Current trends in reducing ground fall accidents in US coal mines

by C. Mark, D.M. Pappas and T.M. Barczak

Abstract Ground falls (roof and rib) have historically been responsible for nearly 50% of all fatalities in bituminous underground coal mines. In recent years, the number of some annual ground fall fatalities has approached zero, indicating that significant progress has been made. On the other hand, the twin disasters at Crandall Canyon in 2007, in which nine miners perished in violent coal bumps, provided a stark reminder that complacency is premature. One important success has been a great reduction in the number of miners killed inby roof supports. Throughout the 1990s, these accounted for nearly half of all roof fall fatalities, but there have just been two inby incidents since 2005. Progress has also been made in pillar recovery, where there has been just one fatal incident since 2005. On the other hand, more than 300 miners continue to be injured each year by rock falling from between supports and 100 more are injured by rib falls. Together, these two categories also account for a large percentage of recent ground fall fatalities. Available technologies such as roof screen, rib bolting and inside control roof bolters could reduce injury and fatality rates if they were used more widely. Further advances in these areas will likely be the next big advance in ground control safety.

Introduction

On Aug. 6, 2007, a violent coal bump occurred at the Crandall Canyon Mine near Price, UT. Six miners working at the time of the incident were presumed trapped. Once again, the nation was transfixed by the drama of a mine rescue. Ten days later, hope turned to horror when three rescuers were killed in a second bump. Rescue efforts were suspended, and the original six miners were entombed in the mine.

The Crandall Canyon disaster was the greatest loss of life caused by a ground fall incident in a generation. Unfortunately, however, in other ways the Crandall Canyon miners were by no means unique. Ground falls have always been the single biggest killer of coal miners, accounting for approximately 50% of all underground fatalities in each decade of the last century. Nearly 45,000 coal miners have perished in ground falls in the U.S., mostly in small accidents claiming just one or two lives at a time.

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Recent decades have seen a substantial reduction in the number of ground fall fatalities and, in some years, the toll has been measured in the low single digits. The improvement can be attributed to three factors. The first is a reduction in the number of miners. For every miner working underground today, there were approximately 15 at the industry's peak in 1920.

The second factor is the development of new technology. For ground control, the greatest single technological innovation was roof bolting. Other advances have included canopies on mobile equipment and automated temporary roof supports (ATRS).

The third factor is change in the "safety culture," which determines the level of risk that miners take (or are exposed to) while underground. The safety culture includes both regulatory mandates and company-specific safety policies. Obviously, the safety culture has changed dramatically since the early 1900s, when, as the old saying has it, "it was cheaper to lose a man than a mule, because the company could always hire a new man, but had to buy a new mule."

A close look at the ground fall fatal incident rate during the last century underlines the importance of the safety culture.[1] Between 1900 and 1968, the incident rate was relatively constant, fluctuating between about 0.6 and 1.0 fatalities per million employee hours (Fig. 1). Over the next eight years, following the passage of the 1969 Coal Mine Health and Safety Act, the rate fell to about 0.15, an unprecedented 75% reduction. Careful analysis indicated that this reduction was not due primarily to new technology, but rather to widespread application of technolo-

[1] Note that by analyzing incident rates, the effect of the number of miners is eliminated.

gies that were already available. In particular, much of the improvement can be attributed to the requirement that essentially all roofs be supported according to a mandated roof control plan (Mark, 2002).

Overview of ground fall fatalities since 1995

In 1995, the Mine Safety and Health Administration (MSHA) started creating electronic versions of its fatality reports. These are available at www.msha.gov/fatals/fabc.htm. A total of 120 bituminous underground coal miners have been killed in ground falls during the period 1995-2009. Figure 2 shows that if Crandall Canyon is excluded, there has been a slight downward trend in the ground fall incident rate during this period. The *r*-squared for the trend is only 0.33, however, indicating that it has low statistical significance.

