Roof and rib fall incident trends: a 10-year profile

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Abstract

From 1999 through 2008, groundfall events resulted in 75 fatalities, 5,941 injuries and 13,774 noninjury roof falls in U.S. underground coal mines, according to the U.S. Mine Safety and Health Administration (MSHA). A comprehensive analysis of these events was conducted to better understand where and why these incidents occurred. The first segment of the study used the MSHA database to evaluate groundfall injury rate trends related to mining method, year, locality, seam thickness, mine size, coalbeds and seasonal effects. In the past decade, roof fall injury rates have dropped 50%, but rib fall injury rates have remained constant. Room-and-pillar mines had a roof fall injury rate that was nearly 2.5 times the longwall rate. High groundfall rates occurred in the Illinois Basin, a finding that correlates with other studies that have shown that roof rock in the Illinois Basin is weaker than that in the central Appalachian coalfields. Finally, noninjury roof fall rates in the eastern and central United States were found to be 50% higher from July through September, possibly because of the changes in humidity levels that may cause shale mine roofs to deteriorate. The second segment of the study evaluated the root causes of failure by reviewing all MSHA groundfall fatality reports for 1999-2008. Pillar recovery was the leading cause of groundfall fatalities (19%), followed by rib falls, roof skin falls and traveling under unsupported roof (16% each). Defining prominent ground control incident trends and hazards will identify areas where additional study is needed and where innovative solutions need to be developed to reduce these severe occupational hazards.

Introduction

Mining has always been recognized as one of the most hazardous occupations in the United States. According to the U.S. Bureau of Labor Statistics (2007) and the U.S. Mine Safety and Health Administration (MSHA) (2009), a ranking of the most hazardous occupations shows that the underground bituminous coal mining industry's fatality rate ranks seventh among all U.S. occupations (Fig. 1). Since 1906, nearly 86,000 underground miners have lost their lives while mining coal. Groundfalls were responsible for 45,000 of these fatalities, more than all other causes combined. Groundfalls include falls of the mine roof and walls, typically referred to in underground coal mines as roof and rib falls.

A historical overview of fatality rates for roof and rib falls, along with landmark mining events, are shown in Fig. 2. Groundfall fatalities averaged around 1,000 deaths every year until the early 1930s. Despite the increased mechanization of coal mines in the 1930s and the introduction of roof bolts in the 1950s, prior to the Federal Coal Mine Health and Safety Act of 1969, roof fall fatality rates remained essentially constant. Implementation of the 1969 act required roof control plans and consistent roof support in every mine, which resulted in a 75% drop in groundfall fatality rates by the late 1970s (Mark, 2002).

During the past 25 years, the reduction of the groundfall fatality rate appears to have slowed or plateaued, even with nearly 50% of production in underground coal mines coming from the safer longwall mining method. The worst groundfall disaster since 1930 occurred in 2007 at the Crandall Canyon Mine in Utah, resulting in the death of six workers on August 6 and three rescuers on August 16.

Nonfatal injuries are another facet of the ground control problems in mining. In 2008, for example, 495 workers were injured in roof and rib falls, resulting in 18,160 days of work lost. Typically, a lost-time ground control injury costs in excess of $100,000 (Moore et al., 2010). Groundfall injuries also exact a human toll on the injured workers and their families. In addition to the injuries, nearly 1,400 noninjury roof falls occurred in 2008. These noninjury roof falls were mainly massive falls that were reported to MSHA because they extended beyond the height of the bolts, damaged equipment, stopped production or disrupted ventilation.

The U.S. National Institute of Occupational Safety and Health (NIOSH)'s previous reviews of groundfall injuries (Pappas and Mark, 2000; Pappas and Mark, 2003) for 1995-2001, found several key trends. The mechanized longwall process of mining coal with a long continuous slice using self-

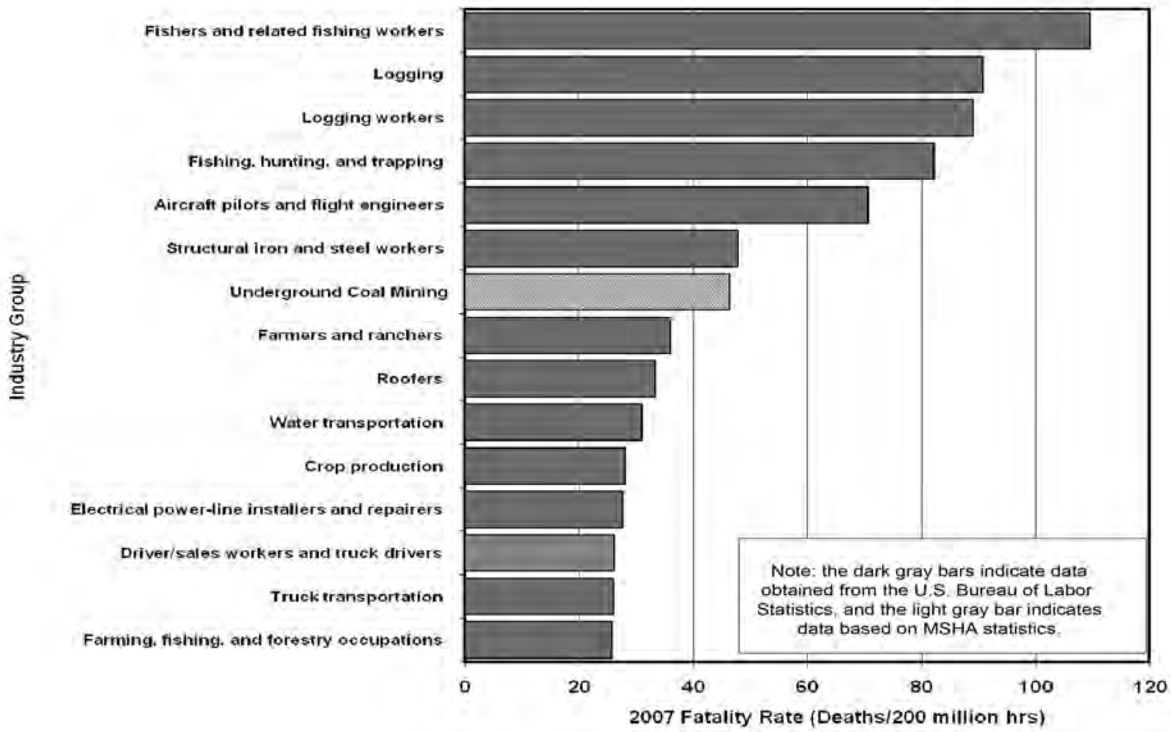

Figure 1 — Fatality rate by industry compared to underground mining, based on USBLS (2007) and MSHA (2009) data.

Figure 2 — Historical groundfall fatality rates, based on MSHA (2009) data for 1906-2008.

advancing roof supports has revolutionized and streamlined the system of mining underground coal in the United States. This method vastly improves mine productivity and reduces exposure to unsafe roof conditions. A comparison of mining methods found that the traditional process of room-and-pillar mining has at least twice the groundfall injury rate than the longwall mining method. Another significant conclusion was that high groundfall rates occurred in regions characterized by weak roof. For instance, the Illinois Basin's high groundfall rates are associated with several key coalbeds: (1) western Kentucky No. 13, (2) Herrin/No. 6/Kentucky No. 11 and (3) Springfield/No. 5/Kentucky No. 9. 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 were found to be 40-50% higher from July through September, possibly due to high humidity, which may cause the shale mine roof to deteriorate.

In the past 10 years, the coal industry has seen many dramatic changes. Underground coal production has decreased 9%, yet underground hours worked increased nearly 20% (MSHA, 2009). Because the economic cycles in coal mining may affect the dynamics of groundfall injury trends, this study was undertaken to update groundfall injury rates and, most importantly, to reveal critical, possibly new, ground control areas that require additional research attention.

Methods

The primary raw data for this first segment of the study was obtained from MSHA's accident/injury and employment databases (MSHA, 2009). The study examined the closeout data for 1999-2008 for underground bituminous coal mines, excluding contractors. The portion of this study that evaluated groundfall injuries by coalbed type used the years 1999-2007 because the coalbed updates for 2008 were not available. Groundfall injuries include all roof and rib falls listed in the database, as well as injuries classified as "machinery," where the source of injury was caving rock. 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.

Groundfall incidents were categorized by the following four types:

- Fatal roof or rib fall incidents (degree of injury: 1).
- Roof fall injury incidents resulting in death, permanent disability, days away from work only, days away from work with restricted activity, days of restricted activity only, or no lost workdays or restricted activity (degree of injury: 1–6).
- Rib fall injury incidents resulting in the same types of injuries as listed for roof fall injury incidents (degree of injury: 1–6).
- Noninjury reportable roof fall incidents (degree of injury: 0). The federal 30 CFR 50.20-5 (CFR) requires that any active working section with a roof fall that occurs above the roof bolt anchorage, impairs ventilation or impedes passage be reported.

Injury rates were computed by calculating the number of roof or rib fall incidents for every 200,000 hours worked underground. The number of hours worked by 100 full-time miners per year is approximately 200,000. Noninjury rates were computed by calculating the number of noninjury roof falls (i.e., reportable roof falls) divided by the underground production (in million metric tons, Mt). This rate was normalized based on 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 and longwall) were separated for most of the analyses. The longwall mines were identified for each year by review of the annual longwall census and knowledgeable mining personnel. Typically, 80%–90% of the production from longwall mines comes from the longwall face and the remainder from gate road development. No attempt was made to apportion production between gate road development and longwall face. Therefore, all production originating from these longwall mines was assumed to be longwall production. In mines that were not identified as longwall, their production was considered to be room-and-pillar mine production.

Major coal-producing locations in the United States were examined to identify trends. The eastern and southeastern Kentucky localities have minimal longwall production, and the Alabama location has minimal room-and-pillar production. Because of low production, groundfall rates from these areas are not included in this analysis.

The MSHA database reports a seam height for each mine,

Table 1 — Attributes of roof and rib fall injuries at room-and-pillar mines, based on MSHA (2009) data for 1999-2008.

Room-and-pillar mine trait	Region	Hours worked		Mines		Rib fall injuries[2]		Roof fall injuries[2]		Noninjury roof falls	
		N	%	N1	%	N	%	N	%	N	%
Locality	Western PA	23,784,492	5	369	6	19	3	163		616	5
	Northern WV/ OH/MD	28,128,587	6	343	6	22	4	231	6	1,622	14
	Southern WV	112,379,537	24	1,567	26	178	32	983	25	2,249	19
	VA	45,884,502	10	907	15	64	12	369	9	1,049	9
	Eastern KY	80,159,705	17	1,400	23	69	13	659	16	918	8
	Southeastern KY	71,508,424	15	996	16	117	21	609	15	1,294	11
	Indiana/Illinois	56,944,111	12	191	3	39	7	592	15	2,475	21
	Western U.S.	9,614,188	2	136	2	28	5	46	1	190	2
	Western KY	39,057,025	8	137	2	13	2	344	9	1,220	10
	Alabama	1,249,328	0	32	1	0	0	7	0	16	0
	Total	**468,709,899**	**100**	**6,078**	**100**	**549**	**100**	**4,003**	**100**	**11,649**	**100**
Mine size	<50 workers	180,300,649	38	4,898	81	203	37	1,481	37	3,779	32
	50–149 workers	178,901,327	38	961	16	248	45	1,520	38	4,224	36
	>149 workers	109,507,923	23	219	4	98	18	1,002	25	3,646	31
	Total	**468,709,899**	**100**	**6,078**	**100**	**549**	**100**	**4,003**	**100**	**11,649**	**100**
Seam height[3]	missing	13,319,671	3	212	3	3	1	111	3	307	3
	<=108.9 cm	86,840,764	19	2,233	37	67	12	646	16	1,234	11
	109-152.1 cm	154,502,304	33	1,728	28	151	28	1233	31	3,670	32
	152.2-182.8 cm	93,219,277	20	849	14	122	22	876	22	2,275	20
	>=182.9 cm	120,827,883	26	1,056	17	206	38	1137	28	4,163	36
	Total	**468,709,899**	**100**	**6,078**	**100**	**549**	**100**	**4,003**	**100**	**11,649**	**100**
All room-&-pillar mines		468,709,899		6,078		549		4,003		11,649	

[1] The total number of mines for 1999–2008 is not mutually exclusive (e.g., if a mine operated all 10 years, it is counted 10 times).
[2] All falls resulting in degree of injury 1–6.
[3] Approximately 2.8% of the hours worked were at mines that did not report or misreported the seam height and are excluded.

defined as the average height of the coal seam currently being mined. Seam height is not necessarily the mining height, which sometimes includes roof and floor rock that is often removed due to equipment size. 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-reported value. Four categories of seam heights were selected based on distribution of employee hours and other constraints: a thin seam height is less than or equal to 108.96 cm (42.9 in.); medium seam height is 109.22-152.14 cm (43-59.9 in.); thick seam height is 152.40-182.62 cm (60-71.9 in.) and ultrathick seam height is greater than or equal to 182.88 cm (72 in.).

