The Synergetic Evaluation Model of Machine-Rock in TBM-EPB Shield Construction and its computer realization

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ABSTRACT: This paper explores the influencing factors, mechanical mechanism and evaluation model of "machine-rock" cooperative mapping in dual-mode shield (TBM-EPB) tunnel construction, and scientifically determines the order parameters of artificial and natural interaction system evolution in dual-mode shield (TBM-EPB) tunnel construction by means of mechanics and Synergetics, and establishes a "machine-rock" cooperative mapping evaluation model for dual-mode shield (TBM-EPB) tunnel construction. The "machine-rock" cooperative mapping of dual-mode shield (TBM-EPB) tunnel construction is evaluated by computer, and verified by a typical case of efficient and safe construction of dual-mode shield (TBM-EPB) tunnel between Liuxiandong Station and Baimang Station of Shenzhen Metro Line 13. Finally, the future development trend and key technologies of dual-mode shield (TBM-EPB) tunnel construction are predicted, and the future research trends. The results of this paper have important guiding significance for the toughening construction of underground tunnel and its cooperative coexistence with the environment.

Keywords: dual mode shield (TBM-EPB), tunnel construction, "machine-rock" interaction, collaborative mapping, evaluation.

1 INTRODUCTION

Urban ground traffic congestion has become one of the main problems in super-first-line, first-line and other major cities at home and abroad, and the development and use of urban underground space transportation resources has gradually become the focus and focus of urban transportation construction. However, urban subway tunnels are mostly built in urban areas with dense personnel, vertical and horizontal traffic flow and numerous buildings, and their construction is underground covert engineering, and there are many uncertainties in underground engineering geological conditions. Tunnel construction is very easy to cause collapse accidents (figure 1). In order to avoid the above disaster problems, the industry is increasingly using the shield method for underground tunnel construction. In the process of urban subway tunnel construction, shield method has been widely used in the development of urban underground rail transit because of its characteristics such as small environmental impact, high tunneling efficiency and high construction safety.

Figure 1. Cases of surface subsidence and collapse caused by tunnel construction.

At present, hard rock tunneling machine (TBM) is widely used in hard rock strata, and earth pressure balance shield machine (EPB) is widely used in soft rock strata. However, under the condition of long and long interval composite strata, soft and hard rock strata are very likely to appear on a subway line, as shown in figure 2. If only a single shield mode is adopted, it is difficult to adapt to the stratum perfectly. For example, if the earth pressure balance shield machine is used to dig the whole subway line, it will seriously affect the construction efficiency of the hard rock section. If the hard rock boring machine is used to dig into the whole subway line, it may cause the collapse of the overlying soil in the soft rock stratum and cause safety accidents.

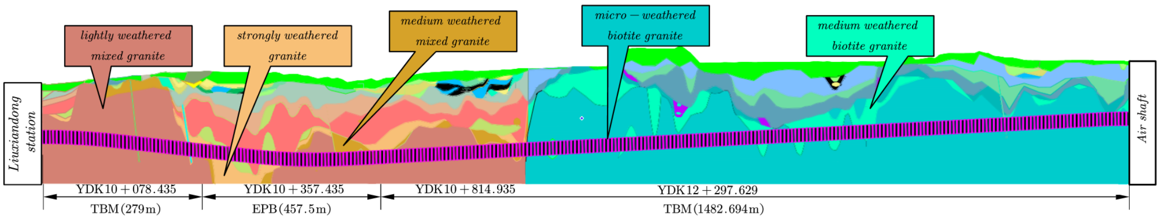

Figure 2. Geological diagram of interaction between soft and hard rocks between Liuxiandong Station and Baimang Station on Shenzhen Metro Line 13.

The construction of double-mode (TBM-EPB) shield tunnel is a brand-new topic, and its application in China has just started, and there are not many successful experiences to learn from [1-5]. Therefore, based on the goal of coordination and coexistence between tunnel toughening construction and surrounding rock and soil mass and surrounding environment, this paper studies the coordination of dual-mode shield (TBM-EPB) tunnel construction with surrounding rock and surrounding environment, and verifies it with a typical case of efficient and safe construction of dual-mode shield (TBM-EPB) tunnel between Liuxiandong Station and Baimang Station of Shenzhen Metro Line 13.

