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PREVENTION AND DRAINAGE TECHNOLOGY FOR ANTI-STUCK AND DISCHARGING DURING SHIELD TUNNELING IN COMPLEX RED ROCK STRATA WITH ULTRA-LARGE DIAMETER UNDER NORMAL AND PRESSURIZED CONDITIONS

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ABSTRACT

During the construction process of shield tunnelling with ultra-large diameter under normal and pressurized conditions, problems such as mud cake formation on the cutterhead, stagnation of mud in the chamber, blockage of slurry discharge chute, high cutterhead torque, and slow excavation speed are prone to occur. In severe cases, these issues can impact construction progress and pose a threat to construction safety. Taking the Guangzhou Haizhu Bay Tunnel project as a case study, this paper proposes prevention and drainage technology for anti-stuck and discharging during shield tunnelling in complex red rock strata with ultra-large diameter under normal and pressurized conditions, focusing on mud slurry control, optimization of cutterhead flushing system, excavation parameter control, and cutter tool optimization.

KEYWORDS

Red rock strata, Normal and pressurized cutterhead, Mud-water balance, Anti-stuck and discharging

BACKGROUND

In recent years, with the development of economy and society, the number of ultra-large diameter shield tunnelling projects constructed in China has been increasing day by day [1-4]. Stuck discharging has a significant impact on shield tunnelling construction. On the one hand, it can cause damage to the shield machine, such as cutterhead wear, main bearing seal damage, excessive wear of the screw conveyor, etc [5,6]. On the other hand, it will lead to difficulties in shield tunnelling, severe over-excavation, difficult control of settlement, and even collapse [7-9].

The shield cutterhead clogging with muck is a common challenge encountered during shield tunnelling in cohesive soil layers such as weathered (full, middle) mudstone, muddy siltstone, muddy sandstone, silty soil, silty clay, etc [10]. It is a phenomenon in which the shield cutterhead cuts through the soil in the above-mentioned layers during tunnelling, causing the excavated muck to become trapped between the cutterhead and the tunnel face. Under the squeezing action of the shield machine, this muck forms solid or semi-solid block-like material that adheres to the cutterhead [11,12]. When the shield cutterhead clogs with muck, the cutter tools on the cutterhead will gradually get stuck in the hardened clay, resulting in reduced penetration depth when cutting through the soil layers. When the tools are completely covered by the muck cake, the cutterhead effectively becomes a cylindrical shield. If tunnelling continues in this state, the friction between the shield machine cutterhead and the tunnel face converts kinetic energy into heat, leading to a physical and chemical process similar to “clay burning pottery.” This will completely compromise the cutting ability of the shield cutterhead and significantly decrease the controllability of tunnelling risks, posing a major threat to equipment safety [13-15]. Therefore, research on the mechanism, prevention, and control technology of muck cake formation is particularly important [16].

This article takes the Haizhuwan Tunnel in Guangzhou as an example to analyze the prevention and treatment of muck cake formation during shield tunnelling with large-diameter EPB (Earth Pressure Balance) and pressurized cutterhead. The composite bottom layers crossed by the tunnel are mainly composed of highly weathered and strongly weathered mudstones and mud siltstones, which are rich in clay mineral particles and powdery materials. These debris and powdery materials with sticky particles serve as the basic materials for muck cake formation during tunnel construction. Mudstones and mud siltstones with clay and debris content exceeding 30% are highly prone to muck cake formation. In order to compare the formation and prevention of muck cakes during shield tunnelling with large-diameter EPB and pressurized cutterheads, the East-West Line Tunnel employed EPB and pressurized cutterhead EPB tunnel boring machines for construction. A systematic study was conducted on the causes and risks of muck cake blockage and accumulation with large-diameter EPB and pressurized cutterheads, summarizing the experience of shield tunnelling with large-diameter EPB and pressurized cutterheads to mitigate the risks of blockage, improve tunnelling efficiency, and provide references for similar projects.

INTRODUCTION TO ENGINEERING BACKGROUND

This project is the Haizhuwan Tunnel project, with the main line design mileage ranging from EK0-415.730 to EK3+933.057, totaling 4348.787 m in length. The starting point of the main line design of this project connects to the existing Dongxiaonan Viaduct, and the route extends southward in the form of a double-tube single-layer shield tunnel, passing under the Pearl River Likeng Waterway, Luoxi Island, and Sanzhixiang Waterway. After the shield tunnel ends at the north end of Nanpu Avenue, it continues in the form of a buried tunnel to cross Nanpu Avenue and connect to the ground, linking up with the bridges of the southern section of the project.

