CHAPTER 23

Ground Control Issues for Safety Professionals

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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, 59 (23%) were caused by falls of ground (Table 23.1). 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 only 6% of the 155 surface fatalities were caused by falls of highwalls or slopes.

The goal of this chapter is to provide guidance to safety professionals tasked with preventing ground fall injuries. This chapter combines an analysis of the Mine Safety and Health Administration's (MSHA) accident and injury data with a survey of industry "best practices" to safeguard miners from ground falls. Ultimately, this approach can help to form the basis of a sound, proactive ground control program for the mining industry.

SOURCES OF DATA

All the injury data examined in this study were derived from MSHA's fatal investigation reports and the MSHA accident database. Because falls of ground often result in serious injury, MSHA "Fatalgrams" and fatal investigation reports provide a useful snapshot of ground control issues in the mining industry. These reports are available to the public (on the MSHA Web site at www.msha.gov). Fatalgrams are one-page summaries that are usually published within a month of an accident. They contain very basic information about the accident with a graphic and a short section on relevant best practices. Fatal investigation reports are the official accident investigation reports filed by MSHA personnel. These reports contain general information about the mine, a description of the accident, physical factors involved in the accident, a conclusion, and enforcement actions. Enforcement actions typically identify citations and discuss violations to the Federal Mining Law.

MSHA also maintains comprehensive statistical data on the mining industry's accident and injury record. The law 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. A short narrative is generally included as well. Accident reports can be searched by many of the above fields.

TABLE 23.1 Fatalities from 1996 to 1998 by commodity for both falls of ground and other mining classifications

	1996		1997		1998		Total	
	Underground	Surface and Prep Plants	Underground	Surface and Prep Plants	Underground	Surface and Prep Plants	Underground	Surface and Prep Plants
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**

From 1996 to 1998, U.S. miners suffered a total of 55,096 injuries, which ranged in severity from death (degree 1) to injuries with no days away from work or 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 23.2 indicate, 98% of all nonfatal fall of ground injuries occurred in underground mines, with underground coal mines accounting for 83% of the total.

Table 23.2 also shows the distribution nonfatal 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. Sixty-five percent of all ground fall injuries resulted in lost time, compared to 54% of all types of mining injuries.

Analysis of the accident database allows safety professionals to learn from the experience of the entire industry. The factors responsible for many ground fall injuries emerge from this analysis, and possible solutions can be identified as well. It also allows for the timely recognition of trends, both from a standpoint of identifying successful interventions as well as focusing on emerging issues.

LEGAL FRAMEWORK

Laws governing mining in the United States are listed in the *Code of Federal Regulations* (CFR) under Title 30—Mineral Resources. Laws pertaining to the control of ground in surface and underground mines are covered in four parts, characterized by surface coal mining (Part 77), underground coal mining (Part 75), metal/nonmetal surface mining (Part 56), and metal/nonmetal underground mining (Part 57). The U.S. Mining Law contains both specific and sweeping statements, and its generalized

TABLE 23.2 Nonfatal fall of ground injuries from 1996 to 1998

Severity	Commodity	Underground	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 (degrees 5 and 6)	Coal	777	9	786
	Metal	269	3	272
	Nonmetal	23	1	24
	Stone	16	7	23
	Subtotal	**1085**	**20**	**1105**
All nonfatal injuries	Coal	2584	32	2616
	Metal	409	8	417
	Nonmetal	38	1	39
	Stone	30	16	46
	Total	**3061**	**57**	**3118**

TABLE 23.3 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

language promotes flexibility and innovation. For example, in coal mining, each mine is required to submit its own roof control plan, which contains, in many cases, many details as to how the mine will comply with ground control aspects of the law.

Underground coal mining roof control is covered in 18 subsections within Part 75. Although 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 23.3). 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 an 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 nine 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 23.4). 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.

Surface mining ground control is covered in 9 subsections within Part 56 for metal/nonmetal mines and 15 subsections within 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.

ROOF CONTROL PLANS

Each coal mine operator is expected to develop and follow a roof control plan, approved by the MSHA district manager, that is suitable to the prevailing geological conditions and the mining system to be used at the mine. The law also outlines what should be contained within the plan (75.221), how the plan will be approved (75.222), and how revisions to the plan will be evaluated (75.223). The data discussed above suggest that violations to the plan can result in serious injury to the miner. Management *must* communicate and enforce the specifics of the roof control plan to the workforce. Additionally, the plan cannot be viewed as a static document. As conditions of mining change, the plan must be updated and resubmitted to the local MSHA district manager for approval. Safety professionals may have no greater tool at their disposal for addressing ground control issues than the roof control plan.

The mine operator is also responsible for taking any necessary measures to protect persons if unusual hazards are encountered. When new support materials, devices, or systems are used as the only means of roof support, the MSHA district manager may require that their effectiveness be demonstrated by experimental installations as part of a test plan.

Roof control plan implementation begins by instructing all persons who are affected by its provisions. The approved plan and any revisions must be available to the miners and their representatives and must be posted on a mine bulletin board.

Subsection 75.221 lists the information that must be included in the roof control plan. Some of the most important issues include:

- Specifications of all supports that may be used, including the length, diameter, grade, type of anchorage, drill hole size, and bolt torque or tension ranges for roof bolts
- Installation procedures for supports, including spacing and sequence of roof bolts
- Maximum automated temporary roof support (ATRS) distance beyond the last row of permanent support
- Entry width, size of pillars, method of pillar recovery, and the sequence of mining pillars
- Frequency of test holes to be drilled at least 12 in. above the roof bolt anchorage horizon
- Special support and mining systems, such as for mine entries within 45 m (150 ft) of an outcrop.

