BEST PRACTICES TO MITIGATE INJURIES AND FATALITIES FROM ROCK FALLS

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INTRODUCTION

Falls of ground continue to be one of the most serious causes of injury to U.S. miners. Of the 256 fatal injuries that occurred in mining between 1996 and 1998, 52 (20%) were caused by falls of ground (Table I). Falls of ground affect some sectors of the mining industry more severely than others. For instance, nearly 40% of the 98 coal mine fatalities between 1996 and 1998 were caused by falls of ground. Underground miners are at much greater risk than surface miners. Nearly half (45 out of 101) of underground mine fatalities were attributed to roof, rib and face falls, while less than 5% of the 155 surface fatalities were caused by falls of highwalls or slopes.

Sources of Data

All of the injury data examined in this study were derived from MSHA's Fatal Investigation Reports (www.msha.gov)and the MSHA accident database. Because falls of ground often result in serious injury, MSHA Fatal Alert Bulletins and Fatal Investigation Reports provide a useful snapshot of ground control issues in the mining industry. MSHA requires that mines file a report on every reportable accident that occurs, containing information on the accident's location, severity, classification, activity, and nature of injury, etc. A short narrative is generally included as well. Accident reports can be searched by many of the above fields.

From 1996 to 1998, miners suffered a total of 55,096 injuries, which ranged in severity from death (degree 1) to injuries with no days away from work nor restricted duty (degree 6). Six percent of the total injuries were from falls of ground, including machine accidents where caving rock was coded as the source. As the data in Table II indicate, 98% of all non-fatal fall of ground injuries occurred in underground mines, with underground coal mines accounting for 83% of the total.

Table II also shows the distribution non-fatal fall of ground injuries by severity and commodity. The injuries are classified into Lost Time Injuries that resulted in permanent disability (degree 2) or days off work (degrees 3-4), and Injuries Without Lost Time that resulted in no more than restricted duty (degree 5-6). Overall, groundfall injuries appear to be more serious than other types of mining injuries. 65% of all ground fall injuries resulted in lost time compared to 54% of all types of mining injuries.

Table I - Fatalities from 1996 to 1998 by commodity for both falls of ground and other mining classifications

	1996		1997		1998		Total	
	Under-ground	Surface & Prep. Plants	Under-ground	Surface & Prep. Plants	Under-ground	Surface & Prep. Plants	Under-ground	Surface & Prep. Plant
Coal falls of ground	13	1	9	0	14	1	36	2
Coal total	33	6	22	8	22	7	77	21
Metal falls of ground	1	0	2	1	3	0	6	8
Metal total	5	3	7	5	5	5	17	13
Nonmetal falls of ground	0	0	0	0	0	0	0	0
Nonmetal total	0	1	1	2	2	4	3	7
Stone falls of ground	2	2	1	1	0	1	3	4
Stone total	2	25	2	26	0	23	4	74
Sand/Gravel falls of ground	0	0	0	0	0	0	0	0
Sand/Gravel total	0	11	0	17	0	12	0	40
Total falls of ground	16	3	12	2	17	2	45	7
Total Mining	40	46	32	58	29	51	101	155

Legal Framework

Laws governing mining in the U.S. are listed in the Code of Federal Regulations under Title 30 - Mineral Resources.

Underground coal mining roof control is covered in 18 subsections within Part 75. While each of these sections outlines an important step in controlling falls of ground, some sections are cited more frequently in Fatal Investigation Reports. Between 1996 and 1998, a total of 30 citations were given to mines following fatal accidents, citing 6 of the 18 sections (Table III). The most frequently cited subsection was 75.202 - Protection from falls of roof, face, and rib. Section 75.202 requires that ground support must protect persons from hazards related to falls of the roof, face or ribs and coal or rock bursts in areas where they work or travel. It also states that no person may work or travel under unsupported roof unless in accordance with special procedures. Another common citation listed was violation of the Roof Control Plan. The language also states that additional measures shall be taken to protect persons if unusual hazards are encountered.

Underground metal/nonmetal mining roof control is covered in 9 subsections within Part 57. Between 1996 and 1998, the most frequently cited subsection following fatalities was 57.3200, which requires that hazardous ground conditions be taken down or supported before other work or travel is permitted (Table IV). The law also requires that the affected area be posted with a warning against entry and, when left unattended, that a barrier be installed to impede unauthorized entry. Many of the Fatal Investigation Reports reveal that geologic structures contributed to the conditions referred to in subsection language. In four of the reports, inadequate examination of ground conditions was cited.

Table II- Non-fatal fall of ground injuries from 1996 to 1998.

Severity	Commodity	Under-ground	All other	Total
Lost time injuries (Degree 2 to 4)	Coal	1807	23	1830
	Metal	140	5	145
	Nonmetal	15	0	15
	Stone	14	9	23
	Subtotal	1976	37	2013
Injuries without lost time (Degree 5 and 6)	Coal	777	9	786
	Metal	269	3	272
	Nonmetal	23	1	24
	Stone	16	7	23
	Subtotal	1085	20	1105
All non-fatal injuries	Coal	2584	32	2616
	Metal	409	8	417
	Nonmetal	38	1	39
	Stone	30	16	46
	Total	3061	57	3118

Surface mining ground control is covered in nine subsections within Part 56 for metal/ nonmetal mines and 15 subsections with Part 77 for coal mines. Several violations cited subsection 56.3200, which requires hazardous ground conditions to be taken down or supported before work or travel is permitted. The directive states that until corrective work is completed, the area shall be posted with a warning against entry and, when left unattended, a barrier shall be installed to impede unauthorized entry.

