Grouting reinforcement treatment method for super-shallow buried metro station crossing sand layer

ZHANG Bing1*, ZHANG Shijie2

1Jinan Liwen Geotechnical Engineering Co., LTD., Jinan 250061, Shandong, China
2China Railway Academy Co., LTD., Chengdu 610032, Sichuan, China.
*Corresponding author’s e-mail: 375417356@qq.com

Abstract. The quaternary water-rich sand layer is often traversed during the construction of metro tunnels, and is one of the main geological disaster sources that affect the safety of metro construction. The grouting method is the most commonly used method to control the geological hazards of the water-rich sand layer. Affected by the pore structure of the sand layer and the state of in-situ stress, this paper proposes a method of grouting reinforcement with mould bag piles for sand grouting. Progressive section grouting can successfully solve the problem of sand layer reinforcement. The results show that: (1) The mould bag pile reinforcement can effectively strengthen the sand layer and ensure that the sand layer within the slurry diffusion range can be effectively strengthened, and increase the grouting retention rate; (2) Progressive section grouting can achieve the effect of grouting reinforcement at different depths to ensure the effect of grouting. This method has been successfully applied in metro station, hoping to provide some reference for similar projects.

1. Introduction
During the construction of metro tunnels, it often passes through the quaternary water-rich sand layer. Due to its low medium bonding strength and poor self-stability, it is easily to induce engineering disasters such as tunnel collapse or water collapse. This leads to casualties, economic losses, and delays in the construction period, and even forced the construction to quit.

The prevention and treatment of water-rich sand layer disaster is a dynamic process, and the grouting process control [1-3] is the core factor to ensure the treatment effect. In the research of grouting control of water-rich sand layer disasters, controlling the grouting process can control the slurry within the scope of treatment to meet the grouting requirements. The traditional grouting control method [4-7] mainly includes quantitative control method and constant pressure control method, that is, the grouting amount and grouting pressure are used as the judging grouting ending criteria. When the grouting amount or grouting pressure reaches the design value, it is believed that effective reinforcement has been achieved and the grouting is over. Grouting is an underground concealed project, which involves many factors, it is difficult to intuitively control the grouting process, and there is no relevant perfect and unified theory to guide it.

In this paper, taking the grouting of the metro station passing through the shallow buried sand layer as the engineering background, the method of reinforcing the mould bag pile is proposed. The progressive section grouting reinforcement method is used to effectively solve the grouting reinforcement problem of the shallow buried station through sand layer. We hope that it can provide some valuable references for the similar engineering projects.
2. Engineering background

The stratum distribution of the station area can be divided into artificial fill layer (Q4ml) and bedrock layer from the ground surface. The fillability is poor, mainly composed of silty clay, weathered sand and some gravel, etc which has low strength, poor self-stability, strong water permeability and a thickness of 1.40～4.80m.

The bedrock is dominated by granite, partially revealing the later intrusive veins of porphyry, and the rock quality is the typical massive broken rock. Due to the structural compression, the bedrock is mostly distributed in the impact area of the structural fracture zone, and it is divided into strong, medium, and slightly weathered granite in order from shallow to deep, and the quality grades are V to III. The distribution of the rock layer is relatively undulating. The vault of the underground excavation section of the station is located in the strong and moderately weathered rock layer, and the cave body is located in the medium and slightly weathered rock layer, as shown in Figure 1.

3. Difficulties in project management

3.1. Geological particularity

The stratum in the target area of the local section is mostly coarse gravel sand with cohesive soil, which results in the grouting diffusion mainly splitting and limited penetration. The strength of grouting reinforcement mainly depends on the skeleton network formed by splitting veins, which has higher requirements for the effect of grouting splitting, otherwise local quick-sand instability is likely to occur, affecting the stability of the tunnel. The effect of splitting grouting is directly proportional to the amount of grouting, but a larger amount of grouting will cause the surface uplift to exceed the allowable value.

3.2. Shallow depth of tunnel

The roof of the inclined shaft tunnel directly exposes the quaternary sand layer, the distance from the surface is less than 2m, the surrounding rock grade is grade VI, the surrounding rock has poor self-stability, and the grouting reinforcement effect is not ideal. The consequences of gushing water and sand are extremely serious. The thickness of the coating is not enough, the grouting environment is poor, the splitting pressure is low, and the surface uplift is very sensitive. At the same time, it may be accompanied by the slurry running from the surface, which seriously increases the difficulty of grouting treatment.
3.3. Surface uplift and pipeline deformation
A large number of municipal pipelines will be arranged at 3-5m from the left side of the tunnel, such as water supply and sewage. During the grouting process, under the premise of ensuring the safety of channel excavation, the surface uplift and pipeline deformation must be strictly controlled.

