Deep Cover Pillar Recovery in the US

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ABSTRACT

In the wake of the Crandall Canyon mine disaster, the U.S. Congress asked the National Institute for Occupational Health and Safety (NIOSH) to study the safety of deep cover pillar recovery operations in the US. The legislation defined “deep cover” to be greater than 1,500 ft, but NIOSH is also evaluating mines at depths greater than 1,000 ft when multiple seam interactions are encountered. By these definitions, there about 35 active mines that engage in deep cover pillar recovery, in the states of UT, CO, VA, WV, and KY. To date, NIOSH has documented ground conditions and ground control experience at nearly all of them. This paper provides an overview of current deep cover pillar recovery practice. Specific ground control issues that are discussed include:

- Pillar recovery sequences,
- Pillar and barrier pillar design,
- Coal bumps,
- Thick seam pillar extraction, and
- Multiple seam interactions.

INTRODUCTION

On August 6, 2007, a violent coal bump occurred at the Crandall Canyon mine near Price, Utah. Six miners working in the South Barrier section of the mine were presumed trapped. Ten days later, three rescuers were killed in a second bump. Underground rescue efforts were suspended, and the original six miners were presumed to have been fatally injured.

At the time of the incident, the Crandall Canyon miners were engaged in retreat mining in the South Barrier section. With cover that exceeded 2,200 ft at its deepest point, these were some of the deepest pillar retreat operations ever attempted in the US.

Crandall Canyon was the nation’s fourth coal mine disaster in less than two years. It therefore generated intense interest in the mining community and the public at large. In response to the disaster, Congress directed that NIOSH conduct “a study of the recovery of coal pillars through retreat room and pillar mining practices in underground coal mines at depths greater than 1,500 ft.” They further directed that the study include analyses of:

- Conditions under which retreat mining is used, including conditions relating to seam thickness, depth of cover, strength of the mine roof, floor, and pillars, and the susceptibility of the mine to seismic activity, and;
- Procedures used to ensure miner safety during retreat mining.

NIOSH will submit a report to Congress on December 31, 2009, containing the results of the study. The report will also include recommendations to enhance the safety of miners on retreat mining sections and recommendations for future research.

The study is being conducted in collaboration with the University of Utah (U of UT) and West Virginia University (WVU). At WVU, a team led by Prof. Keith Heasley is investigating pillar design for deep cover retreat mining, focusing on the LaModel numerical modeling program. The U of UT effort, led by Prof. Kim McCarter and Prof. Walter Arabasz, is concentrating on the application of seismic monitoring to reduce the bump risk. The results of these projects will be reported in detail in the final report to Congress, but they will not be discussed here.

The purpose of this paper is to provide an update on the NIOSH study’s progress, and to report some preliminary findings. The study builds upon past NIOSH retreat mining research in the areas of pillar design, deep cover, and roof fall prevention (Mark and Tuchman, 1997; Chase et al., 2002; Mark and Zelanko, 2005). To conduct the current study, NIOSH partnered with 16 different coal companies to obtain information on the industry’s experience with deep cover pillar recovery. NIOSH researchers conducted underground investigations at 18 mines located in UT, CO, WV, VA, and KY, and they collected data from 17 more. These mines have included nearly every active mine that has recovered pillars at depths exceeding 1,500 ft, and the majority of mines with experience between 1,000 and 1,500 ft. In all, more than 200 retreat mining case histories have been documented and added to the Analysis of Retreat Mining Pillar Stability (ARMPS) data base. Roof control professionals at the MSHA have also provided much valuable information. The study has focused particularly on bump control, and included discussions in Germany with German rock burst specialists. It has also made extensive use of the MSHA accident and injury data base.

DEMOGRAPHICS OF DEEP COVER PILLAR RECOVERY

The first task was to determine how many deep cover pillar recovery mines there are, and where they are located. Depth of cover is not a parameter that mines routinely report to either MSHA or the Department of Energy (DOE). Fortunately, in early 2008, the MSHA Roof Control Supervisors developed lists of the deep cover mines in their Districts, and this information was generously shared with NIOSH.

Figure 1 shows that of the approximately 42,000 underground coal miners in the US[1], less than 3%, or 1,200, work at mines that recover pillars at depths greater than 1,500 ft. An additional 3,900 work at retreat mines with depths between 1,000 and 1,500 ft. Past studies have indicated that only about 1/3 of the hours at a retreat mine are actually spent in pillar recovery operations (Mark et al., 1997), and the current study found that at a typical deep cover retreat mine, at least 50% of the pillar extraction is conducted beneath shallow cover. Therefore, it seems likely that total exposure of miners to pillar recovery operations at depths greater than 1,500 ft is less than ½ of one percent of all hours worked underground.

