Study on the flow plasticity and permeability of mixed and improved shield residue in water-rich sand layer

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Abstract. Shield tunneling in water-rich sand layer is prone to problems such as high cutter torque and severe wear, and spiral transporter gushing. Based on this, this paper takes the shield project of Xi'an Metro Line 10 interval as the basis, and carries out the experimental research on the improvement of slag soil in water-rich sand layer through the combination of slag soil slump test, penetration test and field inspection. The test results show that: when the mass ratio of bentonite to water is 1/8 and the concentration of foaming liquid is 3%, the performance of the improver meets the construction requirements; Foaming agent and bentonite improved better. When the slurry injection ratio (BIR) is 10% and the foam injection rate (FER) is 20% -25%, the improvement effect of medium sand is the best. When the slurry injection ratio is 10% and the foam injection rate is 35% -40%, the improvement effect of gravel sand is the best. Applying the test results to engineering practice, the effect of soil conditioning is good, and the parameters of shield tunneling are stable.

Keywords: Shield tunnel; slag improvement; experimental study; water-rich sand layer; flow plasticity; permeability.

1 Introduction

Xi'an water-rich sand formation is characterized by low cohesion, high inter-particle frictional resistance, poor grading, high water content, and high permeability. The formation is responsive, and the cutter disc is prone to excessive torque, cutter jamming and severe wear when rotating and cutting the formation [1]. To ensure that the shield can pass the water-rich sand layer smoothly and safely, it is necessary to improve the residue flow plasticity and reduce the residue permeability by improving the residue. For this reason, many scholars have researched on shield slag improvement technology. Huang et al [2] investigated the effect of different particle sizes of slag on the performance of slag improvement by improvers. vinai et al [3] concluded that the ideal slump of sandy soil is 150-200 mm by foam improvement slag test. sotiris [4] found that particle size is an important factor affecting the effect of sandy soil improvement by their study. Bezuijen et al[5] simulated the change of soil sample properties after mixing

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sandy soil with air bubbles in the shield soil bin by model tests. Wang Leilei et al [6] used two improvement methods, foam and foam mixed with mud, to improve the sand layer. Jingyu et al [7] investigated the effect law of foam injection rate on the shear, seepage and plastic flow state of slag soil improvement with different stone content. Chen Xianzhi et al [8] investigated the improvement effect of various improvers alone or together on water-rich round gravel strata through slump test and infiltration test of slag soil. Zhang Runlai et al. [9] analyzed the interaction between the ratios by relying on a shield project of sand-pebble formation in Chengdu. Mo Zhenze et al. [10] studied the improvement technology of rich silt and mud.

Most of the above studies used one kind of soil sample as the test soil sample for slag improvement, and most of them lacked comparative studies on the improvement effect of slag in different soil layers, and there were few studies considering the effect of different water content on the improvement effect of slag. In this paper, the effect of different water content of slag soil on the effect of foam improvement on slag soil is studied based on the first phase interval project of Xi'an Metro Line 10, and the experimental conclusions are verified in the actual project.

2 Project Overview

Xi'an Metro Line 10 Phase I interval tunnel is about 1678.148m long, the center distance between the left and right lines is 14.0~17.0m, the designed tunnel floor depth is between 16.63~29.57m, the minimum plane curve radius is 450m, and the maximum longitudinal slope of the interval tunnel is 28%. The construction of earth pressure balance shield, cutter excavation diameter 6480mm. interval tunnel mainly through the stratum of medium sand and gravel sand, medium sand, gravel sand stratum grain size greater than 2mm content accounted for 3.8%, 28.7% respectively. The longitudinal section profile of the interval is shown in Figure 1.

