

Practice of water inrush and mud grouting in fractured fracture zone

Li Zhipeng, Song Tianjiao, Li Yaxuan, Zhang Li

School of Transportation and Civil Engineering, Shandong Jiaotong University, Jinan, 250357, China

lizhipengsdu@163.com

Abstract: Start your Through the practice of curtain grouting in the fault zone F2 of Zhongjiashan Tunnel in Jiangxi Province, we explored effective methods for the treatment of fault crushing zone, including key parameters such as grouting drilling design and grouting material selection. The research results show that the full-section grouting method is to treat The effective means of water and mud outburst disasters in the fault crushing zone can be used as a reference for a full-section grouting method. The cement grout and the cement-water glass slurry can be used together to provide an effective grouting material for the curtain grouting treatment in the fault crushing zone; In the implementation of full-section curtain grouting, an outside-in grouting method should be adopted.

1. Introduction

With the rapid development of transportation methods such as roads and railways, the geological conditions traversed by highway tunnels and railway tunnels are becoming more and more complex. Especially when tunnels pass through fault-breaking belts, they can easily induce water inrush and mud-drilling geological disasters, causing serious Casualties and economic losses. Grouting is an effective means to treat the fracture zone of the fault. After the grouting, the target reinforcement area will form a relatively homogeneous slurry consolidation body, its mechanical parameters are greatly strengthened, and it can meet the tunnel excavation stability requirements.

Many researchers have carried out relevant research on the grouting process and the water inrush mechanism in the fault zone. Zou et al. analyzed the law of slurry diffusion based on Newtonian fluid-based radial crack surfaces.(Zou et al.2006). Zhang et al. studied the influencing factors of the diffusion radii of splitting grouting at the bottom of power-law fluids.(Zhang et al.2008). Huang et al. proposed an induced fracture grouting method based on the principle of elastic mechanics, which can control and change the splitting direction of the slurry.Zhang et al. described two main types of water inrush and mud gushing in broken rock tunnels,(Zhang et al. 2017). Reviewing many cases of water inrush and mud gushing in railway tunnels, Zhao et al. Previous studies on the mechanism of water inrush in tunnel construction, such as analysis of the water inrush mechanism in unfavorable geological sections (especially in fault zones and karst strata),determination of the critical condition of water inrush, and quantitative calculation of the inrush water, provided important information for tunnel construction engineers (Guan et al. 2003; Cui et al. 2005; Jiang et al. 2006; Seo et al. 2016; Guan and Zhao 2011). Many researchers studied grouting diffusion and reinforcement mechanisms used to prevent disasters in tunnel engineering(Zhang et al. 2017; Hernqvist et al. 2013; Rahman et al. 2015; Axelsson et al. 2009; Deb et al.2011; Yoon et al. 2015; Nilsen et al. 2014).



Through the practice of curtain grouting in the fault zone F2 of the Zhongjiashan Tunnel in Jiangxi Province, the effective methods for cracking the fault zone are explored, including key parameters such as grouting drilling design and grouting material selection.

2. Project Overview

The F2 fault of the Zhong Jiashan tunnel passed through K91+350 mileage, its strike was SSE, and it intersected with the axial 45 degrees of the tunnel. The action of fault was E, and the dip angle was 84 degrees. The width of the fault was 15~35m, the extension length was 520m, the surface was shown as the valley. According to the geological borehole ZK5, the rock mass in the fault zone was open and fractured, the rock mass was broken, the core rate was 55%~65%, RQD < 10, F. 2 the fault was intersected with the tunnel at the entrance left hole ZK91+313~364 and the inlet right hole near YK91+389~425.

On the right side of the ZK91+316 mileage at the entrance of the left hole, there were 8 water inrushes and mud accidents on the right side of the hand from July 2nd to the end of August 2012. The total mud inrush amount exceeded 14300m³ and a water inrush mouth with a diameter of 1m was formed on the right wall of the tunnel. In the first three water inrush processes, the outburst of mud was large, and then the protrusion was dominated by silt, only a small amount of mud was discharged. During the process of water bursting, the stability of the primary structure was good, and there was no large deformation and collapse. The distance was 121m between the right entrance of the inlet and the secondary lining at the end of June, and the initial section of the YK91+359~YK91+409 segment had been intruded and developed continuously (the largest 3M). In the YK91+370~380 mileage section, there were 7 times of mud burst and water bursting from August 12th to October, and the cumulative mud volume was 19500m³.

