Coal Mine Burst Prevention Controls

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ABSTRACT

Coal mine bursts have represented a major hazard for U.S. mining operations for more than 90 years. During this time, many prevention controls have been developed and tested. This paper reviews 11 prevention control techniques. Although coal mine bursts are not common events in most underground coal mines, their occurrence almost always requires a change in mining practice. Over the many years of dealing with these hazards, specialized requirements for layouts and novel extraction sequences have been developed on a site specific basis. The keys to mitigating risks are to properly assess the coal burst hazards and to possess the knowledge and skills to prevent or remediate their occurrence.

INTRODUCTION

Coal bursts [1] are violent failures of ribs, roof or floor in underground coal mines. This hazard is not new to the US mining industry. Coal bursts are known to occur in complex ways and often under unique sets of conditions. This has made them extremely difficult to control or forecast. As one might expect, there have been many engineered prevention controls proposed to mitigate the devastating effects of these dynamic and violent failures. Over the years, specialized requirements for mine layouts and novel mining sequences have been developed on a site specific basis to more safely extract burst prone coal. While none of these prevention controls should be considered a "stand alone" design method, they are extremely useful when an operation is assessing its coal burst hazard and evaluating controls to help mitigate the associated risks. A coal burst risk assessment calls for engineers, managers and safety professionals, especially those who might deal with this hazard on a regular basis, to understand how to use these historically proven prevention controls.

Coal mine burst prevention controls tend to focus on qualitative solutions to very specific conditions. Operators need to consider the prevention control that most closely relates to the fundamental factors that are capable of producing coal burst hazards at their respective mines. Also, many of the following prevention controls can be thought of as recommendations or definition of things to do or not to do. They rarely provide methodologies to quantify actions lying between these two end-points. It should also be noted that this study did not discuss remediation controls, i.e., destressing.

[1] The authors use the term coal burst to avoid showing a preference for the eastern designation of coal bumps or the western usage of coal bounces.

ROOM-AND-PILLAR MINING ISSUES

Uniform Pillar Size and Shape

Early on, mining practitioners noted that uniform pillar sizes are less likely to produce burst prone conditions than layouts with a range of pillar sizes (Holland and Thomas, 1954). Reeves (1954) expressed apprehension in allowing abutment pillars to occur next to the gob. Large pillars are stiffer, and tend to deform or converge much less than their small chain pillar counter-parts. These stiffer structures tend to gather load. If they are then mined, there is a high potential for violent failure due to the larger pillar's greater energy storage capacity. Uniform pillar sizes are generally considered to be more advantageous during room-and-pillar mining; however, other controls may be necessary to fully mitigate coal burst hazards.

An example of this occurred in 1982 at the Olga Mine in southern West Virginia (Campoli, et al., 1987). Two miners were fatally injured while mining a pillar that contained gob on two sides. At the time of the accident, the pillar had been split into a number of different size pillars, including one large critical-size pillar, one smaller critical-size pillar and nine yield pillars (figure 1). The large critical-size pillar violently burst as it was being mined.

Uniform Extraction Fronts

When coal pillar bursts first began to occur in eastern Kentucky (Bryson, 1936), many of them were occurring along the retreating pillar line where uneven pillar lines were observed. Holland and Thomas (1954) realized that this practice was dangerous and issued a recommendation to avoid "pillar-line points". These section-wide mine plans can contribute to coal mine bursts when overlapping abutment pressures from converging gob lines cause excessive stress conditions in the pillar-line point area. The C-2 Mine bursts on November 20, 1996 that injured 6 miners, two fatally, provides one recent example where converging pillar lines were thought to be at least

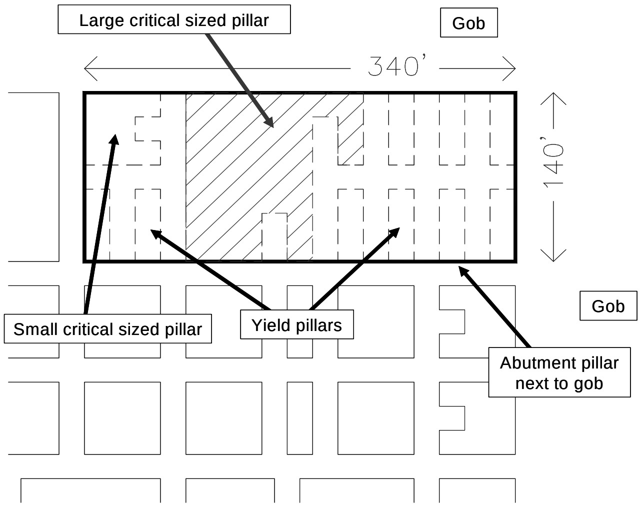

Figure 1. A larger, critically-sized pillar surrounded by smaller, critically-sized pillars and yield pillars near a gob acts to concentrate stresses and pose an increased risk for coal bursts.

partially responsible for the event (figure 2). It should be noted that there may be limits to the width of a uniform extraction front. Notely (1984), writing about coal bursts at the Springhill Coal Mine in Nova Scotia, Canada, provides evidence of this. Early in 1958, a series of bursts occurred at the mine that was thought to be caused by the staggered mining of three adjacent longwall faces. In an effort to rectify this problem, the mine operator altered the mining of these three longwall panels until one large mining front was formed. Unfortunately, this alignment was associated with the devastating October 24, 1958 Springhill coal mine bursts, where 74 miners were fatally injured. In this case, a very wide cave zone may have failed catastrophically, causing the fatal burst condition.

