Research on Seepage Field of Fuzhou Metro Line 4 under The Guangminggang River Section Based on Numerical Simulation

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Abstract. With the increase of economy, traffic congestion is becoming increasingly serious. Underground rail transit projects such as subways and underwater tunnels have been vigorously developed. The seepage field of the Guangminggang section of Fuzhou Metro Line 4 and ABAQUS software was selected for numerical simulation analysis. Based on the simulated results of pore pressure, seepage velocity, and settlement around the tunnel, the effectiveness of grouting on stability of tunnel is discussed. Based on the simulated analysis results of the seepage field, the related construction control measures are proposed. The obtained results can provide technical reference for the construction of similar underwater tunnel.

Keywords: numerical simulation; seepage field; underwater tunnel; pore pressure; grouting

1 Introduction

There is a high risk of water seepage during the construction period of underground engineering. The calculation and analysis of seepage field is important for design and construction of underwater tunnels[1-2].

The external pore pressure of the lining and the seepage velocity are important parameter for determining the type of lining structure[3-4]. The disadvantage of the empirical formula method is that the calculation error caused by the differences in actual geological conditions, and excessive calculation error can cause engineering accidents. The theoretical derivation of the analytical formula method is rigorous, but the disadvantage is that the setting of assumptions has a significant impact on the calculation results[5-7]. Based on the mirror method, the Goodman formula simplified from the analytical formula for water inflow in deep buried tunnels[8] shows that the calculation results for water inflow in shallow buried tunnels or fractured media conditions are too large. The Raymer formula can only calculate the normal water inflow of the tunnel[9]. Hwang et al. transformed the problem of unstable and variable flow (decreasing water inflow) in tunnels into a stable and constant flow (well flow)

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problem solution, and obtained a semi analytical formula of tunnel water inflow under this condition[10].

The combination of numerical calculation method and physical simulation method can better demonstrate the evolution characteristics of seepage field, and can also analyze seepage field with complex boundary conditions and constitutive models. The article conducts numerical simulation research on the seepage field of an underwater tunnel with high permeability soil in the Guangminggang section of Fuzhou Metro Line 4. The research results can provide theoretical reference for similar subway construction projects.

2 Engineering introduction

The main geological layer that subway tunnels pass through is the medium and fine sand layer with mud. The strata with a relatively small proportion the tunnel pass through is mainly strongly weathered granite, silt mixed with sand, and silty clay. The surface water under the ground is well-developed, and the soil layer at the bottom of the riverbed has high permeability.

3 Numerical simulation analysis of seepage characteristics in typical tunnel sections

In order to study the stability of tunnels with rich water and muddy sand layers, the section between Guangminggang Station and Aofengzhou Station in the second section of Fuzhou Metro Line 4 was taken as the research object. ABAQUS software was used for this finite element analysis.

3.1 Typical geometric model of tunnel

In the construction process of the geometric model, the soil was considered as a semi infinite space. The calculation range selected for establishing the geometric model of the tunnel in this article is equal to the actual thickness of the upper overlying rock and soil layer. As shown in Figure 1, a seepage field analysis was conducted on actual tunnel engineering based on this model.

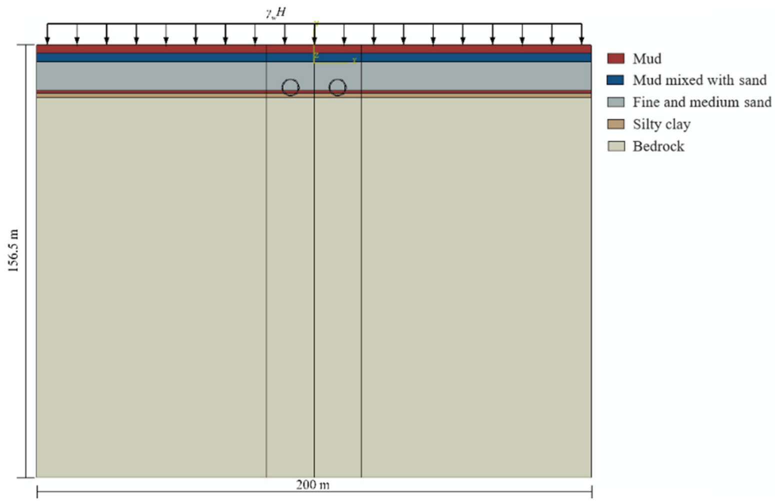

Fig. 1. Typical geometric model of underwater tunnel.

3.2 Constitutive model and material parameters

The materials include surrounding rock, grouting layer, and lining. The Moh-Coulomb constitutive model is used for analysis of the surrounding rock and grouting layer, while the elastic constitutive model is used for analysis of the lining. The physical and mechanical parameters of the strata are shown in Table 1.

Table 1. Physical and mechanical parameters of the strata.

