Journal of Civil Engineering and Urban Planning (2024)
Clausius Scientific Press, Canada
DOI: 10.23977/jceup.2024.060225
ISSN 2616-3969 Vol. 6 Num. 2

Study on Stress and Strain Response Mechanism of Tunnel Excavation under Small Net Distance

Fei Liang*

Guizhou Transportation Planning, Survey and Design Research Institute Co., Ltd, Guiyang, Guizhou, 550081, China
520142364@qq.com
**Corresponding author*

Keywords: Small Net Distance, Tunne, Grouting Reinforcement Method, Bench Method, MJS Method

Abstract: In order to protect the safety and normal operation of the existing tunnel, and to ensure the safety of the tunnel excavation construction and the later operation of the existing tunnel under the small net distance, the stress field and deformation response mechanism in the excavation process of the small net distance are studied to provide the decision basis for the design and construction. Using the numerical simulation method and theoretical calculation analysis method compared grouting reinforcement method, bench method and MJS method (comprehensive high pressure injection method) three kinds of reinforcement after the existing tunnel, small net distance through the existing tunnel shield process stress field and deformation mechanism, and the feasibility of three method, safety and economy of comparative analysis. The results show that the deformation of the grouting reinforcement method does not meet the specification requirements, the MJS method deformation 3.387mm, the bench method deformation is 9.754mm, the deformation meet the specification requirements, but the MJS method cost is twice the bench method, so the principle of safety and economic feasibility, suggest the existing tunnel reinforcement before the tunnel excavation.

1. Introduction

The net distance between tunnels has a significant impact on the stress and deformation of the tunnel advance and back tunnel, especially for small net distance tunnels. In view of the influence degree of net distance between tunnels is restricted by surrounding rock grade, tunnel length, tunnel buried depth and other factors, there is no strict and unified analysis standard on net distance influence in the international academic circle.

As of December 31,2022,53 cities in 31 provinces (autonomous regions and municipalities) and the Production and Construction Corps had opened 290 urban rail transit lines, with a total mileage of 9,584 kilometers and 5,609 stations. In 2022, the average daily throughput of China's subway has reached 12 million people, with a peak day of 40 million people, equivalent to the population of a medium-sized country[1]. Subway has also become a normal national travel, and the safety performance is also quite high. It can be seen that in less than 50 years, China's subway has developed very rapidly.

With the more and more intensive subway construction, the subway shield construction often runs through the existing tunnel condition. For example, Li Jianshe (2014) carried out the research on the key technology of the shield tunnel of Shenzhen Metro Line 11 through the tunnel of the existing line [2]; Yang Kun (2015) systematically studied the influence of the underpass tunnel on the existing subway stations [3]; Xia Jinchun (2017) studied the risk control measures of orthogonal tunnel construction [4]; Zhang Chao (2018) carried out a study on the impact of the small net distance expansion of the subway shield tunnel [5]; Li Chunying (2020) discusses the construction technology of subway tunnel running through existing stations in close distance [6]; Yang Mancang (2021) studied the impact of the new tunnel underpass construction on the existing tunnel [7]; Yang Hui (2022) shield tunnel close down impact on existing operational tunnel [8].. thus, There are more and more conditions under existing tunnels [9~12], Especially under the small net distance conditions, The safety protection of the existing tunnels is extremely important.

In this paper in Changsha city rail transit 1 line in xiangfu road tunnel as the research object, simulated the grouting reinforcement method, bench method and MJS method (comprehensive high pressure injection method) three kinds of construction method after the existing tunnel, small net distance under the existing tunnel shield process stress field and deformation mechanism, and the three method feasibility and safety and economy, to provide security for Changsha city rail transit line 1 construction.