GROUNDFALL HAZARDS AND BEST PRACTICES TO CONTROL THEM

The 51 Fatal Investigation Reports from 1996 to 1998 provide a window on the most significant groundfall hazards facing today's miners. Some of these hazards, such as geologic features, affect all miners to one degree or another. Others are specific to the commodity or mining method.

Geologic Discontinuities

Mines are unique structures because they are not constructed of man-made materials, such as steel or concrete, but are rather built of rock, just as nature made them. Thus, integrity of a mine structure is greatly affected by the natural weaknesses or discontinuities that disrupt the continuity of the roof and rib. Geologic discontinuities can originate while the material is being deposited by sedimentary or intrusive processes, or later when it is being subjected to tectonic forces. Depositional discontinuities include slips, clastic dikes, fossil remains, bedding planes, and transition zones. Structural discontinuities include faults, joints, and igneous dikes.

Table III - Violations of Part 75 from fall of ground Fatal Investigation Reports, 1996-1998.

Subsection Violated	Title	Number
75.202	Protection from falls of roof, face, and ribs	18
75.203	Mining method	1
75.204	Roof bolting	0
75.205	Installation of roof support using mining machine with integral bolter	0
75.206	Conventional roof support	0
75.207	Pillar recovery	0
75.208	Warning devices	0
75.209	Automated temporary roof support systems	1
75.210	Manual installation of temporary support	0
75.211	Roof testing and scaling	0
75.212	Rehabilitation of areas with unsupported roof	1
75.213	Roof support removal	3
75.214	Supplemental support materials, equipment, and tools	0
75.215	Longwall mining systems	0
75.220	Roof control plan	6
75.221	Roof control plan information	0
75.222	Roof control plan--approval criteria	0
75.223	Evaluation and revision of roof control plan	0

Table IV - Violations to Part 57 from fall of ground Fatal Investigation Reports, 1996-1998.		
Subsection Violated	Title	Number
57.3200	Correction of hazardous conditions	6
57.3201	Location for performing scaling	1
57.3202	Scaling tools	1
57.3203	Rock fixtures	0
57.3360	Ground support use	0
57.3400	Secondary breakage	0
57.3401	Examination of ground conditions	4
57.3460	Maintenance between machinery or equipment and ribs	0
57.3461	Rock bursts	0

Discontinuities occur in many shapes and sizes and are generally difficult to recognize in advance of mining. They often contribute to fatal accidents, frequently in combination with other factors. Miners, and particularly roof bolt operators and face drillers, need to be trained to recognize geologic discontinuities as soon as they are exposed by mining. They must also be aware of the proper support techniques and have the necessary support materials available.

Underground Coal Mine Hazards

Between 1996 and 1998, 36 underground coal miners were killed in 33 separate incidents. Table V lists the hazards that contributed to these incidents and their frequency. In some cases, more than one hazard was involved. For example, 13 fatalities occurred during pillar extraction, with 3 of the accidents resulting from premature intersection collapses.

Unsupported roof. Roof bolts and the Automated Temporary Roof Support (ATRS) are the first lines of defense against roof falls in underground coal mines. When miners go under unsupported roof, they are completely unprotected. Between 1996 and 1998, approximately 25% of coal mine roof and rib fatalities occurred when miners were beyond roof supports. While there are no grounds for complacency, the recent record does represent an improvement from a decade ago, when nearly 50% of ground fall fatalities occurred beneath unsupported roof (Peters, 1992). The improvement was achieved through new equipment, enforcement and a persistent educational campaign.

During the early 1990's, the U.S. Bureau of Mines conducted an extensive series of interviews with miners to determine why they might go out under unsupported roof (Peters, 1992). The most common response was that they had unintentionally walked out beyond the supports. The most effective countermeasure, then, is to ensure that all areas of unsupported roof are clearly posted with highly visible warning devices. Training is also essential. Mallett et al. (1992) argue that verbal admonitions and threats of discipline are less effective than training that graphically imparts the severe consequences of roof falls.

Finally, the prevalence of dangerous behavior depends greatly on the miner's perception of the company's policy concerning going under unsupported roof, on how that policy is enforced, and on the attitude and behavior of his supervisor and coworkers. The best prevention programs involve high-level managers who directly communicate their commitment to the goal of keeping people away from unsupported roof.

Table V - Factors in underground coal mine fall of ground fatalities.

Factor	1996	1997	1998	Total
Pillar extraction	4	4	5	13
Inby roof support	4	0	5	9
Intersections	1	3	2	6
Geology	1	4	1	6
Rib	2	3	0	5
Construction	1	0	3	4
Skin Control	1	0	2	3
Longwall face	1	1	0	2

Roof bolter safety. Roof bolt operators are on the front line in the fight against ground falls. They are continually exposed to roof and rib hazards, and historically they have experienced more groundfall-related injuries than any other occupation in mining. While large roof and rib falls have been responsible for several fatalities, most injuries are caused by relatively small pieces of rock.

