Profile of groundfall incidents in underground coal mines

D.M. PAPPAS AND C. MARK

D.M. Pappas and C. Mark, member SME, are civil engineer and supervisory mining engineer, respectively, with the National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, Pittsburgh, PA. Nonmeeting paper number 01-344. Original manuscript submitted for review November 2001. Revised manuscript received and accepted for publication January 2003. Discussion of this peer-reviewed and approved paper is invited and must be submitted to SME Publications Dept. prior to Dec. 31, 2003.

Introduction

Historically, underground coal mining has been recognized as one of the most hazardous occupations in the United States. Since 1910, more than 85,000 underground miners have lost their lives mining coal. Nearly half of these fatalities were due to falls of roof and rib. As shown in Fig. 1, more than 1,000 roof- and rib-fall fatalities occurred annually until the early 1930s. During the late-1940s through the 1950s, mechanization of production greatly reduced the size of the workforce. Although the total number of groundfall fatalities was also reduced, the actual rate of roof and rib fatalities did not significantly drop until after the early 1960s. Since the mid-1980s, the groundfall-fatality-incidence rate has essentially stagnated.

In 2001, groundfalls caused 11 fatalities and 501 serious injuries resulting in 25,781 days lost in underground bituminous coal mines. In addition, 1,442 reportable noninjury roof falls occurred in 2001. Reportable noninjury roof falls are usually massive falls that extend beyond the height of the bolts, damage equipment, halt production or disrupt ventilation. It has been estimated that the total cost of groundfall injuries between 1985 and 1989 was $123,880,800, which is equal to $1,036,000 for every fatality and $6,835 for every injury (Peters and Randolph, 1991).

Critical factors to consider in the analysis of underground coal-mine incidents in recent years have been the dramatic rise of longwall mine production and the steep decrease in the number of small room-and-pillar operations. Longwall mines now account for approximately 50 percent of all underground coal production in the United States. Perhaps the more competitive longwall mines have resulted, to some extent, in the decrease of small mines (<50 underground workers). Between 1991 and 2001 the total number of small mines has decreased more than 50 percent, from 1,317 to 597. These occurrences show the dynamic changes that are affecting U.S. underground coal mines and emphasizes the importance of separating longwall mines during the analysis process.

Methodology

The primary raw data for this study were obtained from the U.S. Mine Safety and Health Administration (MSHA) accident injury and employment databases. The study examined the closeout data for 1995-2001 for underground bituminous coal mines, excluding employees of independent contractors. Groundfall injuries include all roof and rib falls listed in the database, as well as incidents classified as "machinery" where the source of injury was caving rock.[1] Groundfall incidents were categorized into the following three rate groupings:

- *Injury incidence rate:* Groundfall injury incidents include all roof and rib falls that resulted in death, permanent disability, days away from work or days of restricted work (coded in the MSHA data as degree of injury 1 through 5). The incidence rate is calculated as the number of incidents per 200,000 hours worked underground. The 200,000 hours approximates the number of hours worked by 100 full-time miners per year

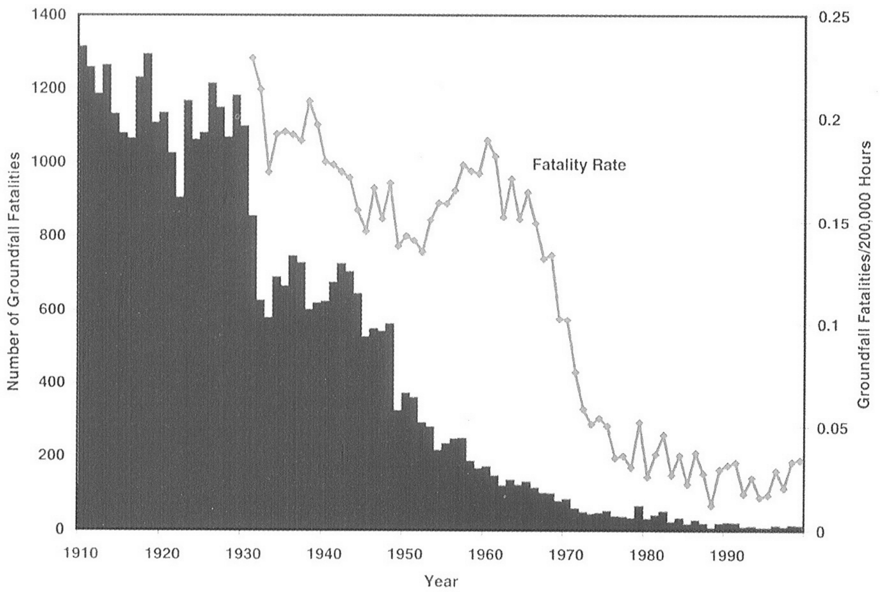
[1]Analysis of the incident narratives revealed that the vast majority of these "machinery groundfalls involved the roof rather than the rib," and so all were categorized as roof falls.

