) (kPa) | Empiric value of osmotic coefficient (kPa) | Empiric value of osmotic coefficient Cm/s | Empiric value of osmotic coefficient Kh Cm/s |
|------------|----------------|-----------------------|---------------------|--------------------------------------------------------|------------------------------------------|----------------------------------------|------------------------------------------|
| 1-1        | Miscellaneous Fill |  |  |  |  |  |  |
| 1-2        | Cultivated soil   |  |  |  |  |  |  |
| 2-1        | Sandy silt        | 30.0 | 19.1 | 4.1 | 22.9 | 8.5 | 6.30E⁻⁴ | 6.70E⁻⁴ |
| 2-2        | Sandy silt        | 27.7 | 19.6 | 3.7 | 25.0 | 11.0 | 5.0E⁻⁴ | 4.0E⁻⁴ |
| 2-3        | Clayey silt       | 32.3 | 18.8 | 4.4 | 23.3 | 7.0 | 5.5E⁻⁵ | 4.5E⁻⁵ |
| 2-4        | Sandy silt        | 26.0 | 19.5 | 2.1 | 27.7 | 11.5 | 6.0E⁻⁴ | 5.0E⁻⁴ |
| 2-5        | Clayey silt       | 35.6 | 18.6 | 3.9 | 21.6 | 6.0 | 7.0E⁻⁵ | 6.0E⁻⁵ |
| 3          | Muddy clay        | 45.3 | 17.8 | 14.2 | 5.4 | 2.5 |  |  |
| 4          | Silty clay        | 24.6 | 20.2 | 30.8 | 16.7 | 6.5 |  |  |
| 6-1        | Silty clay with silt | 24.5 | 20.1 | 30.7 | 17.0 | 7.5 |  |  |
| 6-2        | Silt              | 21.9 | 20.0 | 2.5 | 34.2 | 18.0 |  |  |
| 8-1        | Round gravel      |  |  |  |  | 25.0 |  |  |
| 8-1 interlayer | Gravelly sand   |  |  |  |  | 22.0 |  |  |
| 8-2        | Round gravel      |  |  |  |  | 28.0 |  |  |
| 9-1        | Completely weathered siltstone |  |  |  |  | 25.0 |  |  |
| 9-2        | Strongly weathered siltstone |  |  |  |  | 25.0 |  |  |

2.5. hydrogeological conditions

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3. Monitoring purpose and content

3.1. Monitoring purpose

In the process of foundation pit construction, through monitoring the subway tunnel, timely understanding the actual deformation situation and trend, analyzing and judging the impact of foundation pit excavation on the subway, guiding the construction of foundation pit excavation and
support structure. At the same time, it provides feedback information for dynamic design and information construction in time. Through data analysis, it grasps the change rule of shield structure stability, adjusts construction procedures according to monitoring data at any time, and takes necessary engineering emergency measures to ensure the safety of metro tunnel.

3.2. Monitoring items and workload
According to the enclosure design scheme and the requirements of relevant departments of metro, the protection monitoring scope of Metro Line 2 includes soil inclinometer, water level and surrounding environment (including gas station, pipeline settlement, etc.) on the south side of foundation pit and metro tunnel monitoring. According to the foundation pit retaining design drawings, the soil displacement at the south side of the foundation pit is divided into three areas, i.e. the area close to the foundation pit, the transition area 1 and the transition area 2. The transition area is 11m and 18m away from the edge of the foundation pit respectively, with a total of 12 inclinometer holes; six water level monitoring points at the south side of the foundation pit; 28 monitoring points in the surrounding environment (including gas station, pipeline settlement, etc.); the corresponding subway tunnel area at the south side of the foundation pit Area, specifically including two tunnels on the left and right lines. The control protection area is within 50m outside the outer side of the underground station and the tunnel structure. The total monitoring length of the tunnel is about 220m, including 147m corresponding to the length of the foundation pit. One section is set for every five rings, and one section is set for every ten rings in the additional measuring area at both ends. Each tunnel is set with 34 sections, and two lines have 68 sections. Each section includes one tunnel level Transfer point, 1 set of horizontal convergence point, 1 set of track settlement point and 1 tunnel settlement point. The layout of monitoring points of tunnel monitoring section is shown in Figure 3.

