Analysis of Ground Settlement in Metro Tunnel Construction with Shield Tunneling Method

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Abstract. With the continuous development of underground space, subway tunnel construction methods are constantly updated and developed. And shield tunnel method has become one the most common methods of subway tunnel construction. However, shield construction is often accompanied with the occurrence of surface subsidence. There may be a collapse of the surface when the surface settlement reaches a certain amount and the up buildings on the surface may be seriously influenced. The construction model was established based on FLAC3D software by using the engineering geological characteristic parameters of the study area and the observation data of ground subsidence during construction, which was compared and verified with the field monitoring value, and the subsidence was simulated and predicted. Using FLAC3D to establish a settlement prediction model for tunnel excavation and record the space-time changes of surface subsidence, it can better reflect the land subsidence situation and law in the horizontal and vertical directions of the axis of the subway tunnel.

1 Introduction

The rapid expansion of the urban population has maximized the use of roads, which has forced people to use underground space to reduce road traffic pressure, compared to vehicles such as cars and trains. The subway has the advantages of no pollution, no traffic jams, fast speed, large passenger capacity, comfortable and stable, and small area. Since the construction of the subway is a subsurface work, regardless of the depth and space of the excavation, it is inevitable that during the construction period, the stability of the soil will be disturbed, the original equilibrium state will be lost, and the original stress state of the formation will be changed, resulting in settlement and movement of the ground. The collapse of houses and other buildings has had a serious impact on economic and social development, especially tunnel construction in densely populated and densely populated urban areas. Therefore, it is necessary to analyze the subsidence of the tunnel in time. If measures are taken to support and reinforce the settlement before it occurs, this will reduce the probability of collapse.

There are many reasons for ground subsidence caused by shield construction subway tunnels. Both of them are crucial importance. The first is that during the construction period, the integrity of the surrounding rock and soil was destroyed, the stress was reduced, and the surrounding rock collapsed, resulting in formation loss\textsuperscript{[1]}. Ground subsidence. The second is that in a stratum with a large water content, the water pressure of the adjacent soil body will change during excavation, which will lead to the consolidation of the soil body, the volume will become smaller, and then the ground will settle\textsuperscript{[2]}. There are many factors that affect the size of settlement, which are not only related to the depth of...
tunnel excavation, construction technology, and the size of the excavation surface, but also relate to
the lithology and water content of the formation. In order to ensure the safety of construction and the
safety of pavement buildings, domestic and foreign experts and scholars have conducted data analysis
and research on a large number of subway tunnel settlement cases[3]. Some practical and accurate
forecasting methods are proposed: empirical formula method, model test method, analytical method,
numerical simulation method, etc.

With the development of science, computers have been basically used in various industries. With
the intervention of computers, people's work has become convenient, fast and accurate. Therefore,
numerical simulation is also an indispensable method for some complex geotechnical engineering[4].
The application of numerical simulation method is relatively extensive. The existing numerical
simulation methods include: finite difference method, finite element method, boundary element
method, etc. The method is flexible and changeable, and can simulate the excavation process, the
parameters between soil bodies, and the stress and displacement fields between soil bodies[5]. And the
predicted settlement is close to the actual settlement. The settlement of the ground during the
excavation of subway tunnel studied in this paper is mainly analyzed by numerical simulation.

2 Numerical simulation

2.1 FLAC3D sketch
Numerical analysis has become an important method used by engineering personnel in civil
engineering, geology, and water Conservancy to analyze geotechnical engineering problems. With the
increase of the current engineering, the Advancement of computer technology. Numerical analysis
shows a broad application prospect in geotechnical engineering. The numerical analysis of
gеotechnical engineering needs to be derived under the requirements of basic equations and boundary
conditions. The basic equations and boundary conditions are generally represented by differential
equations. FLAC3D is a software proposed by ITASCA in the 1980s. Many projects are using the
software and solving many difficult problems. FLAC3D software has now been applied to bridge
engineering, tunnel engineering, roadbed engineering, slope engineering and housing engineering in
gеotechnical engineering. I believe that in future projects, there will be more projects that will use
FLAC3D.