3.4. Influence of surrounding buildings
Above the main vault of the tunnel is the construction room of the experience hall and the project department. The depth of the station is super shallow. The surface deformation caused by grouting has an adverse effect on the surrounding buildings. Therefore, dynamic control during grouting is required.

4. Grouting treatment method

4.1. Mould bag pile method
A row of mould bag piles are arranged in the excavation profile, and the length is 12m. The distance between the vaults is determined by the inspection hole effect. If the effect of the vault inspection hole is good, the distance is set to 1200mm. If the effect is poor, the distance is set to 800mm. The distance between the mould bag piles on both sides of the palm face is set to 800mm, and a total of 19 mould bag piles are designed.

(1) The length of the mold bag pile is set at 12m to ensure the effective diffusion and filling effect of the slurry.

(2) The vaults of the bag-shaped piles are arranged along the excavation contour line, with a spacing of 1200mm, horizontally arranged on both sides, with a spacing of 800mm, squeezing the stratum to form a slurry stop layer, preventing the slurry from spreading upward, and effectively controlling the deformation of the stratum.

(3) In order to ensure that the molded bag pile will not be damaged during the excavation process, the φ42PVC grouting pipe is used 1m in front of the molded bag pile to ensure that the supporting framework and compacted stratum function of the subsequent molded bag pile will not be affected by the excavation.

Figure 2. Plan and longitudinal section layout of mould bag pile

4.2. Progressive section grouting
(1) Reinforcement scope
The conventional grouting scheme is adopted in the grouting reinforcement area of the palm face. The reinforcement goal is to improve the overall strength and impermeability of the sand layer, and to ensure the safety of the palm face and the side walls of the tunnel during the excavation.
The full-section grouting reinforcement section adopts the horizontal drilling scheme and the progressive subsection grouting technology. The grouting length of each section is 4m, and the thickness of the tunnel reinforcement ring is 3m.

① The progressive grouting technology is adopted, the length of the grouting section is 4m, and the two-sequence drilling construction is adopted. After the drilling construction and grouting treatment are completed, the targeted inspection holes will be constructed according to the engineering geological conditions for effect inspection and supplement grouting.

② In order to avoid grouting during the grouting process, the holes in each sequence are constructed from both sides to the middle, and the skipping method is used.

(2) Drilling layout

① The reinforced length of the cycle is 12m, the excavation length is 9m, and the 3m grouting section is reserved for the grouting rock disc of the next cycle. In order to avoid the blind grouting area, the length of each circulating grouting section is divided into 3 sections, respectively reinforced in the range of 0 ~ 4m, 4 ~ 8m and 8 ~ 12m.

② Five rings of grouting holes are arranged in the face of the palm. The number of grouting holes is 47, and there are 6 inspection holes for a total of 53 drill holes. The hole spacing is 0.5m and the row spacing is 0.5m.

③ Open the inspection hole at the end of grouting to check the effect of grouting, and conduct the small pipe grouting and strengthening treatment for the weak grouting area. The design layout is 12 and the depth of the hole is 3m.

![Figure 3. Plane and section of grouting hole](image)

5. Grouting material and parameter design

5.1. Type of slurry
The slurry is mainly selected from 425 cement single liquid and cement-water glass double liquid slurry. The ratio is \( \frac{W}{C} = 1:1 \), \( C: S = 1:1 \sim 4:1 \), and the slurry ratio can be real-time Feedback regulation.

5.2. Grouting pressure and grouting diffusion radius
Combining the grouting construction experience of similar strata in Qingdao Metro and other grouting engineering experience of shallow buried tunnels, the grouting pressure is determined to be 1 ~ 1.2MPa, and the grouting diffusion radius is 1.2 ~ 1.5m.
5.3. Ending standard of grouting
Taking the single-hole grouting volume and grouting pressure as the control indicators, the "volume-pressure dual control" grouting end standard is used for grouting control. The specific standards are as follows:
① When the grouting volume does not reach the design standard but the grouting pressure reaches the design final pressure, and maintains for more than 5min, stop the grouting;
② When the grouting volume reaches the single-hole design grouting volume, if the grouting pressure does not reach the design final pressure, the sizing gel time can be adjusted to reach the design final pressure and the grouting is stopped.

6. Conclusion
(1) The mould bag pile reinforcement can effectively strengthen the sand layer and ensure that the sand layer within the slurry diffusion range can be effectively strengthened, and increase the grouting retention rate.
(2) Progressive section grouting can achieve the effect of grouting reinforcement at different depths to ensure the effect of grouting.
(3) The new method of mould bag pile grouting method has been successfully applied in a super shallow buried metro station. And it can effectively guarantee the whole excavation safety and stability.

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