2. Project Overview

2.1 Project Overview

The total length of Xiangfu Road tunnel is about 2150m, with six lanes in both directions and about 29.2m wide. The tunnel is constructed by open excavation and smooth construction method. The dark buried section of the main structure is a double-hole rectangular cast-in-place concrete structure (single hole and three lanes), and the open section is a U-shaped structure. The maximum soil cover of Xiangfu Road tunnel is about 3.1m, and the maximum buried depth is about 11.3m. In addition, the east and west sides of the tunnel are equipped with external auxiliary rooms, and the pump room is about 2.5m low. The bottom plate of the tunnel structure is mainly located in & lt; 1-2 & gt; filling soil, & lt; 4-14 & gt; pebble soil layer. The envelope structure adopts 800 thick underground continuous wall, 600 thick underground continuous wall, D800@1000 rotary excavation pile or slope, open excavation and smooth construction, partial semi-reverse cover excavation construction. At the entrance of Furong Road, crossing the Youyi Road station of Line 1 and provincial government station (Figure 1), there are many important buildings around Xiangfu Road, the northwest quadrant is the Hunan Provincial Government, the southwest quadrant is the People's Government of Tianxin District, the southeast quadrant is the Star City Rongcheng Complex Building, and the northeast quadrant is the Xiangfu Cultural Park, etc.

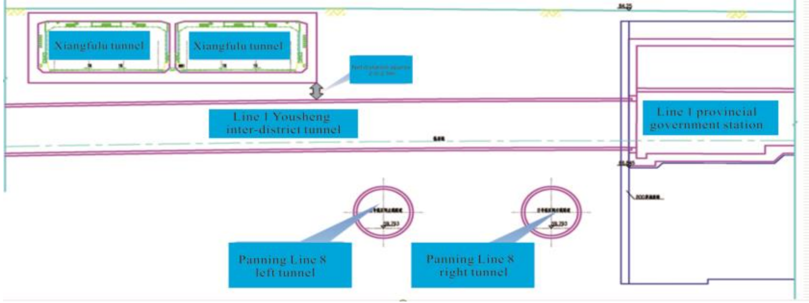

Figure 1: Profile diagram between Xiangfu Road tunnel and planned subway tunnel

The nearest distance of Xiangfu Road tunnel is about 2m from the provincial tunnel of Line 1.

2.2 Engineering Geological Conditions

This site belongs to the Xiangjiang River ~V terrace landform, and the underlying bedrock is the tertiary purple red siltstone, with open terrain, slightly undulating and a ground elevation of 83.07~90.09m.

The shield tunnel body is mainly located in the round gravel layer and the coarse sand layer, and between the Xiangfu Road tunnel and the shield tunnel are mainly located in the round gravel layer (see Figure 2). Coarse sand layer, saturated, medium to dense, mainly quartz coarse sand particles. Round gravel layer, medium dense, locally dense, quartz, particle size is generally 10-20mm. Pebble layer, saturated, medium to dense, quartz, particle size is generally 20-40mm. Normal water level is about 7m underground.

