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Numerical investigation of load shedding and rockburst reduction effects of top-coal caving mining in thick coal seams

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ABSTRACT

By comparing the overburden structure characteristics and the distribution of stresses around roadways and coalfaces in slice mining and top-coal caving mining in thick coal seams, this study analysed the effects of the two mining methods on rockburst prevention. Furthermore, by using FLAC3D numerical simulation, this research studied the distribution of surrounding rock stress in the first mining panels, subsequent panels, solid coal roadways, and gob-side roadways and the influence of parameters including mining height, bottom coal, and coal seam thickness on stresses in the surrounding rocks. On this basis, the effects of load shedding and rockburst reduction of top-coal caving mining of thick coal seams were summarised and verified through field investigation. The results show that compared with slice mining, overburden structures in top-coal caving mining of thick coal seams weakened the stress concentration in surrounding rocks, resulting in lower peak values but wider ranges of advanced abutment stress and side abutment stress in panels. The point of peak stress was observed deeper into the coal masses. With the increase of mining height and the decrease of bottom coal thickness, the stress concentration around roadways and coalfaces decreased rapidly and then tended to be stable. Therefore, top-coal caving mining can reduce the stress concentration around roadways and coalfaces to decrease rockburst risk. While mining thick coal seams, top-coal caving mining needs to be conducted preferentially over a reasonable range of mining heights. Field practice in Xing'an and Junde mines revealed that the top-coal caving mining induced a lower rockburst frequency, over a smaller range and with lower intensity, which validated the effects of load-shedding and rockburst reduction of the proposed mining method.

1. Introduction

Rockbursts threaten the safety and effectiveness of mining operations. As the mining intensity of thick coal seams increases, fierce rockbursts occur more frequently therein. For example, slight rockbursts mainly take place in thin coal seams, while thick and medium-thick coal seams suffer stronger rockbursts.[1] According to incomplete statistics, more than seven hundred rockbursts have occurred in thick coal seam mining in China since 2008.[2] Therefore, there is an urgent need to prevent rockburst disasters in thick coal seam mining.

Currently, research concerning rockbursts mainly concentrates on the causes,[3,4] influence factors,[5,6] mechanisms,[7,8] risk evaluation,[9–11] burst-prone zone detections,[12] and its monitoring,[13,14] prediction,[15–18] and prevention.[19,20] The pre-conditioning approach prevents rockbursts by changing the properties of the coal-rock mass,[21] which generally includes destress blasting,[22–24] destress boreholes,[25,26] hydraulic fracturing,[27,28] *etc*. As an important line of defence, rock support in rockburst-hazardous coal mines has been widely investigated.[29,30] It is concluded that rockburst support is significantly different from conventional support[31,32] in terms of the high dynamic loads imposed on the supports.[33–35] To control rockburst risks effectively, special measures must be taken.[36] These steps include (i) early prediction, (ii) design modification, (ii) *in situ* prevention (*i.e.*, pre-conditioning methods), and (iv) final retention (*i.e.*, rock support and reinforcement systems). The literature contains all steps except for "design modification" which has a major influence on rockburst occurrence. Research shows that rockburst risk can often be reduced by reasonable mining designs,[37–39] such as selecting appropriate mining methods and sequences. Therefore, the demand on time-consuming measures against rockburst is reduced.

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Changes of *in situ* stress[40] and mining induced stress[41] are two fundamental factors, which influence rockburst occurrence in underground excavations. Rockbursts frequently occur near highly stressed excavation boundaries,[42] especially in roadways and coalfaces, and more rockbursts are found in roadways.[37] As thick coal seams are generally extracted through slice mining and top-coal caving mining, it is essential to prevent rockbursts by selecting appropriate mining methods in design to ensure lower stresses in the surrounding rocks of roadways and coalfaces. Field studies of top-coal caving mining have been conducted in Tangshan[43] and Zhaogezhuang[44] mines in China to prevent rockbursts and obtained good effects as a result. By analysing the overburden and abutment stress distributions in top-coal caving mining, scholars[45–47] studied the relieving effects of top-coal caving mining on rockbursts.

Based on previous research, by comparing the overburden structure characteristics and the distribution of stresses around roadways and coalfaces in slice mining and top-coal caving mining in thick coal seams, this study analysed the effects of the two mining methods on rockburst prevention. Moreover, the effects of parameters, such as, mining height, bottom coal and coal seam thickness on the stress distribution of surrounding rocks were also analysed. The purpose is to provide a basis for the design of rockburst prevention in thick coal seam mining, especially, for determining reasonable mining height and bottom coal thickness.