Stratum lithology	Tickness (m)	Void ratio	porosity	Permeability coefficient(m/d)	gravity	Elastic modulus(Mpa)	Cohesive force(kpa)	internal friction angle(°)	Poisson's ratio
Mud	3	1.596	0.61	0.0005	16.3	4.5	14	18	0.3
Mud mixed with sand	3	1.667	0.63	0.01	16.1	6	20	16	0.4
Fine and medium sand	10.5	0.65	0.39	30	18.5	8	4	24	0.28
Mud	0.87	1.596	0.61	0.0005	16.3	4.5	14	18	0.3
Silty clay	1.54	0.789	0.44	0.04	19.1	13	26.8	13.2	0.35
Bedrock	137.59	0.4	0.29	0.7	19	80	30	28	0.25

When the geometric model of the tunnel in this article was meshed, the four-node plane strain solid element with pore pressure (CPE4P) was used for simulating. The horizontal displacement of the boundaries on both sides and the horizontal and vertical displacement of the boundaries on the bottom are constrained. The pore pressure on both sides of the boundary is fixed, which is a fixed head boundary, and an impermeable boundary is set on the bottom.

3.3 Distribution characteristics of seepage field in typical underwater tunnel

The article simulated and analyzed the seepage and displacement fields of tunnels with only lining and grouting layer, respectively.

3.3.1 Distribution characteristics of pore pressure.

Figure 2 shows the distribution of pore pressure around the tunnel with only lining. Meanwhile, the water pressure at the arch crown is 0.141 MPa, and the pore pressure at the inverted arch is 0.202 MPa. Figure 3 shows the distribution of pore pressure around the tunnel reinforced by grouting layer with the thickness of 2 m. The pore pressure on the vault of the tunnel after grouting is 0.095 MPa, and the pore pressure on the inverted arch is 0.148 MPa. In summary, grouting measures can reduce the external pore pressure on the lining to a certain degree. Under the conditions of the article, as grouting measures was taken within a thickness of 2m around the tunnel, the pore pressure on the vault of the tunnel decreased by 37%, and the pore pressure on the inverted arch decreased by 27%.

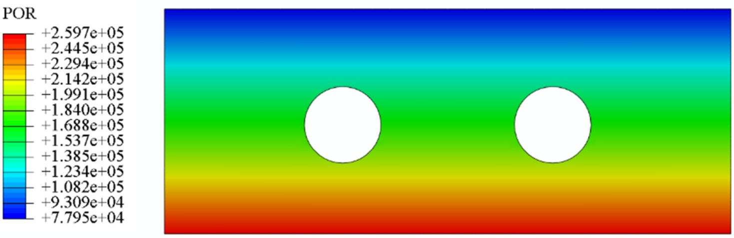

Fig. 2. Pore pressure distribution (Without grouting).

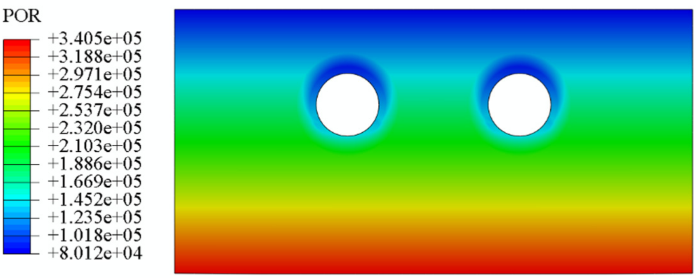

Fig. 3. Pore pressure distribution (Grouting layer with the thickness of 2 m).

Figure 4 shows the distribution of seepage velocity around the tunnel without grouting. It can be seen from the figure that the seepage velocity near the inverted arch is the highest, which is 8.75E-9 m/s. Figure 5 shows the distribution of seepage velocity around the tunnel with grouting layer, as the thickness of grouting layer is 2 m. After grouting measures, the seepage velocity near the inverted arch is the highest, which is 6.52E-9 m/s. In summary, it can be seen that the seepage velocity around the tunnel decreases after grouting measures. In the engineering condition of the article, grouting layer with the thickness of 2m can reduce the seepage velocity around the tunnel by 26%.

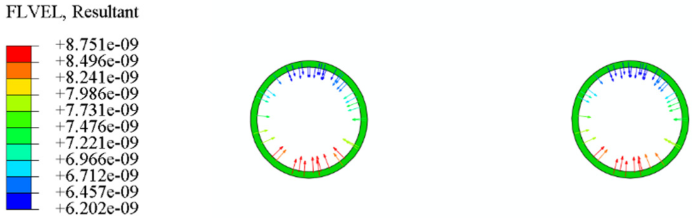

Fig. 4. Distribution of seepage velocity (Without grouting).

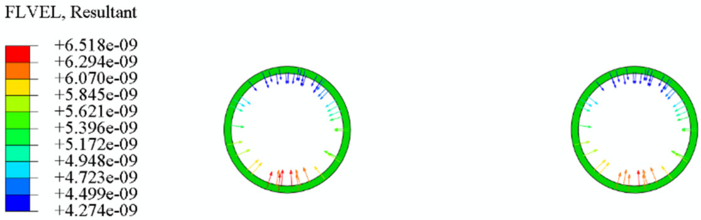

Fig. 5. Distribution of seepage velocity (Grouting layer with the thickness of 2m).

