Research on Key Technology of Mechanical Construction of Connecting Passages

Junyong Wang *, Li Hang, Guozheng Wang, Han Chao

CREG Tunnel Boring Machine Manufacturing Co., Ltd. Zhengzhou, China

* Corresponding Author Email: 8058666@qq.com

Abstract. Conventional connecting passages construction usually uses mining method with freezing or grouting method of reinforcement, generally has a long construction period, high construction risk, costly problems, which has an urgent need for a mechanical way of construction technology to improve the speed and quality of construction. The critical technologies for the mechanical construction of connecting passages mainly include the design of the main tunnel and the connecting-passage segment, TBM fully enclosed launching and receiving, the waterproof design, and the design of the built-in pump chamber of the TBM. Its construction process mainly includes TBM assembly, sleeve installation, breaking of the tunnel door, the tunnel boring, the machine receiving, and the fabrication of the tunnel door seal. Based on the above vital technologies analysis, this paper demonstrates the significant advantages of the mechanical construction of the connecting passage with practical construction cases, which provides an essential reference for the subsequent research.

Keywords: Conventional construction; connecting passage segment; Enclosed launching and receiving; TBM; Tunnel door seal.

1. Introduction

Statistics from the Ministry of Transport of China website show that in 2020 alone, 39 new urban rail lines will be added, with an additional 1,240.3 kilometers of operation, increasing by 20.1% compared to last year.

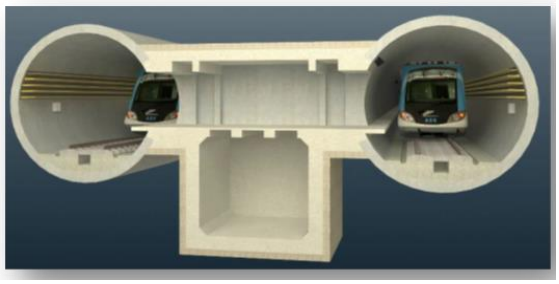

Fig 1. Tunnel connecting passage.

In the future, China's rail transit industry will continue to maintain the momentum of high-speed development. on August 1, 2003, the newly promulgated "subway design specifications" stipulated that "between the two single-line interval tunnels, when the tunnel length is greater than 600m, there should be a connecting passage, at both ends of the channel with two-way open Class A fire doors." As a mandatory provision, this regulation must be strictly enforced only in the field of urban subway tunnels. China needs to build more than 2,000 connecting passagess every year. The construction of connecting passages will usher in the peak growth period and should urgently strengthen the research on the key technology of connecting passages mechanical construction [1].

2. Conventional cross-passage construction method.

The construction of the connecting passages generally adopts the mining method, by freezing method, or the grouting method to strengthen the excavation surface. The construction of the mining method has more outstanding defects, mainly reflected in the following 5 aspects.

a. Given the uncertainty of the effect of freezing and grouting, there is a risk of accidents such as water gushing and collapse, which has a greater safety risk.

b. When using the mine freezing method [2], its settlement cycle is long, the settlement value is significant, and the subway tunnel construction will affect the quality of its subsequent track paving and operational safety.

c. The quality of construction personnel significantly influences the construction quality when the mining method is used. The quality of spraying concrete and initial support is easy to leave hidden defects when the construction is not in line with standard procedures [3].

Fig 2. Poor quality of mining construction.

3. Key Technology Research on Mechanical Construction of Connecting Passages

3.1. The basic concept of mechanical construction

Based on the existing construction cases of the connecting passage, it is proposed to adopt the cuttable tunnel door and unique structure design to realize the micro-reinforcement construction; adopting full closed launching and receiving in the sleeve to realize the complete secure construction of the connecting passage and improve the safety of the tunnel construction; adopting mechanized support system in the main tunnel to ensure the safety of the whole construction process [4].

3.2. Segment design of connecting passages

The construction of the connecting passage by the mechanical method is characterized by high construction quality, convenient maintenance, high quality of T-joint forming, no initial diseases such as water seepage and leakage, and no freezing and melting settlement during the operation period, which can significantly reduce the risk of hidden quality problems and diseases.

