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Prediction of relative displacement for entry roof with weak plane under the effect of mining abutment stress

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ABSTRACT

In coal mining, the entry roof with a weak plane (ERWP) is vulnerable to large relative displacement, and even caving influenced by the mining stress from the adjacent working face (AWF) for underground mining engineering. A typical field case in a chinese coal mine demonstrates that the mining abutment stress can strengthen the relative displacement along the weak plane for the entry roof. To address this conditions, a method to improve the width to height ratio (W/H) of the coal pillar to reduce the effect of the mining stress on the stability of the ERWP based on a numerical model is proposed. In order to improve the reliability of the numerical model, the double-yield model for the gob material, the Mohr–Coulomb model for the pillar material, and the interface element for the weak plane were validated in detail. The results of the validated model indicate that the relative displacement induced by the mining abutment stress is divided into four stages, and it decreases significantly as the W/H increases. In the final, the W/H more than 8 is determined to reduce the effect of the mining abutment stress on the ERWP. The modelling procedure can be repeated and is necessary in other geological and engineering conditions since the determined W/H may be another value.

1. Introduction

Three entries are developed on both sides of every longwall panel, called the three-entry system in US coal mines (Barton et al., 1990; Carr et al., 1985), while two-entry system is the popular method used (Colwell et al., 2003; Shabanimashcool and Li, 2012; Yu et al., 2015) in underground mining engineering throughout the world. With the development of longwall mining, the two-entry system has been widely and successfully used in chinese coal mines as shown in Fig. 1 (Shen et al., 2016; Bai et al., 2015; Hou, 2011; Zhang et al., 2004). Influenced by the evolution of the abutment stress of the adjacent working face (AWF), the entry roof with weak plane (ERWP) will undergo large relative displacement, which will induce large deformation and even caving.

Most of the researches have studied the mechanical behaviour of entry with weak plane under static geological stress, which are helpful in the design of the entry (Liu et al., 2002; Wu et al., 2011; Zhang et al., 2009, 2007). Shou (2000) demonstrated that the lesser angle between the axial direction of the entry and the dip direction of the weak plane contributed larger deformation for the roof based on the method of three-dimensional hybrid boundary element. Using the methods of scaled model tests and numerical model calculation, Jeon et al. (2004) found that the displacement of the rock around the entry was quite large, since the shear deformation occurred along the weak plane. Zhao et al. (2009) revealed that the shear slipping mainly occurred along the weak plane since the normal stress of the weak plane would decrease after the entry was developed with the numerical analysis. Under the condition of a verified compression-shear strength criterion, Zhao et al. (2015) pointed out that the coal-rock combination with weak interface trended to isotropic rock when the confining pressure is raised to a specific value.

Many other researches (Dou et al., 2006; Indraratna et al., 1998; Jaeger and Cook, 1979; Li et al., 2015) have made great contributions to the mechanical behaviour of the coal-rock combination, but cannot explain the deformation mechanism of coal-rock mass around the entry influenced by the mining abutment stress in underground mining engineering. The tail entry II was developed prior to the extraction of panel I as shown in Fig. 1. From the mechanical point of view, the ERWP will be loaded with the in situ stress during the tail entry II development. Second, it will be loaded by the evolution of the front abutment stress, and then it will be loaded by the evolution of the side abutment stress of the AWF.

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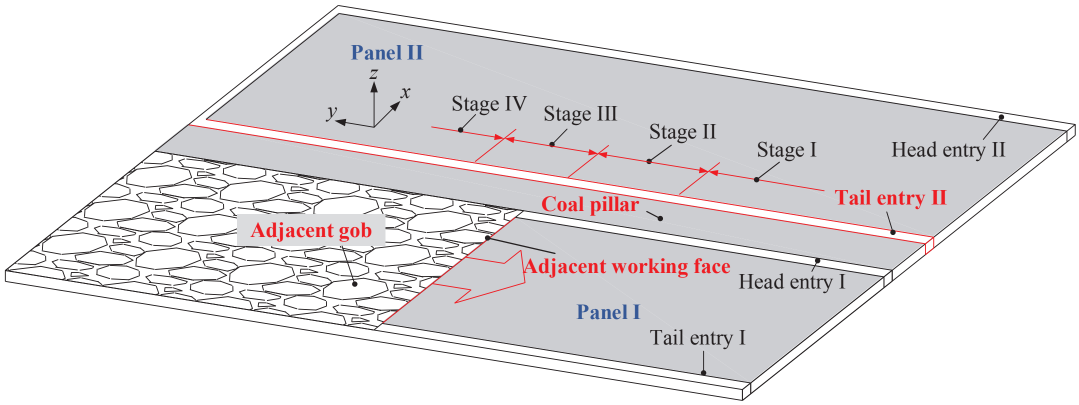

Fig. 1. Longwall panel layout. Stage I represents the loading of in situ stress; Stage II represents the loading of front abutment stress; Stage III represents the loading of side abutment stress in evolution; Stage IV represents the loading of the side abutment stress in stabilization.

