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Numerical investigation of the effects of coal seam dip angle on coal wall stability

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ABSTRACT

Instability and failure mechanism of coal wall at coalface is one of the hot-button and difficult issues in the study of coal mine ground control. Research to date has mainly focused on the macro-characteristics of coal face failure whereas few efforts have been devoted to the micro aspects or to the mechanisms behind these failures. The work described here takes coal face 8102 in the Wolonghu Mine, China, as an example and employs distinct element numerical software (UDEC) to investigate the distribution of abutment stress in front of the coal face at different mining dip angles from micro and macro perspectives, and reveal the main failure form and location of coal rib. The numerical results indicate the following six points. (1) The distance between the location of the peak abutment stress and the coal face increases with greater mining dip angles. (2) The rank by angle of abutment stress concentration factors is horizontal > up-dip > down-dip coal faces.(3) Tensile fractures dominate the failure of horizontal and up-dip coal faces and the only difference between the two is the form of the failure. (4) Shear fractures are the dominant failure components of down-dip coal faces. (5) The coal face failure forms include integral rib spall and a combination of upper-rib shear failure and roof caving. (6) Tensile fractures are mainly responsible for roof failures. The difference in roof movement between up-dip and down-dip coal faces is reflected in the forms of failure of their coal faces and of their roofs. Moreover, the effect of coalface depth, mining height, panel advance velocity and coal strength on the stability of coal rib is studied. The conclusions obtained from numerical simulation are consistent with engineering result, which verifies the reasonability of simulation analysis by UDEC. Finally, we propose measures to avoid coal face failure in the Wolonghu mine considering the numerical outcomes, the monitored strata behavior, and the recorded setting support resistance.

1. Introduction

Fully mechanized mining at significant depths has been widely implemented in mining areas in China[1–3] and is regarded as paramount for efficient coal production with high recovery rates. Many researches[4–7] have been conducted on both up-dip and down-dip mining technologies, with an emphasis on the followings: (1) ground pressure; (2) factors affecting coal rib stability and failure mechanism; (3) structural characteristics of overlying strata; (4) stability and its control of surrounding rock; (5) control measures of coal rib stability; and (6) deformation of overlying strata and the mine surface. Most investigations into the failure of coal rib stability have concentrated on up-dip mining, in which the coal rib and roof of the end face are more difficult to control than in down-dip mining. Additionally, there is a lack of studies on different failure mechanisms of coal rib stability during up-dip mining, especially for coal ribs that contain soft joints. Therefore, further analysis of the influencing factors and failure mechanisms of coals rib is needed to guide the design of coal rib stability and ensure safe and effective production in both up-dip and down-dip mining faces.

Greater mining depth results in increasing risk of coalface spalling, the formation of which is strongly influenced by intensive mining. Coalface spalling can be accompanied by worsening roof conditions and roof collapse, especially in geologically complex conditions. The control and prevention of rib spalls is not only economically beneficial but also improves mine safety. Most researchers have focused on controlling spalling by investigating coalface stability, fracture location and mechanical modeling of coalface damage. These factors exert the strongest influence over spalling and associated mining accidents. Yin et al.[8] employed C++ programming to develop a security assessment system of a rib spall in a fully mechanized mining face, and applied it in the field. Wang et al.[9] investigated the mechanisms of coalface instability and the impact of associated faults, and proposed that the expanding range of plastic yield in the coalface near a fault increased the risk of a rib spall accident. Chang[10] was able to sub-divide the abutment

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pressure zone into three zones: the fracture zone, plastic zone and elastic zone. These authors also built a mechanical model to examine coalface deformation while considering support resistance. Wang[11] analyzed rib spalling of a soft coal seam and concluded that stress relief above the seam and improving coal shear strength were most effective in preventing spall. Yuan et al.[12] conducted a microscopic study of fracture propagation, concluding that rib spall occurs when original crack damage reaches a critical level. Suorineni et al.[13,14] described the failure risk of an orebody subjected to different shear loads, the influence of the aspect ratio of a coal pillar and excavation geometry, and assessed passive and active high stress envelopes that form during excavation in eccentrically loaded orebodies. Brady[15] and Peng[16] found that coal mining disturbs the original equilibrium state, causing redistribution of in situ stress and movement of stress deeper into the coal in front of the coal face.

Overall, literature pertaining to coal wall stability has mainly focused on the physical and mechanical properties of the coal, mining depth, support performance and strata behavior, with only limited work on the stability of complex coal walls and seams, such as those that dip steeply.

This paper reports on work conducted on coal face 8102 in the Wolonghu coal mine, Anhui Province, China. This work involves numerical modeling and analysis of four aspects of fracture development in and near the coal face, including (1) abutment stress distribution; (2) fracture evolution and fracture distribution; (3) evolution of tensile and shear fractures in differently angled coal faces and their roofs and (4) the effect of roof fractures on coal face stability. This study also aims to predict the most likely forms of failure for coal faces at different angles according to fracture distribution. The mechanism of rib spall and roof caving is defined and the effects of depth, mining height, panel advance velocity, and seam strength are investigated in terms of crack length and failure form.