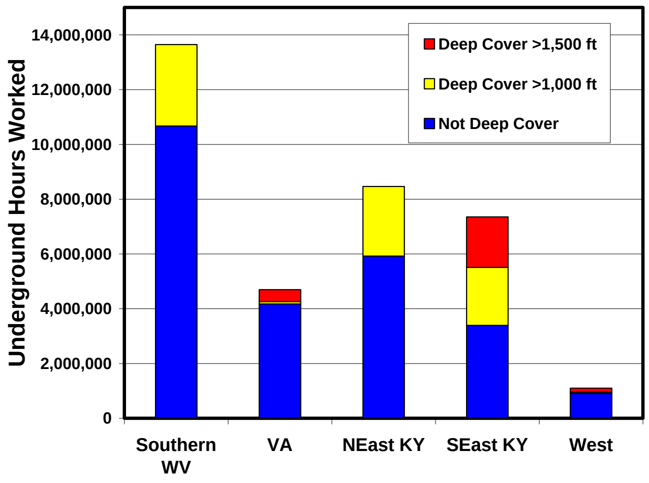

Figure 1. Location of deep cover pillar recovery operations in the U.S., 2007.

Figure 1 also shows that the greatest concentration of deep cover retreat mining is in southeastern KY, specifically in Harlan County. The next largest grouping is in adjacent Wise County, VA. Active mines with pillar recovery experience at depths greater than 1,000 ft are located throughout eastern KY and southern WV. In the West, there are two, deep cover room-and-pillar retreat mines, one in UT and the other in CO. One western longwall mine (in addition to Crandall Canyon) has also recovered pillars prior to abandoning a worked-out seam. There is apparently no deep cover pillar recovery at all in the Northern Appalachian, Illinois, or Alabama coal regions.

GEOLOGY AND MINING CONDITIONS

Previous studies have found that roof rocks in the Central Appalachian, Utah, and Central Colorado coalfields are relatively hard and strong (Rusnak and Mark, 2000; Mark, 2007). Observations in the deep cover retreat mines conform to this trend. The lowest CMRR values measured were approximately 45, which is considered "intermediate strength" roof. Most of the mines had CMRR values in the 50's, and some were as high as 75. As evidence of the relatively benign conditions, more than 80% of the deep cover mines employ 4- or 5-ft fully grouted bolts as primary support, despite their depth. MSHA statistics also indicate that the rate of unplanned roof falls is about 25% lower in this group of mines than in other room-and-pillar mines.

The overburden is also relatively competent, typically consisting largely of thick sandstones and siltstones. The floor rocks tend to be firm, and groundwater is seldom a major issue.

On the other hand, multiple seam interactions are an important concern at a big majority of these operations. Almost 80% encounter workings less than 200 ft above or below their active mining.

GROUND CONTROL SAFETY IN DEEP COVER PILLAR OPERATIONS

Pillar recovery accounts for no more than 10% of the coal mined underground, yet it has historically been associated with more than 25% of all ground fall fatalities (Mark et al., 2003). Within retreat mining, deep cover has long been identified as a "risk factor" (Mark et al., 1997). During the past 15 years, there have been 24 fatal incidents during retreat mining (Figure 2), and six of those have occurred at depths greater than 1,000 ft (see Table 1). The data shown in Figure 1 indicates that only about 10% of retreat mining is conducted at depths exceeding 1,000 ft (assuming that half of the pillars recovered at the deep cover mines are actually beneath shallower cover.) Since 10% of the exposure was associated with 25% of the fatal ground fall incidents during this period, the risk to deep cover miners was significantly greater than that faced by other retreat miners, which was already elevated relative to the ground fall risk to underground coal miners in general. Moreover, 4 of the 6 deep cover incidents resulted in multiple fatalities.

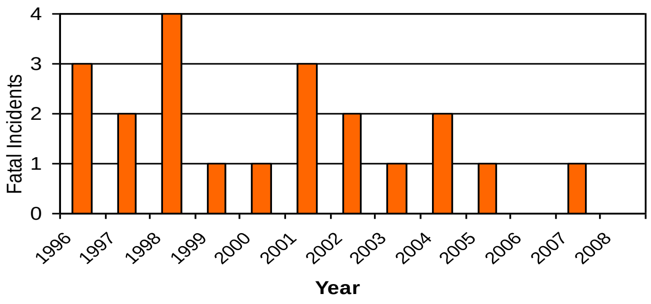

Figure 2. Trends in retreat mining fatal incidents, 1996-2008.

