Keynote Paper

Research and Application of TBM Safe, Efficient and Intelligent Tunneling Technology

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ABSTRACT

The hard rock tunnel boring machine (TBM) has been widely used in the construction of water conservancy, hydropower, railway and other tunnels. Due to TBM operations are highly dependent on human experience, lack of information perception and scientific decision-making, leading to frequent occurrence of various engineering accidents, causing serious economic losses and construction delays. It is urgent to study intelligent tunneling technology to ensure safe and efficient construction of TBM. The TBM construction big data platform was developed and the TBM rock-machine database was established. The technical research work had been carried out such as rock real-time sensing, optimization of excavation parameters, intelligent correction, intelligent support decision-making, etc. The TBM-SMART intelligent excavation system was developed. After multiple project applications, the stability and accuracy of the system have been improved. Related technologies and products can increase the operating rate of TBM, effectively avoid major construction risks, and escort TBM construction.

1. INTRODUCTION

Tunnel boring machine (TBM) construction has the advantages of safety, efficiency, and environmental protection, and has become the preferred method of construction for long and large tunnels. Because TBM is extremely sensitive to changes in geological conditions, the tunneling control relies on the operator's personal experience. Once the stratum status changes, it is difficult for the operator to judge the changes in the state of the rock mass and equipment in time and then make scientific decisions. During the TBM construction process, the geological disasters or engineering accidents occurrences frequently such as water, collapsed jamming machines, damage to cutter heads or main bearings, have caused huge construction delays and economic losses to the project.

The occurrence of TBM engineering accidents is not accidental, and there are still many technical problems in the industry that need to be solved urgently: (1) TBM rock-machine interaction mechanism research is not clear, TBM design basis is not clear; (2) TBM rock-machine information perception is not comprehensive , Not timely; (3)

Insufficient sharing of TBM construction information and in-depth data analysis; (4) The selection of TBM tunnelling parameters relies on human experience, and the intelligent control theory and decision-making methods are immature.

In response to the above problems, domestic and foreign scholars have conducted a lot of research work in numerical simulation analysis, cutting and breaking rock test, and field data analysis. The most famous ones include CSM model (OZDEMIR, 1977), NTNU model (ROSTAMI, 1993) and so on. With the accumulation of data volume and the development of artificial intelligence technology, big data analysis and artificial intelligence technology are increasingly used in TBM tunneling performance prediction. Yagiz et al. (YAGIZ, 2009) used the ANN model to predict penetration in the Queens water tunnel in the United States; Adoko et al. (ADOKO, 2017) used the Bayesian model to predict the advancing speed of the Queens water tunnel; Armahani et al. (ARMAGHANI, 2017) Comparing the performance of PSO-ANN and ICA-ANN methods in the penetration prediction of Pahang-Selangor water tunnel in Malaysia; Sun Wei et al. (SUN, 2017) used random forest algorithm for the prediction of TBM dynamic load. In the above-mentioned TBM tunneling performance research, whether it is a traditional method or an artificial intelligence method, the on-site rock-machine database is often established first, and on this basis, the TBM tunneling performance prediction is achieved through various modeling methods. The above research focuses on construction period and cost estimation. It has few practical significance for reasonable decision-making control parameters and real-time construction guidance. Moreover, there are huge differences in geological parameters and construction parameters between different TBM projects, and models are often difficult to use between different projects.

This paper proposes a TBM-assisted intelligent construction technology system. This system covers multiple links of information perception, information transmission, status evaluation, and autonomous decision-making in the TBM tunnelling process, and builds the overall technical framework of TBM contains "edge information perception, platform information fusion, and terminal intelligent decision-making".
At the edge information perception layer, study the law of rock-machine interaction in the TBM tunneling process, develop the TBM slag slice online analysis system and the machine operating state monitoring system, realize the perception and acquisition of rock machine state information; on the platform information fusion layer , build the TBM construction information management cloud platform, collect massive information data from TBM construction to realize effective data management、 analysis and mining; At the terminal intelligent decision-making level, establish an intelligent control system for TBM tunneling parameters, support levels and tunneling attitudes. Develop the TBM-assisted intelligent construction system intelligent terminal TBM-SMART to provide TBM operators with excavation decision-making and optimization suggestions, and realize TBM-assisted intelligent construction.

