# Ground-fall Accident Trends in Mining: 2010 to 2019

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## Abstract

Mining has been recognized among the most hazardous industries in the United States, despite the significant reduction in injury and fatality rates over the past century. This study focuses on the ground-fall incidents classified in the Mine Safety and Health Administration (MSHA) database as "fall of roof, back, or brow from in-place" and "fall of face, rib, pillar, side, or highwall." The main objective of this study is to conduct a comprehensive statistical analysis of the reported ground-fall incidents from 2010 through 2019 including both coal and metal/non-metal mines. Since most of the ground-fall injuries and fatalities occurred in underground coal mines and were attributed to falls of roof and rib, an additional analysis was directed to evaluate roof- and rib-fall incident trends in underground coal mines associated with the mining method, coal-seam thickness, mine size, and the seasonal effects.

The authors studied 8,303 ground-fall incident-narratives from both coal and metal/non-metal mines and classified them into one of the following types: roof fall, rib fall, face fall, highwall failure, and rock burst. Classifying the ground-fall accidents into these five categories and determining injuries and fatalities associated with each category will help identify areas where additional research is needed and where innovative solutions need to be developed to reduce these potentially severe occupational hazards. These ground-fall incidents resulted in 46 fatalities, 33 permanent disabilities, 3,082 injuries, 119,520 non-fatal days lost, and 12,433 days of restricted work activities.

For the period between 2010 and 2019, the average ground-fall injury and fatality rates in room-and-pillar coal mines are higher than those of longwall mines. The average fatality rate in room-and-pillar mines was 2.36 times that of longwall mines. The average injury rate in room-and-pillar mines was 0.82, while it was 0.51 in longwall mines. Of the injuries occurring in longwall mines, 52% occurred during development. The rib-fall fatality rate was higher than the roof-fall fatality rate for both room-and-pillar mines and longwall mines. The severity of rib-fall injuries tends to be higher than that of roof-fall injuries. Ground-fall rates were found to be higher between July and October, reinforcing research findings suggesting this could happen as a result of increased humidity.

## Introduction

Accidents due to ground falls have the potential for significant consequences including both fatal and non-fatal injuries. These injuries have the potential for lasting impacts, not only on the affected employee but also their families, friends, and co-workers. Many of these non-fatal injuries result in partial or total permanent disability, which results in a financial impact due to limiting the mine worker's ability to generate income. Additionally, these accidents have a significant impact on mining operations including damaged equipment, impaired ventilation, and production stoppages.

Over the past three decades, improved ground control support design and safety training for miners have managed to significantly decrease the number of ground fall accidents and related injuries and fatalities. According to the Mine Safety and Health Administration (MSHA) statistics during the 10-year period from 1986 to 1995, ground falls were responsible for the largest proportion (31.7%) of fatal incidents in the coal mining industry and about 50% of fatal incidents in underground coal mining (Biswas and Zipf, 2003). From 1999 through 2008, ground-fall events led to 75 fatalities, 5,941 injuries, and 13,774 noninjury roof falls in U.S. underground coal mines (Pappas and Mark, 2012). Based on this study between 2010 and 2019, ground falls in underground coal mines were responsible for about 13% of all injuries in underground coal mines (2,754 injuries out of 22,012), 26% of all fatalities (31 fatalities out of 121), and 27% of all accidents (7,744 accidents out of 28,429). In this study, a statistical analysis was conducted using a subset of data collected by MSHA and recorded in its employment and accident/injury databases. MSHA classifies reported accidents into twenty-one different categories where the accident classification identifies the circumstances which contributed most directly to the resulting accident (MSHA, 1986). For a detailed definition of a mine accident, see 30 CFR § 50.2 (MSHA, 1986). The authors reviewed 8,303 ground-fall incident-narratives—from coal and metal/nonmetal mines—and classified them into one of the following types: roof falls, rib falls, face falls, highwall failures, and rock bursts. Face fall includes both ground falls at longwall face and development face.