For this paper, each of the fatality reports was analyzed in detail. In Fig. 3, the fatalities are categorized by the type of the ground fall hazard. The remainder of this paper will be devoted to evaluating five of these categories, which together accounted for 96 fatalities, representing 80% of all the fatalities during the period:

- Fatalities occurring inby support (20%).
- Fatalities during retreat mining (21%).
- Rib falls (17%).
- Rock falls from between or around supports (12%).
- Major roof falls not associated with retreat mining (10%).

For each category, this paper will discuss trends over time in fatalities (and injuries where appropriate). The state-of-the-art in ground control safety technology for each category will also be described.

The remaining 20% of fatalities, or 24 total fatalities, involved:

- Coal bursts during retreat mining (11, discussed under "retreat mining").
- Longwall recovery (3).
- Underground construction or roof fall rehabilitation (3).
- Longwall face bursts (2).
- Red zone violations (5, discussed under "inby roof support").

Fatalities occurring inby roof support

One clear success story told by the ground fall statistics is the reduction in the number of fatalities occurring inby support. Although traveling inby for any reason has been illegal since the 1969 Act, throughout the 1970s and 1980s approximately half of all ground fall fatalities were attributed to this cause (Peters, 1992). Figure 4 shows that as late as 2002, there were still two or three fatalities occurring inby each year. Since 2002, however,

Figure 1

Historical overview of roof fall fatality rates for underground bituminous coal mines, contractors included after 1983 (BOM, MSHA 1900-2009).

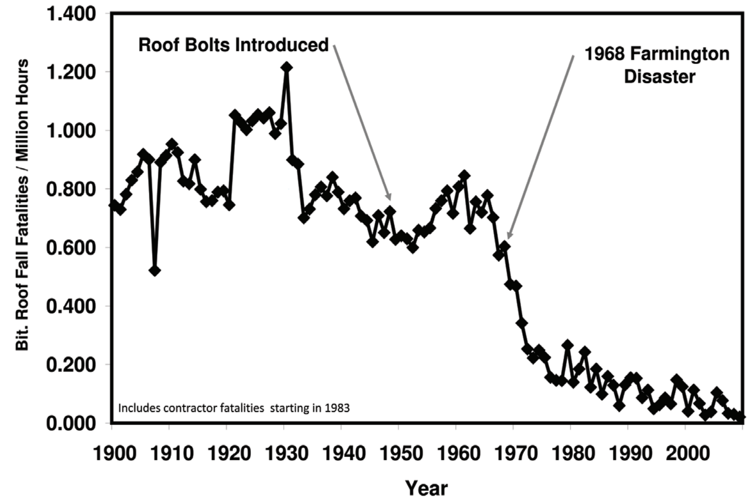


Figure 2

Recent ground fall (roof and rib) fatality rates for underground bituminous coal mines. The trendline was determined for the data set excluding the Crandall incident (MSHA, NIOSH, 1995-2009).

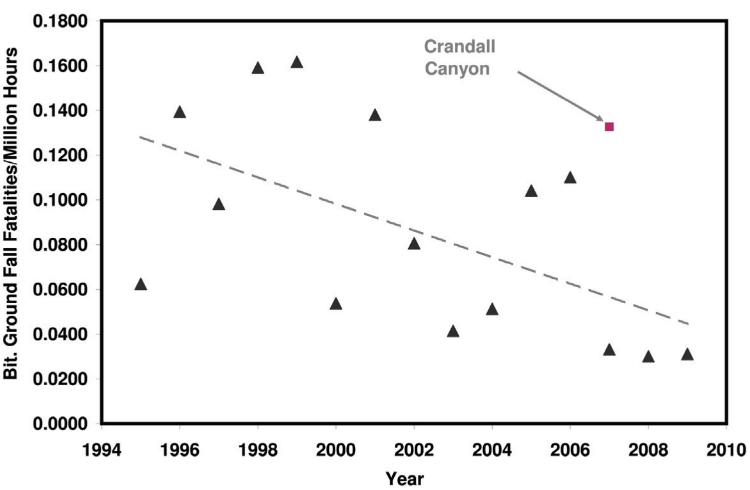


Figure 3

Classification of ground fall fatalities, proportioned for 1995-2009. Includes bituminous operators and contractors. The total number of fatalities for the period is 120 (MSHA, NIOSH, 1995-2009).