2.2 Model Parameter Settings
(1) The excavation part of this model uses the Null zero model, and other surrounding rocks and soils
use the Coulombmoer model.
(2) The simulation area of this project is 10m underground and belongs to shallow buried tunnels. Therefore, the stress received is mainly self-weighted stress.
(3) By setting up different buried depths, the maximum settlement at excavation 6M, 12m, and 18m
is simulated and analyzed. The physical parameters of stratigraphic lithology are shown in Table 1
(4) Failure to consider the effects of groundwater

| stratum      | b(m) | E(MPa) | G(MPa) | K(MPa) | ρ(g/cm) | μ    |
|--------------|------|--------|--------|--------|---------|------|
| Qml          | 1.2  | 3.12   | 1.16   | 3.47   | 1.75    | 0.35 |
| Qal          | 1.2  | 3.12   | 1.16   | 3.47   | 1.75    | 0.35 |
| Medium sand  | 3.0  | 18.0   | 7.09   | 13.04  | 1.68    | 0.27 |
| land pebble  | 3.0  | 18.0   | 7.09   | 13.04  | 1.68    | 0.27 |

Figure 1 is local magnification of shield tunnel 3d model.
3 Analysis of Simulation Results

3.1 Horizontal settlement analysis
The measured surface measurement of Y = 18m is used to observe the lateral ground settlement when the shield machine pushes in different positions.

From the figure 2 above, the following conclusions can be drawn:
(1) The maximum settlement occurs at the tunnel entrance. The closer we get to the tunnel, the greater the settlement.
(2) As the length of the shield tunneling increases, the width and depth of the settling tank have increased significantly, but the amplitude has become smaller and smaller. The settlement will also increase with the shield, but the increase will be smaller and smaller.

3.2 Analysis of longitudinal subsidence
(1) Figure 3 is a vertical displacement map at the time of excavation of 6m. From the figure, it can be seen that the maximum settlement occurred at the top of the tunnel and the settlement was 27.620 mm. The maximum uplift occurs at the bottom of the tunnel and the uplift is 19.703 mm.
Figure 3 Vertical displacement map during tunnel excavation at 6m

Figure 4 Vertical displacement map during tunnel excavation at 12m
Figure 5 is a vertical displacement map at the time of excavation of 18m. From the figure, it can be seen that the maximum settlement occurred at the top of the tunnel and the settlement was 35.458 mm. The maximum uplift occurs at the bottom of the tunnel and the uplift is 22.129 mm.

It can be seen from the figure 3–figure 5 that the settlement did not occur only on the positive side of the tunnel, and the soil around the tunnel also settled. This is due to the disturbance to the surrounding soil during the excavation process, which undermines the stability of the surrounding soil, resulting in its unstable settlement.

The following conclusions can be drawn from the above vertical displacement charts:

1. When the tunnel is excavated, the horizontal settlement of the tunnel is about 10m, and the settlement on both sides is basically similar. The settlement in excess of 10m is getting smaller and smaller until the settlement at 15M is basically zero.

2. Settlement will occur above the tunnel, and the closer to the tunnel, the greater the settlement. Due to grouting, uplift will occur below the tunnel, and the higher the amount of uplift near the tunnel mouth.

4 Conclusion

1. During the excavation process of the shield machine, the maximum settlement usually occurs at the top of the tunnel entrance, and the maximum uplift occurs at the bottom of the tunnel entrance. As the depth of excavation increases, the maximum settlement becomes larger and larger, but the increase will decrease. In the same state, the farther away from the tunnel, the smaller the settlement or uplift.

2. The thickness of the overburden has a considerable impact on the ground subsidence caused by the excavation of subway tunnels. As the thickness of overburden increases, the settlement decreases gradually.

3. Using FLAC3D to establish a settlement prediction model for tunnel excavation and record the space-time changes of surface subsidence, it can better reflect the land subsidence situation and law in the horizontal and vertical directions of the axis of the subway tunnel.
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