The roof control plan sets forth minimum requirements, specifically in areas such as bolt length and bolt spacing. Additional support measures must be used to adequately support local adverse conditions. When conditions indicate that the plan is not suitable for controlling falls of ground, the operator must propose revisions of the roof control plan (Sec. 75.223). Conversely, when the accident and injury experience at the mine indicates the plan is inadequate, MSHA will generally require changes to the plan. MSHA reviews the roof control plan at each mine every six months. To assist with the review, all unplanned roof falls, rib falls, and coal or rock bursts that occur in the active workings must be plotted on a mine map.

TABLE 23.4 Violations from 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

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. Many are the subject of recent or ongoing NIOSH research and are addressed in papers available at www.cdc.gov/niosh/pit. Best practices can also be obtained from MSHA literature, including the "cards" available at www.msha.gov/s&hinfo/prop/prophome.htm.

Geologic Discontinuities

Mines are unique structures because they are not constructed of manmade materials, such as steel or concrete, but are 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. Some of the most important discontinuities that affect mine safety are described below.

- *Slips* are breaks or cracks in the roof, and they are the features most often cited in underground coal mine fatality reports. When slips are more than several feet long and are steeply dipping, they form a ready-made failure surface. Their surfaces are usually *slickensided*–i.e., smooth, highly polished, and striated. Two slips that intersect form an unsupported wedge that is commonly called a *horseback*. Undetected slips that do not fail during development have a tendency to pop out when subjected to abutment pressures generated during pillar recovery operations. Longer or angled bolts may be used to support slips, and straps or truss bolts can be even more effective.
- *Joints* are fractures commonly found in hard rocks. They occur in sets with similar orientation. Often several sets of joints occur at angles to each other, creating unstable blocks that must be supported by roof bolts.
- *Fossil remains* are the remnants of plants and animals that lived during the time when the sediments that later became rocks were being deposited. For example, kettlebottoms are fossil trees that grew in ancient peat swamps (Figure 23.1). They occur in every U.S. coal basin, but are especially abundant in southern West Virginia and eastern Kentucky. Dinosaur footprints are another fossil remain found in the roof rocks of coal mines in Utah, Wyoming, and Colorado. Fossil remains can fall without warning and should always be carefully supported (Chase 1992). Roof boltholes should never be drilled directly in fossil remains, because the vibrations could cause them to be dislodged.
- *Bedding planes* are typically found in sedimentary rocks and can extend great lateral distances. Bedding planes represent sharp changes in deposition (e.g., limestone to clay, or sandstone to coal). These planes can separate readily and are frequently involved in roof falls.

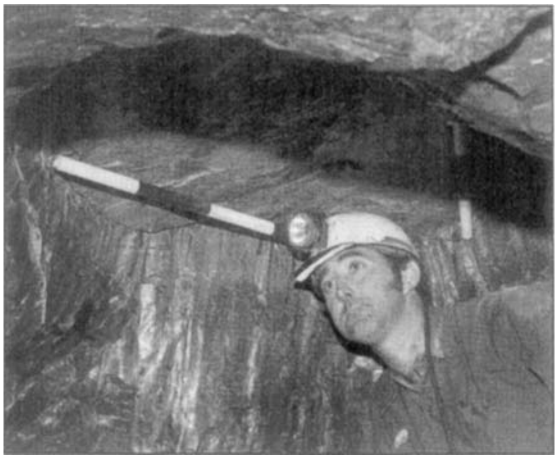

FIGURE 23.1 Large kettle bottom in an underground coal mine (photo by F. Chase)

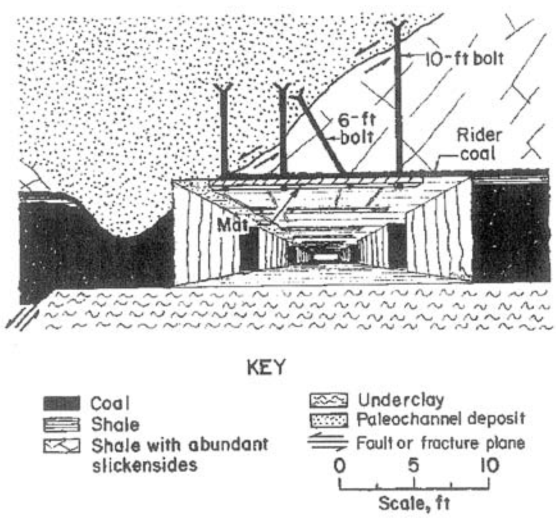

FIGURE 23.2 Suggested roof support for a stream channel transition zone (Chase 1992)

- *Transition zones* occur in many types of strata but are particularly common in sedimentary rocks. A transition zone occurs when some change in deposition causes a change in sedimentation. Different types of sediments compact at different rates. Discontinuities are abundant in the transition zones between distinct strata. For example, where ancient streambeds eroded the adjacent sediments, remnants of the stream channel disrupt the continuity of the normal roof beds, resulting in large slip planes (Figure 23.2).
- *Faults* are structural displacements within the rock. Tectonic forces can cause rocks to break and slip. Faults often contain weak *gouge* material, and the country rock around them can be distorted, fractured, and hazardous (Figure 23.3). Faults are often cited as contributing to surface mine highwall failures.

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.