Approximately 3% of the total room-and-pillar underground production and 1% of the total longwall production were from mines where no seam heights were recorded or where the seam heights were misreported. These mines were excluded from this segment of the study.

Mine size is based on the average annual number of employees working in the underground mine. The following three categories of mine size were selected for this study and are based on distribution of employee hours: small-sized mines (fewer than 50 workers), medium-sized mines (50-149 workers) and large-sized mines (more than 149 workers).

The second segment of this study is a review of the actual MSHA (2008) fatality reports. To obtain a greater understanding of the specific hazards associated with roof or rib fall fatalities, all groundfall fatality reports for 1999–2008 for underground mining were examined. This second segment includes bituminous operator and contractor fatality reports, whereas the first segment did not include contractor incidents. The fatality reports provide much more information than can be obtained from the MSHA injury narratives, which are brief and do not include detail. The cause of failure for each groundfall fatality was reviewed by several individuals to minimize subjectivity; the various causes of failure were then categorized into eight groundfall groups. To establish long-term frequency trends, some of these categorized groundfall groups were reviewed back to 1995.

Results and discussion

This study is broken into two segments associated with an in-depth assessment of the MSHA injury database and a detailed review of the actual MSHA fatality reports.

Analysis of MSHA injury database. Table 1 breaks out several characteristics with room-and-pillar coal mines, including locality, mine size and seam height. Table 2 lists these same characteristics for longwall mines. Specific factors that quantify these mine attributes for the 1999-2008 analysis include the number of hours worked underground, number of mines and the number and percentage of rib fall injuries, roof fall injuries and noninjury roof falls.

Mining method. One of the most definitive factors affecting roof fall incident rates is the mining method. Table 3 compares the attributes of the two mining methods, including numbers and percentages for production, groundfall incident frequency and groundfall incident rates. Remarkably, the 48 longwall mines produced as much coal tonnage as the 608 room-and-pillar mines, but accounted for only 22% of the total roof fall injuries for both mining methods; in comparison, the remaining 78% of the total roof fall injuries occurred in room-and-pillar mines. According to Fig. 3, the roof fall injury rate for room-and-pillar mines is more than double the roof fall injury rate for longwall mines. The lower rate of roof fall incidents for longwall mines may be related to the continuous protection provided by the longwall face supports at the active mining face and the greater number of support workers located away from the mining face.

A similar ratio of incidents for the two mining methods was identified for noninjury roof falls—15% from longwall mines

Table 2 — Attributes of roof and rib fall injuries at longwall mines, based on MSHA (2009) data for 1999-2008.

Longwall mine characteristic	Region	Hours worked		Mines		Rib fall injuries[2]		Roof fall injuries[2]		Noninjury roof falls	
		N	%	N[1]	%	N	%	N	%	N	%
Locality	Western PA	61,017,685	20	61	13	44	16	240	22	278	13
	Northern WV/ OH/MD	73,252,320	24	96	20	41	15	155	14	337	16
	Southern WV	34,187,120	11	67	14	31	11	184	17	385	18
	Virginia	10,579,732	3	18	4	5	2	25	2	86	4
	Eastern KY	1,900,600	1	5	1	2	1	11	1	37	2
	Southeastern KY	1,234,825	0	5	1	1	0	8	1	8	0
	Indiana/Illinois	21,007,442	7	25	5	21	7	219	20	443	21
	Western U.S.	51,138,410	17	133	28	91	32	72	6	313	15
	Western KY	5,641,605	2	10	2	7	2	69	6	106	5
	Alabama	46,840,227	15	59	12	38	14	125	11	132	6
	Total	**306,799,966**	**100**	**479**	**100**	**281**	**100**	**1,108**	**100**	**2,125**	**100**
Mine size	<50 workers	530,144	0	9	2	1	0	2	0	11	1
	50–149 workers	20,178,166	7	84	18	31	11	94	8	203	10
	>149 workers	286,091,656	93	386	81	249	89	1,012	91	1,911	90
	Total	**306,799,966**	**100**	**479**	**100**	**281**	**100**	**1,108**	**100**	**2,125**	**100**
Seam height[3]	missing	4,228,928	1	11	2	5	2	22	2	1,554	73
	<=108.9 cm	0	0	0	0		0	0	0	5,804	273
	109-152.1 cm	25,388,890	8	47	10	20	7	86	8	11	1
	152.2-182.8 cm	44,860,454	15	61	13	26	9	159	14	203	10
	>=182.9 cm	232,321,694	76	360	75	230	82	841	76	1,911	90
	Total	**306,799,966**	**100**	**479**	**100**	**281**	**100**	**1,108**	**100**	**2,125**	**100**
All longwall mines		306,799,966		479		281		1,108		2,125	

[1] The total number of mines for 1999–2008 is not mutually exclusive (e.g., if a mine operated all 10 years, it is counted 10 times).
[2] All falls resulting in degree of injury 1–6.
[3] Approximately 1.4% of the hours worked were at mines that did not report or misreported the seam height and are excluded.

Table 3 — Comparison of mining methods, based on MSHA (2009) data for 1999-2008.				
Attribute	**Mining Method**			
	Room and pillar		**Longwall[1]**	
	Number	**%**	**Number**	**%**
Production				
Metric tons produced (millions)	1,637	49	1,679	51
Underground hours (millions)	469	60	307	40
Average number of underground workers/year	22,251	62	13,681	38
Average number of mines/year	608	93	48	7
Groundfall frequency				
Roof/rib fall fatalities	59	83	12	17
Roof fall injuries[2]	4,003	78	1,108	22
Rib fall injuries[2]	549	66	281	34
Noninjury roof falls	11,649	85	2,125	15
Groundfall incident rates[3]				
Roof/rib fatalities/200,000 hours	0.025		0.015	
Roof fall injuries/200,000 hours	1.71		0.72	
Rib fall injuries/200,000 hours	0.234		0.183	
Noninjury roof falls/million metric tons	7.12		1.27	

[1] Longwall data includes gateroad development.
[2] All falls resulting in degree of injury of 1 to 6 between 1999-2008.
[3] The combined rates are the total number of incidents divided byte total number of hours worked or total tonnage mined.

and 85% from room-and-pillar mines (Table 3). One reason longwall mines have lower noninjury roof fall rates is that fewer entries are mined, resulting in less exposed roof and most of the production comes from the longwall face, which is continuously supported and has minimal roof exposure. Conversely, the rib fall injury rate for both room-and-pillar mines and longwall mines are nearly identical. This may be because many room-and-pillar mines work thin-seams, where the rib fall hazard is minimal, while nearly all longwalls are mining thicker seams.

Because there is such a large and distinct difference between the groundfall safety records of the two mining methods, they will be evaluated separately in the remainder of this report.

Trends over time. In the past 10 years, productivity (metric tons/worker) in underground coal mines has dropped 9% for longwall mines and 20% for room-and-pillar mines (Fig. 4). For the room-and-pillar sector, during this period the number of workers increased by 12%, production decreased by 10% and there were 126 fewer mines. The number of longwall mines dropped by 10 over the same 10-year period, while the number of workers remained steady and production dropped by 7%. A previous study found that periods of increasing productivity are often associated with decreasing incident rates (Spokes, 1986). However, during this recent period of decreasing productivity, the converse has not been the case. The roof fall injury rates decreased by more than 50% in the 10-year period (Figs. 3 and 5) for both methods. These decreases in both roof fall injury rates and productivity may, perhaps, be attributed to the recent coal boom. After years of struggling financially, many coal mines were able to finally invest in updated equipment, better technology and more workers; these factors may have led to lower productivity and decreased roof fall injury rates.

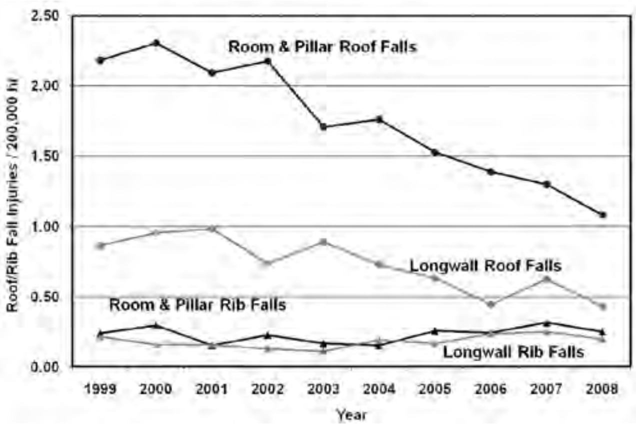

Figure 3 — Groundfall injury rates by mining method, based on MSHA (2009) data for 1999-2008.

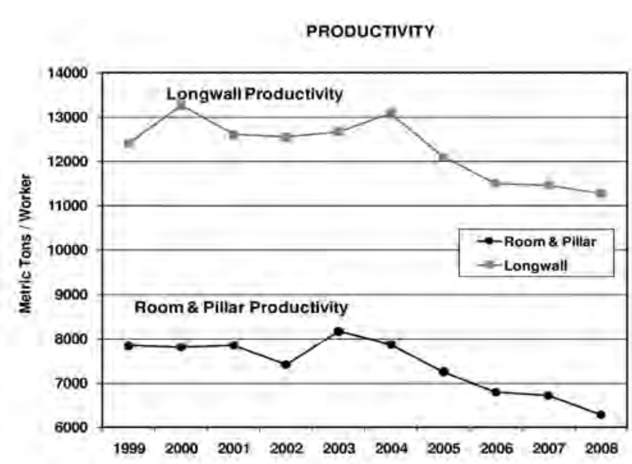

Figure 4 — Productivity by mining method, based on MSHA (2009) data for 1999-2008.

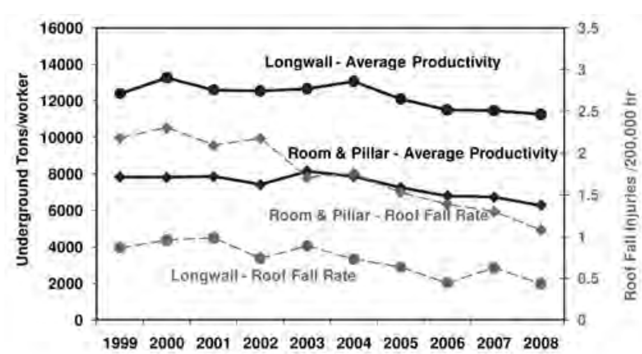

Figure 5 — Comparison of roof fall injury rate and productivity, based on MSHA (2009) data for 1999-2008.

