# Research on the Application of Backwall Grouting in Leakage Treatment of Operating Tunnels

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**Abstract.** In order to study the application of grouting behind the lining wall in the treatment of leakage of subway tunnel during the operation period, the diffusion effect of grouting behind the wall in dense fill and loose fill was studied by the method of numerical simulation and model test, and the distribution of grouting vein in the process of grouting was analyzed. The results show that the results of numerical simulation and model test are basically the same, mainly as follows: In the dense soil, although the slurry will also expand along the tunnel lining wall, it is mainly jacking in the direction perpendicular to the lining structure, and it is unable to form a large area of enclosed solid behind the lining structure; In the loose soil, with the increase of grouting pressure, the slurry gradually approaches the wall After approaching the wall, it will expand along the wall, and, at the end of grouting, the slurry will be evenly distributed along the back of the tunnel lining structure and form an obvious closed reinforcement. It is concluded that: for the tunnel structure in loose soil, when the measures of grouting behind the wall are adopted to treat the leakage water, the spacing of grouting holes can be appropriately enlarged; for the tunnel in dense soil, the spacing between grouting holes should not be too large. More importantly, the correct grouting scheme design must be considered from the whole reinforced soil, rather than from the effect of a certain point. According to the specific situation and the expansion process of the slurry, the expansion direction of the slurry vein should be considered scientifically, so as to achieve good treatment effect of leakage water.

## 1. Project Overview

As of December 2022, 52 cities in mainland China have opened urban rail transit, with an operating mileage of 9788.64 kilometers, including 7209.7 kilometers of subway operation, accounting for 78.31% of the total line length. China has the longest operating mileage of urban rail transit in the world. With the increase of operation time, the lining (segment) of subway tunnel has various degrees of diseases, of which cracking and water leakage are typical diseases, which pose a serious threat to the safety of subway operation.

Backwall grouting, as a means of effectively improving the storage environment of subway stations and tunnels during operation and thus protecting the structure itself, has always been of great concern to scholars at home and abroad [1-2]. Zhang Dongmei [3] conducted in-depth research on the application of grouting in shield tunnels, and conducted in-depth research on the changes in pore water pressure caused by grouting leakage in shield tunnels. Grouting technology, as an economical and practical method for rock and soil reinforcement and anti-seepage and water blocking, has been widely applied in the fields of civil engineering such as water conservancy, transportation, mining, power, construction, and municipal engineering [4-8]. Many scholars and engineering technicians at home and abroad have carried out a lot of scientific research and engineering project implementation for the treatment and reinforcement of tunnel diseases, but the research found that there is a lack of systematic methods and processes for the treatment of cracks in the lining structure of subway tunnel [9-14].

Grouting behind the wall is a commonly used method in tunnel disease treatment. However, due to the understanding of the mechanism of grouting water blocking, some disease treatment projects have failed, and even repeated repairs, more blockage and leakage have occurred. The same grouting reinforcement technology was used for two operating subway tunnel, but one project achieved good results, while the other failed. This article analyzes the reasons for the success and failure of two practical projects using numerical simulation and model experiments. The aim is to provide reference for the grouting treatment technology of tunnel leakage during the operation of the subway. In the practical application of grouting technology, designing according to scientific methods can ensure good governance effects.

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## 2. Numerical calculation model and working condition design

### 2.1. Auxiliary Equipment Installation and Layout

The numerical calculation model is modeled using a program independently developed by the author. The basic situation of the model is as follows: the thickness of the tunnel lining wall is 0.4m. Considering that most tunnel lining walls can be considered as a semi infinite body, the thickness of the backfill behind them is set to 4m, the model edge length is set to 4m, and the model height is also set to 4m. The grouting nozzle is set at 40cm behind the tunnel lining wall. The numerical calculation model is shown in Figure 1.

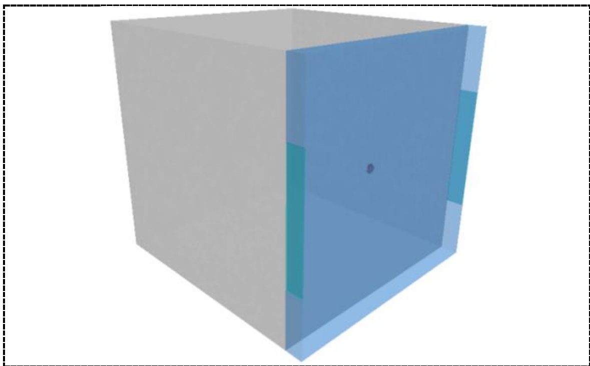


**Figure 1.** geometric dimension of numerical calculation model

Since this article mainly studies tunnels during operation, it is assumed that the stress in the surrounding rock where the tunnel is located has returned to the original rock stress state. The numerical calculation uses finite element and fluid volume function methods to simulate grouting, the interface between the slurry and the soil is determined using the fluid volume method, and the constitutive relationship of the soil is determined using the Duncan Chang model. Apply a load at the top to simulate the overlying soil layer (with a thickness of 10m). The grouting material is Malisan, which will expand when encountering water. The expansion coefficient is about 2. During the simulation process, when new cracks are generated and grouting material enters, the volume of the grouting material expands, and this part becomes deformed as the initial strain treatment.

