Research on protection monitoring of existing subway tunnel based on high precision automatic monitoring system

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Abstract: In order to ensure the safety of the subway in the process of excavation, combining with the geographical location and geological situation of the project, with the high-precision automatic monitoring system, it sets up the corresponding monitoring points to protect and monitor the subway near the project, so as to ensure the normal construction of the foundation pit iron impact is minimized. The monitoring results were in line with the requirements of the specification, providing guarantee for the subsequent construction.

1. Introduction
With the reconstruction and expansion of urban housing, more and more urban construction is developed beside the existing subway[1]. The excavation of high-rise structure foundation will inevitably affect the operation of the existing metro line[2-8]. In order to study the influence of structural foundation pit excavation on the existing subway, it is necessary to monitor the subway on the spot, so as to ensure the safety of subway operation and make the foundation pit excavation smoothly.

2. Project overview
2.1. Summary
The project is located in yanjianong, Xintang community, Jianggan District, west of Xintang Road, east of Xinyuan Road, south of yanjianong road and north of Jingfang District IV. The proposed building has a two-story underground garage. The bottom elevation of the foundation bearing platform is -10.85 ~ -12.45m, and the design excavation depth is about 10.35m (local 11.95m). The plane of the foundation pit is roughly rectangular, with a length of 134m in the north-south direction and a width of 55m in the east-west direction.

The east side of the proposed site is the municipal green belt, and the outside of the green belt is Xintang road. Under Xintang road is the tunnel between Xintang station and Jingfang station of Metro Line 4 (as shown in Figure 2). The buried depth of the right line is 7.332-8.425m, the nearest to the foundation pit is 35.01m, the buried depth of the left line is 12.420-15.769m, and the nearest to the foundation pit is 40.46m. The plane relationship between foundation pit and metro tunnel is shown in Figure 1.
2.2. Engineering geology

According to the survey report, the foundation soil of the site is divided into 7 engineering geological layers and 17 engineering geological sub-layers according to the genetic type, combination characteristics and physical and mechanical properties within the exploration depth of 66.00m. See Table 1 for the physical and mechanical properties of each layer.

| sequence | Geotechnical name          | water content $\omega_0$ (%) | Void ratio $e_0$ (%) | Solid fast method Cohesion $c$ (KPa) | internal friction angle $\phi$ (°) | Characteristic value of bearing capacity of foundation $f_{ak}$ (KPa) |
|----------|---------------------------|------------------------------|----------------------|--------------------------------------|-----------------------------------|----------------------------------|
| 1        | Miscellaneous fill        |                              |                      |                                      |                                   |                                  |
| 2-1      | Clayey silt               | 27.1                         | 0.791                | 12.0                                 | 28.2                              | 130                              |
| 2-2      | Sandy silt                | 25.5                         | 0.762                | 10.0                                 | 29.4                              | 160                              |
| 2-3      | Sandy silt with silt      | 23.5                         | 0.716                | 8.2                                  | 30.5                              | 180                              |
| 2-4      | Sandy silt                | 25.5                         | 0.758                | 10.1                                 | 28.2                              | 170                              |
| 3        | Muddy silty clay          | 38.9                         | 1.137                | 13.7                                 | 9.9                               | 70                               |
| 4-1      | Silty clay                | 26.7                         | 0.788                | 41.0                                 | 14.5                              | 180                              |
| 4-2      | Silty clay                | 23.6                         | 0.693                | 47.5                                 | 14.7                              | 210                              |
| 6-1      | Silt                      | 16.1                         | 0.472                |                                      |                                   | 220                              |
| 6-2      | Round gravel              |                              |                      |                                      |                                   | 320                              |
| 6-2 interbed | Silt                 | 19.9                         | 0.644                |                                      |                                   | 220                              |
| 7-1      | Silty clay                | 25.2                         | 0.738                | 17.0                                 | 13.0                              | 160                              |
| 7-2      | Silt                      | 18.1                         | 0.567                |                                      |                                   | 240                              |
| 7-3      | Round gravel              |                              |                      |                                      |                                   | 400                              |
| 10-1     | Completely weathered argillaceous sandstone |          |                      |                                      |                                   | 220                              |
| 10-2     | Strongly weathered argillaceous sandstone |          |                      |                                      |                                   | 360                              |
| 10-3     | Moderately weathered argillaceous sandstone |          |                      |                                      |                                   | 800                              |

The excavation depth of the foundation pit is mainly 1 layer of miscellaneous fill, 2-1 layer of clayey silt and 2-2 layers of sandy silt; the bottom of the tunnel is located in 2-3 layers of sand paper Silt Mixed with silt and 2-4 layers of sandy silt.

