Analysis on Influence of Metro Shield on Ground Subsidence

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Abstract. The shield tunnel construction inevitably disturbs the surrounding strata, which in turn causes ground subsidence, and the excessive sedimentation will endanger the normal use and structural safety of adjacent buildings. Based on the analysis of the ground subsidence during the construction of the shield tunnel, the settlement trough of the surface cross section in the process of metro shield is similar to the normal distribution curve. The maximum settling volume usually occurs within 5 meters from the center of the tunnel. The ground subsidence arising from shield construction can be roughly divided into three stages: firstly, before the shield machine reaches the observation section, the subsidence (-30m-0m) occurs, and the settling volume is about 10% to 20% of the total settlement; secondly, when the shield machine passes through the observation section, the subsidence occurs (0-30m), and the settling volume is about 40% to 70% of the total settlement; and finally, after the shield machine passes through 30m of the observation section, the later consolidation settlement of the section occurs, and the settling volume is 10% or less of the total settlement. The transverse influenced range of the ground subsidence is about 30 meters or less and the main influence area of shield construction is around 5 meters from the left or right of the tunnel axis. In the case of the shield pass-through or the shield tail pull-away, the ground subsidence is relatively larger, accounting for 30% to 50% of the maximum settlement value.

1. Introduction
The shield thrust technology is widely used in the urban metro construction, but the shield tunnel construction inevitably disturbs the surrounding soil and causes the soil to move, which may lead to the tilt or even cracking and collapse of houses, viaducts and other buildings and destroy the underground pipelines, so the influence of the shield construction process on the surrounding environment has become a matter of great concern. Many scholars at home and abroad have carried out extensive and in-depth research on the ground subsidence caused by the shield tunnel construction. Japan has accumulated rich experience in the construction of long-term urban tunnels, so it is very concerned about the problem of surface subsidence caused by tunnel construction. Based on the measured data, Hanya put forward the prediction method of the maximum ground settlement. Fujita carried out the research on the influence of different shield construction methods on the strata in soft soil strata, and the practical formulas were also put forward by Mori and Shimada. Lin Zhenhong studied the influence of the expansion construction of the existing tunnel on the tunnel structure mechanics behavior and the stability of the surrounding rock; Wu Zhangzhong derived the specific form of the complex stress function in the case of the lateral enlarging excavation of the existing tunnel. The engineering practice shows that the shield tunnel construction technology has been developed very maturely, but it inevitably produces disturbance to the soil and causes different levels of formation displacement and deformation, which is usually expressed as ground subsidence. In this paper, the metro shield construction of one project under construction in Tianjin was taken as an example to study the ground subsidence law of horizontal and vertical sections along the subway...
tunnel in the process of Tianjin subway tunnel shield construction, and to analyze the influence of metro shield on the surrounding environment.

2. Field experiment

2.1 Arrangement of measuring points

The test section for the shield tunnel construction was about 1,000 meters long, the four test sections were selected, and eight observation points were arranged at each observation section (the specific locations are shown in figure 1 and figure 2), so as to monitor and master the changing situation of the vertical displacement of the ground point during the shield construction and the characteristics of the subsidence of the soil of the measuring section perpendicular to the direction of the shield axis. The Leica DNA03 digital level was chosen as the observation instrument.

![Figure 1. Arrangement diagram of the measuring points of cross-section for ground subsidence in shield zone.](image1)

![Figure 2. Arrangement diagram of the measuring Transverse.](image2)

2.2 Project overview

According to the exploration, the depth range can be divided into Quaternary Holocene artificial fill layer (Q4ml), beach alluvium (Q42al) Tertiary (N) sandstone and conglomerate. The geology of the region consists of a set of settled layers varying from the fine particles gradually to thick ones, usually expressed as clay, silt, medium sand, coarse sand, gravelly sand and thick pellet soil, and the silt and fine sand are rarely seen, with part strata of the local section missing. The permeability coefficient is generally between 50 to 100 m/d, hydraulic slope is around 1 ‰.