The centerline design adopts the revised planned centerline based on the urban planning and starts with a two-way 4-lane bridge connecting to the Dongxiaonan Viaduct. After crossing Nanzhou Road, it goes underground, with a shield tunnel passing under the Pearl River Likeng Waterway, Luoxi Island, and Sanzhixiang Waterway. Heading south, it transitions to an underground tunnel to cross Nanpu Avenue, then emerges at the surface to connect with the bridges of the southern section of the project. The tunnel has a total length of 3463.057 m, with the shield tunnel section totaling 2077 m and the cut-and-cover section totaling 1386.057 m. The outer diameter of the shield tunnel is 14.5 m, providing a double 6-lane configuration. The minimum horizontal radius of the shield tunnel section is 1000 m, while the onshore section has a minimum horizontal radius of 450 m, and the minimum radius for the Dongxiaonan Viaduct is 160 m. The net distance between adjacent tunnel sections is generally not less than 1.0 D, with the connection between the starting and receiving sections controlled at 0.6-0.7 D. The minimum distance between the slope change points inside the tunnel is 342.467 m, all meeting the standard requirements. The main line has a minimum gradient of 0.3% and a maximum longitudinal slope of 4%. The vertical curve minimum radius for the viaduct section is 3000 m, meeting the requirement for a design speed of 60 km/h; while for the tunnel section, the minimum vertical curve radius is 3800 m, also meeting the design speed requirement of 60 km/h.

The strata mainly crossed by the shield tunnel section are composed of strong, medium, and slightly weathered silty sandstone. The longitudinal section layout is shown in Figure 1.

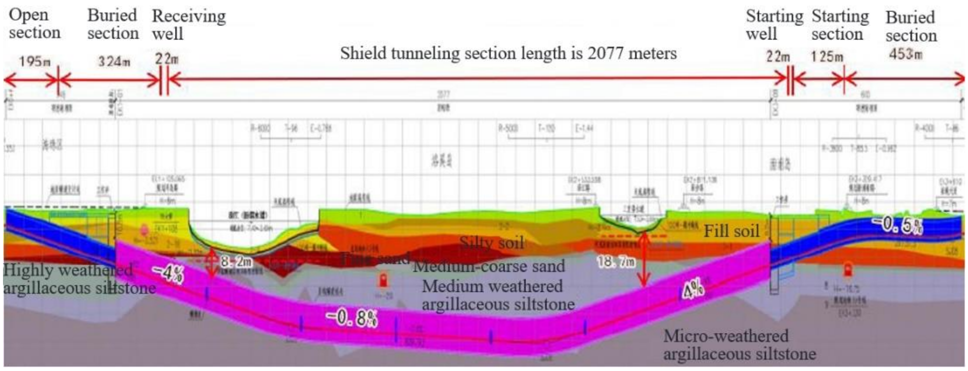

Fig. 1 – Schematic Diagram of Geological Conditions in the Hai Zhu Wan Tunnel Shield Section

The middle section of the tunnel is constructed using the shield tunnelling method, with a circular cross-section for the shield tunnel section. The outer diameter is 14.5 m, inner diameter is 13.3 m, and the thickness of the segment is 0.6 m. The cross-section layout is shown in Figure 2.

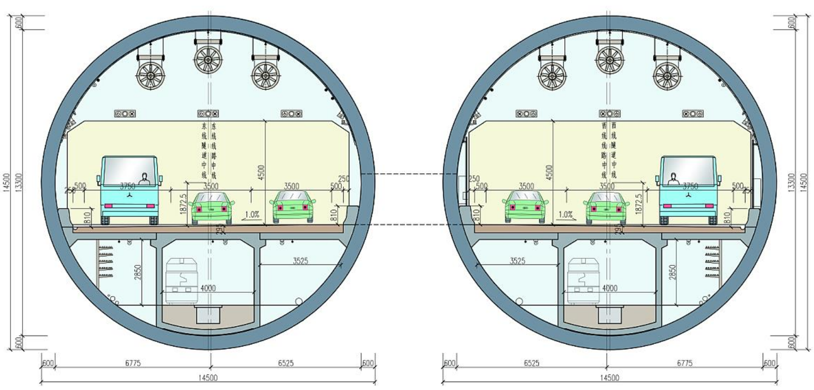

Fig. 2 – Diagonal Splitting of Bridge Abutment Cap Beam Block

OVERVIEW OF THE SHIELD TUNNELING MACHINE

Two slurry balanced shield tunnelling machines are used in the shield tunnelling section. The excavation diameter of the shield machine is 15.07 m. The shield machine on the east line consists of a shield machine main body and 4 trailing gantries; the shield machine on the west line consists of a main body and 5 trailing gantries, with a maximum excavation speed of 50 mm/min.