Abstract

Between 1995 and 2001, groundfall incidents resulted in 69 fatalities and were responsible for 47 percent of all deaths in U.S. underground bituminous coal mines. To better understand where and why these incidents occur, a comprehensive analysis of groundfall injuries and reportable noninjury roof falls was conducted. Using U.S. Mine Safety and Health Administration (MSHA) data from 1995 through 2001, the study examined the effects of mining method, mine size, seam thickness and season on roof- and rib-fall injury rates and reportable noninjury roof-fall rates. In addition, for the first time, groundfall rates were calculated for individual coal beds. The study found that room-and-pillar mines had significantly higher groundfall rates than longwall mines. Small room-and-pillar mines with less than 50 workers were found to have high groundfall fatality rates. Another significant conclusion was that high groundfall rates occurred in regions where there were numerous problematic coal beds, such as in the Illinois Basin. This appears to correlate to other studies that have shown that the compressive strengths of typical roof rocks in the Illinois Basin are much lower than those of their counterparts in the central Appalachian coalfields. Finally, roof-fall rates nationwide were found to be 50 percent higher between July and September, possibly because of changes in humidity levels that may be causing shale mine roofs to deteriorate.

FIGURE 1

Historical overview of groundfall fatalities (BOM, MSHA, 1910-2000).



- *Fatality incidence rate:* Groundfall fatal incidents include all roof and rib falls that resulted in death. The incidence rate is calculated as the number of incidents per 200,000 hours worked underground. Both groundfall fatality and injury rates are normalized based on hours worked underground, rather than tonnage, to reflect an underground miner's exposure to hazardous conditions.
- *Noninjury roof-fall incidence rate:* Noninjury incidents (degree of injury of 0) are required to be reported if the roof fall occurs in the active workings of the mine and extends above the roof bolt anchorage, impairs ventilation or impedes passage (Federal regulation subsection 50.20-5). The incidence rate is calculated as the number of reportable roof falls per million tons mined. The noninjury roof fall rates were normalized to mine production, rather than hours worked, because production generally relates to the amount of roof exposed during the mining process.

The two methods of mining, room-and-pillar vs. longwall, were separated out for most of the analyses. The longwall mines were identified for each year by review of the annual longwall census (Fiscor and Merritt, 1996; Fiscor, 1997 through 2001). This information was also supplemented by personal knowledge. All production originating from longwall mines, including gate-road development, was considered longwall tonnage.[2]

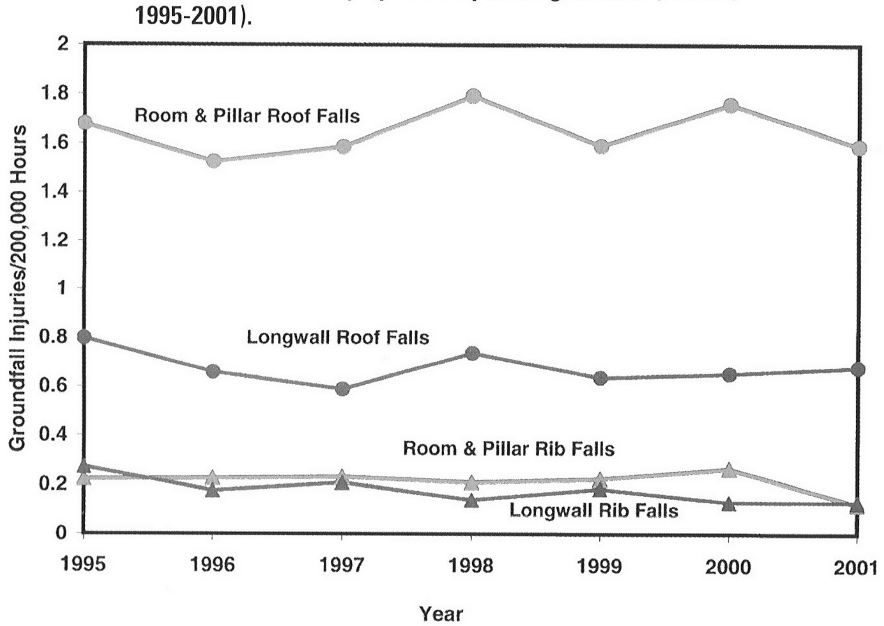
Major coal-producing locations in the United States were also examined to identify trends. The eastern Kentucky region had minimal longwall production, and the Alabama region had minimal room-and-pillar production. Because of low production, groundfall rates from these areas are not mentioned in the analysis.