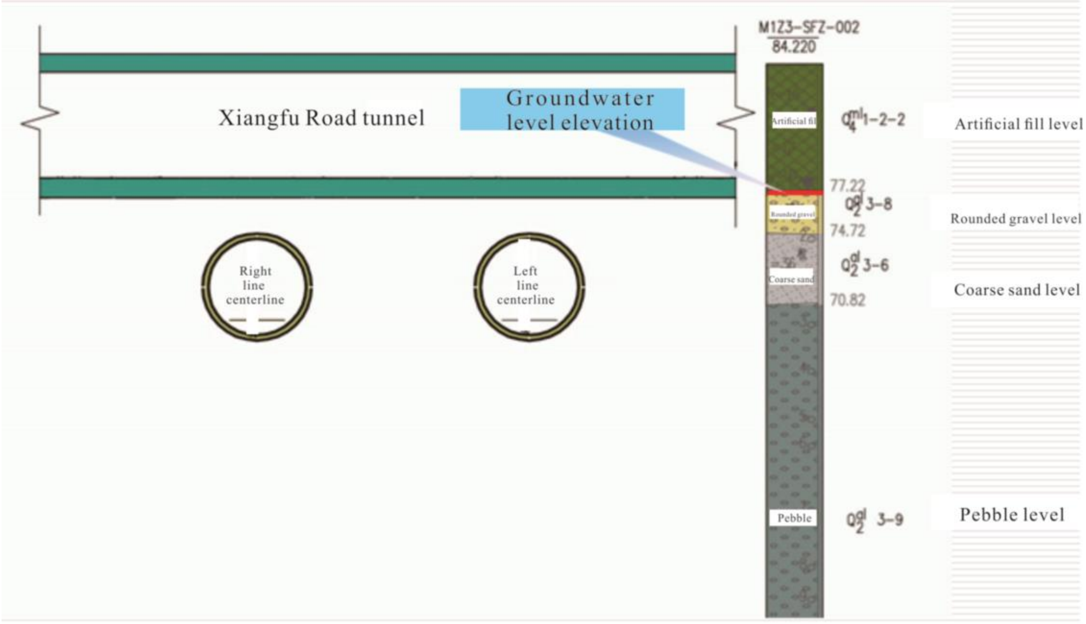

Figure 2: Geological profile of Xiangfu Road Tunnel and planned Subway Tunnel

3. Modeling and Analysis

In order to study the existing tunnel by grouting method, bench method, construction method and MJS method), and the stress field and deformation mechanism of the shield tunnel after small net distance, Midas / GTS is used for numerical simulation and calculation analysis.

3.1 Model Building

The whole model size is 50m 90m, the depth is 40m, the top of the tunnel is 9m from the ground and 2m from the bottom of the excavated foundation pit. In the calculation model, the formation, pull-out pile and bottom plate are simulated by solid unit, and the tunnel is simulated by shell unit (shown in Figure 3 and Figure 4).