2.3. Hydrogeology overview

Within the scope of this exploration depth, the type of groundwater is mainly the upper pore phreatic water (the water bearing medium is shallow silt) which has a great impact on the design and construction of the foundation pit of the project. The impact of the lower pore confined water (the
water bearing medium is 6 layers of silt, round gravel and 7 layers of silt, round gravel) and bedrock fissure water on the design and construction of the foundation pit of the project is negligible.

3. Monitoring purpose
In the construction process (including engineering pile construction, foundation pit retaining pile construction, foundation reinforcement, dewatering, foundation pit excavation and other stages), only the comprehensive and systematic monitoring of the subway tunnel can have a comprehensive understanding and control of the safety of the project and the impact of the project on the surrounding environment, so as to ensure the smooth progress of the project and the safety and stability of the surrounding environment.

4. Monitoring scope and content

4.1. Monitoring scope
The east side of this block is close to metro tunnel line 4, about 35.01~40.46m away from the metro tunnel, which belongs to the Metro protection area. The east side line of the foundation pit is 126m long. In addition to the additional survey area on both sides, the total monitoring range is 192m long. The line mileage is K19 + 214 ~ K19 + 406, and the ring number is 490 ~ 650. The schematic diagram of the monitoring range of subway protection is shown in Figure 1.

4.2. Monitoring content
In order to monitor the impact of foundation pit construction on metro station and tunnel and ensure the normal and safe operation of metro tunnel, according to relevant regulations, the monitoring contents are as follows:

The monitoring items of subway tunnel include roadbed settlement, roadbed horizontal displacement, segment convergence and roadbed differential settlement. The core monitoring area of each tunnel is 117m, and one monitoring section is set every 6m (5 rings), and 23 monitoring sections are set for each line, one section is set for every 10 rings in non core monitoring area, and 5 monitoring sections are set for each line; and 56 monitoring sections are set for double lines. See Figure 2 for the layout of monitoring section survey points.

5. Data sorting and analysis
Through monitoring the tunnel of Metro Line 4, analyzing the impact of construction on the metro, 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.

The final cumulative change curve of each monitoring project is shown in Figure 3 and figure 4.

![Figure 3. Final cumulative change curve of each monitoring item on the uplink](image1)

![Figure 4. Final cumulative change curve of each monitoring item on the down link](image2)
The final cumulative change rate curve of each monitoring project is shown in Figure 5 and figure 6.

![Figure 5. Cumulative change rate curve of uplink](image1)

![Figure 6. Cumulative change rate curve of down link](image2)

During the whole monitoring period, the cumulative maximum change of the up and down line tunnel monitoring items under each main working condition is shown in Figure 7 and figure 8.

![Figure 7. Cumulative change rate curve of uplink](image3)

![Figure 8. Cumulative change rate curve of down link](image4)

Condition 1—The construction of retaining pile is completed, engineering pile construction
Condition 2—First support pouring completed
Condition 3—Excavation to - 7m, the second support pouring completed
Condition 4—Foundation pit earthwork excavation to the end
Condition 5—Foundation pit bottom plate pouring completed
Condition 6—Structural construction to ± 0.00
Condition 7—Backfilling on one side of the subway
Condition 8—Three months after backfilling
According to the above test results, the accumulated change rate of the last three months of tunnel settlement, horizontal displacement, tunnel convergence and differential settlement of track bed of the upper and lower line is within 0.02mm/d, and the change is stable. From the construction of retaining pile to the completion of earthwork backfilling, according to the monitoring data, the final accumulated change of each monitoring project is within the alarm value. Meet the requirements of monitoring scheme shutdown.

6. Summary
Based on the monitoring of the settlement, convergence, horizontal displacement and lateral difference of the metro tunnel in the relocation project of the rural to non residents in plot fg20-r21-13 of Kaixuan unit in Jianggan District, combined with the daily inspection, the following conclusions are drawn:

(1) From the construction of retaining pile to the completion of earthwork backfilling, according to the monitoring data, it is shown that the final cumulative change of each monitoring project of the upper and lower line of the tunnel is within the alarm value, and the change is stable, which meets the requirements of the monitoring scheme.

(2) In April 2018, our hospital conducted a tunnel survey on the project. There were 53 upstream lines compared with the initial survey, and 14 new lines (13 new lines with leakage or traces of leakage and 1 new line with repair traces); 72 new lines compared with the initial survey, and 12 new lines (5 NEW lines with leakage or traces of leakage and 6 new lines with repair traces), 1 damaged).

(3) The foundation pit construction has a certain impact on the Metro Line 4 nearby. The value of the automatic monitoring project changes with the working condition of the foundation pit. The automatic monitoring of the tunnel of line 4 basically achieves the expected effect and ensures the safety and stability of the metro operation.

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