Measured analysis of ground settlement deformation of underground tunnel

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Abstract. In the subway tunnel construction. Studying the disturbance effects of construction on the surface and underground pipelines requires not only pre-estimation through theoretical and experimental analysis. And more importantly, dynamic forecasting is required through information obtained from the site during the construction process. Dynamic forecasting is of great significance in engineering. Based on the monitoring and analysis of the construction site of the underground excavation section of Shijiazhuang Metro Line 1, this paper studies the settlement curves of surface settlement and underground pipelines. By analyzing a large number of measured data, the empirical parameters applicable to Shijiazhuang area are summarized..

1. Introduction
There are many factors that cause surface deformation during the construction of the underground excavation method, which is a comprehensive technical problem. For a specific shield construction method, under certain geological conditions, it is difficult to predict the settlement amount correctly. Therefore, before the construction, the surface deformation measuring points should be arranged on a section of open space, so that the surface deformation of the actual test can be tested during construction. On the basis of obtaining test data, the author improved the corresponding construction technical measures and gradually entered the construction of urban streets and buildings.

2. Project Overview
The range of mileage from Zhongshan Park Station to Ping’an Avenue Station is K13+861.6~K14+659.75 (the total length is 798.15 double line meters), including: (1) section of the main line tunnel; (2) construction shaft and cross channel; (3) contact Channel and wastewater pumping station; (4) section of civil air defense section. From the beginning of the interval K13+861.600 to K13+889.8, the construction is carried out by the underground excavation method; K13+889.8~K13+934.5 sections are constructed by the open cut method; the section of the parking line is the dark excavation double-line section, and the rest is the single-hole single-line horseshoe type. The section is constructed by mining method.

Within the depth of exploration, the foundation soil of the site is mainly composed of the Quaternary Holocene and the newer clay soil, sand soil and gravel soil. In the topography, it belongs to the Weihe alluvial fan. The main aquifer is located in the upper part of the alluvial fan. The lithology is mainly gravel sand and round gravel. From top to bottom: 1) miscellaneous fill; 2) fine sand; 3) silty clay, medium coarse sand, gravel sand; 4) gravel, gravel.
3. Tunnel interval measurement point layout

3.1. Surface settlement observation points
From the starting point of the construction of the excavation section, a surface settlement observation section is set every 10m on the ground along the axis of the transverse channel[4]. Set 9 settlement points for each section. The surface settlement observation points are set along the center line axis perpendicular to the left line (or the right line) of the tunnel at a distance of 2 m, 3 m, 4 m, and 5 m from the center line. The layout of each section is shown in Figure 1.

![Fig.1 The observation points’ layout of hidden-digging sections’ ground settlement](image)

3.2. Method for laying out surface settlement observation points
The surface settlement observation points should pass through the hard soil layer and the road structure layer, and be placed in the undisturbed soil layer[5-6]. The layout of the measuring points is shown in Figure 2. The measuring points are generally made of 1000 mm Φ18 ribbed steel. The measuring point is 5-10mm above the ground. The measuring points are filled with cement mortar. After the point to be measured is completely stable, measurement can be started[7-8].

Since Youth Street does not allow any measuring points to be higher than the road surface, the measuring points are protected by a covered iron drum with a height of 300 mm and a diameter of 150 mm when arranging the measuring points on the road surface. The measuring point is 30mm below the road surface, and the top of the iron tube is flush with the ground.

![Fig.2 The observation point of ground settlement](image)

4. Surface settlement data

| Cross section Monitoring points | Cumulative settlement (mm) |
|---------------------------------|-----------------------------|
| H1                              | H1 0.02 H2 -0.14 H3 -0.01 H4 -0.08 H5 -0.21 H6 -0.36 H7 0 H8 -0.16 H9 -0.51 |
| H2                              | H1 -0.08 H2 -1.28 H3 -0.33 H4 -0.58 H5 -0.54 H6 -1.26 H7 -0.08 H8 -0.59 H9 -1.21 |
| H3                              | H1 -0.78 H2 -3.12 H3 -3.65 H4 -2.47 H5 -1.89 H6 -3.21 H7 -0.55 H8 -1.15 H9 -2.51 |
| H4                              | H1 -2.8 H2 -6.78 H3 -5.36 H4 -4.52 H5 -3.97 H6 -4.57 H7 -1.44 H8 -1.48 H9 -4.51 |
| H5                              | H1 -5.37 H2 -7.66 H3 -6.58 H4 -7.42 H5 -4.73 H6 -6.81 H7 -2.8 H8 -2.31 H9 -6.34 |
| H6                              | H1 -3.18 H2 -5.54 H3 -4.59 H4 -5.24 H5 -6.12 H6 -5.87 H7 1.07 H8 -1.58 H9 -4.68 |
| H7                              | H1 -1.64 H2 -4.31 H3 -3.91 H4 -3.12 H5 -4.22 H6 -3.45 H7 0.49 H8 -0.95 H9 -2.85 |
| H8                              | H1 -0.5 H2 -2.68 H3 -0.52 H4 -0.87 H5 -3.64 H6 -1.68 H7 0.12 H8 -0.47 H9 -1.54 |
| H9                              | H1 -0.24 H2 -1.01 H3 -0.26 H4 -0.34 H5 -1.29 H6 -0.97 H7 0.01 H8 -0.12 H9 -0.64 |
The mileage of each cross section is shown in Table 2:

| Section | Mileage  | Section | Mileage  | Section | Mileage  |
|---------|----------|---------|----------|---------|----------|
| H1      | DK14+120 | H4      | DK14+180 | H7      | DK14+220 |
| H2      | DK14+150 | H5      | DK14+190 | H8      | DK14+250 |
| H3      | DK14+160 | H6      | DK14+200 | H9      | DK14+260 |

5. Analysis of monitoring results

5.1. Development law of surface settlement along the longitudinal direction of the tunnel

As shown in Figure 3, the surface settlement of tunnel excavation is divided into four stages.

1. The small stage of settlement: when \( L / D \leq 1 \) (\( L \) - the distance between the face of the face and the direction of the measuring point; \( D \) - the diameter of the tunnel), the distance between the face of the tunnel face and the point of the measuring point is far, and the settlement development is relatively slow;

2. Settlement sharp phase: \( 1 \leq L / D \leq 3 \), at this time the face distance of the face is close to the measuring point, the settlement develops rapidly, the maximum settlement rate can reach 1.65 mm / d, accounting for 60~70% of the total settlement;

3. Slow sedimentation stage: \( 3 \leq L / D \leq 5 \), the distance between the face of the face and the section of the measuring point is slowed down;

4. Settlement stabilization stage: \( L / D \leq 5 \), the face of the face is far away from the section of the measuring point, and the settlement changes tend to be stable.

![Figure 3: Surface settlement of the section changes with the advancement of the face](image)

5.2. Distribution law of surface settlement of tunnel cross section

It can be seen from Fig. 4 that the surface settlement of the cross-section of the single-track tunnel excavation tunnel is basically normal along the midline of the tunnel. The width of the single-side anti-bending point of the settlement trough is about 6m. The maximum surface settlement caused by the settlement is stable, 17.5mm.
6. Surface settlement prediction

6.1. Establishment of predictive model

Currently, settlement tank calculations are widely used. The Peck formula proposed by O. Reilly and New in 1982. Based on the analysis of a large number of measured data, Professor Peck proposed a mathematical model of the settlement cross-section of the tunnel construction surface, following the normal distribution curve, as shown in Figure 5.

From the measured data, the lateral settlement tank curve is similar to the theoretical settlement curve calculated by the Peck formula. The maximum settlement values of the nine sections are all within 10 mm. By analyzing the settlement maps of each section, it is found that the distribution of the settlement tanks is within 3D of the tunnel (D is the outer diameter of the tunnel), and the maximum settlement is 60%~70%, which occurs within 1.5 times span (9m). The 1.5-fold span of the tunnel is the main affected area of tunnel construction, and underground structures within its scope should be monitored.

According to the situation of the underground excavation section of Zhongshan Park Station to Ping'an Avenue Station, according to the geological conditions and the buried depth, take $\phi = 30^\circ$, and the settlement half-slot width can be obtained from the peck formula:
\[ i = \frac{Z}{\sqrt{2 \pi \tan (45 - \frac{\varnothing}{2})}} = kz = 0.69z = 4.4m \sim 6.9m \]

Therefore, the settlement tank width obtained from the peck formula is 8.28m~13.8m, which is consistent with the main influence range measured by the data of 9.6m. Therefore, for the Shenyang geological conditions and the undercut construction method, the settlement tank width coefficient \( k \) is reasonable.

7. Conclusion
1) The monitoring results of surface subsidence of tunnel excavation from Zhongshan Park Station to Ping’an Avenue Station indicate that the development of longitudinal surface settlement along the tunnel along the tunnel face during tunnel excavation mainly undergoes four stages: sedimentary micro stage, rapid subsidence stage, and settlement. Slow phase, sedimentation stabilization phase. In the rapid stage of \( 1 \leq \frac{L}{D} \leq 3 \) settlement, the maximum settlement rate can reach 1.45 mm / d, accounting for 60% - 70% of the total settlement, which is the focus of settlement control.

2) The results of monitoring the surface settlement of tunnel excavation indicate. The surface settlement of the tunnel excavation is basically normal along the midline of the tunnel, and the maximum surface settlement is 17.5 mm. The width of the surface settlement trough caused by excavation of the tunnel is 9m. The surface settlement value and the settlement tank width of the post-excavation tunnel are basically the same as those of the first excavation tunnel.

3) Based on the statistical analysis of the measured data, the Peck formula is used to predict the ground settlement caused by tunnel excavation. The method is feasible and has high precision. It has certain guidance and reference for similar projects.

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