Despite these grim statistics, the accident trends do seem to indicate that some progress is being made in the area of retreat mine safety. Prior to 2003, an average of two fatal incidents occurred

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[1] Calculated from the number of underground worker hours reported to MSHA, assuming that 2000 hours equals one worker-year.

Table 1. U.S. deep cover pillar (depth >1,000 ft) retreat mining fatal incidents --1996-2008.

Year	Cause	Mine	State	No. Fatalities	Link
1996	Pillar Bump	C-2	KY	2	www.msha.gov/FATALS/1996/FAB96C34.HTM
1998	Roof fall	Lightfoot No. 2	WV	1	www.msha.gov/FATALS/1998/FAB98C02.HTM
1998	Roof fall	Darby Fork No. 1	KY	1	www.msha.gov/FATALS/1998/FAB98C24.HTM
2005	Roof fall	Stillhouse #1	KY	2	www.msha.gov/FATALS/2005/FAB05c1112.asp
2007	Roof fall	Cucumber	WV	2	www.msha.gov/FATALS/2007/FAB07c0203.asp
2007	Pillar Bump	Crandall Canyon	UT	9	http://www.msha.gov/FATALS/2007/CrandallCanyon/ CrandallCanyonreport.asp
Total				17	

each year during pillar recovery operations. During the past six years, there have been just five incidents (figure 2). A key cause of the change has been the widespread adoption of safer retreat mining techniques and technology. A concerted effort by MSHA and NIOSH (Mark and Zelanko, 2005; Mark et al., 2003) promoted the following three steps to safer pillar recovery:

- Global stability through proper pillar design;
- Local stability with proper roof support, and;
- Worker safety through proper section management.

The Crandall Canyon incident, like the double bump fatality at the C-2 Mine in Kentucky 11 years earlier, was a clear example of global instability caused by improper pillar design. The MSHA Fatality Investigation Report concluded that the design at Crandall Canyon was “destined to fail” because the remaining production and barrier pillars were too small to carry the overburden load (Gates et al., 2008).

Global stability is a necessary, but not sufficient, condition for creating a safe working area. Proper roof support is required to maintain local stability. The final pillar stump (sometimes called the “pushout”) provides critical roof support during pillar recovery. Traditionally, miners tried to extract all the coal during pillar recovery, and many fatalities occurred during the mining of the final stump. Research has now shown that the optimum pillar extraction plan leaves a final stump that is engineered to provide roof support without inhibiting caving (Mark and Zelanko, 2001). Most roof control plans that are now in use do not allow the mining of the pushout, and specify a cut-to-corner distance that ensures that the stump is properly sized.

One striking feature of the pillar recovery fatalities is that in nearly every case, the victim was beneath bolted roof. In many cases, bolt failure was itself implicated in the fatality. Sheared and broken 5/8-in, fully-grouted rebar bolts contributed to three of the four deep cover roof fall fatal incidents listed in Table 1 (Lightfoot, Darby Fork, and Cucumber). Increasingly, mines are using longer and/or stronger bolts to support areas that will be retreat mined. In addition, cable bolts or other special bolts are employed in intersections, which are the most hazardous locations for miners during pillar recovery.

Traditionally, timber posts provided supplemental support for pillar recovery, but they have many disadvantages. Mobile Roof Supports (MRS) provide better ground control, and they can be set remotely, away from the dangers of the pillar line. Today, perhaps 50% of all retreat coal is mined with MRS, primarily in the thicker seams. Unfortunately, several of the recent victims in pillar recovery fatalities have been MRS operators that were standing unnecessarily in unsafe, inby locations. These incidents have underlined the third factor, effective section management. Careful planning of the production process, good supervision, and training and retraining are necessary to prevent bad habits from developing.

Most rock fall injuries underground, more than 400 per year, are caused by relatively small pieces of rock falling from between supports. Analysis of the MSHA accident and injury statistics shows that miners in deep cover retreat operations are not at significantly greater risk of rock fall injury than other room-and-pillar miners. One part of the explanation may be that roof bolting, which is a significant source of rock fall injuries, is seldom employed during retreat mining.

Rib falls do seem to be a serious problem at deep cover pillar recovery mines. During 2007, fully one-third of all the rib fall injuries in the entire US underground coal industry occurred in the small group of deep cover retreat mines. Rib falls have killed 15 mineworkers since 1995, including three at deep cover pillar recovery mines (though none of the incidents occurred during retreat mining operations). The two main factors that lead to an increased risk of rib falls are thicker coal seams and higher stress levels. For example, analysis of the 15 fatal rib fall incidents revealed that two-thirds occurred at depths exceeding 900 ft, and the mining height was at least seven ft in every case. Rib bolting can be highly effective in reducing the risk of rib falls. It is significant that apparently none of the 15 U.S. fatality sites were ever rib bolted (Mark et al., 2009).

