# ROOF AND RIB FALL INCIDENTS AND STATISTICS: A RECENT PROFILE

By Deno M. Pappas,[1] Eric R. Bauer,[2] and Christopher Mark, Ph.D.[3]

## ABSTRACT

During 1998-99, groundfall incidents resulted in 27 fatalities and were responsible for over 70% of all deaths in U.S. underground coal mines. To obtain a better understanding of where and why these incidents occurred, a comprehensive analysis of groundfall injuries and fatalities was conducted. The first portion of the study examined various factors associated with roof and rib fall injuries and reportable roof fall noninjuries that occurred during 1995-98. The study found that the room-and-pillar mining method has twice the groundfall incident rate than the longwall method. Mine locations with high groundfall rates seem to correlate to regions where there is a higher concentration of problematic coalbeds. For example, the Illinois Basin has very high groundfall rates, which can be traced back to several key coalbeds-Kentucky No. 13, Herrin/No. 6/ Kentucky No. 11, and Springfield No. 5/Kentucky No. 9. High rib fall rates were found in mines located in thick seams. Groundfall rates were found to be 30% to 40% higher during the months of July through September, possibly due to high humidity that may cause the shale mine roof to deteriorate.

The second part of the study examined the root causes of failure by reviewing all groundfall fatality reports for 1996-99. Primary and secondary hazard factors were assigned to each groundfall incident. The primary factors resulting in these groundfall fatalities were pillar extraction, traveling under unsupported roof, skin failure, construction, longwall faces, intersections, and geologic discontinuities. 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.

[1]Civil engineer.
[2]Mining engineer.
[3]Supervisory physical scientist.
Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, PA.

## INTRODUCTION

Underground coal mining has always 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 while mining coal. Approximately 47% of these fatalities, involving 40,000 miners, have occurred because of falls of roof and rib, which is a greater proportion than for any other type of incident classification. As shown in figure 1, more than 1,000 roof and rib fall fatalities occurred annually until the early 1930s. Decreases in roof and rib fatalities in the 1930s and late 1940s seem to coincide with drops in production due to slowdowns in the economy during to the Great Depression and the post-World War II recession. The use of roof bolts and the mechanization of the mining industry in the early 1950s considerably improved productivity and required a smaller workforce. As the number of miners worked underground decreased, so did the number of groundfall fatalities. However, the actual rate of roof and rib fatalities did not significantly drop until after the early 1960s. This drop may be due to several factors, including greater use of mechanical and then resin-grouted roof bolts, the Federal Coal Mine Health and Safety Act of 1969, research by the former U.S.Bureau of Mines (USBM) in the development of automated temporary roof supports (ATRS) and canopies, and the creation of the Mine Safety and Health Administration (MSHA), which mandated ground control safety and training programs [Pappas 1987].

Although the frequency of roof and rib fatalities has significantly decreased, from 1,300 fatalities in 1910 to 14 fatalities in 1998, groundfalls still injured 850 workers in 1998, resulting in 26,000 days lost. In addition to the injuries, more than 1,800 noninjury roof falls occurred in 1998. These noninjury roof falls were usually massive falls that extended beyond the height of the bolts, damaged equipment, stopped production, or disrupted ventilation. It has been estimated that the total cost of groundfall injuries during 1985-89 was $123.9 million, or approximately $1 million for every fatality and $6,835 for every injury [Peters and Randolph 1991].

The USBM identified increases and/or patterns that influenced groundfall injury rates during 1980-84 associated with mining method, mining height, geographic location, and mine size [Pappas 1987]. This study found that during that

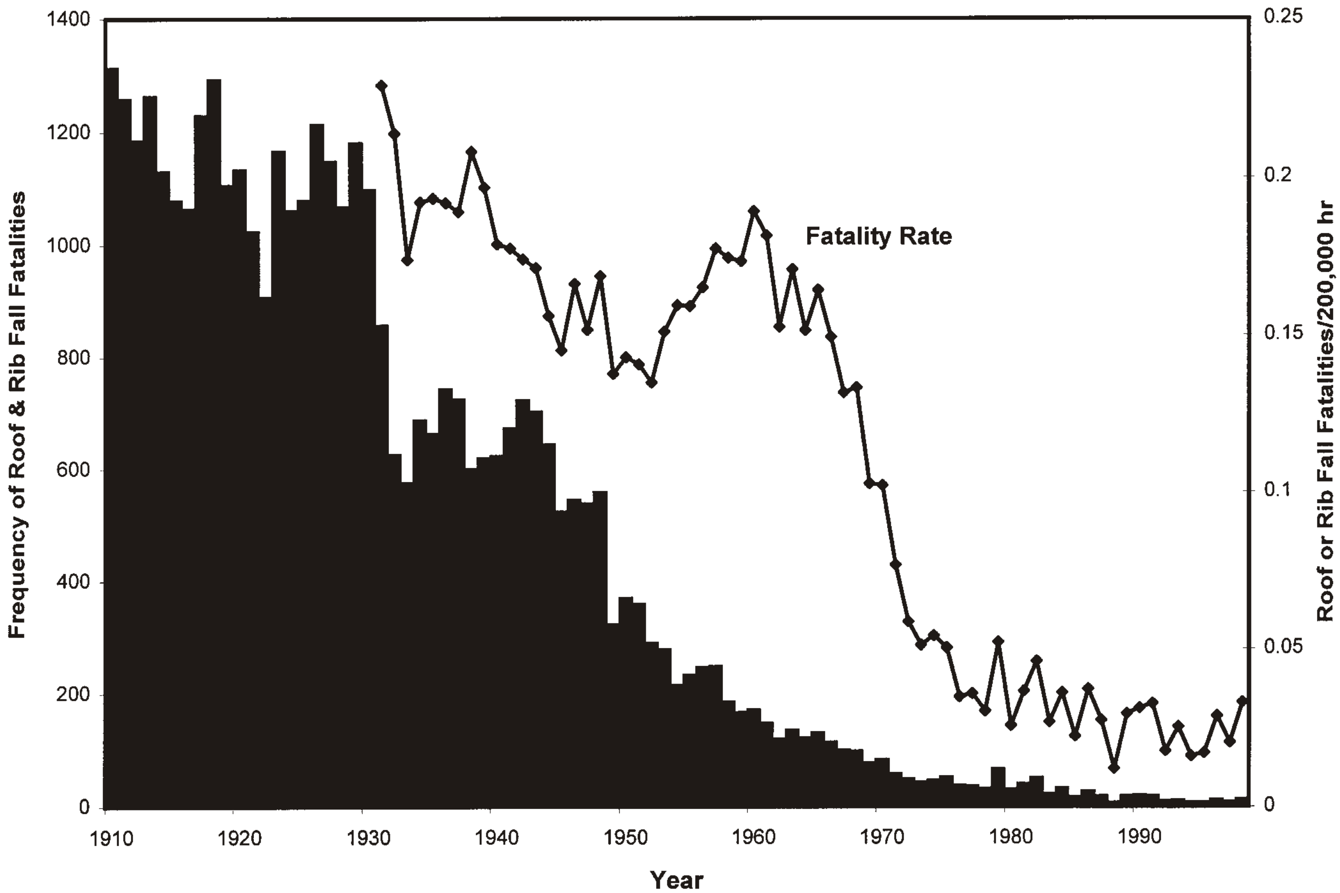


**Figure 1.—Historical overview of groundfall fatalities, 1910-98. (Source: MSHA data.)**

period, small mines (<50 employees) had severe groundfall fatality incidence rates about 5 to 20 times the fatality rate of medium- and large-sized mines. A slightly different study conducted by Fotta et al. [1995] found that in the Appalachian region in the early 1990s, small-mine groundfall fatality rates were elevated, but were significantly decreasing from levels in previous years. Although these studies are not identical, they indicate that dramatic changes were occurring in underground coal mines that were dynamically influencing groundfall patterns and characteristics. A major factor that may have influenced these fatality rate changes is the dramatic rise in use of the longwall mining method. Longwall mining in the United States has revolutionized and streamlined the process of mining underground coal by vastly improving mine productivity and miner safety. When the USBM study was conducted in 1984, longwall mining accounted for about 18% of the underground production; by 1994, however, longwall production doubled to about 37%. These more efficient longwall mines may have resulted in many smaller room-and-pillar mines closing or becoming more productive and safer in order to stay competitive with the longwall mines. This may have resulted in the dramatic decrease in small-mine fatality rates. Consequently, the goal of this study is to update groundfall fatality, injury, and noninjury incidence rates where the significant factor of longwall mining can be evaluated separately from room-and-pillar mining operations. The various attributes examined include mining method, location, mine size, seam height, coalbed, and seasonal patterns. In addition, specific hazards contributing to groundfall fatalities are discussed based on details compiled from MSHA fatality reports.

## METHODOLOGY

Raw data for this study were obtained from the MSHA accident and address (listing of all operating mines) databases. The study examined the close-out data for the period 1995-98 for underground coal mines, excluding contractors. Ground control incidents included all roof and rib falls listed in the database, as well as incidents classified as "machinery" where the source of injury was caving rock. The narratives of these machinery-related groundfalls were reviewed to classify whether the incident was a roof or rib fall. For this study, roof and rib fall incidents were categorized into four groups:

1. Roof fall injury incidents resulting in death, in a permanent disability, in days away from work or days of restricted work activity, or in no lost workdays or restricted activity (degree of injury: 1-6).
2. Noninjury reportable roof fall incident (degree of injury: 0). 30 CFR 50.20-5 requires that every roof fall in active workings that occurs above the roof bolt anchorage, impairs ventilation, or impedes passage be reported.
3. Fatal roof or rib fall incident (degree of injury: 1).
4. Rib fall injury incident resulting in the same injuries listed in item 1 above.

The noninjury reportable roof fall incidence rate is important because it consistently tracks catastrophic roof failures according to MSHA regulations. A high noninjury roof fall rate may indicate situations where severe roof control problems are occurring since these incidents are associated with massive roof failure.

All incidents are converted into an incidence rate by computing the number of roof or rib fall incidents divided by the number of hours worked underground per 200,000 hr. The 200,000 hr approximates the number of hours worked by 100 full-time miners per year.

The two methods of mining-room-and-pillar versus longwall-were separated out for most of the analyses. The longwall mines were identified for each year by review of the annual longwall census and knowledgeable longwall mining individuals. It was determined that most longwall mines are dedicated exclusively to mining longwalls and gate road development; these mines were not proportioned by mining method. Therefore, all production originating from these designated mines were determined to be longwall mines; everything else was designated as room-and-pillar mine.

