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Numerical Simulation Study of the Surface Subsidence Caused by TBM Tunnel Excavation

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Abstract: TBM (shield machine) tunnel excavation is a commonly used method in underground engineering construction, but the construction process will affect the surrounding soil, easy to a certain extent produce soil disturbance, causing surface subsidence and other geological disasters. Therefore, the TBM tunnel excavation cause surface subsidence numerical simulation research has important engineering practical significance. In this study, the TBM tunnel excavation of a section of subway in Shijiazhuang was selected as a case to establish a numerical model, analyze the surface subsidence caused by the construction process, and summarize a series of surface subsidence rules. The lateral settlement of the surface is increasing with the excavation of the tunnel, and its settlement curve conforms to Peck's law; The longitudinal surface subsidence displacement of tunnel excavation has a greater impact than the transverse surface subsidence displacement, and the longitudinal subsidence gradually decreases with the increase of the tunnel buried depth, and the settlement gradually increases with the process of tunnel excavation. By comparing the numerical simulation results with the actual monitoring values of the construction site, it is concluded that the reaction rules on the settlement curve are basically consistent, so as to verify the applicability of the numerical simulation and can provide reference for similar construction projects.

1. Introduction

In recent years, with the rapid development of China's urbanization process, the ground traffic is becoming more crowded. In view of this phenomenon, the rapid development of urban rail transit has reduced the ground traffic pressure to a certain extent. China has a vast territory, and the geological conditions between different cities. Among them, the rock and formation cities represented by Chongqing and Qingdao have begun to use TBM construction method in the construction of urban subway. The market prospect of TBM method in urban subway tunnel construction is considerable. However, due to the complex urban strata, serious formation deformation and settlement will often cause serious consequences, so it is necessary to conduct in-depth study on the ground subsidence law induced by TBM tunnel construction.

Song Kezhi et al.[1-3] used Peck formula to derive the maximum characteristic value of surface settlement, analyzed the reliability and applicability of TBM construction, and summarized a series of surface settlement rules; Peck formula was proposed by R.B.Peck in 1969, he believed that the formation deformation is caused by the formation loss, the surface settlement tank volume is equal to the formation loss volume, and the surface settlement tank conforms to the normal distribution curve[4]; Deng Wenqi [5-8] et al. use soil-structure coupling theory and generalized rheology theory to calculate surface settlement and surrounding rock deformation, tunnel system displacement value, stress value and strain value, so as to quantitatively guide tunnel engineering excavation, collaborative support, etc.Jiang Shuai et al. [9-12] establishes a dynamic prediction model of lateral surface settlement, so as to realize the dynamic prediction of the settlement of the construction site, which provides a reference for the subsequent construction of similar projects. Based on the engineering example of a TBM section of Shijiazhuang metro, the surface subsidence of TBM tunnel excavation is studied and analyzed.

2. Project Overview

Based on the project of a section of Shijiazhuang Metro, most of the strata along the section of this section are mainly rock, some sections are soft and hard, and some sections are soft land, which is difficult to construct. There are high-rise buildings and residential buildings on both sides of the upper part of the tunnel, and the adjacent roads have heavy traffic and the traffic flow is large. During the construction period, the upper part of the passage is closed, and the influence of surface water and groundwater is not considered in the project area.

3. Establishment of the Numerical Model

In this paper, the finite element analysis software MIDAS/GTS-NX is used for numerical analysis, and the grid cell and the overall tunnel model are shown in Figure 1 and Figure 2.

