Construction Technique for TBM to Cross Unfavorable Geological Sections

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Abstract. The diversion tunnel of VI Section, XE Project in Xinjiang Autonomous Region was constructed with an open-type tunnel boring machine (TBM). Concerning the unfavorable geological sections encountered during TBM tunneling in the project construction, the author has summarized the engineering countermeasures used to improve the efficiency and construction safety of TBM tunneling.

1. Foreword
The diversion tunnel of VI Section, XE Project in Xinjiang Autonomous Region was constructed with an open-type tunnel boring machine (TBM). This tunnel section is located in the low hilly area of a denuded structure. The section using TBM is 21.5 km long and the excavation diameter was 7.8 m. The tunnel’s burial depth ranges from 6 to 127 m, with an average burial depth of 34 m, which means it is a shallow buried tunnel. The tunnel crosses 18 shallow buried gullies whose bottoms ranging 6 to 70 m, and 9 large-scale fault fracture zones with a width of 10 to 35 m. The fault fracture zones are mostly made up of cataclasites and mylonites. The angles between the fault directions and the cave axis range from 85° to 87°. Extending 15-18 m, the fracture zones can significantly impact the cave body’s stability and result in a higher risk of tunnel collapse. Concerning the unfavorable geological sections encountered during TBM tunneling in the project construction, the author has summarized the engineering countermeasures used to improve the efficiency and construction safety of TBM tunneling.

2. Identification of unfavorable geological conditions
Warning signs before a soft rock collapsed section: sharp increases in the number and density of joint fissure sets, the decline in rock strength, the appearance of cataclasites, stronger rock weathering and increased shale content.

Warning signs before a fault fracture zone: during TBM’s tunneling, the machine’s vibration gets stronger. People in the main control room can hear the huge noise from the tunnel face. Worst case scenario occurs when the cutterhead is stuck in a stone and unable to rotate. At this time, large pieces exist in the uneven rock slag, for there are no slag cuttings during the tunneling process.

Warning signs before water gushing and mud inrush: increase in the number of joint fissure sets, the rising amount of water seepage, often accompanied with muddy sediments or turbid effluent.
3. Treatment of Soft Rock Collapsed Cavities

3.1. Collapse of a TBM roof shield
Preliminarily seal the exposed broken rock surface with the emergency shotcrete system;

Sub arches are used to strengthen the support of the collapsed cavity. HW125 steel is introduced to support the rock surface on top of the initially designed HW150 steel arch system, φ22 rebars are added to connect the sub arches;

HW125 steel is introduced to connect to the HW150 steel arches of the initially designed system, with the circumferential spacing of the steel support connections ranging from 0.8 m to 1.0 m;

Seal the upper part of the rebars with 3 mm steel plate. The collapsed cavity is backfilled in layers by pumping in C30 fine stone concrete, and then grouted before the steel arch is sealed by the shotcrete;

φ25 random anchor bolts with lengths of 3.5 to 6 m are added based on the surrounding rock conditions on site.

3.2. Collapse of TBM boots
Normally, a TBM tunnels at a low speed to reduce the slag amount and ensure the tunnel face’s stability to avoid large-scale instability. When the surrounding rocks on the cave’s side walls have a strength of less than 30 MPa, sleeper piles can be set up to support the boots to increase the area of support and reduce the thrust and cutterhead speed to prevent the equipment from sinking.

When the surrounding rocks on the cave’s side walls have a strength of less than 25 MPa, the sleepers can no longer support the boots, resulting in serious rock deformations or even collapse. The soft rocks need to be manually cleaned before concrete walls are poured to increase the rock mass strength and ensure the rock walls at the boots can function as support walls. When the inside of the tunnel has a low temperature, especially during winter, an appropriate amount of early strength agent can be added when pouring the concrete walls to shorten the curing time and help the TBM to resume work as soon as possible.

4. Treatment of Fault Fracture Zones

4.1. Small fault fracture zones
Generally speaking, a small fault fracture zone has a width of 5 to 15 m, with fault muds mixed in the zone and the collapsed cavity depth of less than 0.5 m. For such unfavorable geological sections, the following measures can be taken:

The system rebars are installed on the upper part of the first steel arch behind the TBM shield. The rebars are made of φ20 or φ22 screw-thread steel. Their length ranges from 3.0 to 4.5 m. Each slot is installed with a bundle of three to five rebars;

The spacing between each two steel arches of the system is shortened from 1.8 m to 0.9 m. HW125 steel is used to strengthen the connection between every two arches till the circumferential spacing reaching 0.8 to 1.0 m. The steel arches are close to the rock walls, and where there is a gap, a wedge block is set to seal it. Feet-lock bolts are installed at the joints of the steel arches, which will then be welded firmly to the bolts and locked to the cave walls.