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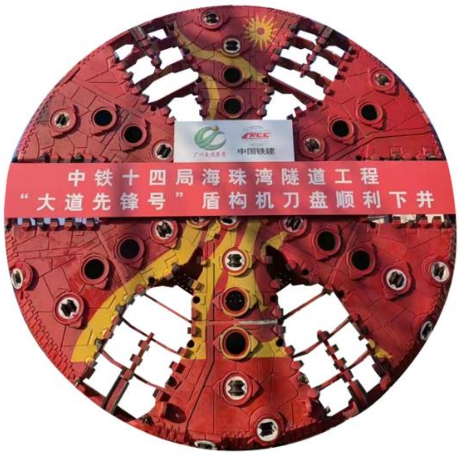


Fig. 3 – Layout Drawing of the Cutterhead (Atmospheric) on the West Line

Fig. 4 – Layout Drawing of the Cutterhead (Pressurized) on the East Line

The West Line features a Herrenknecht slurry balanced shield tunnelling machine with a cutterhead diameter of 15.07 m, a total machine length of 152 m, a machine weight of approximately 4495 t, and a total machine power of about 11200 kW. The main drive power is around 5600 kW, with a rated torque of 42972 kN.m at 1.13 rpm. The working pressure of the shield machine is 9 bar. The cutterhead excavation diameter is 15.07 m, and the cutterhead is equipped with a pressure-controlled tool changing function, featuring a panel structure with an opening rate of 30%. The cutterhead is equipped with a total of 246 cutting tools and 12 sets of edge scraping blade components, with the specific tool configuration including 50 replaceable scraping blades for atmospheric pressure, 12 replaceable center disc cutters for atmospheric pressure, 60 replaceable face disc cutters for atmospheric pressure, 4 replaceable edge disc cutters for atmospheric pressure, 150 standard scraping blades, and 12 sets of standard edge scraping blades, achieving “full coverage” of the cutterhead excavation trajectory, as shown in Figure 3.

The East Line features a CREG slurry balanced shield tunneling machine with a cutterhead diameter of 15.07 m, a total machine length of 128 m, a machine weight of approximately 4300t, and a total machine power of about 9755 kW. The main drive power is around 5600 kW, with a rated torque of 42784 kN.m. The maximum total thrust is 222173 kN, and the shield machine is designed with a maximum pressure capacity of 8 bar. The cutterhead excavation diameter is 15.07 m, and the cutterhead does not have a pressure-controlled tool changing function. It has a star-shaped spoke structure with an opening rate of 35%. The cutterhead is equipped with a total of 387 cutting tools and 16 sets of edge scraping blade components. The specific tool configuration includes 6 center disc cutters with a height of 160 mm and a spacing of 101.5 mm, 77 face disc cutters with a height of 160mm and a spacing of 75 mm, 22 edge disc cutters, 180 wide cutting knives with a height of 115 mm and a spacing of 220 mm, 16 sets of edge scraping blades, and 2 overcutting knives with an overcut of 50 mm, achieving “full coverage” of the cutterhead excavation trajectory as shown in Figure 4.

ANALYSIS OF SLURRY BALANCE SHIELD TUNNELING MACHINE WITH SUPER LARGE DIAMETER FOR MUCK DISCHARGE

The geological strata that the shield tunnel passes through in the middle section of the river mainly consist of strong, medium, and slightly weathered mudstone sandstone. Locally at both ends, it passes through silty clay, medium-coarse sand, and powdery clay layers. The cutterhead at the center of the shield tunnel on the west line has no opening, with a small opening rate of 30%. The cutterhead opening rate for the east line with a pressurized cutterhead is 35%. In the mudstone sandstone formations, the cutterhead and cutter barrel are prone to mud cake formation, leading to blockages in the muck discharge chute and causing muck stagnation. In complex formations such as fractured zones and heterogeneous strata, as well as in formations with developed joint fissures, there may be issues with inadequate muck discharge or blockages, which, if not properly addressed, could lead to serious consequences.

According to the types of muck accumulation, there are three types of muck stagnation in super large-diameter slurry balance shield tunnelling machines: bottom-type, mud cake-type, and middle-type stagnation.