2. CREG ROCK-MECHANICAL MODEL

Through the field tunneling test, the data analysis of the TBM tunneling parameter rising section under different formation conditions found that: the disc cutter thrust increases with the increase in penetration, as shown in Fig.1, there is an obvious linear

relationship, as shown in Eq.1, Moreover, the more complete the rock mass and the greater of the strength, the disc cutter thrust get greater; the speed of the cutter head has little effect on the disc cutter thrust &penetration relationship, as shown in Fig.1. Therefore, when establishing the China Railway Equipment Rock-Machine Relationship Model (CREC model), the speed is not introduced as a calculation parameter.

$$F_n = aP + b , \qquad R^2 > 0.85 \tag{1}$$

In the formula, F_n is the disc cutter thrust, kN; P is the penetration per revolution, mm/r; a is the influence coefficient of the penetration on the disc cutter thrust ; b is the minimum threshold for the cutter to invade the rock mass and produce effective indentation value.
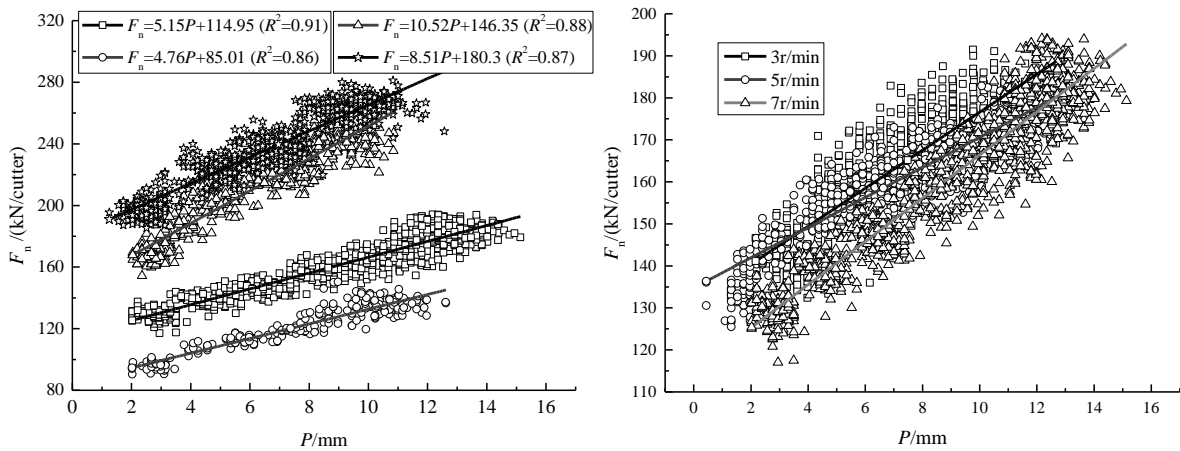

Fig. 1 The relationship between the disc cutter thrust and penetration under different mileage and rotation speed

Perform stepwise regression fitting analysis on the rock machine parameter data of limestone formations. First, the penetration and single-pole thrust data of each tunneling cycle are fitted to obtain the values a and b respectively; then the a value and the rock mass strength UCS, a+b and the rock mass strength UCS and the volume joint number Jv are respectively performed Regression fitting; get the TBM performance prediction model of limestone formation, the expression is as follows:

$$a = 0.0235J_v^2 - 1.223J_v + 19.825 \tag{2}$$

$$a + b = 1.268\text{UCS} - 2.342J_v + 86.019 \tag{3}$$

$$F_n = (0.02J_v^2 - 1.2J_v + 19.8)P + (1.3\text{UCS} - 2.3J_v + 86) \tag{4}$$

Using the TBM excavation performance prediction model, the rock mass parameters are solved by the excavation parameters, and the rock mass parameter prediction method is proposed, which can predict the strength and volume joint number of the rock mass excavated by TBM. It has been verified that the accuracy of the rock

mass parameter prediction can meet the engineering requirements. Provide a reference basis for TBM drivers to adjust the tunneling plan according to the current geological conditions. Transform the TBM performance prediction model formula to obtain the rock mass parameter prediction model, as shown below

$$\begin{cases} F_n = aP + b \\ UCS = b + 22.3J_v - 86 \\ J_v = 30 \pm 25\sqrt{0.08a - 0.144} \end{cases} \quad (5)$$

The CREC model currently only focuses on the performance of TBM in limestone formations. When the lithology changes, the parameters of this model can be adjusted appropriately; when it encounters formations with high ground stress, it can also be adapted by increasing the ground stress correction coefficient. , So this model has good generalizability.