The theory of computation and calculation process related to the test refer to the grouting simulation method proposed by the author. See the first chapter in the literature [12] for details, which will not be repeated.

### 2.2. Working condition design

This article focuses on the diffusion process of grout in two grouting projects. In the treatment of tunnel leakage during the operation period, in order to ensure the safety of existing equipment, the grouting pressure behind the tunnel lining wall and at the tunnel base during grouting is controlled within 0.5MPa. Therefore, the grouting pressure set for this study is 0.5MPa [10].

The numerical simulation parameters for dense soil and loose soil are shown in Table 1 and Table 2, respectively.

**Table 1.** Numerical calculation parameters of condition 1 (dense soil)

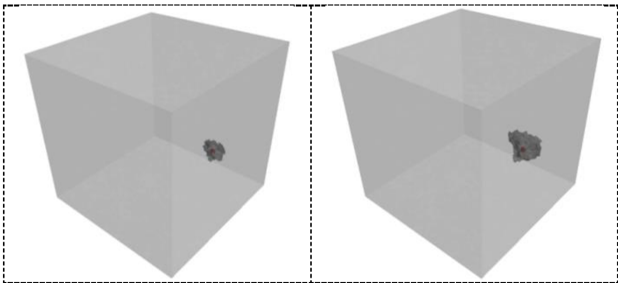
| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Modulus parameter $K$ | 200 | Initial viscosity coefficient $\mu_{g0}$ | 7.1mPa s |
| Modulus parameter $K_b$ | 100 | Viscosity coefficient $\mu_w$ | 1.0mPa s |
| Modulus parameter $K_{ur}$ | 400 | Initial permeability coefficient $k_{g0}$ | 1e-7cm/s |
| Cconstant $m$ | 0.5 | $k_w$ | 1e-5cm/s |
| Cconstant $n$ | 0.6 | Initial elastic modulus of soil $E$ | 10MPa |
| Soil failure ratio $R_f$ | 0.95 | Conversion factor $\xi$ | $10^{-4}$m |
| Cohesive force $c$ | 20kPa | Shape parameter $\alpha$ | 3 |
| Friction angle $\varphi$ | 30° | / | / |

**Table 2.** Numerical calculation parameters of condition 2 (loose soil)

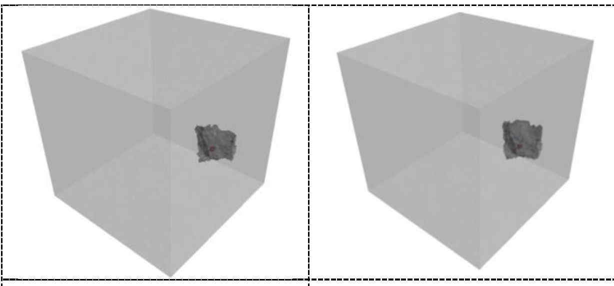
| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Modulus parameter $K$ | 50 | Initial viscosity coefficient $\mu_{g0}$ | 7.1mPa s |
| Modulus parameter $K_b$ | 20 | Viscosity coefficient $\mu_w$ | 1.0mPa s |
| Modulus parameter $K_{ur}$ | 100 | Initial permeability coefficient $k_{g0}$ | 1e-7cm/s |
| Cconstant $m$ | 0.4 | $k_w$ | 1e-4cm/s |
| Cconstant $n$ | 0.5 | Initial elastic modulus of soil $E$ | 2MPa |
| Soil failure ratio $R_f$ | 0.95 | Conversion factor $\xi$ | $10^{-4}$m |
| Cohesive force $c$ | 5kPa | Shape parameter $\alpha$ | 3 |
| Friction angle $\varphi$ | 20° | / | / |

