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Investigation on support pattern of a coal mine roadway within soft rocks — a case study

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ABSTRACT

Supporting coal mine roadway within soft rocks is a typical challenge in underground mining practices. As the most widely used support structure, rock bolt system has been successfully used to support coal mine roadways in various complex geological and geotechnical conditions, including roadway in extremely weak rock masses, roadways 1000 m below ground, open-off cut roadways with large section, and roadways along the edges of mined-out areas with thin pillars or even no pillars. However, the effectiveness and applicability of rock bolt system for the reinforcement of soft rock masses has not yet been established. In this paper, we present a case study of rock bolt system as used for ground reinforcement of longwall entries within soft rock masses. The study site was the tailgate of the longwall panel 5-2S at the Hongmiao coal mine in the Pingzhuang coal-mining district in China, a typical soft rock coal mine of the region. Since traditional rock bolt system failed to maintain the stability of the tailgate, the effectiveness of rock bolt systems for this application remained doubtful. The reasons for the failure of the rock bolt system were first examined. A discrete element method simulation was then performed to better understand the mechanism of rock bolts in supporting soft rocks. An improved rock bolt system was finally proposed that was used to support the tailgate. The field monitor showed that the improved rock bolt system successfully suppressed cracking and dilation of the tailgate. This case study is useful in enhancing engineering applications of rock bolts to support longwall entries excavated in soft rock masses.

1. Introduction

Rock bolt systems have been extensively used for ground reinforcement in underground coal mine roadways around the world (Brown, 1999; Peng and Tang, 1984). In China, more than 70% of roadways in key state-owned coal mines are supported by the system (Kang et al., 2010). As an active support pattern, rock bolts suppress the deformation of and damage to rock masses immediately after installation. Rock bolts are economical, easily installed and reliably supportive. The principal objective of rock bolting is to help rock masses support themselves. Bolts increase the stress and the frictional strength across joints, causing loose blocks or thinly stratified beds to become wedged together and act as a composite beam (Goel et al., 2007; Karanam and Dasyapu, 2005; Mark, 2000). Rock bolts are generally installed with pretension. The high pretension applied during installation has been proven to be a very important component of the supportive effect of rock bolts (Li, 2006). Pre-tensioned rock bolts compress and reinforce the rock mass in their vicinity. This effect spreads to a further section of the rock surface through accessories such as load-bearing plates and screens, creating a confining pressure on the rock surface (Ghazvinian et al., 2012). Active pretension modifies roof behavior by dramatically reducing bed separation and delamination immediately within 0.5–0.8 m of the roof (Frith and Thomas, 1998). In addition, thinly laminated roof beds can be clamped into a thick beam that is more resistant to bending (Peng, 1998). Bolts installed with pretension increase frictional resistance along bedding planes, minimizing roof sag and defection, and decreasing the likelihood of lateral movement due to horizontal stress (Stankus and Peng, 1996).

Rock bolt systems have been successfully used in complex geological and geotechnical conditions, such as roadways 1000 m below ground, open-off cut roadways with large section and roadways along the edges of mined-out areas with thin pillars or even no pillars (Kang, 2013; Zhang and Gao, 2004). However, the effectiveness and applicability of rock bolt system for the reinforcement of soft rock masses has not yet been established (Jiao et al., 2013; Wang et al., 2000; Yoshinaka et al., 1998). Soft rock refers to a group of geotechnical materials that has a uniaxial compressive strength between 0.5 and 25 MPa and has similar geotechnical characteristics, including slaking, swelling, compressibility, time dependence, and volume change (Jiao et al., 2013; Wang et al., 2000; Yoshinaka et al., 1998). Roadways caved out of soft rocks exhibit large deformation in the form of severe roof sag, wall convexity, and floor heave. These roadways also have distinct characteristics that include a high rate of rapid deformation, a high sensitivity to

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water invasion and stress changes, evident rheological deformation and deformation in all directions of the roadway cross section (Wang et al., 2000). Maintaining the stability of roadways excavated in soft rocks has been a great challenge for underground coal mining engineers. In cases where roadway closure is severe, rehabilitation and re-support of the roadway have to be continually arranged during the roadway's service period to maintain its cross section and guarantee that it remains functional for ventilation and transportation. This causes safety issues, delays of mining activities, and results in dire economic loss.

Some researchers suggested that yieldable and flexible support patterns should be used to support soft rock roadways, instead of stiff supports such as the rock bolt system (Jiao et al., 2013; Wang et al., 2000). A common structure for supporting roadways in soft rocks is the installation of yieldable U-shaped steel sets. This support pattern is believed to provide sufficient support to suppress the deformation of soft rocks surrounding a roadway and has been proven to be successful where implemented (Jiao et al., 2013; Wang et al., 2000). In contrast to rock bolting, the yieldable U-shaped steel sets are passive, costly, and time-consuming to install. In underground coal mine practice, yieldable U-shaped steel sets are more suitable to support main roadways with a long-term service period and the absence of mining activities (i.e., retreat longwall mining) where rock bolting is not applicable. In longwall entries intended for the extraction of a panel, yieldable U-shaped steel sets are not effective; they have a detrimental impact on the shearer and must therefore be removed, at high cost.