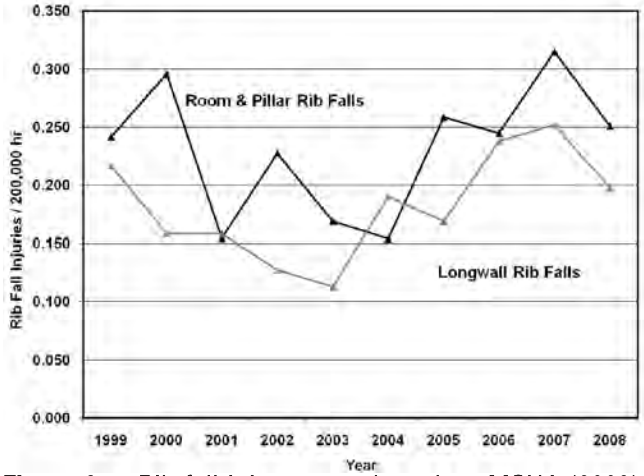

Figure 6 — Rib fall injury rates, based on MSHA (2009) data for 1999-2008.

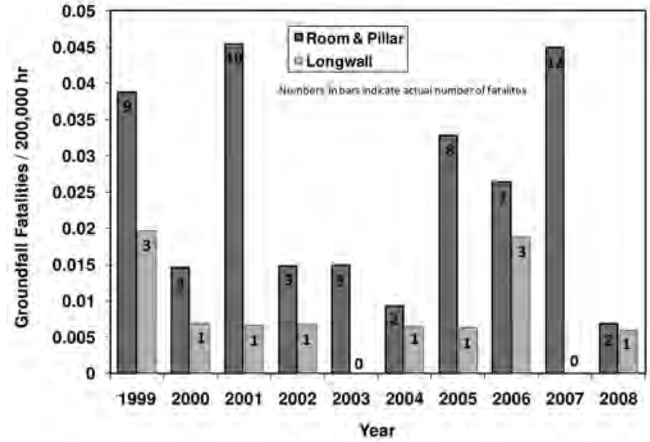

Figure 8 — Groundfall fatality rates, based on MSHA (2009) data for 1999-2008.

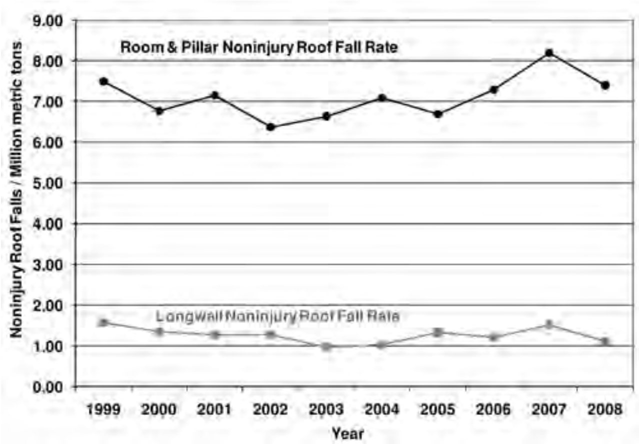

Figure 7 — Noninjury roof fall rates, based on MSHA (2009) data for 1999-2008.

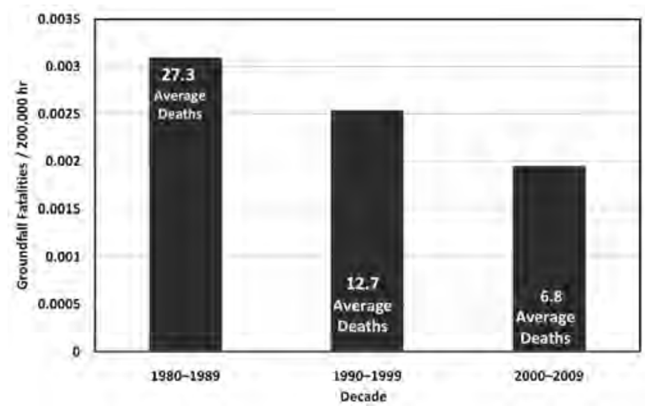

Figure 9 — Groundfall operator fatality rates and averages by decade, based on MSHA (2009) data for 1999-2008.

For both mining methods during the 10-year period, rib fall injury rates have shown a slight increase, while reportable noninjury roof fall rates were essentially constant (Figs. 6 and 7).

Fatal roof and rib falls were examined and grouped together, because these incidents occur infrequently and sporadically. Fatal groundfall rate trends were plotted for 10 years, with the data indicating no definitive trends in the fatality rate (Fig. 8). However, grouping the groundfall fatalities by decade (Fig. 9) shows that in the 1980s, an average of 27.3 groundfall deaths occurred each year. By the 1990s, the average dropped in half to 12.7 annual deaths and, by the first decade of the 21st century, it dropped in half once again to an average of 6.8 deaths per year. A review of the detailed MSHA groundfall fatality reports and classification of these incidents are presented in a later portion of this paper.

Locality. A review of roof fall injury rates at longwall operations (Fig. 10) in all coal mining locations in the United States found that western Kentucky and Illinois/Indiana had roof fall injury rates that were nearly three times the national longwall average. Conversely, the western United States and northern West Virginia/Ohio/Maryland had roof fall injury rates that were at least 40% lower than the national average.

Figure 11 shows similar trends for reportable noninjury roof falls in longwall mines. Western Kentucky and Illinois/Indiana again had noninjury roof fall rates that were about three times the national rate, while western United States and northern West Virginia/Ohio/Maryland together with Pennsylvania again had the lowest rates.

Roof fall injury rates for room-and-pillar mines (Fig. 10) did not vary dramatically among localities. However, the rate of noninjury reportable roof falls for room-and-pillar mines (Fig. 11) exceeded the national room-and-pillar mine average by nearly 50% in northern West Virginia/Ohio/Maryland and Illinois/Indiana.

Overall, it appears that Illinois/Indiana and western Kentucky tend to have higher roof fall incident rates than other areas. Geologic conditions seem to be the most likely explanation (Molinda et al., 2008). One recent study compared the measured uniaxial compressive strength of roof rocks in the Illinois Basin with that of roof 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 rock types (shale, siltstone and sandstone), the strength of the Illinois Basin variety was less than 50% of the strength of the same rock type in West Virginia (Rusnak and Mark, 2000).

It is intriguing that longwall mines in the northern Appalachian region had lower-than-average noninjury roof fall rates, while the rates for the region's room-and-pillar mines

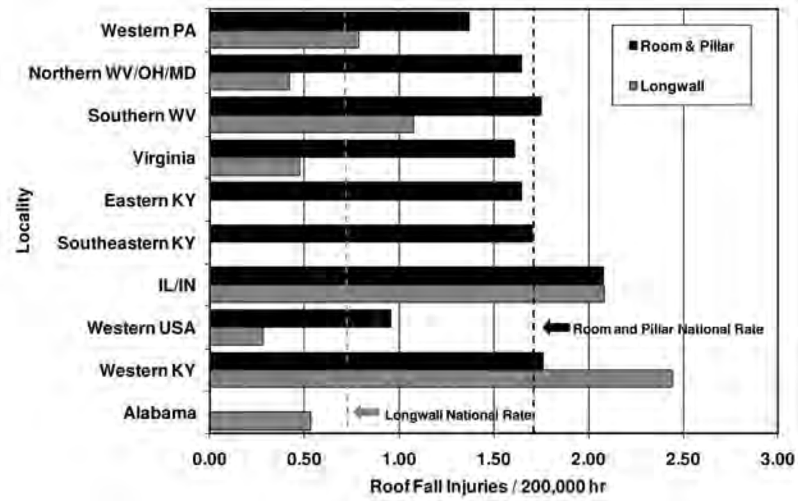

Figure 10 — Roof fall injury rates by region, based on MSHA (2009) data for 1999-2008.

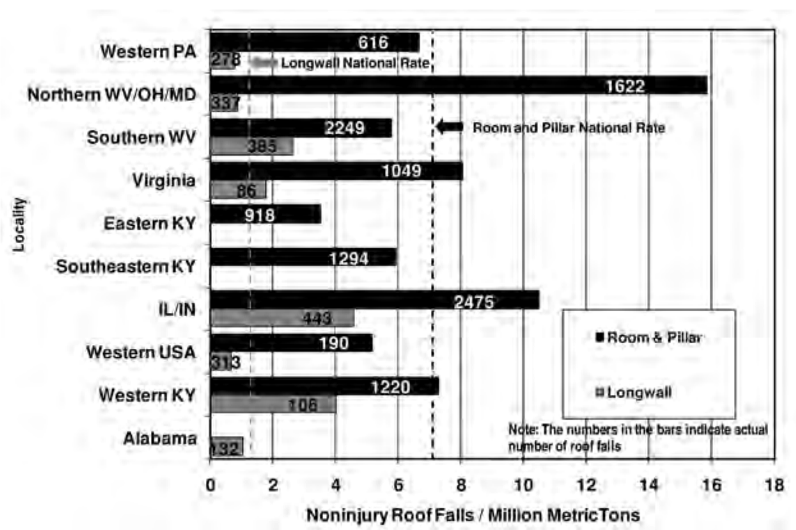

Figure 11 — Noninjury roof fall rates by region, based on MSHA (2009) data for 1999-2008.

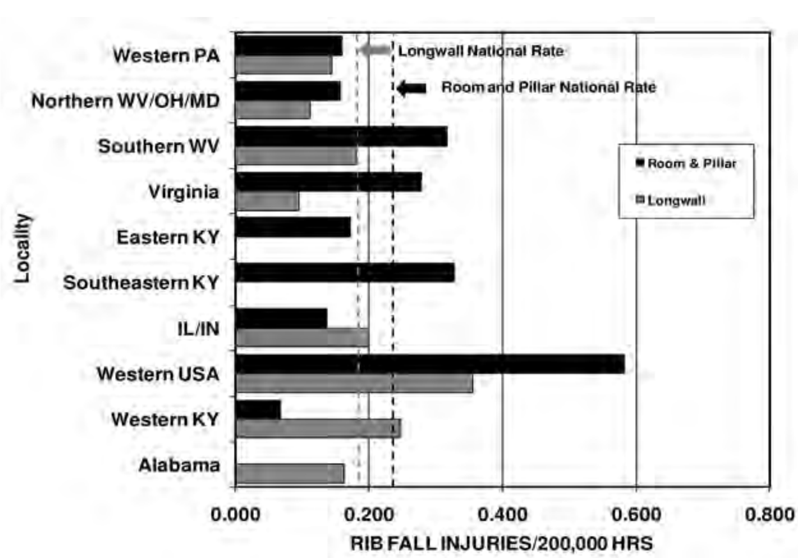

Figure 12 — Rib fall injury rates by region, based on MSHA (2009) data for 1999-2008.

were average or higher than average. Most of the longwalls in northern Appalachia are extracting the Pittsburgh seam, where the typical roof is also quite weak. However, most of these longwall mines drive their development entries with single-pass continuous miners with integral roof bolters. This mining method results in narrower gateroad entries (typically less than 5 m wide) which, combined with the near-immediate installation of roof support, greatly improves overall roof stability. Nearly every other U.S. longwall mine employs the "place changing" mining method, with separate mining and roof bolting machines, and entries that are 5.5-6.2 m wide.