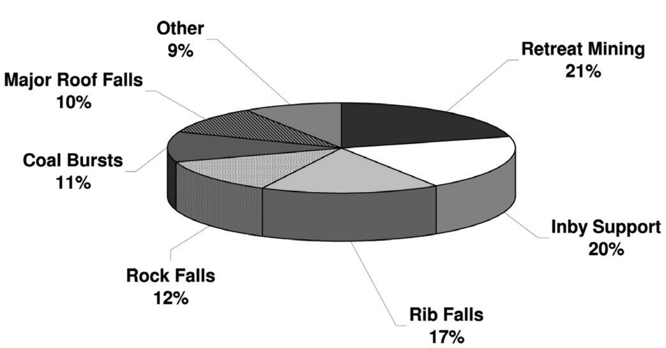


Figure 4

Number of bituminous roof fall fatalities inby roof support during entry development, including operators and contractors (NIOSH, 1995-2009).

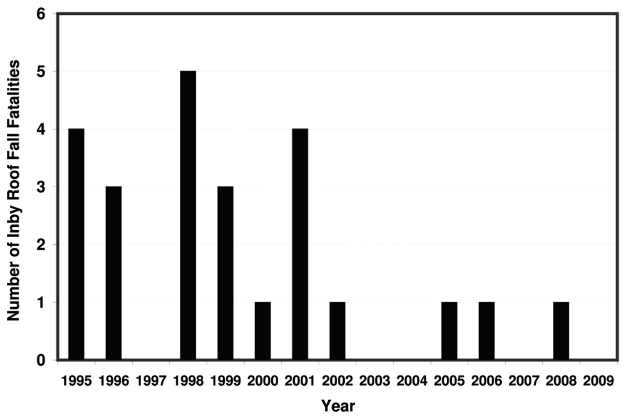
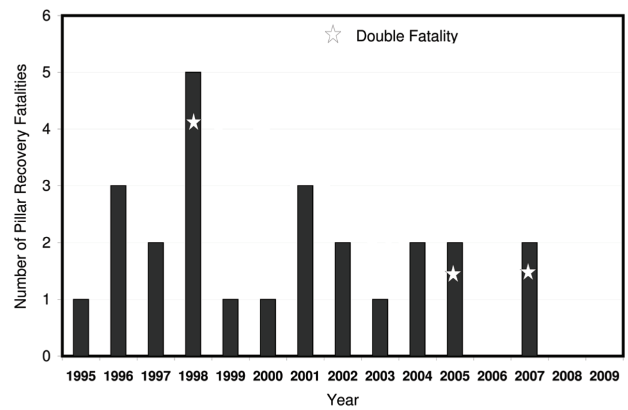


Figure 5

Number of bituminous roof fall fatalities occuring during pillar recovery operations, including operators and contractors (NIOSH, 1995-2009).



there have been just three incidents in bituminous coal mines.

The progress is associated with the industry-wide educational campaign under the slogan "Inby is Out!" Success has come none to soon, because it is essential that the new generation now entering the mining industry not pick up the bad habits of its predecessor.

Another factor contributing to the reduction in inby fatalities is the development of the concept of the "red zone."[2] In many roof control plans, miners must now stay outby the second row of bolts, particularly when making extended cuts or turning a crosscut. There have been three fatalities since 2002 (one each in 2004, 2005 and 2009) that occurred when miners were within the red zones defined for their mine.

Fatalities occurring during pillar recovery

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). However, recent statistics indicate that progress is being made. Prior to 2006, an average of two fatal incidents occurred each year during pillar recovery operations. Since then there has been just one incident, though unfortunately it resulted in a double fatality (Fig. 5).

