Article no. 12

THE CIVIL ENGINEERING JOURNAL 2-2024

CONSTRUCTION METHODS AND APPLICATION OF TBM IN SHENGLI TUNNEL OF TIANSHAN MOUNTAIN UNDER POOR GEOLOGICAL CONDITIONS

Zhao Zhenping[1,2], Chen Jianxun[3], Geng Qi[4], Li Dong[1], Huang Dengxia[1], Luo Yanbin[3], Liu Weiwei[3], Mu Shaoping[4], Peter Anesu Kanhenga[4] and Wu Teligen[1]

1. *CCCC Central-South Engineering Company, LTD, Changsha, Hunan 410114, China, email: 230188190@seu.edu.cn*
2. *School of Civil Engineering, Southeast University, Nanjing, Jiangsu 211189, China*
3. *Highway School, Chang'an University, Xi'an, Shaan Xi 710064, China*
4. *School of Construction Machinery, Chang'an University, Xi'an, Shaan Xi 710064, China*

ABSTRACT

When a tunnel boring machine (TBM) excavates in poor geological conditions like fracture zones, soft rock with high ground stress, hard rock with high ground stress, and water inrush ground, severe problems such as surrounding rock collapse, convergence, rock burst and water and mud outburst are usually encountered. These problems existed in the Tianshan Shengli Tunnel project in Xinjiang, China. Several methods and techniques were adopted to reduce the construction risks and improve the construction efficiency. The seismic wave reflection long-distance geological forecasting method was employed to forecast and predict these adverse geological conditions. The pre-reinforcement construction method was employed on the surrounding broken rocks in front of the tunnel face to lower the risks of tunnel collapse and machine jamming. A combined steel arch was applied to prevent tunnel arch collapse. An artificial cap method was applied to prevent the jamming caused by high-ground stress soft rock. Measures such as spraying water on the tunnel face and drilling stress holes were employed to prevent rock bursts caused by high-ground stress in hard rock. Implementing the advanced pipe shed method during water influx, sudden mud, and other working conditions reduced the risk of groundwater damage to equipment and lowered risks to personnel safety. The successful application of these techniques can provide a reference for TBM tunnel construction in similar ground conditions.

KEYWORDS

TBM, Poor geology, Geological forecasting, Tunnel face pre-reinforcement, Advanced pipe shed method

INTRODUCTION

In recent years, the Full-face Tunnel Boring Machine (TBM) has been widely used for hard rock tunnel construction. A Full-Face Tunnel Boring Machine (TBM) is an engineering device that crushes rock by rotating and pushing the cutter head. It excavates the entire tunnel cross-section in a single pass and has other advantages, such as high construction speed and reliable quality, to mention a few. Recently, it has been popular in highway, railroad, hydraulic tunnels, and other tunneling projects [1].

TBM construction requires strict geological conditions, the machine is sensitive to surrounding rock conditions and is often prone to low tunneling efficiency [2, 3]. During tunnel excavation, unfavorable geological conditions can be encountered, such as fault fracture zones, high-stress soft rock, rock bursts, and water and mud intrusions. More severe problems such as surrounding rock collapse, convergence, rock burst, and water and mud outbursts are usually encountered, resulting in a hazardous and difficult construction process heavily affecting TBM efficiency.

Construction measures under a fault fracture zone:

Addressing the issue of tunnel collapse constructed under a fault fracture zone, Chen et al. [4] put forward the collapse remediation program of "chemical grouting filling in collapsed cavities + chemical grouting reinforcing in loose bodies + spraying anchors supporting + dense arch supporting + overrunning grouting reinforcing". Yang et al. [5] proposed measures to prevent landslides: setting up meandering guide pits, pre-strengthening strata, increasing support strength, optimizing construction methods, and strengthening monitoring and measurement. Longlong et al. [6] used surface grouting, grouting inside the cave, and pipe shed to address landslide issues. Tong et al. [7] employed surface directional holes to improve the surrounding rock conditions, enabling smooth excavation through the fault fracture zone. Chen et al. [8] proposed a design method of pipe shed support parameters to ensure the safe construction of the tunnel and rock stability of the tunnel face in the fault fracture zone. The above studies mainly address the issue of tunnel collapse under a fault fracture zone by grouting reinforcement, strengthening support, and pipe shed support, to mention a few. Further research is needed on forecasting and predicting the surrounding rock conditions in front of the tunnel face and exploring the efficacy of using combined steel arches to mitigate landslides.

Construction measures under high-stress soft rock conditions:

To address the issue of soft rock deformation, enhancing the stiffness of initial support is crucial in controlling significant deformations in high-stress soft rock tunnels [9]. Liu et al. [10] conducted a systematic analysis of the failure mechanism of short anchor support in high-ground stress soft rock tunnels and demonstrated the necessity of lengthening the length of the anchor in high-stress soft rock tunnels. Wang et al. [11] proposed a design scheme based on active support with the combination of prestressed long and short anchor ropes + W-type steel belt + flexible fiber mesh, effectively controlling the deformation of surrounding rock. To mitigate initial support deformation, elevation arch bulging, and secondary lining compression collapse during the construction of high-stress soft rock tunnels, Zheng et al. [12] put forward the measures of elevation arch curvature optimization - early support double-layer steel frame - secondary lining reinforced lining - the perimeter of the hole limiting anchors and so on. Han et al. [13] searched for the optimal reserved deformation through the curvature of the characteristic curve for stress relief. The above research mainly controls the deformation of the surrounding rock by enhancing the support stiffness, and reserves deformation amount to release stress, controlling the release trend of deformation energy of the surrounding rock. However, there is relatively little research on solutions to the occurrence of jamming when there is significant deformation in the surrounding rock in front of the face.

Construction measures under high-ground stress hard rock conditions:

After the occurrence of a strong rock burst, the main beam of the tunnel boring machine got buried, and the construction progress was delayed [14]. Li et al. [15] set up reasonable spacing of tunnels to reduce the probability of rock bursts and used microseismic monitoring to assess the risk of rock bursts. In the slight rock burst and severe rock burst sections, Wang et al. [16] and He et al., [17] used water sprinkling or flooding and stress holes for stress relief, respectively. Li et al. [18] used steel pipe plates instead of steel arch support to improve the initial support operation efficiency and support capacity in the section prone to intense rock bursts and installed the whole annular steel pipe plate in the shield. The above research prevents rock bursts by setting tunnel spacing and microseismic detection and uses methods such as watering and stress holes to weaken the damage caused by rock bursts. However, there is relatively little research on the transformation of TBM water spraying systems under rock burst conditions.