Major coal-producing locations in the United States were examined to identify trends. The eastern Kentucky region has minimal longwall production; by the end of the study period, no longwall was operational. Although the eastern Kentucky rates are listed, they should not be considered in the study since they represent very little production. Eastern Pennsylvania's anthracite coalfields are rather unique due to their folded stratigraphy, which is more similar to hard-rock mines than bituminous coal mines. Ground control conditions in eastern Pennsylvania are not equivalent to the other coal-mining locations, but are listed for consistency purposes.

Seam height used in the MSHA database is defined as the average height of coal seam currently being mined. There may be some variation in the seam height at the actual site of the incident versus the seam height listed in the MSHA database. Although the fatality reports record the actual working seam height at the site of the incident, this information is not available for all of the other types of injuries. To be consistent, this study will use the MSHA database seam height. Three categories of seam height are usually selected based on distribution of employee hours and other constraints [Fotta and Mallett 1997]. Thin-seam heights are ≤42 in, medium-seam heights are 43-60 in, and thick-seam heights are ≥61 in. Approximately 1.3% of the total underground hours are from mines where no seam height was recorded or was misreported and so were excluded from this portion of the study.

Mine size is based on the average annual number of employees working in the underground mine. Three categories of mine size that were selected are based on distribution of employee hours. Small-sized mines have ≤49 workers, medium-sized mines have 50 to 149 workers, and large-sized mines have ≥150 workers.

To obtain a greater understanding of the specific hazards associated with roof or rib fall fatalities, all underground groundfall fatality reports were examined for 1996-99. The fatality reports provide much more information than can be obtained from the MSHA injury narratives. The cause of failure for each groundfall fatality was reviewed by several individuals to minimize subjectivity and were categorized into eight primary and secondary hazard groups.

## MINE CHARACTERISTICS

Table 1 breaks out several characteristics associated with room-and-pillar coal mines, such as the mining method, location, mine size, and seam height. Table 2 lists the same attributes associated with longwall mines. Specific factors that quantify these mine attributes during 1995-98 include the number of hours worked underground, number of mines, frequency of roof and rib fall injuries, and associated incidence rates.

### MINING METHOD

According to figure 2, the roof fall injury incidence rate for room-and-pillar mines is more than double the longwall roof fall rate. On the other hand, the rib incidence rate for the two methods is nearly identical. The significantly lower longwall roof fall rate may be related to the continuous roof protection provided by the longwall face supports at the active mining face and the greater number of support workers located outby the mining face. The nearly identical rib fall rate probably reflects the thicker seams that are mined using longwalls. Table 3 compares the two mining methods. It is interesting to note that even though longwall mines represent only 6% of the underground coal mines, they are significantly larger on average, accounting for 48% of all the underground coal produced and 22% of all roof falls. Room-and-pillar operations represent 94% of the mines and account for 52% of the tonnage and 78% of all roof falls. It is also of interest that the percentage of reportable noninjury roof falls is very similar

**Table 1.—Attributes of roof and rib fall injuries at room-and-pillar mines, 1995-98**

| Room-and-pillar characteristics | Hours worked | | Mines | | Roof falls[2] | | Rib falls[2] | | Incident rate | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. | % | No. | % | No. | % | No. | % | Roof falls per 200,000 hr | Rib falls per 200,000 hr |
| Location: | | | | | | | | | | |
| Eastern PA | 1,090,084 | 0.5 | 180 | 5.0 | 2 | 0.1 | 3 | 0.9 | 0.37 | 0.55 |
| Western PA | 16,332,658 | 7.6 | 189 | 5.3 | 134 | 6.1 | 15 | 4.4 | 1.64 | 0.18 |
| Northern WV/OH/MD | 9,829,896 | 4.6 | 185 | 5.2 | 85 | 3.8 | 9 | 2.6 | 1.73 | 0.18 |
| Central WV | 51,605,701 | 24.2 | 908 | 25.5 | 504 | 22.8 | 114 | 33.4 | 1.95 | 0.44 |
| VA | 24,543,233 | 11.5 | 583 | 16.4 | 273 | 12.4 | 32 | 9.4 | 2.22 | 0.26 |
| Eastern KY | 35,843,027 | 16.8 | 719 | 20.2 | 341 | 15.4 | 40 | 11.7 | 1.90 | 0.22 |
| Central KY and TN | 28,965,438 | 13.6 | 557 | 15.6 | 311 | 14.1 | 51 | 15.0 | 2.15 | 0.35 |
| IL/IN | 22,411,104 | 10.5 | 76 | 2.1 | 314 | 14.2 | 36 | 10.6 | 2.80 | 0.32 |
| Western U.S. | 5,584,663 | 2.6 | 76 | 2.1 | 48 | 2.2 | 35 | 10.3 | 1.72 | 1.25 |
| Western KY | 15,279,890 | 7.2 | 73 | 2.0 | 163 | 7.4 | 4 | 1.2 | 2.13 | 0.05 |
| AL | 2,150,106 | 1.0 | 19 | 0.5 | 35 | 1.6 | 2 | 0.6 | 3.26 | 0.19 |
| Mine size: | | | | | | | | | | |
| <50 workers | 96,827,951 | 45.3 | 3,049 | 85.5 | 963 | 43.6 | 128 | 37.5 | 1.99 | 0.26 |
| 50-149 workers | 80,891,498 | 37.9 | 439 | 12.3 | 855 | 38.7 | 145 | 42.5 | 2.11 | 0.36 |
| >149 workers | 35,916,351 | 16.8 | 77 | 2.2 | 392 | 17.7 | 68 | 19.9 | 2.18 | 0.38 |
| Seam height:[3] | | | | | | | | | | |
| <43 in | 60,797,201 | 28.5 | 1,581 | 44.3 | 540 | 24.4 | 56 | 16.4 | 1.78 | 0.18 |
| 43-60 in | 86,382,352 | 40.4 | 1,177 | 33.0 | 957 | 43.3 | 115 | 33.7 | 2.22 | 0.27 |
| >60 in | 63,556,005 | 29.7 | 706 | 19.8 | 686 | 31.0 | 168 | 49.3 | 2.16 | 0.53 |
| All room-and-pillar mines | 213,635,800 | — | 3,565 | — | 2,210 | — | 341 | — | 2.07 | 0.32 |

[1]The total number of mines for 1995-98 is not mutually exclusive (e.g., if a mine operated all 4 years, it is counted four times).
[2]All falls resulting in degree of injury of 1 to 6.
[3]Approximately 1.3% of the hours worked were at mines that did not report or misreported the seam height and are excluded.

**Table 2.—Attributes of roof and rib fall injuries at longwall mines, 1995-98**

| Longwall characteristics | Hours worked | | Mines | | Roof falls[2] | | Rib falls[2] | | Incident rate | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. | % | No. | % | No. | % | No. | % | Roof falls per 200,000 hr | Rib falls per 200,000 hr |
| Location: | | | | | | | | | | |
| Eastern PA | — | — | — | — | — | — | — | — | — | — |
| Western PA | 23,198,139 | 16.1 | 29 | 11.7 | 114 | 17.8 | 29 | 13.5 | 0.98 | 0.25 |
| Northern WV/OH/MD | 35,971,363 | 24.9 | 57 | 23.1 | 100 | 15.6 | 20 | 9.3 | 0.56 | 0.11 |
| Central WV | 14,040,850 | 9.7 | 23 | 9.3 | 80 | 12.5 | 18 | 8.4 | 1.14 | 0.26 |
| VA | 7,454,159 | 5.2 | 16 | 6.5 | 23 | 3.6 | 3 | 1.4 | 0.62 | 0.08 |
| Eastern KY | 341,450 | 0.2 | 1 | 0.4 | 2 | 0.3 | — | — | 1.17 | — |
| Central KY and TN | 3,537,063 | 2.5 | 7 | 2.8 | 24 | 3.8 | 8 | 3.7 | 1.36 | 0.45 |
| IL/IN | 10,787,674 | 7.5 | 18 | 7.3 | 91 | 14.2 | 32 | 14.9 | 1.69 | 0.59 |
| Western U.S. | 16,881,139 | 11.7 | 56 | 22.7 | 35 | 5.5 | 62 | 28.8 | 0.41 | 0.73 |
| Western KY | 5,886,406 | 4.1 | 9 | 3.6 | 75 | 11.7 | 10 | 4.7 | 2.55 | 0.34 |
| AL | 26,087,525 | 18.1 | 31 | 12.6 | 96 | 15.0 | 33 | 15.3 | 0.74 | 0.25 |
| Mine size: | | | | | | | | | | |
| <50 workers | 376,146 | 0.3 | 9 | 3.6 | 3 | 0.5 | — | — | 1.60 | — |
| 50-149 workers | 10,374,482 | 7.2 | 46 | 18.6 | 40 | 6.3 | 29 | 13.5 | 0.77 | 0.56 |
| >149 workers | 133,435,140 | 92.5 | 192 | 77.7 | 597 | 93.3 | 186 | 86.5 | 0.89 | 0.28 |
| Seam height:[3] | | | | | | | | | | |
| <43 in | — | — | — | — | — | — | — | — | — | — |
| 43-60 in | 34,490,334 | 23.9 | 55 | 22.3 | 145 | 22.7 | 33 | 15.3 | 0.84 | 0.19 |
| >60 in | 108,855,545 | 75.5 | 188 | 76.1 | 491 | 76.7 | 182 | 84.7 | 0.90 | 0.33 |
| All longwall | 144,185,768 | — | 247 | — | 640 | — | 215 | — | 0.89 | 0.30 |

[1]The total number of mines for 1995-98 is not mutually exclusive (e.g., if a mine operated all 4 years, it is counted four times).
[2]All falls resulting in degree of injury of 1 to 6.
[3]Approximately 0.5% of the hours worked were at mines that did not report or misreported the seam height and are excluded.

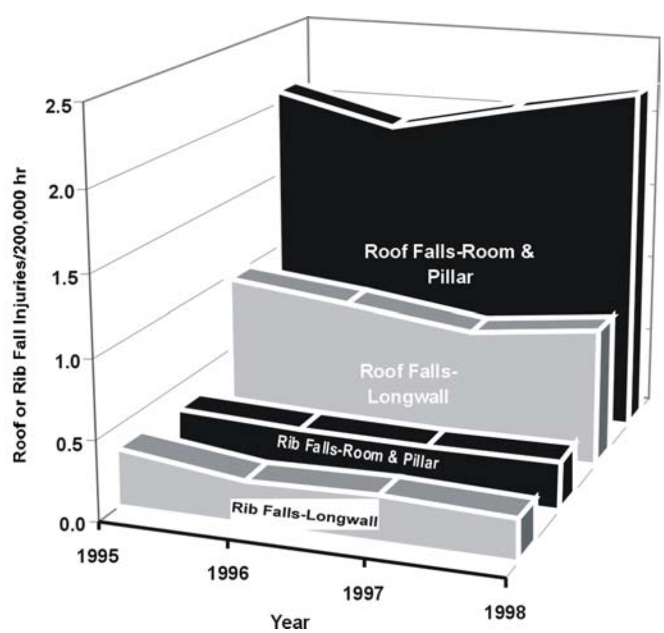


**Figure 2.—Roof and rib fall injury rates by mining method, 1995-98. (Source: MSHA data.)**

to the percentage of roof fall injuries for both mining methods. This may indicate that the geotechnical conditions that result in roof falls may be a function of the mining method used. Since there is such a large and distinct difference between the two mining methods, the remaining characteristic evaluations will break out the mining methods separately.