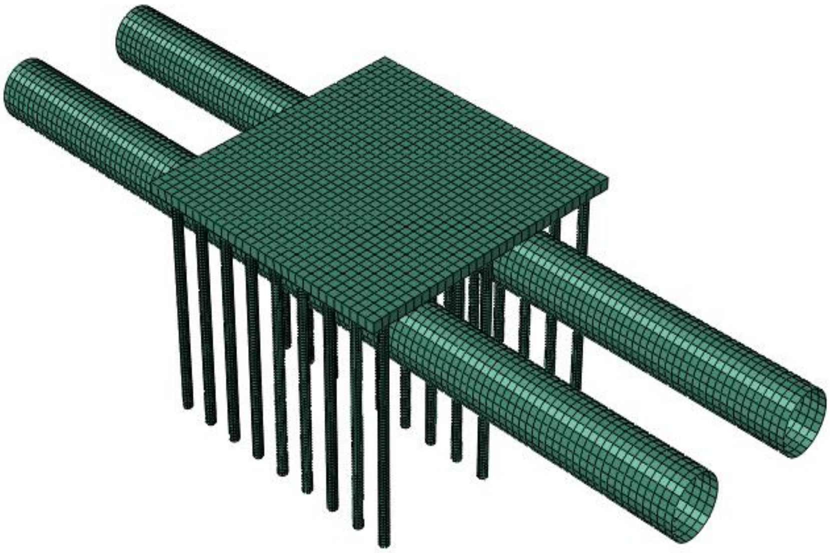

Figure 3: Bench method model

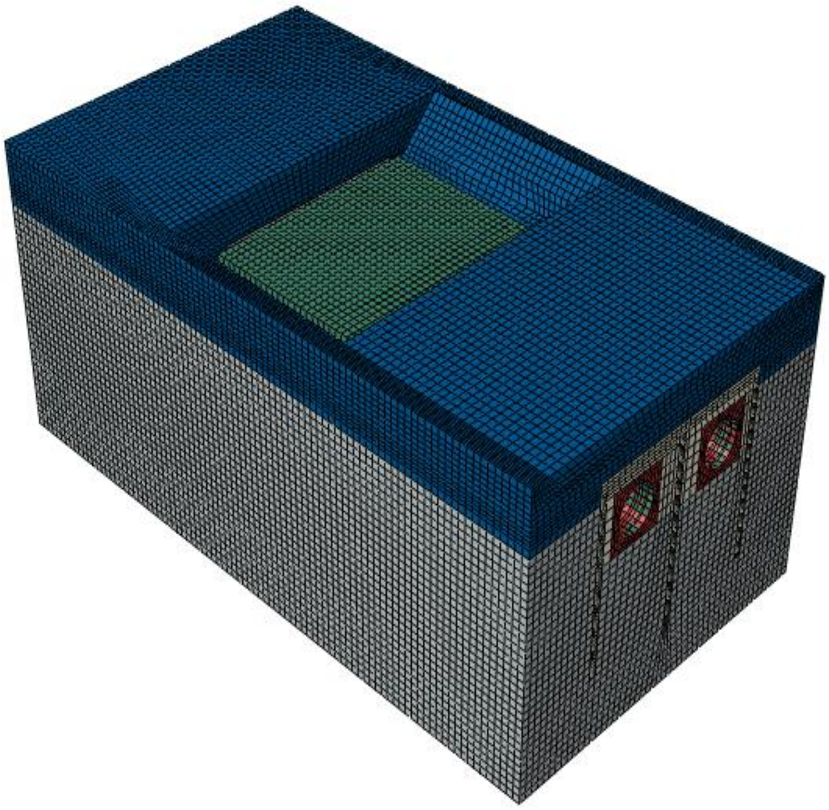

Figure 4: Grouting method and MSJ engineering models

3.2 Calculation Parameters

(1) Calculation parameters of rock and soil mass (shown in Table 1)

Table 1: Geotechnical physical and mechanical parameters

Soil layer and number	severe γ	shear strength				modulus of compression Es0.1-0.2	modulus of resilience Ed	Osmotic coefficient K	The standard value of the extreme lateral resistance of the bored piles q_{sik}
		Quick cut		Firing fast shear					
		c_q	φ_q	c_{cq}	φ_{cq}				
	KN/m^3	kPa	linear measure	kPa	linear measure	MPa	MPa	m/d	kPa
<1-3> plain filling	20.4	15	10	16	12	3	/	0.5	0.30#
<4-5> silty clay	19.8	35	14	40	17	8	33	0.002	80
<4-9> fine sand	21.2	/	30	/	/	15(Deformation modulus)	/	10	65
<4-11>coarse	21.5	/	32	/	/	20(Deformation modulus)	/	25	90
<4-14>pebble	22.5	/	45	/	/	30(Deformation modulus)	/	50	170
<5-1>fully weathered argillaceous siltstone	20.2	35	15	40	19	10	33	0.004	80
<5-2>fully weathered argillaceous siltstone	22.5	/	35	45	25	50(Deformation modulus)	/	0.004	140

(2) MSJ process parameters
MSJ test pile parameters proposed:
1) Design pile diameter: 2.0m;
2) Design lap thickness: <400mm;
3) Grouting pressure is 40MPa;
4) Air pressure: 0.7MPa;
5) Internal ground pressure control range: 0.10~0.30MPa;
6) cement slurry dosage: about 2m3 / / m;
7) Return speed: 15min / m;
8) Rotary speed: 4 r/min;
9) Lift step distance: 25mm;
10) Serous flow rate: 85 ~ 100 L/min.

3.3 Calculation Results and Analysis

According to the technical Specification for Safety Protection of Urban Rail Transit Structure (CJJT 202-2013), the additional load on the outer wall of the tunnel structure should not be more than 20 kpa, and the tunnel settlement and radial convergence value should be less than 20mm.