Construction measures under the conditions of water and mud outbursts:

Water outbursts in the tunnel occur near the main channel of groundwater, and the magnitude of the water outburst is significantly related to the amount of rainfall [19]. Shi et al. [20] carried out overrunning small conduit grouting and secondary grouting at the tunnel vault and precise grouting at the tunnel foot and lower part of the tunnel, which can effectively reduce the occurrence of tunnel disasters, such as water surge and mud outbursts. To mitigate water and mud outbursts, Liu et al. [21] constructed drainage channels consisting of drainage wells and connecting channels to make pressurized karst water flow to the surface by itself to address water gushing and mud bursting. Lang et al. [22] proposed a water discharge treatment plan of "temporarily shelving the inclined well, high-pressure water discharge in the main cave work area, implementing in phases, and steadily approaching the head of the inclined well" to realize the safe discharge of the water in the inclined well. The above studies mainly control water and mud outbursts by grouting and plugging reinforcement and setting up the drainage. However, fewer researchers have used the over-advance pipe shed method to deal with surging water and mud-surge conditions.

This paper uses the Tianshan Shengli Tunnel project in Xinjiang, China, as a case study to address challenges encountered during construction in adverse geological conditions. It proposes construction measures such as over-advance geological forecast, pre-reinforcement construction method for tunnel face, reinforcement construction methods for the surrounding rock at the TBM gripper shoe, over-advance pipe shed method and the artificial cap method, and so on. These measures aim to achieve a holistic approach to prevention before, during, and after construction, ensuring both construction quality and the safety of personnel and equipment while enhancing construction efficiency.

OVERVIEW OF THE PROJECT AND MAJOR ISSUES

Wuwei Expressway is an integral part of China's highway G0711 Urumqi to Ruoqiang and Xinjiang across the Tianshan Mountains, connecting the north and south of Xinjiang's transportation trunk line.

Among them, the Tianshan Shengli Tunnel is the control project of Wuwei Expressway; the tunnel is 22105m long, the maximum depth is about 1150m, the import elevation is about 2767m, and the export elevation is about 2900m. The technical standard is designed according to a two-way, four-lane highway design at 100km/h. The tunnel is located near the No.1 glacier of Tianshan Mountain.

The tunnel is located in the Tianshan No.1 glacier. the tunnel has 16 fracture zones, fracture zones affect a length of 2000m, the core section length of 768m, rock burst section length of 3940m. The surrounding terrain is complex and variable, the tunnel geologic cross-section is shown in Figure 1. Water-rich fault fracture zone, soft rock with high ground stress, hard rock with high ground stress, and water inrush ground are the unique poor geology of this tunnel, severe problems such as surrounding rock collapse, convergence, rock burst, and water and mud outbursts are usually encountered.

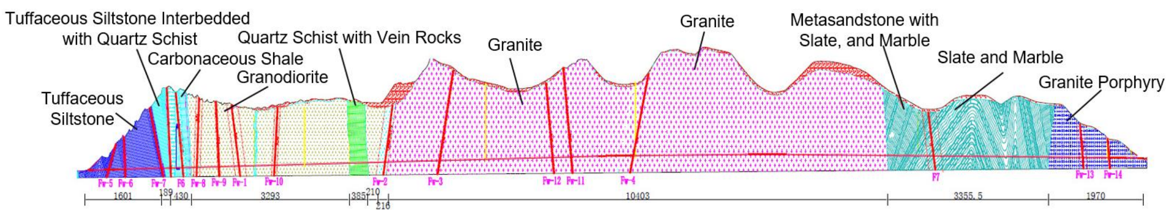

Fig. 1 - Geological longitudinal section of the tunnel

TBM CONSTRUCTION TECHNOLOGY AND APPLICATION IN FAULT FRACTURE ZONE

Long-range geologic forecasting method for seismic wave reflection

The seismic wave reflection long-distance geologic prediction method is used to detect the exact condition of the strata in front of the TBM face. This technique utilizes the seismic reflection

DOI 10.14311/CEJ.2024.02.0012

wave and surround wave to detect the geological conditions in front of the tunnel face. During the propagation of the seismic wave generated by the source to the tunnel front, the rock's relatively large acoustic impedance interfaces will generate reflected waves, and the relatively small acoustic impedance interfaces will generate wrap-around waves, collectively called seismic echo waves. The equipment collects seismic echo data from the tunnel's surrounding rock. The interface position, spatial distribution, polarity, and energy of the echo are extracted through the professional processing system, and combined with the comprehensive analysis of the tunnel geologic survey data, the purpose of the tunnel geologic advance prediction is realized.

Taking the mileage pile number PK76+108~PK76+208 of the Tianshan Shengli Tunnel project in Xinjiang, China, as an example, this project adopts the TGP (Tunnel Geology Prediction) Tunnel Geology Advance Prediction System for tunnel geology prediction work. The system is developed by the Beijing Institute of Hydropower Physical Exploration. Through the work of over-advance geological prediction, the three-component original record map of seismic wave (as shown in Fig. 2(a)) and the three-dimensional spatial cross-section scanning result map (as shown in Fig.2(b)(c)(d)) are obtained.

