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An anchorage experimental study on supporting a roadway in steeply inclined geological formations

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ABSTRACT

The support of rock bolt plays a significant role in maintaining the stability of a roadway in steeply inclined geological formations, yet choosing a reasonable support scheme of rock bolt in this situation is still not well understood. To reveal the force or stress distribution mechanism of anchor bolts and design an effective support scheme, an *in situ* anchorage experiment was conducted in a deep-buried roadway in steeply inclined rock strata. This results of this study demonstrate that in the steeply inclined rock formations, the intersection angle of a bolt length direction and the interface of rock layers have a great effect on the distribution and variation of axial force in bolts. The axial forces at the positions near the intersection of the interface and bolt increase a lot with time. In addition, the existence of no small or non-zero axial force at the end of anchor bolts indicates that much longer bolts should be used to prevent further deformation in steeply inclined rock.

1. Introduction

Mining in steeply inclined rock may result in instability problems, which have become a significant concern in the past few years. Because of the presence of a steeply inclined dip, the heterogeneity of the surrounding rock and the large variety of joints therein, excavation-induced asymmetrical large deformation in surrounding rock has been frequently encountered, resulting in a difficult problem to mitigate for the support of roadways in steeply inclined rock. In general, conventional support methods including yieldable support systems or stiff support systems with strengthened lining, combined with rock bolts or cables are widely used in horizontal or low-angled dip strata (Brodny, 2012; Cai et al., 2004a, 2004b; Majcherczyk et al., 2014; Shen, 2014; Torano et al., 2002); the support methods for mining in steeply inclined rock are not known in literature, particularly with regard to the methods of selecting anchor bolts or cables. Therefore, understanding the force mechanism of the anchor bolts to design a competitive support in steeply inclined rock is of great significance with regard to reducing the severity of project accidents and project costs (Alejano et al., 1999; Kang et al., 2010; Liu et al., 2015; Yang et al., 2014; Zhang, 1999).

Due to the existence of bedding and interfaces in or between steeply inclined rock formations, mining-induced stress in the surrounding rock easily causes dislocation and shear slip along the rock interface, complicating the support stability much more than under other common geological conditions (He, 2011; Ma and Li, 2011; Ran et al., 1994; Souley and Homand, 1996). In recent years, most of the studies focused on investigating bolting mechanism of grouted bolts in rock mass with joint planes. Spang and Egger (1990) performed approximately 70 laboratory and field tests on fully-bonded and untensioned rock bolts in stratified or jointed rock masses and evaluated the contribution of bolts to the shear resistance of rock joints with high friction along the joint and inclination of the bolt or dilatancy of the joint. Pellet and Egger (1996) proposed an analytical model for the prediction of the contribution of bolts to the shear strength of a rock joint, accounting the interaction of the axial and the shear forces mobilized in the bolt. Jalalifar and Aziz (2010) experimentally studied the bolt installed perpendicular to sheared joints, and found that the distance of the hinge point from the shear joint plane increases when the bolt is in a plastic state. Chen and Li (2015) proposed that the deformation capacity of the bolts increased with the joint gap, and the energy absorption capacity of the D-Bolt is 3.7 to 1.5 times that of the rebar bolt, depending on the displacing angle. Liu and Li (2017) analysed the contribution of the axial and shear forces acting at the intersection between the bolt and the joint plane to the stability of a rock slope and proposed that the bigger the dip of the bolt to the joint plane, the more significant the dowel effect. Deb and Das (2014) found that rock bolt reduces the rock and joint movements and also reduces the yielding zone along the joint, and higher axial load occurs in the rock bolts intersected by the joint as

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Fig. 1. Inclined geological formation.

Fig. 3. Asymmetrical large deformation.

compared to the nonintersecting bolts. The bolt rod bends because of the shear movement of the joint, and the bending moment attains a maximum value at two hinge points. These studies ultimately revealed the distributions of the axial stress in the bolt and the shear stress at the bolt – grout interface, considering the interaction of jointed or stratified rock masses with bolt. The bolt activates an axial force because of the opening of the joint, inducing a shear force by the transverse displacement of the joint (Deb and Das, 2011; Delhomme et al., 2010).