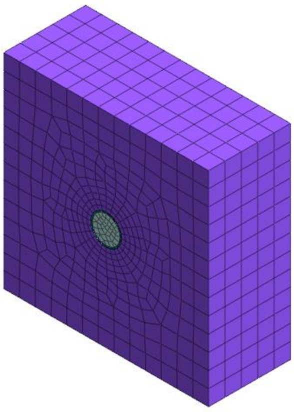

Figure 1: Schematic diagram of the grid division

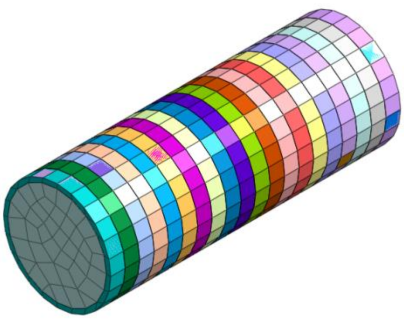

Figure 2: Overall tunnel model

Considering the boundary conditions of the tunnel excavation and the layout range of the monitoring point, the dimension of the model is defined as 50m*50m*20m, where the Y axis is the tunnel axis and the length is 20m; Z axis is the depth direction; the dimension of shield excavation is 3.7m according to the diameter of 3.7 m, and the segment thickness is 0.3m. The formation adopts solid units, using the Mohr-Coulomb constitutive model; the segment adopts solid unit, using linear elastic constitutive model, and the shield shell and grouting use plate unit, both using linear elastic constitutive model simulation. The load of the model mainly considers the dead weight of the building, tunneling soil pressure, jack thrust, shield shell outer pressure and pipe segment outer pressure. The excavation progress is set to 1m, where the excavation soil pressure is 0.2MPa, the jack thrust is 4.5MPa, 0.05MPa outside the shield shell and 1MPa outside the segment. The specific physical constants for strata and materials are shown in Table 1 below:

Table 1: Table of strata and material parameters

Material type	modulus of elasticity E/MPa	Poisson Ratio μ	volume-weight KN/m3	cohesive strength C (MPa)	Angle of friction Φ
soil mass	1300	0.3	19	15	30
duct piece	21000	0.3	24	-	-
shield shell	250000	0.2	78	-	-
slip casting	10000	0.3	22.5	-	-

4. Analysis of the Numerical Simulation Results

4.1 Horizontal Surface Settlement

Through the model calculation, the surface settlement after the final step of TBM construction is analyzed, as shown in Figure 3:

The point above the axis of the tunnel is the maximum settlement point, and the farther away from the axis, the smaller the settlement amount;

The settlement curve is close to the normal distribution, that is, the model conforms to the cross-section surface settlement law predicted by Peck's formula.

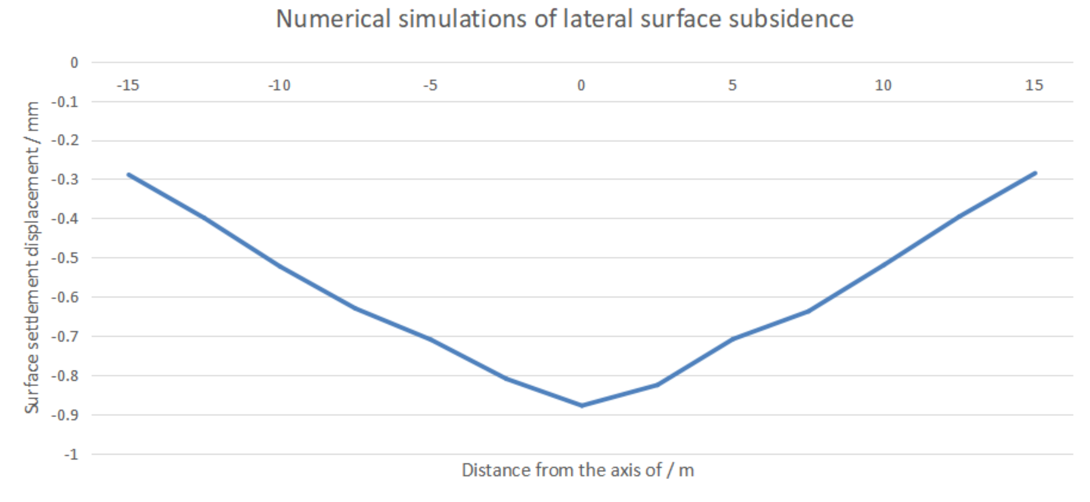

Figure 3: Lateral surface subsidence curve

The actual monitoring data and simulated data of this section were fitted and analyzed, as shown in Figure 4 below:

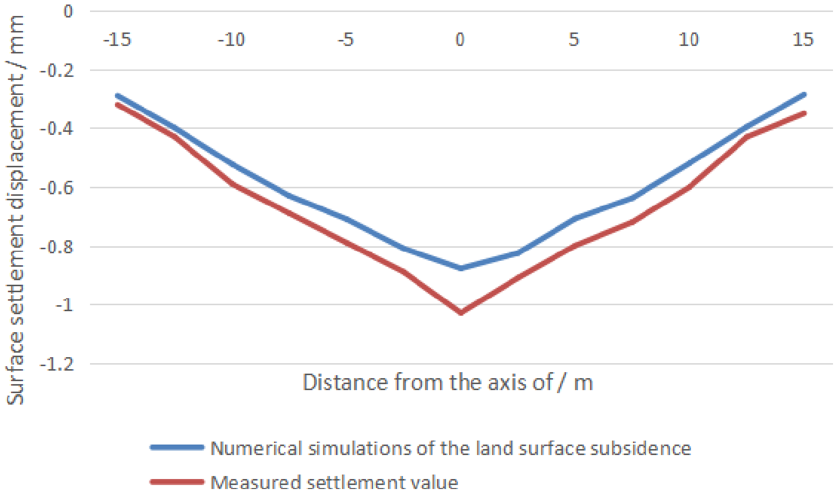

Figure 4: Comparison of simulated values and measured values of surface subsidence

From the analysis curve, the measured settlement value is slightly greater than the surface settlement value simulated by value. The settlement difference of the point above the tunnel axis is the largest, reaching 0.21mm. The difference between the two is not large, so the numerical simulation value can be used as a reference to simulate the actual construction of the construction site. Due to the ideal assumption of the model, the slight difference in the setting of construction parameters, the neglect of the influence of groundwater on the formation, and the operation difference of the construction personnel, the simulated settlement value and the actual monitoring settlement value are slightly different, but the settlement law of the two reactions is the same.

4.2 Longitudinal Surface Settlement

Longitudinal surface subsidence is a long process, and the longitudinal surface subsidence will gradually stabilize and reach the maximum value along with the advancement of the construction and excavation steps. According to the research of many experts and scholars and a lot of engineering experience summary, the longitudinal surface subsidence can be roughly divided into four stages:

1) First settlement stage: Before excavation, the monitoring surface will be slightly raised under the influence of thrust and torque of TBM shield machine. After the excavation is close to the monitoring surface, the upper surface of the tunnel will be first settled under the influence of excavation;

2) TBM passing stage: when the excavation surface of the shield machine is flush with the detection surface and the blade passes through, the tunnel is in a state without support at this time, the soil layer is disturbed, the stress state changes to produce shear stress, the surface settlement speed is fast, and the settlement value increases rapidly;

3) TBM tail through the settlement stage: due to the construction process, shield machine shell diameter is slightly greater than the tunnel lining diameter, so when the shield tail, the shield machine and segment will appear part between the formation support resistance, the surface will continue to surface subsidence, now should be grouting filling in time to prevent large deformation;

4) The following stage of grouting completion: after the completion of grouting, the formation state tends to stabilize and the surface settlement gradually stops, reaching the maximum settlement value.

According to different construction sections, the shield tunneling length of every 4 m is selected as the analysis point to conduct the surface settlement analysis of the five construction stages. The displacement cloud map is shown in Figure 5~9.