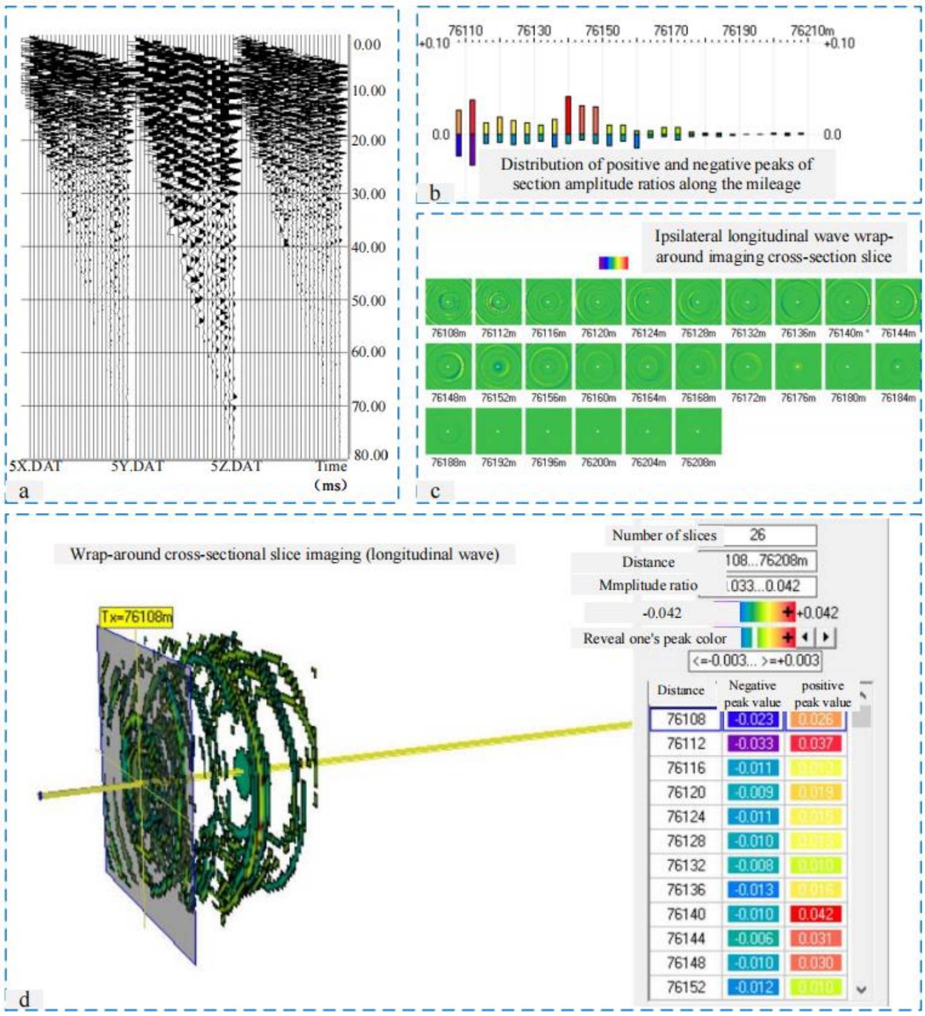

Fig. 2 (a) - The three-component original record map of the seismic wave;(b), (c), (d) the three-dimensional spatial cross-section scanning result map

The construction method of grouting pre-reinforcement on the tunnel face

According to the results of the over-advanced geological forecast and prediction, the fault fracture zone in front of the tunnel face is pre-reinforced in advance, and then the TBM will dig through it, as shown in Figure 3(a)(b). The construction method of grouting pre-reinforcement on the face can also be used in the construction of a water-rich subgrade.

The Manual handheld YT28-type hand air drilling rig drilled and grouted holes at the gap between the tool and the cutter plate. In the front of the tunnel face, twenty-two deep grouting holes were strategically arranged, each with a depth of 10m, as shown in Figure 3(c)(d). The grouting pipe adopts D25 fibreglass anchors with grouting holes. In situations where the surrounding rock is broken, and hole formation is difficult to achieve, the self-entry fibreglass anchors are used. The grouting material adopts chemical grouting, cement water glass slurry, and cement slurry. The initial grouting pressure ranges from 1.2-1.5 times hydrostatic pressure, and the inal pressure is 2-3 times hydrostatic pressure. The length of the grouting hole is about 4m, and the length of each cycle of grouting is 4m; 2m is excavated after the completion of grouting, and 2m is reserved without excavation for the next cycle of lapping.

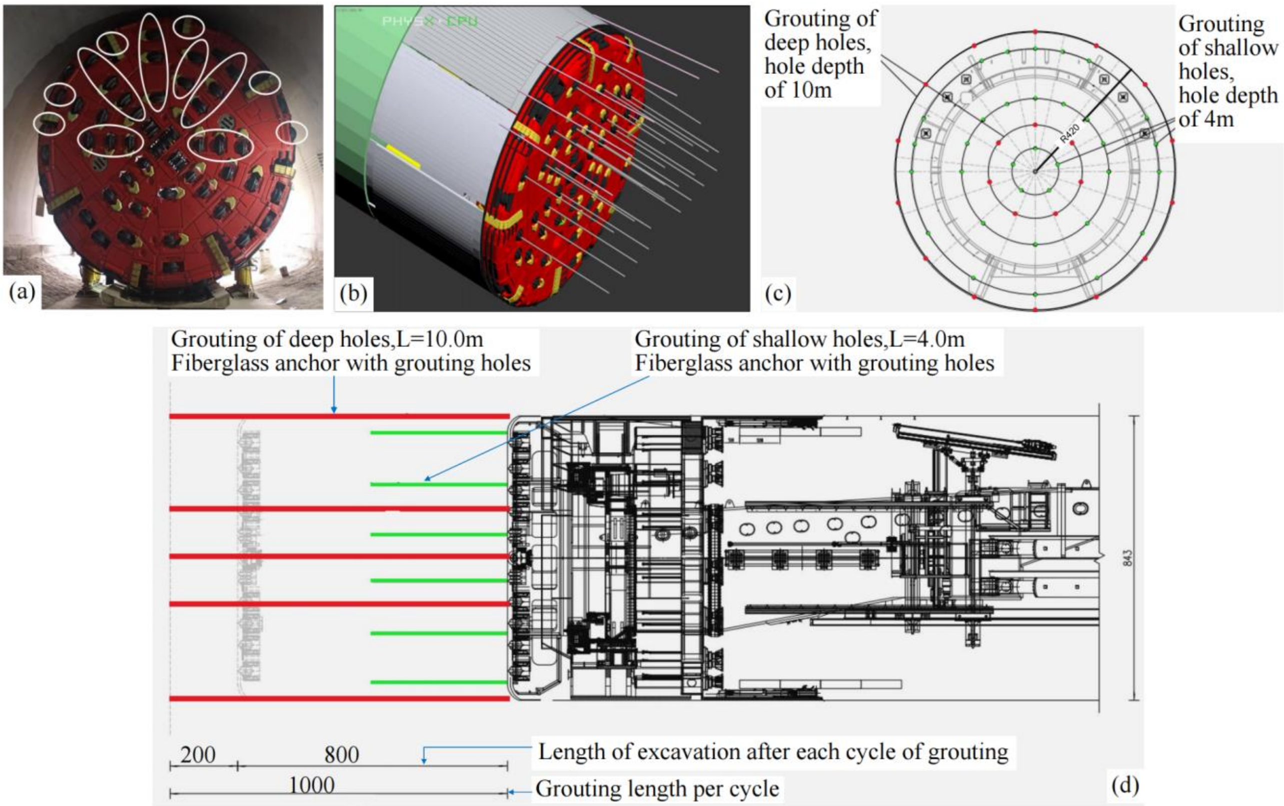

Fig. 3 (a)(b) - Schematic diagram of grouting on tunnel face;(c), (d) design drawing of overtopping grouting on tunnel face

