Research on Deformation Control of Underpass River in Shield Tunnel Based on Orthogonal Test Method

Junhai Han[1*], Jinlong Wang[2], Sheng Wang[2], Chaojun Mao[2], Ruicai Ju[2], Ping Yang[2]

[1] Qinghai Province traffic construction management Co., Ltd, Xi'an, China
[2] CCCC No.3 Engineering Co., Ltd, Beijing, China

* Corresponding author's e-mail address: 664830889@qq.com

Abstract. During the construction of shield tunnel under the river, the shield machine digs in the water-rich sand layer with rich water content and strong permeability, so it is difficult to control the disturbance and deformation of the stratum during the construction. In this paper, based on the shield tunnel under the river, the deformation caused by the shield tunnel under the river is studied and the safety control measures are put forward, a three-dimensional fluid-structure coupling model was established to study the sensitivity of soil silo pressure, grouting pressure and grouting layer thickness to ground deformation, and the main excavation parameters were determined. The results show that the main and secondary order of influencing sensitivity are grouting pressure, grouting layer thickness and soil bin pressure. Therefore, in the construction of river shield, the changes of synchronous grouting pressure and grouting amount should be controlled preferentially according to monitoring data and parameter feedback, and timely optimization and adjustment should be made.

Keywords: Shield Tunnel; Cross River; Muck Improvement; Numerical Simulation; Strata Deformation

1 INTRODUCTION

As more and more cities build underground tunnels for various purposes, it is inevitable that the shield tunnel penetrates buildings, existing tunnels, railway lines and various rivers and lakes. Shield tunnel is mainly located in confined water and fissure water, which is prone to water seepage. Due to large water pressure, water leakage and sand flow will be caused, and soil erosion will further aggravate tunnel deformation, tunnel water seepage and pipe segment damage, etc., resulting in high construction risk.

At present, most studies of shield tunnel focus on underpass structures, Bridges, existing tunnels and existing pipelines [1-7]. The research on the construction control technology related to the small diameter shield crossing river is still insufficient. Generally, the turning radius of small-diameter shield tunnel is smaller, and the smaller the curve radius, the longer the shield, the greater the deviation correction. If the construction process is not properly controlled, there will be problems such as fragmenta-

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tion, jamming and hysteresis, which will increase the difficulty of construction and surface settlement control. Therefore, the research conclusions of this paper can supplement the relevant theories and engineering practical experience.

2 NUMERICAL SIMULATION

2.1 Brief Introduction of Finite Difference Model

The length of the river tunnel is 480m. The earth pressure balance shield machine is used for construction. The outer diameter of the shield is 4m, the inner diameter is 3.5m, the width of the segment ring is 1.2m, and the thickness of the segment is 0.25m.

In this paper, FLAC 3D finite difference numerical simulation software is used to establish a three-dimensional calculation model for the small diameter shield underpass river project. The size of the calculation model is 48m×52m×35m.The upper surface of the model is a free surface, and 40kPa vertical uniform load is applied to the upper surface to simulate the river load. FLAC 3D has a powerful seepage calculation function, which can solve the seepage problem of full saturation and groundwater change. The three-dimensional fluid-solid coupling calculation model is shown in Figure 1.

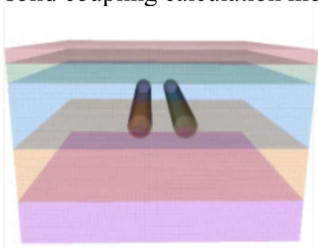


Fig. 1. Perspective of 3D fluid-structure interaction model

The soil is a solid unit, and the physical and mechanical parameters of the soil layer are obtained based on engineering geological prospecting data by adopting Moore-Coulomb constitutive relationship, as shown in Table 1.

Table 1. Physical and mechanical parameters of soil layer

Name	thickness (m)	density (kg/m^3)	bulk modulus (MPa)	shear modulus (MPa)	c(kPa)	f(°)	permeability coefficient (m/d)
fine sand	2	1940	9.33	5.60	0.8	29	25
silty clay	4	1910	10	3.33	37	19.2	0.5
medium sand	11	1960	10.9	6.85	0.6	31	30
coarse sand	10	1980	11.9	8.2	0.3	33	35
boulder	8	2010	25.64	16.13	0.1	34	45

The layers of shield shell, pipe segment and grouting are also solid units and adopt elastic constitutive relation. Combined with the above empirical theory, the length of the shield in this numerical simulation is 7.2m and the width of the 6-ring tube is 7.2m. Parameters of shield machine and lining materials are shown in Table 2.