## LOCATIONS

Examination of roof fall injury rates at longwall operations (figure 3) in all coal mining districts in the United States found that western Kentucky and Illinois/Indiana have roof fall injury rates that are 3 and 1.7 times the national longwall average, respectively. Conversely, the western United States, northern West Virginia/Ohio/Maryland, and Virginia have a longwall rate that is at least 25% less than the national average. To determine if these same trends are observable with massive roof falls, noninjury reportable roof falls were evaluated. Figure 4 shows a similar trend; western Kentucky and the Illinois Basin were found to have significantly higher longwall noninjury roof fall incident rates, and Alabama, Virginia, and northern West Virginia/Ohio/Maryland had lower rates. High fatality rates were identified in longwalls in southeastern Kentucky/Tennessee, the western United States, and Illinois/Indiana, while Virginia and western Kentucky had zero fatalities in longwall mines (figure 5). Longwall rib fall rates were high in the western United States, Illinois/Indiana, and southeastern Kentucky/Tennessee and low in Virginia and northern West Virginia/Ohio/Maryland (figure 6).

Locality trends of room-and-pillar operations found Alabama and Illinois/Indiana with high roof fall injury rates (figure 3); no location was found to a have significantly low rates except eastern Pennsylvania. Noninjury roof fall rates revealed that western Kentucky and northern West Virginia/Ohio/Maryland exceeded the national room-and-pillar mine average by 140% and 40% (figure 4), respectively, and eastern

**Table 3.—Comparison of mining methods, 1995-98**

| Attribute | Mining method: Room-and-pillar No. | % | Longwall No. | % | Combined |
|---|---|---|---|---|---|
| Production: | | | | | |
| Tons produced | 861,172,448 | 52 | 783,644,012 | 48 | 1,644,816,460 |
| Underground hours worked | 213,635,800 | 60 | 144,185,768 | 40 | 357,821,568 |
| Workers | 109,425 | 62 | 65,976 | 38 | 175,401 |
| Mines[1] | 3,565 | 94 | 247 | 6 | 3,812 |
| Groundfalls: | | | | | |
| Roof fall injuries[2] | 2,210 | 78 | 640 | 22 | 2,850 |
| Rib fall injuries[2] | 341 | 61 | 215 | 39 | 556 |
| Roof fall noninjuries | 6,093 | 80 | 1,543 | 20 | 7,636 |
| Incident rates:[3] | | | | | |
| Roof fall injuries per 200,000 hr | 2.07 | — | 0.89 | — | 1.59 |
| Rib fall injuries per 200,000 hr | 0.32 | — | 0.3 | — | 0.31 |
| Roof fall noninjuries per 200,000 hr | 5.70 | — | 2.14 | — | 4.27 |

[1]The total number of mines for 1995-98 is not mutually exclusive (e.g., if a mine worked all 4 years, it is counted four times).

[2]All falls resulting in degree of injury of 1 to 6.

[3]The combined rate is the total number of incidents divided by the total number of hours worked.