The rib fall injury rates for both mining methods (Fig. 12) show that the western United States had rates that were double the national rate. High rates for room-and-pillar mines are also found in three of the four central Appalachian regions. This trend may be related to a recent study that found just 40 deep cover (depth greater than 1,000 ft) mines in this area, but these mines accounted for about one quarter of all rib fall injuries in room-and-pillar mines nationwide (NIOSH, 2010). In addition, during this period, few of these operations employed any rib support.

Seam height. Mines operating in thin seams <108.96 cm (43.9 in.) tend to be smaller mines that exclusively use the room-and-pillar extraction methods, whereas longwall mines operate only in a few medium seams 109.22-152.14 cm (43-59.9 in.), with the majority of longwall mines operating in thick seams >152.4 cm (60 in.). Because there is not a wide distribution of seam heights for longwall mines, data from room-and-pillar mines will only be used in this analysis. Figure 13 shows the results of reportable noninjury roof fall rates, based on seam height, and indicates that thin-seam mines had a 30% lower noninjury roof fall rate than the national average. Conversely, the ultrathick seams had a 20% higher (Fig. 13) noninjury roof fall rate than the national average. However, a further inspection of these noninjury falls reveals that they occur predominantly in the Illinois Basin area (Fig. 14). The weak roof rock typically encountered in the Illinois Basin is the most likely explanation for the higher roof fall rate in those mines. Once the Illinois Basin mines are removed, the noninjury roof fall rate for the remaining ultrathick-seam mines is not significantly above the overall average.

The ultra-thick seams had a 50% higher groundfall fatality rate than the national average (Fig. 15), which is in contrast to the thin and medium seams that had fatality rates 30% lower than the national rate. This significantly higher fatality rate can be attributed to the Crandall Canyon disaster, which occurred in an ultrathick seam and represented 30% of the ultrathick seam, room-and-pillar mine fatalities.

Figure 16 shows that, nationwide, rib fall injury rates increase approximately in proportion to the seam height. A deeper look at the locations of these rib fall rates (Fig. 17) shows that the ultrathick seam mines in the western

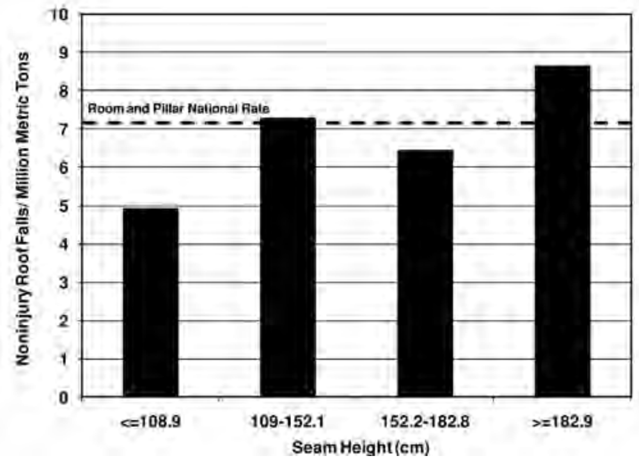

Figure 13 — Noninjury roof fall rates by seam height for room-and-pillar mines, based on MSHA (2009) data for 1999-2008.

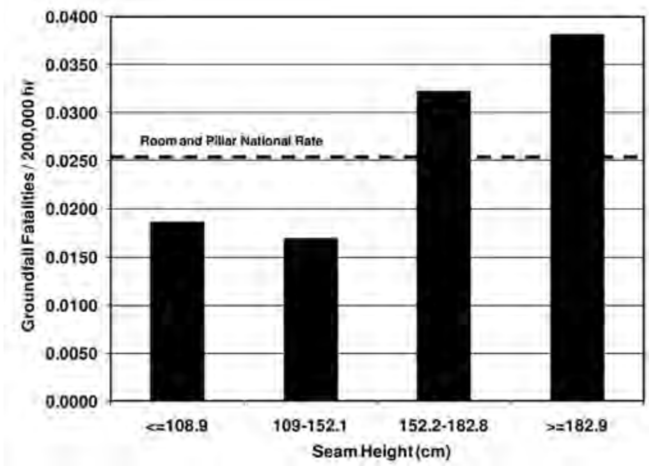

Figure 15 — Groundfall fatality rates by seam height for room-and-pillar mines, based on MSHA (2009) data for 1999-2008.

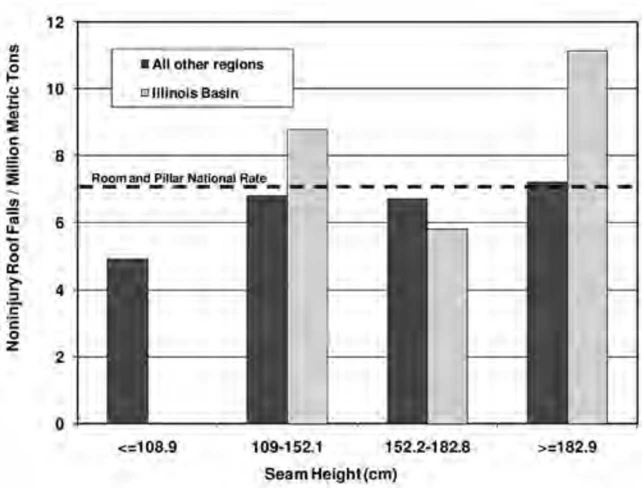

Figure 14 — Comparison of noninjury roof fall rates for Illinois Basin and the remaining United States, based on MSHA (2009) data for 1999-2008.

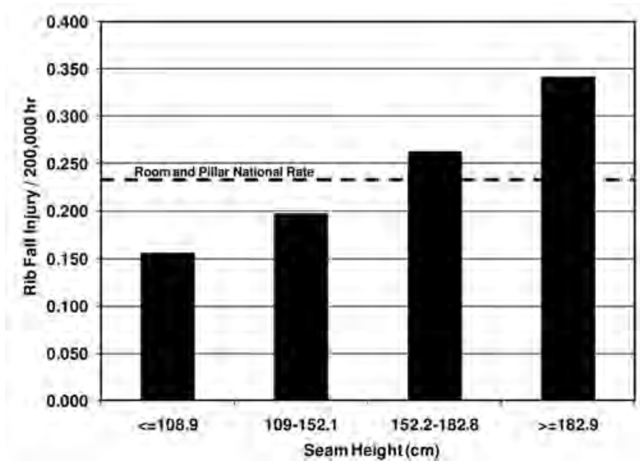

Figure 16 — Rib fall injury rates by seam height for room-and-pillar mines, based on MSHA (2009) data for 1999-2008.

United States and in southern West Virginia had rib fall rates that were significantly above the industry average. The ultrathick coal seams in the western United States are much thicker than elsewhere, averaging 263 cm (104 in.) compared to the rest of the country at 223-230 cm (88-90 in.) (Fig. 18). Perhaps as the mining height increases, a great surface area of the rib is exposed and is at risk of becoming unstable or prone to collapse. The western U.S. coal mines are also associated with deeper coalbeds (Mark et al., 2009). Another contributing factor related to the higher rib fall injury rates in the ultrathick seams is the

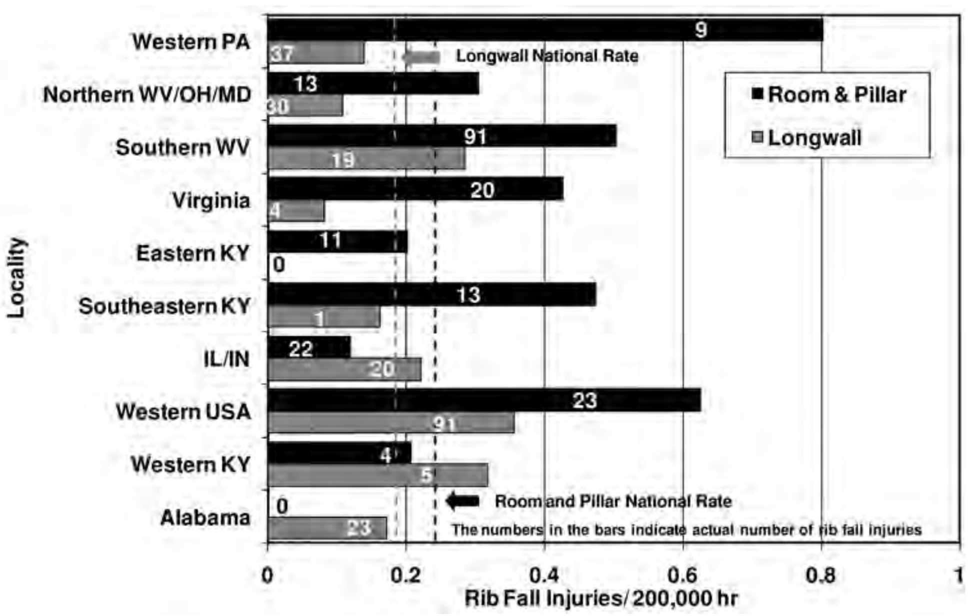

Figure 17 — Rib fall injury rates for ultra-thick seams by region, based on MSHA (2009) data for 1999-2008.

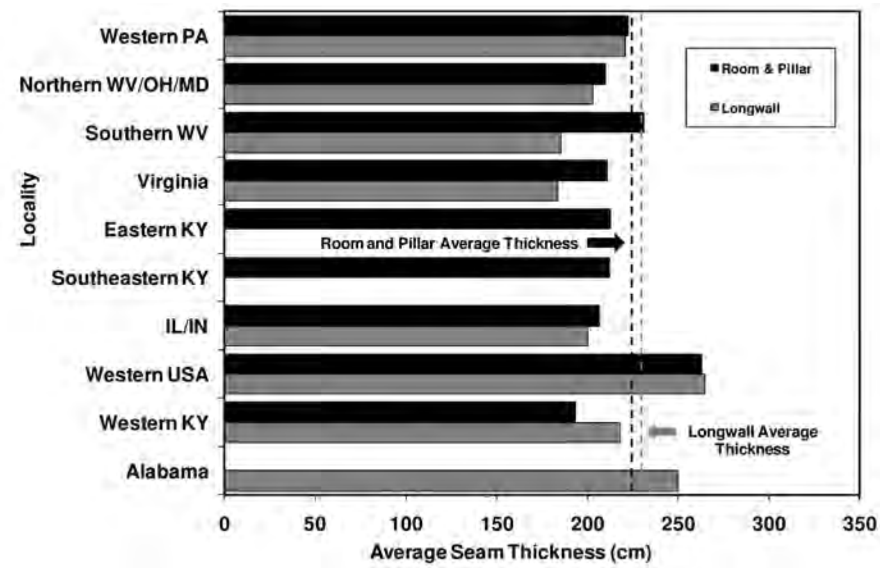

Figure 18 - Average seam thickness for ultra-thick seams by region, based on MSHA (2009) data for 1999-2008.

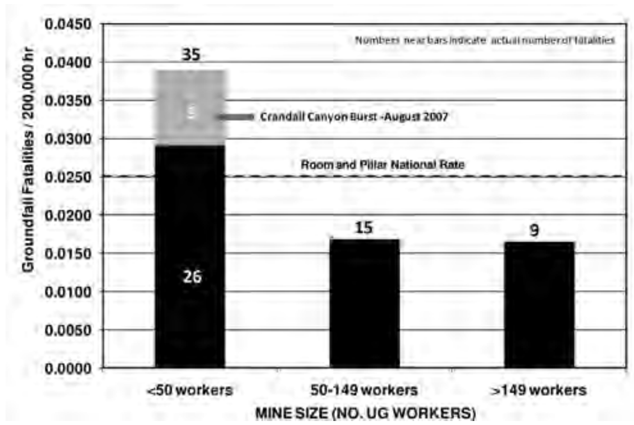

Figure 19 — Groundfall fatality rates by mine size for room-and-pillar mines, based on MSHA (2009) data for 1999-2008.

bump/burst events that routinely occur in the western United States and are categorized in the MSHA database as rib fall incidents. Analysis of the rib fall incident narratives indicates that one-third of the rib fall injuries in the western United States are associated with bump/burst events.