The MSHA database reports a seam height for each mine, defined as the average height of the coal seam now being mined. There may be some variation in the actual seam height at the site of the incident, but to be consistent, this study used the MSHA value. Three categories of seam heights are selected based on distribution of employee hours and other constraints (Fotta and Mallet, 1997). Thin seams are less than 1.1 m (43 in.), medium seams are from 1.1 to 1.5 m (43 to 60 in.) and thick seams are greater than 1.5 m (60 in.). Approximately 4.1 percent of the total room-and-pillar underground production were from mines where no seam heights were recorded or where the seam heights were misreported. These mines were excluded from this portion of the study.

Mine size is based on the average annual number of operator employees working in the underground mine. Three categories of mine sizes that were selected are based on the distribution of employee hours. Small-sized mines are those with less than 50 workers, medium-sized mines have 50 to 150 workers and large-sized mines have more than 150 workers.

FIGURE 2

Roof- and rib-fall injury rates by mining method (MSHA, 1995-2001).



Mine characteristics

Groundfall incident rates were compiled based on several physical

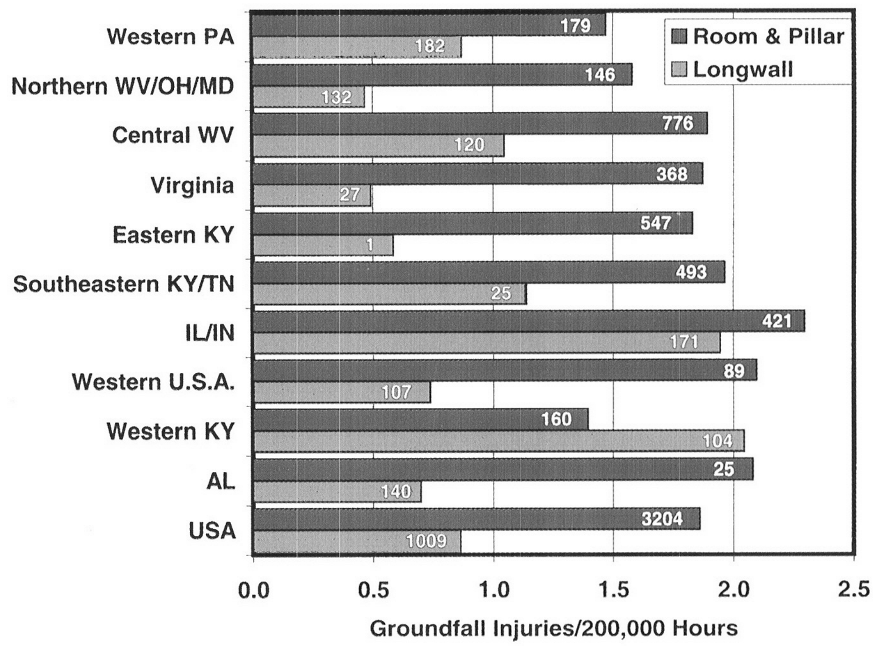
[2]The authors are aware of just two longwall mines that regularly produce coal from room and pillar sections that are not related to longwall gate entry or mains development. Even in these cases, the room and pillar production is a very small percentage of the total mine production.

characteristics associated with each mine, such as mining method, regional location, mine size, seam height and coal bed. Also examined was the seasonal period that the roof fall occurred. Most of these factors are related to noninjury incidents, because these types of massive roof falls are more indicative of broad geological and mining trends.

Mining method. Table 1 compares the two mining methods. During the seven-year study period, 58 longwall mines produced almost as the same coal tonnage as 775 room-and-pillar mines. However, room-and-pillar mines accounted for 78 percent of the total roof-fall injuries and 81 percent of the total noninjury roof falls. Therefore, the roof-fall-injury incidence rate for room-and-pillar mines was more than double the longwall roof-fall rate, as shown in Fig. 2. The significantly lower longwall roof-fall rate may be related to the continuous roof protection provided by longwall faces supports, and to the greater percentage of workers in outby support functions in a typical longwall mine. On the other hand, the rib-incidence rates for the two mining methods were similar. The nearly identical rib-fall rate probably reflects the thicker seams that were mined using longwalls. One recent study found that 75 percent of longwall production comes from seams that were more than 1.5-m (60-in.) thick, while just 30 percent of room-and-pillar production comes from thick seams (Pappas et al., 2000).