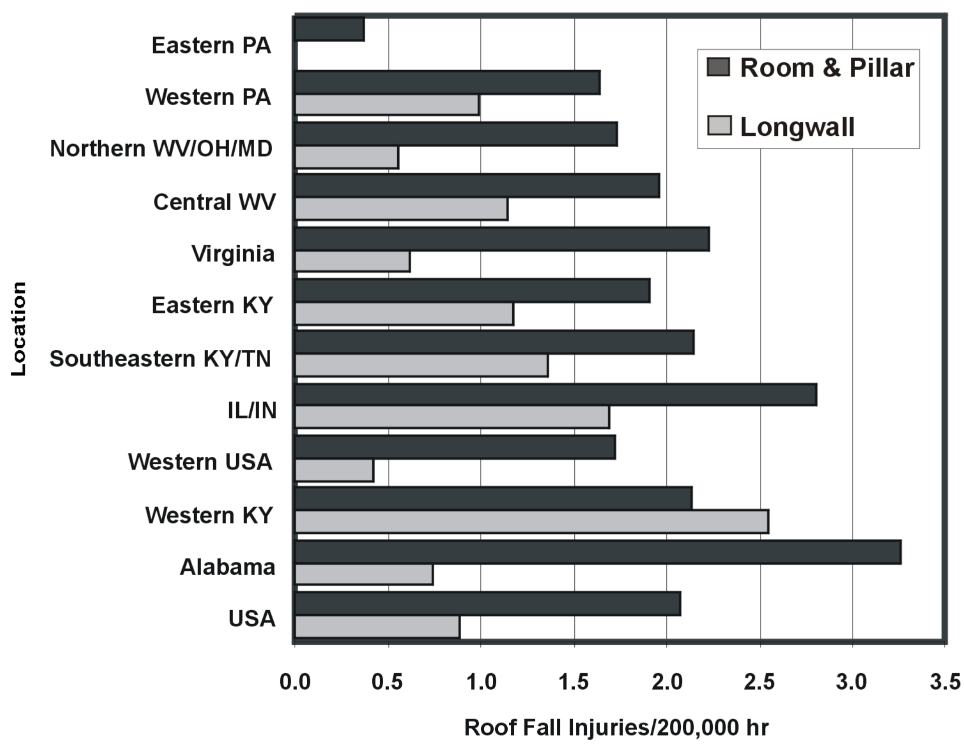


**Figure 3.—Roof fall injury rates by location, 1995-98. (Source: MSHA data.)**

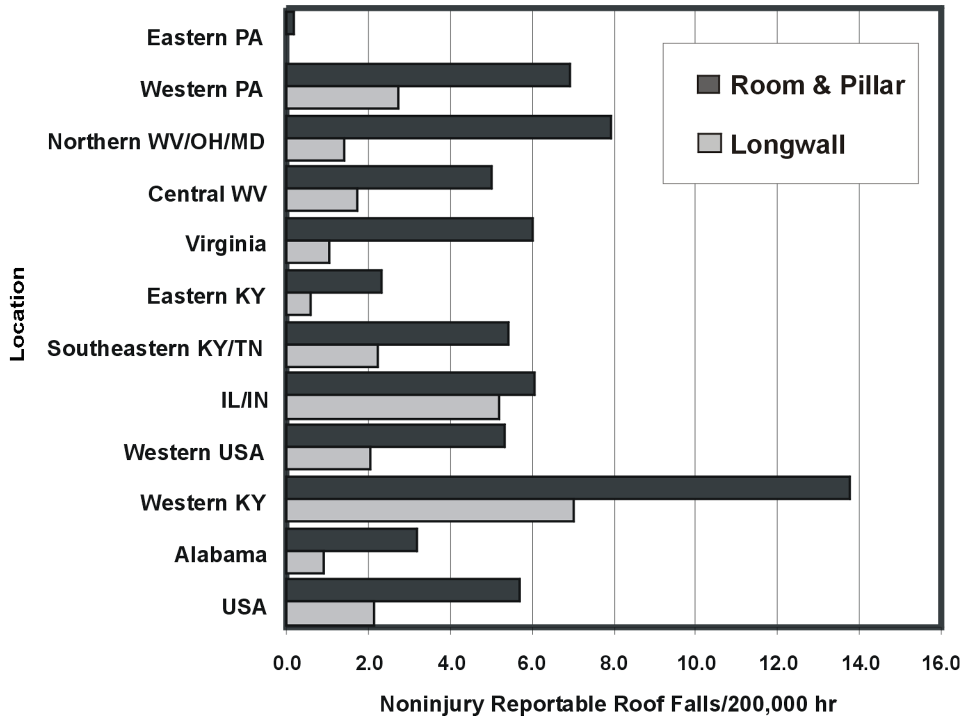


**Figure 4.—Roof fall noninjury rates by location, 1995-98. (Source: MSHA data.)**

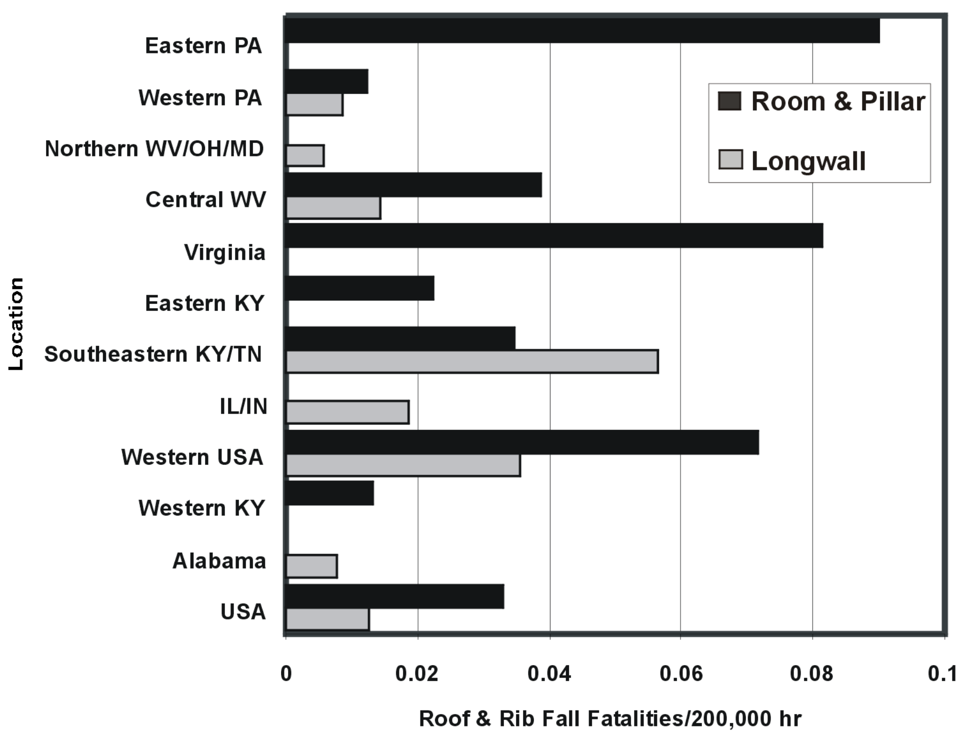


**Figure 5.—Roof and rib fall fatality rates by location, 1995-98. (Source: MSHA data.)**

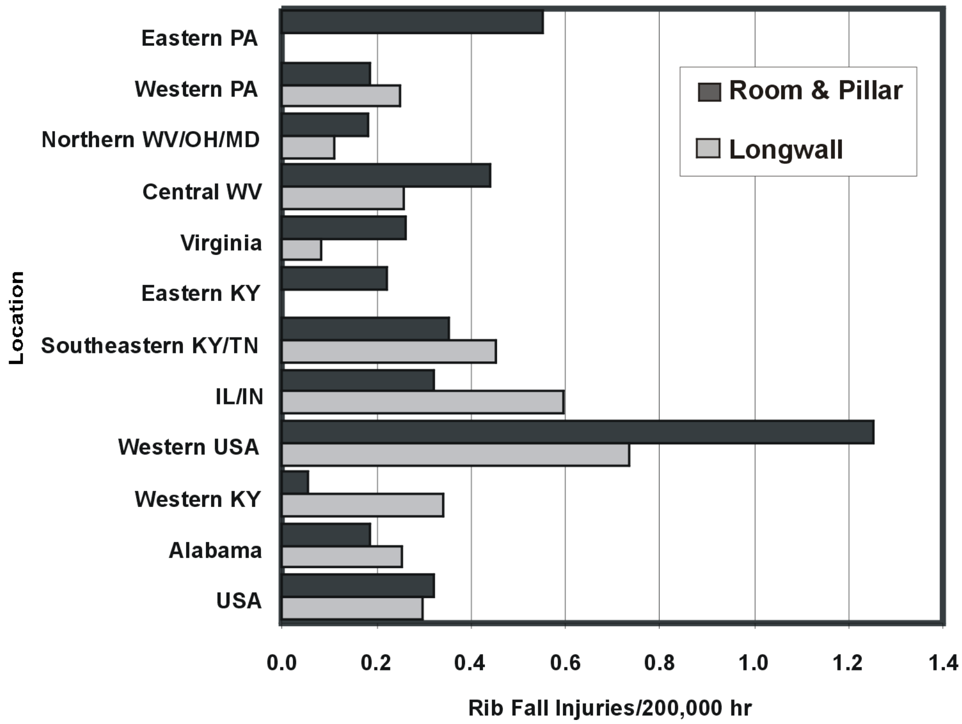


**Figure 6.—Rib fall injury rates by location, 1995-98. (Source: MSHA data.)**

Kentucky, eastern Pennsylvania, and Alabama were below the national average. Figure 5 displays the high groundfall fatality rates occurring at room-and-pillar mines in eastern Pennsylvania, Virginia, and the western United States and zero fatalities in northern West Virginia/Ohio/Maryland, Alabama, and Illinois/Indiana. The rib fall injury rate at room-and-pillar mines was four times the national average for the western United States; other high rates were found in eastern Pennsylvania and central West Virginia. Low rib fall rates occurred in western Kentucky, western Pennsylvania, and northern West Virginia/Ohio/Maryland (figure 6). High groundfall fatality and rib fall rates were found in eastern Pennsylvania and may be associated with the unusual folded stratigraphy of anthracite mines (figures 5-6). It is interesting to note that room-and-pillar mines in northern West Virginia/Ohio/Maryland had a noninjury reportable roof fall rate that is 40% higher than the national rate, yet the injury roof fall rate is 16% lower than the average, its rib injury rate is 44% less than average, and its fatality rate during this period was zero (figures 3-6).

Table 4 gives an overview of all of the high (at least 25% higher than the national average) and low (at least 25% lower than the national average) rates, ranking the locality for each type of groundfall rate. It is evident that for longwall mining,

**Table 4.—Overview of coal mining locations with extreme groundfall rates, 1995-98**

| Mine type/rate | Above the national rate by 25% | Below the national rate by 25% |
|---|---|---|
| Room-and-pillar mines: | | |
| Roof fall injury rate | IL/IN, AL | Eastern PA. |
| Roof fall noninjury rate | Western KY, northern WV/OH/MD | Eastern KY, AL, eastern PA. |
| Roof/rib fatality rate | Eastern PA, VA, Western U.S. | IL/IN, northern WV/OH/MD, AL. |
| Rib fall injury rate | Western U.S., eastern PA. central WV | Western KY, western PA, northern WV/OH/MD. |
| Longwall mines: | | |
| Roof fall injury rate | Western KY, IL/IN, southeastern KY/TN | Western U.S., northern WV/OH/MD, VA. |
| Roof fall noninjury rate | Western KY, IL/IN | Eastern KY, AL, VA, northern WV/OH/MD. |
| Roof/rib fatality rate | Southeastern KY/TN, western U.S., IL/IN | VA, eastern KY, western KY. |
| Rib fall injury rate | Western U.S., IL/IN, southeastern KY/TN | VA, northern WV/OH/MD. |

western Kentucky, southeastern Kentucky/Tennessee, and Illinois/Indiana are fairly consistently listed for each rate type, indicating that these regions have higher risk of groundfall hazards than any other parts of the country. Localities that had consistently lower risk of groundfall hazards for longwall operations include Virginia and northern West Virginia/Ohio/Maryland. Eastern Kentucky is listed with low rates; however, longwall activity in this region is almost negligible and is excluded. Room-and-pillar operations indicate a higher risk in the western United States and eastern Pennsylvania and a lower risk in northern West Virginia/Ohio/Maryland and Alabama.

Combining both mining methods shown in table 4 reveals that Illinois/Indiana and western Kentucky are consistently listed for both mining methods and for nearly all groundfall rate types. The unique coalbed conditions of this area may be an overriding factor producing this regional trend and will be discussed further in the "Coalbed" section below. Also evident in table 4 is the high rib fall injury rate in the western United States for both mining methods. The high groundfall fatality rate in the western United States may also be attributed to fatal rib falls. These occurrences in the western United States may be related to the higher and unstable ribs in the western United States, as well as deeper overburdens, which are more prone to bump and burst.

## SEAM HEIGHT AND MINE SIZE

Previous studies [Fotta et al. 1997] have examined relationships between underground coal mine injury rates and mining height and have emphasized the importance of controlling the analysis for mining method and mine size. Mines operating in thin seams (<43 in) tend to be smaller mines that exclusively use the room-and-pillar extraction method. All longwall mines operate in medium or thick seams (>43 in) and are predominantly large mines (>149 workers). To control for mining method, all longwall mines are excluded from the study. It should be noted that there is not a wide distribution of mine sizes and seam heights for longwalls mines, so excluding longwalls will not overlook any seam height or mine size trends. Controlling the study for room-and-pillar mines, mine size, and seam height produces the groundfall incidence rate trends shown in figures 7 through 10. The roof fall injury incidence rates shown in figure 7 do not show any significant trends (±25% of the national average). However, the noninjury roof fall incidence rates (figure 8) reveal that small mines (<50 workers) and large mines (>149 workers) in thick seams (>61 in) have a significantly greater risk of massive roof falls. Conversely, mines in thin seams with small- and medium-sized workforces have a significantly lower noninjury roof fall rate. This trend slightly deviates with the groundfall fatality incidence rates shown in figure 9. Small mines in thin seams have a groundfall fatality rate that exceeds the national average by 44%, whereas small mines located in thick seams have a groundfall fatality rate that is 53% lower than the national average. With regard to rib fall injury incidence rates (figure 10), small- and medium-sized mines in thick seams exceed the national average by over 100% and 60%, respectively. Conversely, small- and medium-sized mines in thin seams have a significantly lower rib fall incidence rate (42% and 36% lower than the national average, respectively).

A comparison of all groundfall incidence rate trends in the table 5 generally shows a higher risk of groundfalls for thick seams for most mine sizes. By contrast, small thin-seam mines have an extraordinarily high fatality rate. A reverse trend occurs for groundfall rates of lower risk, particularly for small- and medium-sized mines in thin seams and for the fatality rate of small mines in thick-seam mines. Perhaps the lack of cabs and canopies in small, low seams results in higher groundfall fatality rates, especially when massive falls occur. Another explanation may be that not all of the groundfall injuries that occur in small mines are reported.

Parallel trends occur for rib fall incidence rates, with high rib fall rates at small- and medium-sized, thick-seam mines and low rates in similar-sized mines with thin seams. As the mining height increases, a greater surface area of the rib is exposed and at risk of becoming unstable or prone to collapse. Perhaps these high ribs are adequately supported in the large-sized mines, whereas small- and medium-sized mines may have a minimal staff to maintain the unstable ribs, little capital to purchase and install rib bolts, or they may be located in unusual coalbeds with complex ground control problems.

## COALBED

To determine if certain coalbeds are more susceptible to groundfalls, the coalbeds where groundfalls occurred were evaluated. Since this is not a defined parameter in the MSHA database, a listing of all underground coal mines and associated coalbed names was obtained from the U.S. Department of Energy's Energy Information Agency and merged with the MSHA address information associated with every underground coal mine. All MSHA district offices were surveyed to find any missing coalbed names. Coalbed names were not identified for 15% of the room-and-pillar mines, which accounts for 2.4% of room-and-pillar mine hours worked; these were mostly small mines. All longwall coalbeds were accounted for.

Since more than 122 coalbeds were identified that produced coal during 1995-98, a process was developed to select the more significant coalbeds. Removed from the analysis were all coalbeds with fewer than 400,000 hr worked or with fewer than 4 incidents (for each type of incident: roof fall injury, rib fall injury, or noninjury reportable roof fall). The more significant coalbeds were determined by calculating the percentage that the coalbed groundfall rate exceeded the national average rate. All coalbeds that exceeded that national rate by at least 25% are listed regionally for each mining method in tables 6-7. The

