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Application and prospect of hard rock TBM for deep roadway construction in coal mines

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ABSTRACT

With increasing coal mining intensity, the number, length and depth of coal mine roadways is increasing drastically, the traditional drill-&-blast method and comprehensive mechanized driving method, and corresponding support methods are incapable of controlling the surrounding rock stability gradually. Hard rock TBMs (Full-face tunnel boring machine) have significant advantages in terms of fast advance rates, high support capacity, being favorable to environmental protection and low construction costs. Meanwhile some modern mines are possible target for TBM application. TBMs have been successfully used for some roadway and inclined shaft construction. Therefore, it can be foreseeable that the TBM tunnelling method will be the first choice and preferred future method for deep rock roadway construction in coal mines. However, because of the complicated construction environments, many technical challenges are encountered during TBM tunnelling in deep roadway including the presence of: (a) mixed and changing grounds; (b) high geostress; (c) squeezing deformation and the induced TBM entrapment or overstressing on supports; (d) fractured and faulted zones; (e) special requirements for TBM assembly, explosion-proof, influences of roadway or cavern groups, drainage due to the construction environments in coal mine. Therefore, in order to cope with these challenges in deep roadway tunnelling, the following scientific problems are identified as needing urgent examination: ground stress distribution and geological conditions investigation of deep roadway; interaction mechanism between the surrounding rock and the TBM; safety control for surrounding rock stability; informatization construction, optimization decision and intelligent control for TBM tunnelling. Some research progresses are also presented. Solution to these problems will provide an important theoretical foundation for application of TBMs in deep coal mines.

1. Introduction

With increasing resource demand and exploitation, coal mines are entering into new depths (He et al., 2005). The state of coal mining in China is taken as an example to illustrate the roadway construction status here. Coal is abundant in China, and will be a significant energy source for a long time. At present, coal mine depths are increasing at a rate of 8–12 m/a, even 10–25 m/a in eastern China (He et al., 2005). Recently, more than 17 coal mines have exceeded 1000 m depth. The deepest mine is greater than 1300 m deep. More and more mines will likely enter into or exceed the 1000–1500 m depth, which can be called over-1000 ms burial coal mine.

However, in deep coal mines, the surrounding rock behaves quite differently from shallow mines. This difference in behaviour results in many emergent engineering accidents and catastrophic phenomena (Fig. 1), and poses a series of severe challenges to rock stability. The traditional drill-&-blast method (D&B) or comprehensive mechanized excavation method with 'anchor bolts - steel sets - grouting' does not satisfy the roadway excavation and support needs of mine roadways below 600–800 m deep. When mining depth increases to 1000 m or even 1500 m, these traditional excavation and supporting methods fail gradually, and barely satisfy the deep roadway construction. Therefore, a new construction method for roadways in deep coal mines is urgently needed.

It is well known that the TBM is the most advanced tunnelling machine in the word. The TBM combines the functions of cutting rocks, support installation, mucking and conveying into one machine (Barla and Pelizza, 2000) (Fig. 2). Compared with the drill-&-blast method, TBM tunnelling has significant advantages, including high construction efficiency and low

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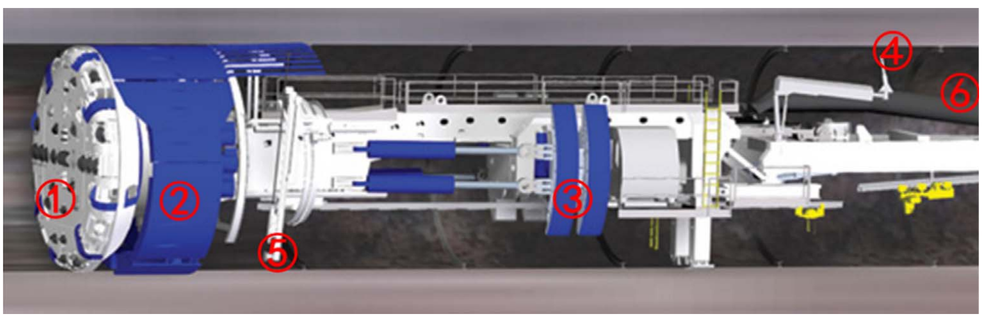
(a) Crown subsidence (b) Cracks produced on the roadway floor

Fig. 1. Photos of deformation and failure of the roadway.