The reasons for the high rib fall injury rate in southern West Virginia's ultrathick seam mines are less clear. Unlike the western United States, the ultrathick seam mines in southern West Virginia have average seam heights that are similar to or less than the national ultrathick seam heights (Fig. 18). Western Pennsylvania also has a severe rib fall injury rate for room-and-pillar mines, but this may be a statistical anomaly because of the small number of mines in this category.

Mine size. The proportion of room-and-pillar mine sizes are fairly evenly distributed among the three mine-size categories (i.e., small, medium, and large) based on underground hours worked (Table 1). However, longwall mines are disproportionately distributed among the three categories, with 93% falling into the large-mine category (Table 2). Therefore, the mine-size analysis includes only the room-and-pillar mines.

The analysis found that there were only minor differences between the mine-size groupings for the injury and reportable noninjury groundfall incident rates. However, the fatality rate for small mines (< 50 workers) was about twice that for smaller mines (Fig. 19). Approximately 60% of the fatal room-and-pillar groundfalls from 1999 through 2008 occurred in mines with <50 workers. The Crandall Canyon disaster again explains some of this discrepancy, but the small mine fatality rate is still high, even with those nine deaths removed. An elevated groundfall fatality rate in small mines was also identified in two studies, one in the early 1980s and one in the late 1990s (Pappas, 1987; Pappas and Mark, 2000).

Coalbed. A critical analysis was conducted to determine if certain coalbeds were more susceptible to groundfall. Every coalbed is assigned a three- or four-digit identification bed code number by the U.S. Geological Survey. Frequently, several coalbed names are grouped together in one code number since they are geologically similar. Because the coalbed is not a defined parameter in the MSHA database, bed codes from 1999 through 2002 were obtained from the U.S. Department of Energy's Energy Information Agency and updated using the various state agency websites that compile coalbed classifications for individual mines. This data was merged with the MSHA employment and injury data associated with every underground coal mine in the study. Bed codes were identified for 90% of the room-and-pillar mines, accounting for 96% of the hours worked at room-and-pillar mines. Bed codes were identified for every longwall mine in this study.

To filter out coalbeds with low production and ambiguous incident rates, all coalbeds with fewer than nine million tons produced (cumulative 1999–2007) were removed from the analysis. For comparison purposes, a national roof fall rate was determined from the entire dataset, which included incidents from all coalbeds. The more significant coalbeds were selected by calculating the percentage that the coalbed groundfall rate exceeded the national rate. All coalbeds with extreme rates (higher or lower than the national rate by at least 25%), are listed regionally for room-and-pillar mines (Tables 4a, 5a and 6a) and longwall mines (Tables 4b, 5b and 6b). A critical factor in evaluating coalbed groundfall rates is the proportion of production represented in each region with the extreme groundfall rates. The broad regions used in Tables 4-6 are not necessarily the same as the more specific regions used in the earlier analyses (shown in Figs. 10-12). Many coalbeds in these specific regions were found to overlap; broader regions were found to be a more accurate method of defining the location of coalbeds (e.g., the central Appalachian area is comprised of southern West Virginia, Virginia and eastern and southeastern Kentucky).

The most notable trends in Tables 4a-4b are the high noninjury roof fall rates in the Illinois Basin coalbeds. For longwall mines, coalbeds that account for 100% of the coal production in that region (i.e., all longwall mines) have exceptionally high noninjury roof fall rates. The same trend is also found for room-and-pillar mines, where coalbeds accounting for 91% of the

Table 4a — Extreme noninjury roof fall rates by coalbed for room-and-pillar mines, based on MSHA (2009) data for 1999-2007.

Mining method	Region	Coalbed [2]	Bed code	No. UG workers	Under-ground hours worked	Under-ground production (metric tons)	Representation of production by region	No. Mines[1]	No. Non-injury roof falls	Noninjury roof fall rate falls/million metric tons	Above/ below national rate
Room-and-Pillar	Northern Appalachian	Upper Kittanning	76	3,841	7,979,284	24,316,755	44%	68	565	23.235	226.4%
High Rates		Sewickley	29	1,225	2,392,396	8,814,187		51	144	16.337	129.5%
		Upper Freeport	71	3,690	7,730,388	28,104,466		111	405	14.411	102.5%
		Pittsburgh	36	2,417	4,857,596	15,293,166		69	138	9.024	26.8%
	Central Appalachian	Jawbone/ Iaeger	266	3,150	5,852,508	15,939,548	4%	125	206	12.924	81.6%
		Pocahontas No. 12	311	1,520	3,127,059	8,549,472		64	82	9.591	34.8%
		Kellioka	152	2,416	5,446,341	15,815,355		64	140	8.852	24.4%
	Illinois Basin	Danville/ No. 7	480	2,573	5,993,202	22,249,348	91%	16	273	12.270	72.4%
		Springfield/ No. 5/KY No. 9	489	20,600	48,260,389	209,520,412		146	1992	9.507	33.6%
		Herrin/No. 6/ KY No. 11	484	9,144	20,399,665	91,716,293		75	820	8.941	25.6%
Room-and-Pillar	Central Appalachian	Glamorgan	185	1,921	3,416,299	8,380,872	36%	88	23	2.744	-61.4%
Low Rates		Stockton-Lewiston/ Mercer	103	3,230	6,822,547	33,539,857		57	103	3.071	-56.9%
		Lower Cedar Grove/Elk-horn No. 2	154	3,291	6,366,000	20,609,795		126	70	3.396	-52.3%
		Winifrede/ Hazard No. 5	121	4,359	9,468,744	42,158,759		94	152	3.605	-49.3%
		Eagle	176	3,070	6,347,100	21,822,016		64	87	3.987	-44.0%
		Alma/Elk-horn No. 1/ Blue Gem	157	6,159	11,659,956	32,327,749		284	141	4.362	-38.7%
		Powellton	170	4,077	9,522,024	34,570,247		75	155	4.484	-37.0%
		Darby/Owl/ Jellico	151	17,680	37,457,321	120,781,921		544	542	4.487	-37.0%
		Splash Dam	210	2,825	5,057,584	12,215,997		125	62	5.075	-28.7%
	Illinois Basin	W. KY No. 13	482	653	1,545,287	9,057,404	3%	12	19	2.098	-70.5%

[1] The total number of mines for 1999-2007 is not mutually exclusive (if a mine worked all nine years, it is counted nine times).

[2] Excludes coalbeds with less than 9 million tons for 1999-2007.

Table 4b — Extreme noninjury roof fall rates by coalbed for longwall mines, based on MSHA (2009) data for 1999-2007.

Mining method	Region	Coalbed [2]	Bed code	No.UG workers	Under-ground hours worked	Under-ground production (metric tons)	Represen-tation of produc-tion by region	No. Mines[1]	No. Non-injury roof falls	Noninjury roof fall rate falls/ million metric tons	Above/ below national rate
Longwall	Northern Appalachian	Upper Freeport	71	1,496	3,288,242	23,014,517	3%	9	47	2.042	61.4%
High Rates	Central Appalachian	Alma/Elkhorn No. 1/Blue Gem	157	1,114	2,805,529	8,936,880	90%	7	39	4.364	244.8%
		Darby/Owl/ Jellico	151	741	1,900,600	8,511,052		5	37	4.347	243.5%
		Upper Alma/ Alma A	156	1,457	3,261,595	13,828,333		6	47	3.399	168.6%
		Powellton	170	1,099	2,784,709	12,653,594		8	33	2.608	106.1%
		Eagle	176	5,383	12,862,791	65,661,292		28	152	2.315	82.9%
		Pocahontas No. 3	344	7,982	17,261,528	66,998,359		26	140	2.090	65.1%
	Southern Appalachian	Pratt/Corona	227	2,526	5,553,543	25,536,993	22%	9	64	2.506	98.0%
	Illinois Basin	Springfield/No. 5/KY No. 9	489	6,221	14,601,051	66,508,393	100%	14	313	4.706	271.9%
		W. KY No. 13	482	1,454	3,311,715	14,157,666		5	63	4.450	251.6%
		Herrin/No. 6/KY No. 11	484	3,291	6,920,811	32,930,280		14	135	4.100	223.9%
Longwall	Northern Appalachian	Pittsburgh	36	49,635	112,698,999	638,752,782	95%	128	503	0.787	-37.8%
Low Rates	Central Appalachian	Lower Cedar Grove/Elkhorn No. 2	154	493	1,075,294	12,618,884	6%	3	6	0.475	-62.4%
	Southern Appalachian	Blue Creek/Mary Lee	280	15,273	33,876,693	83,940,082	73%	43	54	0.643	-49.2%
	Western USA	Upper Hiawatha	1,847	1,647	3,326,723	57,287,896	67%	9	2	0.035	-97.2%
		Hanna No. 5	1,820	1,141	2,424,633	21,877,364		8	1	0.046	-96.4%
		Lower Sunnyside	1,802	878	1,999,146	18,382,537		7	1	0.054	-95.7%
		Wadge/Roland of Tuff	1,750	2,844	6,208,771	67,025,030		9	20	0.298	-76.4%
		Hiawatha	1,846	2,344	4,718,039	39,319,055		15	15	0.381	-69.9%
		Blind Canyon	1,855	1,292	2,551,196	18,016,004		5	9	0.500	-60.5%
		D Seam	1755	2,648	5,289,815	59,850,807		14	38	0.635	-49.8%

[1] The total number of mines for 1999-2007 is not mutually exclusive (if a mine worked all nine years, it is counted nine times).

[2] Excludes coalbeds with less than 9 million tons for 1999-2007.

Table 5a — Extreme roof fall injury rates by coalbed for room-and-pillar mines, based on MSHA (2009) data for 1999-2007.

Mining method	Region	Coalbed [2]	Bed code	No. Work-ers	Under-ground hours	Under-ground production (metric tons)	Representation of production by region	No. Mines[1]	No. Roof fall injuries	Roof injury rate (falls/200khrs)	Above/ below national rate
Room-and-pillar high rates	Central Appalachian	Eagle	176	3,070	6,347,100	21,822,016	27%	64	93	2.930	63.1%
		Jawbone/ laeger	266	3,150	5,852,508	15,939,548		125	79	2.700	50.2%
		Powellton	170	4,077	9,522,024	34,570,247		75	118	2.478	37.9%
		Coalburg/ Hazard No. 7	111	8,063	16,584,352	74,604,733		221	202	2.436	35.6%
		Imboden/ No. 6/KY No. 11	168	12,536	28,513,845	96,858,114		245	325	2.280	26.9%
	Illinois Basin	Herrin/No. 6/KY No. 11	484	9,144	20,399,665	91,716,293	26%	75	252	2.471	37.5%
Room-and-pillar low rates	Northern Appalachian	Lower Freeport	74	1,822	4,180,325	16,503,700	9%	37	19	0.909	-49.4%
	Central Appalachian	Splash Dam	210	2,825	5,057,584	16,503,700	8%	125	24	0.949	-47.2%
		Glamorgan	185	1,921	3,416,299	12,215,997		88	17	0.995	-44.6%
		Lower Winifrede	122	1,013	2,360,274	8,380,872		19	12	1.017	-43.4%
		Pocahontas No. 12	311	1,520	3,127,059	9,942,945		64	18	1.151	-35.9%
	Illinois Basin	W. KY No. 13	482	653	1,545,287	9,057,404	3%	12	2	0.259	-85.6%

[1] The total number of mines for 1999-2007 is not mutually exclusive (if a mine worked all nine years, it is counted nine times).
[2] Excludes coalbeds with less than 9 million tons for 1999-2007.

