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Evaluating the risk of coal bursts in underground coal mines

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A B S T R A C T

Coal bursts involve the sudden, violent ejection of coal or rock into the mine workings. They are almost always accompanied by a loud noise, like an explosion, and ground vibration. Bursts are a particular hazard for miners because they typically occur without warning. Despite decades of research, the sources and mechanics of these events are not well understood, and therefore they are difficult to predict and control. Experience has shown, however, that certain geologic and mining factors are associated with an increased likelihood of a coal burst. A coal burst risk assessment consists of evaluating the degree to which these risk factors are present, and then identifying appropriate control measures to mitigate the hazard. This paper summarizes the U.S. and international experience with coal bursts, and describes the known risk factors in detail. It includes a framework that can be used to guide the risk assessment process.

1. Background

Coal bursts involve the sudden, violent ejection of coal or rock into the mine workings. They are almost always accompanied by a loud noise, like an explosion, and ground vibration. Bursts are a particular hazard for miners because they typically occur without warning. During the years 2012–2014, serious coal bursts occurred at three different U.S. room and pillar mines. These events resulted in three fatalities and two permanently disabling injuries. In all three instances, the events occurred during pillar recovery at depths exceeding 300 m. None of these three mines had previously reported a burst to MSHA. Coal bursts also occurred at three longwall mines during this same time period.

Despite decades of research, the sources and mechanics of bursts are not well understood, and therefore these events are difficult to predict and control. Experience has shown, however, that certain risk factors are associated with an increased likelihood of a coal burst. A coal burst risk assessment consists of evaluating the degree to which these risk factors are present. In addition, some control techniques are effective in reducing the likelihood of an event or protecting miners from their effects.

2. Factors contributing to the risk of coal bursts

The one universal characteristic of burst-prone environments is the presence of highly stressed coal. The overburden depth is responsible for the overall level of stress, but pillar design or multiple seam interactions can concentrate stresses in distinct locations. Geology also plays a big role where strong roof and floor are characteristic of most, but not all, burst prone environments. Geologic features, including sandstone channels, faults, and seam dips, have been associated with the events. Certain mining layouts and practices also increase the burst risk, as does a past history of bursts. Each of these factors is discussed in more detail below.

2.1. Depth of cover

Very few bursts have occurred at depths less than 300 m, although there were two incidents that occurred during pillar recovery under 230 m of cover during the early 1980s. Experience shows that the burst risk increases with depth. An analysis of the NIOSH Analysis of Retreat Mining Pillar Stability (ARMPS) database showed that for case histories where the depth of cover was less than 450 m, only 2% encountered bursts. For the handful of cases where the depth of cover exceeded 600 m, however, almost half encountered bursts (Fig. 1). Another study found that of 34 burst events that occurred in mines located in the North Fork Valley of Colorado, only three occurred where the overburden depth was less than 450 m, and 13 occurred at depths exceeding 600 m [1]. Consequently, the MSHA Handbook on Roof Control Plan Approval and Review Procedures includes the following statement: "pillar recovery at depths exceeding 600 m may not be appropriate due to the heightened risk of bursts at such unusual and extremely deep cover."

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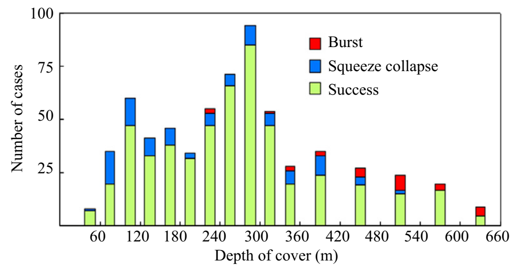

Fig. 1. Distribution of pillar failures and pillar bursts with depth in the ARMPS database.

2.2. Pillar design

A pillar that is properly designed and large enough to distribute the load that it carries is unlikely to be burst prone. On the other hand, a pillar that is sufficiently small and yielding, is also not burst-prone. The burst hazard is greatest for poorly designed pillars that are too small to properly distribute the loads they carry, but too large to yield. NIOSH studied the 17 largest burst events in room and pillar mines that occurred between 1980 and 2010. Each of these events resulted in extensive damage to at least several pillars. The analysis showed that 12 of the 17 multi-pillar bursts could be attributed to inadequate pillar design. These 12 events all occurred during pillar recovery mining. In nine instances, the barrier pillars were too small, were being extracted on retreat, or were not used at all. In five of the 12 cases, pillar splitting operations without a barrier pillar apparently triggered the multi-pillar burst. Barrier pillars are particularly important in room and pillar mining because they protect each new panel from the abutment loads arising from previously mined areas. The NIOSH ARMPS program was revised in 2010 specifically for evaluating production and barrier pillars in deep cover applications [2].