The main tunnel segment is divided into the standard segment and a particular segment. The particular segment is mainly applied at the connecting passage tunnel entrance, in the composite segment (steel pipe segment + concrete pipe segment), and bolts connect the segments to achieve the following purposes [5].

They are improving the bearing capacity of the lining at the opening location.

The cuttable material, such as fiberglass-reinforced concrete, is used at the position of the tunnel door, which makes it easy for the machine cutter to break the tunnel door.

Tunnel door sealing and waterproofing is easy to be realized.

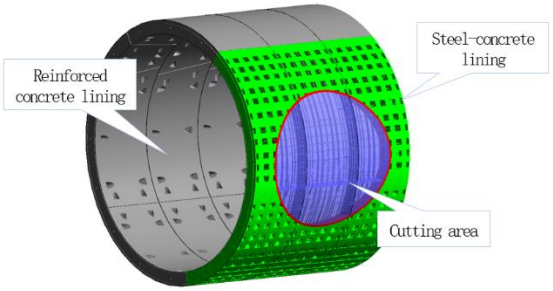

Fig 3. Main tunnel segment.

Based on the different connecting passage segments, the connecting passage segments are divided into 2 types of segments, which is the ring used in and out of the tunnel and standard ring pieces. The standard ring adopts a prefabricated concrete structure. In contrast, the ring in and out of the tunnel adopts a prefabricated steel segment, and the connection between the segments of connecting passage and each ring is bolted.

Fig 4. Concrete segment and steel segment.

3.3. Enclosed launching and receiving in sleeve

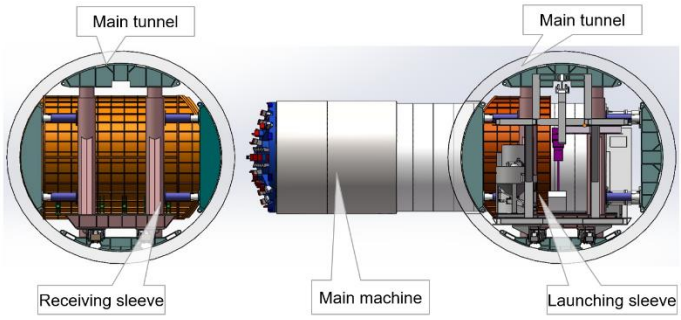

Fig 5. Mirco TBM enclosed launching and receiving in sleeve.

During the construction of the connecting passage, the launching and receiving of the micro TBM are carried out inside the steel sleeve to ensure the safety of the building under unreinforced conditions. The launching steel sleeve is set on the launching tunnel door of the contact channel. The launching steel sleeve is equipped with sealing brushes and grease joints, through which sealing grease is injected to block the water pressure generated in the direction of the tunneling machine, thus playing a sealing effect. The receiving steel sleeve is set on the receiving tunnel door of the connecting passage. When the Mirco TBM enters the receiving steel sleeve, the receiving steel sleeve acts as a closed box to block the water pressure generated by the groundwater in the direction of Micro TBM, thus playing a sealing effect [6-7].

Fig 6. Sleeve for Mirco TBM launching and receiving.

3.4. Conical cutterhead design

The cutterhead adopted the conical structure design of 4 main beams + panels to fit the main tunnel segment coherence, which can effectively liaise with the cutting efficiency of the channel mini-TBM and maximize the space-saving in the narrow tunnel. The overall opening rate of the cutter disc is 38%, which also can prevent the mud cake in the soft soil layer [8].

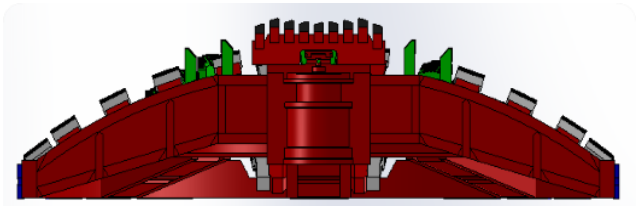

Fig 7. Conical cutterhead design.