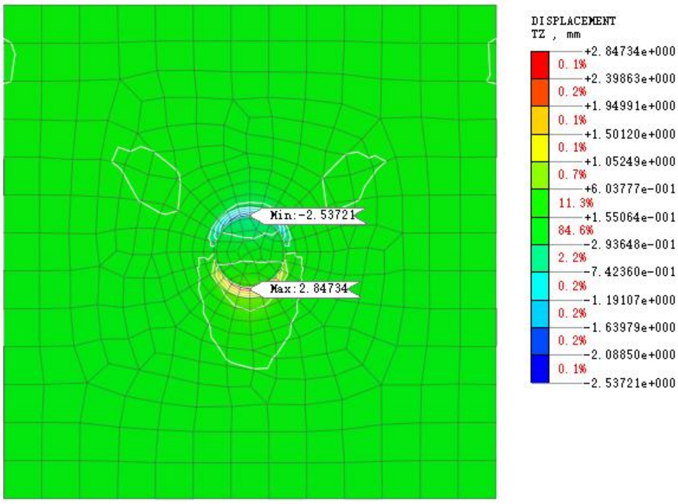

Figure 5: Vertical displacement cloud map of 4m tunneling

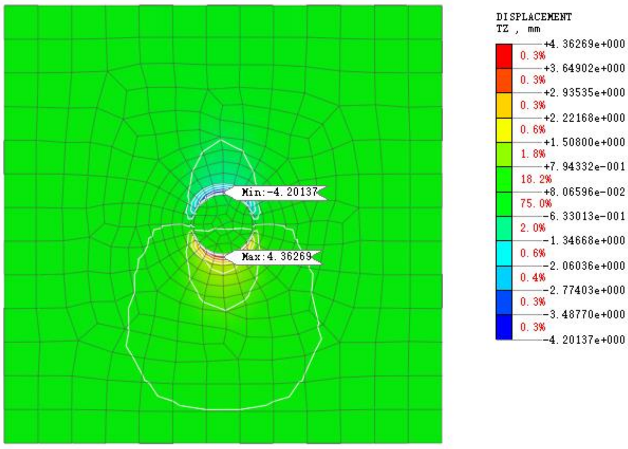

Figure 6: Vertical displacement cloud map of 8m tunneling

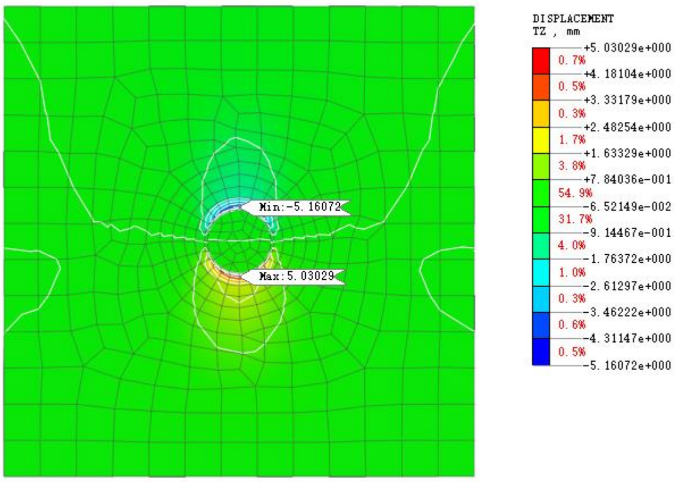

Figure 7: Vertical displacement cloud map of 12m tunneling

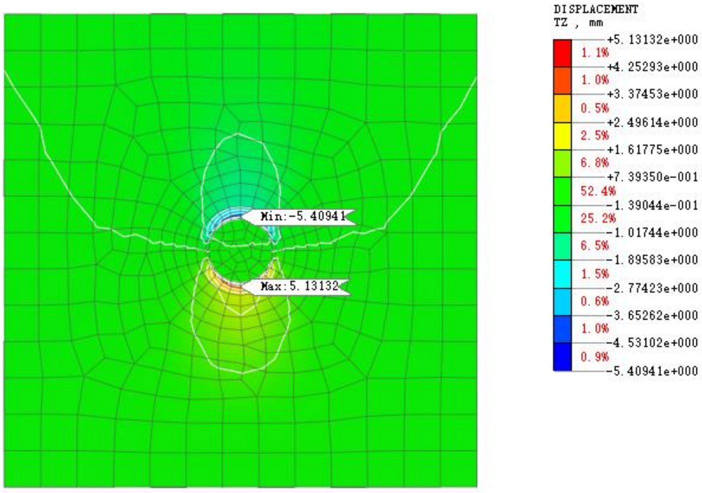

Figure 8: Vertical displacement cloud map of 16m tunneling

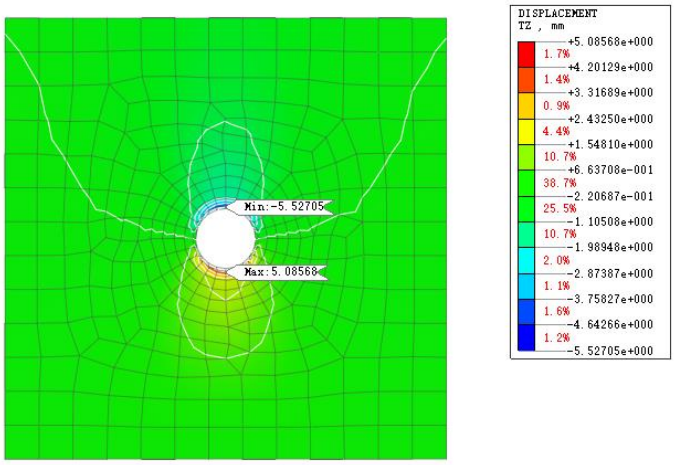

Figure 9: Vertical displacement cloud map of 20m tunneling

According to the analysis of the displacement cloud Figure 5~9, it can be learned that after TBM excavation, the bottom of the tunnel rises, and the top of the tunnel produces the settlement and the maximum settlement occurs in the vault, the farther away from the center line of the tunnel, the smaller the settlement value will be. In the shield tunneling of 4m, 8m, 4 m, 12m, 16m and 20m, the maximum surface subsidence value is 2.54mm, 4.2mm, 5.16mm, 5.41mm, 5.53mm respectively, so the surface settlement is also increasing with the tunnel tunneling.

The numerical simulation of the measuring point on the center line of the engineering tunnel and the actual site monitoring data are analyzed. With the advancement of construction and excavation steps, the longitudinal surface settlement curve of the measuring point is shown in Figure 10 below:

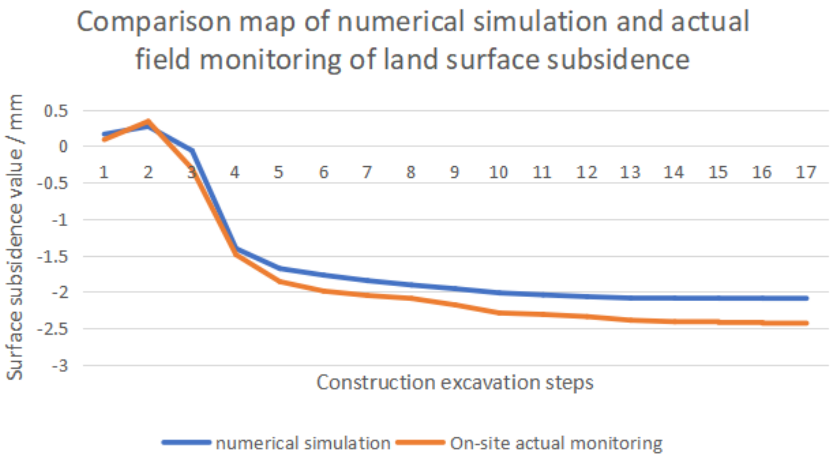

Figure 10: Comparison of numerical simulation and actual field monitoring of longitudinal surface settlement

As shown in the above figure, the numerical simulation figure is basically consistent with the actual monitoring figure on the site. In the excavation construction 1-2 steps, the surface uplift phenomenon, and then the construction excavation is close to the monitoring surface, the surface settlement phenomenon, corresponding to the first settlement stage; When the TBM shield machine passes through the monitoring surface, the surface settles rapidly, corresponding to the TBM passing stage; after the shield machine leaves the tail, the surface settlement trend gradually slows down, corresponding to the TBM tail passing through the post-settlement stage; after the grouting, the surface consolidation reaches the maximum, corresponding to the subsequent stage.

