Influence of Shield Propulsion on Longitudinal Soil Mass Near Subway Structure

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Abstract. Metro construction has important significance to the safety of the structure, based on a line existing Beijing subway, with air shaft and station structure as the background, research on soil displacement near the existing structure. The results show that: (1) The shield to the main structure from about 28.8m-7.2m (except for the shield at the center line testing point), the displacement and the shield is the same direction, the displacement changes generally decrease from the surface to the deep level, the variation is in the range of 1-5mm, with a linear distribution; (2) The displacement direction is as same as shield direction from 7.2m-3.6m, the displacement increases continuously is in the range of 5-15mm, the displacement accord with normal distribution; (3) 1 times diameter range and the shield to the existing structure of 7.2m-3.6m range should be regarded as significant influence area in the process of shield construction. The displacement of soil increases with the approach of shield, the maximum displacement point appears at the center of shield or above the top of shield of 1m. The above results can provide reference for shield driving parameters.

Keywords: shield propulsion; existing structure; longitudinal soil; soil displacement

1. Introduction

With the acceleration of urbanization process, the subway has the ability to transport large, convenient and fast features and shield construction is the main method of subway construction in China. There are many problems of shield construction in China, although the soil conditions and the environment is complex and changeable, but the mainly refers to the soil environment damage due to the construction disturbance caused by the movement of the surrounding strata and the ground settlement or uplift to the geotechnical environment of surrounding buildings (structure) and underground pipelines. [1] If there is an existing structure or pipeline in the area where the shield is being propelled, the advance of the shield may have a devastating effect on the soil when the displacement of the soil is not monitored in time [2-3].

The research on the influence of subway construction on soil displacement in China has obtained many achievements. Sun Jun [1] discussed the construction disturbance to the soil mass and the mechanical mechanism causing the ground movement and the settlement and deformation of the ground surface, and the main factors affecting the construction disturbance are summarized. Liao ShaomIng [4] considered the interaction between the shield tunnel overlap construction and the distribution of the displacement field caused by the formation and the mutual influence. Li Chunlin [5] used static probe to test the scene of construction shield disturbance range. Zhang Xiaoqing [6] believes that the ground settlement changes at different stages are uniform after the first down and
crossing construction, and finally the surface subsidence is relatively small. Si Jinbiao [7] considered that the influence area of the rectangular shield construction is about 20m ahead of the excavation face. Liu Shujia [8] believes that due to the excess pore water pressure and other factors of deep stratum in soft soil area, after adjusting the shield parameters, the later displacement of the section soil will be more affected. Zheng Chen [9] studied the soil stress deformation during the construction of earth pressure shield, and established the influence model of the earth pressure shield machine on the ground settlement during the tunnel excavation.

At present, most studies mainly focus on the control of the displacement of the earth’s surface by the shield construction method. In the construction, the displacement of the earth’s surface is the most important control factor, that is, the vertical displacement of the soil that namely uplift or subsidence. However, there is not much concern about the shield horizontal displacement of the soil near the advancing direction. So this is the starting point of this study, through the establishment of monitoring points in the structure of the shaft and the station has been built to monitor the impact of the shield to promote the vertical soil longitudinal direction of the study to explore the response law.

2. Project Overview
The first phase of a certain line of Beijing Metro is 31.31km long. Choosing Maquanying - Cuigezhuang station section as test site, which including two station structure and a wind shaft structure. Inter-regional use of earth pressure balance shield construction and the tunnel diameter 6m. The direction of shield advancement from Maquanying Station to Cuigezhuang station and the test site selected Cuigezhuang station.

3. Test Scheme

3.1. Test Ideas and Equipment
In order to test the displacement of the longitudinal soil (the depth of shield machine) in the direction of shield driving. The test mainly uses C008A type inclinometer and PVC inclinometer tube to cooperate with each other, and the range of the inclinometer parameter is ±50 degree, the precision is 0.02mm and a group of data is tested every 2.0m.

3.2. Test Plan
Field test plan considering the research results of site survey and shield propulsion construction influence range. The monitoring scheme in the station structure is illustrated in Fig.1 and Fig.2.

![Figure 1. The floor plan of measuring points](image-url)
Drilling arrangements using percussion drill. When compositing the depth design requirements, the inclinometer tube segment lengthened and placed, and filled the cement mortar between the hole wall and the pipe wall. And the final monitoring of mortar end point is carried out to ensure the normal operation of the test system.

The test frequency at the station structure is 1417 ring to 1438 ring, specifically for the shield from the main structure about 28.8m-3.6m at a frequency of 1 ring / times, a total of 21 ring monitoring.

4. Test Results and Analysis

4.1. Test Results

![Figure 2](image2.png)

**Figure 2.** The profile layout diagram of measuring points

![Figure 3](image3.png)

**Figure 3.** Deep soil vertical displacement curve of 1# testing point

![Figure 4](image4.png)

**Figure 4.** Deep soil vertical displacement curve of 2# testing point (unit: mm)
Figure 5. Deep soil vertical range displacement curve of 3\# testing point (unit: mm)

Figure 6. Deep soil vertical range displacement curve of 4\# testing point (unit: mm)

Figure 7. Deep soil vertical displacement curve of 5\# testing point (unit: mm)

Figure 8. Deep soil vertical displacement curve of 6\# testing point (unit: mm)
4.2. Analysis of Test Results

① Test point 1# (Fig.3). When the shield reaches to the station structure of 28.8m-7.2m, the direction of longitudinal soil displacement is consistent with the direction of shield driving. When the displacement changes within -1mm-7mm, the change of the displacement of each working condition is inconsistent, and the test results of each group gradually decrease from the ground surface to the depth of the soil. And in the process of 6m-3.6m, the direction of soil displacement in the depth of shield is consistent with the direction of shield driving, and the displacement changes within the range of 1mm-14mm.