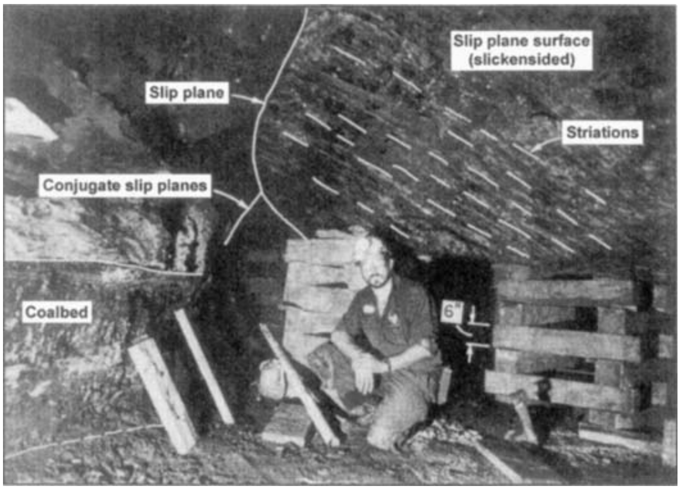

FIGURE 23.3 Fault in an underground coal mine (photo by G. Molinda)

TABLE 23.5 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

Underground Coal Mine Hazards

Between 1996 and 1998, 36 underground coal miners were killed in 33 separate incidents. Table 23.5 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 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.

By definition, roof support activities take place very close to unsupported roof. Therefore it is not surprising that most of the fatal accidents involved roof bolt operators or other miners engaged in roof support. Based on the accident record, single-head roof bolt machines appear to be a risk factor. Roof control plans carefully specify the sequence of bolt installation with single-head machines to avoid placing the operator inby support. If these guidelines are not followed, the roof bolt operator can be at risk.

During the early 1990s, the U.S. Bureau of Mines (USBM) 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. Other activities that were associated with going inby supports included:

- Operating a continuous miner or scoop
- Hanging or extending ventilation tube or curtain
- Retrieving items left lying on the ground
- Repairing or restoring power to a continuous miner
- Marking the roof for bolt installation.

Relatively simple procedures or technologies can be implemented to reduce the temptation for workers to intentionally go beyond support. However, training is essential. Mallett and colleagues (1992) argue that verbal admonitions and threats of discipline are less effective than training that graphically imparts the severe consequences of roof falls. A series of three videos was prepared that shows actual miners being interviewed about roof fall accidents that they experienced. The videos also emphasize the impact that roof fall accidents have on people other than the one caught in the fall. These highly effective videos, together with training manuals, are available from the MSHA Academy in Beckley.

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.

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. Although large roof and rib falls have been responsible for several fatalities, most injuries are caused by relatively small pieces of rock.

A detailed study of the hazards associated with roof bolting was conducted in West Virginia (Klishis et al. 1992; Grayson et al. 1992). The average time for bolting a place was 26.9 minutes, and that time was spent engaged in four primary activities:

- General face preparation
- Tramming, positioning, and setting ATRS
- Drilling holes
- Installing bolts.

The most hazardous face preparation activity was scaling and barring roof. Thick coal seams where the roof is high posed particular hazards. Having a long scaling bar available was essential.

The most severe injuries (with an average of 45 days lost) were associated with setting the ATRS. Pressurizing the ATRS against the top can disturb the roof, and large pieces may rotate and actually fall underneath the support. It is particularly important, then, that other miners stand back while the ATRS is being set.

The greatest number of injuries occurred during the drilling process, which also involved the greatest amount of the total cycle time. Drilling also disturbs the rock, causing pieces to fall. Analysis of the injury data found that operators placed themselves at risk whenever a part of the body left the protective coverage of the canopy. Placing hands around the drill steel or across the drill head also resulted in a number of injuries.

Bolt installation required only 17% of the cycle time but was associated with 25% of the injuries. Miners sometimes went out from under the canopy during installation, particularly in high top. Accidents appeared to be more frequent during the installation of the last row of bolts in a place, because of face falls and a tendency to overextend the ATRS.

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 it is used. 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).

A wide variety of roof bolts are now available, and installation problems may be caused by geologic changes, incorrect practices, or malfunctioning supports. To help identify and resolve problems with roof supports, an extremely valuable *Trouble Shooting Guide* is available (Mazzoni et al. 1996).

If there are any indications of adverse conditions, additional test holes should be drilled and additional support installed. Roof conditions detected during drilling should be communicated to coworkers and management.

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. Nonfatal 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 (Figure 23.4). 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

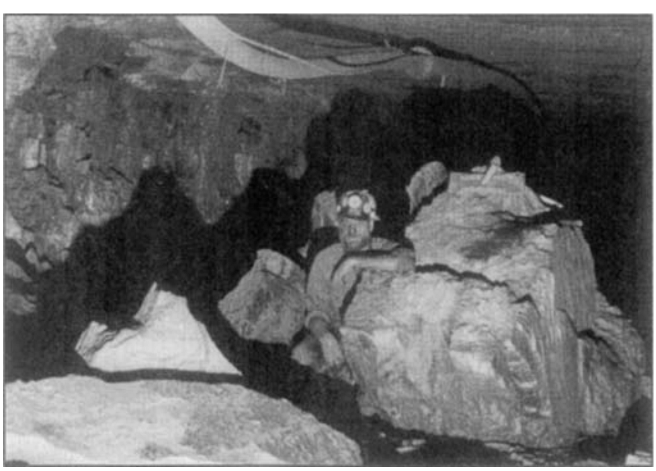

FIGURE 23.4 Large rib failure in a thick coal mine seam (photo by Chase)