## 3. Analysis of numerical simulation results

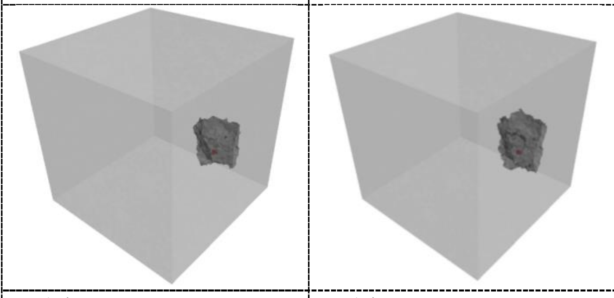
### 3.1. Calculation Results of Project A



（a）Grouting pressure is 0.05MP （b）Grouting pressure is 0.1MP



| (c) Grouting pressure is 0.2MP | (d) Grouting pressure is 0.3MP |
|---|---|



| (e) Grouting pressure is 0.4MP | (f) Grouting pressure is 0.5M |
|---|---|

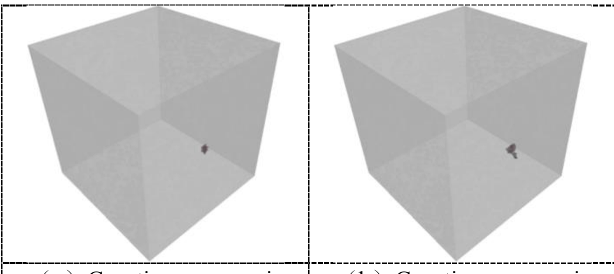
**Figure 2.** The spreading process of grouting liquid in dense soil and the distribution of grouting vein

As shown in Figure 2, the diffusion effect of Malisan injection slurry in dense soil and the distribution of slurry veins are shown. The following conclusion can be drawn from the graph:

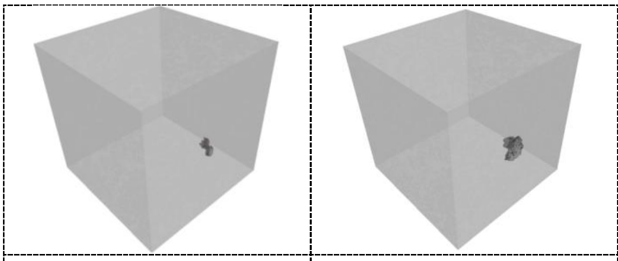
(1) When the grouting pressure is 0.05MP, the soil begins to split. When the grouting pressure increases to 0.2MP, there is a clear vertical expansion trend, and the grouting vein is perpendicular to the tunnel lining structure.

(2) As the grouting pressure continues to increase, the grout vein continues to expand and the thickness also increases accordingly. Until the grouting is completed, a vertical (perpendicular to the tunnel lining structure) expanding grout vein is formed. That is to say, in dense soil, it is difficult for the grout injected behind the lining wall to form a large enclosed reinforcement body to block the invasion of external water. At the same time, during the grouting process, the slurry reacts on the tunnel lining structure. When the grouting pressure is higher, it is easy to cause deformation of the lining structure, leading to the emergence of new permeable joints.

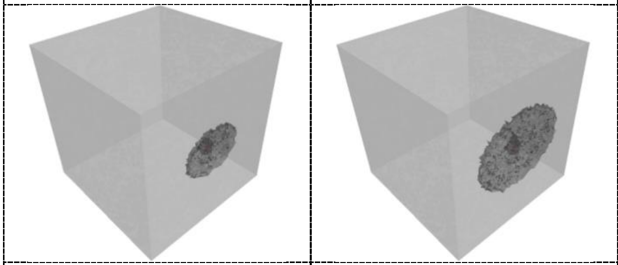
### 3.2. Engineering B Calculation Results



| (a) Grouting pressure is 0.05MP | (b) Grouting pressure is 0.1MP |
|---|---|



| (c) Grouting pressure is 0.2MP | (d) Grouting pressure is 0.3MP |
|---|---|



| (e) Grouting pressure is 0.4MP | (f) Grouting pressure is 0.5M |
|---|---|

As shown in Figure 3, the diffusion effect of Malisan injection slurry in loose soil and the distribution of slurry veins are shown. The following conclusion can be drawn from the graph:

(1) The grouting pressure is 0.05MPa, and the slurry is mainly compacted grouting. This is mainly because in this situation, the soil is relatively loose and has a high water content. When the grouting pressure is greater than 0.1 MPa, a branched slurry vein extends towards the lining, which widens with the increase of grouting pressure;

(2) As the grouting continues, the slurry gradually approaches the wall and then expands along the wall. At the end of grouting, the slurry is evenly distributed along the back of the tunnel lining structure and forms a clearly enclosed reinforcement body.