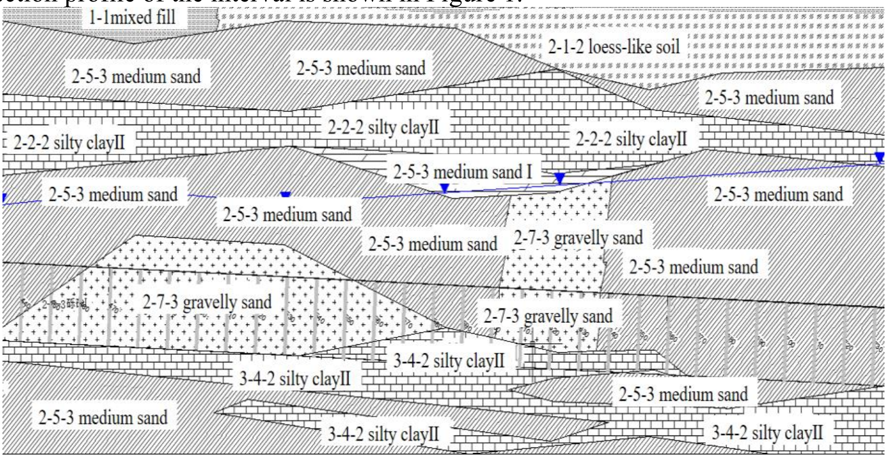


Fig. 1. Longitudinal Section of a Section of Xi'an Metro Line 10 Phase I Project.

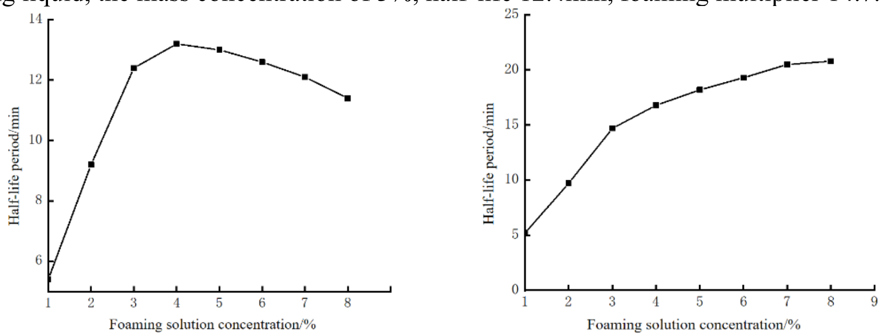
3 Modifier Blending Test

Under the premise of considering the safety, efficiency and economy of the shield, this paper uses foam and bentonite as the improver for this test. When foam is mixed with bentonite slurry for improvement, bentonite is equivalent to fine particles in the soil, and when bentonite slurry is injected into the sand layer, it can improve the internal structure of the sand and optimize the effect of foam to improve the sand layer, so as to achieve a good improvement effect.

3.1 Foam blending test

The half-life and foaming multiplier of foam are the main reference basis for judging the performance of foam. According to engineering experience, the half-life of foam is more than 5min, and the foaming multiplier is 10~20 to meet the requirements of shield construction.

From Figure 2, it can be seen that when the foam concentration is low, the foam half-life and foam multiplier increase rapidly with the increase of foam concentration, but when the foam concentration is more than 3%, the growth trend of foam half-life and foam multiplier becomes flat, and even the half-life decreases instead of increasing after the foam concentration is more than 4%. Combined with engineering tests, in consideration of safety, efficiency and economy, this test took the Guangzhou tunnel Ji foaming liquid, the mass concentration of 3%, half-life 12.4min, foaming multiplier 14.7.



(a) (b)

Fig. 2. Variation curve of half-life and foaming multiplicity with foaming solution concentration

3.2 Bentonite slurry blending test

This slurry test was conducted to evaluate the performance of bentonite slurry by testing the viscosity of bentonite slurry. The bentonite and water mass ratios (mud-water ratio) of 1:10, 1:9, 1:8, 1:7, and 1:6 were configured into five different ratios of bentonite mud, which were expanded for 24 h. The mud viscosity at each concentration was measured every 4 h during the period using a martensite funnel. From Figure.3, it can be seen that the viscosity of the mud at different mud-water ratios increased with time and reached a peak after 16h and remained stable. The viscosity of bentonite mud with 1:8 mud-water ratio is 50s, which fully meets the requirements of shield mud, so under the premise of considering safety, efficiency and economy, this test uses bentonite mud with 1:8 mud-water ratio as the test mud ratio.

