International Journal of Mining Science and Technology 24 (2014) 171–176

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Stability control of surrounding rocks for a coal roadway in a deep tectonic region

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ARTICLE INFO

Article history:
Received 8 September 2013
Received in revised form 17 October 2013
Accepted 9 November 2013
Available online 21 February 2014

Keywords:
Tectonic stress
Coal roadway
Bedding plane
Controlling
Yielding coupling support

ABSTRACT

In order to effectively control the deformation and failure of surrounding rocks in a coal roadway in a deep tectonic region, the deformation and failure mechanism and stability control mechanism were studied. With such methods as numerical simulation and field testing, the distribution law of the displacement, stress and plastic zone in the surrounding rocks was analyzed. The deformation and failure mechanisms of coal roadways in deep tectonic areas were revealed: under high tectonic stress, two sides will slide along the roof or floor; while the plastic zone of the two sides will extend along the roof or floor, leading to more serious deformation and failure in the corner of two sides and the bolt supporting the corners is readily cut off by the shear force or tension force. Aimed at controlling the large slippage deformation of the two sides, serious deformation and failure in the corners of the two sides and massive bolt breakage, a "controlling and yielding coupling support" control technology is proposed. Firstly, bolts which do not pass through the bedding plane should be used in the corners of the roadway, allowing the two sides to have some degree of sliding to achieve the purpose of "yielding" support, and which avoid breakage of the bolts in the corner. After yielding support, bolts in the corner of the roadway and which pass through the bedding plane should be used to control the deformation and failure of the coal in the corner. "Controlling and yielding coupling support" technology has been successfully applied in engineering practice, and the stability of deep coal roadway has been greatly improved.

1. Introduction

With increasing depth of coal mining operations, roadway support is becoming more difficult, especially in tectonic regions. The greater the tectonic stress, the more prominent the support problems will be. Substantial studies of the deformation rules and controls of surrounding rocks along a coal roadway under tectonic stress have been conducted both at home and abroad. The Australian scholar W J Gale developed the influencing rules of horizontal stress on the deformation of roadway roofs and floors through field observations and numerical simulation analysis [1,2]. Hou, Kang, Gou et al. pointed out that high stress may cause the surrounding rocks in the roadway to slide along vulnerable surfaces such as bedding planes, joints, etc., and lead to bed separation and crack growth [1–4]. Zhang and Gao studied slippage failure of a rock mass with the help of block theory and shear failure theory [5,6]; Zhu, Jiang, and Lu analyzed the influence of tectonic stress and direction on the stability of a roadway, suggesting that the greater the included angle between the roadway direction and tectonic stress, the poorer the stability of the roadway will be [7–9]. In this paper, combined with engineering practice, it is discovered that the two sides slide along the macroscopic bedding plane of the floor and roof under tectonic stress, showing 'severe damage in the corner and massive failure in the rock bolt at the corner' with dramatic strata behavior. This aspect has not been further analyzed in previous studies.

The destruction and instability of roadways in deep structural regions can be reduced to two aspects [10–16]. Firstly, there has been a failure to recognize the internal mechanism of deformation and destruction in the surrounding rocks, which leads to ineffectiveness in the design of supporting structures. Secondly, the supporting structure has low stability, which may be lost easily under high pressure. Therefore, the stable bearing structure that is coupling with the mechanical characteristics of surrounding rocks is an effective approach for solving the difficulties in roadway support. In this paper, the 'controlling and yielding coupling support' technology which targets the large slippage at the macroscopic level of surrounding rocks under high tectonic stress is proposed. This can effectively improve the stability of surrounding rocks and reliability of the supporting structure, and provide references for roadway support under similar conditions.

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2095-2686/$ - see front matter © 2014 Published by Elsevier B.V. on behalf of China University of Mining & Technology.
http://dx.doi.org/10.1016/j.ijmst.2014.01.005

2. Characteristics of roadway deformation and failure in deep tectonic regions

Located in the southwest part of Shandong province, Juye mining area is in the criss–cross 'checkerboard' tectonic region formed by north–south and east–west faults resulting from several tectonic movements. In this mining area, the first mining level of Xinjulong mine was about 800 m deep. The belt conveyor roadway in the north region (Beijiao roadway) advances along the third coal bed, which averages about 4.0 m in thickness. In some sections, it advances towards the FL11 fault and becomes parallel to it, and is only about 10–20 m away from the fault, as shown in Fig. 1. The fault hade is about 70°, with a fault throw of 0–15 m.

The roof of the coal is comprised of 2.6 m of siltstone and 4.0 m of fine sandstone successively from the bottom to the top, while the floor includes 3.5 m of siltstone and 4.2 m of fine sandstone successively from the top to the bottom. The strength of the roof and floor rock is 50–70 MPa with good integrity.