Bump-Cut

When pillar extraction occurs under excessive stresses and the pillars are critically-sized chain pillars, it is sometimes advisable to take a bump-cut of approximately 20 ft in length driven from the center of the rib toward the pillar core. The name was given to this individual cut sequence because of the frequent occurrence of audible seismic events that sound like thumps or bumps. The origin of the bump-cut method is unknown, but examination of old mining maps in the central Appalachian Coal Fields show that it was in use by the 1960's. The bump-cut should be the first cut that is extracted from a pillar during retreat mining. Typically this cut is made in the center of a critically-sized pillar so that the remaining coal, left on either side of the bump-cut, will readily yield. If the pillar is highly stressed, the bump-cut can act to release the load in a controlled fashion to adjacent pillars. In this way, a bump-cut is a means of destressing the pillar prior to full extraction with the continuous mining machine. The Deer Creek Mine in Utah (figure 3) has used the bump-cut method to destress a number of highly-stressed critical pillars along one of its gate entry developments (Iannacchione and Zelanko, 1995).

Pillar Sequencing

In the west, the Kenilworth Mines used a sequencing method to mine pillars along retreating extraction fronts (Reeves, 1954). This technique involved moving between as many as 5 pillars along the extraction line to gradually destress the pillars. The drill-and-blast mining system used at the Kenilworth Mine, lent itself to multiple active working faces. In the east, the Olga

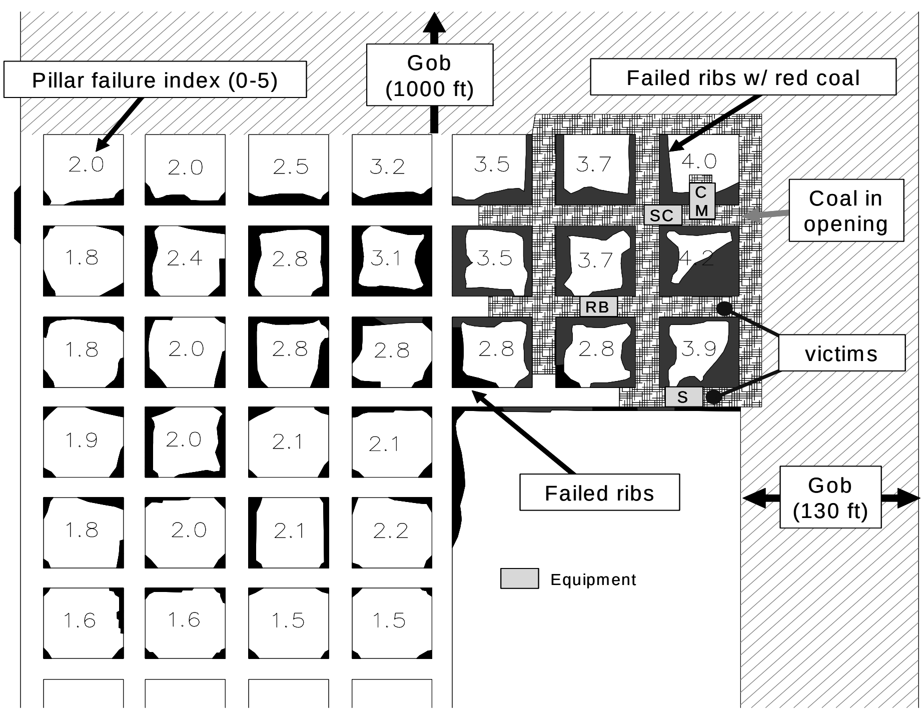

Figure 2. Map of the conditions observed by MSHA personnel after the C-2 Mine burst where converging pillar extraction fronts concentrated stresses at points of intersection.

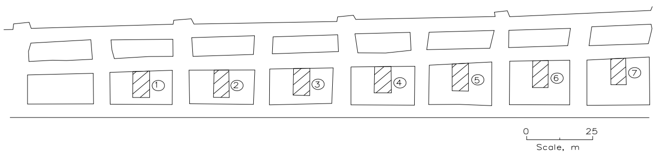

Figure 3. Example of partial pillar destressing method employed at the Deer Creek Mine.

Mines in southern West Virginia developed a systematic pillar sequencing method over many years of trial-and-error work. This retreat mining technique involves the sequential mining of numerous places over three to four rows of pillars in order to gradually direct the overburden loads away from the pillar line, where most of the miners and machines are located. An idealized schematic of the extraction sequence is shown in figure 4. By design, all coal pillars three rows outby the gob line would have at least a bump-cut. This bump-cut is mined from the middle of the crosscut toward the pillar core. When the pillars are two rows outby the gob line, they are split in half by extending the bump-cut entirely through the pillar. Finally, the pillar wings or fenders are extracted in the row closest to the gob line. Observations of the redistribution of rock pressures associated with this specific mining sequence were made by Campoli, et al., (1990a). The advantage of this system is that it avoids the use of multiple working places within a single pillar.

