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Influence of abnormal stress under a residual bearing coal pillar on the stability of a mine entry

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A B S T R A C T

Mine entries close to residual bearing coal pillars (RBCPs) will suffer large deformation that may cause rock burst. To better understand the deformation mechanism and develop safe and practical guidelines for entry design, most studies focus on the absolute size of the stress field in and around the pillar. In this paper, we present a new approach to analyze the abnormal stress field close to a RBCP that uses the stress concentration coefficient (SCC), stress gradient (SG), and coefficient of lateral pressure (CLP) to describe the stress state induced by the RBCP. Based on elastic theory and a mathematical model for the abutment stress in the RBCP, an analytical solution for the abnormal stress in the strata below the RBCP was derived and the characteristics of the abnormal stress for a case study of a coal mine in China were analyzed. The results show that the abnormal stress field around the pillar is characterized by four distinct zones: a zone of high SCC, high SG, and CLP less than 1, a zone of high SCC, low SG, and CLP less than 1, a zone of low SCC, SG close to 0, and CLP greater than 1, and a zone of SCC close to 1, SC close to 0, and CLP close to 1. Based on this zoning pattern, a numerical model was established to study the combined effects of the abnormal stress on the stability of the entry. The most stable zone was determined based on a model of the Xinrui coal mine and verified by field measurements at the mine. Our conclusions can be used as guidelines for designing safe entry layouts in similar geological and mining settings.

1. Introduction

The stress state of rock below and around a residual bearing coal pillar (RBCP) strongly affects the stability of underground passages in mines [1–6]; this depends on the bearing characteristics and stress-transmission behavior of the close RBCP [7–11]. Strength theories applied to mining settings point out that the stress state play an important role in determining whether the rock reaches the failure state because the level of triaxial compression strength in the rock changes when the confining pressure varies [12–15]. Generally, for underground passages or entries under uniform symmetrical load, homogeneous convergence of the rock layers surrounding the entry will occur and local instability will not be induced [16]. However, entries around RBCPs will be affected by inhomogeneous or abnormal stresses that can be characterized by parameters such as the stress concentration coefficient (SCC), stress gradient (SG), and coefficient of lateral pressure (CLP).

Many studies have produced effective designs for the entry position around a RBCP, focusing on the absolute size of the stress [17–21]. Numerical simulations have shown that the best position for the lower entry should be in the stable stress zone rather than the areas of concentrated vertical stress induced by the upper mined coal seam [22–24]. Based on the stability factor model for a coal pillar under a mined coal seam, the translational layout yielded better results than the inward and outward layouts [25,26]. By analyzing the stress field and deformation surrounding the entry, the difference between the vertical stress and horizontal stress in the strata below the RBCP was found and shown to be an important factor for the stability of the lower entry [27]. All the studies mentioned above indicate that the area of stress induced from the RBCP can be divided into three zones: the concentrated stress zone, the relaxed stress zone, and the zone of original stress along both the horizontal and vertical directions, and that the lower entry should not be located in the concentrated stress zone.

Inhomogeneous stress is also a subject of interest in mining engineering because it can induce local deformation and failure around the entry leading to local unconsolidated rock failure and weakening of the rock structure which affects the stability of the

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adjacent rock structures [28–34]. Previous analyses of the influence of inhomogeneous stress on the rock and structural stability in underground mines mainly concentrated on the maximum bending moment obtained by a simplified roof beam model under plane strain conditions. The results verified the existence of local unconsolidated and rock-failure structures. It should be noted that most of the studies concentrated on one factor (such as the SCC or SG) to analyze the stability of the entry below and around RBCPs, ignoring the combined effects of these factors; such approaches cannot fully explain the real stress state.

In this paper, we present an improved model of the stress field surrounding the entry near RBCPs based on a case study; the results can help design a safer entry layout. First, based on analysis of the bearing capacity of the RBCP, a mathematical model for the abutment stress in the RBCP is proposed. Then, based on the elastic theory, the abnormal stress induced by the RBCP is estimated and the characteristics of the abnormal stress for the case of a coal mine in China are obtained. Based on the obtained abnormal stress values, a simulation model is established to analyze the overall effects of the abnormal stress on the stability of the entry. Finally, a new method to determine the most stable location for the entry under close RBCP is proposed.