3.5. Mobile segment prestressing support system

The mobile segment sheet prestressing support system can be loaded and unloaded into the main tunnel step by step to ensure that the main tunnel bears the reaction force state and the tunnel structure is in a stable support state during the construction of the connecting passage. The system should ensure sufficient safety clearance when transporting into the tunnel [8].

The support system can be widely used in strata such as silt, chalk, sand, pebbles, clay, and rock formations.

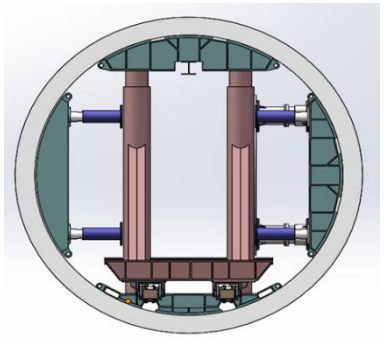

Fig 8. Segment prestressing support system.

3.6. Pump chamber layout

In conventional construction, the pump chamber is usually set at the lowest point of the connecting passage. A built-in pump chamber should be used when the mechanical method of connecting passage construction is adopted, i. e. the pump chamber is arranged at the bottom of the two main tunnels respectively, and the wastewater in the tunnel flows through the drainage ditch through the sedimentation pond into the water collection pit and finally discharged through the sump pump [9].

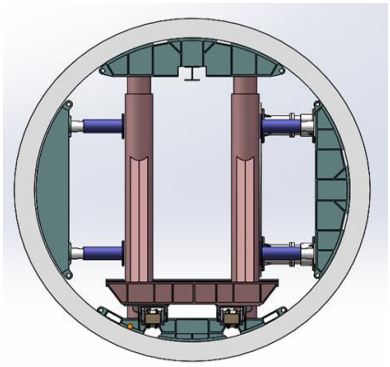

Fig 9. Build-in pump chamber.

3.7. Waterproofing design

The waterproof design of the connecting passage is an integral part of tunnel safety. Waterproof design is based on the self-waterproofing of the concrete structure of the segment and the key points of joint waterproofing to ensure that the overall waterproof performance of the system is reliable. The specific implementation relies on the following three main points [10].

The main feature is the self-waterproof performance of the segment.

EPDM rubber elastic gasket is installed at the joints of the segment as an additional waterproofing measure,

Grouting behind the wall of connecting passage segment to form a waterproof mortar to achieve additional waterproofing.

3.8. Research on modular integration technology of Micro TBM

The Micro TBM for connecting passage construction integrates excavation, discharge, support, assembly, propulsion, sealing, and material transfer to achieve rapid mechanization of connecting passage construction.

Depending on the construction conditions, the Micro TBM can be flexibly constructed by TBM or pipe jacking method. Most of its component modules, including cutterhead, main drive, front shield, guidance system, etc., can be shared [11].

The pipe jacking method can construct simple, low-cost, short-distance connecting passages. In contrast, the shield method is highly adaptable, with high integration of the whole machine, and can be extended to the construction of various curved pipe tunnels. However, its construction cost is relatively high [12].

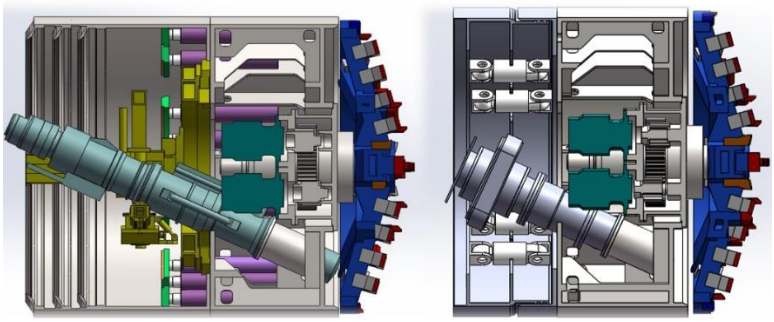

Fig 10. TBM and pipe jacking machine.