After a number of mud inrush, there were obvious surface collapses near the inside 20m of the design line above the inlet right hole YK91+371~YK91+389. The height of the top and the design line of the tunnel was about 190m, the subsidence was irregular ellipse, the diameter was 55, 33m, the area was about 2000m², and the depth was about 30m. In order to ensure the stability of the surrounding rock, and avoid the continuous failure of the structure and prevent the occurrence of worse engineering accidents, it was the primary consideration to reinforce the surrounding rock and control the surrounding rock in the water inrush section.



(a) Site of water inrush from left hole mud



(b) Water inrush scene of right cave mud

Fig1. Field photos of water inrush from tunnel

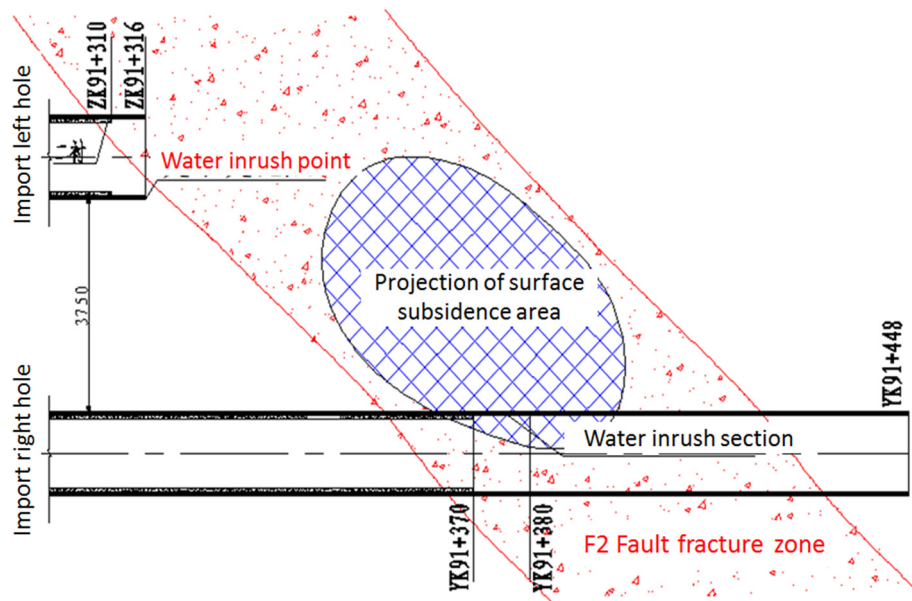


Fig2. A sketch map of the water inrush area of the Jiashan tunnel

3. The grouting design

The geological characteristics of the F2 fault were analyzed according to the situation of the left inlet tunnel mud and the right inlet tunnel mud and landslide in zhongjiashan tunnel. This paper presents a comprehensive treatment scheme which combines grouting after detection, grouting reinforcement with curtain grouting and cavity filling. Based on new grouting materials and process control grouting technology, Based on the real-time geophysical survey results and monitoring information, Conventional dual-fluid grouting combined with a new type of controlled rapid solidification paste material (GT-1) and progressive segmental control grouting technology are applied. Grouting process control technology and split-extrusion grouting, On the basis of anti - penetration measures of stop - grouting wall, The imported left hole has carried out advanced curtain grouting reinforcement and treatment project for surrounding rocks of F2 fractured fault zone within ZK91+310~400 range. In the right entrance tunnel, the surrounding curtain grouting reinforcement and treatment project was carried out for the fractured F2 fault zone of ZK91+370~445 mileage segment and the section of mud inrush. In the right entrance tunnel, the surrounding curtain grouting reinforcement and treatment project was carried out for the fractured F2 fault zone of ZK91+370~445 mileage segment and the section of mud inrush. Before the implementation of the curtain around the right hole, the drilling chamber (YK91+340~345) should be used to reinforce the extremely loose surrounding rock area (YK91+345~400) on the left side of the right hole, especially the section with mud water inrush. Prior to the implementation of the curtain surrounding the right hole, the key caverns (YK91+340~345) shall be used to carry out key anti-injections for the extremely loose surrounding rock area (YK91+345~400) on the left side of the right hole, especially the mud outburst area. Slurry reinforcement creates safe conditions for dredging in the right tunnel and surrounding curtain grouting. After the two-hole curtain grouting is finished, the three-step method is used to excavate the grouting section of the curtain, and during the excavation, the small radial pipe grouting is added to the weak area of the curtain.