(1)Analysis of the stress state of the bench method

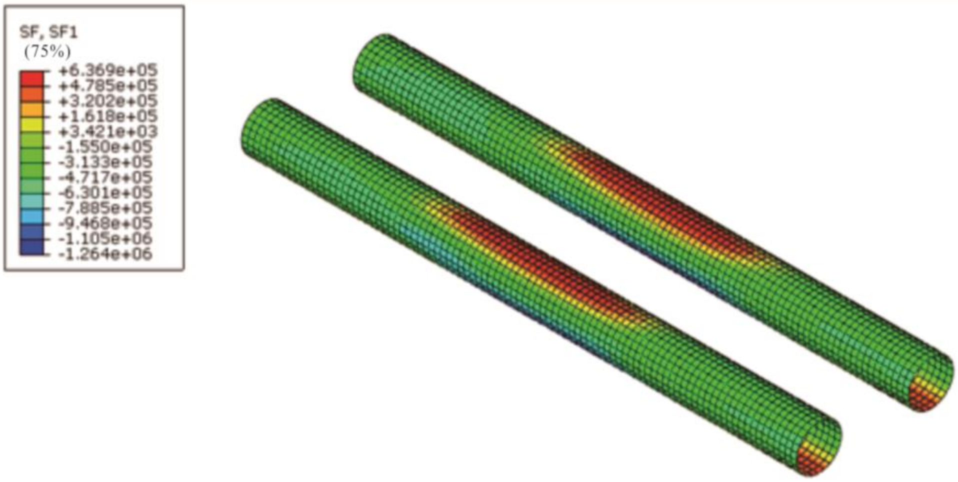

Figure 5: Cloud diagram of axial force (kN) during the construction process of section segments

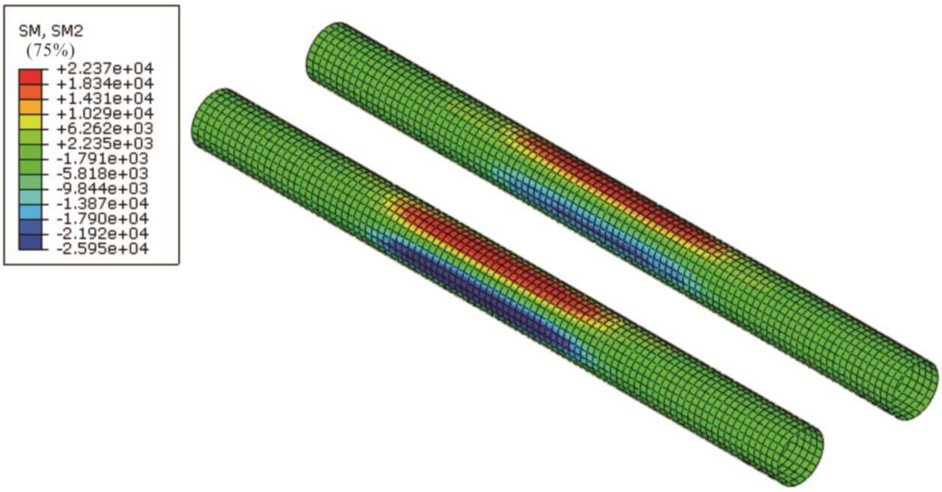

Figure 6: Cloud bending moment (kNm) of section segment construction

The calculation results show that the maximum axial force of the bench method is 637 kN and the maximum bending moment is 22.4kNm (shown in Figure 5 and Figure 6).

(2) Analysis of the deformation state of the bench method

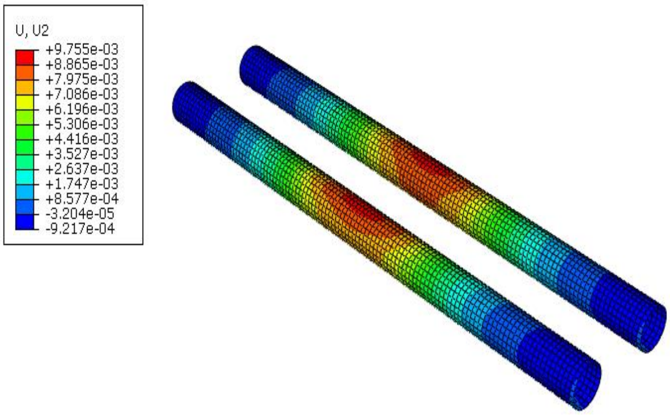

Figure 7: Vertical deformation cloud of shield

The calculation results show that the maximum settlement deformation of the bench method is 9.754mm (shown in Figure 7).