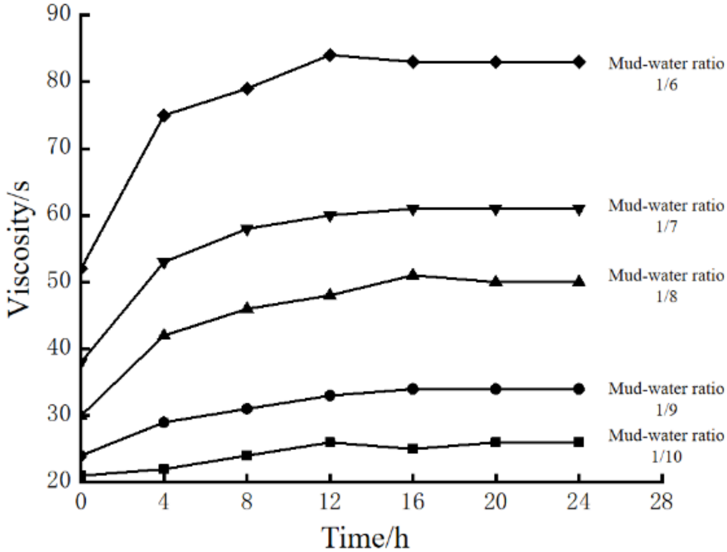


Fig. 3. Variation curve of mud viscosity and mud concentration with time

3.3 Foam modification test

The results of slump variation with foam injection rate (FER) at different water contents are shown in Figure 5. When the water content is 2.5% and the FER is less than 10%, the foam improvement is not effective because of the insufficient free water content inside the slag soil. When the water content is 5.0% and 7.5%, the slump can meet the shield demand with the increase of FER, but in the actual construction process, the change of soil water content occurs from time to time, and the effect of improved flow plasticity cannot be achieved by foam improvement alone.

When the water content is 5.0%, 7.5% and FER is less than 15%, the permeability coefficient decreases with the increase of FER. When the FER is greater than 15%, the permeability coefficients of these two permeability curves increase rather than decrease with the increase of FER. This phenomenon occurs because when the FER is larger, a large amount of foam precipitates after injecting the specimen, which leads to the formation of fine water gushing channels inside the soil and reduces the water retention capacity and cohesion capacity of the soil, so it causes the permeability performance of the slag soil to decrease instead of increase. When the water content reaches 10%, the pores within the slag soil are almost filled with free water, resulting in poor foam improvement of the slag soil.

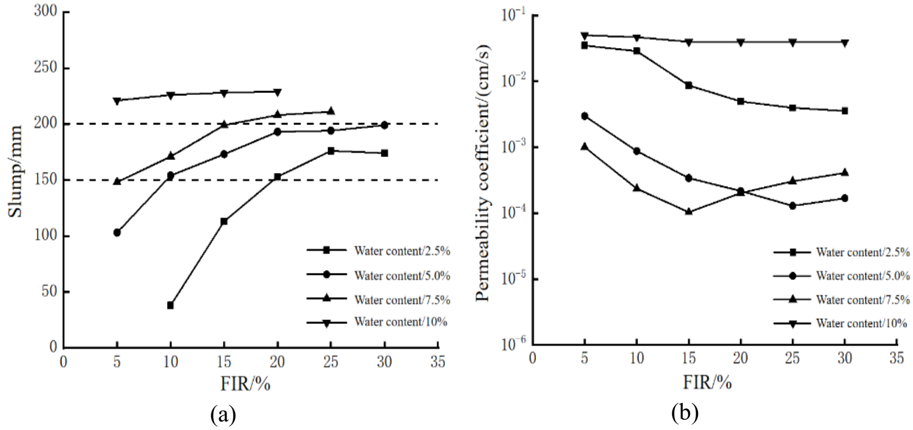


Fig. 4. Variation of slump and permeability coefficient with foam injection rate at different water content

