# Simulation Study on Grouting Effect of Zhengzhou Subway Tunnel


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**Abstract.** With the continuous development of urbanization and subway tunnel engineering, more and more overlying projects are constructed near the existing subway tunnels. Therefore, the grouting reinforcement of the subway tunnel soil layer has become more and more important, and the grouting effect has also received more attention. Based on the tunnel project of Zhengzhou East-Boxue Road Station in Zhengzhou City, this paper uses the numerical simulation method to compare and analyze the influence of grouting aperture, grouting pressure on the grouting effect of subway tunnel. The results show that with the expansion of grouting aperture, the grouting effect is continuously enhanced, but after reaching a certain degree, it will slowly increase ; with the increase of grouting pressure, the grouting effect in the early stage increases with the increase of pressure, and will remain a certain value in the later stage.



**Keywords:** subway shield tunnel, mathematical model, numerical simulation, grouting reinforcement


## 1 INTRODUCTION

Full-section curtain grouting is often used for large-scale mud inrush in subway tunnels. The construction parameters such as grouting hole spacing, grouting diffusion radius, grouting pressure and material, grouting amount and curtain grouting thickness are the key technical indicators to determine the grouting reinforcement effect of strata, and the grout ability of strata and the principle of grouting reinforcement are the premise to determine the process parameters. In the construction of subway tunnels, there will be engineering problems such as sand gushing, water gushing and mud gushing, as well as fault fracture zones. In view of these problems, advanced pipe roof grouting, advanced small pipe grouting, advanced curtain grouting, advanced pre-grouting, full-section grouting and other reinforcement measures are commonly used.

Aiming at the technical parameters, grouting process and effect of grouting reinforcement technology, Zheng Gang et al. [1] used two-dimensional tunnel model test



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to explore the influence of shield tunnel excavation and compensation grouting on surface settlement change under different buried depths in sand. Relying on the lateral deformation of an interval tunnel of Shanghai Metro, Wang Rulu et al. [2] used grouting reinforcement technology to repair structural diseases such as tunnel deformation, water leakage and mud leakage, and quantitatively analyzed the repair effect of lateral micro-disturbance grouting technology. LI et al. [3] proposed a quantitative design method for sand layer grouting, based on which the quantitative design of grouting mode judgment, grouting range determination and grouting reinforcement effect calculation was realized. Ye Fei et al. [4] introduced the TOPSIS evaluation method of game theory weight and developed a one-dimensional injection device to carry out indoor injection experiments, and obtained the specific value of the matching slurry ratio of the round gravel stratum in the actual project. Li Jialu et al. [5] used the method of numerical simulation combined with on-site monitoring and measurement to compare and analyze the stress and deformation characteristics of the primary support under three working conditions: no grouting reinforcement, advanced half-section curtain grouting and full-section curtain grouting, and evaluated the grouting effect under different working conditions.

Based on the underground passage project of Zhengzhou East-Boxue Road Station interval tunnel, this paper studies the influencing factors of grouting reinforcement effect of subway tunnel by numerical simulation method, mainly on the numerical simulation analysis of grouting aperture and grouting pressure.

# 2 MODELLING

## 2.1 Project Profile

The underground traffic project of Zhengzhou Comprehensive Transportation Hub-East Square Project is located on the east side of the station building of Zhengzhou East High-Speed Railway Station in Zhengdong New Area, which is surrounded by the north of South Power Road, the south of North Power Road, the east of 107 National Road and the west of Putian West Road. The surrounding land mainly belongs to administrative office land, commercial and financial land and second-class residential land. The east side of the East Square is Putian West Road, the main road of Zhengzhou, and a pedestrian passage is set under the road. The south side belongs to the reserved land of the urban public transport hub station; the west side of the east square is Zhengzhou 's high-speed rail east station, and the south side is the underground transfer station of Metro Line 5, Line 1 and Metro Line 3-Zhengzhou East Station ; on the north side is the highway passenger station. The 107 National Road passes under the west side of the East Square, and the Zhengbo shield section of the Metro Line 1 passes through the middle of the East Square plot.