The construction method for reinforcement of surrounding rock at TBM gripper shoe

In the event of a localized slump in the tunnel sidewall, adjustments are made to the support force of the TBM gripper shoe to alleviate pressure on the surrounding rock. Concurrently, the thrust and propulsion speed of the TBM is reduced accordingly, allowing the TBM to pass through the slumped section without stopping. In cases where the sidewall is relatively weak, the TBM gripper shoe is padded with sleepers to increase the grounding area, before proceeding. If the surrounding rock strength at the support boots is insufficient to provide thrust, a YT28 hand air drilling rig is deployed to drill holes at the support boots. The reinforcement method is φ42mm×3.0m grouting small conduit with a longitudinal and transverse spacing of 120cm, as shown in Figure 4. The grouting slurry is cement slurry. Cement grouting materials mainly include: cement, water, admixtures, admixtures, etc. Its water-cement ratio is generally 0.8:1 and 0.6 (or 0.5):1. The cement strength grade of grouting should not be less than P42.5, and acid-resistant cement should be used for harmful groundwater caverns. The TBM water supply system is used for water supply, the water quality meets the requirements of drinking water, and the temperature of the slurry mixing water shall not be higher than 40 ℃. For the section with complex geological conditions, sand, fly ash and other admixtures can be mixed into the cement slurry. The cement grouting equipment adopts 4 sets of double-barrel vertical mortar high-speed mixers (2 sets standby), 4 sets of 250/50 grouting pumps (2 sets of standby), and 1 set of DXHB-10II. multi-function fine stone concrete pumps. The 250/50 grouting pump is a multi-cylinder plunger grouting pump with a maximum working pressure of 5Mpa. The grouting equipment is arranged near the TBM post-supporting and connecting bridges.

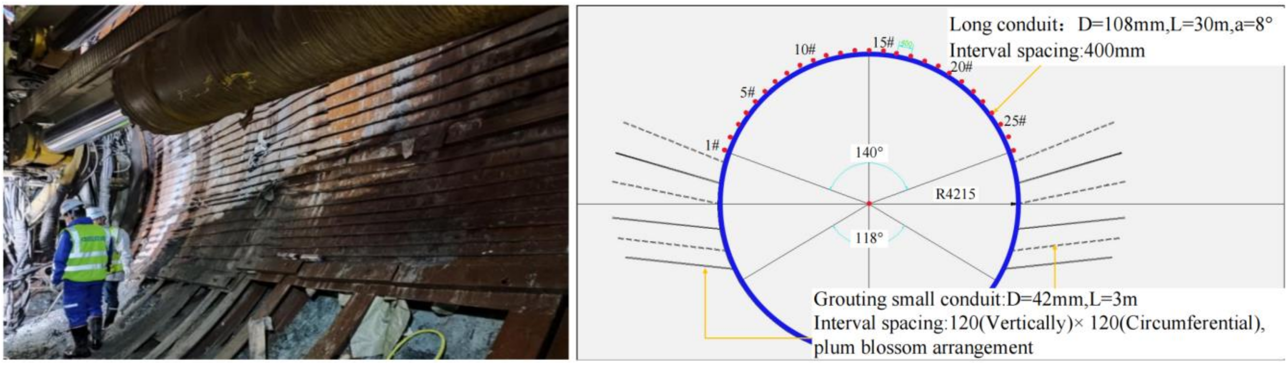

Fig. – 4 Construction site diagram and schematic diagram of the surrounding rock reinforcement at the TBM gripper shoe

Construction measures for collapsing rock surrounding the arch based on combined steel arches

In cases where a substantial amount of slag removal is required after the collapse of a large amount of rock, and the duration of slag removal is prolonged, it becomes highly unfavorable for TBM to pass through the fault fragmentation zone. To address this, a combined steel arch is employed to intercept the slag and rock debris from the collapsed body, ensuring the swift and safe passage of the TBM. , as shown in the figure (as shown in Figure 5(a)). The combined steel arch is symmetrically installed from bottom to top; the specific sequence is bottom pipe piece → side pipe piece → top pipe piece (the first ring and the second ring), and the subsequent rings are assembled in the order of top pipe piece → side pipe piece → bottom pipe piece. After the first and second rings are assembled, to enhance the stability, two locking anchor rods are set at the arch foot position of the side pipe pieces on both sides, and the locking anchor rods adopt 3m long φ22 drug coil anchor rods. After the combined steel arch is positioned, 8cm thick steel plate pads are installed to adhere to the rock surface, and the auxiliary push cylinder of the assembling machine tightens the steel arch, connecting the transverse and circumferential devices, respectively, to form a whole. Table 1 shows the parameters of each component of the steel arch, and Figure 5(c) shows the scheme of the combined steel arch.

On the exterior of the top pipe piece of the combined steel arch, several holes are reserved at intervals of 5m from high to low. These holes are designated for burying the exhaust pipe, blowing and filling the buffer layer pipe, and concrete backfill pipe, as shown in Figure 5(b). The exterior of the hole pipe is sealed with geotextile to prevent blocking of the hole pipe when spraying concrete. The grouting pipe should be inserted into the highest point of the collapsed cavity body, and the concrete transfer pump is used to fill C25 fine stone concrete or fibre concrete into the collapsed cavity body from the reserved grouting holes, as shown in Figure 5(d).