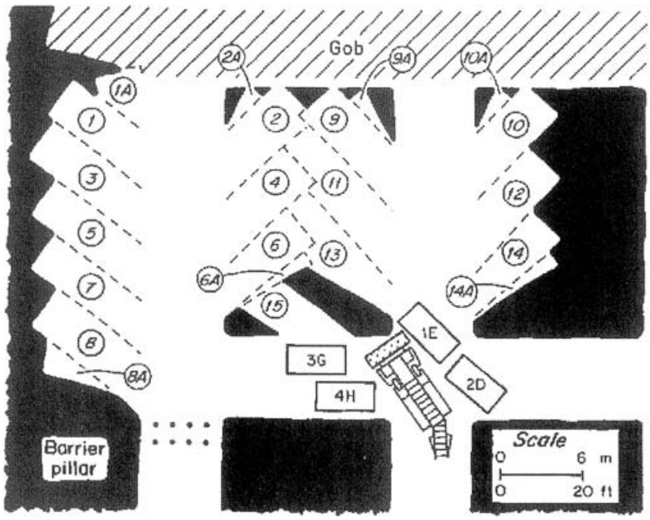

FIGURE 23.5 Christmas tree pillaring plan (Chase et al. 1997)

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.

A wide variety of pillar recovery techniques are used. "Partial pillaring" methods include pillar splitting, split-and-tee, three-cuts, and many others. These plans leave a substantial amount of coal in the remnant fenders and therefore postpone the caving action of the roof. When "full pillaring" is practiced, roof caving normally occurs soon after mining is completed. Popular full-pillaring techniques include the outside lift and the Christmas tree (Figure 23.5).

Today, most pillar recovery plans employ 9 to 12 m (30 to 40 ft) extended cuts. The pillars are usually sized so that no roof bolting is required during second mining. One apparent consequence is that because roof bolting accidents are eliminated, nonfatal roof/rib accident rates at pillar recovery mines are actually lower than at other room-and-pillar mines (Mark et al. 1997).

Traditional roof control plans require that numerous timber posts be set during each stage of pillar recovery (Figure 23.6). Recently, mobile roof supports (MRS) have become available that replace many of the timbers (Figure 23.7). 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.

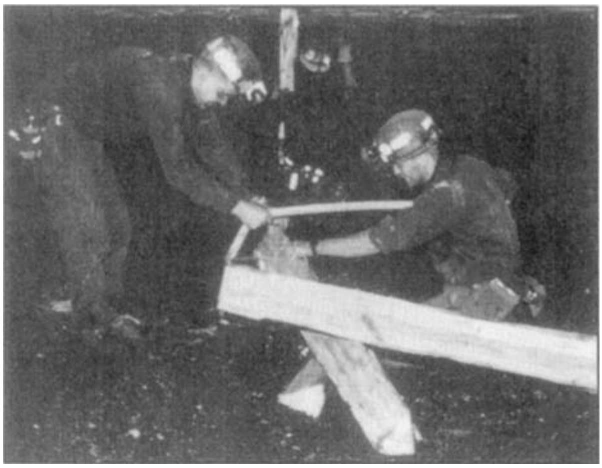

FIGURE 23.6 Timber support being set on a retreat mining section

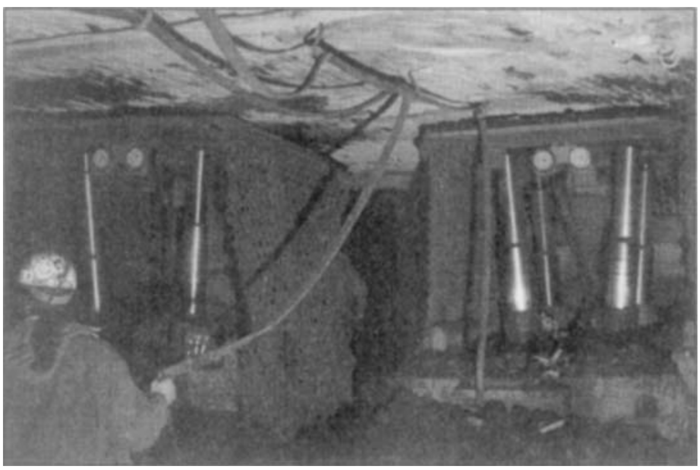

FIGURE 23.7 Mobile roof support (MRS) for retreat mining (photo by Chase 1992)

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.

Many fatal investigation reports cite geologic features, especially slips, as contributing to the accident. Geologic features should be carefully supported and observed during retreat mining. Special precautions need to be taken near the outcrop, where the presence of groundwater and weathered joints (sometimes called "hill seams") can reduce roof competence. In general, pillar recovery should not be conducted when the distance to the outcrop is less than 45 m (150 ft).

Pillar recovery can also be difficult under deep cover. Between 1996 and 1998, nearly half of the pillar recovery fatalities occurred where the depth of cover exceeded 200 m (650 ft). Under deep cover, barrier pillars and special mining sequences may be required.

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 23.8), spray fan systems, and flooded-bed scrubbers has provided the technology to

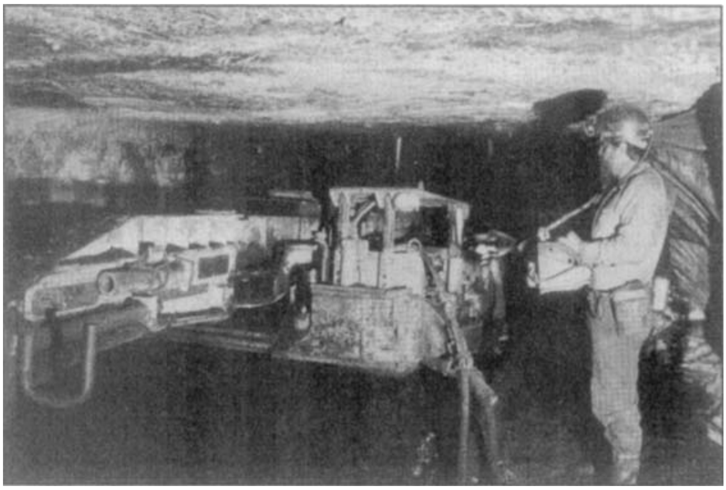

FIGURE 23.8 Miner operating a continuous mining machine by remote control (photo by E.R. Bauer)

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 factor 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).