The system bolts (L=3.5 m) are made of φ25 screw-thread steel with an array pitch of 1.0 m. If necessary, random long bolts can be introduced to lengthen the bolts to 4.5 to 6 m.

The thickness of the shotcrete is 20 cm, and φ8@100*100mm dense meshes are adopted as the reinforced meshes.

4.2. Large fault fracture zones
With a width of over 15 m, large fault fracture zones are filled with mylonites and fault gouge, and the depth of the collapsed cavity, once occurs, generally exceeds 0.8 m. Based on the burial depth of the
fault fracture zones, the following two treatment plans are often adopted: surface grouting reinforcement and advance tunnel support.

4.2.1 Surface grouting reinforcement. In case that the fault fracture zone is buried less than 30 m underground, and the earth’s surface is rather open and flat, the method of surface grouting reinforcement shall be adopted. The advantage of this method lies in the fact that during the earth’s surface construction, it enables advanced tunneling construction, advanced pre-judgment and advanced treatment, so that TBM’s tunneling process won’t be affected, the construction period will be shortened and we don’t need to shut down the TBM equipment during the process.

4.2.2 Advanced tunnel support. If we fail to prejudge the conditions of the fault fracture zone, post-treatment needs to be carried out in the cave, or the fault fracture zone is buried over 30 m below the ground, and the earth’s surface is located in an undulating ridge area, the method of advanced tunnel support shall be adopted. The process of advanced tunnel support is as follows: arch installation for roof shield pipe shed positioning → advanced pipe shed drilling above the roof shield → drill hole flushing → grouting with cement → sealing → advanced glass fiber bolt drilling in front of the cutterhead → grouting with chemical materials.

5. Gushing Water Treatment

Gushing water can be divided into bedrock fissure water, interstitial water, Quaternary interstitial water and karst water. The gushing water can be treated in two ways: drainage and plugging. Mostly we adopt drainage in conditions without external water supply, and plugging in those with external water supply.

Before tunneling, advanced drilling is conducted to measure the water flow, water pressure and mileage of the water gushing points. If the water flow is small, and the water pressure reduces during the drainage, the TBM can continue with the excavation on the premise of a well-prepared drainage system; if the water flow is large, and the water pressure remains high during the drainage, grouting, among other measures, is conducted to plug the water before excavation. Otherwise, the working face and side walls may collapse in the face of incoming gushing water, or the drainage system cannot fully function to prevent the equipment from drowning.

After the tunneling is finished, the gushing water on the working face or the remaining water of grouting is removed in a timely manner, followed by the strengthening of the primary support. In case the water pressure is so high that the primary support is damaged, it can be treated by drainage or grouting behind the walls; in case the water pressure is too high and the water flow is too large, grouting can be performed on surrounding rocks to trap the water inside them.

When a tunnel passes through a water-rich stratum or fault fracture zone, water gushing accidents are very likely to occur, which makes the construction extremely difficult and risky. The grouting to block the water starts from the areas without water gushing and gradually moves to the water gushing areas. Eventually, the water gushing areas will be grouted one by one through the designed apertures until the gushing water reduces or disappears. Normally, we adopt the single-fluid jet grouting (cement grouting) and double fluid jet grouting (cement and water glass grouting) for grouting construction.

6. TBM Cutterhead Sinking Treatment

If the geological condition allows, the core sample of the rocks should be taken for geological analysis, while at the same time, the pressure of the boot should be adjusted based on the conditions of the surrounding rocks to provide technical support for TBM tunneling.

Advancement should be made at a short distance at a time with frequent step changes and posture adjustments. When the TBM is passing through a fracture zone, the progress should be short and slow, and the step should be changed frequently to reduce the rear support’s load on the shield. The boot’s pressure should be increased properly based on the conditions of surrounding rocks to alleviate the shield’s sinking. For surrounding rock fracture zones at the bottom of the shield tail, we can support
them with HW150 arches (30 cm spacing), or cover the shield tail with 20 mm steel plates and screw-thread steel, among other measures, to ensure construction safety.

7. Conclusions

Based on what we have seen during the on-site excavation and construction, the open-type TBM showed excellent adaptability and high efficiency in conditions with types II and III surrounding rocks. In contrast, poor adaptability was demonstrated in conditions with types IV and V surrounding rocks, as well as in soft rock fault zones. Engineering and technical personnel should meticulously select the tunneling parameters based on the geological conditions. A full set of advanced reinforcement and emergency shotcrete system is needed to pre-reinforce the unfavorable geological sections and seal the surrounding rocks beforehand to prevent rock deformation and contain collapse expansion.

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