The roof bolt machine, with its ATRS and canopy, is the critical piece of safety equipment. It should always be in proper operating condition before use. The proper bolting sequence, as defined in the Roof Control Plan, must always be followed. Several fatalities have resulted when operators of single-boom machines installed bolts out of sequence and placed themselves under unsupported roof.

Rehabilitation of roof falls and construction of overcasts and boom holes present special hazards. In many such areas the roof is unusually high, and often the ATRS cannot effectively contact it. If the ATRS cannot be set against the top, it is necessary to set jacks for temporary support or use a manufacturer's approved ATRS extension. Two roof bolt operators have been killed in recent years while bolting high top during mine construction activities.

Roof bolt operators are also responsible for protecting the entire crew with high-quality bolt installations. Poorly installed roof bolts can be worse than none at all, because they provide a false sense of security. Manufacturers' recommendations regarding resin spin and hold times must always be followed. Holes must be drilled to the proper length (not more than one-inch deeper than the bolt's length). The torque on tensioned roof bolts must be checked as required by CFR 75.204(f).

Skin failures of roof and rib. Skin failures are those that do not involve failure of the roof support elements, but result from rock spalling from between roof bolts, around ATRS systems, or from ribs. They are of particular concern because they cause injuries and fatalities to workers who should have been protected by supports. In 1997, 98% of the 810 roof and rib injuries suffered by mine workers were attributed to skin failures (Bauer et al., 1999).

Roof skin failures almost always involve pieces of rock that are less than 0.6 m (2 ft) thick. About 40% of the 669 roof skin injuries in 1997 involved roof bolt operators, and occurred beneath the ATRS. The other roof skin injuries occurred beneath permanent support and involved workers in a wide variety of activities. Common roof skin control techniques include oversized plates, header boards, wood planks, steel straps, meshing, and (in rare instances) spray coatings (sealants).

Between 1996 and 1998, rib failures resulted in 6 fatalities in underground coal mines. Only one of these fatal injuries was to a face worker, the other five were all mechanics and electricians performing their duties well outby the face. Nearly 80% of the 128 rib injuries that occurred in 1997 took place beneath permanently supported roof. Non-fatal rib injuries resulted in an average of 43 lost workdays each, versus 25 days for the average roof skin injury.

The seam height is the single greatest factor contributing to rib failures. The seam height was greater than 2.5 m (8 ft) in all six of the fatalities, and was greater than 3 m (10 ft) in three of them. The incidence of rib injuries increases dramatically once the seam height reaches 2.2 m (7 ft). Interestingly, mines with the very thickest seams see lower rib injury rates, probably because most of them routinely use rib support. No rib support was used in any of the six fatal accidents, however. Rib failure is often associated with rock partings and/or discontinuities within the pillar, or with overhanging brows created by roof drawrock. The most effective rib supports employ full planks or mesh held in place by roof bolts.

Pillar recovery. Pillar recovery has always been an integral part of U.S. underground coal mining. It can be a less capital-intensive, more flexible alternative to longwall mining for small, irregular reserves. A recent study estimated that pillar recovery accounts for about 10% of the coal mined underground (Mark et al., 1997).

The process of pillar recovery removes the main support for the overburden and allows the ground to cave. As a result, the pillar line is an extremely dynamic and highly stressed environment. Safety depends on controlling the caving through proper extraction sequencing and roof support. Historically, retreat mining has accounted for a disproportionate number of roof fall fatalities, including 13 between 1996 and 1998. Three of the accidents during this period resulted in double fatalities.

Traditional roof control plans require that numerous timber posts be set during each stage of pillar recovery. Recently, Mobile Roof Supports (MRS) have become available that replace many of the timbers (Figure 1). MRS resemble longwall shields mounted on bulldozer tracks. They can have many safety advantages over timbers. In particular, they are more effective as roof supports, they do not require workers to approach the mined-out gob area to set them, and they reduce the potential for materials handling injuries (Chase et al., 1997).

Following the Roof Control Plan is absolutely critical to safe pillar recovery operations. Fatality investigations have frequently found that lifts were too wide, too deep, or out of sequence. The Plan may also specify the minimum dimensions of the remnant coal left in place called *stumps* and *fenders*. However, the Roof Control Plan is a minimum plan, and additional supports should be used at any indication of bad roof.

