Engineering practice of surface grouting treatment through soft surrounding rock stratum by TBM

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Abstract. When the TBM passes through the weak and broken strata, it is easy to get stuck and be buried. Through the advance pre grouting engineering practice of TBM crossing fault zone in Qingdao area, the pre grouting reinforcement measures for preventing the occurrence of TBM card machine are explored, including grouting pressure, grouting drilling design, grouting material and other key parameters. The research results show that the surface pre grouting method is an effective grouting measure to prevent the occurrence of TBM stuck and buried accidents. Single cement slurry and C-S double slurry are used as grouting materials. The cement slurry is used to fill the void in soft broken stratum and C-S double slurry is used to improve the controllability of slurry diffusion. In the process of advanced pre-grouting construction on the ground surface, the application of progressive segmental grouting technology and membrane bag sealing grouting technology can effectively guarantee the strengthening range of soft ground and improve the effect of grouting reinforcement.

1. Introduction

Compared with conventional drilling and blasting method, TBM has become a common technical means of highway and railway tunnel excavation because of its advantages in construction speed, cost, safety, stability of surrounding rock and so on[1]. A large number of engineering practices show that TBM is suitable for tunneling in medium hard rock tunnel, and the excavation speed and working efficiency are high[2-3]. However, for the deep weak strata with high ground stress and the strata with weak structural plane of rock mass, the stress state of surrounding rock changes and the surrounding rock produces strong extrusion deformation under the influence of TBM tunneling disturbance. The tunnel is prone to collapse, water inrush and mud outburst during tunnel excavation. Once the above situation occurs, TBM will appear in the tunneling process, card machine, buried accident. Especially for the soft surrounding rock, good penetration of joints and weak bite force, once the TBM is stuck or buried, the construction progress will be seriously affected, resulting in a large number of economic losses. Because of the limitation of construction operation of TBM, when TBM passes through this kind of stratum, the method of advance pre-grouting is often used to prevent and control the possible TBM card machine and buried accident. The slurry is injected into the strata to fill the voids in the...
weak strata, which makes the consolidated area become a unified whole, and improves the mechanical parameters of the strata, so as to meet the safety requirements of the TBM passing through the fracture zone.

In view of the reinforcement methods adopted by TBM through weak fractured strata, a lot of researches have been carried out by scholars at home and abroad \[4-9\]. The research focuses on the following aspects: ①Taking the front section of TBM cutter head as the working section, the pre-grouting reinforcement of soft surrounding rock is carried out, and the selection of grouting material and grouting technology is discussed. ②The pressure anchor grouting method is used as the main method to solve the water seepage problem in the cavity caused by the incomplete filling of the space between TBM lining and surrounding rock.③TBM card machine, after being buried, is used to release the TBM from the hole grouting method, mainly study the grouting parameters and the selection of grouting material.

However, there is little research on the advance reinforcement method of TBM in soft ground excavation. Whether the method of ground surface pre-grouting reinforcement is reliable or not, and whether the reinforcement effect can ensure the smooth passage of TBM through soft and broken strata is rarely discussed. Based on TBM crossing soft surrounding rock of Qingdao Metro Line 1, this paper discusses the advance pre-grouting reinforcement method to prevent TBM from appearing in burying machine.

2. Engineering situation
The project is located between Wawuzhuang station and Guizhou road station of Qingdao metro line 1. The whole interval is about 8.2 km, and the length of the sea segment is 3.45km. The TBM drivage line enters the sea from the Guandao military camp area, passes through the mouth of Jiaozhou Bay Bay, makes landfall at the western end of Xuejia Island and crosses the Ring Island Road, which is basically parallel to the Jiaozhou Bay Subsea Tunnel and Binhai Avenue. The sea area is located at the mouth of Jiaozhou Bay, with a flat topography and dense surface construction on the side of the island.