② Test point 2# (Fig.4). When the shield reaches the main structure of 28.8m-9.6m, the displacement direction of the soil in the shield depth is opposite to that of the shield. The displacement is about -4mm-1mm. From the surface to the top of the shield, the displacement of the ground surface is relatively the largest. With the decreasing of the depth, the displacement of soil body begins to increase again from the top of the shield to the center of the shield, reaches the relative maximum at the center of the shield, and then gradually decreases with the depth of the shield small. In the shield to the main structure of 8.4m-3.6m process, the amount of displacement ranges of -5mm-15mm. From 8.4m, the direction of soil displacement along the shield depth is the same as that of the shield. From 7.2m to the depth of the shield, a larger displacement point appears.

③ Test point 3# (Fig.5). In the process of 28.8m-7.2m from shield to main structure, the displacement range is -2mm-4mm. From the ground surface to the top of the shield, the direction of soil displacement in the shield buried depth is opposite to the thrust direction of the shield, and the displacement value decreases gradually along the buried depth. At the bottom of the shield to the bottom of the measuring point, the direction of soil displacement in the scope is consistent with the direction of the shield driving, and the displacement value begins to increase along the buried depth. During the process from shield to main structure of 6m-3.6m, the displacement direction of the soil in shield depth range is consistent with that of shield, and the displacement range is -1mm-12mm. Within the range of shield depth, larger protrusion point displaced.

④ Test point 4# (Fig.6). In the process from shield to main structure of 28.8m-9.6m, the displacement varies from -2mm to 3mm. From the surface 8m to the depth of the shield, the displacement direction of the soil in this area is opposite to that of the shield, while from the buried depth of 8m to the top of the shield, the displacement direction of deep soil is basically the same as that of the shield. During the process from shield to main structure of 6m-3.6m, the direction of soil displacement is the same as that of shield advancement with the displacement within the range of -1mm-11mm. The maximum protrusion displacement point appears at about 1m above the top of the shield.

⑤ Test point 5# and 6# (Shield tracking point) (Fig.7 and Fig.8). The variation law of soil displacement in shield buried depth is similar to that of 1# monitoring point. But the maximum thrust displacement point is not located at the center of shield, but appears at about 1m above the top of shield.

4.3. Comprehensive Analysis of Test Results

① In addition to the measuring points at the shield center, when the shield is within 28.8m-7.2m from the main structure, the displacement direction of the deep soil is generally in the same direction as the shield, and the displacement generally shows a step-by-step change from the surface to the depth. The displacement data fit well with the five polynomial function distribution curve, as shown in Fig.9a.

② The measuring points in the shield center are in the range of 28.8m-7.2m. The displacement direction of deep soil in the opposite direction to shield advancement, the displacement decreases gradually from the surface to the top of the shield, and the displacement data fit more in line with the linear distribution curve. From the top of the shield to the test depth, the displacement data fit well to the normal distribution curve, as shown in Fig.9b.
When all the measuring points from the shield to the main body structure from about 7.2m to 3.6m, the displacement direction of the deep soil is the same as that of the shield. And as the shield continues to move, the displacement increases and the displacement data fitting is in good agreement with normal distribution curve, as shown in Fig. 9c. The maximum protuberance displacement point appears at 1m above the shield center or shield top.

![Figure 9. Fitted curve of soil displacement from shield to main structures depth](image)

5. Conclusions
The following conclusions can be drawn from the comprehensive analysis of the field test results:

1. When the distance is less than 28.8m, the displacement direction of longitudinal soil shows certain regularity with the advancing direction of shield, and the linear change of 28m-7.2m is dominant. The displacement of 7.2m-3.6m accords with the normal distribution curve, and the maximum displacement point appears at 1m above the shield center or the top.

2. When the distance between the shield and the main structure is 28.8m-7.2m and 7.2m-3.6m, the displacement of longitudinal soil is 1-5mm and 5-15mm respectively. Within a distance of 7.2m from the existing structure, the advancement of the shield shall be regarded as a significant area of influence. Look at each measuring point displacement numerical results from the horizontal distribution, the maximum displacement is only 1-2mm. Therefore, the transverse 1 times shield diameter range should be considered as a significant influence area during the shield driving process, which should be paid more attention to during construction.

3. When the distance between the shield and the main structure is more than 7.2m, the displacement of the soil is not increasing with the approaching of the shield, but as the shield approached, there was a concussion. It is shown that in this area, the deep soil displacement of shield driving should be determined by the construction parameters, state and soil properties of the shield. While it is less than 7.2m, the displacement of the soil increases with the shield approaching at the same depth of each measuring point. It shows that the displacement of deep soil under shield driving is mainly determined by the shield construction parameters and state in this region, and the nature of soil layer no longer plays a decisive role.

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