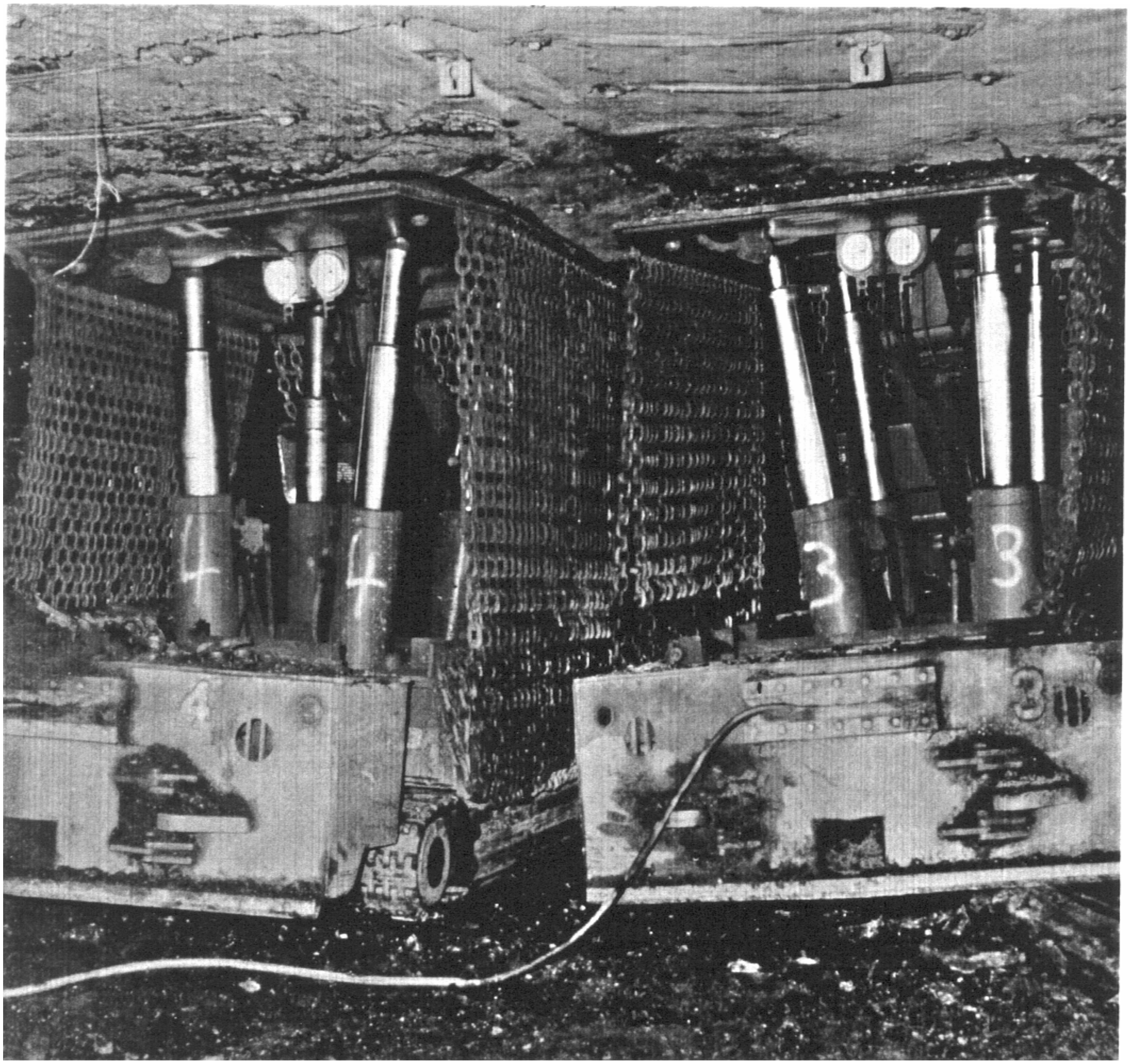

Figure 1. - Mobile Roof Supports (MRS)for retreat mining

The recovery of the final stump, or pushout, is the most hazardous aspect of pillar recovery operations. During the past 20 years, nearly half of all fatalities during retreat mining have occurred while the pushout was being mined. The pushout should never be mined if conditions do not look safe or if adverse conditions arise during mining. All unnecessary personnel should remain outby the intersection at all times during pillar recovery, but especially while the pushout is being mined.

Extended cuts and remote control mining. Extended (deep) cut mining is where the continuous mining machine advances the face more than 6 m (20 ft) beyond the last row of permanent supports. The development of remote-control for continuous miners (Figure 2), spray fan systems, and flooded-bed scrubbers has provided the technology to enable deep cuts. By 1997, about 75% of all underground labor hours were worked at mines with extended cut permits. However, extended cuts raise a number of ventilation, ground control, and human factors issues. Between 1988 and 1995, extended cuts may have been a factor in 26% of all roof fall fatalities in underground coal mines (Bauer et al., 1997).