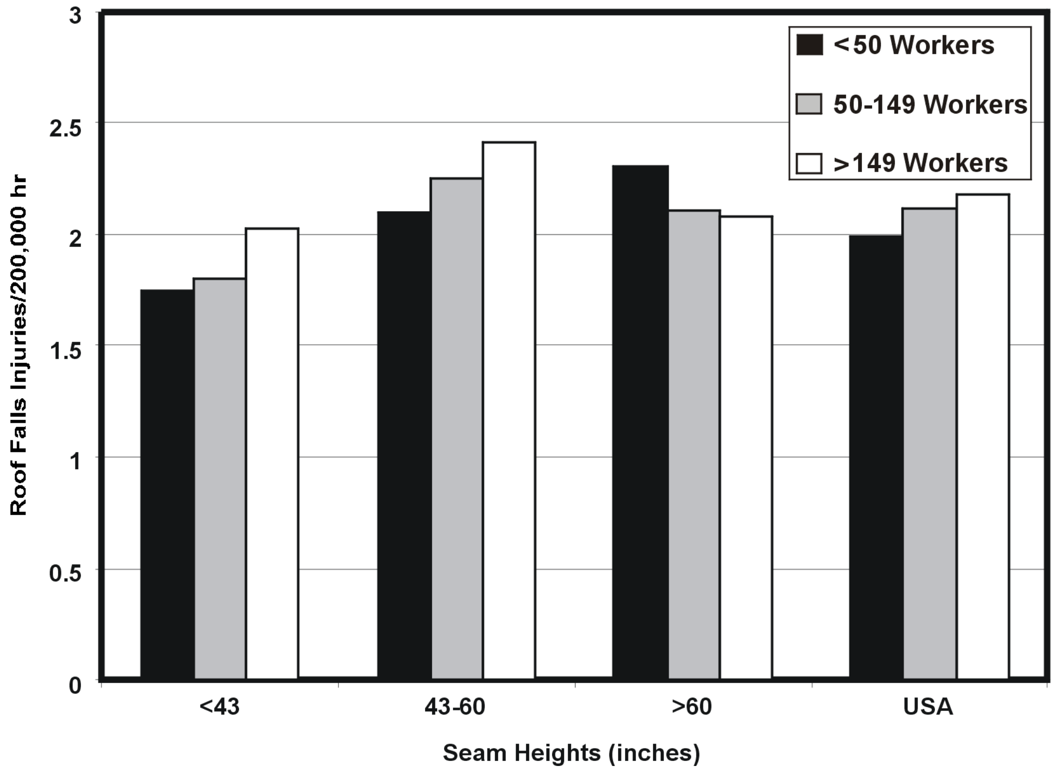


**Figure 7.—Roof fall injury rates by mine size and seam height for room-and-pillar mines, 1995-98. (Source: MSHA data.)**

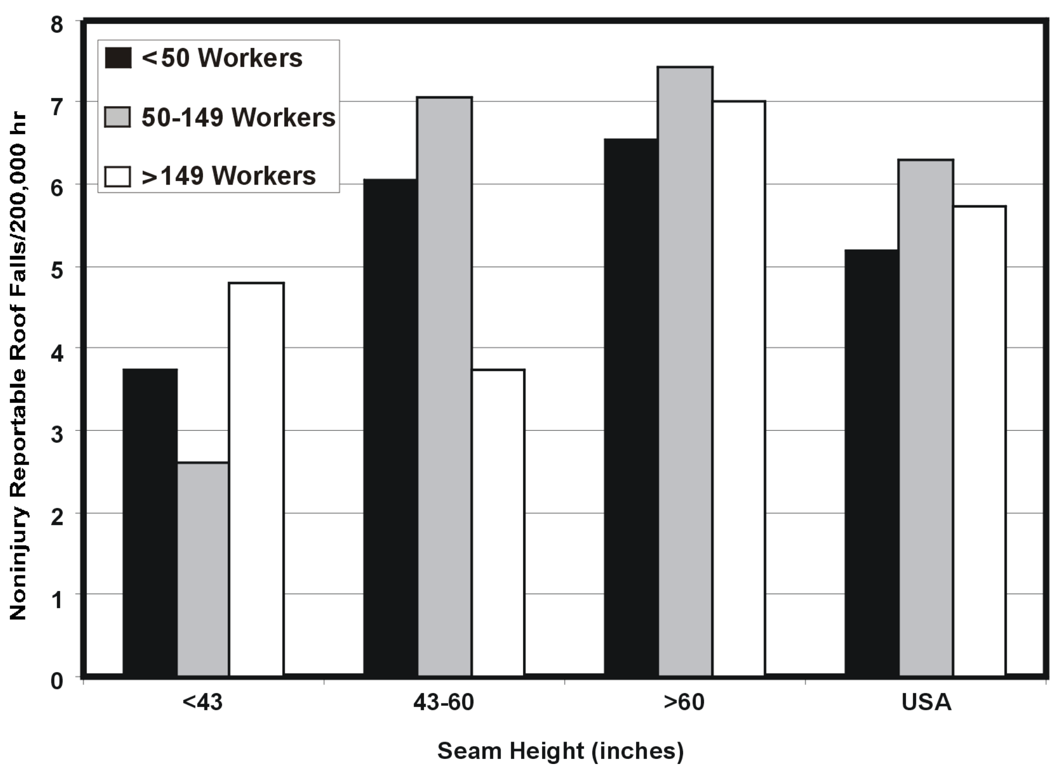


**Figure 8.—Roof fall noninjury rates by mine size and seam height for room-and-pillar mines, 1995-98. (Source: MSHA data.)**

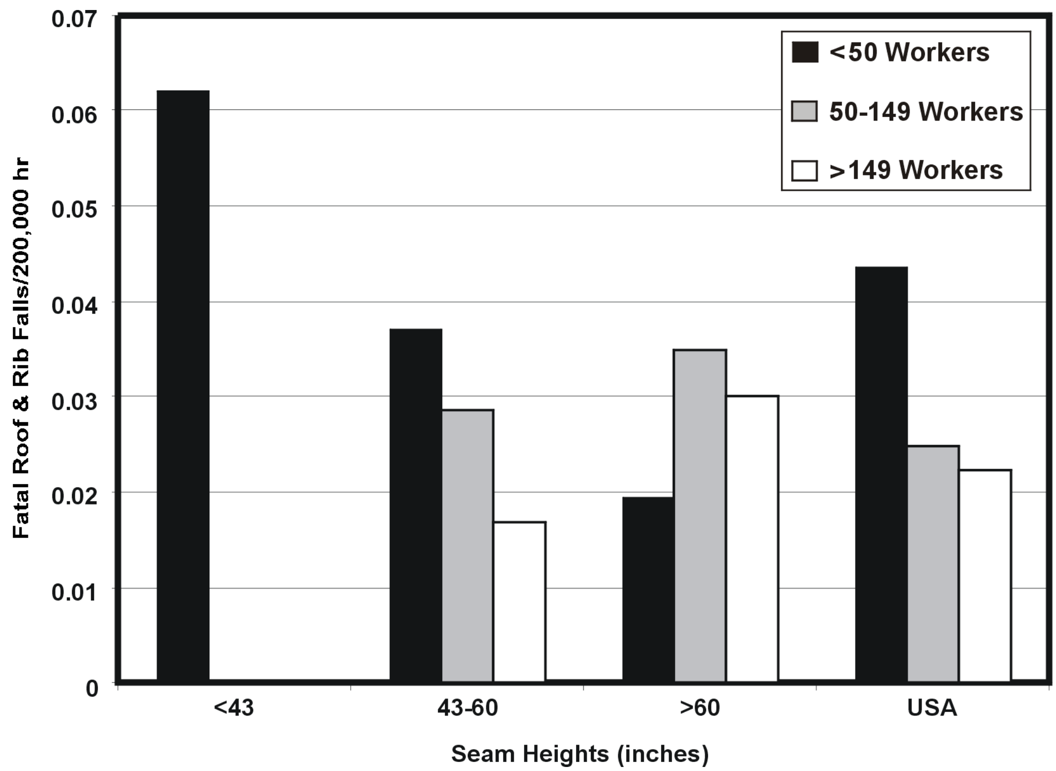


**Figure 9.—Roof and rib fall fatality rates by mine size and seam height for room-and-pillar mines, 1995-98. (Source: MSHA data.)**

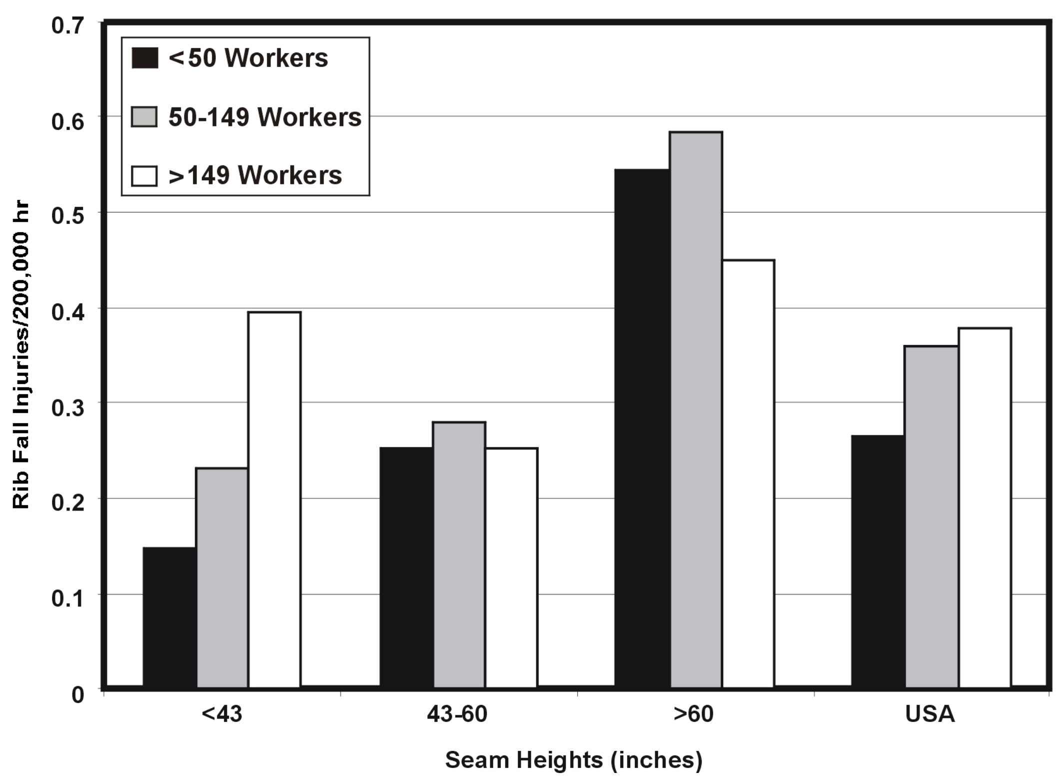


**Figure 10.—Rib fall injury rates by mine size and seam height for room-and-pillar mines, 1995-98. (Source: MSHA data.)**

**Table 5.—Overview of mine size and seam height factors with extreme groundfall rates, 1995-98**

| Mine type/rate | Above the national rate by 25% | Below the national rate by 25% |
|---|---|---|
| Small mines (<50 workers): | | |
| Roof fall injury rate | None | None. |
| Roof fall noninjury rate | Thick seam | Thin seam. |
| Roof/rib fatality rate | Thin seam | Thick seam. |
| Rib fall injury rate | Thick seam | Thin seam. |
| Medium mines (50-149 workers): | | |
| Roof fall injury rate | None | None. |
| Roof fall noninjury rate | None | Thin seam. |
| Roof/rib fatality rate | Thick seam | Thin seam. |
| Rib fall injury rate | Thick seam | Thin seam. |
| Large mines (>149 workers): | | |
| Roof fall injury rate | None | None. |
| Roof fall noninjury rate | Thick seam | Medium seam. |
| Roof/rib fatality rate | Thick seam | Thin seam. |
| Rib fall injury rate | None | Medium seam. |

NOTE: A thin seam is ≤42 in; a medium seam is 43-60 in; a thick seam is ≥61 in. "None" indicates that seam thickness and mine size did not result in significant change (±25%) in incidence rate.

broad regions shown in the tables do not match the more specific locations listed earlier in the paper. Many of these coalbeds in specific locations were found to overlap, and broader regions were found to be a better indicator of defining the location of the coalbed.