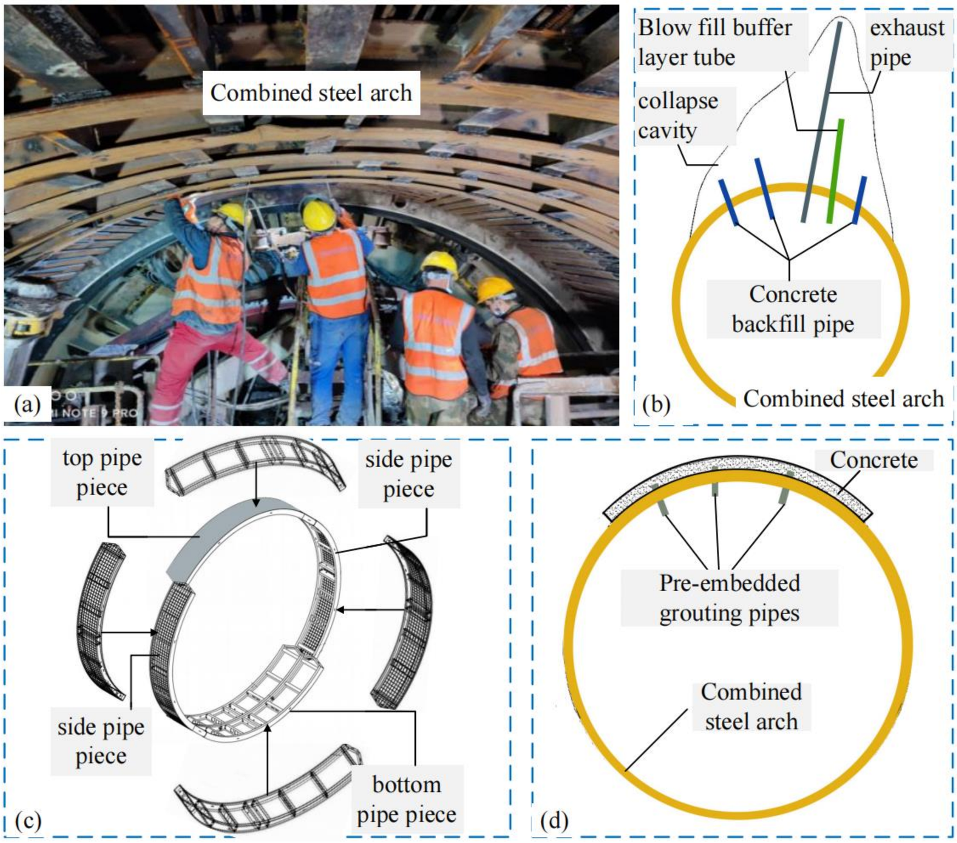

Fig. 5 - (a) Combined steel arch construction site; (b) layout of pre-buried pipes ;(c) combined steel arch construction program diagram; (d) concrete backfill schematic

Tab. 1 - Parameters of each component of combined steel arch

Item	Makeup	Quantity (Ring)	Weight (Kg)	Segment arc length (m)
Top pipe piece	Annular rib: 20b channel steel	1	1006.24	6.46m/ piece
	Longitudinal stiffener: I20 I-beam			
	Outside: 10mm steel plate			
Side pipe piece	Annular rib: 20b channel steel	2	626.04	6.46m/ piece
	Longitudinal stiffener: I20 I-beam			
	Outside: A10 steel mesh			
Bottom pipe piece	Annular rib: 20b channel steel	1	569.62	6.46m/ piece
	Longitudinal stiffener: I20 I-beam, removable			

TBM CONSTRUCTION TECHNOLOGY AND APPLICATION IN HIGH-GROUND STRESS SOFT ROCK SECTION

Measures to cope with large deformations high-ground stress in soft rock

When surrounding rock convergence deformation is severe, the TBM's expansion function is utilized to increase the excavation diameter through the overbreak cutter, which helps increase the amount of reserved deformation. Once the surrounding rock emerges from the shield, timely initial support is applied. Measures such as encrypting steel arch, spraying steel fiber concrete, and applying anchor cables strengthen the support. In instances where the bearing capacity of the tunnel wall is insufficient to provide enough counterforce to the support boots, a combination of spray anchor network, steel arch, and concrete joint support is utilized to reinforce the parts of the cave wall before excavation. When encountering significant and rapid convergence deformation in the soft surrounding rock, leading to the TBM shield becoming stuck, the thrust of the TBM digging is increased. Waste oil and other lubricants are also injected into the shield to reduce friction. Immediate application of the initial support system follows after passing through the affected area.

TBM drifting solution under deformed soft rock

When there is a significant deformation of the surrounding rock in front of the tunnel face, which makes the TBM prone to jamming risk, the "artificial cap method" is adopted to over-excavate from the position of the cutter plate. The excavation adopts the method of reserving the core soil ring through artificial division excavation, and TBM digs the core soil. TBM lagged behind the manual excavation surface to shorten the manual slagging distance. The TBM begins digging 3m behind the manual excavation surface and excavates forward manually. When the manual excavation encounters surrounding broken rock, which affects construction safety, it is reinforced by overrunning small conduits or chemical grouting before excavation.

Among them, the "artificial hat method" refers to further expanding the excavation scope based on a small guide hole and expanding the space radially in the range of 150°～220° from the upper center of a small guide hole circle. To facilitate manual work, the outer radial direction of the pipe sheet or shield shell is generally taken as 1500 mm~1700 mm. Support parameters are selected: System anchor L=3m/Φ22@1.0m×0.5m. The H150 steel arch is made of single or multi-layer steel sections with a spacing of @0.5m. The longitudinal connection of the steel arch is made of the U12 channel steel with a pitch of @1.0m. Reinforcing steel mesh with double layer Φ10@10cm×10cm. The lining is made of C40 concrete with a thickness of 30cm.

TBM CONSTRUCTION TECHNOLOGY AND APPLICATION IN HIGH-GROUND STRESS HARD ROCK SECTION

Modification of water spray system for TBM cutter under high-ground stress hard rock conditions

Construction under high-ground stress hard rock sections is prone to rock explosion, threatening the safety of construction personnel and equipment. To mitigate this risk, the TBM cutter spray system uses water to soften the surrounding rock. However, the original TBM cutter spray system has drawbacks, such as a high failure rate of rotary joints, prone-to-clog nozzles, and limited water spray volume. As a result, the cutter spray system was upgraded to a system that is less susceptible to failures and has a higher water output capacity.

The use of a single pipe pump to the blade water spray system water supply, with an 11KW booster pump from the tank direct water supply (as shown in Figure 6(a)(b)), the water output from the original 120L per minute into the current 380L per minute. 1.5-inch water supply pipe will be thickened for the original 2-inch high-pressure water pipe, give up the original blade water spray nozzle and rotary joints from the back of the blade to install a spray system on the blade for the full-coverage spraying, as shown in the figure. After the transformation, the cutter spray system water spray volume increased, effectively reducing the risk of rock explosion, and the water supply pipe blockage is reduced, the cooling makes the tool wear and tear, reducing the delay caused by the failure of the downtime, and improve the construction efficiency.