1. High-strength muck chunks are prone to form bottom-type muck stagnation

The muck consists of large particle size and high-strength muck chunks that accumulate at the bottom of the shield tunnel, blocking the muck discharge chute and outlet, affecting the circulation of the slurry, preventing timely muck removal, resulting in increased tunnelling torque, thrust, decreased speed, abnormal tunnelling parameters, leading to tunnelling difficulties, and causing wear on the surrounding cutter tools, forming bottom muck stagnation.

2. Mud cake-type muck stagnation

The muck is in the form of mud cakes, which adhere to the cutterhead and cutter barrel, causing mud cake buildup in the central area of the cutterhead and cutter barrel, leading to the loss of rock-breaking and soil-cutting functions of the cutter tools. If the mud cakes are severe, it can also result in abnormal shutdown of the tunnel boring machine.

3. Soft on top and hard below easily form midsection muck stagnation

Midsection muck stagnation primarily accumulates in uneven formations with soft on top and hard below, leading to midsection muck stagnation at the cutterhead, unbalanced shield thrust, difficult excavation, and challenging posture control.

MUCK SLURRY ANTI-STAGNATION TECHNOLOGY

Enhancing slurry carrying capacity of muck

1. Principle of mud treatment

This project mainly crosses the mudstone layer, with strong agitating ability and quick density increase, which easily causes mud-cake formation on the cutter head and tool adhesion. For high-density waste slurry, it is first pretreated through a separation system, and then subjected to secondary treatment through a centrifuge and filter press to achieve the purpose of reducing mud performance indicators. To expedite the density reduction process, a suitable coagulant solution for this density is prepared in advance and mixed in the pipeline before centrifugation or filtration. By operating the centrifuge at high speed, the soil and coagulant are separated, thereby achieving the desired density reduction effect. The mud treatment process is shown in Figure 5.