4. Key Technology Research on the construction process

The construction of the connecting passages mainly includes the steps of assembling equipment, TBM commissioning, TBM tunneling construction, removal of the auxiliary ring, and withdrawal from the site, whose general construction process is shown below [13].

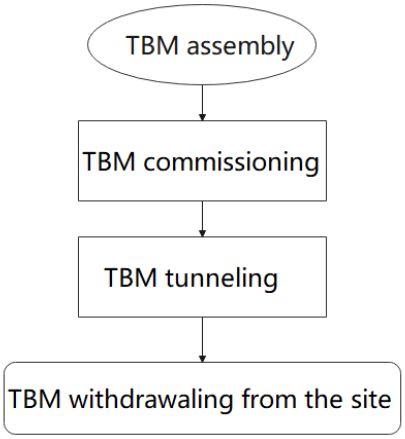

Fig 11. Construction of the connecting passages.

4.1. Machine assembly

The connecting passage boring machine is towed into the construction location and assembled inside the working shaft accordingly. The process mainly includes the assembly of the TBM, the assembly of the launching sleeve, and the assembly of the segment prestressing support system [14].

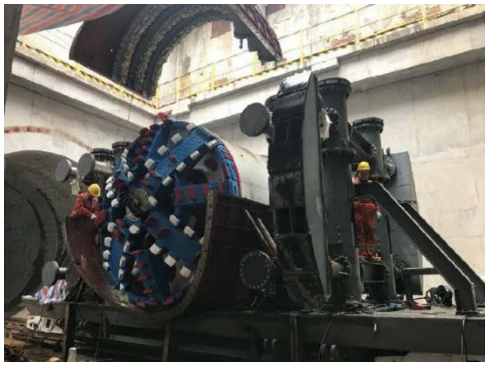

Fig 12. TBM assembling in launching shaft.

4.2. TBM commissioning

The commissioning of the TBM mainly includes the preparation of the machine's electrical, hydraulic and fluid systems and the inspection of the mechanical equipment to ensure the safety and reliability of the tunneling process.

4.3. TBM tunneling

Fig 13. Breaking the main tunnel door.

After completing the assembly and commissioning of the TBM, the conical cutterhead is used to break the cuttable fiberglass reinforced concrete of the main tunnel, which facilitates the cutterhead to break the tunnel door. After the cutterhead breaks the tunnel door, the procedure of discharging should be completed, and finally, the closed sleeve is used to complete the receiving work [15].

Following the reception of the connecting passage TBM, polyurethane was injected into the steel segment. The tunnel door angles were welded, and the concrete ring beam was applied to complete the sealing of the tunnel door.

Fig 14. Formed connecting passage.

4.4. TBM is withdrawing from the site

After completing the connecting passage construction, gradually remove the negative ring segment, the launching and receiving steel sleeve, and move the TBM with its supporting devices to the launching area, thus completing the tunnel construction.

5. Case Study

The connecting passage boring machine has completed the industrial testing in Ningbo Metro, showing good efficacy and cost advantages, and solving the safety and quality hazards of mining method construction. The number of subsequently completed connecting passages has reached more than 30, which are applied in Ningbo, Wuxi, Qingdao, Hangzhou, Fuzhou, etc.

Table 1. Construction cases.

Project	Location	No.
Wuxi Line No. 2 Period 2	Ningbo	2
Ningbo Line No.3 Period 1	Ningbo	2
Ningbo Line 4	Ningbo	21
Wuxi Line 3	Wuxi	1
Qingdao Line 8	Qingdao	3
Hangzhou Line 7	Hangzhou	2
Fuzhou Line 5	Fuzhou	1

Taking the project of Ningbo Line No.3 Period to analyze the construction effect of the project, the overburden of connecting passage is 16.94m, mainly in silty clay and chalky clay, and the total tunnel length is 17m.

Fig.15. Crossing geological profile

During the project's construction, the maximum ground settlement was about 22mm, the width of the settlement groove in the horizontal profile was about 60m, and the influence range in the vertical profile was about 50m. The overall ground settlement was as expected, and the construction performance was excellent.