There are many military and civil facilities on the ground above the tunnel, and the underground municipal pipelines are dense (water supply, power supply, gas pipeline and communication cable etc.). The buried depth of underground pipelines is generally not more than 2m. TBM drivage strata are dominated by lower Cretaceous volcanic rocks and late Yanshanian intrusive rocks. Diabase veins formed in Himalayan period and structural fracture zone are interspersed in the rock mass. The strong weathering zone on the surface is relatively developed, and the degree of weathering and fragmentation is more serious. There are moderate weathered and strongly weathered fault zones in this section. The tunnel passes through the strongly weathered zone, and the foundation is not uniform, as shown in fig.1. Therefore, in order to ensure the smooth passage of TBM, it is necessary to carry out pre grouting reinforcement for TBM tunnelling formation.

3. Grouting design
Grouting in tunnel often causes surface uplift, especially the existence of municipal pipeline on shallow surface. If grouting pressure is too high and grouting quantity is too large, it will easily lead to deformation and rupture of municipal pipeline and induce secondary disaster. This project area, the
tunnel overlying the ground municipal pipeline, the building density. According to the site construction conditions and the geological prospecting data, it is proposed to adopt the method of ground surface pre-grouting reinforcement to reduce the probability of secondary disasters. The method of arranging holes in triangular triangles with 2 m side length is adopted.

3.1. Drilling design

(1) Drilling plane layout

As in Figure 2, the horizontal layout of the drill holes is mainly:

① If there is no surface vegetation or building in the construction area, the spacing and spacing of the boreholes are 3 m, which are arranged in the form of plum blossom. The final hole falls within ±6 m of the central axis of the tunnel.

② If the surface vegetation and buildings are blocked and the road or construction area is in the sea area, it cannot be constructed, then it is suitable for opening the hole in the nearby area. The final hole is still located within ±6 m of the central axis of the tunnel.

(2) Drilling section layout

As shown in figure 3, the layout of the borehole section is mainly as follows:

① According to geological data, the thickness of grouting reinforcement ring of weak surrounding rock is designed 3m.

② When there is no surface vegetation or building in the construction area, the borehole is vertical hole, and the final hole is located below the floor of the tunnel 3m.
(3) Local vegetation and building occlusion, or in the sea area, cannot be constructed, the hole is inclined hole, the final hole is located 3 m below the bottom of the tunnel. The azimuth and deflection angle of the borehole are shown in Fig. 4.

![Inclined hole borehole section](image)

Figure 4. Inclined hole borehole section

### 3.2. Grouting material

(1) Single cement slurry

As the main grouting material, ordinary Portland cement slurry can effectively strengthen the weak medium. In single liquid grouting, the primary filling is mainly filled with grouting. With the increase of grouting quantity and the increasing of grouting pressure, seepage grouting and compacting grouting are the main factors to improve the permeability coefficient of grouting reinforcement, and form a certain thickness grouting reinforcement ring around the tunnel to prevent the influence of underground water on the surrounding rock of the tunnel. The principle of grouting is to dilute before thickening. At the beginning of grouting, the thinner slurry is first used. When the slurry is injected beyond the 30min pressure, the slurry is slowly thickened, and the concentration of the cement slurry can be poured at 1.3~1.70g/cm³. When the grouting reaches a certain level, the pressure will slowly increase, and then gradually reduce the slurry concentration, and lower the gear, until the end of the grouting standard. In order to improve the early strength of cement slurry, 0.3% triethanolamine or salt can be added to the cement slurry.

(2) C-S double slurry

When it is difficult to control the dispersion of grouting over the reinforcement range during grouting, the grouting material is replaced, that is, C-S double liquid slurry is used. The material is made of cement and water glass, which are injected by double liquid grouting in a certain proportion. According to the requirement of grouting, the cement slurry with a certain volume of water cement ratio is mixed with a certain volume of water glass slurry of a certain volume and a certain volume of water glass slurry according to the requirement of grouting. The concentration of selected sodium silicate should be between 35 and 42 Be, and the modulus should be in the range of 2.3~3.0. The volume ratio of cement to water glass is generally between 1:1 and 5:1. In order to ensure the quality of grouting reinforcement, the solidification time and consolidation strength of cement water glass slurry should be mastered accurately before each grouting.

### 3.3. Grouting technology

After studying the engineering geological conditions and site construction conditions, the following grouting key technology is applied in grouting construction.