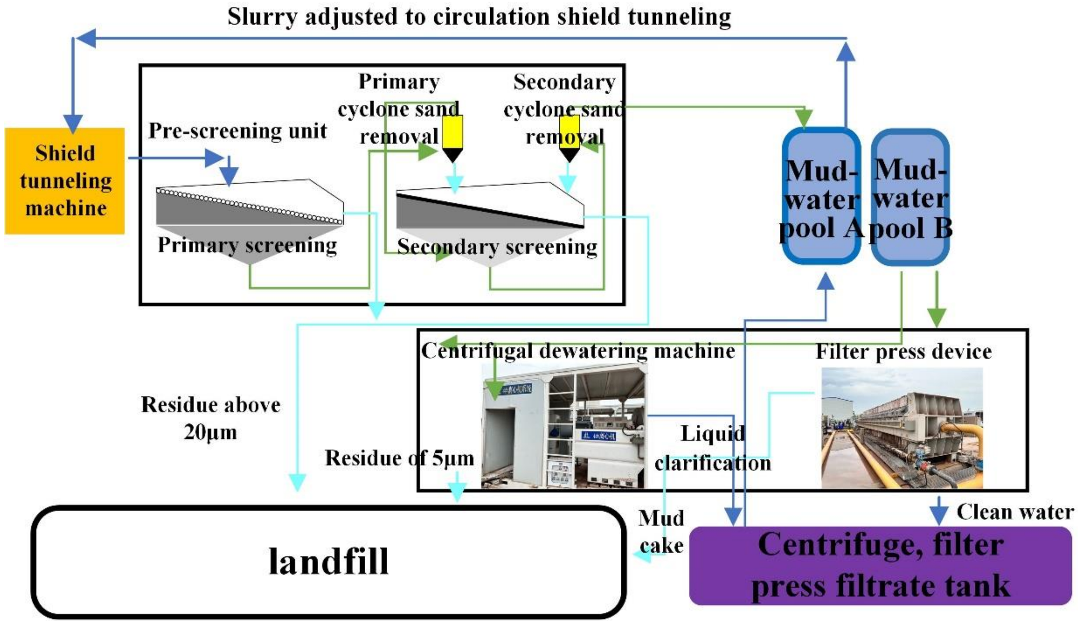


Fig. 5 – Mud-water Treatment Process

2. Pre-treatment of mud separation system

After the mud discharged by the shield tunnelling machine is pre-separated by a 2-layer coarse sieve vibrating screen in the mud separation system, the slag with particle size >3mm is separated, and the screened mud enters the primary slurry tank. The project is equipped with 12 sets of slurry pump feeding into 12 sets of primary cyclone units (6 sets for the east line and 6 sets for the west line), where the mud undergoes sand removal through the cyclone desander. The fine mud and sand are discharged from the lower end sand nozzle into the lower fine sieve of the mud removal screen. The overflow from the cyclone desander enters the primary intermediate tank, where it is discharged via the drainage pipe or enters the primary and secondary slurry tanks. The thick slurry from the bottom outlet of the secondary cyclone desander enters the upper fine sieve of the mud removal screen. The underflow from the primary and secondary cyclones is dewatered and sieved, separating the dried fine slag material, while the screened slurry liquid enters the primary slurry tank. The overflow from the secondary cyclone enters the settling tank, slurry conditioning tank, or secondary sand removal system. During the shield tunnelling process, if the primary sand removal system is insufficient to reduce the mud density and sand content to a reasonable range, the slurry outlet valve can be switched to allow the mud to enter the secondary sand removal system (which operates on the same principle as the primary sand removal system). Clusters of small diameter cyclone desanders can remove residual powder particles with a particle size >20 μm in the mud. If the secondary sand removal system also cannot reduce the mud density to a reasonable range, chemical coagulants from the chemical tank can be pumped into the slurry conditioning tank for viscosity reduction treatment.

3. Waste pulp centrifuge + filter press treatment

In this project, polyacrylamide is used as a coagulant, and the solute and solvent are added quantitatively. After fully dissolving through stirring with a stirrer, the expansion time is >15 min, and the settling time is ≤12 h. After the solution is fully expanded, the solution and high concentration slurry are mixed at the pipeline before the centrifuge using a diaphragm pump. The flow rate of the solution is dynamically adjusted according to the slurry density and flow rate.

The amount of excavation slurry for one ring (2 m) of shield tunnelling in this project is 360 m^3, which will be treated using a centrifuge. Calculated based on the assumption that particles with a particle size <20 μm account for 30% of the total volume of the excavated stratum, 3000 m^3 of mud circulation is required during normal excavation to increase the mud density by 0.05 t/m^3. If the adjusted density of the standby mud is 1.10 t/m^3, then a maximum of two rings can be excavated, and the mud density will rise to 1.2 t/m^3. Calculated based on the efficiency of one centrifuge processing mud at 60-80 m^3/h, it will take 50 h to process 3000 m^3 of mud. Assuming each ring of shield tunnelling takes 4 h, excavating two rings would require 8 h. Therefore, it can be calculated that 6 centrifuges are needed to meet the normal excavation requirements of the shield tunneling.

4. Dynamic control of mud parameters

During each circulation, mud parameters are tested at least twice to ensure that the mud performance meets the excavation requirements. Simultaneously, mud particle analysis should be conducted to understand the separation capabilities of the mud equipment and the distribution of various particle soils in the strata. Mud control indicators include density, viscosity, and sand content. In the shield tunnelling process, mud density is the main control parameter, and its value should neither be too high nor too low. An excessively high density will affect the mud carrying capacity, while an excessively low density will affect the stability of the face. According to the actual excavation conditions of this project, the mud density should be controlled between 1.1 and 1.2 g/cm^3. Mud viscosity is also a key control parameter in the shield tunnelling process. In terms of suspended soil particles, higher mud viscosity is preferred, but excessively high viscosity can lead to mud cake formation on the cutterhead and blockage of the cutter. Based on the actual excavation conditions of this project, the mud viscosity should be controlled between 16.5 and 26.3 Pa·s. In highly permeable strata, the formation speed of the mud film is directly related to the sand content in the mud. This is because sand particles play a role in plugging the pores of the soil mass; therefore, the sand particles should have larger grain sizes compared to the soil mass pores, and the content should be moderate. Therefore, when excavating in mudstone with a shield, attention should be paid to the formation speed of the mud film, and the sand content should be controlled at 10-20%. The control range of mud parameters in the red bed geology is shown in Table 1.

Tab. 1 - Mud Parameters in Red Bed Geology

Mud Parameters	Density	Viscosity	Sand content
Range	1. 1～1. 2 g/cm^3	16. 5～26.3 Pa·s	10～20%