The authors relied on several measures of potential ground-fall risk including: 1) the number of injuries/fatalities, 2) injury/fatality rates, and 3) lost workdays as an index to show the relative level of risk among different operations and conditions in U.S. mines. These metrics can also be used to determine both problem areas and the progress in preventing work-related injuries. Incidence rates may be computed from the following formula:

*Incidence rate/200,000 hours = (number of injuries in a year * 200,000 / exposed employee hours worked in a year)*

The exposed employee hours worked in a year are the total employee hours in a year excluding the office and preparation plant employee working hours. The 200,000 number provides the standard base for calculating incidence rate for an entire year representing the number of hours for 100 employees working 40 hours per week, 50 weeks per year. The underlying assumption in the incidence rate is that all exposed mine workers experience the same risk no matter where they work at (active or inactive areas, inby or outby). This assumption has a potential limitation because the miners working at the face or active areas are at a more elevated risk than those working outby the face or inactive areas. Mark et al. (2003) claimed that a miner on a pillar recovery section was at least three times more likely to be fatality injured by ground-fall than a miner on an advanced section.

MSHA has three different lost workday indices: 1) Days lost from work are the number of workdays an injured miner takes before returning to work, commonly known as the non-fatal days lost (NFDL), 2) the number of days of restricted work activity after returning to work (DRWA), and 3) the number of statutory days lost. Days lost from work and days with restricted work activity depend on healing times, the nature of the work being done, and other factors. These lost workdays have been used to develop risk indices for specific mining tasks (Coleman and Kerkering, 2007).

In this study, accidents and incidents are used interchangeably throughout the paper. "Ground fall accident" refers to an incident that was reported to MSHA and may or may not result in an injury or death of a mine worker. Injury cases include all accidents that resulted in an injury including partial or total permanent disability of mine workers. Fatality incidents are not included among the injury cases. Eight of the injury cases included in this study required only first-aid treatment, and they happened to occur in coal mines. All accidents related to machinery or involving contractors in the MSHA database were excluded. Roof-fall accidents in this paper were not differentiated as to whether the accidents occurred under supported or unsupported roof. Also, rib-fall accidents were not differentiated as to whether the rib was supported or not. The outcome of this study will help pinpoint future ground-control research activities and could be used as a tool to measure the impact of the ground control research in underground mines in the U.S.

## Ground-fall results in coal and metal/nonmetal mines combined

Mine operators are classified according to whether they mine coal (anthracite or bituminous/subbituminous), metal, nonmetal, stone, or sand and gravel. The term "metal/nonmetal" is used to designate all non-coal mining operations. In the ten-year period from 2010 to 2019, there were 8,303 ground-fall accidents for both surface and underground mines that resulted in 46 fatalities, 33 total or partial permanent disabilities, 3,082 injuries, 119,520 days lost from work, 12,433 days of restricted work activities, and 5,175 noninjury ground-falls as shown in Table 1. Some of the noninjury ground-falls shown in Table 1 were mainly massive falls that were reported because they extended beyond the height of the bolts, damaged equipment, stopped production, or disrupted ventilation. Most roof-fall injuries involve falls of small chunks of roof rock from the immediate roof beam, similar finding was reported by (Robertson & Hinshaw, 2002). Noninjury roof falls are often large and could comprise an entire intersection or extend to an entire pillar length (Bajpayee et al., 2014).

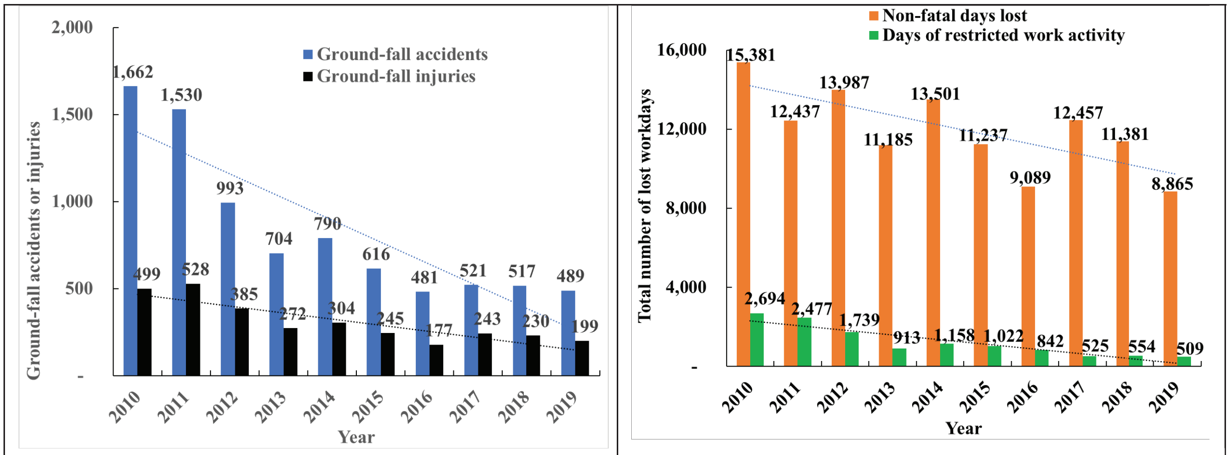
**Table 1: Ground-fall results in coal and metal/nonmetal mines by year**