Table 2. Shield machine and lining material parameters

name	density (kg/m^3)	volume modulus (MPa)	shear modulus (MPa)
scutellum	7800	1.11×10^5	8.33×10^4
segment	2500	1.92×10^4	1.44×10^4
grouting layer	1890	56.2	38.7

2.2 Orthogonal Test Numerical Simulation Condition Design

In order to study the influence degree of the construction on the formation and ground deformation when the shield tunneling undergoes the river, three influencing factors, soil bin pressure, grouting pressure and grouting layer thickness, were selected, and four different levels were taken for each factor. The soil bin pressure (A) was 0.08, 0.11, 0.14 and 0.17Mpa, the grouting pressure (B) was 0.10, 0.15, 0.20 and 0.25Mpa, and the grouting layer thickness (C) was 0.12, 0.16, 0.20 and 0.24Mpa. That is, the orthogonal test of three factors and four levels is used to simulate different construction conditions. The orthogonal test table $L_{16}(4^3)$ was selected to simulate the working conditions according to the actual engineering conditions, and there were 16 kinds of simulated working conditions.

3 ANALYSIS OF ORTHOGONAL EXPERIMENTAL RESULTS

The main quality evaluation indexes of the river under the small-diameter shield tunnel include the maximum surface settlement value, the maximum vertical displacement value of the formation and the maximum horizontal displacement value of the formation. According to the orthogonal test, the above evaluation indicators were numerically simulated and measured, and the results were shown in Table 3.

Table 3. Orthogonal test result

number	Max surface settlement/m	Max vertical displacement of formation/m	Max horizontal displacement of formation/m	number	Max surface settlement/m	Max vertical displacement of formation/m	Max horizontal displacement of formation/m
1	13.23	13.88	2.52	9	14.75	15.42	2.80
2	11.56	12.29	2.09	10	12.32	13.00	2.23
3	11.43	12.11	2.57	11	11.27	11.89	2.56

4	10.83	11.29	2.15	12	10.60	11.38	3.34
5	11.02	11.63	2.29	13	12.27	12.81	2.24
6	11.60	12.35	2.69	14	11.60	12.20	2.14
7	10.82	11.34	2.15	15	11.08	11.82	2.50
8	12.98	13.67	2.68	16	10.72	11.49	3.44

3.1 Analysis of Vertical Displacement

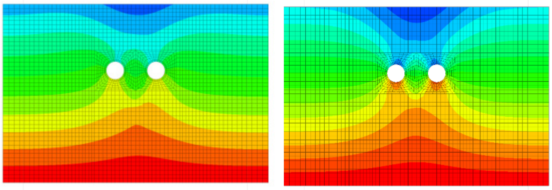


Fig. 2. Vertical displacement cloud image of stratum in working Condition 12 and 9

It can be seen from Figure 2 that the vertical deformation of the strata above the tunnel presents concave subsidence tanks with large middle and small sides, which conforms to the classic peck formula.

3.2 Horizontal Displacement Analysis of Strata

It can be seen from Figure 3 that the maximum horizontal displacement of the stratum basically occurs at the outer arch waist of the left and right tunnels, and the displacement at the outer arch waist of the two tunnels is almost the same. Compared with the vertical displacement, the horizontal displacement value is smaller, which is because the shield segment and the grouting material have certain stiffness and different forces.

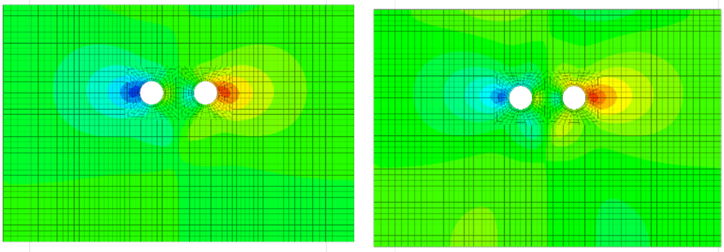


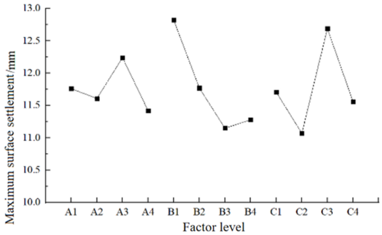
Fig. 3. Formation horizontal displacement cloud image in Condition 16 and 2