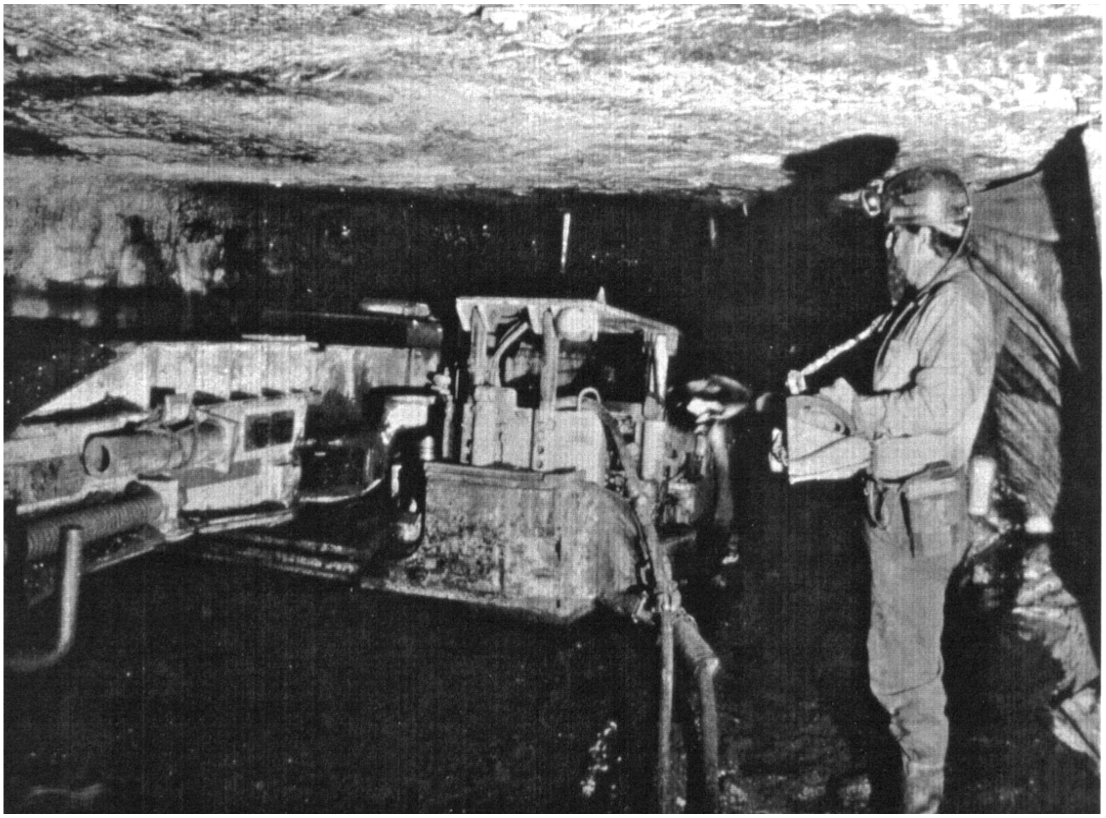

Figure 2. - Miner operating a continuous mining machine by remote control

In practice, many mines with permits only take extended cuts when conditions allow for them. Where the roof is competent, extended cuts are routine. At the other extreme, when the roof is poor, miners may not even be able to complete a 6 m (20-ft) cut before the roof collapses. A premature roof collapse can trap the continuous miner or endanger the crew, or it can create uneven and hazardous conditions for the roof bolters. Where premature collapses are likely, additional roof supports (extra bolts, planks, mesh or straps) should be used within the last two rows of supports to prevent the fall from overriding these supports.

Remote control mining allows the operator to stay further back from the unsupported roof, but it also removes him from the protection provided by the canopy. The freedom of movement, combined with a lack of visibility, can tempt the operator to stray into dangerous locations. Several fatalities have occurred during the mining of the first cut in a 90 degree crosscut to operators who had gone inby permanent supports (Figure 3). In response, some companies have limited the length of the initial cuts in a crosscut to 20 ft, and others have angled the crosscuts to provide better visibility.

Hazards in Underground Metal and Nonmetal Mines

Between 1996 and 1998, nine fatal fall of ground injuries from eight different accidents occurred in underground metal and nonmetal mines (Table VI). Two major contributing factors were the failure to conduct proper roof and rib examinations and problems with removing loose rock. Overall, metal and nonmetal underground mines have lower ground fall injury rates than coal mines.

Large openings. Many metal/nonmetal mines have large openings, especially nonmetal stone and salt mines and metal mines with stopes Large mine openings have roof or back greater than 5 m (16 ft) high, with spans greater than 10 m (30 ft) wide.

When the back is high, a miner's ability to observe the ground conditions is greatly reduced. Additionally, many metal/nonmetal mines use roof bolts on an infrequent basis. Ventilation of large openings is sometimes poorly controlled, promoting dramatic fluctuations in humidity, and sometimes fog. High humidity can cause even strong rocks to split and crack, creating hazards for miners. Because of these factors and others, mines with large openings rely on mining both a stable roof beam and a stable roof line to reduce ground control hazards (Iannacchione et. al, 1998(a)).