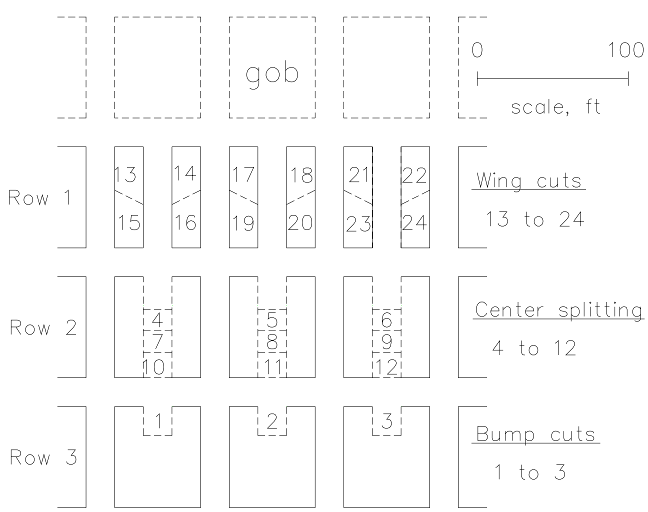

Figure 4. An idealized schematic of the extraction sequence used at the Olga Mine.

Barrier Pillar Splitting (Thin-Pillar Method)

In many large drift mines, during the later portion of a mines life-cycle, when it has developed to the full extent of its available reserves, the mine will begin to retreat toward its original mine entries. During this process, the barrier pillars that had been left to protect the main developments from the full extraction sections are mined. Many of these barrier pillars are bounded by at least one gob and can have in many cases two gob boundaries. Holland and Thomas (1954) recommended the barrier pillars be split into smaller sized pillars far in advance of the full-extraction mining process. The barrier pillars are highly loaded from the mining-induced stresses of the main entry development and the pillaring operations of the old gob. The additional loading from the current pillar line only compounds this situation.

The thin-pillar mining method was developed at the Gary No. 2 Mine in the 1950's and reported by Talman and Schroder (1958). The thin-pillar method segments the large barrier into chains of yield pillars (figure 5). During thin pillar mining, it is imperative that mining does not occur in areas that are excessively stressed. However, the thin yield pillars need to undergo some softening due to the pillar line loading. Therefore, outby thin pillar development must remain near the gob line. By design, the first cut into the barrier pillar that begins to outline a new thin pillar, encounters the most critical stresses. Mucho, et al. (1993) documented this process and analyzed the various signs used by the mine operator to evaluate the conditions of the pillars.

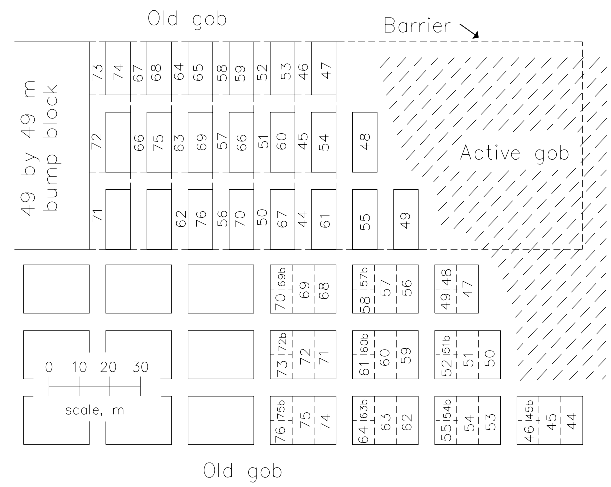

Figure 5. Typical mining sequence utilizing the thin-pillar method. Numbers indicate mining sequence order. Dual numbers indicate areas mined simultaneously (After Talman and Schroeder, 1958).

LONGWALL MINING ISSUES

Gate Entry Designs

In the eastern U.S., longwall mine designs in burst-prone ground centered on altering the size and shape of the gate entry pillars. This distinction between western and eastern coal mines was a direct result of their different ventilation requirements. Methane gas accumulations in the longwall gob and longwall bleeder entries represented a continuous challenge for these mining operations. Multiple gate entry designs were employed to increase provided the delivery of greater fresh air to the longwall face and inby to the bleeder entries in gassy mines. The gate entry pillars are designed to remain sufficiently stable to allow ventilating air to pass through the headings and into the inby bleeder entries where the methane coming from the longwall gobs is diluted to acceptable levels. These pillars had the added advantage of resisting load ride-over onto the active longwall face, thereby minimizing burst hazards in the face area.

Originally longwall gate entries were comprised of two or three rows of chain pillars (figure 6a). The first burst control technique was to use the yield-chain-chain design (figure 6b) to protect miners working near or within the tailgate entries. The yield pillar is designed to shed load and therefore is not expected to present a burst hazard at the tailgate corner. The yield-chain-yield design (figure 6c) positions the yield pillars adjacent to both the head and tailgate, again to lessen the potential for bursts adjacent to these high traffic areas. The yield-abutment-yield design (figure 6d) utilizes an abutment pillar to protect the active longwall panel from the adjacent gob. This design was first utilized at the Jim Walters coal mines and brought to Virginia in the mid-80's to help control bursts in the gassy Pocahontas coal mines (Hendon, 1998). Campoli et al., (1990b) verified the performance of these systems through a series of detailed field studies.