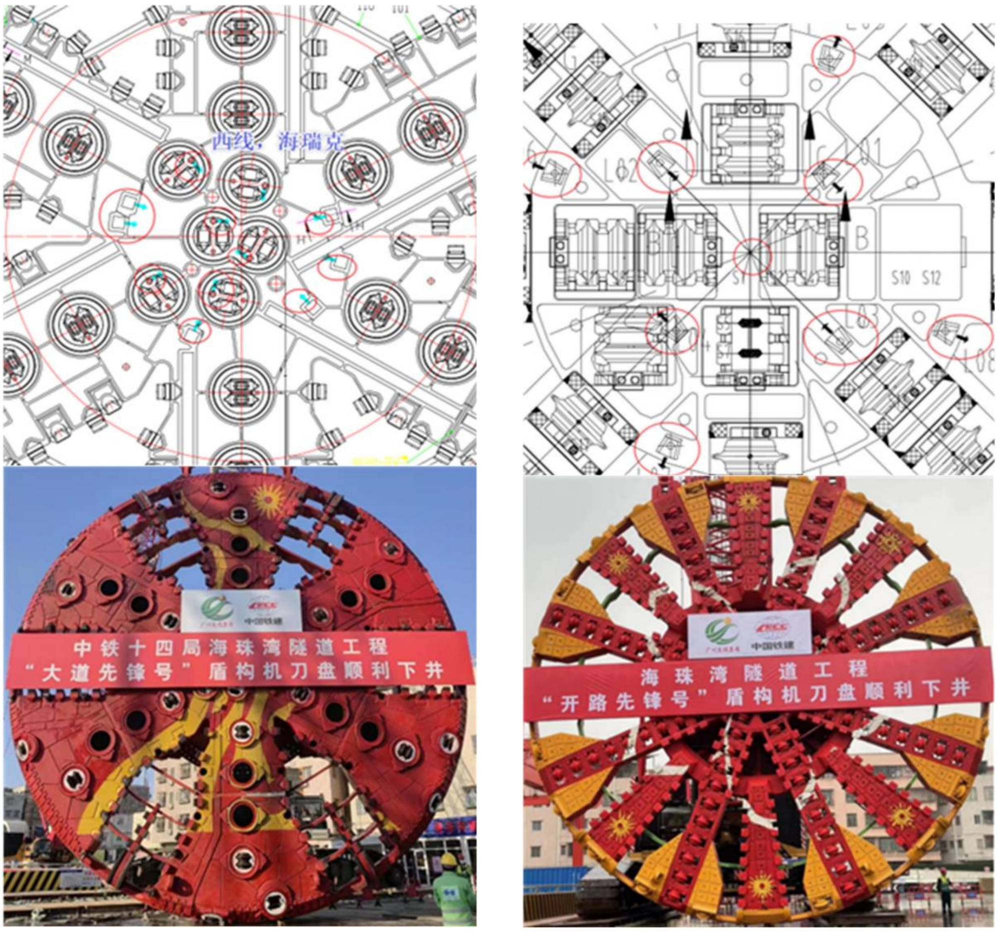
Enhanced layout of high-flow radial flushing system at the center of the cutter disc.

Utilize the cutter disc’s built-in flushing system to perform high-pressure flushing on the slurry discharge chute, central area of the cutter disc, and cutterhead during shield tunnelling or downtime, strengthen the layout of the high-flow radial flushing system at the center of the cutter disc to prevent mud cakes in the central area of the cutter disc.

During shield tunnelling, ensure constant slurry flow and strengthen the bottom and center flushing of the cutter disc, while other pipelines can be alternately flushed. The number of center flushes on the cutter disc is shown in Table 2. During the manufacturing process of the cutter disc, 12 and 9 flushing holes are respectively designed at the center positions of the normal pressure cutter disc and the pressurized cutter disc panel (see Figure 6). To prevent tool wear caused by mud sticking to the cutter disc, cyclic flushing of the panel is carried out continuously during shield tunnelling.

Tab. 2 - Number of Center Flushes on the Cutter Disc

Cutter disc type	Normal pressure cutter disc	Pressurized cutter disc
Center brush (each)	12	9



（a）West Line Normal Pressure Cutter Disc （b）East Line Pressurized Cutter Disc

Fig. 6 – Cutter Disc Flushing Port Setting

Handling cutter disc mud cakes.

In this project, the west line is operated with normal pressure for unloading. It was found that the cutter disc center was clogged with mud cakes and all 6 slag discharge slots at the cutter disc edge were completely blocked. The east line has fewer blockages. The following measures were taken to solve the issue. A comparison of mud cake handling methods for normal pressure and pressurized cutter discs is shown in Table 3.

1. Reduce the mud density, the slurry density during excavation must be＜1. 15 t/m^3.

Add a central flushing port in the center of the cutter disc, increase the flushing pressure to generate a pressure difference of 0.3 MPa between the flushing pressure and the mud water tank pressure.

2. Add a flushing port to the center cutter barrel, realize real-time flushing by branching off from the central flushing pipeline. At the same time, cut off the failure wear monitoring blade near the center of the cutter disc.