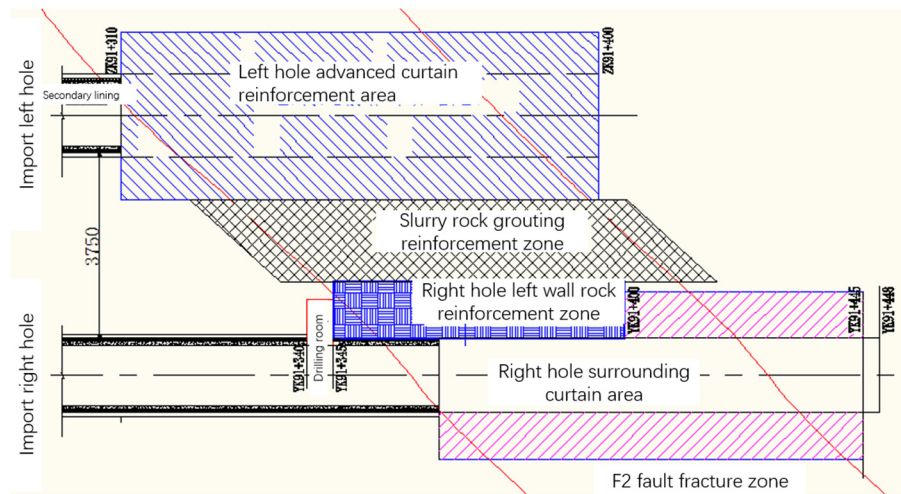


Fig3. Overall governance design

3.1. Drilling design

The following describes the specific design scheme with the left hole as an example. Imported left-hole curtain grouting reinforcement section is divided into three grouting cycles for implementation. The first cycle and the second cycle are advanced full-section pre-grouting. The third cycle is the pre-grouting of the surrounding curtain. The first cycle and the second cycle are divided into three grouting section lengths A, B and C. The reinforced section of section A is 0-10m, the reinforced section of section B is 10-20m, and the reinforced section of section C is 20-30m, the reinforcement range is 8m outside the excavation contour. The full-surface curtain grouting borehole and final hole intersection diagram are shown in Figs. 4~5. The third cycle is divided into three injection section lengths A, B and C. The reinforced section of section A is 0-15m, the reinforced section of B section is 15-30m, and the reinforced section of C section is 30-40m. For excavation 8m outside the outline.