FIGURE 3

Groundfall injury rates by location. The numbers in the bars indicate incident frequency (MSHA, 1995-2001).



Locations. For longwall mines, Fig. 3 shows that western Kentucky and Illinois/Indiana had groundfall

TABLE 1

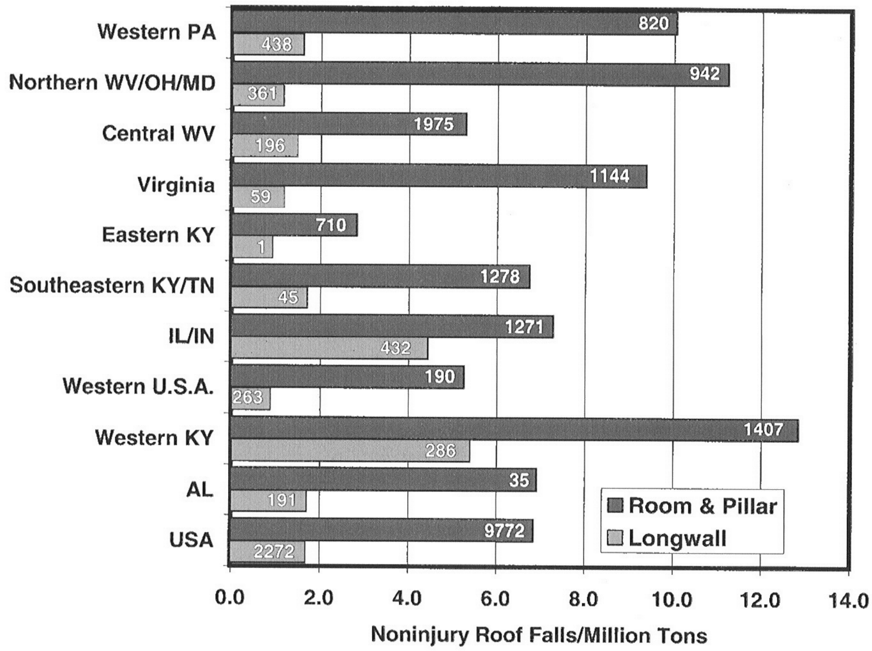
Comparison of mining methods (MSHA, 1995-2001).

	Mining method				
	Room and pillar		Longwall[1]		7-year
Attributed	**Number**	**%**	**Number**	**%**	**total**
Production					
Tons produced (millions)	1,428.7	51	1,358.2	49	2,786.9
Underground hours (millions)	344.5	60	233.8	40	578.3
Average number of underground workers/year	24,919	62	15,249	38	40,168
Average number of mines/year	775	93	58	7	833
Number of groundfalls					
Number of roof/rib fall fatalities	55	80	14	20	69
Number of roof falls injuries[2]	2,833	78	797	22	3,630
Number of rib fall injuries[2]	371	64	212	36	583
Number of noninjury roof falls	9,772	81	2,272	19	12,044
Groundfall incident rates[3]					
Roof/rib fatalites/200,000 hours	0.008		0.002		0.005
Roof fall injuries/200,000 hours	1.645		0.682		1.255
Rib fall injuries/200,000 hours	0.215		0.181		0.202
Noninjury roof falls/million tons	6.840		1.673		4.322

[1]Longwall data includes gateroad development.
[2]All falls resulting in degree of injury of 1 to 5 between 1995-2001.
[3]The combined rates are the total number of incidents divided by the total number of hours worked or total tonnage mined.

FIGURE 4

Roof-fall noninjury rates by location. The numbers in the bars indicate incident frequency (MSHA, 1995-2001).



injury rates that were at least twice the national longwall average. Conversely, the northern West Virginia/Ohio/Maryland and Virginia longwalls had injury rates that were at least 40 percent less than the national average.

Figure 4 shows similar trends for reportable noninjury roof falls in longwall mines. Western Kentucky and Illinois/Indiana had longwall noninjury roof-fall rates that were more than 2.5 times the national rate, while Western United States, northern West Virginia/Ohio/Maryland and Virginia had the lowest rates.