DEEP COVER RETREAT MINING METHODS

Most room and pillar mines in the US employ continuous mining machines with shuttle car haulage, and this holds for 26 of the 30 active deep cover retreat mines that were visited or whose Roof Control Plans (RCPs) were reviewed for this study. The exceptions were four KY operations, primarily in thinner seams, that employed continuous haulage.

Development panels are typically driven five to nine entries wide, with pillars recovered on retreat. Among this group of mines, it is very unusual to widen the panel by driving rooms on retreat. Barrier pillars are almost always left between panels, for both ventilation and ground control. Most of the mines do take slab cuts from the barriers during retreat, but they do not completely remove the barriers.

In most cases the pillars in a row are recovered in sequence, beginning with the pillar nearest the previous panel gob. The mines that employ continuous haulage typically prefer to "close in the center," taking their last lifts from the belt entry.

By far the most popular methods of pillar recovery used today are those that require no additional roof bolting during retreat. Most plans can be classified as either "*left-right*," (also called Christmas tree mining or twinning) in which lifts are taken on both sides of the entry, or as "*outside lift*," in which cuts are taken on just one side (see Figure 3). "*Split and fender"* plans can be used when the pillars are so large that they can't be fully recovered by lifts taken from the entries. The roof in the splits must be bolted, however, which is undesirable from both the worker safety and operational standpoints.

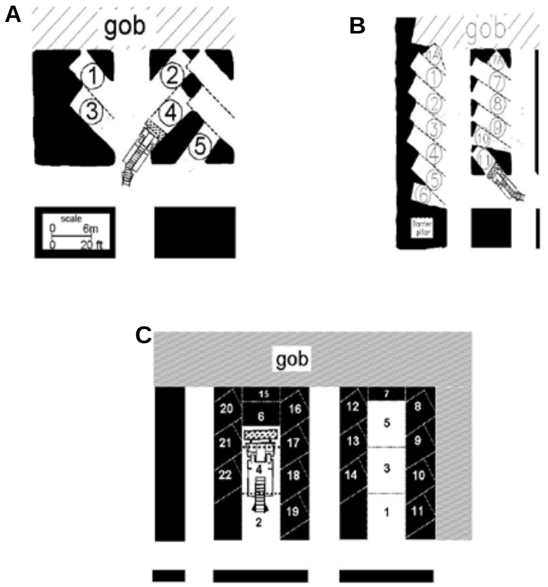

Figure 3. Methods for recovering coal pillars. A) Left-right. B) Outside lift. C) Split and fender.

A NIOSH study (Mark et al., 2003) estimated that, nationally, about 60% of retreat mining used left-right techniques, 35% used outside lifts, and only 5% some form of split and fender. Among the deep cover retreat mines, left-right plans were even more popular, used by 28 of the 30 mines. Again, the exceptions were two of the continuous haulage mines that employed outside lifts. In spite of the fact that deeper cover usually means larger pillars, none of the mines routinely employed split and fender techniques. Left-right plans were used to extract pillars as large as 75 by 75 ft (95 by 95 ft centers), even though in this configuration a 20-ft-wide fender of coal had to be left down the center of the pillar because the lifts could not reach the pillar center.

Three of the mines, all in the east, are mining two seams simultaneously. When both seams are mined on advance, the entries are 12-15 ft high. To minimize rib control issues, one of the mines extracts only the top seam and the parting on development. The floor in the entries and both seams in the pillars are then recovered during retreat. This floor mining sequence has the additional advantage that smaller pillars can be used, because of the reduced width-to-height ratios for the intact pillars outby the pillar line.

The deep cover mines have adopted many of the local stability "best practices" that NIOSH and MSHA have advocated (Mark and Zelanko, 2004). Of the 28 mines using left-right extraction sequences, only 4 extract the final pushout. At the others, an engineered stump, usually measuring 8 by 8 ft or 10 by 10 ft, is left as a roof support. Six of the mines do not even take any lifts from the crosscut. Only four of the mines rely solely on timber for standing support, and the remainder all employ MRS. All but four routinely install extra supplemental support in the intersections where retreat mining is planned. The extra support typically consists of a pattern of 4 to 6 cable bolts or resin-assisted mechanical shell bolts, 8 to 12 ft long.