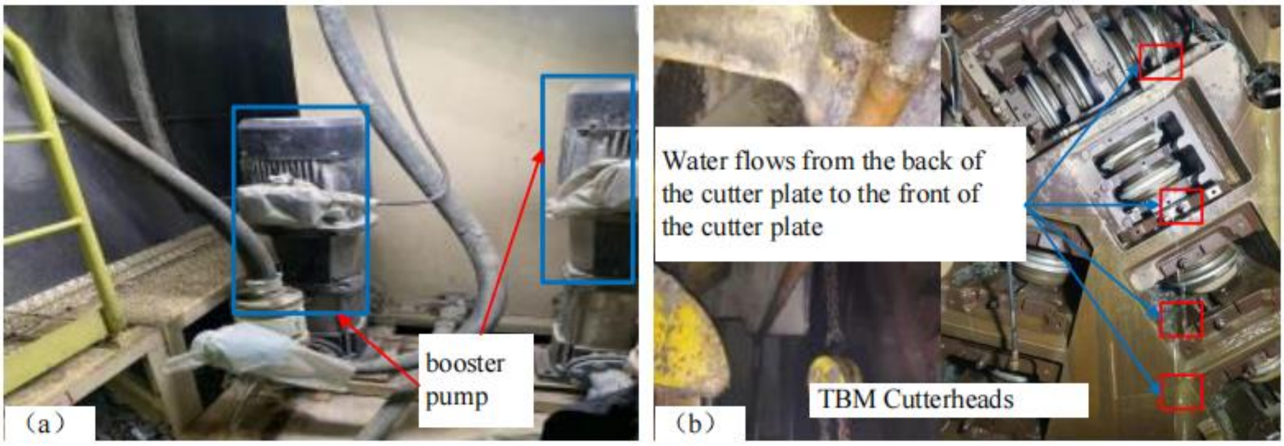

Fig. 6 - (a) Add a booster pump;(b) TBM cutter head water spray system retrofitted to the back of the cutter head

Construction measures for rock burst

To reduce the risk of rock explosions, the first countermeasure involves utilizing a cutter spray system and high-pressure water pipe behind the shield to spray water and soften the peripheral rock (as depicted in Figure 7(a)). This action facilitates stress release and adjustment. Subsequently, within the 120° arch range, H150 steel arches are employed along with Φ22 steel rows to reinforce joint support (as shown in Figure 7(b)). The longitudinal spacing of the arches is set at 0.9m. Finally, steel fiber concrete is sprayed with a thickness of 15cm (as illustrated in Figure 7(c)). The second measure involves preemptively drilling stress-release holes before excavation and then drilling radial stress-release holes after excavation. These stress-release holes are drilled perpendicular to the rock wall (as shown in Figure 7(d)).

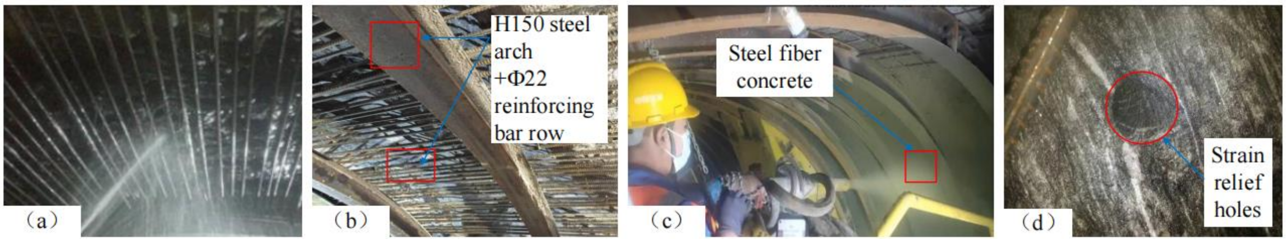

Fig. – 7 (a) Water jetting to soften the surrounding rock;(b) Combined support of H150 steel arches and Φ22 reinforcing bar row; (d) Strain relief holes

TBM CONSTRUCTION TECHNOLOGY AND APPLICATION IN WATER-SURGE AND MUD-SURGE SECTION

Construction Measures for Surging Water and Mud Surging Section

Construction of a small-scale water-surge section: water seepage from surrounding rock is in the form of dripping and linear seepage, while the TBM continues to excavate normally. In the process of digging, the anchor drilling machine that comes with the TBM is used to set up drainage holes at the water outlet, bury conduits to drain water and set up blind ditches or water cut-off rings if the event of poor water conduction.

Construction of large-scale water influx section**:** The water influx flow ahead of the tunnel face is assessed using overrunning geological forecasting methods. If the bottom of the tunnel does not meet the operating conditions, excavation must stop. Overrunning conduits and grouting are employed to block and treat the influx. Additionally, temporary high-power submersible pumps and pipelines are installed to pump water away from the TBM, ensuring at least a 50m area is adequately supported. If there is no substantial improvement in the surrounding rock conditions at the tunnel face despite these measures, the TBM's equipment is utilized to reinforce the tunnel face with overrunning grouting. If conditions still do not improve, the cutter is retracted, and access to the tunnel face is gained from the shield by drilling winding holes. Subsequently, the overrunning pipe shed method is implemented to support and block water influx.

Sudden mud section construction: A pre-predictive geological forecast is conducted to gain an in-depth understanding of the engineering geological conditions. This helps detect the geological conditions ahead of the tunnel face. To prevent the mud influx from compromising the safety of the TBM equipment and personnel, the pre-pre-pipe shed grouting method is adopted to pre-strengthen the surrounding rock before excavation.

Construction measures of over-advance pipe shed method in water surging and mud surging sections

The over-advance pipe shed method is employed to support, grout, and reinforce the surrounding rock while also plugging water influx and mud bursts. A schematic overrun pipe shed reinforcement diagram, is shown in Figure 8(a).

The over-advance pipe shed adopts L=25m, Φ=108mm, δ=6mm seamless steel pipe with a section length of 2m (matching with the drill pipe of the overrun drilling rig), and the joints are connected by wire fasteners with a wire fastener length of 15cm, and D=6mm grouting holes are drilled on the steel pipe with a longitudinal spacing of 15cm, and a plum blossom type of holes, and the length of the flower pipe section is 15.25m, as shown in Figure 8(b)

Within the 100° tunnel arch, the circular spacing is set at 40cm, with an external insertion angle of 8°. A total of 19 holes are arranged, as illustrated in Figure 8(c)(d). Following the completion of each cycle of pipe shed construction, the excavation proceeds by 10.1 meters. The sequence of pipe shed construction is from bottom to top, with a long steel pipe installed after drilling each hole.