The specific monitoring items and workload are as follows:

| Item | Project Name | Unit       | Quantity | Remarks                                      |
|------|--------------|------------|----------|---------------------------------------------|
| 1    | Horizontal displacement of Metro Tunnel | Numbers | 68        |                                              |
| 2    | Vertical displacement of Metro Tunnel | Numbers | 68        |                                              |
| 3    | Convergence of subway tunnel diameter | Groups   | 68        | Horizontal convergence                       |
| 4    | Metro Tunnel track settlement | Groups   | 68        | One for each of the two tracks              |
| 5    | Displacement of deep soil | hole counts | 12        |                                               |
| 6    | Water level observation | hole counts | 6         |                                               |
| 7    | Surrounding environment | points   | 36        | Including gas station, pipeline settlement, etc |
Note: there are 68 sections for every 5-10 rings in the tunnel, 34 sections for the left and right lines. All of them adopt automatic monitoring.

4. Burying and monitoring methods of monitoring points

4.1. Manual monitoring part
The manual monitoring part includes regular manual recheck and measurement, soil inclinometer, water level outside the pit, surrounding environment settlement, etc.

4.2. Tunnel automatic monitoring
According to the design drawings, the tunnel measurement range is estimated to be nearly 220m, and installed a total station in the middle position, and two datum points were set at each end to establish a baseline, which was the horizontal axis (Y axis) of the relative coordinate system, and determined three-dimensional coordinates (x, y, z) by polar coordinate method. The displacement of the tunnel in the direction of the foundation pit is reflected by the change of the vertical length of the vertical coordinate (x) relative to the horizontal axis. A prism is installed on both sides of convergence, and the variation of the distance between two points is the variation of convergence. The settlement adopts the method of triangle elevation, that is, the change of z-axis direction is the tunnel settlement. See Figure 4 for details.

5. Monitoring results and analysis

5.1. Arrangement of monitoring results
Through monitoring the tunnel of Metro Line 2, analyzing the impact of construction on Metro Line 2, timely understanding the actual deformation situation and trend, timely and accurate prediction of potential safety hazards or accidents, so as to take effective measures in time and ensure safety. During the whole construction process, through monitoring the subway tunnel, the final cumulative change range of each monitoring project is shown in the table below:

| Monitoring items       | Cumulative change range | Cumulative alarm value |
|-----------------------|-------------------------|-----------------------|
|                       | Uplink                  | Down line             |                       |
| Tunnel settlement     | -2.6mm ~ -0.2mm         | -2.4mm ~ 0.2mm        | ≥±4mm                 |
| Horizontal displacement| -1.6mm ~ 0.3mm          | -1.9mm ~ 0.2mm        | ≥±4mm                 |
| Tunnel convergence    | 0.7mm ~ 2.9mm           | 0.5mm ~ 3.0mm         | ≥±8mm                 |
| differential settlement| 0.7mm ~ 1.9mm           | 0.6mm ~ 1.8mm         | ≥±4mm                 |

From the construction of retaining pile to the completion of earthwork backfilling, according to the monitoring data, the final cumulative change of each monitoring project is within the alarm value.

5.2. Analysis of monitoring results
Combined with the monitoring data, the impact of subway is analyzed. The final cumulative change curve of each monitoring project is as follows:
During the whole monitoring period, the cumulative change rate of the last three months of the tunnel settlement, horizontal displacement, tunnel convergence and differential settlement of the track bed is basically within 0.01mm/d, and the individual points of the tunnel settlement and horizontal displacement of the down line are 0.02mm/d, with stable change. The monitoring results are within the control range, which shows that the impact of the foundation pit construction on the nearby subway is safe.

6. Conclusion

Based on the monitoring of the subway tunnel settlement, tunnel convergence, horizontal displacement, track horizontal difference, deep soil horizontal displacement, water level outside the pit and surrounding environment settlement of Xiaozhengchu (2010) No. 43 plot commercial service project, the following conclusions are drawn in combination with daily inspection:

1) During the whole construction process from the construction of retaining pile to the completion of earthwork backfilling, according to the monitoring data, it is shown that the cumulative changes of each monitoring item of the tunnel up and down line and foundation pit are within the alarm value. In the last three months, the cumulative change rate of the settlement, horizontal displacement, tunnel convergence and differential settlement of the track bed is basically within 0.01mm/d, and the individual points of the settlement and horizontal displacement of the downline tunnel are 0.02mm/d, with stable change.

2) During the construction of the retaining pile, the excavation of Xiaochu (2010) No. 19 plot had a certain impact on the tunnel. The horizontal displacement of the tunnel up and down appeared a negative value and shifted to the opposite direction of the foundation pit. With the excavation of the foundation pit of the 43 plot and the corresponding construction in the later stage, the horizontal displacement of the tunnel slowly shifted to the direction of the 43 plot.

3) Foundation pit construction has a certain impact on the nearby metro line 2. The value of the automatic monitoring project changes with the working condition of the foundation pit. The automatic monitoring of the tunnel of line 2 basically achieves the expected effect and ensures the safety and stability of the metro operation.
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