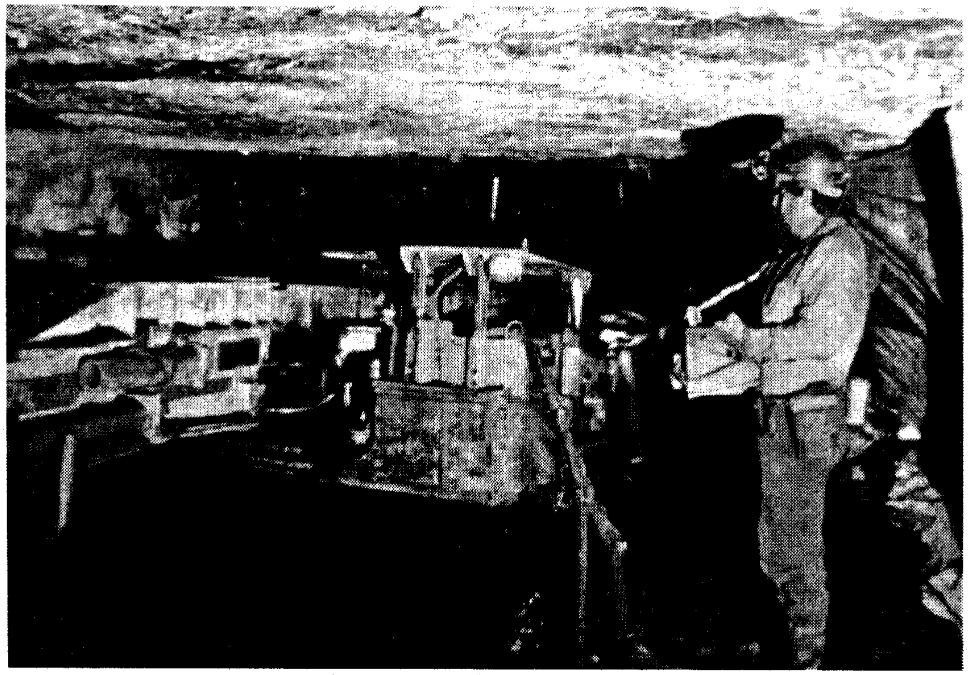

Figure 2. Miner operating a continuous mining machine by remote control

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)).

