Research on Full-Face Grouting Reinforcement Technology in the Soil Chamber of Shield Tunneling through Rich Water-bearing Rock Layers

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Abstract— **The implementation of this technology addresses the shortcomings of traditional earth pressure balance shield tunneling in groundwater loss through highly water-bearing rock layers and screw conveyor surging, resolving the technical challenges in earth pressure balance shield construction. It effectively reduces construction risks and enhances efficiency. With the development of China's economy and society, the expansion of urban and intercity rail transit networks has led to increasing tunnel depths, more complex geological conditions, and a growing number of sensitive structures beneath. The safety risks of shield construction have consequently risen. The technical achievements presented in this paper effectively tackle these challenges.**

Index Terms— **water-rich strata; shield tunneling; full-section, grouting.**

I. INTRODUCTION

With the increasing number of tunneling projects such as intercity rail transit, subways, and hydraulic engineering in China, the burial depth of shield tunnels continues to grow, and the number of sensitive structures beneath them is rising. This places higher demands on controlling groundwater loss during shield construction and ensuring the safety of surface structures.

In the traditional earth pressure balance shield tunneling method, reasonably controlling the excavation parameters of the shield, combined with synchronous grouting technology and auxiliary reinforcement measures, generally ensures stratum stability and effectively controls surface settlement. However, in deep, water-rich rock layers, especially when there is a certain connectivity between bedrock fissure water and confined aquifer water in the overburden, deep-hole grouting for water cutoff or drainage excavation often fails to meet the expected quality requirements and progress targets, rendering the shield unable to advance normally and compromising the safety of surface structures.

This technology explores the excavation techniques for shields in deep, fissure-developed rock layers, proposing a full-section grouting reinforcement method within the shield's muck chamber. By pressurizing and injecting novel grout solutions through muck chamber replacement, it directly acts on the face to seal bedrock fissures, fundamentally addressing groundwater loss issues. This approach facilitates full-section filling of face fissures for water cutoff, improves the shield excavation environment, prevents screw conveyor surging, enables rapid shield advancement, and enhances construction efficiency.

The technology is primarily applied in shield tunneling through deep, fissure-developed, water-rich rock layers where sensitive surface structures exist, achieving full-section filling.The fissures in the tunnel face effectively reduce groundwater loss, improve the tunneling environment, and enhance surface structures.The stability and safety. The construction method can be extended to shield tunneling in complex urban geological environments, facilitating the construction of similarThe proposed project introduces new technical measures, thus holding promising application prospects.

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II. PROCESS PRINCIPLES

This technology primarily focuses on systematically studying how to seal or reduce fractured water in the bedrock at the tunnel face during shield tunnel construction. It mainly investigates the mechanisms of ground settlement, construction techniques for sealing fractured water, the formulation of sealing materials, and shield excavation modes. A full-section grouting reinforcement technique within the shield muck chamber is developed, where new grouting materials are pressurized and injected directly into the tunnel face to seal the bedrock fractures. This fundamentally addresses groundwater leakage issues, facilitates rapid shield advancement, effectively controls surface building settlement, and ensures the safety of shield construction. The method is convenient and simple in terms of operational procedures, with high efficiency, safety, and environmental friendliness.

III. OPERATION POINTS

3.1 Shield tunneling strengthened sealing

Before conducting full section grouting, fill the tail sealing area, hinge sealing area, and inner and outer sealing areas of the cutterhead with grease to ensure the sealing degree of the corresponding areas, thereby preventing the slurry from entering the shield machine and damaging the shield machine equipment during grouting. Due to the injection of slurry through the opening positions of the soil silo and cutterhead, special attention should be paid to the sealing effect of the inner and outer periphery of the cutterhead.

3.2 Filling and grouting in over excavation area

Due to the excavation diameter of the cutterhead being slightly larger than the outer diameter of the shield body, a certain gap is formed between the surrounding rock and the shield body. During the construction process, in order to prevent the slurry from spreading to the gap between the surrounding rock and the shield body during grouting and wrapping the shield body, bentonite slurry and water glass (bentonite: water=1:1.2, water glass percentage: 8%) are injected into the outer periphery of the shield body through the injection hole on the shield body to fill the gap on the outer side of the shield body. The pressure during filling is slightly higher than that of the soil silo.

3.3 Secondary grouting after pipe segment wall

Due to the slower deformation of the surrounding rock after detachment, there will be a certain gap between the lining of the pipe and the surrounding rock. Underpass underground,during the full section grouting construction of rock layers with abundant water and developed fissures, in order to block the incoming water channel behind the pipe segments, injection is carried out.Double liquid slurry is injected into the gap behind the wall through the slurry hole to ensure the clearance between the 10 ring pipe segment behind the shield tail and the surrounding rock which fill the gaps densely without forming pathways for groundwater.