3. Experimental data analysis

The transverse subsidence data of four monitoring sections were selected from the right line of the test section for analysis. According to the shield construction process, the continuous measurement was applied to measure the four monitoring sections firstly with 30 meters from the shield, until 40 meters of the section were passed by the shield machine and the surface subsidence stabilized. The transverse subsidence of ground surface of these four monitoring sections is shown in figure 3 to figure 6. The longitudinal surface subsidence can help analyze the influence range and size of front and rear soils.
during shield construction. In this paper, four monitoring sections were selected, and figure 7 to figure 10 were drawn based on the surface subsidence values of the measuring points distributed from about 30 meters from the sections to 40 meters of the sections.

**Figure 3.** The Transverse surface settlement process chart of section A.

**Figure 4.** The Transverse surface settlement process chart of section B.

**Figure 5.** The Transverse surface settlement process chart of section C.

**Figure 6.** The Transverse surface settlement process chart of section D.

It can be seen from the ground subsidence curve that:

1. The settlement trough of the surface cross section is similar to the normal distribution curve. When the shield machine is on the flat surface with no ground load, the maximum settling volume occurs at the center of the tunnel.

2. The ground subsidence caused by shield construction can be divided into five stages:
   ① As to the ground subsidence before the arrival of the shield, the shield machine is around -30 to 10 m away from the observation section, and the surface subsidence value is 1 to 2 mm at this stage, as small as 5% to 10% of the maximum settlement value.
   ② As to the ground subsidence when the shield reaches, the shield machine is -15 to 0 m away from the observation section, and if the earth pressure of chamber is higher, the upheaval of the earth surface may occur at this stage, like Section DK6+608.680. According to the general data, the ground subsidence value is 2 to 4 mm at this stage, equal to 10% to 20% of the maximum settlement value.
   ③ As to the ground subsidence when the shield passes, the shield machine is 0 to 10 m from the observation section, and due to the friction shear stress between the shield and soil and changes in stress of the sandy soil resulting from the shield’s “head-up” and “kowtow”, the subsidence at this stage generally has a sudden change, up to 5 to 8 mm, equal to 30% to 50% of the maximum settlement value.
   ④ As to the ground subsidence when the segment pulls away from the shield tail after the shield passes through, the shield machine is 10 to 40 m from the observation section, and mainly due to
“shield tail gap” and stress release, the subsidence value at this stage is 5 to 8 mm, as large as 30% to 50% of the maximum settlement value.

⑤ As the soil is disturbed by the shield excavation to lead to the re-consolidation of the soil, the long-term consolidation settlement occurs after the shield passes. The sedimentation value at this stage is not large, which generally accounts for 10% or less of the maximum settlement value.

(3) The transverse influenced range of the ground subsidence is about within 30 meters and the main influence area of the shield construction is within 5 meters from the left or right of the tunnel axis. The ground subsidence turning points of the four monitoring sections are located within 5 meters from the left or right of the center of the shield tunnel axis. In this area, the settlement trough’s volume accounts for 60% to 70% of the total volume, and the average settlement value is 60% to 80% of the maximum settlement value.

The ground settlement in longitudinal surface indicates that:

(1) The influence range of the shield thrust on the front soil is within 30 m. As can be seen from the figure, the settling volume for the front soil is generally not more than 5 mm, but the duration is longer. The subsidence is done in a slow process and there is a phenomenon of surface upheaval.

(2) The influence range of shield thrust on the disturbance and settlement of the rear soil mainly ranges from 0 to 10 m, and the sand strata are different from the clay strata in such range. The shear strength and cohesion of the sandy soil are very weak, so the deformed settlement occurs quickly after the soil is disturbed, without the delay-time effect of the sticky soil. Therefore, the settlement
generally has a sudden change at this stage, with the maximum rate of change of 5 to 8 mm, accounting for 30% to 50% of the maximum settlement value.

(3) The ground subsidence is also larger at the stage of shield pass-through or shield-tail pull-away, accounting for 30% to 50% of the maximum settlement value.

4. Conclusion

Based on the analysis of the ground subsidence during the construction of the shield tunnel, the following conclusion is obtained:

(1) The settlement trough of the surface cross section in the process of metro shield is similar to the normal distribution curve.

(2) The maximum ground settlement which caused by shield construction is occurs between the shield machine reaches the observation section and leave the observation section 30m, and the settling volume is about 40% to 70% of the total settlement.

(3) The influence of shield construction is within 15m on both sides of the subway line.

5. References

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