In longwall mining, several different pillar design strategies have been employed in burst prone conditions (Fig. 2). Conventional approach employs at least one large abutment pillar in a multi-entry system, sometimes flanked by small yield pillars. Experience has shown that appropriately sized abutment pillars can reduce the incidence of bursts [3,4]. In Utah, two-entry yield pillar layouts have been used since the 1960s, and they can virtually eliminate gate pillar bursts [5]. Mining engineers also learned to avoid critical pillars which are too large to yield non-violently yet too small to support large abutment loads. The width-to-height ratios of such burst-prone, critical pillars normally exceeded 4 or 5 [6].

While the yield pillar system typically performs well at depths up to approximately 600 m, it can concentrate the load on the tailgate corner of the longwall face, and this can result in severe face bursts near the tailgate corner of the longwall. A tailgate corner event killed a miner in 1996. At greater depths, interpanel barrier pillars have been used at several Utah longwalls [7]. In some cases, rather than leave a full barrier, mines have elected to make mid-panel move around the area of deepest cover. The unmined panel provides a local interpanel barrier for the next panel [8].

The interpanel barrier effectively protects the tailgate corner from the influence of previous panels, but at greater depths the single-panel stresses on the longwall face reach the same levels as were present with abutment loads from adjacent extracted panels separated by yield pillars. After a fatal bump occurred on a longwall face near the headgate at 840 m depth of cover, one major Utah operator announced that it would consider reserves at depths exceeding 900 m to be unmineable [9].

2.3. Multiple seam interactions

The U.S. underground coal mining industry has extensive regions where multiple seams have been mined. The interaction of the active mining with overlying and/or underlying old workings can generate stress concentrations. The severity of a multiple seam stress concentration typically depends on two factors:

(1) The thickness of the interburden between the active seam and the previously-mined seam (or seams). In general, the thicker the interburden, the less likely that the interaction will result in a severe stress concentration.
(2) The type of remnant structure present in the previous seam. Isolated remnants, with worked out areas on two or more sides, are the most hazardous.

Remnant structures are typically created when coal is left in place adjacent to areas of full extraction. However, bursts have occurred above and beneath large remnants adjacent to smaller developed pillars [10,11]. In these cases, the smaller developed pillars apparently behaved as a pseudo gob area, transferring much of their load onto the larger pillar (Fig. 3). A burst risk assessment should take such situations into account particularly when in-mine evidence suggests a stress concentration exists.

As noted in Fig. 3, the large pillar was surrounded by a "pseudo gob area" consisting of smaller developed pillars that had apparently yielded and transferred load to the large pillar.

Interactions between all previously mined seams should be considered in the assessment. The workings in several seams may overlap, creating very high stress zones, particularly if the interburdens separating the older workings from the active seam are thin (Fig. 4).

Empirical or numerical computer models should be a part of a thorough burst risk assessment. Models such as the Analysis of Multiple Seam Stability (AMSS) or LaModel can identify potentially high stress zones due to multiple seam mining [12]. However,

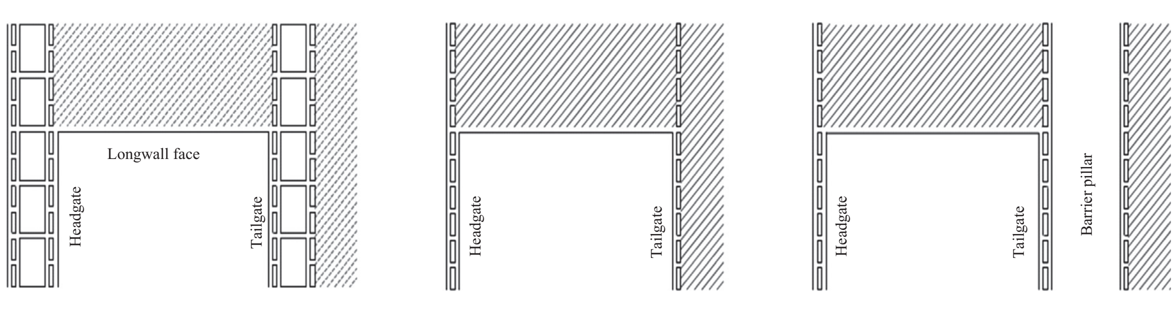

Fig. 2. Pillar design approaches used for burst control.