A key cause of the change has been the widespread adoption of safer retreat mining techniques and technology. Most incidents prior to 2002 occurred during the mining of final stump, while posts were being set, or because of insufficient roof bolt support. In many of these cases, the miners were following their roof control plan, but the plan itself proved to be inadequate (Mark et al., 2003). A concerted effort by MSHA and the National Institute for Occupational Safety and Health (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). The report documented how the two pillar design software packages used to develop the design, Analysis of Retreat Mining Pillar Stability (ARMPS) and LaModel, were both employed improperly, resulting in the flawed design. In the wake of Crandall Canyon, MSHA published a *Program Information Bulletin* (MSHA, 2008a) and a *Procedure Instruction Letter* (MSHA, 2008b) on ARMPS to help ensure that pillars are designed properly.

ARMPS was developed by NIOSH in the mid 1990s (Mark and Chase, 1997.) Its main strength is that it uses a large database of actual mining case histories to suggest the proper stability factors (SF) to employ under different circumstances. The original database was later updated with several hundred retreat mining case histories from mines operating at depths in excess of 229 m (750 ft). A key finding of the deep cover research was that substantial barrier pillars were essential to maintain stability when the mining depth exceeds 198 m (650 ft) (Chase et al., 2002; Mark, 2010).

ARMPS has been used extensively to design pillars and evaluate roof control plans in the central Appalachian coalfields for nearly a decade. Since ARMPS came into widespread use, the number of pillar squeezes has been greatly reduced and massive pillar collapses have been largely eliminated (Mark et al., 2003). NIOSH has also developed the Analysis of Multiple Seam Stability (AMSS) program, which extends ARMPS to multiple seam situations (Mark et al., 2007).

Global stability is necessary, but not sufficient, 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 of the coal during pillar recovery and many fatalities occurred during the mining of the final stump. Research has now shown

[2] Note that the "red zone" concept employed in roof control plans is distinct from the "red zone" that is associated in some circles with miner positioning relative to moving equipment.

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, ensuring 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. 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 victims in pillar recovery fatalities have been MRS operators who were standing unnecessarily in unsafe locations. These incidents have underlined the third factor, effective section management.

Management begins before mining, with crew training that focuses on the roof control plan and hazard identification. A careful geologic survey of the section should be conducted before mining commences and pre-shift evaluations and test holes should be used to identify hazards as the section is retreated. Good supervision means ensuring that the plan is followed precisely every time, that miners always are stationed in safe locations and that safe operating procedures are followed for the MRS units and the other equipment on the section.

Rib falls

Falls of coal and/or rock from the sidewalls of coal mines or pillar ribs injure approximately 100 coal miners annually. As Fig. 6 indicates, the number of injuries has actually been trending upward in recent years. In addition, rib falls have killed 23 mineworkers since 1994, including three more rib fall fatalities during the first seven months of 2010.

Increased risk of rib falls is associated with thicker coal seams and higher stress levels. Analysis of the 23 fatal incidents reveals that all but three occurred at depths exceeding 183 m (600 ft) and the mining height was at least 2 m (7 ft) in every case. On the other hand, more than half of the rib fall injuries that occurred in the 2005-2007 period were in mines where the reported seam height is less than 2 m (7 ft).

Technology is available to prevent rib fall injuries. Rib bolting can be highly effective and it is routinely employed by many U.S. coal mines, particularly in the West, where thicker seams are prevalent. A recent Australian research project concluded that under more difficult conditions, the rib support system "should incorporate mesh that is firmly secured to the ribline with steel bolts and plates" (Colwell and Mark, 2005). It is significant that apparently only two of the 23 U.S. fatality sites were even rib bolted.

About a quarter of the rib fall fatalities were suffered by roof bolter operators. In every case, the machine involved was an "outside control" roof bolter, where the operator works between the coal rib and the machine. A much safer alternative is the "inside control" (or "walk through") roof bolter that removes the operator from direct contact with the rib. Such machines are available for mining heights as low as 127 cm (50 in.).