2 SCIENTIFIC CONNOTATION AND MECHANICAL MECHANISM OF "MACHINE-ROCK" COLLABORATIVE MAPPING IN DOUBLE-MODE SHIELD (TBM-EPB)

When the dual-mode (TBM-EPB) shield machine is sent underground to propulsion, there is an interaction between the shield machine and the rock mass, which is called "machine-rock" interaction, in which the machine refers to the shield machine, and rock refers to the rock mass (mainly including face, surrounding rock and overlying rock). In a broad sense: the shield machine exerts destructive force on the rock mass in the process of tunneling, and the stress in the rock mass, surrounding rock and overlying rock in front of the face is redistributed, which leads to the splitting and breaking of the rock mass, and even causes the surrounding rock to collapse and then cause the surface subsidence. When the surrounding rock enters the state of damage expansion and rupture tunnel expansion, it is very easy to cause large deformation of the surrounding rock, squeeze and react to the shield machine, and cause the shield machine to be blocked. Thus, it extends a series of negative phenomena, such as geological risk accidents, environmental risk accidents and so on.

It can be seen that the study of "machine-rock" interaction is a very important topic in shield tunnel construction, and it is of great significance to efficient construction, disaster prevention, environmental protection and safety guarantee of shield tunnel. However, the problem of "machine-rock" interaction is an extremely complex system of artificial and natural interaction. As shown in figure 3, the system consists of three subsystems: shield machine, rock mass and risk factors, which influence each other. On the basis of manual control and adaptive control of shield machine, high tunneling efficiency, low tool wear and strong rock mass stability are realized in coordination. The engineering goal of light environmental damage and high construction safety. In order to achieve the above engineering goals, it is necessary to study the cooperation in the "machine-rock" interaction system.

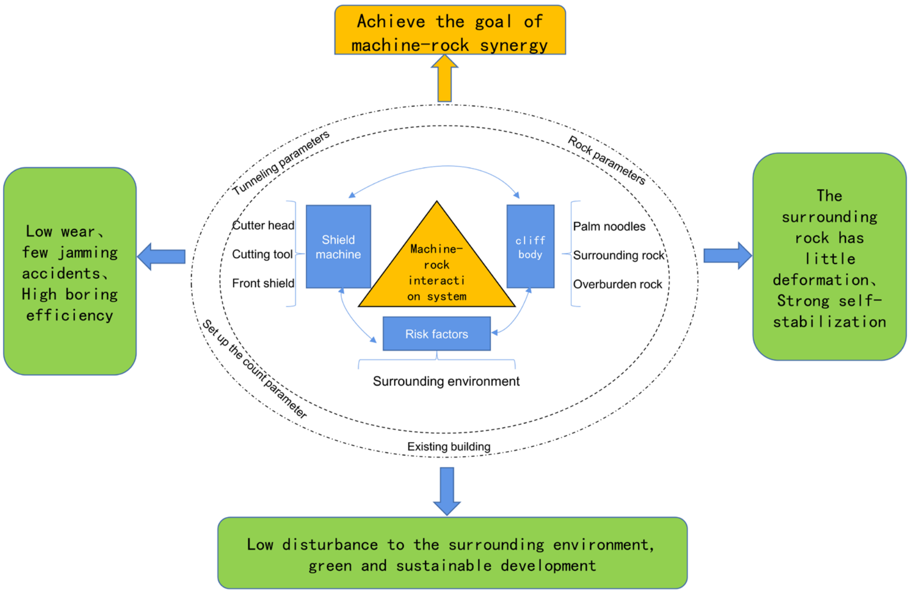

Figure 3. "Machine-rock" interaction system in shield tunnel construction.

3 CONSTRUCTION OF "MACHINE-ROCK-ENVIRONMENT" COMPOUND SYSTEM IN DOUBLE-MODE SHIELD CONSTRUCTION

Taking the double-mode shield construction of Shenzhen Metro Line 13 as an example, the "machine-rock-environment" compound system of double-mode shield construction is constructed. With the application of the idea of system theory, the whole research object involving shield machine, surrounding rock and surrounding environment in the process of dual-mode shield construction is regarded as a complex system. the realization of the function and goal of this kind of complex system depends on the internal activities of the subsystem itself and the interaction between the subsystems, that is, each subsystem coordinates with each other while realizing its own functions and goals. Work together to promote the realization of the overall functions and goals of complex systems. The core idea of the "machine-rock-environment" compound system of dual-mode shield construction is to combine the characteristics of tunneling mode, geology and environment of the dual-mode shield tunnel construction project to realize the scientific and reasonable development of the project. so that each part of the integration into a more efficient shield construction system, serving the macro-social economy. Therefore, the current dual-mode shield construction "machine-rock-environment" compound system can be understood as follows: based on complex geological and environmental conditions, relying on "TBM-EPB" double-mode shield construction technology, in order to achieve the safety, efficiency and economy of the construction process, so that all parts coordinate and cooperate with each other.