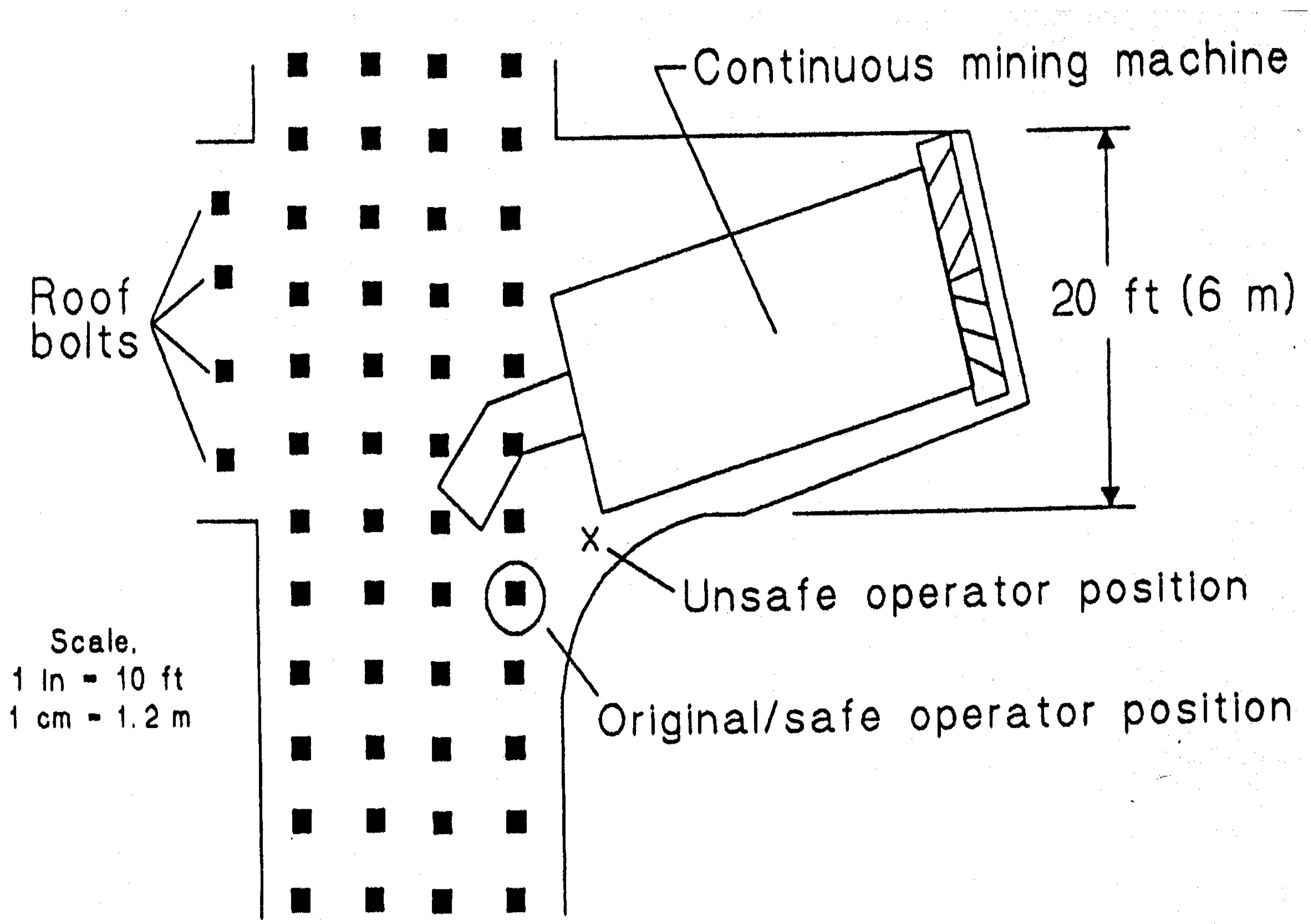

Figure 3. - Unsafe location for a continuous mining machine operator while mining a crosscut

A stable roof beam is generally massive, strong, thick, and persistent. Natural laminations, bedding planes, or interfaces between rock layers often provide the best roof lines (Figure 4). If a natural smooth roof plane does not exist, special blasting procedures like pre-splitting or smooth blasting can be used to produce an artificial smooth roof plane. Conversely, poor blasting practices often have a negative influence on roof and rib stability. Overbreak can damage the roof and rib rock, while bootlegs (poor rock breakage at the end of a blasthole due to inadequate explosive burn) can leave broken rock along uneven rib and face surfaces.

Figure 4. - Smooth roof line produced by a persistent bedding plane lamination within the roof rock beam

Table 6 - Factors associated with the 9 metal/nonmetal underground fatalities, 1996-1998.						
Date	Commodity	Factor	State	Type of fall	Job	Mining height, m
11/4/98	Metal	inadequate examination/failure to remove loose ground	CO	Rib	Driller	3
3/4/98	Metal	failure to remove loose ground	AZ	Roof	Installing support	NA
1/19/98	Metal	failure to support or remove loose ground	MO	Roof	Surveying	4.9
4/1/97	Stone	inadequate examination/geology	TN	Rib	Driller	7.6
2/5/97	Metal	unsafe location	NV	Roof	Scaling	2.4
2/3/97	Metal	large span/geology	TN	Roof	Driller	5.5
7/24/97	Metal	unsafe practice/loose ground	NV	Rib	Driller	12.2
5/10/96 (double fatal)	Stone	failure to support loose ground	MO	Roof	Blasters	7.6

Scaling. Scaling is necessary to remove loose rock from the sidewalls (rib) and hanging walls (roof) of mine openings. It is particularly important when the rock and ore are removed by blasting, as in most underground metal and nonmetal mines.

Scaling may be conducted either with a hand-held pry bar or with mechanical equipment. Mechanical scalers usually remove the greatest portion of the loose rock, using an assortment of prying, or hammering scraping attachments. Hand scaling is often conducted by a worker mounted in a lift basket in high openings.

A study of accidents in underground stone mines between 1985 and 1994 found that nearly one-third of the ground control injuries involved scaling (Grau and Prosser, 1997). More than 90% of these involved hand scaling. Mechanical scaling generally affords greater protection, because the miner is positioned in a protective cab at a greater distance from the loose rock. The data from this study also showed that the extremities and limbs were the body parts most often injured during scaling. Arm and leg padding, such as worn by athletes, may be one way to cushion the blow from falling rock and may also lessen the severity of an accident.

Global Safety Strategies

Best practices, as discussed in the previous section, generally address ground control safety in the immediate vicinity of the miner. Creating a stable mine environment begins much earlier, however, during the process of mine design. Ground monitoring can also be central to the creation of a ground control safety culture at a mine.

Safe Mine Design: Mine design includes pillar sizing, layout of drifts and entries, dimensions of openings, and artificial support. Mine planners seek optimum designs that balance the competing goals of ground control, ventilation, equipment size, production requirements, and costs. In recent years, a number of design aids have been made available to assist with the ground control aspects of design.