Figure 6 shows the distribution of seepage flow around the tunnel without grouting. It can be seen from the figure that the seepage flow near the inverted arch is the highest, which is 2.737E-9 m3/s. Figure 7 shows the distribution of seepage flow around the tunnel with grouting layer, as the thickness of grouting layer is 2 m. After grouting measures, the seepage flow near the inverted arch is the highest, which is 2.008E-9 m3/s. In summary, it can be seen that the seepage flow around the tunnel decreases with grouting layer. In the engineering condition of the article, grouting layer with the thickness of 2m can reduce the seepage flow around the tunnel by 27%.

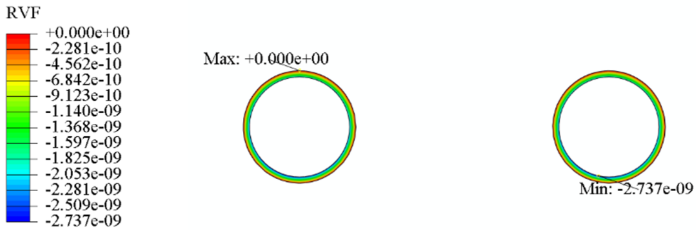

Fig. 6. Distribution of seepage flow (Without grouting).

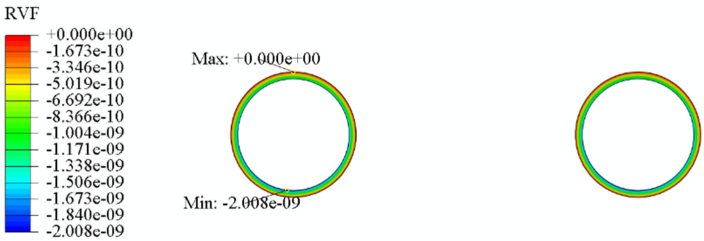

Fig. 7. Distribution of seepage flow (Grouting layer with the thickness of 2m).

3.3.2 Distribution characteristics of displacement.

Figure 8 shows the distribution of displacement around the arch crown without grouting. At this time, the maximum settlement on the arch crown is about 147.8 mm. Figure 9 shows the distribution of displacement around the arch crown with grouting layer, as the thickness of grouting layer is 2 m. The maximum settlement on the arch crown is about 54.0. It can be concluded that grouting measure can effectively reduce the settlement on the arch down of the tunnel. In the engineering condition of the article, grouting layer with the thickness of 2 m can reduce the amplitude of settlement on the arch down of the tunnel by 64%.

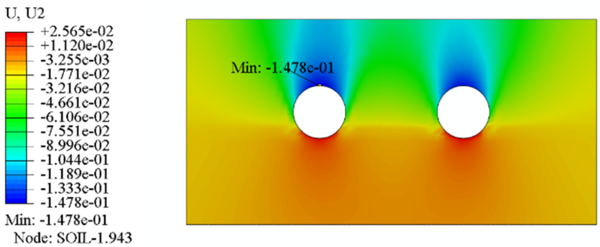

Fig. 8. Distribution of displacement around the arch crown (Without grouting).

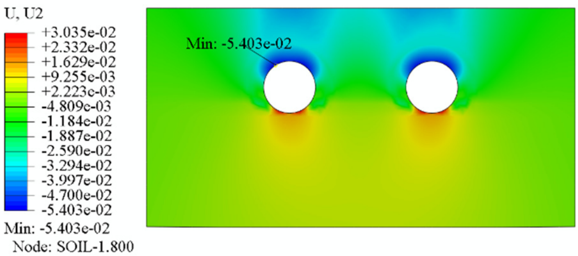

Fig. 9. Distribution of displacement around the arch crown (Grouting layer with the thickness of 2m).

In summary, grouting measures can effectively reduce the seepage inflow and the pore pressure of the tunnel, which can also reduce the settlement of the tunnel effectively. During the construction process, grouting measures can be used to reduce the risk of water inrush and settlement collapse in tunnels, which helps to ensure the safety and orderly construction of engineering projects.

4 Conclusions

The article is based on the engineering background of the section across the Guangminggang River in Fuzhou Metro Line 4. Seepage field and displacement field of the characteristic section across the river is simulated, and the conclusion is as follows: compared with tunnel without grouting layer, appropriate grouting measures can reduce the external pore pressure of the lining to a certain extent, as well as reduce the seepage velocity and the seepage flow around the tunnel. It can also reduce the settlement on the arch crown of the tunnel effectively, which can ensure the safety during the construction of engineering projects. During the construction of underwater shield tunneling, attention should be paid to the changes in water level of the river and safety and progress of construction should be controlled strictly by timely feedback on measurement results.

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