Fig.1 Secondary grouting after pipe segment wall

3.4 Gas for slag exchange

Under the principle of maintaining a constant pressure in the soil silo, compressed air is injected through the top injection hole of the soil silo partition, and the slag is discharged through a screw conveyor. The amount of slag discharged is about one-third of the volume of the soil silo, forming a stable pressure chamber inside the soil silo (in this project, the soil silo pressure is maintained at 3.8~4.0 bar), temporarily blocking the groundwater in the formation crack water inflow channel, and effectively avoiding the influx of crack water into the soil silo while discharging the soil silo slag.

3.5 Ventilation with slurry

Under the principle of maintaining a constant pressure in the soil silo (approximately 3.8~4.0 bar in this project), filling slurry is injected into the soil silo through the top injection hole of the soil silo partition to fill the gas chamber (with a grouting pressure of approximately 4.1 bar in this project), thereby pressing gas into the crack channel to block the inflow of crack water and ensure the subsequent grouting effect. Repeat the above two steps until all the soil in the silo is replaced by the slurry.

3.6 Crack grouting

Continue to inject the filling slurry through the top injection hole of the soil silo partition, and maintain the soil silo pressure within a certain range (above 4.2 bar in this project). Under the action of grouting pressure, the injected filling slurry is pressed into the formation fracture channel, blocking the water inflow channel in the formation and reducing the water inflow of the excavation face. Observe the changes in soil chamber pressure. If the soil chamber pressure can remain stable above 4.2 bar for a long time, stop grouting and wait for the grout in the crack channel to solidify; If the pressure in the soil silo drops rapidly and cannot be maintained above 4.2 bar for a long time, the grouting flow rate should be reduced to continue grouting. During the process of pressurized grouting and static observation, intermittently stir the cutterhead to prevent the slurry from solidifying.

3.7 Micro disturbance excavation of shield tunneling

Micro disturbance refers to the disturbance caused by construction disturbance that is controlled within a small strain range or strain control threshold. For shield tunneling construction in water rich rock layers under sensitive buildings, after filling and grouting treatment, it is left to stand for a certain period of time (12 hours in this project). After the slurry solidifies, the shield tunneling is carried out with micro disturbance to reduce disturbance to the grouting area and prevent water inflow during the excavation process. During the process of shield tunneling after full section grouting, if it is found that the rare earth pressure of the excavated soil has increased and the incoming water at the excavation face position has increased, it indicates that the grouting and water blocking effect has weakened, and excavation should be stopped and full section grouting construction should be carried out again. During the construction of shield tunneling with micro disturbance, attention should be paid to the following aspects: (1) Controlling the tunneling speed: During the shield tunneling process, the cutterhead speed and propulsion speed should be set reasonably, and the uniform propulsion should be maintained as much as possible to avoid the disturbance of the formation and grouting cracks caused by the rapid rotation and propulsion of the cutterhead, which may cause loosening of the surrounding formation and water influx into the grouting cracks. (2) Control soil chamber pressure: In shield tunneling, the data acquisition system of the shield machine is used to monitor the soil chamber pressure in real time, and the fluctuation amplitude of the soil chamber pressure is controlled within 20KPa. In this way, regardless of whether the shield machine is in excavation or shutdown state, the balance between the soil chamber pressure and the face can be relatively maintained, avoiding large fluctuations in soil pressure and disturbance to the excavated strata. If the pressure in the soil silo increases and the slag becomes thinner, it indicates that the water blocking effect of the grouting cracks has weakened and corresponding measures need to be taken. (3) Controlling the shield tunneling posture: Controlling the shield tunneling posture can not only reduce the disturbance to the formation and grouting cracks, but also ensure uniform clearance at the shield tail and prevent a decrease in the sealing effect at the shield tail. Therefore, in excavation, it is advisable to ensure that the axis of the shield machine is aligned with the design axis as much as possible to reduce the amount of deviation.

CONCLUSION

The full face grouting reinforcement technology in the shield earth silo in the water rich rock stratum has the characteristics of construction safety, reliability, environmental protection, etc., which avoids a large number of house acquisition and demolition and surface construction constraints. It is creative and progressiveness in similar technologies, and has obvious advantages in shield construction in the complex urban environment. With the expansion of urban rail transit construction scale, there are more and more projects using shield tunneling in water rich strata under sensitive buildings. The technical research of this project will provide important references for similar projects in the future, and the social benefits are significant. The economic benefits are mainly reflected in the following aspects: firstly, the use of full section grouting reinforcement technology in the shield soil chamber of water rich rock layers reduces the cost of house demolition and reinforcement; Secondly, it reduces the construction cost of deep hole grouting and waterproofing from the surface; Thirdly, the construction technology of full section grouting shield tunneling has high efficiency, saving construction period and reducing project management costs.

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