The role of pillars is to support the great weight of the overburden above the mine. No man-made supports (except filled stopes in metal mines) have anything near the tremendous load-carrying capability of mine pillars. Longwall panel extraction, pillar recovery, and multiple seam operations can all increase pillar loads, and benching can reduce pillar strength.

Mining layout can often be used to minimize the effects of geologic hazards. Traditionally, features such as joints, cleats, and faults have been considered in design. More recently, horizontal stress has become an important concern. Global plate tectonics are the primary source of horizontal stress in mines, and measurements have shown that horizontal stresses are often three times as great as vertical overburden stresses. Horizontal stresses have caused roof potting, cutter roof, and roof falls in coal and limestone mines (Mark and Mucho, 1994; Iannacchione, 1998b). Their destructive effects can be reduced by orienting the mine so that most of the drivage parallels the direction of the maximum horizontal stress.

The maximum stable size of mine openings depends greatly on the geology. The back in some stone and salt mines is so competent that it can routinely maintain spans of 15 m (45 ft), while 5 m (15 ft) spans may be unstable in the weak, fractured ground found in some coal and hard rock mines.

U.S. mines use more than 100 million roof bolts every year. Only mines with exceptionally competent country rock can do without pattern roof bolting, and even they require some spot bolting. A wide variety of rock bolts are available, but matching the proper bolt type and pattern with the ground conditions remains as much an art as a science (Mark, 2000).

Controlling Catastrophic Failures in Underground Mines: Catastrophic failures that create hazards for miners in coal, metal, and nonmetal underground mines include coal mine bumps, hard rock bursts, large collapses, and outbursts. Hazards to miners range from injuries associated with flying rocks to complete burial in ejected rock. Pressure waves from large collapses can throw miners into natural and manmade structures. When large quantities of gas are instantaneously released, gas ignition or asphyxiation can occur.

Coal mine bumps have presented serious mining problems since the early 1900's. In 1996, 3 miners were killed in two different bump events. Two Kentucky miners were fatally injured when six pillars suddenly failed violently during pillar recovery operations. The second event claimed the life of a Utah miner when coal along a longwall face violently ejected into the shields. Both of these events occurred in characteristic settings for coal bumps, with elevated overburden, proximity to a gob area, and a strong hanging roof.

Hard rock bursts have been occurring in deep metal mines for as long as records have been kept (White et al., 1995). Federal regulations have been developed mainly in the form of administrative controls (subsection 57.3461). When a rock burst causes miners to withdraw, impairs ventilation or impedes passage, MSHA must be notified. A rock burst control plan should then be developed and implemented. This plan is required to reduce the occurrence of rock bursts through monitoring and minimizing exposure. Monitoring can range from simple deformation measurements to mine-wide microseismic monitoring systems. Minimizing exposure can range from administrative controls to the use of remote controlled equipment.

A *pillar collapse* is a sudden, violent event that can pose a serious hazard in a room and pillar mine. A collapse occurs when one pillar in a mining layout fails, transferring its load to neighboring pillars, causing them to fail, and so on in a domino fashion. A pillar collapse can induce a devastating airblast which can disrupt the ventilation system and send flying debris that can injure or kill miners. In recent years, at least 13 coal mines and 6 metal/non-metal mines in the U.S. have experienced pillar collapses. Fortunately, only one fatality has resulted, following a collapse of hundreds of pillars at a Wyoming trona mine (Zipf and Mark, 1997).

Outbursts of gas and rock have occurred mainly in evaporite and to a lesser degree coal mines. With the occurrence of the multiple fatal explosion at the Belle Isle Salt Mine in 1981, domal salt mines in Louisiana and Texas were recognized as potential locations for large outbursts. Modifications to mining regulations were made in 1984 creating special levels of gassy metal/nonmetal mines (Subcategory II-A and II-B, 57.22003). Each advance in the gassy level requires additional operational safeguards. Outbursts in Canadian bedded salt and New Mexico potash mines have periodically created serious safety hazards.

Roof Monitoring. Roof falls seldom occur entirely without warning. Often, however, miners are not aware of the warning signals until it is too late. Most underground mines use observational techniques, primarily visual inspection, as a means of determining roof stability. Traditionally, miners have sounded the rock, listening for the drummy sounds that signal loose rock. Also the act of drilling exploration roof bolt or blast holes can provide much information about the rock. During drilling, blasting, and scaling operations, additional knowledge related to roof conditions can be gained. For example, a driller preparing to bolt may notice a sudden increase in the penetration rate, and then realize that possibly a gap or clay seam was encountered. Much of this “hands-on” information provides an overview of the general conditions related to roof stability. Observational techniques can be extended by monitoring the movement of the mine roof in boreholes using mechanical tools (Figure 5).

A comprehensive ground control plan not only includes the basic observational, visual, and hands-on components, but also uses supplemental observational and monitoring techniques and regularly reads, analyzes and displays information gained from these efforts. Mines that follow these practices and promote open communication and participation from everyone at the site are the mines with the most pro-active approaches towards ground control safety.

SURFACE HIGHWALLS AND SLOPES

Surface mines have relatively few serious falls of ground, with 6 fatalities in the period 1996 to 1998. However, six additional fatal falls of highwalls and slopes fatalities occurred in the first half of 1999. Two of these six were initially classified as Powered Haulage, but they were actually caused by slope failure beneath haulage equipment. The large jump in fatalities in 1999 is hopefully an aberration, but it may signal a new safety issue caused by a change in mining method or equipment, different enforcement practices, or a social issue such as the experience level of the mining workforce.