(1) Progressive segmented grouting process

In order to prevent the uneven diffusion of the slurry in the weathered and broken surrounding rock and improve the overall reinforcement effect, it is considered that the reinforcement section is mostly weak medium, the single hole grouting is easy to cause hole collapse jam and the slurry cannot reach
the expected range of diffusion reinforcement. Therefore, the progressive segmented grouting process is adopted, that is, from the shallow to the deep, step by step, and then push forward layer by layer, as shown in fig 5. Drilling in construction, injection alternately, grouting section length is 4 m, using orifice pipe for grouting.

![Progressive segmented grouting process](image)

**Figure 5. Progressive segmented grouting process**

(2) Grouting Technology of sealing holes in Mould bag

The device is shown in figure 6. One of the difficulties existed in this project is that the shallow layer of the surface is a soft and mixed fill, and there is a lack of sufficient strength cap at the opening point, so it is difficult to seal the casing. In the process of grouting, it is difficult to deal with the problem of running-grouting. In view of this difficulty, the sealing of grouting pipe is carried out by using the sealing technology of mould bag. The mixed soil layer of 5m below the surface is isolated by grouting expansion mold bag, and the permeation and splitting diffusion of the slurry is limited to the 6m range of the central axis of the TBM tunnel, so as to avoid the ineffective grouting diffusion in the unexpected area of the reinforcement ring.

![Grouting Technology of sealing holes in Mould bag](image)

**Figure 6. Grouting Technology of sealing holes in Mould bag**

In the grouting of mould bag grouting pipe, the bag sealing is carried out first for drilling holes. Using cement water glass double liquid grouting, cement slurry water cement ratio 1: 1, cement slurry to water glass volume ratio is 1:1. Through the small iron pipe at the top of the mould bag, the double liquid grouting is carried out on the mold bag. When grouting pressure reaches 1 MPA, stop grouting.
After initial solidification of cement-glass double-liquid slurry in the mould bag, the surrounding rock of the tunnel is grouting through the grouting pipe.

In the grouting of the surrounding rock surrounding the tunnel through the grouting pipe, the grouting pipe is firstly injected with the silicate cement single-liquid slurry with the water-to-cement ratio of 1:1. According to the condition of slurry running and slurry string in formation, adjust the volume ratio of C-S grouting material. According to the different initial setting time of C-S grouting material with different volume ratio, different proportion of slurry is selected to realize the control of dynamic water plugging. When the grouting pressure of the bag is 1 MPA, when the stratum begins to swell or the amount of suction is less than 1 L/min, the grouting will be stopped. After grouting, we stop the grouting pump. Then close the orifice gate valve, then flush the grouting pump and the grouting pipeline until the water is clear. After grouting, we stop the grouting pump. Then close the orifice gate valve, then flush the grouting pump and the grouting pipeline until the water is clear. Disassemble the cylinder block of the grouting pump to check and flush again, leaving no residue.

3.4. Grouting reinforcement effect

The test results of drilling and coring before and after grouting reinforcement is shown as Fig. 7. After grouting reinforcement, the cementation of broken zone, mud, sand and gravel granular slurry stone can achieve the predicted effect. Local fault gouge (sand) is dewatered by high pressure compaction and has the ability of self-stabilization. At present, TBM has passed this section smoothly. It is indicated that the surface advance pre-grouting can effectively reinforce the fault zone and effectively ensure the TBM crossing the weak stratum of surrounding rock.

![Figure 7. Drilling core before and after grouting reinforcement](image)

4. Conclusions

(1) The method of surface advance grouting is an effective grouting measure to prevent TBM from sticking machine and burying accident, which can guarantee TBM to pass through soft and broken strata smoothly. The related engineering of TBM crossing soft and broken strata can be used for reference of surface advance grouting method.

(2) The cement slurry is used to fill the void in the weak broken stratum, and the cement-water glass double liquid slurry is used to improve the controllability of the slurry diffusion. The combination of the two can provide the material guarantee for the advanced pre-grouting method on the ground.

(3) In advance pre-grouting engineering, the advanced stage grouting technology and the film bag sealing hole grouting technology can effectively guarantee the reinforcement range of the soft stratum and improve the grouting reinforcement effect.
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