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.

A study conducted at 36 mines found that in 50% of all underground coal operations, extended cuts were routinely used nearly all the time (Mark 1999). In 22% of the mines, extended cuts were rarely feasible. In the remaining mines, extended cuts were sometimes stable, sometimes not. The prevailing conditions were found to be determined by the roof quality, the entry width, and depth of cover. Another study found that extended cut mines were no more prone to roof falls after bolting than non-extended cut mines (Bauer et al. 1997).

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 23.9). 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.

Training is an essential element in safe deep cut mining. Other workers on the section should know not to go in by the continuous miner operator unless they are operating coal haulage equipment at the face. If the continuous miner breaks down inby permanent roof support, the roof must be properly supported before repairs are made. Finally, all crosscuts must be supported before a cut is taken inby or the opposite crosscut is started.

Intersection Stability

In underground coal mines, tens of thousands of intersections are driven each year. Intersections create diagonal spans of 8 to 12 m (25 to 40 ft), well over the normal width of an entry. The hazards of wide spans can be increased when pillar corners are rounded for machine travel (turnouts), or when rib spalling increases the span.

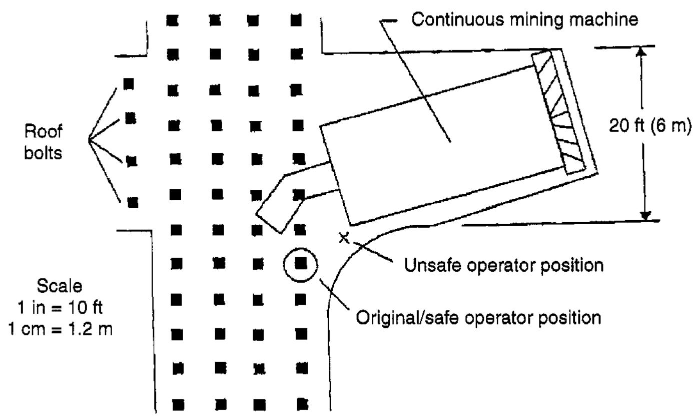

FIGURE 23.9 Unsafe location for a continuous mining machine operator while mining a crosscut (Bauer et al. 1997)

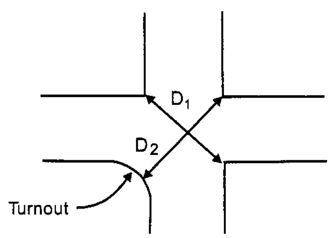

FIGURE 23.10 Sum-of-the-diagonals for intersection span measurement (G. Molinda et al. 1998)

Subsection 50.20-5 requires every roof fall in the active workings that occurs above the roof bolt anchorage, impairs ventilation, or impedes passage be reported. In 1996, there were 2,105 noninjury reportable roof falls. More than 71% of these occurred in intersections, despite the fact that intersections probably account for less than 25% of all drivage underground.

Intersection spans are often measured as the sum of the diagonals (Figure 23.10). Because the rock load increases in proportion to the cube of the span, even a small increase in the span can greatly reduce the stability of an intersection. For example, widening the entry from 5.5 to 6 m (18 to 20 ft) increases the rock load from 82 to 120 tonnes (96 to 132 tons)! A study conducted at one mine in western Pennsylvania found that 83% of the roof falls occurred in 13% of the intersections where the sum of the diagonals exceeded 22 m (70 ft) (Molinda et al. 1998).

Many roof control plans specify the maximum spans that are allowed. Mining sequences can also be designed to limit the number, location, and size of turnouts, and to restrict turnouts to specific entries. Extra primary support, such as longer roof bolts, installed within intersections can also be very effective in reducing the likelihood of roof falls. On the other hand, replacing four-way intersections with three-ways may be not be an effective control technique. Three-way intersections are more stable, but since it normally takes two three-ways to replace one four-way, the total number of falls is likely to increase (Molinda et al. 1998).

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 23.6). Two major contributing factors were the failure to conduct proper roof and rib examinations and problems with removing loose rock. Both of these activities are more difficult in large mine openings. Overall, metal and nonmetal underground mines have lower ground fall injury rates than coal mines. For example, a study by Iannacchione et al.

TABLE 23.6 Factors associated with nine 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	Not applicable
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

(1999) found that 92 falls of ground injuries from 1990 to 1996 were reported from the underground stone mining industry, which employs approximately 2,000 miners. This high groundfall rate is certainly related to the large size of the openings in stone mines, and to the problems of scaling them.

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 and Prosser 1998).

A stable roof beam is generally massive, strong, thick, and persistent. Additionally, a persistent, smooth roof profile at the bottom of the stable roof beam is very helpful in creating a stable roof. Natural laminations, bedding planes, or interfaces between rock layers often providing the best roof lines (Figure 23.11). Too many bedding planes or rock layer interfaces can allow the roof to separate with time into many thin layers that are inherently unstable. Thicker roof beams sag less than thinner beams and therefore are less likely to fail (Figure 23.12). A meter or more of competent rock has been observed to form a stable beam in rooms up to 15 m (50 ft) wide.

However, as more joints intersect the roof beam or the associated room is widened, the chances for instabilities increase.