3. Weld cutting teeth on the cutter barrel to timely scrape away the uncut debris from the roller cutter, reducing the probability of cutter head clogging.

Tab. 3 - Mud Cake Treatment Methods for Atmospheric Pressure and Pressurized Cutter Discs

Type	Method
Earth Pressure Balance Shield	Increase scouring pressure and flow rate
	Move the suction port forward
	Add swelling agent
	Clean with high-pressure water gun arm by arm
	Remove with a pickaxe
Pressure Balance Shield	Cut off the spokes
	Clean arm by arm with a high-pressure water gun
	Cut off the spokes

Control the excavation parameters

1. Optimize the excavation parameters

Based on the geological conditions of shield tunnelling, changes in tunnel depth, etc., control the construction process. By using advanced geological coring, mud particle detection, monitoring of the quality of formed tunnel segments, and measurement data, make timely adjustments and optimizations to various excavation parameters. Recommended values for excavation parameters and control measures are shown in Table 4.

Tab. 4 - Recommended Values of Excavation Parameters and Control Measures

Tunnelling parameters	Recommended values	Control measures
Mud-water tank top pressure /MPa	Tunnel burial depth /10+0.02 MPa，Burial depth unit: m	The pressure fluctuation control range for each cycle is±0.01 MPa，Strictly prohibited to make large adjustments to the pressure
Slurry density / (g /cm^3)	1.1~1. 2 g/cm^3	Comprehensively considering the ability to carry slag and the ability to maintain stable tunnel face pressure with slurry shield
Slurry viscosity / (Pa·s)	16.5~26.3 Pa·s	Adjust accordingly based on the slurry carrying capacity
Discharge slurry density / (g/cm^3)	1.2~1. 3 g/cm^3	After the slurry discharged by the shield tunneling machine is treated by the separation equipment, centrifugal treatment is conducted for the slurry with a density greater than 1.18 g/cm^3
Discharge slurry viscosity / (Pa·s)	17.3~26.8/ Pa·s	Adjust the slurry with viscosity not meeting the requirements based on previous experience
Excavation speed / (mm/min)	8~16	The fluctuation of the speed per ring should not be too large
Total thrust	—	Combine torque with advance rate, and make appropriate adjustments based on the pressure situation of the cutterhead
Cutterhead torque	—	Strictly control the torque fluctuation, and the torque fluctuation of a single ring should be≤500 kN·m
Cutterhead rotational speed / (r/min)	2.0~2.4	Match with the torque fluctuation value
Penetration rate	3.1~5.2	Control the penetration depth
Cutterhead thrust force	—	Control the fluctuation value within 5000 kN

2. Excavation parameters management

Control the pressure in the slurry chamber, strictly control the slurry balance during the excavation process, calculate the pressure based on the tunnel depth using hydrostatics, and make dynamic adjustments during actual construction by combining past construction experience and monitoring data.

During shield tunnelling, strictly control the performance of the slurry, conduct tests on slurry density, viscosity, and sand content, and make dynamic adjustments to ensure the quality of slurry film formation and its ability to transport debris. Sample the excavated soil and compare it with the survey and design report to guide the optimization of excavation parameters.

During shield tunnelling, use torque fluctuation and cutterhead thrust as reference parameters to match thrust, torque, and speed, ensuring uniform advancement.

Increase the center flushing flow rate of the cutterhead to 1200-1500 m^3/h.

PREVENT STICKING AND BLOCKING DURING TUNNELING IN SOFT UPPER AND HARD LOWER STRATA

1. Utilize a hydraulic breaker to crush rock blocks

Increase the operational frequency of the crusher to crush the rock blocks accumulated at the slag discharge outlet, prevent the rocks from getting stuck at the slag discharge outlet or crusher position. At the same time, increase the circulation flow rate of the mud to flush the rock blocks crushed at the slag discharge outlet position and bottom, preventing blockage at the slag discharge outlet.

Extend the circulation time to completely discharge the sediment in the silo, maintaining the liquid level in the silo as close to zero as possible. Increase the flushing flow rate at the bottom of the mud, while adjusting the viscosity of the mud to a higher level to enhance the slurry's carrying capacity of slag.

2. Increase the pressure in the mud-water tank appropriately

Slightly increase the pressure in the mud-water tank to prevent the dropping of rock blocks from the top. The pressure set value of the mud-water tank is the calculated theoretical pressure value + 0.02 MPa, with the pressure fluctuation range per cycle controlled within ±0.01 MPa. It is strictly prohibited to make significant adjustments to the pressure.