Table 5b — Extreme roof fall injury rates by coalbed for longwall mines, based on MSHA (2009) data for 1999-2007.

Mining method	Region	Coalbed [2]	Bed code	No. Workers	Under-ground hours	Under-ground production (metric tons)	Representation of production by region	No. Mines[1]	No. Roof fall injuries	Roof injury rate (falls/200khrs)	Above/ below national rate
Longwall high rates	Central Appalachian	Powellton	170	1,099	2,784,709	12,653,594	44%	8	24	1.724	127.4%
		Darby/Owl/ Jellico	151	741	1,900,600	8,511,052		5	11	1.158	52.7%
		Eagle	176	5,383	12,862,791	65,661,292		28	72	1.120	47.7%
	Illinois Basin	W. KY No. 13	482	1,454	3,311,715	14,157,666	71%	5	60	3.624	378.0%
		No. 5/ Springfield/ KY No. 9	489	6,221	14,601,051	66,508,393		14	186	2.548	236.1%
Longwall low rates	Northern Appalachian	Clarion	87	1,442	3,344,288	11,877,851	2%	6	3	0.179	-76.3%
	Southern Appalachian	Pratt/Corona	227	2,526	5,553,543	25,536,993	22%	9	12	0.432	-43.0%
	Illinois Basin	Herrin/No. 6/ KY No. 11	484	3,291	6,920,811	32,930,280	29%	14	18	0.520	-31.4%
	Western USA	Wadge/Ro-land of Tuff	1,750	2,844	6,208,771	67,025,030	96%	9	3	0.097	-87.3%
		Castle Gate A	1,830	1,583	3,487,030	21,145,399		10	2	0.115	-84.9%
		Blind Canyon	1,855	1,292	2,551,196	18,016,004		5	2	0.157	-79.3%
		Fruitland No. 8	1,488	1,302	2,936,028	28,336,005		5	3	0.204	-73.0%
		Hiawatha	1,846	2,344	4,718,039	39,319,055		15	7	0.297	-60.9%
		Lower Sun-nyside	1,802	878	1,999,146	18,382,537		7	3	0.300	-60.4%
		Hanna No. 5	1,820	1,141	2,424,633	21,877,364		8	4	0.330	-56.5%
		Upper Hiawatha	1,847	1,647	3,326,723	57,287,896		9	6	0.361	-52.4%
		D Seam	1,755	2,648	5,289,815	59,850,807		14	11	0.416	-45.1%
		B Seam	1,753	4,395	8,792,193	74,436,886		25	23	0.523	-31.0%

[1] The total number of mines for 1999-2007 is not mutually exclusive (if a mine worked all nine years, it is counted nine times).
[2] Excludes coalbeds with less than 9 million tons for 1999-2007.

room-and-pillar production in the region have high noninjury roof fall rates. The four coalbeds with the highest noninjury roof fall rates in the Illinois Basin include the (1) Springfield/ No. 5/Kentucky No. 9, (2) Herrin/No. 6/Kentucky No. 11 , (3) Danville/No. 7 (room-and-pillar only) and (4)Western Kentucky No. 13 (longwall only). Several of these same coalbeds also had high roof fall injury rates (Tables 5a-5b). However, fewer Illinois Basin coalbeds had high roof fall injury rates (compared to noninjury roof fall rates), and they accounted for only 26% of the room-and-pillar production and 71% of the longwall production. Certainly, a unique set of geological circumstances are responsible for this regional concentration of roof falls, as mentioned previously.

Other troubling trends from this analysis were the exceptionally high (greater than 100% higher than the national rate) noninjury roof fall rates associated with 44% of the room-and-pillar production in the northern Appalachian region, specifically the Upper Kittanning, Sewickley and Upper Freeport coalbeds (Table 4a). Weaker geology is the most likely explanation (Mark et al., 2004). The data also confirms that, despite the weak roof, longwall mines in the northern Appalachian region (Pittsburgh coalbed) maintained an admirable record, with noninjury roof fall rates significantly lower than the rest of the country for 95% of the longwall production in

Table 6a – Extreme rib fall injury rates by coalbed for room-and-pillar mines, based on MSHA (2009) data for 1999-2007.

Mining method	Region	Coalbed [2]	Bed code	No. UG Workers	Underground hours	Underground production (metric tons)	Representation of production by region	No. Mines[1]	No. Rib fall injuries	Rib fall injury rate (falls/200khrs)	Above/ below national rate
Room-and-pillar - high rates	Northern Appalachian	Upper Kittanning	76	3,841	7,979,284	24,316,755	23%	68	16	0.401	72.9%
		Pittsburgh	36	2,417	4,857,596	15,293,166		69	8	0.329	42.0%
	Central Appalachian	Eagle	176	3,070	6,347,100	21,822,016	46%	64	24	0.756	226.0%
		Pocahontas No. 12	311	1,520	3,127,059	8,549,472		64	11	0.704	203.2%
		Powellton	170	4,077	9,522,024	34,570,247		75	21	0.441	90.1%
		Alma/Elkhorn No. 1/Blue Gem	157	6,159	11,659,956	32,327,749		284	25	0.429	84.8%
		Lower Winifrede	122	1,013	2,360,274	9,942,945		19	5	0.424	82.6%
		Winifrede/Hazard No. 5	121	4,359	9,468,744	42,158,759		94	18	0.380	63.9%
		Pocahontas No. 11	318	2,157	3,686,514	10,257,263		113	7	0.380	63.7%
		Imboden/Warfield	168	12,536	28,513,845	96,858,114		245	45	0.316	36.1%
		Jawbone/laeger	266	3,150	5,852,508	15,939,548		125	9	0.308	32.6%
		Pardee/Parsones/ Limestone	126	1,474	2,620,248	9,170,018		68	4	0.305	31.6%
		Kellioka	152	2,416	5,446,341	15,815,355		64	8	0.294	26.6%
		Darby/Owl/Jellico	151	17,680	37,457,321	120,781,921		544	55	0.294	26.6%
Room-and-pillar - low rates	Northern Appalachian	Middle Kittanning	80	1,764	3,368,944	15,784,209	73%	45	0	0.000	-100.0%
		Lower Freeport	74	1,822	4,180,325	16,503,700		37	0	0.000	-100.0%
		Upper Freeport	71	3,690	7,730,388	28,104,466		111	4	0.103	-55.4%
		Lower Kittanning	84	6,295	12,961,566	59,074,308		195	10	0.154	-33.5%
		Sewickley	29	1,225	2,392,396	8,814,187		51	2	0.167	-27.9%
	Central Appalachian	Splash Dam	210	2,825	5,057,584	12,215,997	17%	125	1	0.040	-83.0%
		Sewell	285	1,898	3,926,347	11,985,683		76	1	0.051	-78.0%
		Stockton-Lewiston/Mercer	103	3,230	6,822,547	33,539,857		57	3	0.088	-62.1%
		Glamorgan	185	1,921	3,416,299	8,380,872		88	2	0.117	-49.5%
		Pocahontas No. 3	344	2,443	4,696,647	11,293,561		90	3	0.128	-44.9%
		Hazard No. 4	135	11,320	24,161,669	79,800,733		294	18	0.149	-35.8%
	Illinois Basin	W. KY No. 13	482	653	1,545,287	9,057,404	68%	12	0	0.000	-100.0%
		No. 5/Springfield/ KY No. 9	489	20,600	48,260,389	209,520,412		146	14	0.058	-75.0%
		Danville/No. 7	480	2,573	5,993,202	22,249,348		16	2	0.067	-71.2%

[1] The total number of mines for 1999-2007 is not mutually exclusive (if a mine worked all nine years, it is counted nine times).
[2] Excludes coalbeds with less than 9 million tons for 1999-2007.

Table 6b – Extreme rib fall injury rates by coalbed for longwall mines, based on MSHA (2009) data for 1999-2007.

Mining method	Region	Coalbed [2]	Bed code	No. UG workers	Underground hours	Underground production (metric tons)	Representation of production by region	No. Mines[1]	No. Rib fall injuries	Rib fall injury rate (falls/200khrs)	Above/ below national rate
Longwall High Rates	Central Appalachian	Upper Alma/ Alma A	156	1,457	3,261,595	13,828,333	41%	6	5	0.307	69.4%
		Eagle	176	5,383	12,862,791	65,661,292		28	17	0.264	46.0%
	Illinois Basin	W. KY No. 13	482	1,454	3,311,715	14,157,666	12%	5	5	0.302	66.8%
	Western U.S.	Lower Sunnyside	1,802	878	1,999,146	18,382,537	48%	7	9	0.900	397.4%
		D Seam	1,755	2,648	5,289,815	59,850,807		14	16	0.605	234.2%
		Blind Canyon	1,855	1,292	2,551,196	18,016,004		5	5	0.392	116.6%
		Hiawatha	1,846	2,344	4,718,039	39,319,055		15	8	0.339	87.4%
		Wadge/Roland of Tuff	1,750	2,844	6,208,771	67,025,030		9	8	0.258	42.4%
Longwall Low Rates	Northern Appalachian	Upper Freeport	71	1,496	3,288,242	23,014,517	5%	9	0	0.000	-100.0%
		Clarion	87	1,442	3,344,288	11,877,851		6	0	0.000	-100.0%
	Central Appalachian	Lower Cedar Grove/ Elkhorn No. 2	154	493	1,075,294	12,618,884	45%	3	0	0.000	-100.0%
		Pocahontas No. 3	344	7,982	17,261,528	66,998,359		26	6	0.070	-61.6%
		Alma/Elkhorn No. 1/Blue Gem	157	1,114	2,805,529	8,936,880		7	1	0.071	-60.6%
	Southern Appalachian	Pratt/Corona	227	2,526	5,553,543	25,536,993	22%	9	3	0.108	-40.3%
	Illinois Basin	Herrin/No. 6/ KY No. 11	484	3,291	6,920,811	32,930,280	29%	14	2	0.058	-68.1%
	Western U.S.	Castle Gate A	1,830	1,583	3,487,030	21,145,399	5%	10	2	0.115	-36.6%

[1] The total number of mines for 1999-2007 is not mutually exclusive (if a mine worked all nine years, it is counted nine times).
[2] Excludes coalbeds with less than 9 million tons for 1999-2007.

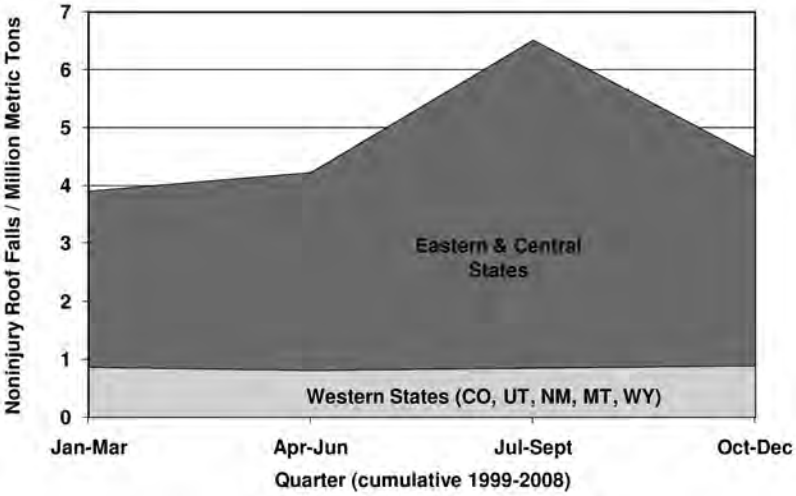

Figure 20 — Noninjury roof fall rates by quarter for both mining methods, based on MSHA (2009 and 2010) data for 1999-2008.