If a natural smooth roof plane does not exist, special blasting procedures like presplitting or smooth blasting can be used to produce an artificial smooth roof plane. Pre-splitting requires additional drill holes along the roof and rib line. Postsplitting or trimblasting is another technique used to produce an even, stable roof line. 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 as a result of inadequate explosive burn) can leave broken rock along uneven rib and face surfaces.

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 is removed by blasting, as in most underground metal and nonmetal mines.

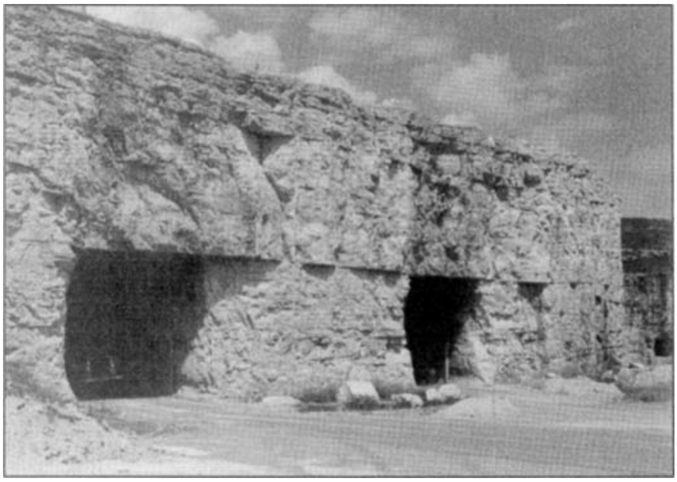

FIGURE 23.11 Smooth roof line produced by a persistent bedding plane lamination within the roof rock beam

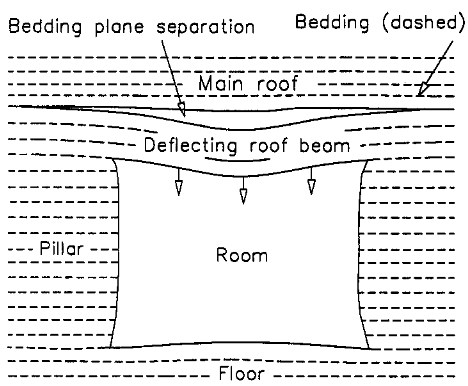

FIGURE 23.12 A common mode of roof rock failure in underground stone mines

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, hammering, or scraping attachments. Hand scaling is often conducted by a worker mounted in a lift basket in high openings. It can be the primary means of scaling or it can be done on an as-needed basis before any mining operation (drilling, blasting, mucking, haulage, etc.). Periodic reexamination of working areas is essential to identify new loose rock.

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.

Although nearly two-thirds of the scaling accidents were caused by a direct hit from falling rock, many are related to loss of balance of the worker because of machine movement or a loss of bar control. Scaling bars that are too short can put workers in danger, but longer bars can be too heavy. A scaling bar experiment in 1988 indicated that a counterbalanced bar might be a better ergonomic design. At one coal mine, workers welded a 0.6-m (2-ft) end piece of a scaling bar to the end of an 2.4 m (8-ft) metal pipe, creating a bar that was relatively lightweight and strong (Klishis et al. 1992).

Training is a basic consideration for reducing scaling accidents. The stone mine data cited above indicated that nearly two-thirds of the accidents occurred to miners with less than two years of scaling experience (Grau and Prosser 1997). Workers should stand under supported top whenever it is available. To prevent hand injuries when using a scaling bar, one method suggested by MSHA is to slip a piece of water hose about half way down the bar. If the material being pried away slides down the bar, it will then be deflected away from the hands. Finally, miners should always pry *up* when scaling, so that if they lose their balance they do not fall underneath the loose rock.

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 manmade supports (except filled stopes in metal mines) have anything near the tremendous load-carrying capability of mine pillars. The tributary area concept is often used to estimate the loads applied to pillars. Mine designers must consider all of the loads the pillars may be required to carry during their service lives, however. Longwall panel extraction, pillar recovery, and multiple seam operations can all increase pillar loads, and benching can reduce pillar strength. Design aids for coal mines include the Analysis of Longwall Pillar Stability (ALPS), the Analysis of Retreat Mining Pillar Stability (ARMPS), and LAMODEL (Mark 1999b; Heasley and Chekan 1999). Guidelines for sizing limestone pillars were recently published (Iannacchione 1999).

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 et al. 1998). 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. Rock mass classification systems can be especially helpful in estimating the safe span. In hard rock mines, examples include the RMR system, the Q system, the MBR system, and the Stability Graph System (Hoek et al. 1995). The Coal Mine Roof Rating System is increasingly used for many aspects of coal mine design (Molinda and Mark 1994).

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 (Peng 1999).

Controlling Catastrophic Failures in Underground Mines

One of the most difficult and longstanding ground control issues is the catastrophic failure of mine structures. 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. The driving mechanisms include both excessive stresses from geologic forces like faults or from mining induced situations. Catastrophic failures of mine structures range in size from small pieces of ribs or roofs to entire mining sections. When gases under elevated pressures are present in the strata, outbursts of rock and gas can occur. 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 1900s. Iannacchione and Zelanko (1995) compiled a coal bump database that included 172 specific events. The database was constructed from USBM and MSHA coal bump accident and incident reports written between 1936 and 1993. A total of 87 fatalities and 163 injuries were identified. The 1980s witnessed the greatest outbreak of bumps, accounting for 31% of the total. In 1996, three 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.