Yield-Barrier Gate Entry Designs

As longwall mining increased during the 70's and 80's a number of innovative designs for controlling bursts were developed. The Mid-Continent coal mines in Colorado began to use a mining method where the longwall face advances slightly behind the developing gate entry headings (Reeves, 1978). This method is a modification of the advancing longwall system used extensively in Europe and Asia. It may help to control the burst hazards by reducing gate entry developments. In Utah, the Sunnyside coal mines, in cooperation with the US Bureau of Mines, experimented with a single entry system (Koehler, 1994). This system had the advantage of eliminating a major source of the burst hazards in longwall mining, the gate entry pillar. However, the major design used to mitigate bursts conditions in the western U.S. was the two-entry yield pillar system.

The ventilation requirements in western deep cover longwall mines were much different than eastern mines (Ferriter, 1985). First, the rugged terrain makes it very difficult to penetrate the longwall gobs with gob-vent boreholes or to place high-pressure, small diameter ventilation shafts within the bleeder system to adequately dilute the methane coming from the longwall gobs. These techniques are more popular in gassy eastern coal mines. Without these ventilation controls, it became increasingly difficult to dilute the methane gas to acceptable levels. Second, spontaneous combustion is a serious problem for western coal mines (Smith and Lazarra, 1987). The techniques most successful in mitigating spontaneous combustion rely on the removal of oxygen, largely by removing ventilating currents into the gob by deployment of ventilation seals around the longwall gob. This technique is known as the bleederless longwall system with U-shaped ventilation. The fresh air is typically delivered through the headgate entries, forced along the active longwall face, and carried away in the tailgate entries. In these ventilation systems, it is undesirable to have ventilation air pass beyond the face into the gob areas. The yield pillars are designed to yield outby the longwall face to facilitate full (tight) caving of the entries inby the face to hinder air movement between longwall gobs. A potential disadvantage of this design is that these yield pillars allow abutment load to ride over onto the longwall face and can increase bursts in the face area.

The traditional shallow-cover western gate entry design has been the double row of chain pillars (figure 7a). Under burst prone conditions, this gate entry design proved inadequate because the chain pillars had the potential to burst as the longwall face passed. At some mines, a row of yield pillars were placed next to the longwall tailgate (figure 7b) to lessen the potential for bursts in this area. However, this layout didn't eliminate the potential for headgate bursts. The two-entry yield pillar design was developed at the Sunnyside Mine to mitigate pillar bursts (figure 7c). This design is now used by many deep western