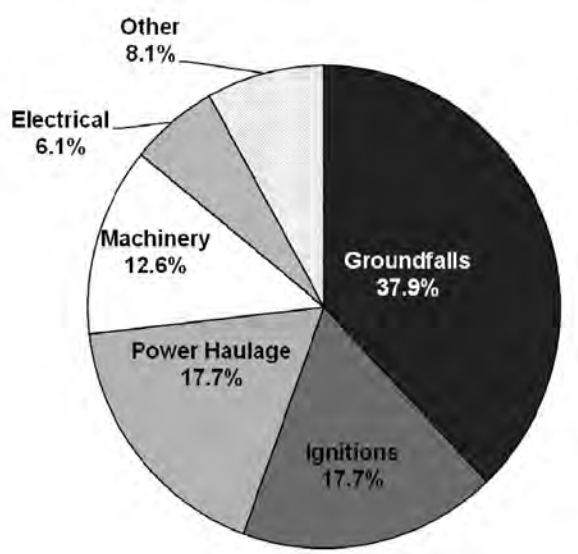

Figure 21 — Proportion of groundfall fatalities compared to all fatalities, based on MSHA (2008) data for 1999-2008.

that region. In central Appalachia, 36% of the room-and-pillar production was linked to coalbeds with low noninjury roof fall rates and 90% of the longwall production linked to coalbeds with high noninjury roof fall rates (Tables 4a-4b). The four most problematic coalbeds were the (1) Alma/Elkhorn No. 1/ Blue Gem, (2) Darby/Owl/Jellico, (3) Upper Alma/Alma A and (4) Powellton coalbeds.

Similar to rib fall injuries is the central Appalachian region, where coalbeds representing 46% of the room-and-pillar production and 41% of the longwall production have rib fall injury rates that exceed the national average (Tables 6a-b).

A severe rib fall injury rate, several magnitudes higher than the national rating, is associated with 48% of the longwall production in the western United States (Table 6b). The thick seams and deep overburdens associated with the western United States probably contribute to the rib control problems and make the rib face more prone to mountain bumps and bursts. Conversely, the roof fall injury trends in the western United States were significantly lower than the national rate and represented 96% of the longwall production in this region (Table 5b). These low roof fall injury rates can be attributed to the nearly universal use of roof screening in the western United States (Compton et al., 2008).

Seasonal patterns. The chronological quarterly roof fall rates were evaluated to determine if seasonal patterns, such as fluctuations in temperature, barometric pressure and humidity, affect 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, the data from Colorado, New Mexico, Montana, Utah and Wyoming were evaluated separately. Although monthly production data is not compiled, quarterly production data was accessed from MSHA's Standardized Information System (MSHA, 2010), which allowed the groundfall incidents to be normalized based on the quarterly underground production. Figure 20 shows that the noninjury roof fall incident rate was fairly consistent, except for the third quarter (July–September), where the roof fall rate was more than 50% higher than the overall 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. Further confirmation of this hypothesis is provided by the data from the western mines, which have less change in humidity and do not display a seasonal trend (Fig. 20).

Other studies have found similar seasonal patterns. The U.S. Bureau of Mines (Stateham and Radcliffe, 1978) found in its report of investigations that humidity has a strong influence on roof fall occurrence rates. Those results indicated that the probability of a roof fall is greatest in August and lowest in February.

Analysis of MSHA fatality reports. For the second segment of the study, the individual MSHA fatality reports (MSHA, 2008) were reviewed, and critical details related to the cause of the incident were compiled for both bituminous operator and contractor groundfall incidents. From 1999 through 2008, 66 of these events resulted in 75 fatalities (71 operator and four contractor), which accounted for 38% of all underground fatalities (Fig. 21). Figure 9 shows groundfall operator fatalities by decade for the past 30 years. With each passing decade, the number of groundfall fatalities has dropped by half, and the fatality rates by about 20%–25%, from the previous decade. Because yearly groundfall fatality rates from this past decade (1999–2008) are volatile (Fig. 8), these rates were converted into three-year, running-average fatality rates in Fig. 22. There are slight downward trends in both room-and-pillar and longwall groundfall fatality rates, but the *R*-squared values are very low.

Pillar recovery. 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. As shown in Fig. 23, pillaring fatalities accounted for

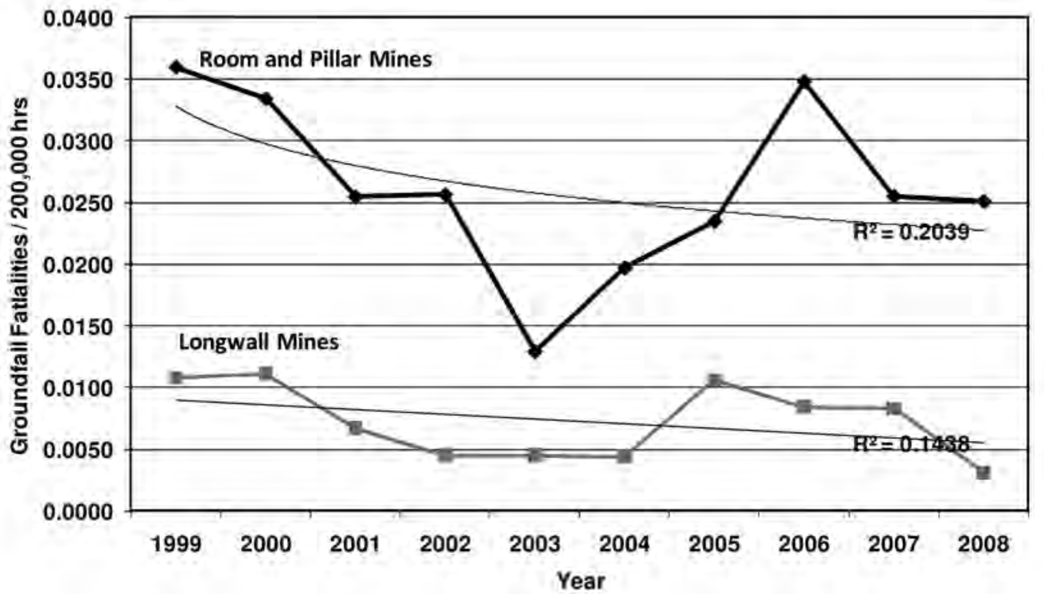

Figure 22 — Three-year running average of groundfall fatality rates, based on MSHA (2008) data for 1999-2008. The fitted curves are logarithmic for the room-and-pillar mines and linear for longwall mines.

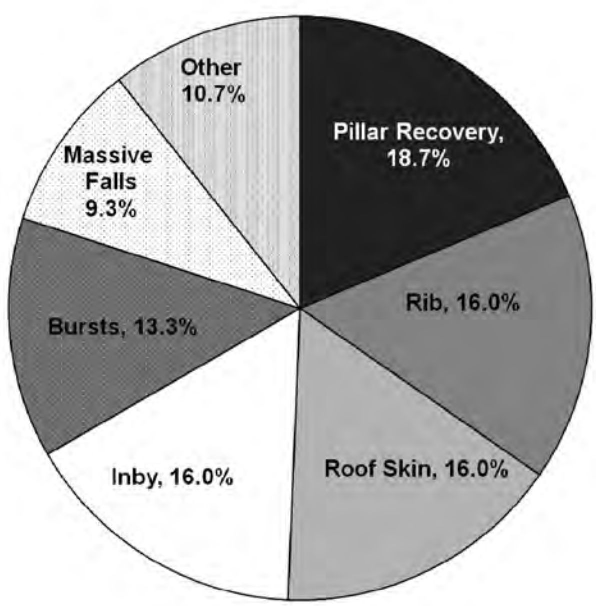

Figure 23 — Causes of groundfall fatalities, based on MSHA (2008) data for 1999-2008.

19% of all groundfall fatalities during 1999–2008, including two multiple fatality incidents. According to Fig. 24, most of these roof fall incidents occurred in the earlier part of this period (prior to 2001). Only one incident, a multiple fatality, has occurred since the end of 2005. The improvement has been attributed to widespread use of safety technologies, including mobile roof supports, engineered final stumps and additional roof support (Mark et al., 2009).

Rib failures. Rib failure is often associated with rock partings, discontinuities within the pillar or overhanging brows created by roof drawrock. During the past 10 years, rib failures resulted in 12 fatalities, or 16% of all groundfall fatalities, as shown in Fig. 23. These rib fall fatalities do not include bursts, which were included for previously reported rib fall injuries; burst fatalities will be addressed separately in this paper. Although rib fall fatalities are at about the same level as they were during the previous study (Pappas and Mark, 2000), rib fall injuries have generally increased (Fig. 6). As mentioned previously, seam height is a significant factor in rib failures. Because the seam height defines only the average height of the seam, mining height is a more accurate value available only with the more detailed fatality reports. Mining height defines the actual height of the mine opening at the site of the fatality, which may include roof rock. The average mining height related to all rib fall fatalities was 248.92 cm (98 in.) compared to 172.72 cm (68 in.) for the average roof fall fatality. All rib fall fatalities occurred with mining heights greater than 208.28 cm (82 in.). In addition, the incidence of rib fall injuries increases dramatically once the seam height reaches above 182.88 cm (6 ft), as shown in Fig. 16. For room-and-pillar mines, the rib fall injury rate exceeds the national average by 45% for seam heights greater than 182.88 cm (72 in.) (Fig. 16).

Roof-skin failures. Most roof-skin injuries occur under permanently supported roof and involve workers in a wide variety of activities. Roof-skin failures are incidents that do not involve failure of the roof-support elements, but result from rock spalling from between roof bolts or automated temporary roof-support systems. Roof-skin failures are of particular concern, because they cause injuries and fatalities to workers who should have been protected by these support systems. A previous study (Pappas and Mark, 2000) found roof-skin fatalities to be the fourth-leading cause of groundfall (12% of fatalities during 1996-1999) compared to this current study, in which roof-skin fatalities are the third-leading cause of groundfalls (16% of fatalities 1999-2008). The median size of a fatal roof-skin failure in this study is approximately 1.31 m x 1.28 m x 0.146 m (4.3 ft x 4.2 ft x 0.48 ft) compared to 1.34 m x 1 m x 0.125 m (4.4 ft x 3.3 ft x 0.41 ft) in the previous study. By far, the most effective roof-skin-control method is the use of roof screening (Compton et al., 2008). Other common roof-skin-control techniques include oversized plates, header boards, wood planks, steel straps and (in rare instances) spray-on coatings.