PILLAR DESIGN

The MSHA report on Crandall Canyon (Gates et al., 2008) emphasized the role of the flawed pillar design in the disaster. In the report's words, the "pillar dimensions were not compatible with the deep overburden and high abutment loading that existed in the South Barrier section," and as a result the "stress level exceeded the strength of a pillar or group of pillars near the pillar line, and that local failure initiated a rapid and widespread collapse that propagated outby through the large area of similar sized pillars." The report documented how the two pillar design software packages used to develop the design, ARMPS and LaModel, were both employed improperly, resulting in the flawed design. In the wake of Crandall Canyon, MSHA published a Product Information Bulletin (MSHA, 2008a) and a Procedure Instruction Letter (MSHA, 2008b) on ARMPS to help ensure that pillars are designed properly.

ARMPS, for Analysis of Retreat Mining Pillar Stability, was originally developed by NIOSH in the mid 1990's (Mark and Chase, 1997.) ARMPS estimates the magnitude of the loads that develop during the various stages of the retreat mining process, and calculates a "stability factor" (SF) by comparing the loads to the estimated load bearing capacity of the pillars that must carry them. The power of ARMPS is not derived from the accuracy of its calculations, but rather from the large data base of case histories that it has been calibrated against. Statistical analysis has been used to propose design guidelines that do the best job of separating the "successful" case histories from those that were "unsuccessful." A case history is considered a success when an entire panel was recovered without significant ground control incident. The unsuccessful cases include:

- *Squeezes*, which are non-violent pillar failures that may take hours, days, or even weeks to develop;

- *Collapses,* which occur when large areas supported by slender pillars (w/h < 4) fail almost simultaneously, resulting in an airblast, and;
- *Bumps,* which are sudden, violent failures of one or more highly stressed pillars.

The original ARMPS data base consisted of approximately 150 case histories, representing a broad range of cover depths. Analysis indicated that when the depth of cover was less than 650 ft, a SF of about 1.5 was a reasonable starting point. However, for deep cover cases, two conclusions were drawn:

- Many panels with a SF well below 1.5 were successful, and;
- No single SF was able to separate the successful from the unsuccessful cases.

Accordingly, a follow-up study was conducted which focused on deep cover pillar recovery (Chase et al., 2002). During this study, an additional 100 case histories were collected from mines in Central Appalachia and the West where the depth of cover exceeded 750 ft. The analysis indicated that squeezes were the most likely failure mode when the depth of cover was less than 1,250 ft, but bumps predominated in the deeper cover cases. Design guidelines, including suggestions for barrier pillars to isolate active panels from nearby gobs in bump prone ground, were also proposed (Figure 4).

ARMPS SF	Weak and Intermediate Roof Strength	Strong Roof
650 ft ≤ H ≤ 1,250 ft	1.5 - [H-650] / 1000	1.4 - [H-650] / 1000
1,250 ft ≤ H ≤ 2,000 ft	0.9	0.8
Barrier Pillar SF		
H > 1,000 ft	≥ 2.0	≥ 1.5 *
		≥ 2.0 **
		* Nonbump prone ground
		** Bump prone ground

The ARMPS case history data base, showing the suggested ARMPS SF for design.

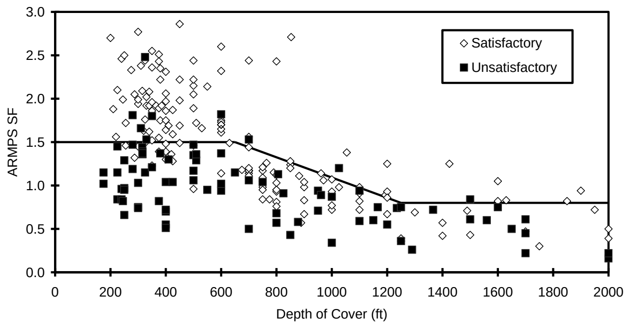

Figure 4. ARMPS deep cover design criteria (Chase et al., 2002).

The current deep cover study has added another 200 cases to the ARMPS data base. Additional cases have also been added from the Analysis of Multiple Seam Stability (AMSS) data base (Mark et al., 2007), and there are now nearly 800 cases in all. Figure 5 shows that the trends in the expanded database are very similar to those found in 2002. For example:

- Of the 518 successful cases, 298 (57%) met or exceeded the suggested design criteria, while 220 did not. For the unsuccessful cases, only 20 (17%) met the design criteria, while 100 (including all but one of the bump and massive collapse cases) did not.
- Of those 56 multi-panel retreat cases that employed barrier pillars with a BP SF>2.0, just 10% were failures. For the 72 cases where the BP SF< 2.0, 47% were failures.
- At depths greater than 1,500 ft, 16 of the 20 failures are bumps, while only 4 were squeezes. Between 1,000 and 1,500 ft the proportions are nearly reversed, with 24 squeezes and 4 bumps.