In steeply inclined formations, interfaces are the primary factors. Although there are many similarities between rock joints and interfaces, some differences still exist, e.g., rock joints always have existing cracks or surfaces, whereas interfaces between the rock layers are dense before being disturbed by external pressure; rock joints are always rambling, while interfaces are regular. Further, at present, a few technological methods are known to help design the support scheme of anchor bolts in steeply inclined rock roadways. Therefore, considering the effect of the excavation of roadway in steeply inclined rock formations, the anchorage performance of rock bolts needs further study.

In this study, a deep-buried roadway in steeply inclined rock was chosen as a case study; using an *in situ* experiment and automatic monitoring, the force mechanism of the anchor bolts mounted in the rock mass surrounding a roadway was analysed to provide evidence for a reasonable design for anchor bolt supports.

2. Situation of the engineering construction

A roadway in a coal mine, with a mining depth of 700 m, is located at the lower wing of an overfold between the fourth and the fifth crossheading. For the purpose of both geologic survey and haulage, the roadway is designed as one-orbital tunnel with the height and width of 3.4 and 4.7 m, respectively, and the main support consists of 36U-shaped steel sets, wire netting, steel bands, and rock bolts around the perimeter, as shown in Fig. 1.

This roadway is mainly constructed in a coal seam, characterized by the layered black massive structure with glassy luster, mingled with several layers of dirt bands. The immediate roof is made of light-grey sandy mudstone, and the immediate floor is mainly grey sandy mudstone, dense and thick-layered with a sand shale structure. The main roof and main floor are grey-white quartz sandstone and grey-white fine sandstone, respectively. According to the geological profile map of the roadway ranging from 30 m above the roof to 30 m below the floor, the geological formations include mudstone, quartz sandstone, sandy mudstone, coal seam, sandy mudstone, fine sandstone and mudstone, as illustrated in Fig. 2. The rock formations are almost parallel at the interfaces and considered as steeply inclined rock strata (dip 60°).

The roadway construction encounters severe deformation problems. One challenge is the severe asymmetric large deformation, induced by asymmetrical ground pressure during mining, as shown in Fig. 3. The deformations at the roof and the right side were observed up to 50 cm and > 1 m, respectively. In addition, the U-shaped steel support was damaged, and the steel ribs at the lower right sidewall were severely twisted (Fig. 4), mostly caused by the dominant tectonic ground stress.

For these reasons, the original support, using conventional support scheme, is not capable of maintaining the stability of the roadway.

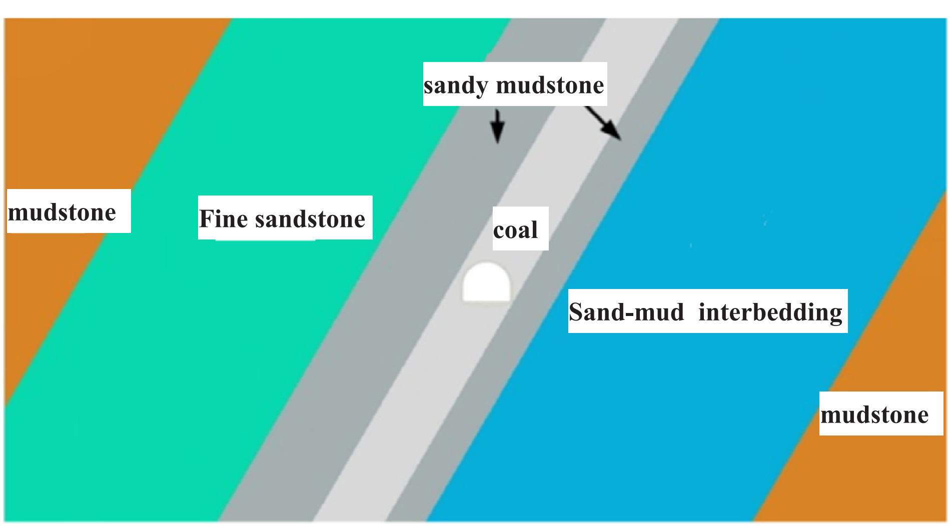

Fig. 2. Geological model of the boring roadway.