This paper presents a case study on the application of rock bolt systems for ground reinforcement of longwall entries within soft rock masses. The study site was the tailgate of the longwall panel 5-2S at the Hongmiao coal mine, Pingzhuang coal-mining district, China. Traditional rock bolt system failed to support the entries. The failure reasons were first examined. A discrete element method simulation was then performed to investigate the effects of rock bolts on suppressing cracking and dilation in soft rock masses. An improvement on the rock bolt system was finally proposed and used to support the tailgate. Field monitoring of roadway deformation was conducted to evaluate the success of the improved rock bolt system in maintaining the stability of the tailgate.

2. Geological and geotechnical conditions

The Hongmiao coal mine, Pingzhuang coal-mining district was a typical soft rock mine located in the Inner Mongolia Autonomous Region in China, see Fig. 1(a). It extracted coal seams formed during the Cretaceous period. The coal seams were separated by a few rock layers, as illustrated in Fig. 2. The first coal layer was the Coal 5-1 with a thickness varying between 2.63 and 4.94 m. The material situated immediately below the Coal 5-1 was made up of 0.5–2.0 m of sandy mudstone. Below the sandy mudstone was the Coal 5-2. The thickness of the Coal 5-2 varied between 3.66 and 7.0 m, and it had a compressive strength of 6.2 MPa. It was sub-horizontal with a dip angle of 15°. Below the Coal 5-2 was found a sandy mudstone with a thickness of 1.0–2.0 m and a compressive strength of 13.4 MPa. The Coal 5-3 was 2.55–8.04 m thick and was situated immediately below the sandy mudstone. Below the Coal 5-3 was a fine-grained sandstone with a thickness varying between 0.6 and 15 m. The material situated immediately below the fine-grained sandstone was the Coal 6-1 with a thickness of 1.67–5.58 m.

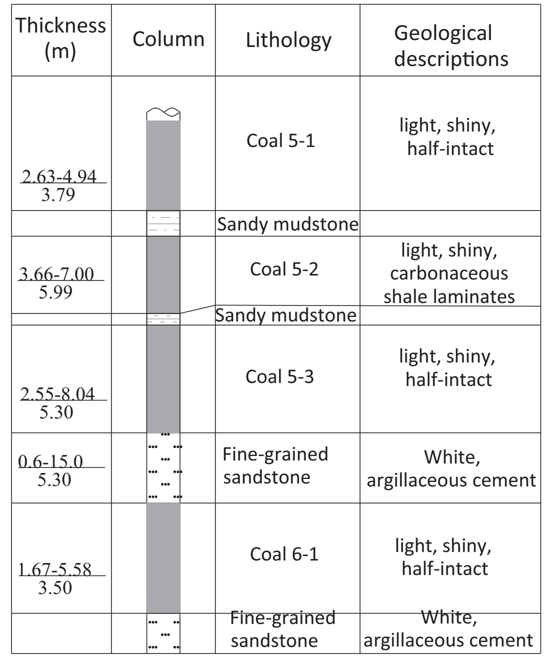

Fig. 2. Lithological descriptions of the rock units at the Hongmiao coal mine.

The Coal 5-1 had been mined out, and current mining activity was extracting the Coal 5-2 using the longwall mining method. The longwall panel 5-2S was the first panel in the Coal 5-2. The depth of this panel varied between 350 and 400 m. The panel 5-2 had a length of 560 m in the strike direction and a width of 156 m in the dip direction of the Coal 5-2, see Fig. 2.

In situ tests including in situ stress measurement, borehole strength measurement and borehole optical televiewer imaging had been performed in a vertical borehole in the main roadway close to the panel 5-2S, see Fig. 1(b). The borehole was 56 mm in diameter and 20 m in length. The in situ stress was measured using the hydraulic fracturing method and the results were $\sigma_H = 14.62$ MPa, $\sigma_h = 7.35$ MPa, and $\sigma_v = 9.68$ MPa. The direction of σ_H was N72°E, leading to an angle of approximately 80° with respect to the direction of the 5-2S tailgate. In borehole strength tests, a rod with a probe attached to the top was

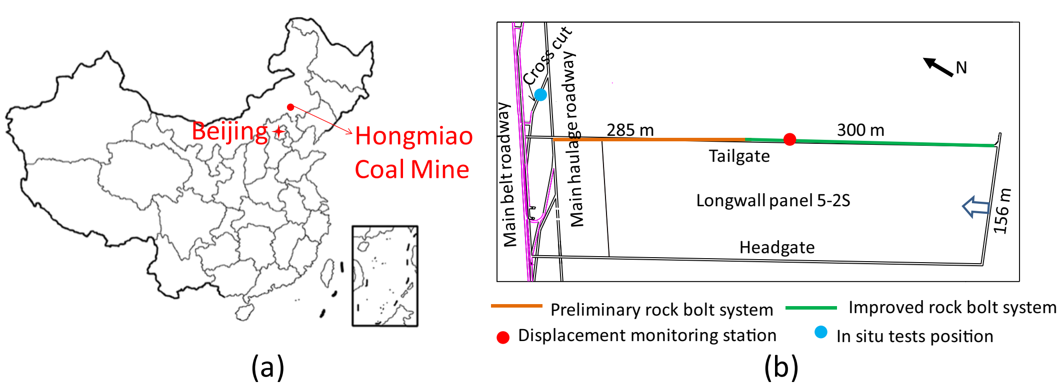

Fig. 1. (a) The location of the Hongmiao coal mine, Pingzhuang coal mining district, China. (b) Plan view of the roadways and panel at the study site in the Hongmiao coal mine.