The results of crustal stress measurements show that the horizontal stress in the Beijiao roadway should be the maximum principal stress-more than 40 MPa, which is about 1.67–1.92 times that of the vertical stress. The included angle between the maximum horizontal stress and the Beijiao roadway is relatively large (see Fig. 1), about 40°, and may be 90° at local sections near the fault.

It has been revealed by field observation that the maximum horizontal stress direction has a significant influence on the stability of the roadway: the included angle between the 4th connection roadway in Fig. 1 and the maximum horizontal stress is relatively small, nearly parallel, and there is no obvious deformation and failure in the roadway. But the included angle between the Beijiao roadway and the maximum horizontal stress is relatively great and is almost vertical in some sections, resulting in severe damage in the surrounding rocks and support structure of the Beijiao roadway. The convergence of the two coal sides at the upper shoulder is about 400–500 mm, with the result that the external bolt tray at the roof is covered, and there is evident failure in the coal at the shoulder, as shown in Fig. 2a, while the displacement of the lower coal on the two sides is relatively small. The shoulder bolt crossing the interface of the coal bed and roof (the bolt at the top of the two sides) also breaks at the interface or the bolt tray, as shown in Fig. 2b.

From the results of field observations, it can be shown that under high horizontal tectonic stress, there is slippage between the two sides along the roof, leading to large displacement in the top and small displacement in the medium and bottom. As a result, the bolt breaks under the shear force generated by the slippage of the two sides along the roof. Therefore, roadway stability is closely related to the interface between the coal bed and rock stratum. The deformation and failure mechanism will be studied further as follows using a numerical simulation method.

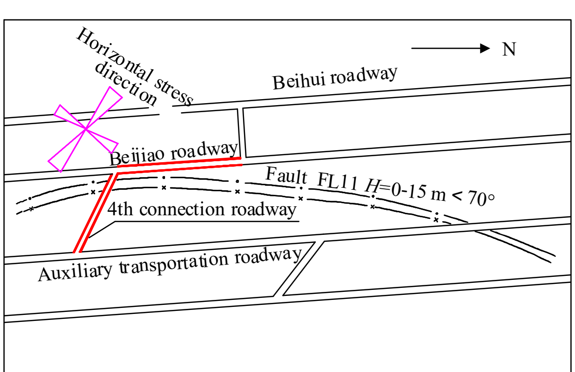

Fig. 1. Relationship between roadway and fault.

(a) Deformation and failure of shoulder coal.

(b) Deformation and failure of shoulder bolts.

Fig. 2. Deformation and failure of surrounding rocks and bolts in Beijiao roadway.

3. Numerical analysis of the roadway stability in deep tectonic region

Using FLAC numerical simulation software, four coal roadway numerical models have been established, including a full coal roadway, a roadway excavated along the roof and floor, a coal-roof roadway and a coal-floor roadway. The positions of interfaces between the coal bed and the roof and floor (bedding plane) are quite different, and the simplified model is shown in Fig. 3.

In order to highlight the influence of the bedding plane on the stability of the surrounding rocks and eliminate the influence of the surrounding rock structure on the stability of the roadway, the surrounding rocks having average quality have been adopted. The Mohr–Coulomb elastic–plastic constitutive model has been employed. The gravity stress of the overlying strata, estimated to be 20 MPa (800 m depth), has been exerted on the co-boundary of the model, the coefficient of horizontal pressure is about 2.0, and the horizontal stress of approximately 40 MPa has been exerted on the two sides of the model. On the left and right margin of the model, the displacement in the x direction has been limited, while in the lower margin of the model, displacement in the x and y direction has been limited. The roadway cross-section is a rectangle, 5 m × 3.5 m in width and height. With numerical simulation, the characteristics of the deformation and failure, as well as the internal mechanism of the surrounding rocks under tectonic stress, have been analyzed.

3.1. Analysis of the plastic zone in surrounding rocks

Under tectonic stress, the distribution of the plastic zone in the surrounding rocks of the deep coal roadway is shown in Fig. 4. It can be seen that the bedding plane between the coal bed and roof or floor has a small influence on the plastic zone of the roof and floor, but a significant influence on the plastic zone of the two sides. There are bedding planes in both the top and bottom of the roadway (Fig. 4b), with greater plastic zones in the two sides than the surrounding rocks without bedding planes (Fig. 4a). But where there is only one bedding plane in the top or bottom of the roadway (Fig. 4c and d), the two sides have greater plastic zones near the bedding plane. With increasing distance from the bedding plane, the plastic zone decreases gradually, and the plastic zone of the two sides occurs in a ladder shape with 'shallow roof