Figure 6

Number of bituminous rib fall operator injuries, excluding bursts (MSHA, NIOSH, 1995-2009).

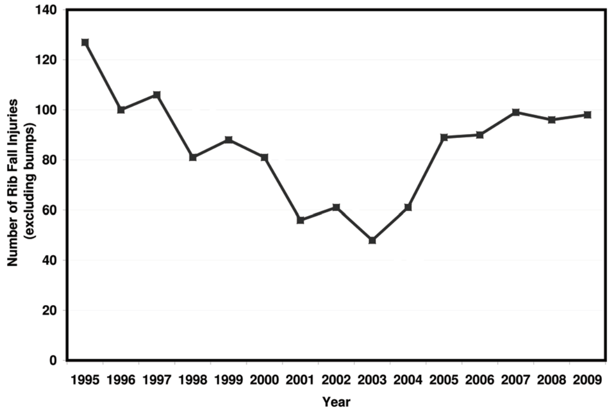
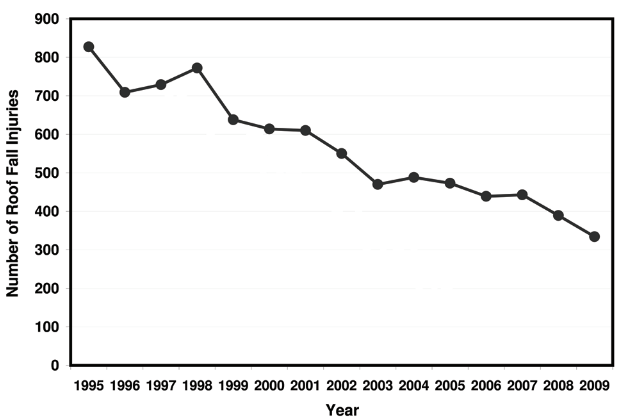


Figure 7

Number of bituminous roof fall operator injuries, including machinery-related roof falls (MSHA, 1995-2009).



Rock falls from between or around supports

Since the 1969 act, any roof that coal miners work under is required to be supported. Yet, as Fig. 7 shows, more than 300 coal miners are injured each year by rock falls while they are beneath supported roof. Another 15 miners were killed by these rock falls during the first decade of the 21st century.

The problem is that roof supports, like bolts or ATRS, are designed primarily to prevent large rock falls and major roof collapses. They do not protect miners from smaller pieces of rock that fall from between or around the supports. Figure 8 shows the size of a rock that fell between roof bolts and killed one miner in 2008.

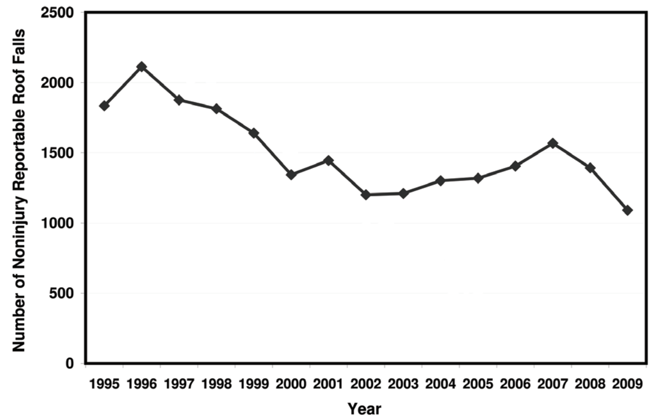
Technology is available to prevent the majority of these injuries and fatalities. Surface controls like straps, headers and large roof bolt plates can help, but by far the most effective prevention technique is roof screen. Screen works

Figure 8

Photograph of rock that fell from between roof bolts and fatally injured a mineworker (MSHA, 2008).