At the time of this writing, further analysis of the ARMPS case history data base is ongoing. The goal is to determine if further refinements to the ARMPS design criteria, or to ARMPS itself, could result in improved predictions of pillar design performance. Additional parameters in the data base that will be investigated include:

- Seam Hardgrove Index (HGI),
- Uniaxial compressive strength,
- Mine location (state, county),
- Coal seam,
- Roof quality (CMRR),
- Panel width, and;
- Panel width-to-depth ratio.

Preliminary analyses have indicated that narrow panels at depth may be successful with lower ARMPS SF than wider panels provided they employ adequate barrier pillars. The implication of this finding is that a narrow panel may create a "pressure arch" which transfers some of the tributary area development load, and subsequent abutment loads, from the production pillars to the barriers. Numerical modeling is also being employed to investigate this possibility. If both the analytical and empirical lines of research ultimately confirm the pressure arch approach, it may be incorporated into an adjusted ARMPS loading model.

BUMP CONTROL IN DEEP COVER RETREAT MINES

Bumps have long been among the most feared hazards in deep retreat mines. As long ago as 1935, Rice described bumps in the coal mines of Harlan County, KY and Wise County, VA. A comprehensive data base of 172 bump events compiled in 1995 indicated that more than 80% of the bumps reported by room-and-pillar mines occurred during the process of pillar or barrier pillar recovery (Iannacchione and Zelanko, 1995).

Unfortunately, despite decades of research, the sources and mechanics of bumps are imperfectly understood, and the means to predict and control them remain elusive. Coal bumps share these characteristics with both bursts in hard rock mines and natural earthquakes.

Some valuable generalizations can be made, however. First and foremost, high stress is a universal feature of bump prone conditions. Deep cover is the primary source of high stress, but stress levels can be further increased by retreat mining abutment loads or multiple seam interactions.

Most bumps are also associated with mining activity. In a highly stressed coal pillar, the greatest stress is not generally right at the edge of the pillar, but rather some distance from the rib. The situation is stable because of the confinement provided by the