The graphs of permeability coefficient with FER at different water contents are shown in Figure 4. It can be seen from the figure that when the water content is 2.5% and FER is less than 10%, the permeability performance of slag soil is almost unchanged, which is because there is not enough water in the soil sample, the liquid film ruptures quickly and it is difficult to play the effect of filling pores and stopping water, and the improvement effect is not obvious. When the water content is 10%, due to the high water content, the soil sample is easy to precipitate water and bubble phenomenon after injecting foam, which cannot play the role of improving the permeability of slag soil.

In summary, foam alone is not effective in improving water-rich sand layer. In this test, foam and bentonite slurry are mixed to improve the water-rich sand layer in order to get the best ratio of foam and bentonite slurry together.

3.4 Penetration test and result analysis

The rich water sand layer has the characteristics of high water content and high permeability. During shield tunneling, there may be hidden dangers such as spiral conveyor surging and instability of the working face. To prevent the surging of the screw conveyor and maintain the stability of the palm surface, the permeability of the slag soil is an important indicator that cannot be ignored. This article uses a self-made variable head permeameter to measure the permeability of slag soil. The main body of the device is an organic glass cylinder with an inner diameter of 200mm, a thickness of 10mm, and a height of 650mm. The upper part of the test column is connected to an air compressor and a pressure regulating device. as shown in Figure 6.

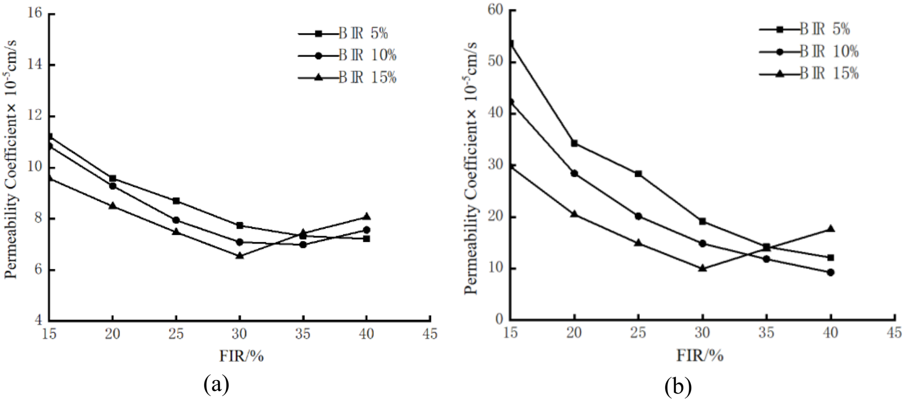


Fig. 5. Variation of slump and permeability coefficient with foam injection rate at different water content

Fig. 6. Self-made permeameter

Test the sealing of the device before the experiment and check for any water or air leaks. Under the condition of ensuring good airtightness, lay a layer of crushed stone as a filter layer at the bottom of the instrument, and then fill the improved soil sample layer by layer into the permeability meter in a 30mm high manner. After each layer is filled, evenly hit it with a tamping rod 20 times, and repeat this step until all soil samples are filled. Finally, inject water about 10cm higher than the soil surface from the top, seal the instrument, open the air compressor, increase the air pressure to 100kPa (determined by the pressure of the soil chamber during shield tunneling) and maintain it constant. Open the drainage valve, record the average amount of water discharged within a certain period of time, and calculate the corresponding permeability coefficients. The permeability test results of medium sand and gravel sand are shown in Figure 5.