(3) Cloud diagram of stress status by MSJ method (shown in Figure 8)

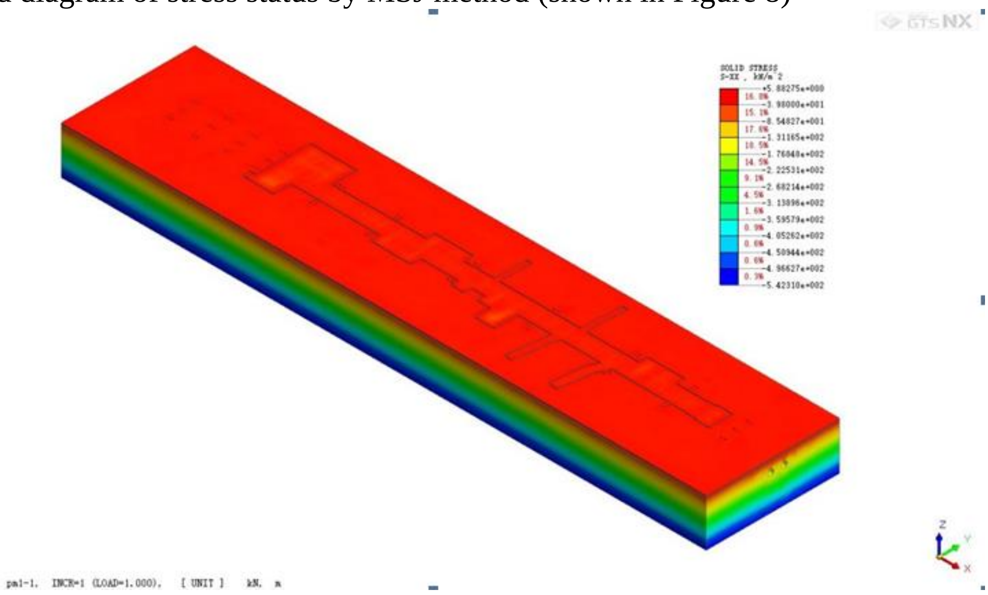

Figure 8: Vertical deformation cloud diagram of interval shield tunneling

(4) Cloud map of MJS work method deformation state

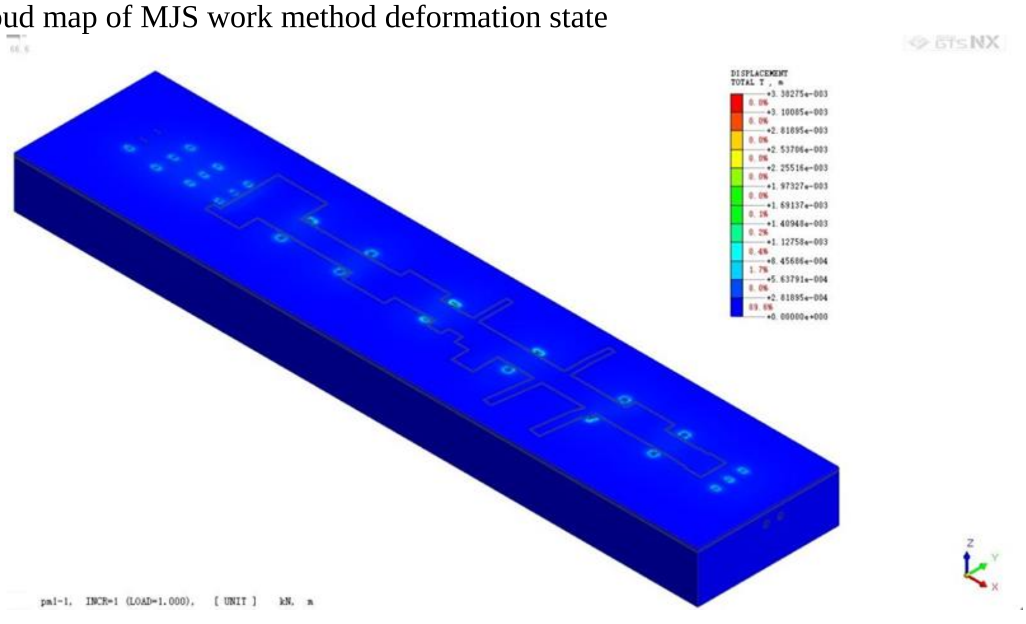

Figure 9: The maximum settlement deformation

The calculation results show that the maximum settlement deformation of MJS method is 3.387mm (shown in Figure 9).