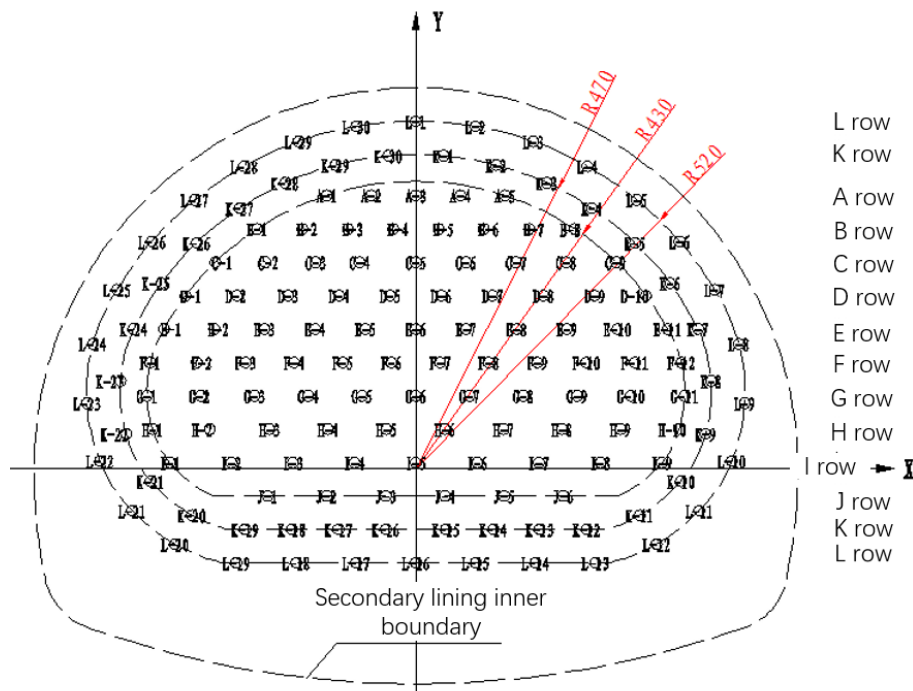


Fig4. Plane layout of drilling for full-face curtain of imported left hole

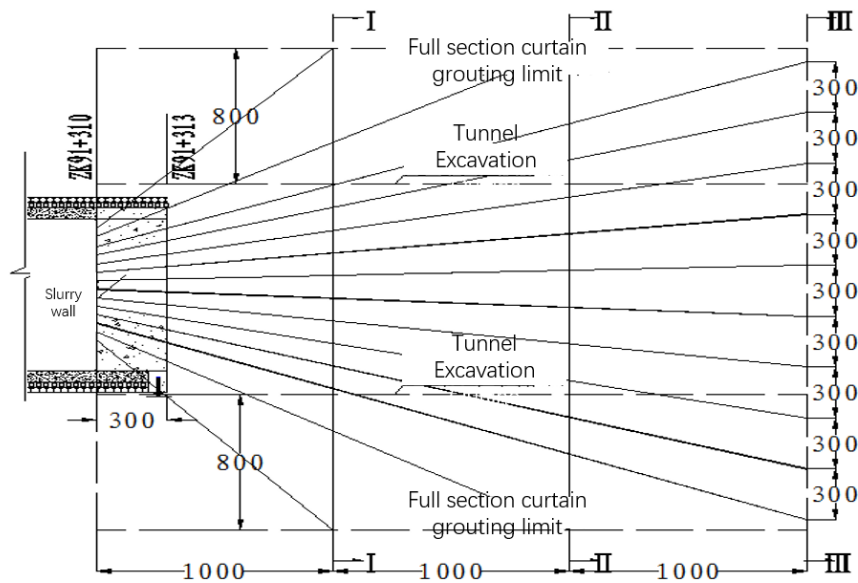


Fig5. Cross-section grouting drilling design section of the inlet left hole full section curtain

3.2. Grouting material

Due to multiple water inrush and mud outfalls in the left hole, the collapsed cavity formed by the cavern and the filling material of the original fault impact zone are in a muddy flow-plastic state. In such conditions, various grouting schemes must be used to implement gradual progress. For grouting, the selected materials must have good injectability ,durability and have features such as early strong, high-strength, setting time control, According to Zhongjiashan tunnel management section of complex hydrogeological conditions and grouting scheme, Select the following grouting materials and grouting technical parameters.

3.2.1. Single liquid slurry

For the curtain grouting around the tunnel surrounding rock, 42.5R ordinary portland cement is generally used. In the initial grouting, grouting pressure was used as the main reference index, and the injection pump volume is an indicator, the grouting pressure increased gradually as the grouting volume increased. The general principle of grouting is the principle of thinning, thickening, and then thinning. When a single fluid is injected, the slurry is pumped out and then enters the hole directly. The grouting begins with the use of a thinner slurry. Generally, when the slurry is injected for more than 30 minutes without pressure, the slurry is slowly adjusted. The concentration of the single-liquid cement slurry is generally about 1.3-1.70 g/cm³. When the grouting reaches a certain level, the pressure will slowly increase. At this time, the slurry concentration should be gradually reduced, and the stalls should be lowered until the grouting end criterion is reached. To improve the early strength of the slurry, 0.3-0.5% of triethanolamine or salt may be added to the slurry.

3.2.2. Cement - Sodium silicate dual liquid slurry

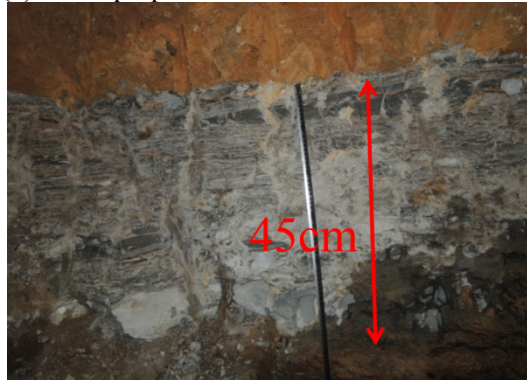
When the slurry spread during the grouting process is far beyond the control of the reinforcement range, the grouting material can be replaced. That is, the cement- sodium silicate dual liquid slurry is used. The selected Sodium silicate concentration is between 35-42Be and the modulus is controlled between 2.3-3.0. In order to ensure the strength of the cement after the two-fluid grouting, the volume of the cement to sodium silicate in the grouting is generally between 1:1 and 3:1, and the two-slurry solidification ratio test is performed before each grouting. in order to accurately Cement- sodium silicate slurry's coagulation time and consolidation strength, so as to ensure the quality of grouting reinforcement.