Unsupported roof. Twenty years ago, nearly 50% of all groundfall fatalities occurred beneath unsupported roof (Peters, 1992). Although there are no grounds for complacency, the current fatality trend for miners traveling under unsupported roof has been significantly reduced to 16% of all groundfall fatalities (Fig. 23). Figure 25 shows that the number of unsupported-roof fatalities dropped dramatically during the past 14 years, and that only three fatalities have occurred in the past six years. The improvement was achieved through new

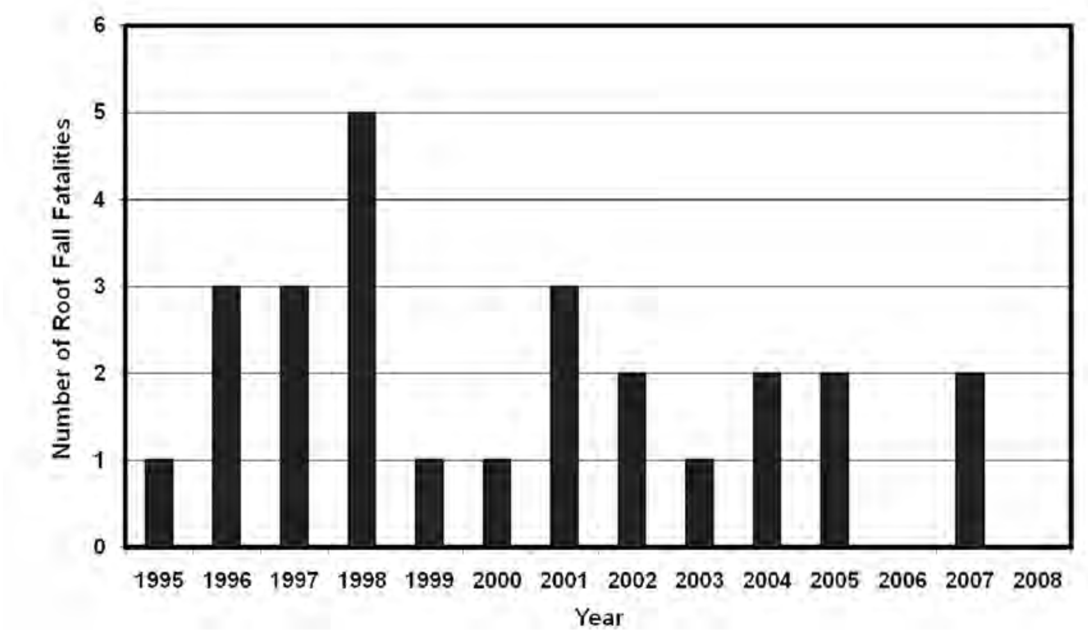

Figure 24 — Fatality trends for pillaring operations, based on MSHA (2008) data for 1995-2008.

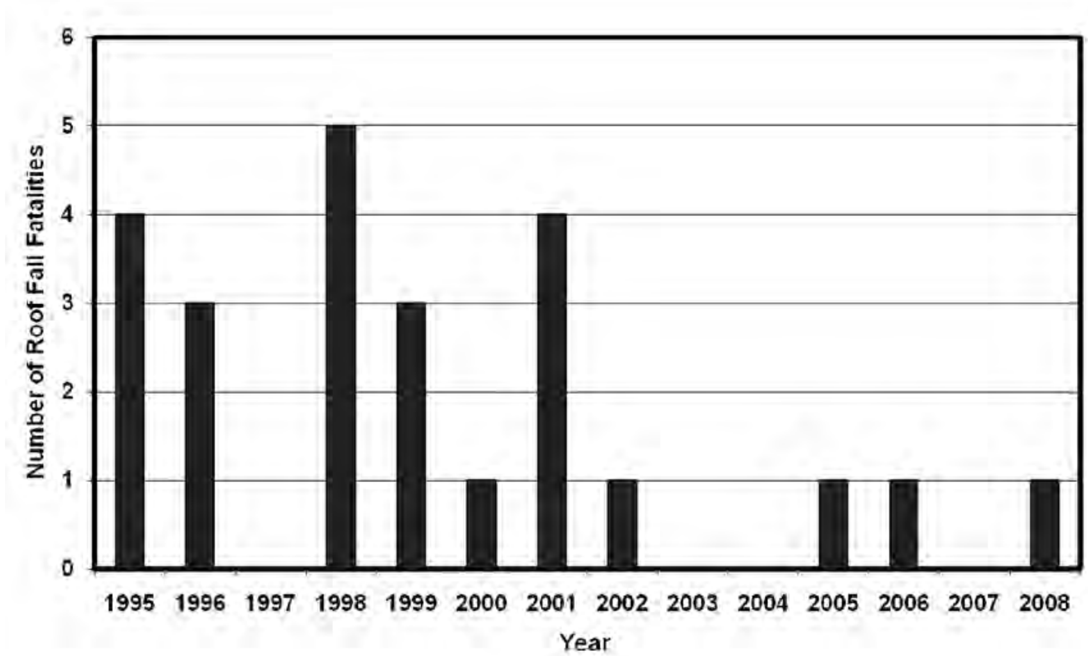

Figure 25 — Fatality trends for travelling under unsupported roof, based on MSHA (2009) data for 1995-2008.

equipment, enforcement and a persistent educational campaign organized by MSHA.

Bursts. Bursts, also known as mountain bumps, are sudden violent ground failures of highly-stressed coal. Typically, bursts are not a separate category, but have been included under the rib fall category. However, largely due to the recent Crandall Canyon disaster, burst incidents accounted for more than 13% of all groundfall fatalities during the past 10 years (Fig. 23). Bursts generally occur when the coal deposit is sandwiched between strong floor and roof strata, where the overburden exceeds 305 m (1,000 ft), and where longwall or pillar-retreat mining is employed. These types of incidents are usually limited to the coalfields of the western United States and the central Appalachian region. In fact, all of the recent fatalities occurred in the Utah coalfields.

Massive falls. Massive roof falls, typically as large as an entire coal mine intersection, can usually be attributed to the failure of the roof-support system. In 70% of the massive fall fatalities, geologic discontinuities, such as transition zones with slickensides, horseback and drag folds, were contributing factors. These roof defects were either undetected or were not recognized as hazardous. Other fatalities occurred when the depth of cut or width was not reduced due to adverse conditions, and/or supplemental support was not used. Other failures were attributed to weathered rock near the outcrop during the development of a mine opening, or to a fall during rehabilitation of a previous fall.

Other roof fall fatalities. Roof falls that do not fit into any of the previous categories comprised 11% of all groundfall fatalities, or eight fatalities. Four fatalities in this category are associated with miners working in "red zone" areas. These red zone areas are noted in many recent roof-control plans where miners must stay outby the second row of roof bolts, particularly when making extended cuts or turning a crosscut. Perhaps the recent downward trend in inby fatalities mentioned earlier can be partially attributed to this "red zone" concept (Mark, 2009). The 5th and 6th fatalities are associated with longwall mining. One miner was changing shearer bits over a hanging brow that fell, and the other miner was drilling into the roof between the longwall shield tips and the face. The 7th fatality is due to a rock fall during slope sinking. Finally, the last fatality resulted from a complex situation where a boom hole was blasted out, and the miner was attempting to install roof bolts without an automated temporary roof support system (ATRS) due to the extreme height involved.

Research application

Despite the fact that groundfall injuries have decreased in the past decade, there is a definite need to identify areas where continued or new research is needed to accelerate this downward trend. Probably the most noticeable trend within this data review was the higher noninjury and injury roof fall rates that continue to plague the Illinois Basin. It appears that geological conditions of regional coalbeds are the controlling factor associated with a weaker roof. Further study of this phenomenon is needed, as well as practical preventative methods to mitigate noninjury and injury roof falls. Techniques such as reduction of entry widths, cable bolting combinations, roof screening and sealants that prevent rock weathering might be highly effective. It is speculated that the use of single-pass continuous miners used with integral roof bolters is beneficial in reducing roof fall injury rates in the northern Appalachian coalfields, and perhaps experimentation with this machinery in the Illinois Basin might yield valuable results. In addition, the weathering issue can be related to the higher trend of roof falls during the summer months, possibly due to changes in humidity levels that may cause moisture sensitive mine roofs to deteriorate. Perhaps the use of mine air conditioning during the summer months or the use of an inexpensive spray-on coating could minimize these problems. Another research area that needs to be addressed are the high rib fall injury rates in central Appalachia and the western United States. Identifying the most appropriate rib support for different mining applications might be the most effective role for research in this area.

Conclusions

The consequences of roof fall and rib fall incidents are extensive, ranging from the economic loss of equipment and production to fatal and nonfatal injuries that result in lasting physical and financial impairments suffered by the victims and the victims' families. In addition, the mining industry is severely impacted by these injuries, as well as thousands of noninjury incidents that damage equipment, stop production or disrupt ventilation. This study used a two-pronged approach in analyzing the current trends in groundfall injuries. The largest portion of the study used the MSHA database, where groundfall injury rates could be determined based on mining method, yearly trends, locality, seam height, mine size and seasonal effects. The second segment of the study reviewed the MSHA groundfall fatality reports to break down the specific causes of groundfall incidents. Mines using the room-and-pillar mining method had a roof fall injury rate that was 2.4 times the longwall roof fall injury rate.

The study found that, compared with the previous decade, groundfall fatality rates decreased by 25%, and the number of fatalities was cut in half. Roof fall injury rates dropped 50% for both the longwall and the room and pillar mining methods. Overall, however, longwall mines compiled a much better groundfall safety record. Longwall mining accounted for 51% of the production and 40% of the hours worked, but only 17% of groundfall fatalities, 22% of the roof fall injuries and 15% of the noninjury roof falls.

The regional analysis showed that mines in the Illinois Basin (western Kentucky and Illinois/Indiana) had roof fall injury and noninjury rates that exceeded the national rate. Their high rates are attributable to the generally weak roof rocks that are found in the region. Nearly every coalbed that is mined in the region was associated with high roof fall rates.

In contrast, longwall mines in the northern Appalachian area (Pennsylvania, Ohio and northern West Virginia) had lower than average rates, despite their weak roof. The integral continuous miners used in the region, which develop narrow entries that are supported immediately, are the likely explanation. However, several coalbeds in the region had exceptionally high noninjury roof fall rates for the room-and-pillar mining method.

Rib fall injury rates in the western United States were double the national rate for both mining methods, due to their thick seams and deep cover. However, western U.S. longwalls had very low roof fall injury rates, because of the widespread use of roof screen.

Nationwide, ultrathick seam room-and-pillar mines (seam heights greater than 182.88 cm (72 in.)) had a 45% higher rib fall injury rate than the national average. These higher rates are concentrated in the western United States and southern West Virginia. Ultrathick seam mines also had a 50% higher groundfall fatality rate, primarily due to the large number of rib fall fatalities in the Crandall Canyon Disaster and the prevalence of retreat mining operations in southern West Virginia.

A review of seasonal patterns revealed that, for mines located in the eastern U.S., the third quarter (July–September) had a 50% increased risk of noninjury roof falls compared to the other three quarters. This is likely due to higher humidity levels during the summer months, which was further confirmed by the observation that there was no seasonal trend in the roof fall data from the western mines.

A total of 66 fatal groundfall incidents, resulting in 75 fatalities, occurred from 1999 through 2008. The detailed MSHA fatality reports were probed to identify the underlying causes. During this period, pillar recovery was still the leading cause of groundfall fatalities, responsible for 19% of the total. However, in the latter part of the study period, the pillar recovery fatality frequency dropped due to the widespread use of safer pillar recovery techniques. The second-leading cause was rib falls, resulting in 16% of the fatalities. All the rib fall fatalities occurred with seam heights greater than 208.28 cm (82 in.); 62% of the fatalities occurred with overburden depths greater than 213.40 m (700 ft).

Roof-skin fatalities that occurred beneath supported roof, accounted for another 16% of the total. Roof-skin incidents are of particular concern, because they also were responsible for almost all of the more than 400 roof fall injuries that occurred each year. Nearly all of these incidents could be prevented by better surface controls, such as roof screen. In recent years, the number of fatalities caused by miners going under an unsupported roof has dropped significantly; however, these fatalities still accounted for 16% of all groundfall fatalities during the period. Coal bursts accounted for 13% of all groundfall deaths, most of which occurred at the Crandall Canyon mine in 2007. Massive roof falls, linked to roof support failures, resulted in nearly 9% of groundfall fatalities and more than 1,000 noninjury roof falls that occur each year. They underline the need for better design of roof support systems.

These groundfall statistics and fatality report trends offer the most current profile of roof and rib falls in the United States. This study identifies areas where additional research is needed so that innovative solutions can be developed to reduce these severe hazards to underground mine workers.

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