The most startling indication from previewing the room-and-pillar coalbed listings in table 6 is the severe roof fall rates in Illinois Basin coalbeds that affect 95% of the coal mines in that region. This same trend is found in the longwall coalbed listing for the Illinois Basin, shown in table 7, which affects 100% of the longwall mines in the region. The notorious coalbeds include the Kentucky No. 13, Herrin/No. 6/Kentucky No. 11, and Springfield No. 5/Kentucky No. 9. These coalbeds have injury and noninjury roof fall rates that significantly exceed the national average for both mining methods, as well as high rib fall injury rates for longwall mines. These high groundfall incident rates in the Illinois Basin seem to correlate with the high rates indicated in a previous section of this paper that examined various mining localities, most notably Illinois/Indiana and western Kentucky. Obviously, some unique set of geological circumstances or stress fields are producing this regional concentration of groundfalls.

Other troubling trends from this analysis are the high injury and noninjury roof fall rates associated with 64% of the room-and-pillar mines in the northern Appalachian coalbeds, specifically the Sewickley, Redstone, Pittsburgh, Bakerstown, and Upper and Lower Freeport Coalbeds (table 6). These high roof fall injury rates are not carried over into the longwall mines of this region, except for the Upper Freeport and Sewickley Coalbeds. Possibly the geology in this region is more flexible and conducive for abutment load transfers that typically occur with longwall mining. However, the longwall mines in the Sewickley and Upper Freeport Coalbeds of the northern Appalachian region, which represent only 10% of the mines, have very high noninjury reportable roof fall rates. Perhaps the long-term standup time for these coalbeds is considerably shorter due to the high content of degradable shales that comprise the immediate roof.

Coalbeds that engender difficult longwall mining conditions seem to be located in the regions of central Appalachia and the western United States. Over 55% of the longwall mines in the central Appalachian region are located in coalbeds that have groundfall incident rates that exceed the national average by at least 25%. By contrast, only 29% of the room-and-pillar mines in this same region have rates that exceed the national average. Specifically problematic are the Eagle and Hazard No. 4 Coalbeds, which significantly exceed the national longwall rate for roof fall injuries and noninjury roof fall injury rates. Although the number of room-and-pillar mines in the central Appalachian region with problematic coalbeds do not represent a majority of mines, there are many coalbeds with high roof fall rates, including the Ben Creek/Blair, Upper Banner, Jawbone/Iaeger, and Walnut Mountain. In the same region, severe room-and-pillar rib fall injuries that exceed the national rate by over 100% include the Pocahontas No. 12, Eagle, Peerless, Powellton, and Amburgy/Low Splint Coalbeds.

Another problematic area is the western United States, with high rib fall rates that occur in 80% of the region's thick-seam longwall mines. Longwall coalbeds that have rib fall rates that exceed the national rate by over 100% include the Upper Hiawatha, Hiawatha, Blind Canyon, Wadge, and B Seam. Room-and-pillar coalbeds with high rib fall rates include the D Seam and B Seam. The thick seams and deep overburdens associated with the western United States probably contribute to the rib control problems and make the rib faces more prone to mountain bumps.

**Table 6.—Room-and-pillar coalbeds with extreme groundfall rates, 1995-98**

| Region/coalbed[1] | DOE-EIA coalbed ID No. | Underground, hr | No. of mines[2] | Regional mines represented, % | Percentage above national rate | | |
|---|---|---|---|---|---|---|---|
| | | | | | Roof injury | Rib injury | Roof noninjury |
| Northern Appalachian: | | | | | | | |
| Sewickley | 29 | 727,722 | 26 | — | — | — | 223 |
| Redstone | 33 | 830,127 | 23 | — | 51 | — | 82 |
| Pittsburgh | 36 | 1,960,405 | 37 | — | 78 | — | 57 |
| Bakerstown/Freeport | 62 | 401,283 | 6 | — | 45 | — | — |
| Upper Freeport | 71 | 7,783,479 | 82 | — | — | — | 25 |
| Lower Freeport | 74 | 1,329,040 | 14 | — | — | — | 45 |
| Upper Kittanning | 76 | 6,505,446 | 53 | — | — | — | 27 |
| Total | — | 19,537,502 | 241 | 64.44 | — | — | — |
| Central Appalachian: | | | | | | | |
| Hazard No. 8 | 100 | 677,371 | 11 | — | 28 | — | — |
| Hazard No. 7/High Splint | 104 | 592,004 | 14 | — | — | — | 54 |
| Coalburg/Hazard No. 6 | 111 | 11,558,414 | 143 | — | 30 | — | — |
| Winifrede/Hazard No. 5 | 121 | 4,138,977 | 45 | — | — | 51 | — |
| Hatfield/No. 9 | 127 | 614,743 | 3 | — | — | — | 25 |
| Walnut Mountain | 128 | 488,422 | 12 | — | — | — | 180 |
| Hernshaw/Whitesburg | 137 | 1,787,018 | 37 | — | 41 | — | — |
| Amburgy/Low Splint | 142 | 6,700,453 | 112 | — | — | 96 | — |
| Peerless | 167 | 1,352,385 | 18 | — | — | 132 | — |
| Powellton | 170 | 4,253,833 | 34 | — | — | 121 | — |
| Eagle | 176 | 2,614,897 | 48 | — | — | 164 | 33 |
| Bens Creek/Blair | 177 | 890,525 | 17 | — | 139 | — | 136 |
| Glamorgan | 185 | 1,855,293 | 52 | — | 35 | — | — |
| Splash Dam | 210 | 3,504,704 | 85 | — | — | 25 | — |
| Upper Banner | 214 | 904,347 | 36 | — | 60 | — | 28 |
| Jawbone/Iaeger | 266 | 3,755,667 | 84 | — | 26 | — | 38 |
| Lower Iaeger/No. 4 | 269 | 476,014 | 15 | — | — | — | 47 |
| Pocahontas No. 12 | 311 | 2,939,232 | 27 | — | — | 199 | — |
| Total | — | 49,104,299 | 793 | 28.66 | — | — | — |
| Southern Appalachian: | | | | | | | |
| Gholson | 223 | 1,182,661 | 4 | — | 137 | — | — |
| Total | — | 1,182,661 | 4 | 21.05 | — | — | — |
| Illinois Basin: | | | | | | | |
| Danville/No. 7 | 480 | 2,228,338 | 8 | — | 47 | — | — |
| KY No. 13 | 482 | 784,239 | 4 | — | 147 | — | 937 |
| Herrin/No. 6/KY No. 11 | 484 | 14,943,246 | 58 | — | 36 | — | — |
| No. 5/Springfield/KY No. 9 | 489 | 18,216,127 | 63 | — | — | — | 87 |
| Western KY No. 4 | 520 | 900,097 | 9 | — | — | — | 99 |
| Total | — | 37,072,047 | 142 | 95.30 | — | — | — |
| Western United States: | | | | | | | |
| B Seam | 1753 | 744,443 | 5 | — | — | 574 | — |
| D Seam | 1755 | 621,980 | 6 | — | 102 | 1,210 | 47 |
| Cameo | 1770 | 401,341 | 7 | — | — | — | 127 |
| Lower O'Connor | 1830 | 675,148 | 4 | — | 29 | — | 56 |
| Total | — | 2,442,912 | 22 | 28.95 | — | — | — |

[1]This analysis excludes coalbeds with fewer than 400,000 hr worked and fewer than four groundfall incidents.
[2]The total number of mines for 1995-98 is not mutually exclusive (e.g., if a mine worked all 4 years, it is counted four times).

**Table 7.—Longwall coalbeds with extreme groundfall rates, 1995-98**

| Region/coalbed[1] | DOE-EIA coalbed ID No. | Underground, hr | No. of mines[2] | Regional mines represented, % | Percentage above national rate | | |
|---|---|---|---|---|---|---|---|
| | | | | | Roof injury | Rib injury | Roof noninjury |
| Northern Appalachian: | | | | | | | |
| Sewickley | 29 | 741,827 | 2 | — | — | — | 505 |
| Upper Freeport | 71 | 2,737,966 | 7 | — | 73 | — | 200 |
| Total | — | 3,479,793 | 9 | 10.47 | — | — | — |
| Central Appalachian: | | | | | | | |
| Hazard No. 4 | 135 | 1,729,817 | 4 | — | 95 | — | 30 |
| Alma/Elkhorn No. 1/Blue Gem | 157 | 2,193,175 | 6 | — | 34 | 84 | — |
| Imoboden/Warfield | 168 | 1,259,612 | 5 | — | 43 | — | — |
| Eagle | 176 | 5,093,936 | 11 | — | 46 | 71 | 71 |
| Total | — | 10,276,540 | 26 | 55.32 | — | — | — |
| Southern Appalachian: | | | | | | | |
| Pratt/Corona | 227 | 2,040,393 | 4 | — | — | — | 143 |
| Total | — | 2,040,393 | 4 | 12.90 | — | — | — |
| Illinois Basin: | | | | | | | |
| KY No. 13 | 482 | 3,254,456 | 4 | — | 357 | 44 | 285 |
| Herrin/No. 6/KY No. 11 | 484 | 6,780,473 | 14 | — | 49 | 88 | 148 |
| Springfield/No. 5/KY No. 9 | 489 | 6,639,151 | 9 | — | 87 | 62 | 144 |
| Total | — | 16,674,080 | 27 | 100.00 | — | — | — |
| Western United States: | | | | | | | |
| Wattis | 1236 | 1,225,605 | 3 | — | — | — | 83 |
| Wadge/Roland of Tuff | 1750 | 2,388,299 | 4 | — | — | 153 | — |
| B Seam | 1753 | 2,692,812 | 9 | — | — | 149 | 87 |
| Lower O'Connor | 1830 | 2,264,391 | 8 | — | — | 78 | — |
| Castle Gate B/Upper O'Connor | 1832 | 829,604 | 4 | — | — | — | 46 |
| Hiawatha | 1846 | 2,340,148 | 9 | — | — | 187 | — |
| Upper Hiawatha | 1847 | 1,059,750 | 4 | — | — | 280 | — |
| Blind Canyon | 1855 | 1,694,672 | 4 | — | — | 256 | — |
| Total | — | 14,495,281 | 45 | 80.36 | — | — | — |

[1]This analysis excludes coalbeds with fewer than 400,000 hr worked and fewer than four groundfall incidents.
[2]The total number of mines for 1995-98 is not mutually exclusive (e.g., if a mine worked all 4 years, it is counted four times).