4. Grouting reinforcement effect

At present, the curtain grouting has been completed. From the perspective of the excavation of the grouting section, the curtain grouting program can effectively treat the water inrush and mud outbursts in the Yonglian Tunnel. The surrounding rock is stable and filled with grouting reinforcement. With a thickness of up to 45cm, the tunnel face is virtually water-free, ensuring the safe excavation.



(a) Core pulp consolidation of the tunnel face



(b) Thickness of the slurry vein

Fig6. Excavation of surrounding rock after grouting

5. Conclusions

(1) The full-section grouting method is an effective means to control the water inrush and mud disaster in the fractured zone of the fault. For similar projects, the grouting method of the whole section can be used for reference.

(2) The combination of cement slurry and cement-glass slurry can provide an effective grouting materials for the curtain grouting treatment of fault fracture zone.

(3) During the implementation of full-section curtain grouting, an outside-in grouting method should be adopted.

References

- [1] ZOU Jin-feng, LI Liang, YANG Xiao-li, et al. Mechanism analysis of fracture grouting in soil[J]. Rock and Soil Mechanics, 2006, 27(4): 625—628(in Chinese).
- [2] ZHANG Zhong-miao, ZOU Jian. Penetration radius and grouting pressure in fracture grouting[J]. Chinese Journal of Geotechnical Engineering, 2008, 30(2): 181—184. (in Chinese).
- [3] HUANG Ming-li, GUAN Xiao-ming, LÜ Qi-feng. Mechanism analysis of induced fracture grouting based on elasticity[J]. Rock and Soil Mechanics, 2013, 34(7): 2059—2064(in Chinese).
- [4] Marchi, M. G., Gottardi, K. S., 2014. Fracturing Pressure in Clay. J. Geotech. Geoenviron. Eng.

- 140(2): 1-9.
- [5] Bezuijen, A. R. Grotenhuis, A. F., van Tol, B., 2011. Analytical Model for Fracture Grouting in Sand. *J. Geotech. Geoenviron. Eng.* 137(6): 611-620.
 - [6] Zhang, G. H., Jiao, Y. Y., Wang, H., 2017. On the mechanism of inrush hazards when Denghuozhai Tunnel passing through granite contact zone. *Tunn. Undergr. Space Technol.* 68: 174-186.
 - [7] Guan B. 2003. Key points in tunnel designing. Beijing: China Communications Press. (in Chinese).
 - [8] Cui J. 2005. Tunnel and underground project construction technology. Beijing: Science Press. (in Chinese).
 - [9] Jiang J. 2006. Mechanism and countermeasures of water-bursting in railway tunnel engineering. *China Railway Science.* 27(5):76-82. (in Chinese).
 - [10] Seo, H., Choi, I., 2016. Numerical and experimental investigation of pillar reinforcement with pressurized grouting and pre-stress. *Tunn. Undergr. Space Technol.* 54: 135-144.
 - [11] Guan B, Zhao Y. 2011. Construction technology in tunnels with soft and weak surrounding rocks. Beijing: China Communications Press (in Chinese).
 - [12] Zhang, L., 2017. Study on Penetration and Reinforcement Mechanism of Grouting in Sand Layer Disclosed by Subway Tunnel and Its Application. Jinan: Shandong University, (doctoral thesis) (in Chinese).
 - [13] Hernqvist, G. L., Gustafson, Å., 2013. A statistical grouting decision method based on water pressure tests for the tunnel construction stage – A case study. *Tun. Under. Sp. Tech.* 33: 54-62.
 - [14] Rahman, M., Håkansson, U., Wiklund, J., 2015. In-line rheological measurements of cement grouts: Effects of water/cement ratio and hydration. *Tun. Under. Sp. Tech.* 45, 34-42.
 - [15] Axelsson, M., Gustafson, G., Fransson, Å., 2009. Stop mechanism for cementitious grouts at different water-to-cement ratios. *Tun. Under. Sp. Tech.* 24, 390-397.
 - [16] Deb, D., Das, K.C., 2011. Modelling of fully grouted rock bolt based on enriched finite element method. *Int. J. Rock Mech. Min.* 48, 283-293.
 - [17] Yoon J, Mohtar C S E., 2015. A filtration model for evaluating maximum penetration distance of bentonite grout through granular soils. *Computers and Geotechnics.* 65, 291-301.
 - [18] Nilsen A H V H., 2014. Rock Mass Grouting in the Løren Tunnel: Case Study with the Main Focus on the Groutability and Feasibility of Drill Parameter Interpretation. *Rock Mechanics and Rock Engineering.* 47, 967-983.