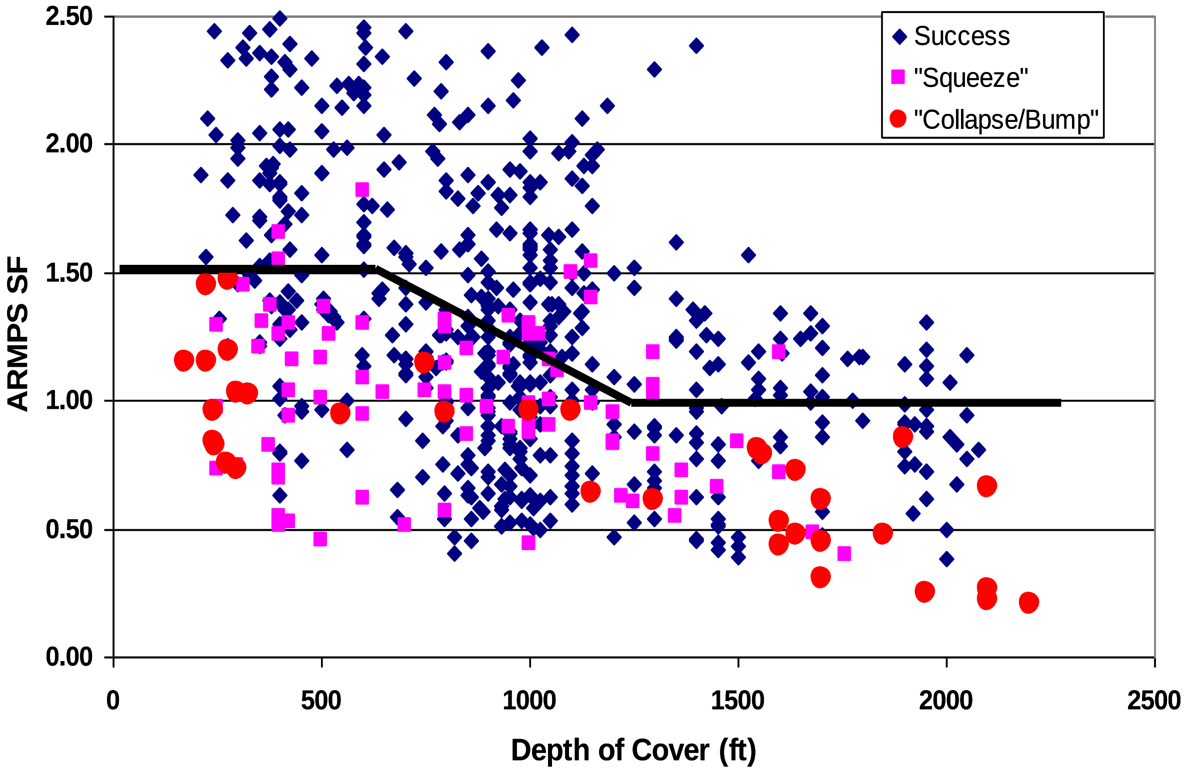

Figure 5. The 2009 ARMPS case history data base, showing the Chase et al., (2002) design criteria.

coal nearer the rib. When that coal is extracted, the confinement is removed, and the highly stressed coal can fail suddenly and violently. Pillar splitting, which removes the coal that is confining the most highly stressed pillar core, is an activity that is particularly prone to cause bumping.

Coal bumps themselves generate seismic events, though they are usually small ones. But seam level bumps can also be triggered by seismic events that originate elsewhere. Full extraction mining causes much seismicity that originates when stored energy is released by rock failure occurring up to several hundred feet above (or below) the seam. The failures include sudden roof-to-floor convergence in the worked out areas, shear slip motion on rock fractures in the overburden, or some combination of these two mechanisms (Pankow et al., 2008). Mining activity can also reactivate pre-existing faults, which in turn can result in a bump (Swanson, 2008). Only a tiny fraction of seismic events induced by mining result in coal bumps, however. For example, German seismic monitoring stations recorded 4,623 mining-induced events over one ten year period, but only 18 coal bumps occurred during that same period (Brauner, 1994). In fact, even very large events may have little impact on the mine if they occur well above the workings, such as the magnitude 4.2 event that was located approximately 500 ft above the Willow Creek mine but did not result in a coal bump at the mining horizon (Ellenberger et al., 2001). On the other hand, an event that is too small to register on a regional seismic network can result in a serious injury if a miner is in the wrong place at the wrong time.

Geologic factors also contribute to bump proneness. The presence of strong, massive sandstone near the seam has often been noted where bumps have occurred (Iannacchione and Zelanko, 1995). On the other hand, coal seam characteristics do not seem to play an important role. Iannacchione and Zelanko (1995) noted that bumps have occurred in at least 25 different US coalbeds, varying from strong, blocky seams to the very friable Pocahontas No. 3 and No. 4 seams. Laboratory studies conducted by Babcock and Bickle (1985) showed that most coals can fail violently if they are highly stressed and the confinement is suddenly reduced. Extensive German laboratory studies using large-scale specimens have also concluded that nearly all types of coal, with the exception of anthracites, can burst. In their experiments, coal seams ranging in unconfined compressive strength from 700 to 7,000 psi have all been shown to be bump prone (Brauner, 1994).

Table 2 lists the coal bump events that have occurred in US room and pillar mines from 1983-2008. Most of the events were identified by conducting a search of the narratives in the MSHA accident and injury database, using key words like “bump” and “bounce.” The narratives were carefully screened to remove all but those cases that clearly referred to a violent ejection of coal from the rib. Most of the events were relatively small, and were only reported to MSHA because they happened to result in an injury. A second group of events resulted in extensive damage to at least several pillars, and many of these have been further documented by additional sources. By far the largest of this second group was the disaster at Crandall Canyon, and the three other fatal incidents listed in Table 2 were also multi-pillar bumps.

Table 2. Bump events in U.S. room and pillar mines, 1983-2008.

Years	State	Seam	No. Events	Multi- Pillar Events	Fatalities	Injuries	Depths (ft)	Source
1996	CO	D	1	1	0	0	1,560	
2007	CO	B	1	1	0	0	1,400	Maleki (2009); Swanson (2008)
1995-2001	CO	D	9		0	4	1,550-2,200	
1990, 1996	KY	Creech	2	1	2	3	1,300	Foutch et al., (1996)
2002-2003	KY	Darby	4		0	4	1,500-1,900	Newman (2008)
1998	KY	Kellioka	1		0	0	1600	
1989	KY	Harlan	1		0	1		
1999-2002	KY	Darby	3	3	0	0	1,400	Newman (2002)
2002	KY	Harlan	1		0	0		
1995, 2007	UT	Hiawatha	5	2	9	1	1,600, 2,100	Gates et al., (2008)
1983-1991	UT	Hiawatha	11	2	0	0		
1989, 2004	UT	Centenial	2		0	2	1,100	
1986-1993	UT	Rock Canyon	7	2	0	6	1,800	Boler et al., (1995); Maleki (1995)
1987	UT	Hiawatha	3	1	0	3	1,600	
1993	WV	Beckley	2	1	0	2	1,150	
1984	WV	No. 2 Gas	2	1	1	1	800	Campoli et al., (1987)
1984	WV	Chilton	1	1	0	5	750	Campoli et al., (1987)
1983-1985	WV	Pocahontas No. 4	5	1	1	4		
2006	WV	Powellton	1	1	0	0	1,100	Gauna and Phillipson (2008)