There is about 70 meters long open-cut tunnel connecting the station air shaft of Zhengzhou Metro Line 1 from Zhengzhou East Station to Boxue Road Station, and the air shaft to Boxue Road Station is a shield tunnel. The tunnel line spacing of Zhengbo interval is 13.0 m ~ 16.0 m. The longitudinal slope of the line is designed as a ' V ' slope, with a maximum slope of 22 ‰ and a minimum slope of 2 ‰. The radius of the two curves of the interval line is 2000 m, and the line spacing is 13.0 m ~ 16.0 m. The maximum buried depth at the top of the interval tunnel is 13.7m, and the minimum buried depth is 8.7m. The tunnel adopts reinforced concrete flat segment and staggered joint assembly. The segment is divided into 1K + 2B + 3A, the inner diameter is 5.4m, the outer diameter is 6.0m, and the segment thickness is 0.3m. The segment concrete is C50, impermeability grade P10; there are 16 connecting bolts in the longitudinal direction of the segment and 12 connecting bolts in the circumferential direction.

## 2.2 Slurry Diffusion Theory in Soil Layer

According to the rheological properties of the slurry, the slurry can be divided into Newtonian fluid, expansion fluid, pseudo-plastic body, Bingham flow. The two most commonly used fluids in the study of grouting are Newtonian fluid and Bingham fluid, and the rheological curves of these two fluids are straight lines, and the others are curves. Most of the chemical slurry and the slurry with water-cement ratio not less than 1 belong to Newtonian fluid. The following introduction mainly introduces the penetration and diffusion theory of slurry under Newtonian fluid.

(1) Magg spherical diffusion formula [6]

$$r = \sqrt[3]{\frac{3kh_1r_0t}{\beta n}} \tag{1}$$

In the formula : t represents the grouting time ; r represents the slurry diffusion radius ; $r_0$ represents the radius of grouting pipe ; k denotes the permeability coefficient of soil ; $h_1 = ( H - h_0 )$ represents the difference between the grouting pressure head and the groundwater pressure head ; n denotes the porosity of the medium ; β is the ratio of slurry viscosity to water viscosity ; where $\mu_w$ denotes the dynamic viscosity of water ; $\mu_g$ represents the dynamic viscosity of the slurry.

(2) Cylindrical diffusion formula [7]

$$Q_g = \frac{2\pi L \Delta P}{\gamma_g \ln \frac{R}{r}} \tag{2}$$

In the formula: $Q_g$ is the grouting flow; R is the slurry diffusion radius; r is the radius of grouting pipe; △P is grouting pressure and underground; the difference of water pressure; $Y_g$ is the weight of slurry; L is the length of grouting hole.

## 2.3 Grouting Model

In this paper, the finite element method is used to study the seepage grouting process of grouting holes. The calculation state is transient. The overall size of the model is 50 m × 30 m × 19.86 m, in which the heights of floor, coal seam and roof are 0.74 m, 6.86 m and 12.26 m respectively, and the length of grouting pipe is 30 m. The calculation model is shown in Fig.1.

The grouting is extended to 10 ~ 30 m in front of the working face through the grouting pipe, and the roof is reinforced by advanced pre-grouting. The inlet boundary is set as the pressure boundary and enters from the grouting hole orifice. The exit boundary is set as a free flow boundary.

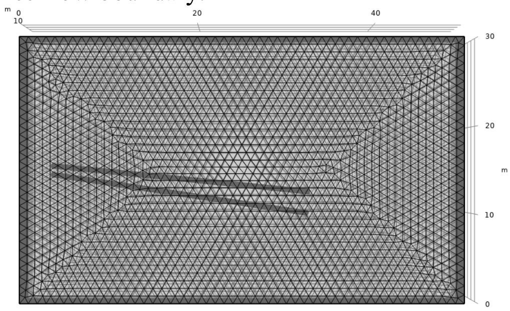


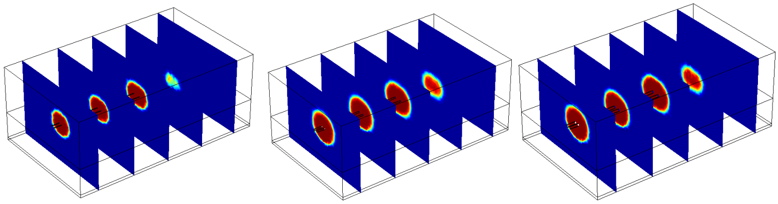

**Fig. 1.** Calculation model for two-hole grouting

# 3 SIMULATION ANALYSIS OF GROUTING EFFECT

In this paper, cosmol software is used to study and analyze the grouting effect under different grouting conditions from two aspects: grouting hole diameter, grouting pressure.