Many recommendations have been proposed to mitigate bump hazards. Special mining techniques like the Olga pillar extraction technique and U.S. Steel's thin-pillar method have the ability to reduce stresses around pillar extraction areas. Longwall mines can use techniques like abutment and yielding pillars. Finally as a last resort, several destressing techniques, such as shot firing, auger drilling, water infusion, hydraulic fracturing, and partial pillaring, have proven useful in combating the most hazardous conditions.

"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 that 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/nonmetal mines in the United States 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).

The mechanics of pillar collapses are very different from either coal bumps or the more common slow pillar failure. Collapses occur when the pillars are so thin that they cannot carry any weight once they fail. Pillar collapses can be *prevented* by increasing the stability factor of the pillar design, or *contained* by conducting high extraction in localized compartments that are protected by barrier pillars.

"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. Outbursts in coal have been relatively rare, occurring most frequently along the grand hogback of Colorado. However, the most deadly outbursts in the recent U.S. history occurred in 1981 at the Dutch Creek No. 1 Mine in Colorado where 16 miners were killed. It is commonly felt that outbursts will become much more prevalent as average mining depths increase below 600 m (2,000 ft).

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

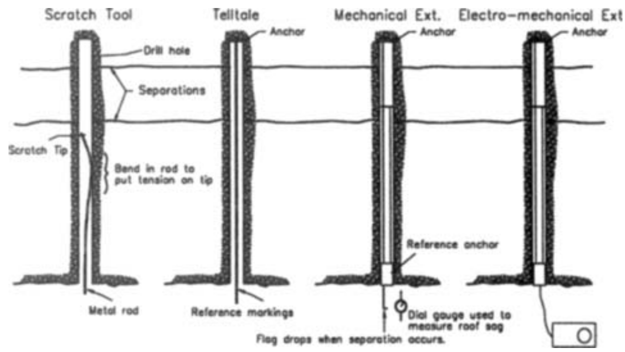

FIGURE 23.13 Four types of mechanical tools

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 23.13). Four types are available (Iannacchione et al. 1999):

- *Scratch tools* can detect separations and provide an indication of loose rock layers or roof beam deflection. Information on the location and size of the separation can be marked on the roof and used to assess potential future roof degradation.
- *Telltales* are rigid bars, possibly just a roof bolt, anchored into the roof. A small section of rod protruding from the borehole is covered with three bands of reflective tape. The portion of the bar closest to the roof is generally green, followed downward by yellow and then red. As the roof deflects downward, the roof line can easily be seen to move through the green, yellow, and finally red tape zones. Telltales are required by law in British and Canadian coal mines (Altounyan et al. 1997).
- *Mechanical extensometers* consist of a top and bottom anchor, steel wire or rigid tubing, and some kind of micrometer or dial gauge. These devices have been used for decades in metal mines in Michigan, Missouri, and Idaho. The most common commercially available mechanical extensometer monitoring devices are the Miners Helper and the Guardian Angel. These monitors generally have one or two anchor points that measure the overall separation of rock layers in the immediate roof. If roof deflection is detected, a reflecting flag drops from the roof line, signaling the potential for imminent roof failure. In some cases, this information has been used to indicate a need to add roof support, remove roof rock, or mark off affected areas.
- *Electromechanical extensometers* include sonic probes that allow for up to 20 permanent anchors up to a 6-m (20-ft) height. The probes have the added benefit of being remotely read by portable devices or by connection to a data acquisition system. Recently, NIOSH introduced an easy to fabricate and install extensometer called the Remote Monitoring Safety System (RMSS). This instrument can be read remotely with a multimeter or can be connected directly to a data acquisition system.

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. When this type of information is logged or mapped, it provides a documented history of ground conditions. Data from monitoring can be analyzed and prepared either by consulting firms or with in-house expertise. The information is extremely useful in deciding a course of action or alteration of the mining plan at the time of a major groundfall or when unstable geologic conditions are encountered. Mines that follow these practices and promote open communication and participation from everyone at the site are the mines with the most proactive approaches towards ground control safety.

SURFACE HIGHWALLS AND SLOPES

Surface mines have relatively few serious falls of ground, with six fatalities in the period from 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.

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.

Good work practices can also help reduce rockfall hazards. Workers should not position themselves beneath highwalls except when absolutely necessary to perform their duties. Where possible, equipment cabs should be designed for object protection, and equipment should be positioned with the cab away from the highwall.

The stability of spoil piles can be reduced by extra surface loads ("surcharges") or by removing the bottom ("toe") of the slope. One recent fatality occurred when an uncompacted spoil pile gave way beneath the weight of a loaded truck. Another miner was killed when he excavated material at the base of the slope to widen a road, causing the pile to collapse.

CONCLUSION

This chapter 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.

REFERENCES

Altounyan, P.F.R., D.N. Bigby, K.G. Hurt, and H.V. Peake. 1997. Instrumentation and procedures for routine monitoring of reinforced mine roadways to prevent falls of ground. Paper presented at the 27th International Conference of Safety in Mines Research Institute. New Delhi, India. 759–766.

Bauer, E.R., D.M. Pappas, D.R. Dolinar, F.E. McCall, and D.R. Babich. 1999. Skin failure of roof and rib in underground coal mines. In *Proceedings 18th International Conference on Ground Control in Mining*. West Virginia University, Morgantown, WV. 108–114.

Bauer, E.R., G.J. Chekan, and L.J. Steiner. 1997. Stability evaluation of extended cut mining in underground coal mines. *International Journal of Rock Mechanics and Mining Science* 34(3-4): Paper No. 302.

Chase, F.E. 1992. Geologic structures that affect Appalachian coal mines. In *Preventing Coal Mine Groundfall Accidents: How to Identify and Respond to Geologic Hazards and Prevent Unsafe Worker Behavior*. USBM IC 9332. 3–14.