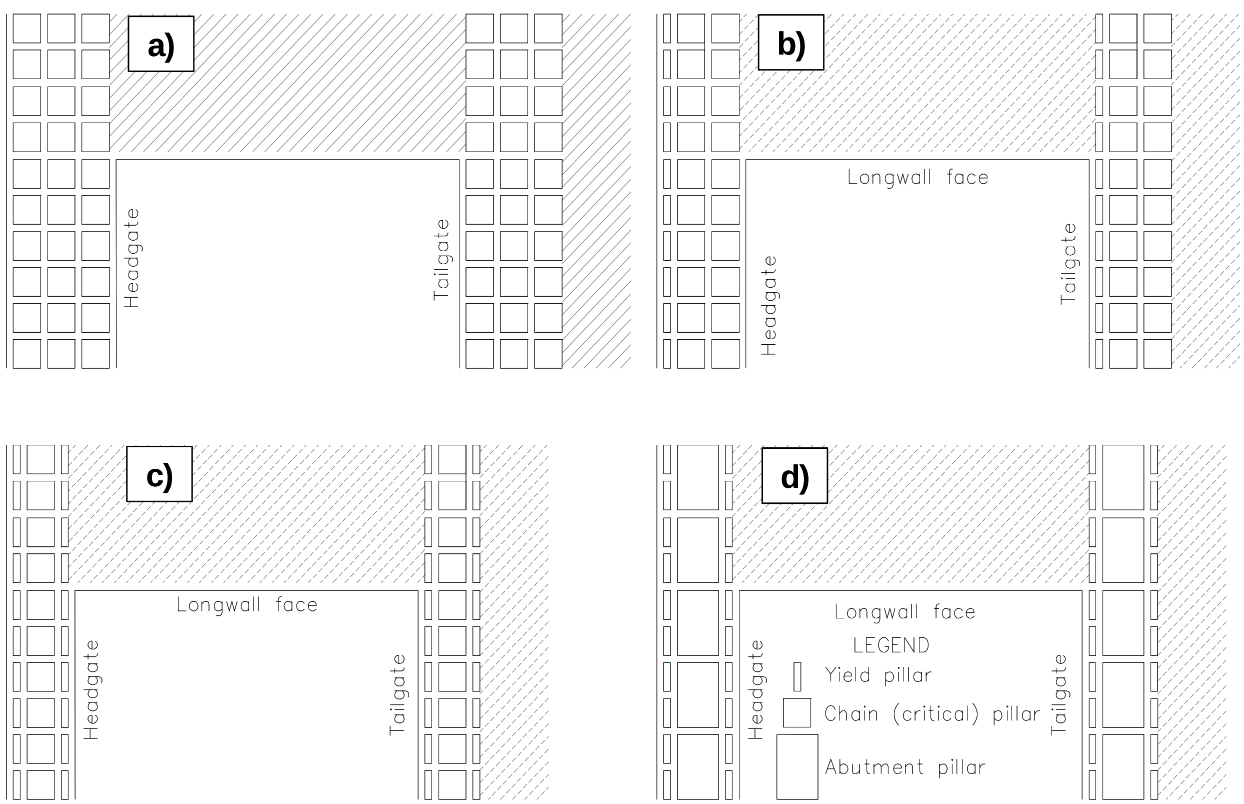

Figure 6. Yield-chain-abutment gate entry designs used in mines with high methane emission rates and coal burst potential – a) chain pillar design, b) yield-chain-chain pillar design, c) yield-chain-yield pillar design, and d) yield-abutment-yield design.

longwall mines. Unfortunately, under depths greater than 2000 ft, the frequency of longwall face bumps increased. To combat this trend, the Andalex Mine began to leave a barrier pillar between the previously mined panel and the tailgate of the adjacent panel (figure 7d). This yield-barrier design has now been used by several deep longwall mines as a means of mitigating longwall face bursts. The barriers range in width from 300 ft to more than 600 ft.

Critical Pillar Concept

The critical pillar concept for longwall gate entry systems identifies a certain range of pillar sizes that are more susceptible to coal bursts. Koehler, et al., (1996) define a critical pillar as one that is too large to either yield nonviolently or yield before the roof and floor sustain permanent damage, but is too small to support full longwall abutment loads. Ground control problems commonly associated with the use of critical pillars include frequent coal bumps, severe floor heave or roof damage and subsequent roof falls. A conceptualization of the relationship between critical pillars and yield and abutment pillars is presented in figure 8. The horizontal axis represents the minimum performance standard separating stable from unstable gate entry configurations. A pillar design whose performance falls above the horizontal axis is considered successful (stable), while a design whose performance falls below the horizontal axis is considered unsuccessful (unstable).

Where the use of pillars with width-to-height ratios greater than 3 to 5 is concerned, the concept of the critical pillar has often governed the performance experienced in deep western coal mines. DeMarco, et al., (1995) emphasized that increasing pillar width toward the critical-pillar range only invites the full weight of the overburden to be transmitted to a gate system that cannot possibly support it. As a result, critical pillars are to be considered extremely bump prone, even at shallow depths, when strong mine roof and floor conditions exist.

MULTIPLE-SEAM DESIGN

In an influential publication on multiple-seam mining, Mark (2007) discussed the different types of interactions:

- Undermining, where stress concentrations caused by previous full extraction in an overlying seam is the main concern; and
- Overmining, where previous full extraction in an underlying seam can result in stress concentrations and rock damage from subsidence.

In this study, overmining was generally found to produce more difficult ground conditions than undermining, and isolated remnant pillars cause more problems than gob-solid boundaries.

Multiple-seam mining has long been recognized as a contributing factor to the occurrence of coal bursts. One of the first U.S. longwall faces, Moss No. 2, experienced a burst on Jan. 8, 1970 and a second burst occurred on July 30, 1970 on an adjacent room-and-pillar panel (Iannacchione and Zelanko, 1995). Both of these events occurred while mining under a transition from the