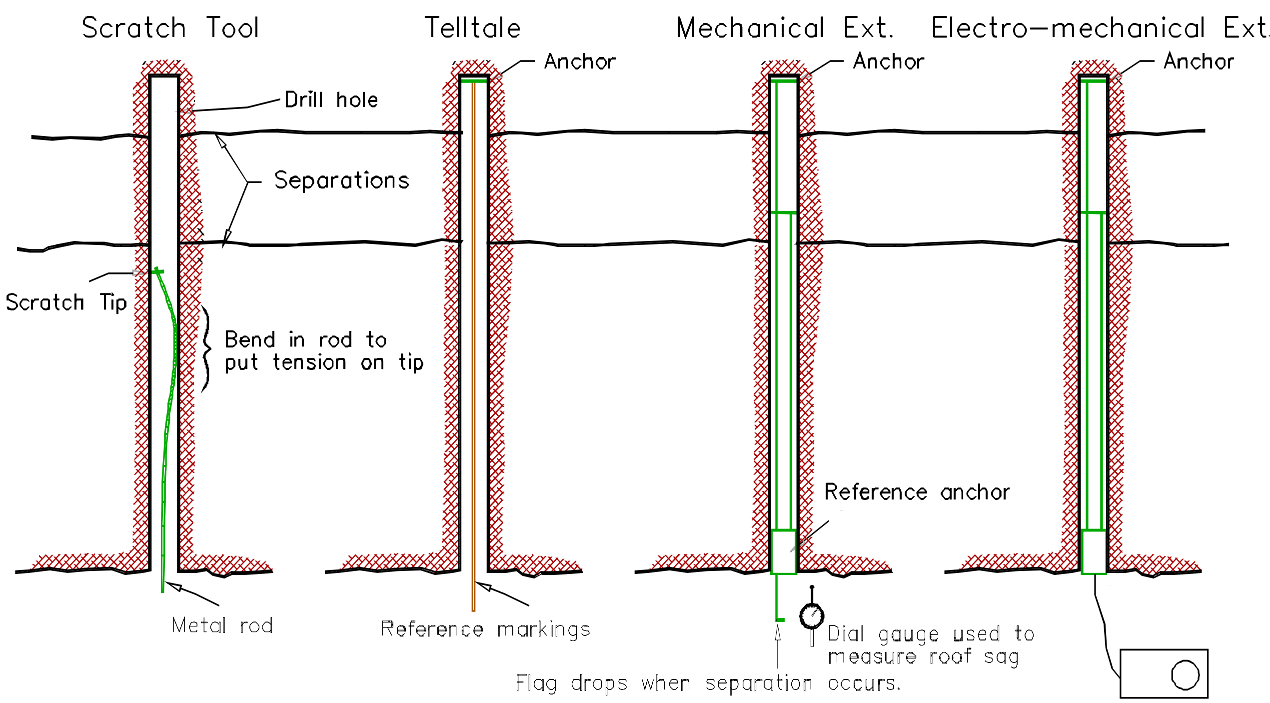

Figure 5. - Four techniques used for roof monitoring

Most highwall injuries occur when loose pieces of rock fall on workers located below. Small pieces of rock can be dangerous when they fall from great height; even a fist-sized rock caused one recent fatality. At the other extreme, an entire section of a highwall or spoil pile may collapse, endangering miners working either on or beneath it.

Good basic design is essential to highwall safety. The height should be limited for stability and to allow scaling. Where the pit is deep, benches should be used to limit the slope height. Angling the highwall back from vertical also increases stability. Good blasting practices make for a smoother wall and reduce the need to scale. Drainage ditches should be used to divert springs and groundwater away from slopes.

Geologic features have contributed to many rockfall injuries from highwalls. Faults or "hillseams" (weathered joints) can create wedges of unstable ground that can slide into the pit. In dipping strata, the rock can also be prone to slide along bedding planes. Freeze-thaw action acts to loosen rocks, and has been cited in several fatality reports. A review of accident records indicates that highwall accidents are twice as likely to occur in December and January than they are in the summer months. The presence of abandoned underground mine openings in the highwall has contributed to three of the recent fatalities.

Rock faces should be monitored frequently to check for loose rocks, and scaling should be conducted as needed. As highwalls age, weathering may cause additional loosening. The surface at the top of the highwall should also be checked for tension cracks that could indicate pending massive slope failure. In very large pits, various kinds of electronic surveying and monitoring systems are in use to provide early warning.

CONCLUSIONS

This paper has presented an overview of the most significant ground control hazards facing today's mineworkers. Underground miners, particularly in coal mines, are at the greatest risk from ground falls. The six highwall and slope fatalities that occurred in the first half of 1999 show that surface miners are at risk as well.

The analysis of recent fatality investigations and accident statistics identified certain job categories, mining techniques, and geologic environments that appear to pose the greatest hazards. Best Practices have been developed through experience and research to reduce these risks. They combine engineering design, roof support, equipment, mining methods, and human factors to create safer workplaces and work practices. The Roof Control Plan is another valuable tool in this effort.

Unfortunately, recent trends indicate that ground fall injury rates have stopped decreasing, and may even be on the increase. A renewed effort by the entire mining community will be necessary to finally eradicate the groundfall hazard.

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