2. Engineering conditions and geological background

Mining at the Xinrui coal mine in Shanxi province is conducted mainly in coal seams 4 and 5 with an average interlayer spacing of 3.25 m. Coal seam 4 was mined out in 2013, leaving many RBCPs and gobs. The mining entry of coal seam 5 passes next to the RBCP of coal seam 4 (Fig. 1). The average thickness of coal seam 4 is 1.7 m and that of coal seam 5 is 2.76 m; the seams are monoclinal with an average stratigraphic dip of 6°. The stratigraphy surrounding the coal seams is simple; the stratigraphic column is shown in Fig. 2. Analysis of the drill core samples indicates that the uniaxial compressive strength of coal seam 5 is 12.2 MPa which is comparatively hard. The immediate roof is mostly soft mudstone, easily weathered medium-hard rock whose uniaxial compressive strength is 33.2 MPa. The immediate bottom is mainly mudstone with some sandy mudstone, with a uniaxial compressive strength of 40.6 MPa, which is within the range of medium-hard rock. The 1501 working face is the primary face of coal seam 5 and its head entry, which has a rectangular cross-section of 4500 mm × 3000 mm, was drilled along the roof of the coal seam, horizontally through multiple RBCPs, a single RBCP, and double RBCPs (Fig. 1). After the excavation of the head entry, large asymmetric deformation and rock failure occurred along the axial direction of the entry, which led to severe deformation and even closure of some entry sections. Based on this case, we carried out a study on the effect of the abnormal stress induced by the RBCP on the stability of the entry. We explored the primary cause of the rock deformation and rock failure around the entry near the RBCP and derived a model of the stress field that can help in designing a practical and safe entry layout in similar geological and mining settings.

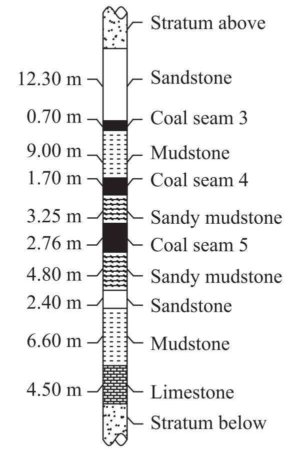

Fig. 2. Comprehensive drilling histogram for close multiple coal seams.

3. Conceptual model and analysis of the abnormal stress

The RBCP causes stress redistribution in the layer below the coal seam, changing from a uniform stress field to that of non-uniform deformed stress. Under the load-bearing coal pillar is a concentrated high-stress zone while under the gob lie the medium-stress and low-stress zones. Under the area where the gob and coal pillar meet is a low-stress area which is the boundary zone between the higher-stress and lower-stress zones. The concept of abnormal stress is introduced to describe the degree of non-uniformity of the stress under the RBCP caused by the excavation of the rock. We use the parameters SCC, SG, and CLP to analyze the abnormal stress. The solution is divided into three stages: estimating the bearing stress in the RBCP, analysis of the stress under the RBCP, and estimating the abnormal stress under the RBCP.

3.1. Bearing capacity of the RBCP

Previous studies have used analytical and numerical methods, the Tributary Area method, beam deflection, and photo-elastic

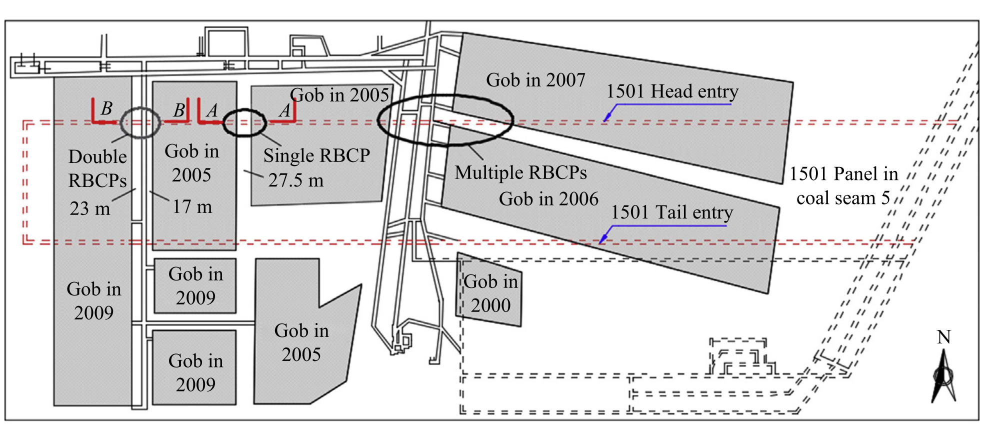

Fig. 1. Panel layout for close multiple coal seams.

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