Study on Surface Settlement of Water-Rich Sand Pebble Bed Shield Construction in Nanchang

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Abstract. Water-rich sand pebble layer is a kind of common bad geology that is difficult to control and has great harm. It is easy to cause serious problems such as collapse, water inrush and sand burst, and surface collapse, etc. Through the analysis of shield tunnel of water-rich sand layer in Nanchang city, a numerical model was established to study the influence of different working conditions on surface settlement. The results show that the influence of boundary conditions should be considered more than other soil layers, the influence of different grouting pressures on the surface settlement of the sand and gravel soil layer is not obvious, the surface settlement caused by the water level reduction is greater than that caused by the water level reduction, and increasing the grouting pressure has a certain control effect on the ground settlement after precipitation.

Keywords. Water-rich sand pebble, shield tunnel, numerical simulation, surface subsidence.

1. Introduction

With the increasingly complex hydrogeological conditions of underground engineering, the control of adverse geological disasters has become an important research subject [1]. Water-rich sand layer is a kind of common bad geology that is difficult to control and has great harm. It is easy to cause serious problems such as collapse, water bursting and sand bursting, and surface collapse [2]. When shield tunneling in water-rich sand and pebble beds with rich water, strong permeability and poor stability, it is easy to cause formation loss and soil disturbance, and cause surface settlement [3]. Nanchang city of Jiangxi province has good groundwater storage conditions and abundant groundwater resources (as shown in figure 1). Compared with cohesive soil, the interaction and influence between sand and water are clearer, and the saturated sandy soil layer produces greater disaster suddenness and destruction [4]. Under the influence of groundwater, asthenoplastic state is obvious and has certain fluidity [5]. Water seepage signs are relatively unobvious with fast change rate, and have the characteristics of insignificant omen, short early warning and recognition time and ineffective prevention [6]. As a result, once a disaster occurs, it is likely to cause irreversible disasters (see figures 2 and 3).
The research on formation deformation law under the influence of shield tunnel construction mainly includes five methods: empirical formula [7], theoretical analysis [8], field measurement, model test and numerical calculation. Among them, numerical simulation method has been widely used in the analysis of formation deformation caused by tunnel excavation. Lee and Rowe [8] obtained the influence of soil anisotropy on formation deformation based on two-dimensional finite element model. Gao Jian et al. [9] used numerical methods to solve the distribution of seepage field. CAI Yi et al. [10] used FLAC3D software to analyze the deformation of cavitation stratum under the influence of shallow buried subway tunnel construction. Dai Xuan et al. [11] measured and simulated the longitudinal settlement of buildings induced by parallel side penetration of shield tunnel. In this paper, ABAQUS numerical simulation is used to simulate different working conditions under the geological conditions of the water-rich sand and pebble bed in Nanchang, and the law of surface subsidence deformation is analyzed.

2. Project Summary
In this paper, the section from Shida South Road Station to Pengjia Bridge Station of Nanchang Subway Line 1 is analyzed (as shown in figure 4). The diameter of the section tunnel is 6m, the inner diameter of the lining of the tube pieces is 5.4 m, the thickness of the tube pieces is 0.3 m, the longitudinal length is 1.2 m, and the concrete strength grade used for the tube pieces is C50. The buried depth of the middle line of the shield interval is about 19 m, and the soil layer and physical and mechanical indexes across the region are shown in Table 1. The shield tunneling in this section is mainly through sandy and gravel soil, and Nanchang subway is mostly close to the soil. The numerical simulation analysis of this section can provide reference value for the construction of other sections in the future.

Table 1. Physical property parameters of each soil layer.

| The soil type       | ρ /m³ | E MPa | μ  | e   | P kPa | C /°  | W%  | K cm/s  |
|---------------------|-------|-------|----|-----|-------|-------|-----|---------|
| Silty clay          | 1930  | 18    | 0.45| 0.81| 72.6  | 22.4  | 26.4| 3.85×10⁻⁸|
| Fine sand           | 1950  | 29    | 0.33| 0.75| 0     | 30    | 24.7| 5.21×10⁻⁴|
| In the coarse sand  | 1990  | 32    | 0.35| 0.71| 0     | 32    | 22.3| 6.01×10⁻³|
| Gravel sand         | 2020  | 33    | 0.32| 0.69| 0     | 35    | 22.4| 2.78×10⁻²|

Figure 1. Variation of groundwater level.  
Figure 2. Accident 1  
Figure 3. Accident 2  
Figure 4. Location map
3. The Establishment of Numerical Analysis Model

3.1. Model and Parameter Establishment

Established by using finite element software ABAQUS, analysis, finite element numerical analysis model of shield tunnel into fine sand, coarse sand, gravel, sand in typical soil layer in the establishment of the finite element model (see figure 5), Moore - coulomb model defines the soil mechanical parameters, in the process of shield tunneling, because of the shield tail void, overbreak of shield machine factors such as strata loss, shrinkage was simulated by interface [12].