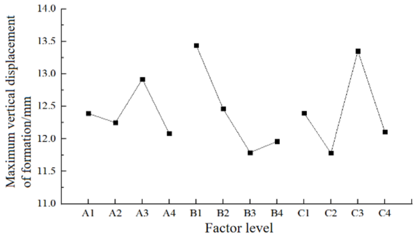
3.3 Test Results Polar Variance Analysis

In this paper, the calculation results of each simulated construction condition are sorted out, and the maximum surface settlement, maximum vertical displacement and maximum horizontal displacement of the formation are respectively taken as evaluation indexes. The range analysis method is used to evaluate the sensitivity of three construction parameters, namely, soil bin pressure, grouting pressure and grouting layer thickness, to the above indexes. The range analysis results of each construction parameter are shown in Figure 4.

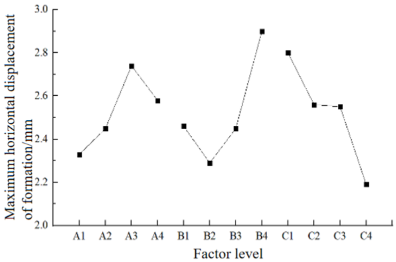
It can be seen from Figure 4 that the main and secondary influencing factors of river shield tunneling construction on the surface settlement are grouting pressure > grouting layer thickness > soil bin pressure. Therefore, from the perspective of controlling the surface settlement, the construction parameters of the shield tunnel in this project are that the grouting pressure is controlled at about 0.2MPa, the thickness of the grouting layer is 0.16m, and the pressure of the soil bin is controlled at about 0.17MPa.

The main and secondary factors affecting vertical displacement are grouting pressure > grouting layer thickness > soil bin pressure. Therefore, from the perspective of controlling the vertical displacement of strata, the construction parameters of the shield tunnel in this project are that the grouting pressure should be controlled at about 0.2MPa, the thickness of the grouting layer should be 0.16m, and the pressure of the soil bin should be controlled at about 0.17MPa.





a.Max surface settlement b. Max vertical displacement curve



c. Max horizontal displacement curve

Fig. 4. Range analysis effect curve

The main and secondary factors affecting the horizontal displacement of the formation are grouting pressure = grouting layer thickness > soil bin pressure. Therefore, from the perspective of controlling the horizontal displacement of strata, the construction parameters of the shield tunnel in this project are that the grouting pressure should be controlled at about 0.15MPa, the thickness of the grouting layer should be 0.24m, and the pressure of the soil bin should be controlled at about 0.08MPa.

It can be seen from Table 4 that the grouting pressure has the greatest influence on the maximum surface settlement value. For the maximum vertical displacement of the formation, the three influence levels are not significant. For the horizontal displacement of strata, the influence of grouting pressure and thickness of grouting layer is very significant, but the influence of soil bin pressure is not significant. The conclusions obtained by the variance analysis and range analysis are basically matched, which mutually verify the accuracy of the analysis method.

Table 4. Analysis of variance table

Evaluation index	freedom	A		B		C	
		S_T	F	S_T	F	S_T	F
Max surface settlement/m	3	1.467	0.601	1.593	0.595	0.354	1.339
Max vertical displacement of formation/m	3	6.874	2.815	6.569	2.452	0.837	3.169
Max horizontal displacement of formation/m	3	5.563	2.278	5.482	2.046	0.756	2.863

Note: $\alpha = 0.15$, when $F > F_{0.15}(3,6)$,the effect is considered significant. When $F < F_{0.15}(3,6)$, thought that the effect was not significant. In other cases, the influence of factors was not significant.

4 CONCLUSION

In this paper, a three-dimensional model of fluid-structure coupling is established by using orthogonal test method and numerical simulation method. The following conclusions are drawn:

- The maximum vertical displacement of the formation is 15.42mm, the maximum horizontal displacement is 3.44mm, and the maximum surface settlement is 14.75mm. The maximum vertical displacement of the formation basically occurs at the arch top of the two tunnels or the center of the concave settling trough, and the maximum horizontal displacement basically occurs at the outer arch waist of the left and right tunnels.
- When using three evaluation indicators, the sensitivity order of the three factors is grouting pressure, grouting layer thickness, and soil chamber pressure.
- The excavation parameters of the river under the shield tunneling are about 0.17MPa, 0.20MPa and 0.16m thickness of the grouting layer.

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