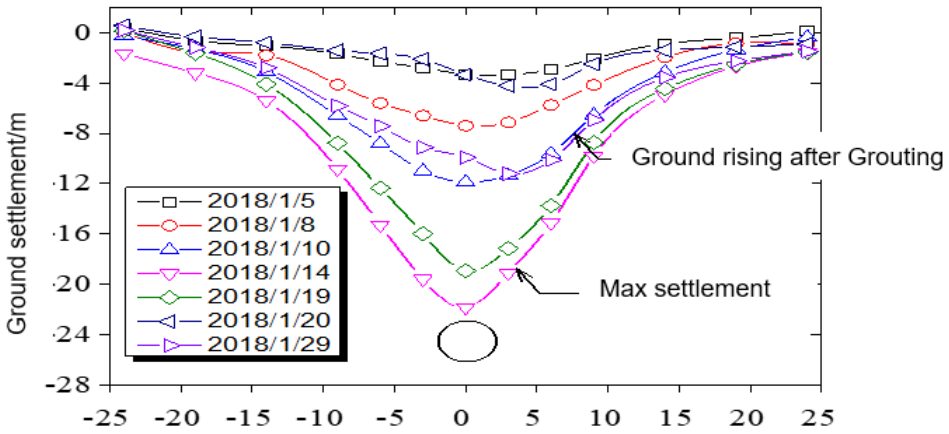

Fig 16. Horizontal ground settlement value.

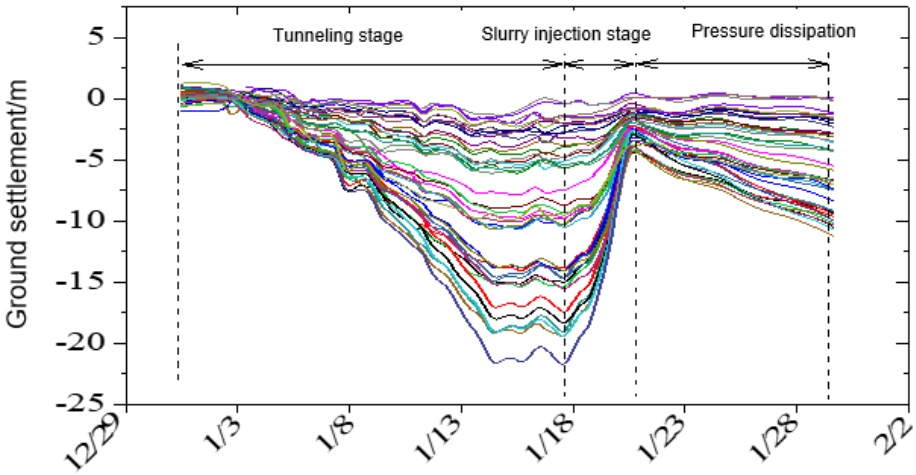

Fig 17. The ground settlement with a time curve.

6. Conclusion

Taking the 10m connecting passage pipe jacking construction case as an example, whose construction period takes only 26 days and the cost is only about 200~300 thousand RMB per meter, the cycle of construction by mining method can be more than 100 days, which will seriously restrict the overall construction progress and cause a massive waste of resources.

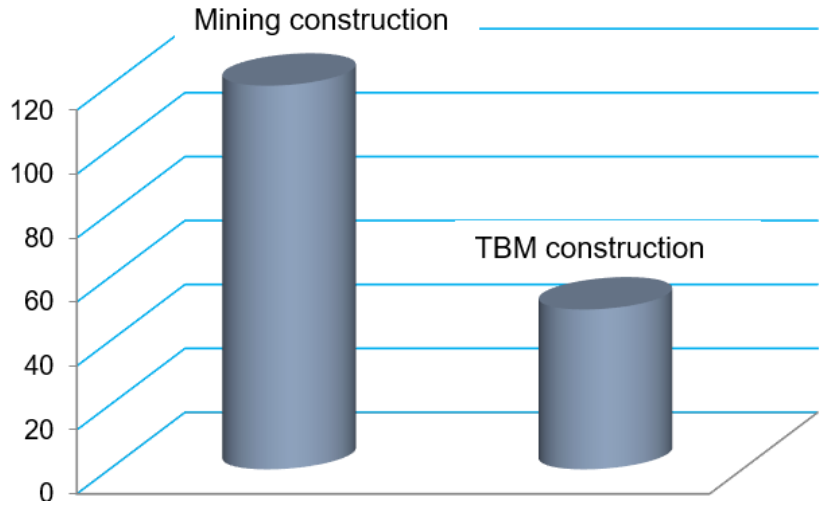

Fig 18. Construction Period Comparison.