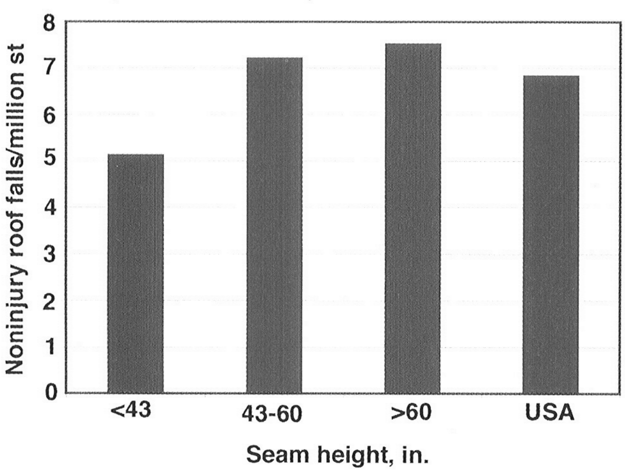
Room-and-pillar roof-fall-injury rates (Fig. 3) did not vary dramatically between regions. However, the rate of noninjury reportable roof-fall-incidence (Fig. 4) rates exceeded the national room-and-pillar mine average by more than 50 percent in western Kentucky, northern West Virginia/Ohio/Maryland and western Pennsylvania. Meanwhile, the rate in eastern Kentucky mines was 50 percent less than the national rate.

Overall, it appears that Illinois/Indiana and western Kentucky tend to have higher groundfall incidence rates than other areas. Geologic conditions seem to be the most likely explanation. One recent study compared the measured uniaxial compressive strength roof rocks in the Illinois Basin with that of rocks from southern West Virginia. The study involved more than 800 rock units and 10,000 laboratory strength tests. It concluded that for each of the three major roof rock types (shale, siltstone and sandstone), the strength of the Illinois Basin variety was less than 50 percent that of the same rock in West Virginia (Rusnak and Mark, 2000).

Groundfall rates also tend to be higher in the northern Appalachian areas of Pennsylvania, Ohio, Maryland and northern West Virginia. This is another area that has been found to have weaker roof rock. Researchers using the Coal Mine Roof Rating (CMRR) found that rock was "weak" (CMRR <45) in 70 percent of their observations in northern Appalachian mines, but it was "weak" in only 18 percent of their observations in central Appalachia (Mark et al., 1994).

FIGURE 5

Roof-fall noninjury rates by seam height for room-and-pillar mines (MSHA, 1995-2001).



Seam height. Mines operating in thin seams, <1.1 m (<43 in.), tend to be smaller mines that exclusively use the room-and-pillar extraction method. All U.S. longwall mines are now operating in medium or thick seams, >1.1 m (>43 in.). Because there is not a wide distribution of seam heights for longwalls mines, only data from room-and-pillar mines were used in this analysis. Figure 5 shows the results of reportable noninjury rates based on seam height and indicate that thin seam mines have a lower roof-fall noninjury rate. A similar trend is noted in Fig. 6 for injury rates, which shows thin seam mines also have lower groundfall injury rates. Perhaps the confined working space in thin seam mines makes assessment of bad roof conditions more detectable due its close proximity whereas in thicker seams visibility of the roof is hindered by the height and lighting conditions.

Mine size. Similar to seam height limitations found in longwall mines in the previous section, most longwall mines are usually large mines (>150 workers). Because there is not a wide distribution of mine sizes for longwalls mines, only data from room-and-pillar mines were used in this analysis.

The analysis found that there were only minor differences between the groups for the injury and reportable noninjury groundfall incident rates. However, the small mines (<50 workers) did have a significantly higher fatality rate (Fig. 7). More than 50 percent of the fatal groundfalls between 1995 and 2001 occurred in mines with <50 workers. Perhaps the smaller mines have less expertise and capital to deal with complex ground-con-

TABLE 2

Coal beds with extreme noninjury roof-fall rates (MSHA, 1995-2001).