3. Increase the mud indices appropriately

Appropriately increase the mud indices, using high-performance mud to fill the cracks on one hand and enhance the mud carrying capacity of slag on the other hand, which is beneficial for slag discharge. The slurry density control is set at 1.1~1.2 g/cm^3， the slurry viscosity control is maintained between 16.5~26.3 Pa·s, the discharge density control is set at 1.18~1.19 g/cm^3， and the discharge viscosity control is maintained between 17.3~26.8 Pa·s.

4. Targeted flushing

Enhance the flushing of the mud circulating at the bottom of the cutterhead, strengthen the flushing of the bottom of the cutterhead and the slag discharge chute, use reverse flushing to prevent silting and blockage that may cause stagnant discharge.

5. Tool optimization

Uneven formation rock strength with soft top and hard bottom can easily lead to abnormal tool damage. Rational selection and configuration of tools, as well as control of cutterhead torque and pressure, are prerequisites for protecting the tools.

The cutterhead is equipped with a single-axis dual-blade roller cutter that can be replaced under normal pressure, with the scraper to break rocks. The red formation has a certain strength, and the smooth blades are prone to wear and impact damage during excavation. Due to the inability to simultaneously meet the wear resistance and impact resistance requirements of the tools based on the hardness and toughness of the metal materials, single-edge and double-edge toothed roller cutters are used after experiments (refer to Figure 7), with wear-resistant tungsten carbide hardfacing on the cutter ring and tooth bed. The embedded teeth enhance impact resistance, while the hardfaced tungsten carbide improves wear resistance, thereby enhancing rock breaking capability and increasing excavation efficiency.

（a）*Single-edge toothed roller cutter* （b）*Double-edge toothed roller cutter*

Fig. 7 – Toothed roller cutter

6. Blade blockage prevention

After the mudstone is crushed, it forms mud powder with a free expansion rate of up to 30%, and a cohesive strength of up to 3 MPa, and a saturated water absorption rate of 2%. During the excavation of the mudstone section, the mud powder enters the cutter barrel with the rotation of the tool. With the increase of excavation time, the tool temperature rises, which makes it easy to cause residue accumulation in the cutter barrel.

Based on the shape of the cutter barrel for the shield tunnel boring machine under normal pressure during the mud-water balance and the condition of debris monitoring pipeline in the cutter barrel during excavation, the inside and outside of the cutter barrel are treated with rubber rings. By installing rubber rings, the accumulation of debris in the cutter barrel is reduced to ensure the normal operation of the tool rotation monitoring system.

CONCLUSION

1. An analysis of anti-blocking and discharge measures in the construction of red bed geology is conducted in terms of improving the slurry carrying capacity. It is found that by dynamically controlling the slurry density, viscosity, and sand content index, the slurry carrying capacity can be enhanced to prevent slurry blockage. High slurry density affects the slurry carrying capacity, while low density affects the stability of the face of the cutterhead.

2. The higher the slurry viscosity, the better the carrying capacity of debris, but excessively high viscosity can lead to mud cake formation on the cutterhead and blockage of the cutter barrel. The formation speed of mud film is directly related to the sand content of the slurry, which should be moderate. According to the actual excavation conditions of this project, the slurry density should be controlled within the range of 1.1 to 1.2 g/cm^3, the slurry viscosity should be controlled between 16.5 and 26.3 Pa.s, and the sand content should be maintained at 10 to 20%.

3. An analysis of anti-blocking and discharge measures in the construction of red bed geology is carried out from the aspects of strengthening the layout of high-flow radial flushing system at the center of the cutterhead and dealing with mud cake on the cutterhead. It is found that during shield tunnelling, maintaining a constant slurry flow rate and enhancing bottom and center flushing of the cutterhead are essential. For the center positions of the cutterhead with normal pressure and pressurized face plates, 12 and 9 flushing holes are respectively designed to prevent tool wear due to muddy cutterhead. Measures such as increasing flushing pressure and flow rate, moving the suction mouth forward, adding bentonite, arm-by-arm cleaning with high-pressure water gun, removing ribs, and chiseling with pneumatic picks are implemented to prevent and control mud cake

formation.

4. Research on anti-blocking and discharge in the upper soft and lower hard strata shows that measures such as breaking rock blocks with a hydraulic hammer, moderately increasing the pressure in the mud chamber, adjusting mud parameters appropriately, targeted flushing, and optimizing tools can effectively prevent blockages.

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