From the curve point of view, there are some errors between the actual field monitoring value and the numerical simulated settlement value, but the overall agreement is good.

In the subsequent stage of TBM construction, the maximum value of numerical simulated surface subsidence is 2.09mm, and the actual field monitoring is 2.43mm, with a difference of 0.34mm. The numerical simulation value is slightly less than the actual monitored settlement value on site.

5. Conclusion

1) The lateral settlement of the surface gradually increases with the excavation process, and the settlement value is the maximum above the tunnel and decreases to both sides. The smaller the buried depth of the tunnel, the faster the curve converges, the narrower the settlement tank is, and the settlement value decreases with the increase of the buried depth.

2) The longitudinal settlement of the tunnel decreases with the increase of the buried depth of the tunnel, and the settlement gradually increases with the process of the tunnel excavation.

3) In the process of tunnel TBM construction, the deformation of the surrounding soil is affected by various factors such as the soil disturbance in front of excavation, building gap closure, shield tail grouting. The influence of various factors must be fully considered to obtain reasonable results.

4) The calculation obtains the displacement field of the surrounding soil and the ground settlement curves of the tunnel during TBM tunneling, and compared them with the measur ed longitudinal section settlement curves. The settlement laws reflected by the two are consi stent, indicating that the numerical simulation is feasible in the calculation of surface settle ment.

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