From the graph, it can be seen that after improvement, except for the BIR 5% curve, the permeability curve of medium sand shows a gradually decreasing trend with the increase of FER, while the other two curves show a trend of first decreasing and then increasing. In contrast, for gravel sand, the situation is just the opposite. The BIR 5%

and BIR 10% curves show a gradually decreasing trend, while only the BIR 15% curve shows a trend of first decreasing and then increasing. This phenomenon occurs because the content of medium sand is more than that of gravel sand fine particles, and the role of bentonite slurry is equivalent to that of fine particles in the soil mass. With the larger BIR, the more space the slag void is filled with free water, bentonite slurry and fine particles in the soil, which makes it more difficult for foam to penetrate into the soil void. When FER increases to a certain extent, foam will be carried out by free water, and the precipitated foam will be accompanied by water and fine particles, The formation of small water inflow channels leads to the phenomenon of water and foam separation, which reduces the water retention capacity and cohesion of the test soil sample, resulting in an increase in the permeability of the slag instead of a decrease.

Combining the mixed improvement slump test and permeability test, taking into account economic costs and construction needs, the optimal ratio for improving medium sand slag soil is determined to be: BIR10%, FER20%~25%; The optimal injection ratio for gravel sand is BIR10%, FER30%~40%. Considering the loss of bentonite slurry and foam in water rich soil mass and the continuous change of stratum during shield construction, the input can be properly adjusted.

4 Practical engineering applications

Combining the data obtained from the indoor tests, the scheme of foam improvement experiment was adopted, i.e., the water-rich sand layer was improved by using an improver with a mud-water ratio of 1/8 and a foam liquid concentration of 3%. The change curves of shield cutter torque and cutter speed parameters before and after the obtained ratio are shown in Figure 5.

It can be seen from Figure 7 that the blade torque is obviously reduced and the blade speed is increased after the improvement, and it can be maintained stable. The propulsion speed of the shield is also maintained between 40~50mm/min, and the soil output per ring is between 50~60 square meters, which indicates that the improvement effect is generally good.

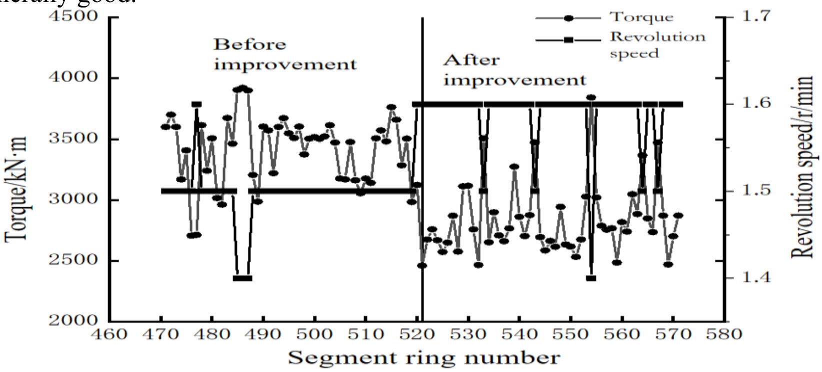


Fig. 7. Curve of change of cutter torque and cutter speed before and after improvement

5 Conclusions and Recommendations

Through the indoor slag improvement test for the shield construction of the first phase of Xi'an Metro Line 10 and the field boring slag improvement test research, the analysis results are as follows:

(1) For the water-rich sand layer, foam alone is not effective in improving the slag, and it is appropriate to use foam and bentonite slurry mixed improvement. Foam concentration of 3%, bentonite slurry mud to water ratio of 1/8, improve the agent to meet the shield requirements and meet the economic needs;

(2) Foam improved slag soil, can effectively improve the slag soil flow plasticity, but by the water content, when the water content is high, foam alone to improve the sand layer prone to precipitation, precipitation bubble phenomenon, the permeability coefficient is not reduced but increased.

(3) This paper lacks the analysis of the effect of different water content of slag on the foam and bentonite slurry mixture improvement, which can be followed by in-depth research.

Considering the loss of bentonite slurry and foam in water-rich soil for shield construction, the amount of participation can be increased appropriately.

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