The shield machine subsystem mainly studies the shield with two modes of TBM-EPB. The surrounding rock system mainly studies the deformation of surrounding rock. The surrounding environment subsystem mainly studies the underground pipeline system and the existing building system, as shown in figure 4.

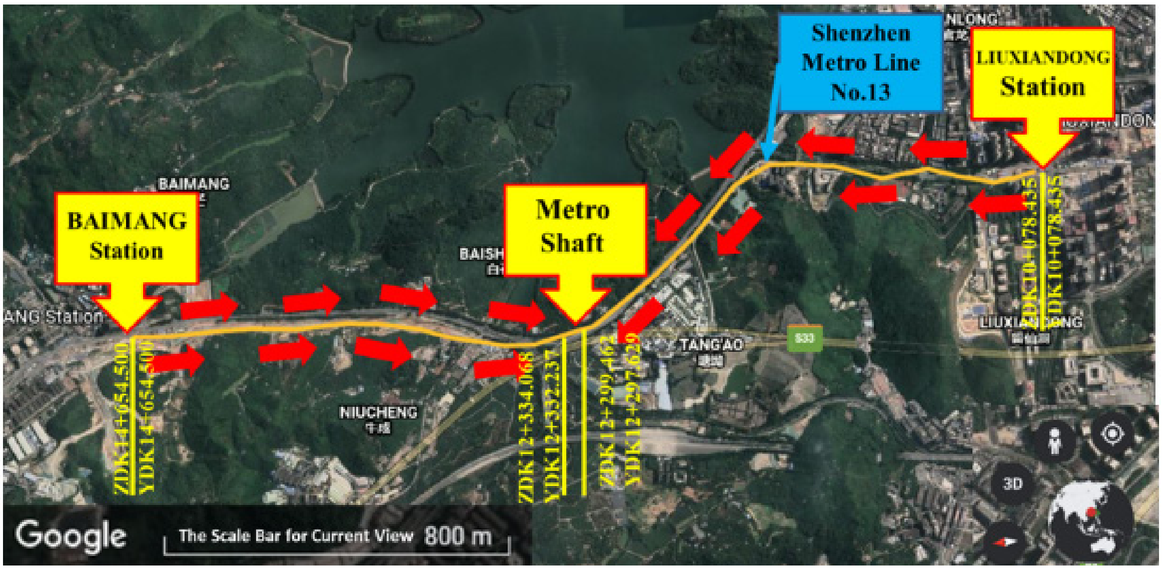

Figure 4. The surrounding environment map of the blank interval.

4 "MACHINE-ROCK" COOPERATIVE EVALUATION MODEL FOR TBM-EPB TUNNEL CONSTRUCTION

The "machine-rock" cooperative evaluation model of dual-mode shield construction system is established by using Synergetics theory. firstly, the order degree of order parameters of each subsystem is calculated, and formula (1) is selected for calculation when the order parameter value is higher, and vice versa. Select formula (2) to calculate:

$$u_{ij} = \frac{x_{ij} - \alpha_{ij}}{\beta_{ij} - \alpha_{ij}} \quad (1)$$

$$u_{ij} = \frac{\alpha_{ij} - x_{ij}}{\beta_{ij} - \alpha_{ij}} \quad (2)$$

Among them, α_{ij} and β_{ij} are the critical threshold for the stability of the double mode shield construction system, and x_{ij} is the j order parameter of the i subsystem. Then, the degree of order of each subsystem is calculated:

$$u_i = \sum_{j=1}^{n} \sigma_j u_{ij} \sigma_j \geqslant 0, \quad \sum_{j=1}^{n} \sigma_j = 1 \quad (3)$$

Where σ j is the weight value of the order parameters of the subsystem.

$$u = \sum_{i=1}^{n} F_i u_i \quad F_i \geqslant 0, \quad \sum_{i=1}^{n} F_i = 1 \quad (4)$$

Where F_i is the weight value of each subsystem.

According to the engineering experience, the determination results of the threshold and weight values of each order parameter are shown in Table 1 below.

Table 1. Threshold and weight table of each order parameter.

Order parameter	Shield machine subsystem				Surrounding rock subsystem				Environment subsystem	
	Daily footage (m)		Number of tool replacement (ring / handle)		Vault displacement (mm)		Headroom convergence value (mm)		Surface subsidence (mm)	
	TBM	EPB	TBM	EPB	TBM	EPB	TBM	EPB	TBM	EPB
Threshold value α_{ij}	0	0	0	0	0	0	0	0	0	0
Threshold value β_{ij}	7.50	9.00	1	0.8	20	20	12	12	30	30
Weight value σ_j	0.7	0.7	0.3	0.3	0.5	0.5	0.5	0.5	1	1
Weight value	1/3				1/3				1/3	

Using formulas (3) and (4). The order degree and compound system coordination degree of each subsystem of the dual-mode shield construction system can be calculated, as shown in figure 9. Among them, the threshold of daily footage and tool change is determined through the collation of on-site data, and the threshold of surface subsidence is determined by questionnaire conducted by on-site project personnel.