## 4. Model Test Research

In order to bring the research results closer to reality and guide the smooth implementation of practical engineering, the dense and loose soil used in this model test were taken from the construction site of the subway station. After retrieving the original soil, add water to the soil until it is saturated, and then place sandbags at the top of the model to simulate the overburden pressure.

### 4.1. Experimental Design

1. Overview of Test Equipment

The model test device adopts an experimental device jointly designed and manufactured by Beijing Municipal Engineering Research Institute and Beijing Municipal Road and Bridge Technology Development Co., Ltd. The device is 800mm high, 350mm behind the lining wall, with a simulated fill thickness of 400mm and a total model length of 800mm. The three sides of the model, except for the tunnel lining wall, are all made of transparent tempered glass to facilitate observation of the distribution of slurry veins. As shown in Figure 4.

**Figure.4** Geometric dimension of numerical calculation model

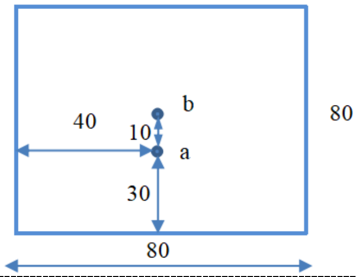



**Figure.5** Layout of grouting holes

**Figure.6** Test device after adding soil

2. Layout of grouting holes

Determine two drilling positions on the concrete slab, as shown in Figure 5. A hole is an observation hole with a diameter of 20mm, B hole is a grouting hole with a diameter of 20mm.

3. Grouting pressure

Given the limited size of the model test, this inevitably leads to limited tolerance for grouting pressure.Compared to numerical simulation calculations, the size of the model test has been reduced by 5 times, and therefore, the grouting pressure has been correspondingly reduced by 5 times, setting the maximum grouting control pressure to 0.1MPa.

4. Test process

(1) Cover soil placement: After retrieving the soil on site, fill it into the device. As this experiment focuses on the treatment of leakage water, add water to the device until it is saturated and stand still for 30 days before starting the test. After saturation with water, place a sandbag with a total weight of 320kg on the top of the device to simulate the overburden pressure, as shown in Figure 6.

(2) Drilling: A hole diameter 20mm, B hole 20mm; In the process of drilling, sulfoaluminate cement is used in combination to prevent a large amount of mud from flowing out;

(3) Embedding grouting pipe: Install a drainage pipe with a ball valve in hole A (ensure that the valve is closed before installation), and install a Malisan grouting pipe in hole B, both of which are fixed with sealing agent;

(4) Grouting process: Open the drainage pipe, use this hole as an observation hole, and control the grouting pressure in 0.1MPa, When there is grout leakage at any position of the observation hole or model, stop grouting, let it stand for 10 minutes, and continue grouting; Stop grouting until there is no water flowing out of the observation hole or when the grouting pressure stabilizes at 0.1MPa;

(5) During the grouting process, closely observe the soil conditions behind it;

(6) After 24 hours of grouting, remove the soil from the model and observe the diffusion of the slurry.

### 4.2. Analysis of Model Test Results

**Figure 7.** Expansion of grouting liquid in dense soil

**Figure 8.** Expansion of grouting fluid in loose soil

As shown in Figure 7, the final distribution of slurry in dense soil is shown. From the figure, it can be seen that in dense soil, the slurry did not eventually expand in a large area, but instead broke through the weak position in front of the grouting nozzle to the right and squeezed forward, forming a slurry vein.

The expansion of slurry in loose soil is shown in Fig. 8. From the figure, it can be seen that in the loose soil, a layer of closed consolidation with a thickness of about 3cm was formed tightly against the tunnel lining wall, and no obvious vertical distribution was observed.

Both in dense and loose soil, the results of the model test are highly consistent with the numerical calculation results. This further demonstrates the reliability of the research results.

## 5. Conclusion

By using numerical calculations and model experiments, the reasons for success and failure of two actual grouting water blocking projects were analyzed, and the following conclusions were drawn:

(1) In Project A, the soil is relatively dense, and the slurry mainly extends in the direction perpendicular to the lining structure, while it cannot form a large enclosed solid behind the lining structure;

(2) In Project B, the soil is relatively loose. As the grouting pressure increases, the slurry gradually approaches the lining and expands along the lining. At the end of the grouting, the slurry is evenly distributed along the back of the tunnel lining structure and forms a clearly closed reinforcement.

(3) The correct grouting scheme design must be considered from the entire reinforced soil, rather than evaluating the effect at a certain point. It is necessary to scientifically consider the expansion direction of the slurry pulse based on the specific situation and the expansion process of the slurry, in order to achieve good leakage water treatment results.

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