2. Research background

Coal face 8102 in the Wolonghu mine is very prone to rib spall because of its geology. The irregularly developed, soft, thick coal seam has well-developed joints and fractures and is internally folded and faulted. The local maximum rib spall depth has exceeded 1.5 m over large areas. Fig. 1 shows five typical coal face failure forms observed during mining of coal face 8102.

Basic information about coal face 8102 is as follows: the strike length of coal face 8102 is in the 623.8–802.2 m range and the dip length is in the 156.5–233.3 m range. The average thickness of the 600 m deep coal seam is 4.1 m. The coal face dips at between 5° and 25°.

Coal face 8102 has been affected by numerous rib spall events, 48% of which occurred in the form of integral spall with a rib spall depth < 300 m. 18% of failures occurred as arcuate spall with a rib spall depth in the 300–600 m range, while 24% of failures occurred as mixed v-shaped and arcuate spalls with a rib spall depth in the 600–1000 m range. Mixed forms of upper-rib spall (roof caving) and upper-rib spall with a rib spall depth > 1000 m account for 10% of the failures.

3. Numerical modeling

The failure of a coal face is a discontinuous process, and may break out unexpectedly. Thus, discrete element software is very useful for modeling this engineering challenge compared with the use of finite element modeling. The discrete method is capable of modeling the evolution and distribution of fractures inside the coal face, and therefore it can predict potential areas of rib spall. In this study, Universal Distinct Element Code (UDEC) software was employed for the simulation of coal face failure.

The investigation is focused on the areas near the coal face because the study was designed to examine the abutment stress distribution in the roof of differently angled coal seams, and fracture evolution. The model dimensions are 200 × 150 m, which allows for sufficient time for calculations. The coal seam is divided into polygons, and this was done using the Taylor polygon method, as it has been proven to be efficient and compatible with engineering practices in previous studies.[17–19] The average edge length of these polygons is 0.2 m and the other strata are divided into rectangles. The Taylor polygon division method and its failure criteria are shown in Fig. 2.[20] In the normal direction, $\Delta\sigma_n = -k_n\Delta U_n$, where σ_n and ΔU_n are the effective normal stress increment and normal displacement increment of a contact, respectively, and k_n is the normal stiffness of the contact. In the shear direction, if $|\sigma_s| \le c + \sigma_n \tan\varphi = \sigma_s^{max}$, then $\Delta\sigma_s = -\sigma_s \Delta U_s^e$. If $|\sigma_s| \ge \sigma_s^{max}$, then $\sigma_s = \text{sign}(\Delta U_s)\ \sigma_s^{max}$, where c and φ are the cohesion and friction angle of the contact, respectively. The terms σ_n and σ_s are the normal and shear stress of the contact, respectively, and ΔU_s^e is the elastic component of the incremental shear displacement. The term ΔUs is the total incremental shear displacement and the ‘sign’ function is a mathematical symbol that allows σ_s to be positive.

Given that DEM does not consider the existence of original cracks and pores in the simulated rock samples it is evident that, when compressed, the stress-strain curve skipped the crack closure stage, directly entering the elastic stage. The specimen experienced the elastic and elastic-plastic yield stages, which occur in both experiment and

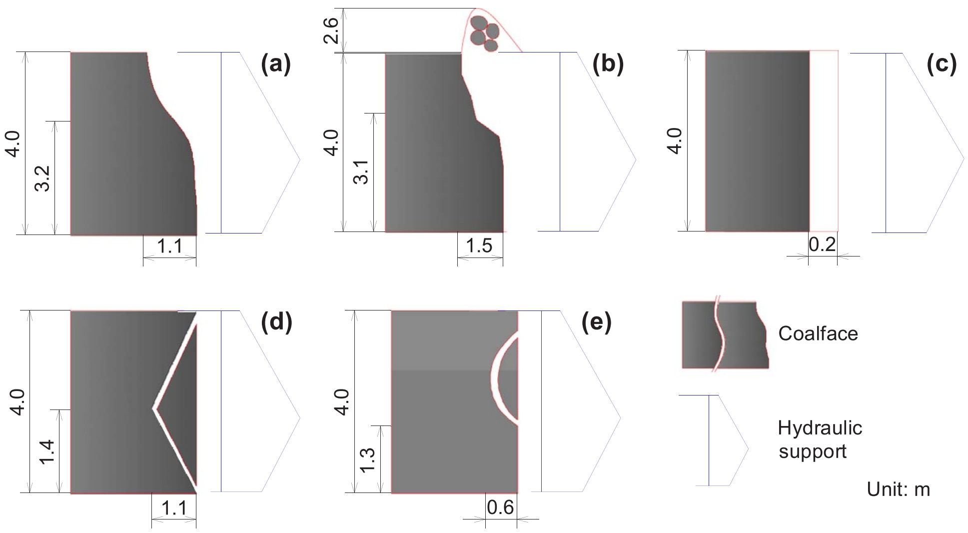

Fig. 1. Typical coal face failure forms in coal face 8102. (a) Upper-rib spall; (b) Upper-rib spall and roof caving; (c) Integral spall; (d) V-shaped spall; (e) Arcuate spall.