2. Influence mechanisms of overburden structures on stresses of surrounding rocks in top-coal caving mining

2.1. Characteristics of overburden structures in top-coal caving mining

Strata movement is closely related to the mining height.[48] The mining height and lithology of coal seams determine the distribution of three zones of overburden[49] and the location of the key strata in the three zones determines their fracture patterns and structural forms. Compared with slice mining, one mining height of top-coal caving mining of thick coal seams significantly increases and the height of caving zones does likewise. Under the same geological conditions, immediate roof caving generally cannot fill gobs. Moreover, owing to large amounts of rotational subsidence, the broken main roof and lower key strata cannot make contact with waste rocks in gobs, and it is difficult to form a stable voussoir beam structure. Therefore, the main roof and lower key strata extracted through top-coal caving mining tend to be broken in the form of cantilever beams and broken rock blocks directly cave into gobs, shown as KS1′ in Fig. 1. Due to the gradual decrease of rotational subsidence, the higher key strata are broken in the form of voussoir beams similar to slice mining, as demonstrated by KS2′ in Fig. 1.

In conclusion, for thick coal seams with similar geological conditions, top-coal caving mining has the following main differences with slice mining: breaking movement in lower key strata changes from voussoir beams to cantilever beams, while that in higher key strata is in voussoir beam form with a large amount of rotational subsidence in the same rock strata. Breaking movement of overburden is the essential reason for stress concentration and mine pressure, so top-coal caving mining showed unique characteristics of stress distribution of surrounding rocks.

2.2. Weakening effects of overburden structures on stress concentration of surrounding rocks in top-coal caving mining

The overburden structures in top-coal caving mining cause lower peaks while wider ranges of front and side abutment stresses in panels and the stress peak are found deeper in coal masses. The influence mechanisms are illustrated in Fig. 1 and expressed as follows.

Breaking movement of cantilever beams in key strata in caving zones. The broken rock blocks briefly overlap at the end of the cantilever in the key strata or cave in gobs in time, thus exerting little, or no, load on unbroken rock strata. Therefore, after the breakage of key strata, their own weight and the overburden weight are mainly borne by gobs while little loads are transferred to the front of coalfaces and both sides of coal masses, as ①.

Breaking movement of voussoir beams in key strata in fracture zones. Due to the large amounts of rotational subsidence of rock strata, broken rock blocks impose a larger lateral thrust but smaller vertical loads on key strata, as displayed in Eq. (1)[50] and Fig. 2. In addition, most broken rock blocks are supported as they are able to make contact with the bulking rocks in gobs, which lets the structure transfer small overburden loads to the front and both sides of coal masses over a long distance, so most overburden stress on the structure is borne by gobs, as ②.

The heights of caving and fracture zones increase. The former increases the thickness and weight of overburden caving in gobs, in the top and behind the coalfaces: the overburden is then transferred to the front and both sides of coal masses decrease. Layer separation generally appears between fracture zones and bending subsidence zones, with large amounts of vertical separation and wide ranges of horizontal separation. Due to layer separation, the overburden pressure in bending subsidence zones in the range of separation is unable to be directly transferred to the gobs below, but is successively transferred to the surrounding coal masses of gobs from top to bottom. Furthermore, the increasing height of the fracture zones can increase the height of layer separation, reduce the vertical range of bending subsidence zones, and even break the principal key strata, leading to the disappearance of layer separation. Meanwhile, the overburden, from bottom to top, is effectively transferred to gobs, thereby reducing the load on the coal, as ③.

Top coal located between coalface and roof is broken under stress induced by mining and repeated support effects. The mechanical parameters including stiffness and strength of such broken top coal reduce and stresses are low under same deformation. Therefore, the

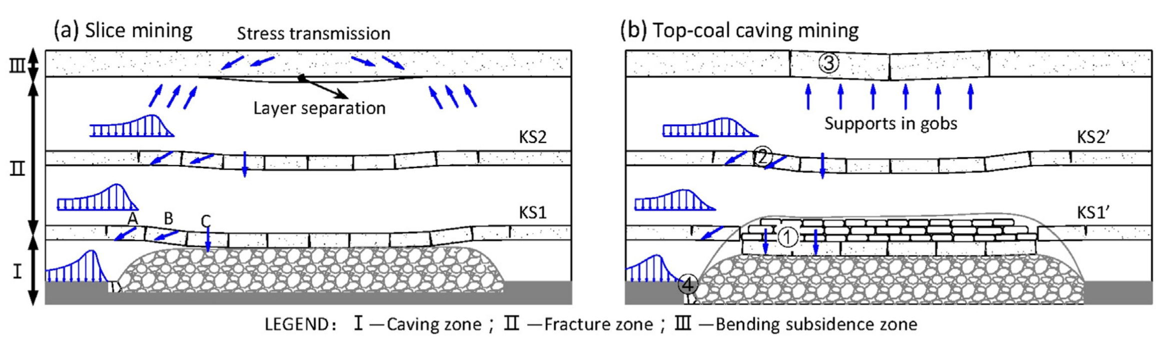

Fig. 1. Model illustrating structures formed within overburden and the abutment stress distribution resulting from load transmitted in top-coal caving mining and slice mining of thick coal seams.