## 3.1 The Influence of Different Apertures on Grouting Effect

The pore size of the grouting hole has an important influence on the grouting reinforcement effect. In order to determine the optimal pore size of the grouting, the grouting pore size of 200 mm, 500 mm and 800 mm is set in the simulation, and the influence on the grouting reinforcement effect is compared and analyzed. The grouting effect is shown in Figure 2.



(a)200 mm (b)500 mm (c)800mm

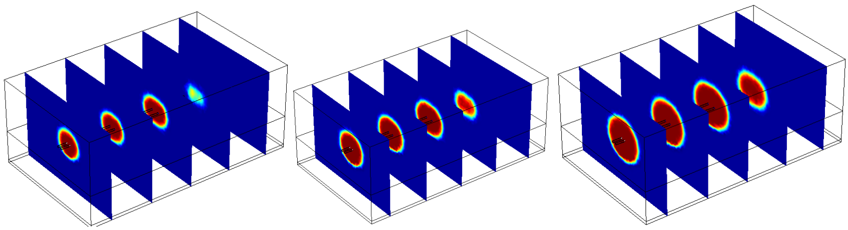
**Fig. 2.** Grouting effect of different apertures

Figure 2 is the grouting effect diagram of 10 h grouting when the grouting aperture is 200 mm, 500 mm and 800 mm respectively. From figure 2, it can be seen that when the grouting aperture is 200 mm and 500 mm, the grouting effect becomes better and better with the increase of the grouting aperture, but when the grouting aperture is 800 mm, the grouting effect becomes worse. It shows that with the increase of grouting aperture, the grouting effect becomes better and better with the increase of aperture at the beginning, but when the grouting aperture increases to a certain extent, the grouting effect becomes worse and worse with the increase of grouting aperture.

### 3.2 The Influence of Different Grouting Pressure on Grouting Effect

The grouting pressure should not be less than the static water and soil pressure at the depth of the tunnel, and should be continuously optimized in the actual process. When the grouting pressure is too large, it will cause engineering accidents of ground uplift and segment deformation, and it is prone to leakage. When the grouting pressure is too small, it is easy to cause surface subsidence. Generally speaking, the grouting pressure is 1.1 ~ 1.2 times of the static soil and water pressure, and the maximum is not more than 3.0 ~ 4.0 bar.

In this paper, the simulation is carried out under the grouting pressure of 15 MPa, 21 MPa and 27 MPa.



(a)15MPa (b)21MPa (c)27MPa

**Fig. 3.** Grouting effect of different grouting pressure

Fig.3 is the grouting effect diagram of grouting for 10 h when the grouting pressure is 15 MPa, 21 MPa and 27 MPa respectively. From Fig.3, it can be seen that when the grouting pressure is 15 MPa and 21 MPa, with the increase of grouting pressure, the grouting effect is getting better and better, but when the grouting pressure is 27 MPa, the grouting effect is not much different from that when the grouting pressure is 21 MPa. It shows that with the increase of grouting pressure, the grouting effect becomes better and better with the increase of grouting pressure at the beginning, but when the grouting pressure increases to a certain extent, there is no difference in grouting effect with the increase of grouting pressure.

## 4 CONCLUSION

In this paper, a finite element model of grouting effect of subway tunnel is established. The calculation shows that the establishment of the tunnel model is reasonable. The influencing factors of grouting effect of subway tunnel are analyzed from three aspects : grouting aperture, grouting pressure and slurry density. The following conclusions are drawn :

(1) Under the condition that other factors are unchanged except the grouting aperture, the influence of grouting aperture on grouting effect is gradually enhanced with the maximum grouting aperture in the initial stage. However, when the aperture increases to a certain extent, the grouting effect is enhanced, but the effect is slight. Based on the engineering project and economic factors, moderate aperture is generally selected for grouting.

(2) Under the condition that other factors except grouting pressure remain unchanged, the influence of grouting pressure on grouting effect gradually increases with the increase of grouting pressure in the initial stage, but when the grouting pressure increases to a certain extent, the grouting effect does not change significantly.

(4) In this paper, cosmol software is used to simulate the influencing factors of grouting effect in subway tunnel. However, in practical engineering, there are many factors affecting the grouting effect of subway tunnels. In addition to the factors considered in this paper, further more comprehensive analysis and research are needed.

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