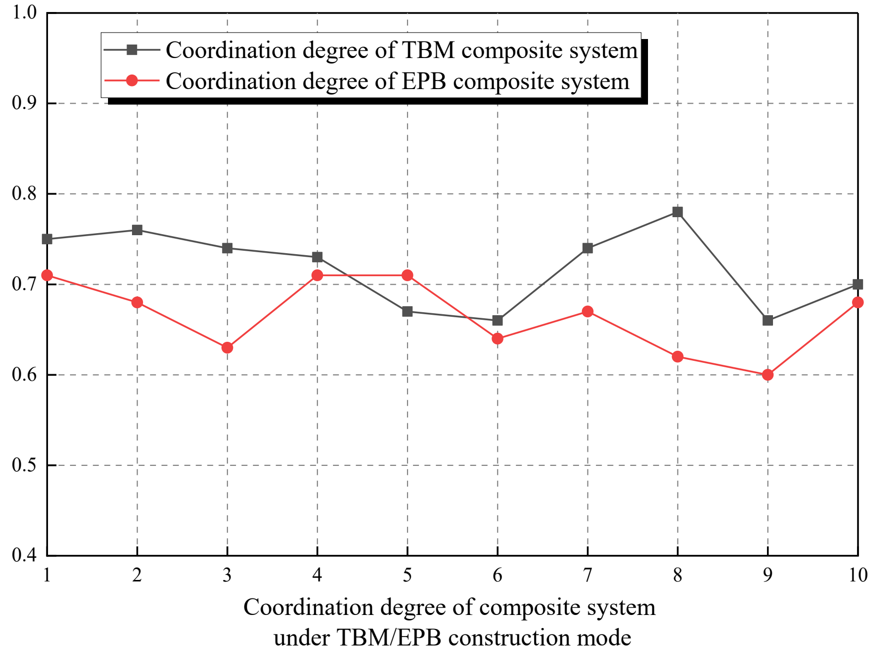

Figure 5. The coordination degree of composite system under TBM/EPB construction mode.

It can be seen from the calculation results that there is a good cooperation among shield machine subsystem, surrounding rock subsystem and environment subsystem in the process of dual-mode shield construction, which indicates that the dual-mode shield construction technology has strong adaptability to the composite stratum in Shenzhen area.

5 FUTURE DEVELOPMENT TREND AND KEY TECHNOLOGY PREDICTION OF SHIELD TUNNEL CONSTRUCTION.

Aiming at the concept of toughening construction of underground tunnel and its co-existence with the environment in the future, the future development trend of shield tunnel construction and the research trend of key technologies include the following three directions.

First, the "machine-rock" interaction shown in the process of shield tunnel construction is very complex, and involves many systems and many kinds of medium elements. It is necessary to study clearly the mechanical origin and mechanism of this complex "machine-rock" interaction, including between systems, elements and elements. Based on the concept of "coordination", we can understand the mechanical process of the interaction between shield machine and surrounding rock, the mechanical process of rock breaking and wear, the stress redistribution process of tunnel surrounding rock, overlying rock and even structures, and study the deformation law of these elements. the establishment of a mechanical model based on "collaborative concept" is the primary task of this special topic in the future.

Second, the setting of shield construction parameters is generally based on the design scheme and construction status. With the development of intelligent control methods and technologies, it is necessary to introduce control theory, computer science, artificial intelligence, operational research and fuzzy logic, neural network, expert system, genetic algorithm and other theories, as well as adaptive control, self-organizing control and self-learning control. This paper studies the technology and method of automatic perception, identification and intelligent regulation of "machine-rock" interaction in shield construction, and carries out intelligent information processing, intelligent information feedback, intelligent control decision-making and adaptive regulation of shield machine.

Third, in order to meet the requirements of geological conditions, environmental conditions, tunnel route design and construction, it is necessary to select the shield machine scientifically, actively adapt to the geological conditions and achieve the behavior of coordination with the surrounding environment. Multi-mode shield tunneling is one of the main directions of the development of tunnel technology. Research on the selection of shield machine and the evaluation of the adaptability of shield tunneling; in addition, the process of changing mode involves safety issues, which is also the core scientific issue in multimodal shield construction.

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