In this paper, we used the ERWP of tail entry II in panel II in the Xichuan Coal Mine as a case study shown in Fig. 1. A comprehensive numerical model was carried out to predict the stress condition and relative displacement of the ERWP influenced by the mining abutment stress. The stability of the ERWP under the mining abutment stress with different W/Hs was studied and the reasonable W/H was determined to reduce the mining effect for the ERWP based on the validated model. More importantly, a detailed method of the numerical model validation was provided for solving the engineering problems in the field.

2. Analysis of a field case in China

2.1. Geological and mining conditions

Xichuan coal mine is located in the city of Tongchuan, Shaanxi Province, China. The longwall top coal caving operation is developed using a two-entry system that is approximately 1200 m long by 200 m wide in every panel (Fig. 1). The average thickness, buried depth, and dip angle of coal seam 4 are 10.9 m, 400 m, and 4°, respectively. The rock strata above coal seam 4 are shale, siltstone, and medium sandstone, whereas those below coal seam 4 are carbonaceous mudstone and thick mudstone (Fig. 2). Coal seam 4 is divided into coal seam 4-1 and coal seam 4-2 by a 0.8 m thick interlayer (mudstone). South of panel II is panel I, which is currently retreating, while north of panel II is panel III, which does not have any mining activities. West of panel II is the mine boundary, while there are three entries east of panel II. The W/H used in the field case is 6. Tail entry II, with dimensions of 5.0 m × 3.5 m, was arranged with 0.8 m thick top coal.

2.2. Measurement method

Two measurement stations were established 30 m apart in tail entry II in the front of the AWF. In every measurement station, three measurement points were arranged on the surface of the entry to measure the surface displacement (Fig. 3). The digital display convergence instrument, shown in Fig. 4a, was used to measure the relative distance between the measurement points, and then the roof displacement and rib to rib displacement was obtained by the simple geometric calculation as shown in Fig. 3. The roof separation instrument (Fig. 4b) was installed in the entry roof at each measurement station to record the relative displacement in the shallow rock between 0 m and 2 m and in the deep rock between 2 m and 10 m as shown in Fig. 3. The evolution of the surface displacement and relative displacement measured in the field are as shown in Figs. 5 and 6, respectively.

2.3. Measurement results

The deformation of the roof and ribs occurred mainly in the beginning (approximately 25 mm and 33 mm, respectively, in 13 days), and then reached relatively stable values during entry development as shown in Fig. 5a. While, these values increased linearly to 160 mm and 300 mm, respectively, as the AWF retreated from −70 m to 80 m from the measurement station (Fig. 5b).

The relative displacement of the roof mainly occurred in the ERWP (Fig. 6), and the mining abutment stress can strengthen the relative displacement along the weak plane between the coal and interlayer by the comparison between Fig. 6a and b. During the development of the entry, the relative displacement is up to 6.3 mm in the ERWP (shallow rock) and it is 2.0 mm in the deep rock. While, influenced by the mining abutment stress, the relative displacement

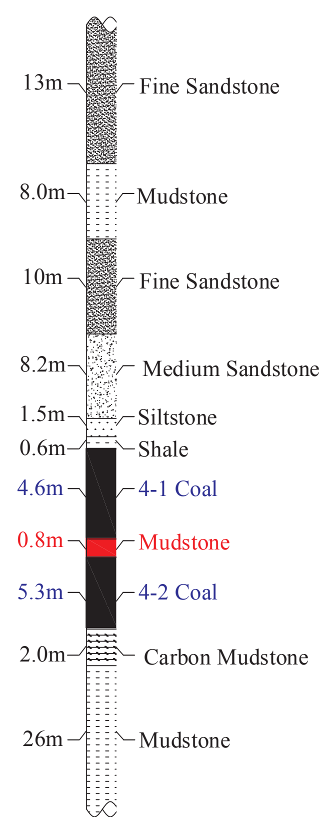

Fig. 2. Geological column for test site.