3. MUCK INTELLIGENT IDENTIFICATION SYSTEM

The muck intelligent identification system consists of four parts: data acquisition subsystem, communication and control subsystem, database and data processing subsystem, and software subsystem. The data acquisition subsystem is used to obtain data such as the image, mass flow and volume flow of the slag piece; the communication and control subsystem is used for data transmission and equipment control; the database and image processing subsystem is used for data storage and image analysis; the software subsystem provide services such as information visualization, data query and user management.
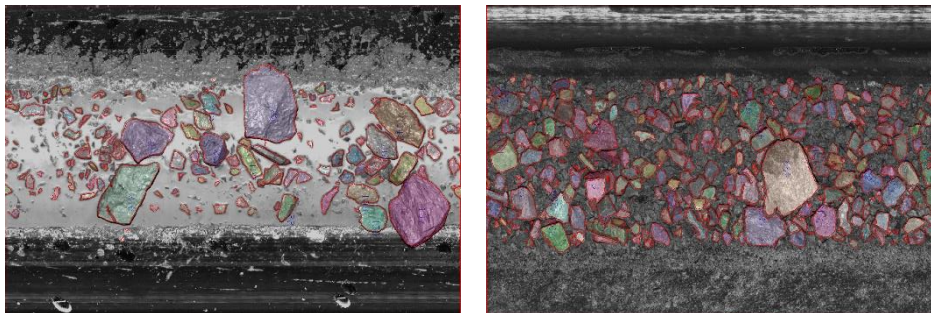
(a) Image recognition with high background contrast (b) Image recognition with complex background
Fig. 2 Segmentation result of slag slice image

In order to solve the problem of muck image segmentation, the region-based segmentation algorithm is used to segment the slag slice image, which effectively improves the error segmentation problem caused by slag slice stacking, as shown in Fig. 2.

4. TBM CONSTRUCTION INFORMATION MANAGEMENT CLOUD PLATFORM

With the development of BIM (building information modeling) technology and IFC (industry foundation classes) standards, more and more information management platforms are used in different construction fields such as buildings, bridges, and tunnels. For the TBM industry, the efficient, scalable, and on-demand TBM construction information management cloud platform can realize TBM remote monitoring, geological parameters and equipment parameter retrieval and analysis, rock mass information perception, equipment safety early warning analysis and other functions. All parties involved in the project can obtain real-time, systematic and complete on-site construction information, and provide guarantee for the safe and efficient construction of TBM.

The TBM construction management cloud platform conforms to the principle of "decentralized collection, multi-level integration, on-demand sharing and hierarchical release", and relies on the TBM big data warehouse to integrate all the information resources of the project. The TBM construction management cloud platform developed by CREG is shown as Fig.3.
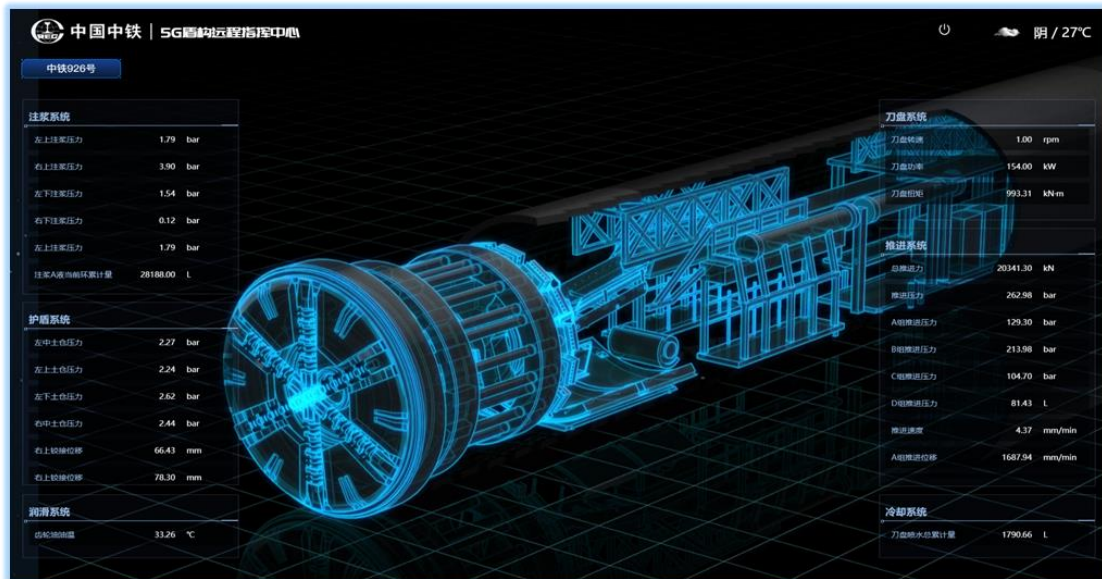