Regional/coalbed[2]	Bedcode number	Tons/U/GNo. 1995-2001	No. Mines[1] 1995-2001	Regional mines represented	Number roof falls 1995-2001	Roof fall rate incidents/ million st	Above/ below national rate
Room and Pillar Mines – High Rates							
Northern Appalachian:			485	85%			
Sewickley	29	4,638,752	46		100	21.56	215%
Redstone	33	6,350,428	48		87	13.70	100%
Pittsburgh	36	15,223,519	71		156	10.25	50%
Upper Freeport	71	39,230,232	118		524	13.36	95%
Lower Freeport	74	10,851,539	20		109	10.04	47%
Upper Kittanning	76	31,137,686	84		318	10.21	49%
Lower Kittanning	84	32,310,532	98		352	10.89	59%
Central Appalachian:			289	7%			
Hazard No. 7/High Splint	104	3,839,413	25		60	15.63	128%
Buffalo Creek	117	4,827,378	13		72	14.91	118%
Upper Banner	214	4,611,130	57		42	9.11	33%
Jawbone/Iaeger	266	18,736,875	145		245	13.08	91%
Pocahontas No. 12/Beckley.	311	12,094,764	49		112	9.26	35%
Illinois Basin:			126	55%			
Western Kentucky/No. 13	482	3,462,948	5		235	67.86	892%
Springfield/KY No. 9/No. 5	489	141,020,179	107		1426	10.11	48%
Millsite	520	6,162,653	14		100	16.23	137%
Room and Pillar Mines – Low Rates							
Northern Appalachian:				5%			
Mahoning	70	5,445,939	21		24	4.41	-36%
Central Appalachian:			867	21%			
Stockton-Lewiston/Mercer	103	24,934,595	51		100	4.01	-41%
Hazard No. 5/Winifrede/Haddix.	121	46,621,629	88		144	3.09	-55%
Hazard No. 4A/Chilton Rider	134	5,619,148	14		23	4.09	-40%
Hernshaw	137	10,718,544	62		51	4.76	-30%
Williamson	142	45,590,826	190		191	4.19	-39%
Lower Cedar Grove/Elkhorn No. 2	154	37,203,333	178		91	2.45	-64%
Upper Alma/Alma A	156	12,687,221	37		25	1.97	-71%
Powell River/Kelly	165	3,772,678	11		17	4.51	-34%
Powellton	170	36,754,504	68		177	4.82	-30%
Clintwood/Matewan	174	6,741,247	52		18	2.67	-61%
Lower War Eagle/Hagy	195	4,154,983	62		15	3.61	-47%
Pocahontas No. 6	334	6,683,928	54		24	3.59	-48%
Longwall Mines – High Rates							
Northern Appalachian:			10	7%			
Upper Freeport	71	26,204,721	10		118	4.50	170%
Central Appalachian:			20	27%			
Eagle.	176	54,059,134	20		143	2.65	58%
Southern Appalachian:			7	9%			
Pratt	227	16,929,153	7		92	5.43	225%
Illinois Basin:			42	100%			
Western Kentucky No. 13	482	28,760,822	7		180	6.26	275%
Herrin/No. 6/KY No. 11	484	53,934,193	20		258	4.78	186%
Springfield/KY No. 9/No. 5	489	67,905,828	15		280	4.12	147%
Western United States:			3	3%			
Wattis	1,236	7,271,636	3		24	3.30	98%
Longwall Mines – Low Rates							
Northern Appalachian:			114	80%			
Pittsburgh	36	519,709,787	114		581	1.12	-33 %
Central Appalachian:			32	43%			
Lower Cedar Grove/Elkhorn No. 2	154	37,335,006	7		21	0.56	-66%
Pocahontas No. 3	344	79,878,346	25		75	0.94	-44 %
Southern Appalachian:			43	57%			
Blue Creek/Mary Lee	280	95,714,628	43		99	1.03	-38%
Western United States:			36	39%			
Wadge	1,750	50,839,750	7		24	0.47	-72%
Castle Gate A	1,830	32,909,021	14		38	1.15	-31%
Hiawatha	1,846	44,888,556	15		26	0.58	-65%

[1]The total number of mines for 1995-2001 is not mutually exclusive (if a mine worked all seven years, it is counted seven times).
[2]Excludes coal beds with less than 2.7 Mt (3 million st) and less than or equal 14 incidents for all seven years.

FIGURE 6

Groundfall injury rates by seam height for room-and-pillar mines (MSHA, 1995-2001).