Chase, F.E., A. McComas, C. Mark, and C.D. Goble. 1997. Retreat mining with mobile roof supports. In *New Technology for Ground Control in Retreat Mining: Proceedings of the NIOSH Technology Transfer Seminar*. NIOSH IC 9446. 74–88.

Grau, R.H. III, and L.J. Prosser. 1997. Scaling accidents in underground stone mines. *Rock Products* 1: 39–41.

Grayson, R.L., L.A. Layne, R.C. Althouse, and M.J. Klishis. 1992. Risk indices for roof bolter injuries. *Mining Engineering* 44(2): 164–166.

Heasley, K.A., and G.J. Chekan. 1999. Practical boundary element modeling for mine planning. In *Proceedings of the Second International Workshop on Coal Pillar Mechanics and Design*. Vail, CO. NIOSH IC 9448. 73–88.

Hoek, E., P.K. Kaiser, and W.E. Bawden. 1995. *Support of Underground Excavations in Hard Rock*. Rotterdam, Netherlands: Balkema.

Iannacchione, A.T., and J.C. Zelanko. 1995. Occurrence and remediation of coal mine bumps: a historical review. In *Proceedings: Mechanics and Mitigation of Violent Failure in Coal and Hard-Rock Mines*. USBM Special Publication 01-95. 27–67.

Iannacchione, A.T., and L.J. Prosser. 1998. Roof and rib hazards assessment for underground stone mines. *Mining Engineering* 50(2): 76–80.

Iannacchione, A.T., D.R. Dolinar, L.J. Prosser, T.E. Marshall, D.C. Oyler, and C.S. Compton. 1998. Controlling roof beam failures from high horizontal stress in underground stone mines. In *Proceedings of the 17th Conference on Ground Control in Mining*. West Virginia University, Morgantown, WV. August 4–6. 102–112.

Iannacchione, A.T., L.J. Prosser, R. Grau, D.C. Oyler, D.R. Dolinar, T.E. Marshall, and C.S. Compton. 1999. "Preventing Injuries Caused by Unrecognized Stone Mine Roof Beam Failures with a Proactive Roof Control Plan." Presented at the Society of Mining Engineering Annual Meeting Preprint 99-87. Denver, CO. March 1–3.

Iannacchione, A.T. 1999. Pillar design issues for underground stone mines. In *Proceedings of the 18th Conference on Ground Control in Mining*. West Virginia University, Morgantown, WV. 271–281.

Klishis, M.J., R.C. Althouse, L.A. Layne, and G.M. Lies. 1992. Increasing roof bolter awareness to risks of falling roof material during the bolting cycle. In *Preventing Coal Mine Groundfall Accidents: How to Identify and Respond to Geologic Hazards and Prevent Unsafe Worker Behavior*. USBM IC 9332. 69–78.

Mallett, L.G., C. Vaught, and R.H. Peters. 1992. Training that Encourages Miners to Avoid Unsupported Roof. In *Preventing Coal Mine Groundfall Accidents: How to Identify and Respond to Geologic Hazards and Prevent Unsafe Worker Behavior*. USBM IC 9332. 32–45.

Mark, C. 1999. Application of the coal mine roof rating (CMRR) to extended cuts. *Mining Engineering* 4: 52–56.

——. 1999. Empirical methods for coal pillar design. In *Proceedings of the Second International Workshop on Coal Pillar Mechanics and Design*. NIOSH IC 9448, 45–154.

Mark, C., F.E. McCall, and D.M. Pappas. 1997. A statistical overview of retreat mining of coal pillars in the U.S. In the *Proceedings of the 16th International Conference on Ground Control in Mining*. West Virginia University, Morgantown, WV. 204–210.

Mark, C. and T.P. Mucho. 1994. Longwall mine design for control of horizontal stress. In *New Technology for Longwall Ground Control: Proceedings of the USBM Technology Transfer Seminar.* USBM SP 94-01. 53–76.

Mazzoni, R.A., G.J. Karabin, and J.A. Cybulski. 1996. *A Trouble Shooting Guide for Roof Support Systems*. MSHA IR 1237. 101 pp.

MSHA. Best Practices. Series of cards available on the Internet at www.msha.gov/s&hinfo/prop/prophome.htm.

Molinda, G., and C. Mark. 1994. *The Coal Mine Roof Rating (CMRR)–A Practical Rock Mass Classification for Coal Mines*. USBM IC 9387. 83 pp.

Molinda, G., C. Mark, E. Bauer, D. Babich, and D. Pappas. 1998. Factors influencing intersection stability in U.S. coal mines. In *Proceedings 17th International Conference on Ground Control*. West Virginia University, Morgantown, WV. 267–275.

Peng, S.S. 1999. Roof bolting adds stability to weak strata. *Coal Age* 12: 32–38.

Peters, R.H. 1992. Miners' views on how to prevent people from going under unsupported roof. In *Preventing Coal Mine Groundfall Accidents: How to Identify and Respond to Geologic Hazards and Prevent Unsafe Worker Behavior.* USBM IC 9332. 25–31.

White, B.G., J.K. Whyatt, and D.F. Scott. 1995. Geologic factors in rock bursts in the Coeur d'Alene mining district. In *Proceedings Mechanics and Mitigation of Violent Failure in Coal and Hard Rock Mines*. USBM SP 01-95. 217–230.

Zipf, R.K., and C. Mark. 1997. Design methods to control violent pillar failures in room-and-pillar mines. *Transactions of the Institution of Mining and Metallurgy* 106 (September–December): A124–A132.