## SEASONAL PATTERNS

The chronological quarterly groundfall rates were evaluated to determine if seasonal patterns, such as fluctuations in temperature, barometric pressure, and humidity, might affect the number of groundfall incidents. Since the western United States has mostly an arid climate with minimum fluctuations in humidity, incidents in Colorado, New Mexico, Utah and Wyoming were excluded. Although monthly production data are not compiled, quarterly hours worked were accessed from MSHA's Terra database. This allowed the groundfall incidents to be normalized based on the quarterly employee hours worked underground. According to figure 11, the roof fall injury incidence rate is fairly consistent, except for the third quarter (July to September), where the incident rate peaks 30% higher than the other three quarters. A similar pattern occurs with the noninjury reportable roof fall rate, as shown in figure 12. The fall rate is fairly consistent until the third quarter, where the noninjury roof fall incident rate peaks 48% higher than the first two quarters. Using the noninjury reportable roof fall rate is an even better indicator of unstable ground conditions, since they usually result in massive falls and are required to be reported. Possibly this trend shows that mine air becomes more humid during the summer months and the moisture is disintegrating the shale roof, resulting in large groundfalls. It is interesting to note that in figure 12 the noninjury fall rate for the fourth quarter (October to December) is slightly elevated compared to the first two quarters. Perhaps the third quarter trend is continuing into the first month of the fourth quarter (October).

Other studies have found similar seasonal patterns. Stateham 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 highest in August and lowest in February.

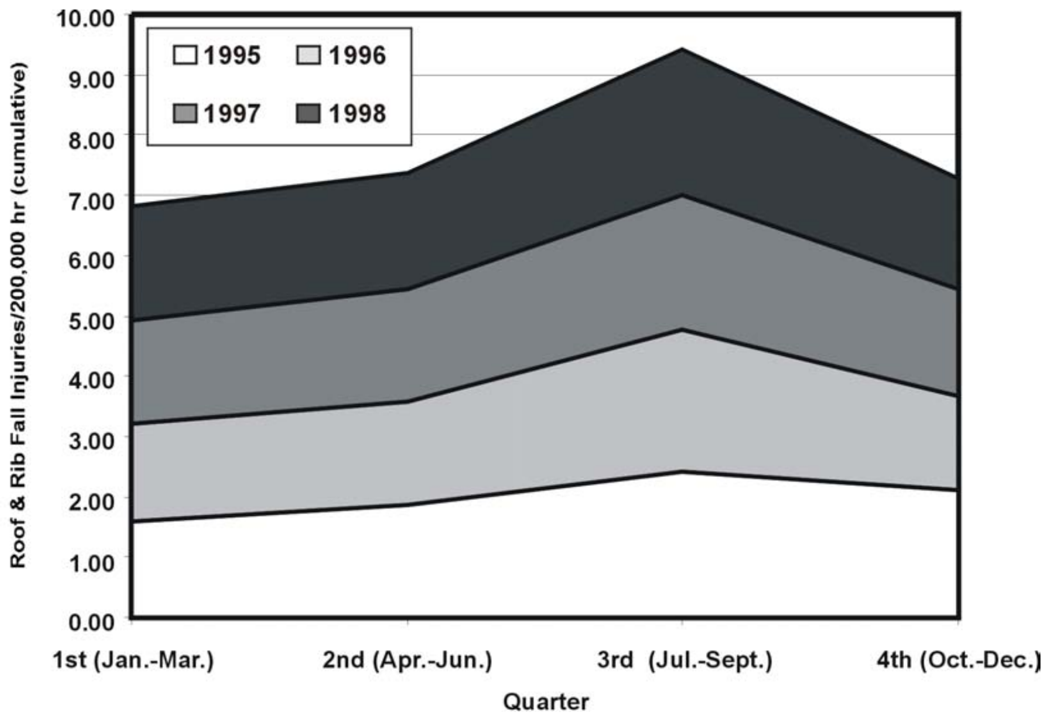


**Figure 11.—Roof and rib fall injury rates by quarter, excluding the western United States, 1995-98. (Source: MSHA data.)**

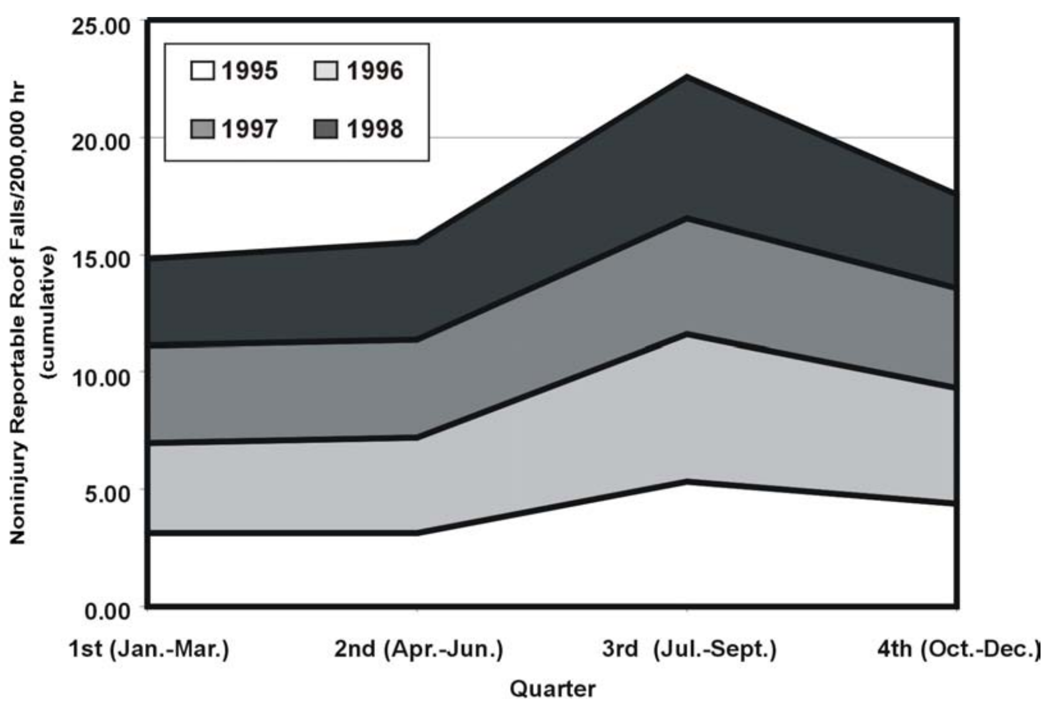


**Figure 12.—Roof fall noninjury rates by quarter, excluding the western United States, 1995-98. (Source: MSHA data.)**

# OVERVIEW OF FATALITY REPORTS ASSOCIATED WITH GROUND CONTROL HAZARDS

During 1996-99, 49 underground coal miners were killed in 46 separate incidents. Table 8 lists the frequency of primary and secondary factors that contributed to these incidents. In some cases, more than one hazard was involved. For example, 12 fatalities occurred during pillar extraction; three of the incidents resulted from premature collapses in intersections.

## UNSUPPORTED ROOF

When miners go under unsupported roof, they are completely unprotected. According to table 8, approximately 24% of all roof fall fatalities during the study period occurred when miners traveled under unsupported roof. While there are no grounds for complacency, the recent record does represent an improvement from a decade ago, when nearly 50% of groundfall fatalities occurred beneath unsupported roof [Peters 1992]. The improvement was achieved through new equipment, enforcement, and a persistent educational campaign.

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

During the early 1990s, the USBM conducted an extensive series of interviews with miners to determine why they risk going under unsupported roof [Peters 1992]. The most common response was that they had unintentionally walked out beyond the supports. The most effective countermeasure, then, is to ensure that all areas of unsupported roof are clearly posted with highly visible warning devices.

Relatively simple procedures or technologies can be implemented to reduce the temptation for workers to intentionally go beyond support. However, training is also essential. Other USBM studies [Mallett et al. 1992] argue that verbal admonitions and threats of discipline are less effective than training that graphically imparts the severe consequences of roof falls. A series of three videos was prepared in which actual miners are interviewed about roof fall accidents that they had experienced. The videos also emphasize the impact of roof fall accidents on people other than the one caught in the fall. These highly effective videos, together with training manuals, are available from MSHA's National Mine Health and Safety Academy near Beckley, WV.

## ROOF SKIN FAILURES

Skin failures are incidents that do not involve failure of the roof support elements, but result from rock spalling from between roof bolts, around ATRS systems, or from ribs. They are of particular concern because they cause injuries and fatalities to workers who should have been protected by supports. In 1997, 98% of the 810 roof and rib injuries suffered by mine workers were attributed to skin failures [Bauer et al. 1999]. Because groundfall fatalities are usually the result of massive roof failure, this study found only 12% of the roof falls were related to smaller scale roof skin failures.

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

## RIB FAILURES

During 1996-99, rib failures resulted in seven fatalities, or 14% of all groundfall fatalities, as shown in table 8. Only one

**Table 8.—Hazards associated with fatal groundfalls, 1996-99**

| Hazard | No. of fatalities | | | Percentage | | |
|---|---|---|---|---|---|---|
| | Primary | Secondary[1] | Total | Primary | Secondary[1] | Total |
| Geologic | 1 | 10 | 11 | 2 | 20 | 22 |
| Roof skin | 6 | 0 | 6 | 12 | 0 | 12 |
| Rib | 7 | 2 | 9 | 14 | 4 | 18 |
| Pillaring | 12 | 2 | 14 | 24 | 4 | 29 |
| Inby unsupported roof | 12 | 0 | 12 | 24 | 0 | 24 |
| Intersection | 3 | 5 | 8 | 6 | 10 | 16 |
| Longwall face | 4 | 0 | 4 | 8 | 0 | 8 |
| Construction | 4 | 3 | 7 | 8 | 6 | 14 |
| Total | 49 | 22 | 71 | 100 | 44 | — |

[1]A secondary hazard was assigned to some groundfall fatalities, but not in all cases.

of these fatal injuries was to a face worker, while five were mechanics and electricians performing their duties well outby the face. Nearly 80% of the 128 rib injuries that occurred in 1997 took place beneath permanently supported roof. Nonfatal rib injuries resulted in an average of 43 lost workdays each versus 25 days for the average roof skin injury.

Seam height is the single greatest factor contributing to rib failures. The seam height was >8 ft in all six of the fatalities and >10 ft in three of them. The incidence of rib injuries increases dramatically once the seam height reaches 7 ft. No rib support was used in any of the six fatal accidents.

Rib failure is often associated with rock partings and/or discontinuities within the pillar or with overhanging brows created by roof drawrock. The most effective rib supports use full planks or mesh held in place by roof bolts.

## 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. In some mines, mobile roof supports have replaced timber supports for each stage of pillar recovery.