Table 2 shows that documented bumps have occurred at just 18 room-and-pillar mines during the past quarter of a century[2]. Almost all of these mines have been located in Utah, the North Fork Valley of Colorado, or Harlan County, KY. There have also been four bumps scattered around southern WV.

The relatively small number of mines with bump experience is striking, as is the relatively small number of bumps at each of them. Even "bump-prone" mines often apparently work for years without encountering a bump. In many cases, there appears to be a tendency for bumps to cluster in distinct areas, indicating that geologic controls are important. Some mines have established "red zones" within which no pillar recovery is conducted. For example, one mine in Harlan County with a history of bumps has defined a red zone wherever the depth of cover exceeds 1,550 ft and a 5-ft-thick sandstone is located within 4.25 ft of the roofline.

It is also significant that most of the multi-pillar bumps occurred in mines that have also had small, injury bumps. It seems that small bumps may be a valuable indicator of the potential for larger bumps. Whyatt (2008) showed that in western longwall mines, an increased frequency of small bumps has often foreshadowed a larger event.

Most of the multi-pillar bumps, including all of those that resulted in fatalities, can be attributed to poor mine design or mining practices. In most instances, the barrier pillars were either too small or were being extracted on retreat. In some of these cases, the bumps were apparently triggered by pillar splitting. Therefore, it seems likely that many of the most dangerous events might be avoided through proper pillar design and the application of the "red zone" concept (Iannacchione and Tadolini, 2008).

Unfortunately, not every multi-pillar bump is so easily classified. Three of the mines listed in Table 2 have experienced bumps in areas that would not have been considered high risk. For example, the incident described by Gauna and Phillipson (2008) occurred in seam that had never had a bump, on a development section, beneath old works that had not been retreat mined. Yet this same mine has extensive bump-free experience recovering pillars under similar depths of cover beneath a variety of highly stressed upper seam remnants. The incidents described by Newman (2002) similarly occurred during development beneath first workings that would not have been considered high risk, and the incident in CO mine described by Swanson et al., (2008) and Maleki (2009) was a similar scenario. In that last instance, the heaviest damage was centered not at the development faces, but in area of steeply dipping faults more than 500 ft outby. Fortunately, none of these events resulted in injury to personnel.

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[2] The table also contains one bump that affected multiple pillars on a mains development at a Colorado longwall. It is worth noting that the MSHA data base also indicates that development sections at almost every longwall mine in Utah and the North Fork Valley of Colorado have experienced injuries caused by small bumps.

CONCLUSIONS

Pillar recovery operations at depths exceeding 1,500 ft are currently conducted in mines located in southeastern KY and western VA, together with two western mines. These operations account for about 2% of all underground hours, but only a small fraction of those hours are actually spent in deep cover retreat mining. About three times as many miners scattered across the central Appalachian coalfields are working in mines that recover pillars at depths exceeding 1,000 ft.

Deep cover pillar recovery operations have had a worse-than-average ground fall safety record over the past 15 years. Currently, however, most deep cover mines are employing best practices in their retreat mining methods, including installing extra roof support, leaving the final stump, and using MRS. Rib control remains a concern at some operations because of high stresses and tall pillars.

More than 200 new retreat mining case histories have been added to the NIOSH ARMPS data base. Preliminary analysis indicates that the current guidelines (Chase et al., 2002) are still appropriate. Ongoing analysis is investigating whether including other parameters or adjusting the loading model could result in an improved pillar design methodology.

Although documented bumps have occurred at only about 20 room-and-pillar mines during the past 20 years, they remain a significant concern. In mines that are considered bump prone, application of “red zones” and adherence to pillar design best practices should significantly reduce the risk. Large, multi-pillar events appear to present the greatest hazard. Unfortunately, several of these have occurred in recent years where the risk would have been considered relatively low. These events underscore the need for continued vigilance and research.

DISCLAIMER

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

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