(5) Grouting and reinforcement method

Because the grouting reinforcement is to change the pore ratio and the strength of the soil, the elastic settlement deformation formula is used to calculate the settlement deformation calculation of the grouting reinforcement method:

$$\triangle h=E\times\triangle b/2\times[1-(1-v^2)/Epl] \quad (1)$$

Where: $\triangle h$ is sedimentation amount, E is the elastic modulus, $\triangle b / 2$ is the drop value of the loading surface, v is Poisson's ratio, and Epl is the equivalent elastic modulus.

According to the calculation of Table 1, the vertical deformation of the existing tunnel in tunnel excavation is: 22.79mm.

4. Comparative Analysis

4.1 Comparative Analysis of Safety and Feasibility

After numerical simulation and theoretical calculation and analysis, the statistics are shown below (shown in Table 2):

Table 2: Table of calculation results

Work method	variable mm	Specification requirements	remarks
Grumination reinforcement method	22.79	20mm	dissatisfaction
MJS	3.387	20mm	satisfied
Bench method	9.754	20mm	satisfied

4.2 Comparative Analysis of Economy

According to the project cost budget analysis, the statistics are shown as follows (shown in Table 3):

Table 3: Economic Comparison Table (budget)

The method	Total cost (ten thousand yuan)	remarks
Grumination reinforcement method	2516	
MJS	5800	On the high side
Bench method	2936	

In Table 3, for example, the bench method has the best safety, feasibility and economy.

5. Conclusion

Through numerical simulation method and theoretical calculation method, grouting reinforcement method, bench method and MJS method) study the stress field and deformation mechanism of the shield tunnel after the small net distance passes through the existing tunnel.

(1) The settlement and radial deformation control of subway shield tunnel is 20mm, the deformation amount of grouting reinforcement method is the largest, reaching 22.79mm, the project cost is 25.16 million yuan, while the deformation amount of MJS method is only 3.387mm, but the highest cost is 58 million yuan, the deformation amount of bench method is 9.754mm, and the cost is 29.36 million yuan.

(2) Through calculation analysis and comparative analysis, the bench method has the best safety, feasibility and economy.

References

[1] https://www.camet.org.cn/

[2] Li Jianshe, Chen Huichao, Li Zheng. Key technology of shield tunnel at Cheongmiao Station-Mangrove Bay Station of Shenzhen Metro Line 11 The construction of tunnel through the existing line [J]. Tunnel construction, 2014, 34 (4): 6.

[3] Yang Kun. The influence of underpass tunnels on existing subway stations [D]. Chongqing Jiaotong University, 2015.

[4] Xia Jinchun. Risk control measures for orthogonal underpass tunnel construction of subway shield tunneling [J]. Tunnel construction, 2017, (S1): 111-115.

[5] Zhang Chao. Study on the influence of small net distance of subway shield tunnel [D]. And Southwest Jiaotong University [2018].

[6] Li Chunying. Discuss the construction technology of the existing station [J]. China Residential Facilities, 2020(1):3.DOI:CNKI:SUN:ZZSS.0.2020-01-05

[7] Yang Mancang. The influence of the new tunnel underpass construction on the existing tunnel [J]. Shandong Transportation Technology, 2021 (002): 46-54.

[8] Yang Hui, Liu Tao, Miao Hongbin, et al. The impact of shield tunnel close distance penetration on the existing operating tunnel [J]. Journal of Dalian University of Technology, 2022, 62 (3): 263-271.

[9] Zhang Jiantao, Yao Aijun, Guo Haifeng, et al. Analysis on the impact of small net distance tunnel construction in different sections [C] / / Collection of 2016 National Engineering Geology Annual Conference. 2016.

[10] Sui T. Three-dimensional Numerical Simulation Analysis on the Shield Tunnel with Small Clear Distance Curve[J]. Special Structures, 2019.

[11] Cao S, Xie Y, Tang W, et al. Research on Construction Methods for Ultralarge Y-Shaped Tunnel Sections[J]. Mathematical Problems in Engineering, 2021.

[12] Eckerter T, Braunisch V, Pufal G, et al. Small clear-cuts in managed forests support trap-nesting bees, wasps and their parasitoids [J]. Forest Ecology and Management, 2022, 509:120076.