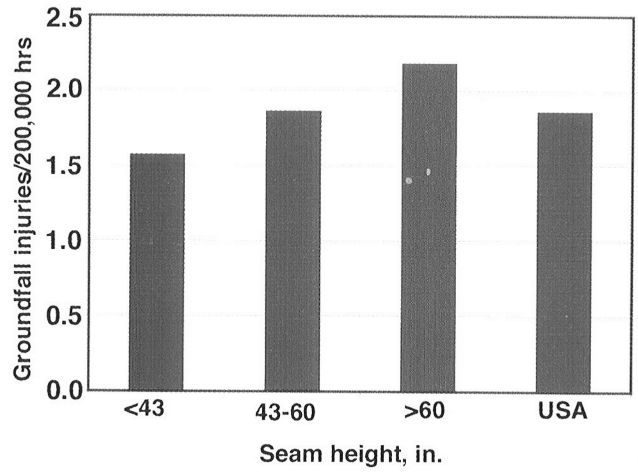
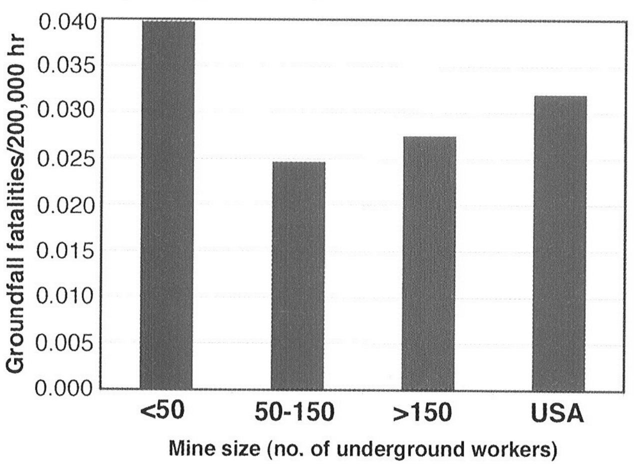


FIGURE 7

Groundfall fatality rates by mine size for room-and-pillar mines (MSHA, 1995-2001).



trol problems. An elevated fatal groundfall rate in small mines was identified in the early 1980s (Pappas, 1985) and, to some extent, by a study of Appalachian coal mines between 1985 and 1994 (Fotta et al., 1995).

Coal bed. A unique analysis was conducted to determine if certain coal beds were more susceptible to groundfalls. Because the coal bed is not a defined parameter in the MSHA database, bed codes were obtained from the Department of Energy's Energy Information Agency and merged with the employment and injury data associated with every underground coal mine. All MSHA district offices were surveyed to find any missing bed codes. Bed codes were not identified for 7.5 percent of the room-and-pillar mines, which accounts for 2.7 percent of room-and-pillar mine hours worked. Bed codes were not identified for less than 1 percent of the longwall hours worked.

Because more than 119 coal beds were identified, all coal beds with less than 2.7 Mt (3 million st) produced or less than 14 noninjury roof-fall incidents (cumulative, between 1995 and 2001) were removed from the analysis. For comparison purposes, a national roof-fall rate was determined from the entire database that included incidents from all coal beds. The more significant coal beds were selected by calculating the percentage that the coalbed groundfall rate exceeded the national average rate. All coal beds that had noninjury roof-fall rates higher or lower than the national rate by at least 30 percent are listed regionally for each mining method in Table 2. The broad regions used in these tables are not necessarily the same as the more specific locations used in the earlier analyses. Many of these coal beds in specific locations were found to overlap, and broader regions were found to be a better indicator of defining the location of the coal bed.

The most striking result shown in Table 2 is the high noninjury roof-fall rates for several of the most important Illinois Basin coal beds, including the Western Kentucky No. 13, the Herrin/No. 6/No. 11 and the Springfield/No. 5/No. 9. All of these coal beds had noninjury roof-fall rates that exceeded the national average, often by more than 100 percent. The high groundfall rate coal beds in the Illinois Basin affected 100 percent of the longwall production and 55 percent of the room-and-pillar production in this region. These high groundfall incident rates for the Illinois Basin coal beds correspond to the high injury rates in Illinois/Indiana and western Kentucky discussed above. They can be explained by the low-strength roof rock.

Other troubling trends from this analysis were the high noninjury roof-fall rates associated with 85 percent of the room-and-pillar mines in the northern Appalachian coal beds, specifically the Sewickely, Redstone, Pittsburgh, Lower Freeport, Upper Kittanning and Upper Freeport coal beds. Again, weaker geology is the most likely explanation. However, despite the weak roof, the data shows that longwall mines in the northern Appalachian region maintained an admirable record with noninjury roof-fall rates lower than the national average. It seems likely that the narrow entries and immediate roof bolting used in gateroad development at Pittsburgh seam longwalls may have contributed to the low noninjury roof-fall rate.