Figure 9

Number of bituminous noninjury roof falls reported to MSHA (MSHA, 1995-2009).



best because it can cover almost the entire roof (Robertson et al., 2003). Screen also offers a first line of defense for roof bolter operators by confining or deflecting small rocks that can come loose during drilling or bolt installation. Numerous studies have now shown that mines that use screen routinely have much lower rates of "struck by" rock fall injuries (Molinda and Klemetti, 2008).

Unfortunately, many mines do not use roof screen because they think installing it would be awkward, time consuming and expensive. However, studies reported by NIOSH have shown that simple machine modifications, well-planned supply methods and best-practice installation techniques can minimize the effects of roof screen installation on a mine's overall mining cycle (Compton et al., 2008). Moreover, at many mines, the savings in workers compensation costs alone could cover much of the cost of roof screen (Moore et al., 2010).

Roof bolter machine manufacturers also offer a number of products that can directly reduce the risk of rock fall injuries. Inside control machines greatly facilitate screen handling and installation, particularly when equipped with semi-automated material handling systems (Robertson and Mark, 2004). Before purchasing a new roof bolting machine, or introducing an old machine into a different mine, mine operators should carefully evaluate all the potential ground fall hazards and ensure that the equipment will address them.

Existing roof bolters can also be retrofitted with "flipper pads" and other safety devices that provide extra protection from rocks falling during roof bolting operations. In 2008, a 25-year-old roof bolting machine operator was killed in Indiana when a piece of rock fell from beyond permanent support and cantilevered outby, pinning him against the foot cylinder of the pressurized ATRS (MSHA, 2008c).

Massive roof falls

Massive roof falls are those that extend higher into the roof than the anchorage horizon of the roof bolts. Such roof falls must be reported to MSHA if they occur in actively traveled parts of the mine, even if they do not result in an injury. More than 1,000 reportable noninjury roof falls occur each year (Fig. 9). These roof falls can threaten miners, damage equipment, disrupt ventilation and block critical emergency escape routes. Roof collapses also helped trigger the 2001 mine disaster in Alabama, which took 13 lives (McKinney et al., 2004).

Massive roof falls usually provide enough warning that miners are seldom caught beneath them. However, since 2004, eight coal miners have been killed by roof falls that extended above the bolts. In early 2010, two miners were killed when 23 m (75 ft) of roof collapsed on them while they were operating a continuous miner (MSHA, 2010). In another incident, three miners were traveling into the mine on a mantrip, when they realized the intersection they were passing through was about to collapse. While two miners barely escaped, the third, a 26-year-old mechanic, was buried under 1.8 m (6 ft) of rock (MSHA, 2006).

Every massive roof fall represents a failure of the installed roof support system at that location. Wide mining spans can also increase roof fall rates (Mark and Barczak, 2000). This is why more than two-thirds of all roof falls take place in intersections, even though intersections constitute much less than one-third of all drivage underground. Focusing additional support on intersections can be an effective control strategy. The extra support can consist of longer, stronger primary bolts or supplemental supports, such as cable bolts.

After studying roof falls at 40 coal mines, NIOSH developed the Analysis of Roof Bolt Systems (ARBS) software package to help mine planners select the most appropriate roof bolt system for their conditions (Mark et al., 2001). Unfortunately, even with tools like ARBS, roof support design is still more of an art than a science. However, if a mine is regularly experiencing roof falls, increased levels of support are clearly warranted.

Conclusions

Ground falls continue to be a major hazard in underground coal mining. The mining community can be proud of the progress that has been made in reducing fatalities occurring inby support and during pillar recovery. Unfortunately, the trends in other accident categories are not so encouraging. Hundreds of injuries and several fatalities occur each year as a result of rock falling from between supports, rib falls and major roof collapses.

Most ground fall incidents could be prevented by available technologies, such as roof screen or rib support. Today, the most conscientious mining companies are taking steps to change their safety culture, by systematically implementing ground fall prevention technologies and lowering the risk that their miners face. It is to be hoped that the rest of the industry will soon follow.

Disclosure

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 any agency determination or policy.

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