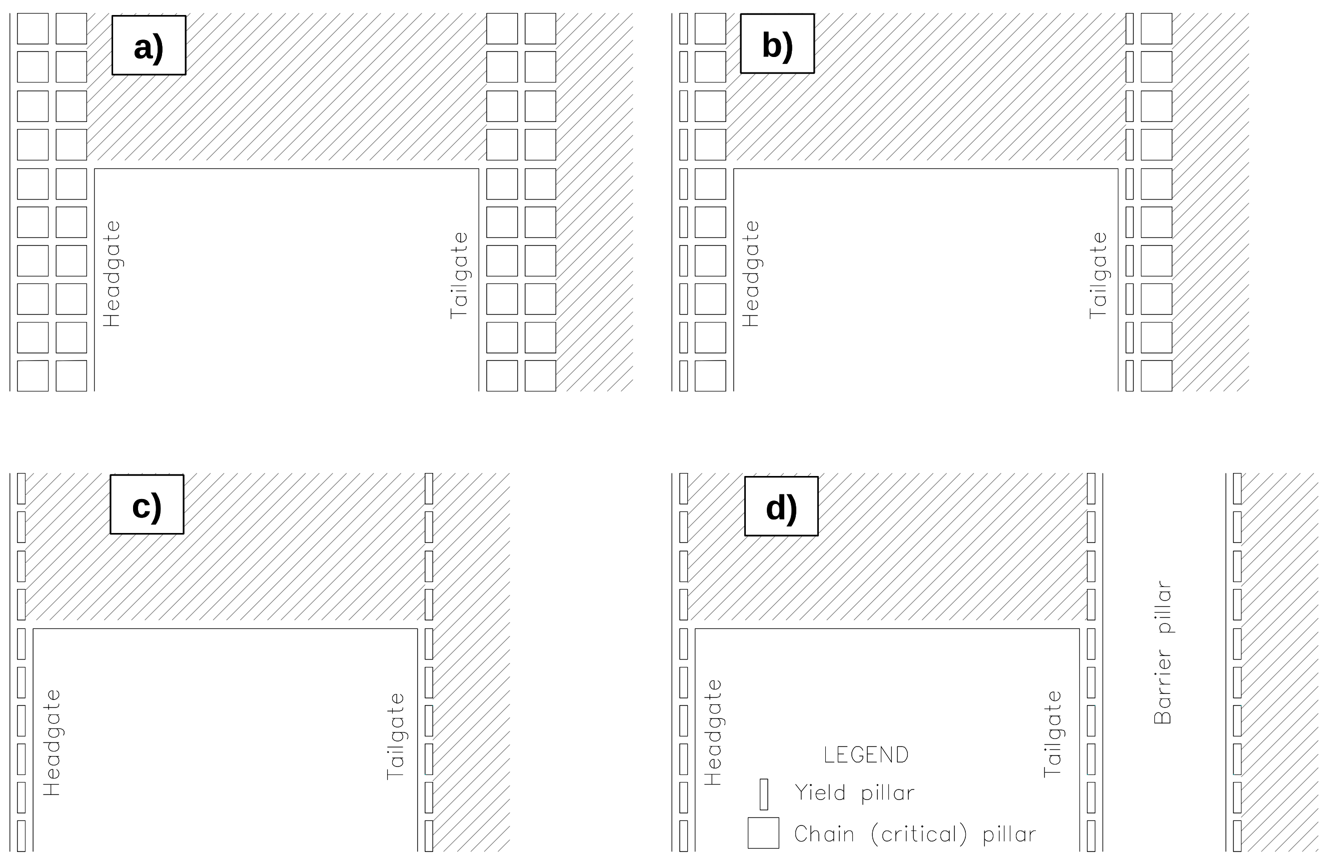

Figure 7. Gate entry designs used in mines with spontaneous combustion and burst potential - a) double chain pillar design, b) yield-chain pillar design, and c) yield pillar design and d) yield pillar-barrier design.

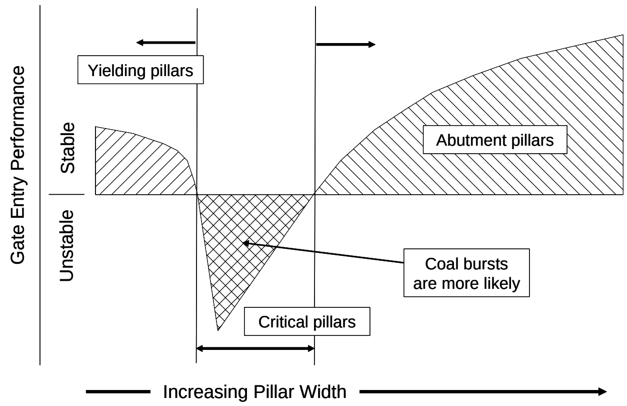

Figure 8. Conceptualization of the critical pillar concept showing the transition from successful yield pillar systems, through unsuccessful critical designs, to successful abutment pillar system (Koehler, et. al, 1996).

remnant pillar to a gob area in an overlying mine (figure 9). A more common factor influencing coal bursts is mining beneath a large remnant. One example of this took place at the Moss No. 3 Mine on Nov. 4, 1977. A burst occurred while splitting an abutment pillar in the Upper Banner Coalbed, located directly below another isolated abutment pillar in the overlying Thick Tiller Coalbed (figure 10). These two examples suggest that active operations may have a greater coal burst threat when mining beneath an overlying mine rather than mining over one, especially when the overlying mine has remnant pillars.

There are a number of rules that have been identified concerning how different overlying and underlying mine layout configurations can impact stress concentrations (Mark, 2007). For example, mining from the gob to the solid generally results in lower stress concentrations than from the solid to the gob. The type of remnant pillar structure (gob-solid boundary or isolated barrier) in overlying and underlying workings influences the degree of multiple-seam interaction. Isolated barriers cause more stress concentration problems than gob-solid boundaries (Mark, 2007).

NIOSH's Analysis of Multiple Seam Stability (AMSS) program can be used to evaluate the impact of multiple-seam mining on ground conditions. For more complex three-dimensional cases, where distribution of gob-side abutment loads between side abutment pillars and chain pillars are present, a numerical simulation is needed to determine the loading conditions. One of the most popular codes for stress and displacement evaluations is LAMODEL (Heasley, 1997).