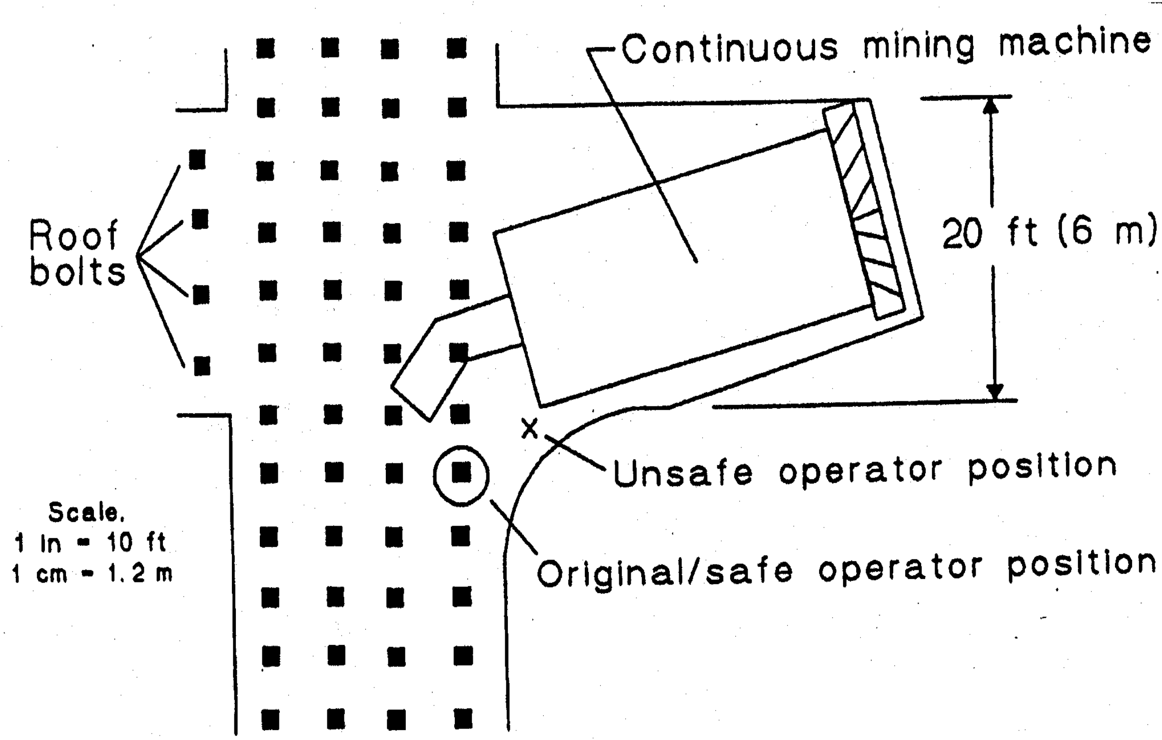

Figure 3. Unsafe location for a continuous mining machine operator while mining a crosscut

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.

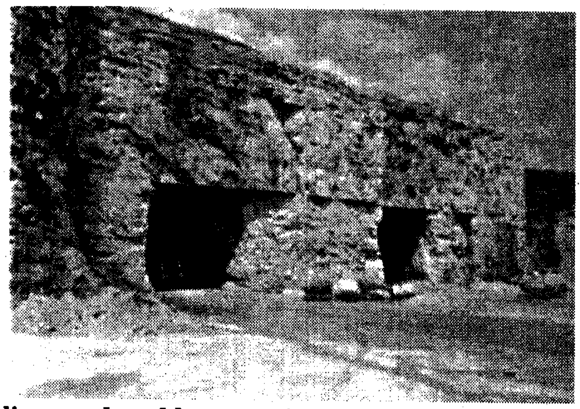

Figure 4. Smooth roof line produced by a persistent bedding plane lamination within the roof rock beam

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.

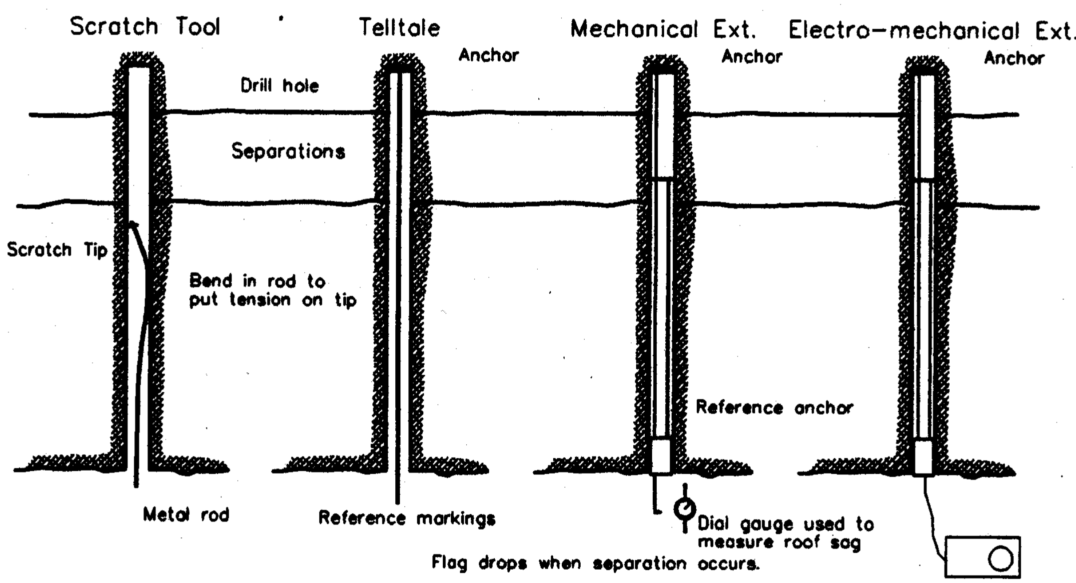

Figure 5. Four techniques used for roof monitoring

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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