Other major longwall coal beds with low noninjury roof-fall rates include the Elkhorn No. 2 and Pocahontas No. 3 in central Appalachia; the Blue Creek/Mary Lee in southern Appalachia; and the Wadge, Castle Gate A and Hiawatha in the western United States.

Seasonal patterns. The chronological quarterly groundfall rates were evaluated to determine if seasonal patterns such as fluctuations in temperature, barometric pressure and humidity might effect the number of groundfall injuries. Because the mines in the western United States are located mostly in arid climates and experience minimum fluctuations in humidity, incidents in Colorado, New Mexico, Utah and Wyoming were excluded. Although monthly production data is not compiled, quarterly production was accessed from MSHA's Terra database. This allowed the groundfall incidents to be normalized based on the quarterly underground production. According to Fig. 8, the noninjury roof-fall incidence rate was fairly consistent except for the third quarter (July through September), where the incident rate peaked 50 percent higher than average for the other three quarters. Possibly, this trend indicates that mine air is becoming more humid during the late summer months and that the moisture is disintegrating the shale roof, resulting in a greater frequency of massive roof falls.

Other studies have found similar seasonal patterns. Statcham and Radcliffe (1978) found that humidity has a strong influence on roof-fall occurrence rates. Their results indicated that the probability of a roof fall is greatest in August and least in February.

Conclusions

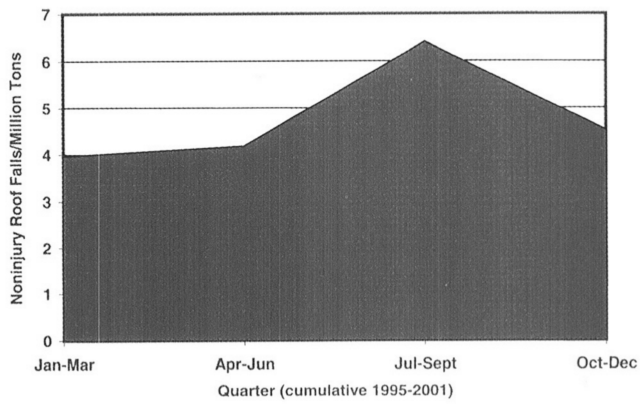
The effects of groundfall incidents are extensive, ranging from the economic loss of equipment and production to the fatal and nonfatal injuries that result in lasting physical and financial impairments suffered by the victims and the victim's family. In addition, the mining industry is severely impacted by these injury incidents, as well as the thousands of noninjury incidents that damage equipment, halt production or disrupts ventilation. This study of groundfall incidence rates identified the following patterns:

- The longwall mining method had less than half the roof-fall injury rate than did the room-and-pillar mining method. However, the rib injury rates were similar for both mining methods.
- The longwall mining method accounts for 49 percent of the production and 40 percent of the hours worked but results in only 19 percent of the reportable noninjury roof falls.
- The longwall mines in western Kentucky and Illinois/Indiana had high injury and noninjury roof-fall rates that are significantly higher than the national average. The most likely explanation is the weaker roof rock found in the Illinois Basin.
- The room-and-pillar mines in western Kentucky, northern West Virginia/Ohio/Maryland, western Pennsylvania and Virginia had higher-than-average rates of noninjury roof falls, while eastern Kentucky had a noninjury roof-fall rate that was significantly lower than the national rate. Weak roof probably also contributes to elevated roof-fall incidence rates in northern Appalachian mines
- Room-and-pillar mines with a workforce of less than 50 workers have a higher groundfall fatality rate. This is a trend that has not changed much since the early 1980s.
- Roof-fall noninjury rates for coal beds in both methods were high in the Illinois Basin, especially for the Western Kentucky No. 13, Herrin/No.6/No. 11 and Springfield/No.5/No. 9.
- Room-and-pillar coal beds in the northern Appalachian coal beds have high noninjury roof-fall rates. The most notable coal beds include Sewickley, Redstone, Pittsburgh, Lower Freeport and Upper Kittanning. However, longwall mines located in the Pittsburgh coal bed had a noninjury roof-fall rate that was lower than the national rate.
- A review of seasonal patterns identified the third quarter (July through September) as having a 50 percent increased risk of injury from roof falls, possibly because of higher humidity levels.

This groundfall incident characterization offers the most current profile of roof-fall statistics and trends. This study identifies areas where additional study is needed, so that innovative solutions can be developed to reduce these severe occupational hazards. ■

FIGURE 8

Roof-fall noninjury rates by quarter, excluding the western United States (MSHA, 1995-2001).



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