Given the surrounding rock conditions of the water surge and mud break section, the grouting process adopts chemical grouting. Chemical grouting material mainly refers to polyurethane (polyurethane: PM-200, composed of white and black materials). The technical parameters of chemical grouting materials are shown in Table 2. The grouting equipment adopts a YZB-200/13 double-group material pump and 3SNS high-pressure grouting machine, which is simple in process, easy to clean for operation, convenient for transportation, suitable for multiple people to operate separately, which is conducive to speed up the progress of the project.

Initially, the grouting pressure is 1.2-1.5 times the static water pressure, and the termination pressure is 2-3 times the static water pressure. According to the actual situation of the site, the grouting pressure will be increased to the maximum allowable pressure to ensure the density of the grouting and increase the effective diffusion range. The grouting process is allowed to continue without interruption.

Tab. 2 - Technical parameters of chemical grouting materials

Product characteristics	Component A (Bevedol WF)	Component B (Bevedan)
Appearance	Light yellow liquid	Dark brown liquid
Viscosity (23±2℃)/mPa.s	200~400	200~400
Specific gravity (23±2℃) kg/m3	1020±10	1230±30
Use ratio (volume ratio)	1:1	
Full curing time (23±2℃)/S	40±5	
Foaming property	It is not foaming in itself and will react to foaming in contact with water	
Maximum compressive strength /MPa	60~80	
Maximum tensile strength /MPa	>10	
Maximum bond strength /MPa	>5	
Flame retardant property	Non-flame retardant	

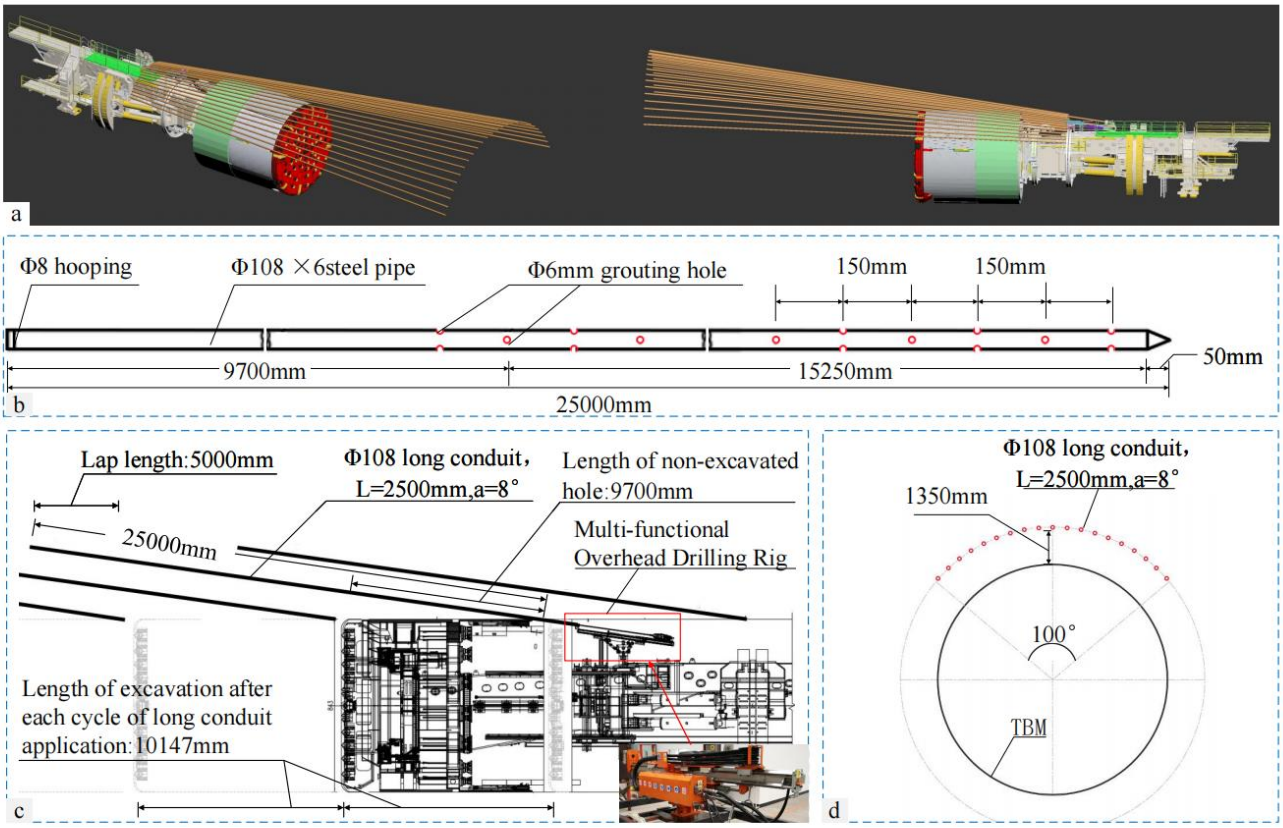

Fig. 8 - (a) Schematic diagram of over-advance pipe shed reinforcement;(b) Steel pipe sample drawing;(c) Section drawing of pipe shed reinforcement;(d) Sectional view of the upper 100 ° range of the pipe shed reinforcement cutter plate

DOI 10.14311/CEJ.2024.02.0012

CONCLUSIONS AND DISCUSSION

When the TBM encounters a fault fracture zone, the seismic wave reflection long-distance geological forecast method is employed to forecast and predict the condition of the surrounding rock ahead of the tunnel face. Based on the over-advanced geological forecast and prediction results, the fault fracture zone in front of the tunnel face is pre-reinforced. If the strength of the surrounding rock at the TBM support boot is insufficient to provide thrust, the rock at the support boot is reinforced by drilling and grouting. In cases where a large amount of slag removal is required and the time for slag removal is prolonged after the peripheral rock collapses, the combined steel arch is used to intercept the slag and rocks of the collapsed body, ensuring the quick and safe passage of the TBM.