ISOLATION AND AVOIDANCE PRACTICE

When the geologic and stress environments are well understood and burst conditions are highly probable, the best alternative is to avoid this area. If the hazard is thought to be associated with a particular geologic discontinuity or with an unwanted multiple seam configuration, isolation and avoidance may be required. An example of this occurred at the Lynch No. 37 Mine in Kentucky. This mine began operating in a new longwall district where a channel sandstone was observed to intersect several panels. The operation had not encountered these features in the past. The channels in this area were relatively narrow and did not scour more than one-foot into the top of the coalbed. Therefore, the coal height was sufficient for continuous longwall mining. However when

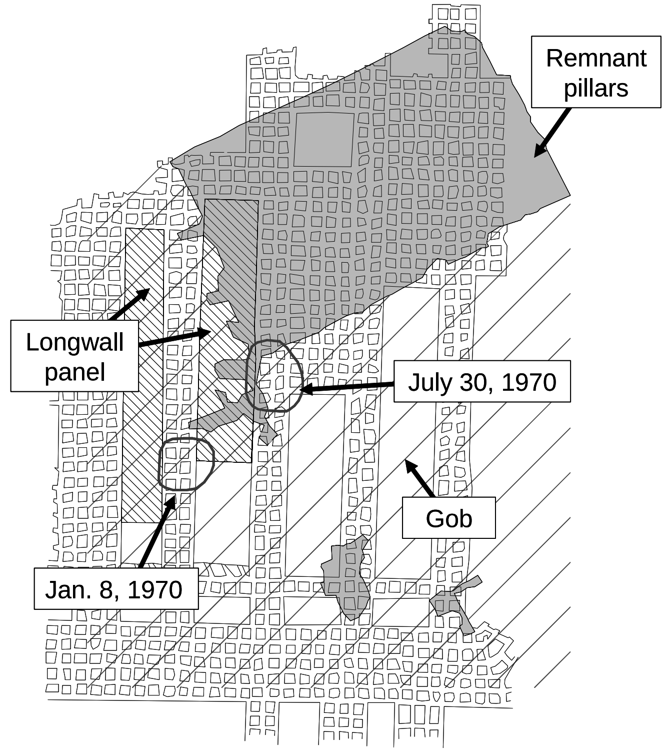

Figure 9. Coal burst events associated with longwall and room-and-pillar mining at the Moss No. 2 Mine and the location of overlying remnant pillar and gob mining.

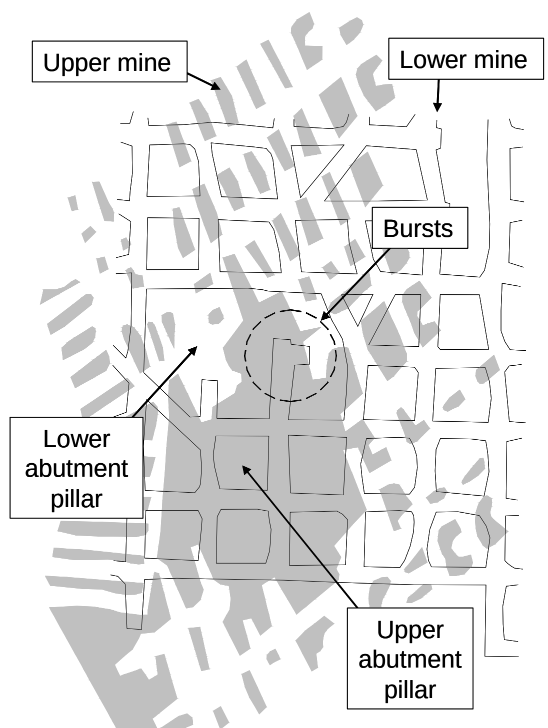

Figure 10. Burst occurred while splitting an abutment pillar located directly below an overlying large remnant pillar, Moss No. 3 Mine.

longwall mining encountered the first channel, a large burst occurred (figure 11). A second burst occurred before the longwall face could mine from underneath the channel. The mine operator had decided to "move around" the channel in the next longwall panel. As the longwall face approached the channel another face burst occurred. For this mine, the primary prevention control was to move around the projected paths of the sandstone channels to

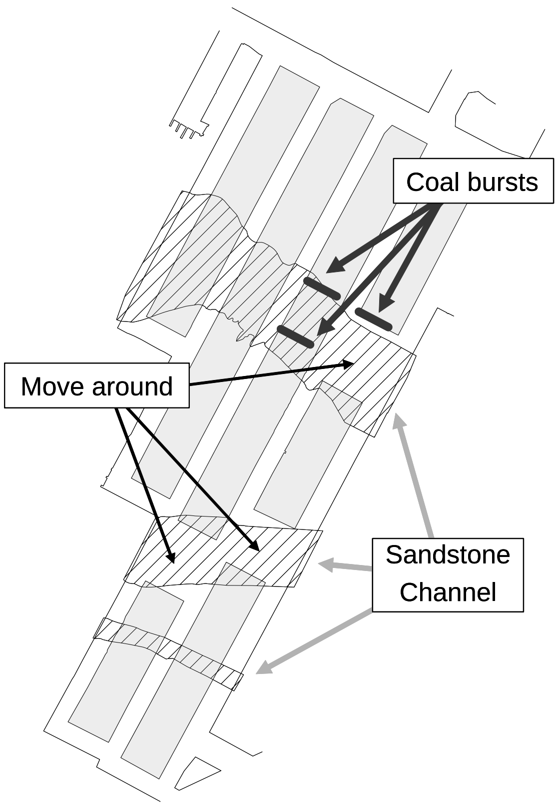

Figure 11. Longwall panels at the Lynch No. 37 Mine with associated sandstone channels and the locations of two large bursts events.

lessen the potential for coal bursts events (figure 11).