According to table 8, pillaring fatalities are directly attributed to 24% of all groundfall fatalities, including three multiple incidents. However, a recent study estimated that pillar recovery accounts for only 10% of the coal mined underground [Mark et al. 1997]. Nearly 50% of these fatal pillaring incidents involved geologic discontinuities, such as slips and slickensides. Even mines that used additional support for these discontinuities were unable to prevent the massive roof failures. These failures often occur suddenly with little warning and result in collapses where MSHA is unable to find any violations. During 1987-96, Mark et al. [1997] found that almost 50% of the pillaring fatalities occurred during the recovery of the final lift or pushout. Since 1996, however, only 20%, or three incidents, involved last-lift incidents. Several incidents also involved situations where excessive cuts were taken, which caused the large exposed intersection to collapse.

Pillar recovery can also be difficult under deep cover. During 1996-98, nearly one-half of the pillar recovery fatalities occurred where the depth of cover exceeded 650 ft. Under deep cover, barrier pillars and special mining sequences may be required.

## GEOLOGIC DISCONTINUITIES

Geologic features such as slips, slickensides, clay veins, kettlebottoms, and ancient stream channels have been closely linked with many groundfall fatalities. These hazardous geologic structures are found predominantly in the Appalachian coal basins [Chase 1992]. Geologic discontinuities were mostly identified as the secondary contributing causes of failure in 20% of all groundfall fatalities (table 8).

Slickensides and slips were found to be the primary and secondary causes of failure of four similar massive groundfalls in 1997 that resulted in four fatalities and seven injuries. All of the falls were so massive that they overran the permanent support, resulting in the collapse of the bolted intersection. Two of the occurrences were attributed primarily to pillaring, which triggered the unstable slips and slickensided joints to collapse. Special precautions need to be taken near the outcrop, where the presence of groundwater and weathered joints (sometimes called hill seams) can reduce roof competence. In general, pillar recovery should not be conducted when the distance to the outcrop is <150 ft.

## LONGWALL FACES

The longwall system of mining, which extracts immense coal panels and allows the roof to cave behind the face, presents a unique ground control situation. The total extraction of the coal causes high stress concentrations along the face and in the gate roads and may pose severe ground control problems depending on the competency of the immediate and main roof rock and the sizing of the gate road pillars [Listak and Pappas 1990].

According to figure 8, approximately 8% of groundfall deaths are associated with longwall face mining. Two incidents involved a similar work activity of installing wire mesh in preparation for recovering the longwall face equipment. Usually, a large redistribution of stresses occurs as the longwall face approaches the recovery room, which may weaken the roof directly above the face. In the first incident, a slickensided piece of top coal fell from the face and struck the victim located under the shield supports. In the second case, a piece of binder rock fell from the face, hitting the victim located between the pan line and the longwall face.

## CONSTRUCTION

Construction relates to any type of outby mining or resupport of the coal or roof strata. Examples include cutting the roof higher to install an overcast or belt line (boom hole) or rehabilitating roof fall areas.

It seems unlikely that these types of incidents would happen with multiple frequency. However, during the study period seven construction fatalities, or 14% of groundfall fatalities, occurred as either a primary or secondary cause (table 8). Four of the construction incidents were related to boom holes, two to overcast construction, and one to rehabilitating a high roof fall area. Several of the boom hole and overcast incidents occurred because the ATRS was not of sufficient height to support the roof. This resulted in the use of other temporary support methods where the procedure was not properly followed. Also, two incidents occurred while the victim went under unsupported roof following boom hole shots. There seems to be some confusion concerning the proper procedure in supporting boom holes. The rehabilitation incident occurred while installing steel arches. The victim was under the last arch that had been installed and slid a mud sill under the unsupported roof when the roof fell. The fall struck the inby edge of the last arch, then toppled under the arches.

### INTERSECTION STABILITY

Thousands of intersections are driven each year and create diagonal spans of 25-40 ft, well over the normal width of an entry. The hazards of wide spans can increase when pillar corners are rounded for machine travel (turnouts) or when rib spalling increases the span. According to table 8, 6% of roof fall fatalities are primarily caused by oversized intersections and 10% are a secondary cause. In 1996, there were 2,105 non-injury reportable roof falls. More than 71% of these occurred in intersections despite the fact that intersections probably account for less than 25% of all drivage underground.

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

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

## CONCLUSIONS

The effects of groundfall 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 victim's family. In addition, the mining industry is severely impacted by these injuries, as well as thousands of noninjuries that damage equipment, stop production, or disrupt ventilation. This study of roof and rib fall injuries and noninjury rates controlled for mining method, seam height, and mine size, and resulted in the identification of the following incident trends:

- The longwall mining method results in less than one-half the roof fall injury rate compared to than the room-and-pillar method. However, the rib injury rate for both mining methods is nearly identical.
- Longwall mining accounts for 48% of the production and 40% of the hours worked, but results in only 22% of the roof fall injuries.
- Longwall mines in western Kentucky and Illinois/Indiana have significantly higher roof fall rates. Northern West Virginia/Ohio/Maryland, Virginia, and the western United States have significantly lower roof fall rates.
- Room-and-pillar mines in western Kentucky have a very high noninjury roof fall rate.
- For both mining methods, rib fall injury rates are significantly higher in the western United States.
- For noninjury falls in room-and-pillar mines, small mines (<50 workers) and large mines (>149 workers) in thick seams (>60 in) have a significantly higher risk of massive roof falls. Conversely, mines located in thin seams with small- and medium-sized workforces have a significantly lower massive fall rate.
- The fatality rate for room-and-pillar mines is very high for small mines in thin seams, but is very low for small mines in thick seams.
- Room-and-pillar mines in small- and medium-sized mines in thin seams have a significantly lower rib fall rate. Small- and medium-sized mines in thick seams have a significantly higher rate.
- For coalbeds in which both methods are used, severe groundfall rates were identified in the Illinois Basin, especially for the Kentucky No. 13, Herrin/No. 6/Kentucky No. 11, and Springfield No. 5/Kentucky No. 9 Coalbeds.
- For room-and-pillar coalbeds, northern Appalachian coalbeds, most notably the Sewickley, Redstone, Pittsburgh, and Bakerstown, have severe roof fall rates. Many coalbeds in the central Appalachian region have high roof fall rates, especially Bens Creek/Blair, Upper Banner, Jawbone/Iaeger, and Walnut Mountain.
- Longwall coalbeds in the central Appalachian coalfields with very high groundfall rates include the Eagle and Hazard No. 4.
- Severe rib fall rates were found for several coalbeds in the western United States. Difficult room-and-pillar coalbeds include the D Seam and B Seam. Problematic longwall coalbeds include the Upper Hiawatha, Hiawatha, Blind Canyon, Wadge and B Seam.

- Severe room-and-pillar rib fall rates were found in coalbeds in the central Appalachian region, including the Pocahontas No. 12, Eagle, Peerless, Powellton, and Amburgy/ Low Splint Coalbeds.
- A review of seasonal patterns revealed that the third quarter (July to September) has a 30%-40% increased risk of injury and noninjury groundfalls. This may be due to higher humidity levels.

To better understand why these groundfalls occurred, all of the detailed fatality reports were analyzed, and the following groundfall hazards contributing to the groundfall were identified:

- Pillaring is the leading cause of fatal groundfall failures. Many of these incidents were triggered by geologic discontinuities present in the roof strata, such as slips and slickensides. These failures often occurred suddenly and with little warning.
- A prevailing factor contributing to groundfall fatalities was miners going under unsupported roof. In recent years, fatalities from this risky activity has dropped significantly; however, it still contributes to 24% of all groundfall fatalities.
- Rib failure is a major hazard associated with groundfall fatalities and is often associated with rock partings and/or discontinuities within the pillar or with overhanging brows created by roof drawrock. None of the mines where rib fatalities occurred used any type of rib mesh or bolting.
- Roof skin failures are of particular concern because they caused 12% of groundfall fatalities and many nonfatal injuries to workers who should have been protected by supports.
- Construction-related groundfalls were associated with 14% of the primary or secondary causes of the fatalities. Several boom hole and overcast incidents occurred because the ATRS was not of sufficient height to support the roof.
- Several longwall-mining-related groundfall fatalities resulted during installation of wire mesh as the longwall face approached the recovery room.

These groundfall statistical characteristics 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 coal mine workers.

## REFERENCES


Bauer ER, Pappas DM, Dolinar DR, McCall FE, Babich DR [1999]. Skin failure of roof and rib in underground coal mines. In: Peng SS, Mark C, eds. Proceedings of the 18th International Conference on Ground Control in Mining. Morgantown, WV: West Virginia University, pp. 108-114.

Chase FE [1992]. Geologic structures that affect Appalachian coal mines. In: Proceedings of the Preventing Coal Mine Groundfall Accidents; How To Identify and Respond to Geologic Hazards and Prevent Unsafe Worker Behavior. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, IC 9332, pp. 3-14.

Fotta B, Mallett LG [1997]. Effect of mining height on injury rates in U.S. underground nonlongwall bituminous coal mines. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, IC 9447.

Fotta B, Turin FC, Murphy JN [1995]. Appalachian coal-mining health and safety trends. Min Eng *47*(12):1115-1119.

Listak JM, Pappas DM [1990]. Longwall automation: a ground control perspective. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, IC 9244.

Mallett LG, Vaught C, Peters RH [1992]. Training that encourages miners to avoid unsupported roof. In: Preventing Coal Mine Groundfall Accidents; How To Identify and Respond to Geologic Hazards and Prevent Unsafe Worker Behavior. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, IC 9332, pp. 32-45.

Mark C, McCall FE, Pappas DM [1997]. A statistical overview of retreat mining of coal pillars in the U.S. In: Peng SS, ed. Proceedings of the 16th International Conference on Ground Control in Mining. Morgantown, WV: West Virginia University, pp. 204-210.

Molinda GC, Bauer ER, Babich DR, Pappas DM [1998]. Factors influencing intersection stability in U.S. coal mines. In: Peng SS, ed. Proceedings of the 17th International Conference on Ground Control in Mining. Morgantown, WV: West Virginia University, pp. 267-275.

Pappas DM [1987]. Roof and rib fall accident and cost statistics: an in-depth study. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, IC 9151.

Peters RH [1992]. Miners views on how to prevent people from going under unsupported roof. In: Preventing Coal Mine Groundfall Accidents; How To Identify and Respond to Geologic Hazards and Prevent Unsafe Worker Behavior. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, RI 9332, pp. 25-31.

Peters RH, Randolph RF [1991]. Miners' views about why people go under unsupported roof and how to stop them. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, IC 9300.

Stateham RM, Radcliffe DE [1978]. A cyclic effect in coal mine roof stability. Washington, DC: U.S. Department of the Interior, Bureau of Mines, RI 8291.