The construction periods for the two different construction methods are shown in the figure above. The mechanical construction has the advantages of not being restricted by geological conditions, small safety risk of mining surface, reliable segment quality, short construction period, and low cost.

Mechanical construction technology of connecting passage has been successfully applied to constructing several tunnel projects in China and abroad. The research analysis of this paper provides a significant reference for further optimization and enhancement of the mechanical method of connecting passage construction.

References

[1] YAO Yanming, HUANG Yi, ZHOU Junhong, et al. Construction methods for connecting passages in shield tunnel of Ningbo rail transit Line 4[J]. Tunnel Construction, 2021, 41(6): 1007.

[2] Qin Wei, YANG Ping, JIN Ming, et al. Application and survey analysis of freezing method applied to an ultra-long connected aisle in metro tunnel [J]. Chinese Journal of Underground Space and Engineering, 2010, 6(5): 1065.

[3] YANG Ping, CHEN Jin, ZHANG Shanggui, et al. Whole range monitoring for temperature and displacement fields of cross passage in soft soils by AGF [J]. Chinese Journal of Geotechnical Engineering, 2017, 39(12): 2226.

[4] SUN Longfei, CHEN Zhenlei, LI Jiancheng. Effects of surface subsidence in metro crossing passage tunnel excavation by shield machine [J]. Geotechnical Engineering Technique, 2019, 33(4): 197.

[5] LIU Jun, HE Meide, SONG Hanyun. Research on the mechanical behavior of shield tunnel construction of connecting passage [J]. Chinese Journal of Geotechnical Engineering, 2013, 35(S2): 271.

[6] WANG Kun, YE Lei, CHENG Yonglong, et al. Sealing device for launching and receiving of tunneling machine for connection gallery with mechanical excavation method [J]. Tunnel Construction, 2020, 40(1): 134.

[7] LYU Hu. Study on construction mechanics for cross passage of tunnel [D]. Shanghai: Tongji University, 2006.

[8] DING Xiuheng, Key technology for constructing shield method of metro interval connecting channel [J]; Building Construction; 2019, 04.

[9] LIU Zongzhou, Design of drainage pump chamber in rail tunnel interval [J]. Tunnel Construction, 2011(10):588-591.

[10] YANG Ping, Chen Jing, Zhang Shanggui. Et al. Study on whole range monitoring for temperature and displacement field of the cross-passage by AGF in soft soil [J]. Chinese Journal of Geotechnical Engineering, 2017, 39(12):2226.

[11] LIU Kaiyang, Peng Wentao, Su Changyi, Luo Yisheng. Underwater reception technology of earth pressure balance shield with high-pressure head [J]. Construction Technology, 2020(10):75-82.

[12] WU Wentao, ZHANG Heng, LI Haiqing. Analysis of mechanics characteristic in metro connecting passage construction [J]. Railway Engineering, 2011(11): 65.

[13] LIU Jun, HE Meide, SONG Hanyun. Mechanical behaviors of shield tunnel segments due to the construction of connecting passages [J]. Chinese Journal of Geotechnical Engineering, 2013, 35(S2): 271.

[14] LU Jiwei, CHEN Yong. Integrated design of under and above urban ground space: Strategies for effective underground space development [J]. Journal of Shanghai Jiaotong University, 2012, 46(1): 1.

[15] ZHU Hehua, LI Xiaojun. Digital underground space and engineering [J]. Chinese Journal of Rock Mechanics and Engineering, 2007, 26(11: 2277.