Large scale geologic discontinuities, i.e. faults, dikes, etc., have also been observed in close proximity to many coal bursts suggesting that they have some effect on the way the coal is loaded by the adjacent strata (Peparakis, 1958; Iannacchione and DeMarco, 1992; Maleki, 1981; Cox, et al., 1995; DeMarco, et al., 1995; and Osterwald, et al., 1993)

ADMINISTRATIVE CONTROLS, PERSONAL PROTECTIVE GEAR AND BARRIERS

Administrative controls, personal protective gear and barriers are generally used when engineering controls are not sufficient to mitigate the burst hazards at a mine. In some cases, it was possible to eliminate the risk presented by coal burst hazards simply through administrative controls that removed the miner from the hazardous environment. In other cases, it was necessary to provide the miners with protective gear to protect against out-bursting material. Barriers, i.e. belting deployed from the tips of shield canopies, etc., are also often used to shield the miners from the hazardous burst. These approaches were recently adopted at the Tower Mine in Utah (Anon, 2007). The mine operator installed equipment that allowed the longwall to be operated remotely or autonomously away from the most hazardous locations. The success of this control has not been determined, but the recent closing of the mine suggests some problems may have been encountered.

SUMMARY AND CONCLUSIONS

Coal mine bursts have been associated with underground mining for at least the last 90 years in parts of five states: Utah, Colorado, West Virginia, Virginia and Kentucky, During this time, much information on the occurrence, control and remediation of these events has been collected, analyzed and documented in technical manuscripts. These reports chronicle the many innovations that characterize the US mining industry. Two forms of engineering controls are used: prevention controls, i.e. layouts that mitigate burst conditions, and remediation controls, i.e. destressing, volley firing, water injections, etc. Prevention controls must be applied early in the mining process, prior to the mining of burst prone coal. Remediation controls are typically used when a recognized burst hazard exists and an action is required to safely mine the coal. Finally, it is sometimes prudent to simply avoid mining in burst prone areas. This paper focuses on the prevention controls developed over the last 90 years.

Coal mine burst prevention controls tend to focus on generic solutions to very specific conditions. Operators need to recognize the prevention control that most closely relates to the fundamental factors that are capable of producing coal burst hazards at their respective mines to achieve effective prevention control. Prevention controls examined in this paper are:

- Uniform pillar size and shape control – Abnormal pillar sizes can act to attract loads that might normally be distributed to adjacent smaller pillars.
- Uniform extraction fronts control - Uneven retreating of pillar lines can cause stress to accumulate at the point of intersection between these lines.
- Bump-cut control - If the pillar is highly stressed, the bump-cut can act to release the load in a controlled fashion to adjacent pillars. In this way, a bump-cut is a means of destressing the pillar prior to full extraction with the continuous mining machine.
- Pillar sequencing control – An effective means to redirect overburden loads away form the pillar line is accomplished by systematically mining small sections of pillars over three to four rows of pillars.
- Barrier pillar splitting (Thin-pillar method) - It is essential that barriers be split into smaller sized pillars far in advance of the full-extraction mining process. The size of these smaller pillars needs to be carefully considered. Sometimes an abutment pillar strong enough to support the overburden should be left in place.
- Yield-chain-abutment gate entry design (deep Eastern longwall mines) – High methane emissions require multiple gate entries (3 or more) in most deep and gassy eastern longwall mines. The use of an abutment pillar, flanked by yielding pillars, has proven to be an adequate gate entry layout in burst prone ground.
- Yield-barrier gate entry design (deep Western longwall mines) – Two entry yielding pillar gate entry layouts have become the standard for mines with spontaneous combustion and burst hazards. Typically, these pillars

are not capable of storing dangerous levels of strain energy during the longwall passage. Barriers between panels have been added for the deepest longwall faces to help protect against abutment ride-over.

- Critically-sized pillars - A critically-sized pillar is one that is too large to either yield nonviolently or yield before the roof and floor sustain permanent damage but is too small to support full longwall abutment loads. Such pillars should be avoided.
- Multiple-seam design – Mining beneath an existing overlying mine can increase the potential for coal mine bursts, especially when the overlying mine has remnant pillars.
- Isolation and avoidance - In some situations the burst hazard may present a risk that the mining operation is not willing to take. In this case, the best alternative is to avoid the area. This is best accomplished when the geologic and stress environments are well understood.

In conclusion, coal mine bursts are not common events in most underground coal mines. However when a burst occurs, it almost always represents a major hazard. There are a number of fundamental factors that influence their occurrence, producing a range of hazards and requiring a complex set of controls to lower mine worker and operational risk. Over the many years of dealing with this hazard, specialized requirements for layouts and novel extraction sequences have been developed on a site specific basis to safely mine coal when fundamental factors are present that promote the occurrence of bursts. The risks associated with these hazards can only be lessened if engineers, managers and safety professionals understand how to assess these risks and possess the knowledge to prevent or remediate their occurrence.

Disclaimer

The findings and conclusions in this paper have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be construed to represent any agency determination or policy.

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