Fig. 3 Tunnel Boring Machine Remote Command Center platform

5. TBM-SMART INTELLIGENT TUNNELING SYSTEM

TBM-SMART includes five functional modules: assisted driving, equipment perception, rock mass perception, intelligent guidance and intelligent support, Part of the interface is shown in Fig. 4. Among them, the two functional modules of rock mass perception and intelligent support are the mapping of geological conditions; intelligent guidance and equipment perception are the mapping of equipment status; the driving

assistance module summarizes the common information of rock mass and equipment to assist TBM operators in making scientific decisions.
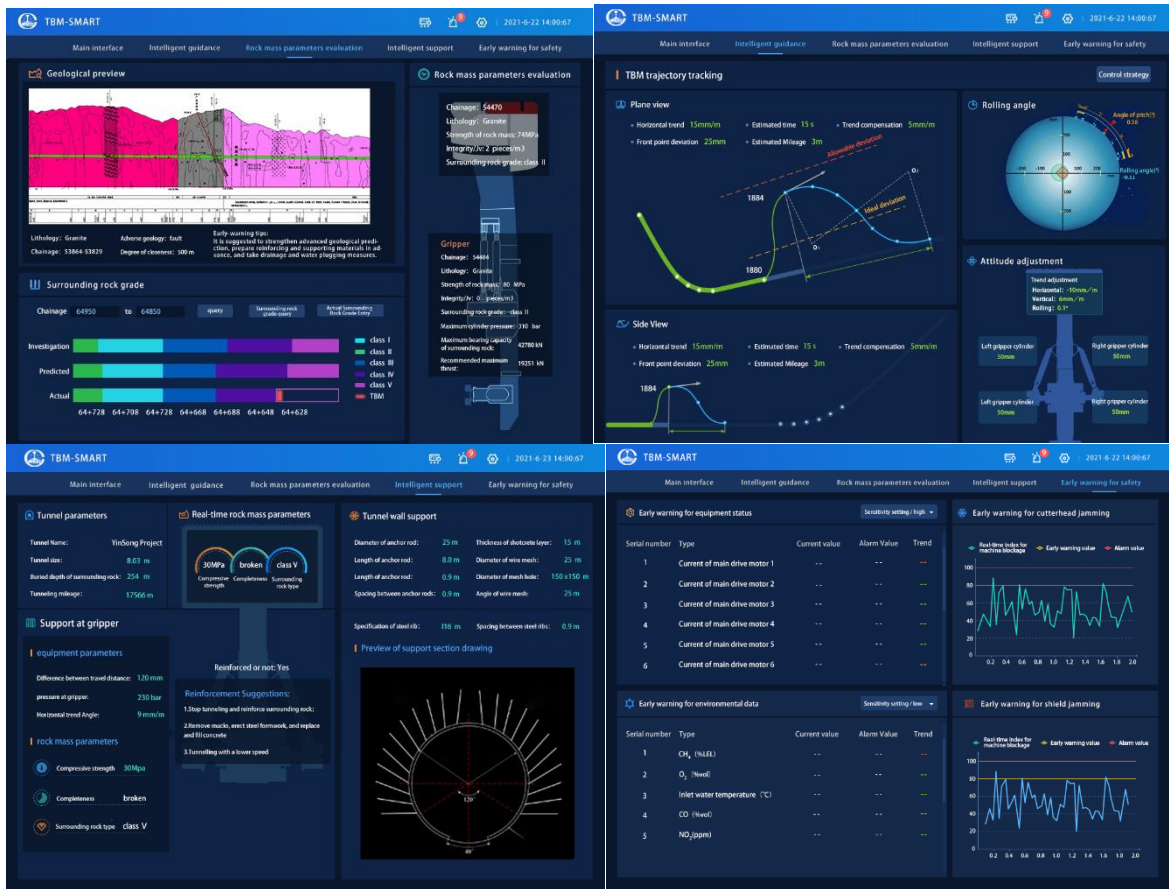

Fig. 4 TBM-SMART INTERFACE

6. CONCLUSIONS

Constructed the overall technical framework of TBM "edge information perception, platform information fusion, terminal intelligent decision-making", proposed TBM big data analysis method, developed slag piece intelligent identification system, host vibration monitoring system, and developed TBM auxiliary intelligent construction system The intelligent terminal TBM-SMART provides tunneling decision-making and optimization suggestions for TBM operators, and realizes TBM-assisted intelligent construction.

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