①Cutterhead ②TBM head ③Gripper ④Guniting ⑤Jumbolter ⑥Belt conveyor

Fig. 2. Gripper TBM (modified from The Robbins Company, 2015).

project cost. The TBM is more conducive to environmental protection and is favorable to the surrounding rock stability control (Liu et al., 2016a; Zheng et al., 2016). Therefore, TBM has been widely applied in water diversion, highway and railway tunnels.

Considering the advantages of the TBM tunnelling method and the demands of deep roadway construction, the feasibility of the TBM application in deep roadway construction is analyzed in this paper. Previous cases of TBM application in coal mine construction are analyzed too. Thus, hard rock TBM tunnelling method is believed to be a suitable approach for deep roadway construction. Applications of TBMs in the mining industry have previously been reviewed by Stack (1982), Handewith (1983), Robbins (1984), Cigla et al. (2001), Home and Askilsrud (2011), Brox (2013) and Zheng et al. (2016). But there have not detailed investigation on the TBM application in coal mine roadway.

Because of the huge differences of the construction environment among the coal mine, metallic ore mine and the civil projects, and poor adaptability of TBMs to the geological conditions, some geohazards and tunnelling accidents are prone to happen in the coal mine, such as squeezing deformation and TBM entrapment. Therefore, the technical challenges and geological hazards are reviewed, and possible countermeasures are provided. Subsequently, in order to cope with these technical challenges of TBM tunnelling in coal mine, the main scientific problems need to solve are discussed, as well as some research progresses are shown briefly. Data presented in this contribution have significant implications for TBM usage in deep coal mine roadway construction.

2. Feasibility and advantages of hard rock TBM application in deep coal mine roadway construction

2.1. Coal mine roadway construction status

60% of the proven coal resources in China is buried deeper than 800 m, and 53% is buried deeper than 1000 m (He et al., 2005, 2015). With the exhaustion of shallow coal resources and enormous coal demands, more and more coal mines are entering deep mining levels, the mining depth is increasing at a rate of 9.39–21.53 m/a. The depth of some old mines is already 800–1000 m, and there are 17 mines in China which have reached 1000 m deep (Fig. 3 and Table 1).

Deep roadways account for 28–30% of the 8000 km/a of constructed coal mine roadways, which is more than 2200 km/a (He et al., 2005). Meanwhile, as long wall mining continues to be the most prevalent mining technology for worldwide underground coal mining, roadways are becoming longer. For example, the main roadways in Shengdong mining area (China) have reached 6 km.

2.2. Demands of new theories and technologies for deep coal mine roadway construction

(1) Geological environment of deep roadways.

Geological conditions significantly deteriorate along roadways over

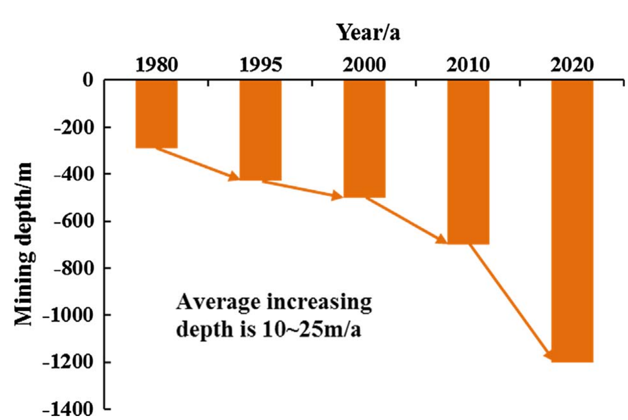


Fig. 3. The developing trend of coal mining depth in China (He et al., 2015).