When the TBM encounters a soft rock section with high stress, it utilizes the TBM's expanding excavation function to increase the reserved deformation volume. This is achieved by enlarging the diameter of the excavation through the overbreak cutter, addressing issues of severe peripheral rock convergence and deformation. In cases where the convergent deformation of the soft surrounding rock is significant and rapid, resulting in the TBM shield becoming stuck, measures are taken to increase the TBM digging thrust and inject lubricants such as waste butter outside the shield to reduce friction force. If the TBM becomes stuck due to the deformation of the surrounding rock in front of the tunnel face, the artificial cap method is adopted to excavate ahead of the cutter plate position.

When the TBM traverses a hard rock section with high stress to mitigate the risk of rock explosion, it employs the cutter spraying system and a high-pressure water pipe behind the shield to spray water on the surrounding rock, softening it. Additionally, stress relief holes are drilled as a precautionary measure. However, the original cutter spray system of the TBM presents challenges such as a high failure rate of rotary joints, easy clogging of nozzles, and limited water spray volume. Consequently, the cutter spray system has been redesigned. Following the remodeling, the cutter spraying system boasts increased water spraying volume, reduced clogging of the water supply pipe, and diminished tool wear. These improvements enhance construction efficiency.

When the TBM traverses the construction section affected by water surges and mud bursts, it employs the overrun pipe shed method to support the area. This involves grouting to reinforce the surrounding rock and constructing water plugging. The overrun pipe shed consists of seamless steel pipe with grouting holes drilled into the steel pipe, arranged in a plum blossom pattern. An overrun drilling machine is utilized to drill holes in the tunnel arch to install the steel pipe. Given the surrounding rock conditions of the water surge and mud burst section, the grouting process utilizes chemical grouting.

REFERENCES

[1] Xu P., Huang J., Zhou J.B., et al., 2020. 3D Numerical simulation of the interaction between rock mass and shield TBM passing through the fault fracture zone. Modern Tunnelling Technology, vol. 57(06): 63-69.

[2] Zhang J.M., Shi K.B., DALAYIHAN Bahetebieke et al., 2023. Evaluation and prediction of TBM′s geological adaptability based on variable-weight set pair-multidimensional linked normal cloud model. Tunnel Construction, vol. 43(04): 645-657.

[3] Xie, W., et al., 2023. Fast perception of rock mass strength and integrity in TBM tunnelling using in-situ penetration test. Tunnelling and Underground Space Technology, vol. 141.

[4] Cheng S.L., Wang L.C., Hu H.Q., et al., 2023. Fault and fracture zone collapse treatment technology for open tunnel boring machine applied in beijiang water diversion project. Tunnel Construction, vol. 43(12): 2122-2132.

[5] Yang J.H., Sheng K., Zhou J., et al., 2023. Mechanism and prevention of tunnel collapse through water-rich fault fracture zone. Journal of Engineering Geology, vol. 31(01): 248-257.

[6] Longlong, C., et al., 2023. Characteristics and treatment measures of tunnel collapse in fault fracture zone during rainfall: A case study. Engineering Failure Analysis, vol. 145.

[7] Tong R.J., Zheng S.T., Wu Y.J., et al., 2022. Key technology of advance pre-grouting of ground directional holesto shield roadway passing fault and broken zone. Coal Science and Technology, vol. 50(06): 196-203.

[8] Chen P., Ma X.Q., Long J., et al., 2022. Method of designing pipe roof support parameters for tunnel in fault zone. Journal of Yangtze River Scientific Research Institute, vol. 39(12): 62-67.
[9] Ma D., Sun Y., Wang W.X., et al., 2021. Key technologies for controlling large deformation of soft rock tunnels with high geostress. Tunnel Construction, vol. 41(10): 1634-1643.
[10] Liu Y.P., Xia C.C., Wu F.B., et al., 2020. A combined support technology of long and short bolts of soft rock tunnels under high ground stresses. Chinese Journal of Rock Mechanics and Engineering, vol. 39(01): 105-114.
[11] Wang W.P., Li J.F., Yan P.B., et al., 2023. Design practice of prestressed anchor cable support technology for soft rock with extremely high geostress and large deformation in muzhailing tunnel. Tunnel Construction, vol. 43(S1): 313-322.
[12] Zheng Y., Guo P., Wang L.J., et al., 2023. Key technologies for treating high ground stress and large deformation of soft rock in daliangshan tunnel of Yunlin expressway. Tunnel Construction.
[13] Han C.L., Xu C., Xia C.C., et al., 2023. Design of reserved deformation for soft rock tunnels with high geostress. Tunnel Construction, vol. 43(11): 1916-1923.
[14] Zhang, Q., et al., 2023. Microseismic characteristic and development mechanism of fault-slip rockburst in a deep-buried TBM excavated tunnel: A case study. Tunnelling and Underground Space Technology, vol. 142.
[15] Li, P., et al., 2023. Rockburst and microseismic activity in a lagging tunnel as the spacing between twin TBM excavated tunnels changes: A case from the Neelum-Jhelum hydropower project. Tunnelling and Underground Space Technology, vol. 132.
[16] Wang K., 2021. Overview of state-of-art of rockburst prediction and prevention techniques for deep-buried tunnels. Tunnel Construction, vol. 41(02): 212-224.
[17] He, S., et al., 2021. Damage behaviors, prediction methods and prevention methods of rockburst in 13 deep traffic tunnels in China. Engineering Failure Analysis, vol. 121.
[18] Li, Z., et al., 2022. Research on the difficulties and countermeasures of TBM tunnel construction in plateau railway. Journal of Railway Engineering Society, vol. 39(9): 70-78.
[19] Fu, K., et al., 2023. Karst hydrogeological characteristics and construction disease analysis of a high-speed railway tunnel. Journal of Railway Engineering Society, vol. 40(10): 86-92.
[20] Shi, Z., et al., 2023. Failure mechanism analysis for tunnel construction crossing the water-rich dense fracture zones: A case study. Engineering Failure Analysis, vol. 149.
[21] Liu, N., et al., 2022. Geological investigation and treatment measures against water inrush hazard in karst tunnels: A case study in Guiyang, southwest China. Tunnelling and Underground Space Technology, vol. 124.
[22] Lang Z.J., Li M.Y., Qiao H.Y., 2023. Key technologies for treating large-scale water and mud inrush in inclined shaft work area of super-long tunnels. Modern Tunnelling Technology, vol. 60(05): 224-233.