![Figure 5 Analysis model.](image)

3.2. Model Validation

In the shield excavation simulation, a monitoring section is set up to measure the surface settlement curve, and the Peck formula [5] and the settlement curve are compared and analyzed at the same time. The settlement curve of the Peck is shown in figure 6, and the Peck formula is expressed as follows:

$$S(x) = S_{max} \exp\left(-\frac{x^2}{2I^2}\right)$$  \hspace{1cm} (1)

In the formula, $S(x)$ is the surface settlement at a position away from the central axis of the tunnel, $x$ is the horizontal distance between the calculation point and the tunnel center, $S_{max}$ is the maximum surface settlement at the center line of the tunnel, and $I$ is the width coefficient of the settlement trough. The observation surface of surface settlement trough was set up in the numerical model, and the settlement curve of shield tunnelling passing was compared with that of peck formula, as shown in figure 6. In order to conveniently evaluate whether the measured land settlement curve can be well described by the Gaussian curve, the width of the land settlement trough can also be obtained. Referring to the processing method of Burland J B [13], it can be seen that the method of changing Peck formula is feasible for regression analysis of measured point data. Combined with figure 6 and figure 7, it can be seen that the model can be fitted with Peck formula, and the model is verified to be feasible.

![Figure 6. Peck curve fitting comparison.](image)

![Figure 7. Data regression analysis.](image)
4. Numerical Simulation Condition
A surface settlement monitoring section is arranged at the 21st ring pipe plate of the model to simulate the surface settlement displacement under each working condition. A total of 4 groups of simulated conditions were designed as shown in table 2 (D is the tunnel diameter). Factor A is the simulated water level at the surface, and factor B is the simulated water level at 10m below the surface. The variation of water level is simulated according to the characteristics of geological conditions in Nanchang.

| Working condition | Turns the soil thickness | Shield-tail grouting pressure | The water |
|-------------------|--------------------------|-------------------------------|-----------|
| 1                 | H=3D                     | 0.2MPA                        | A         |
| 2                 | H=3D                     | 0.2MPA                        | B         |
| 3                 | H=3D                     | 0.4MPA                        | A         |
| 4                 | H=3D                     | 0.4MPA                        | B         |

5. Numerical Simulation Analysis

5.1. Surface Subsidence Model
The surface settlement is the largest near the central axis of the tunnel and decreases with the increase of distance from the central axis of the tunnel. However, there is still settlement disturbance outside the boundary in this model. Therefore, in the soft stratum of sandy soil, the boundary effect should be considered larger and the lateral settlement range should be extended.

5.2. Analysis of Shield Operation Condition
The surface settlement analysis of grouting pressure at 0.2 MPa and 0.4 MPa shows that (As shown in figure 8 and figure 9). The effect of large grouting pressure in the face of soil disturbance on controlling settlement of water-rich sand and gravel stratum is not obvious in shield tunnel tunneling monitoring.

The comparative analysis of surface settlement under the grouting pressure of 0.2 MPa and 0.4 MPa shows that. The surface settlement of shield tunneling through the monitoring surface is not obviously compared with that of no precipitation. As shown in figure 10 and figure 11. The settlement at the axis is larger than the precipitation (about 2 times), and the grouting pressure can control the settlement value under precipitation to a certain extent.
6. Conclusion

Based on four different working conditions, this paper establishes a sand and gravel soil layer model for surface settlement analysis, and draws the following conclusions: Compared with other soil layers, the soft soil layer rich in water and gravel should consider the influence of boundary conditions and widen the monitoring points. Groundwater seepage will form seepage force in front of tunnel excavation, thus increasing the support pressure needed to maintain the stability of excavation face. Compared with the unexcavated one, the excavated one is more disturbed at the same distance. Different grouting pressure has no obvious influence on surface settlement, and the surface settlement caused by water level reduction is larger than that caused by water level non-reduction. Increasing grouting pressure has certain control over land settlement after precipitation.

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