| Year | Ground-fall accidents | Ground-fall injuries | Ground-fall fatalities | Ground fall permanent disabilities | Noninjury ground fall accidents | Non-fatal days lost from work | Days of restricted work activity |
|---|---|---|---|---|---|---|---|
| **2010** | 1,662 | 499 | 6 | 4 | 1,157 | 15,381 | 2,694 |
| **2011** | 1,530 | 528 | 6 | 8 | 996 | 12,437 | 2,477 |
| **2012** | 993 | 385 | 6 | 2 | 602 | 13,987 | 1,739 |
| **2013** | 704 | 272 | 5 | 1 | 427 | 11,185 | 913 |
| **2014** | 790 | 304 | 6 | 4 | 480 | 13,501 | 1,158 |
| **2015** | 616 | 245 | 4 | 4 | 367 | 11,237 | 1,022 |
| **2016** | 481 | 177 | 3 | 0 | 301 | 9,089 | 842 |
| **2017** | 521 | 243 | 4 | 4 | 274 | 12,457 | 525 |
| **2018** | 517 | 230 | 3 | 4 | 284 | 11,381 | 554 |
| **2019** | 489 | 199 | 3 | 2 | 287 | 8,865 | 509 |
| **Total** | **8,303** | **3,082** | **46** | **33** | **5,175** | **119,520** | **12,433** |

Figure 1 illustrates the annual number of ground-fall accidents, injuries, days lost from work, and days of restricted work activity in U.S. coal and metal/nonmetal mines combined. A general downward-moving trend in the number of injuries (see black dotted line in Figure 1a) from ground-falls exists between 2010 and 2019. However, between 2017 and 2019, the number of injuries from ground-falls increased.

Between 2010 and 2019, the number of injuries from ground-falls decreased by 60%. While this decrease seems dramatic, the number of employee hours worked also decreased by 39%, making the apparent decline in injury rate somewhat less impressive. About 38% of the ten-year ground-fall accidents occurred in two years (2010 and 2011 combined). It should be noted that MSHA Program Policy Letter (PPL) P12-V-03, dated May 11, 2012, redefined the term "active workings," reducing the scope of where unplanned roof falls were required to be reported (MSHA, 2012). This resulted in a substantial reduction in reportable noninjury roof falls as evident in the data.

The severity of injuries could be inferred from non-fatal workdays lost and restricted workdays charged to injury cases; these are useful measures of average safety performance in a mine. Between 2010 and 2019, the general trend for both workdays lost and restricted workdays are decreasing as illustrated by the dotted lines in Figure 1b, the number of days spent on restricted work activities ranges from 4% to 20% of the days lost from work. Although the year 2012 has fewer injuries (385 injury cases) compared to the year 2011 (528 injury cases), the severity of the 2012 injuries was higher than the 2011 injuries because they had more days lost from work.




a. Ground fall accidents and injuries

b. Ground fall lost workdays

**Figure 1: Year-by-year ground-fall accidents, injuries, and lost workdays in coal and metal/nonmetal mines.**

Roof-fall and rib-fall accidents remain a leading cause of injuries, fatalities, and lost workdays in coal and metal/nonmetal mines (see Table 2 and Figure 2). The unclassified group shown in Table 2 includes both the misclassified and unknown cases of the database. Between 2010 and 2019, roof and rib falls are responsible for 97% of ground-fall accidents, 72% of all ground-fall fatalities, 88% of ground-fall injuries, 94% of ground-fall permanent disabilities, 94% of ground-fall days lost from work, and 80% of ground-fall restricted work activities.

**Table 2: Ground-fall results in coal and metal/nonmetal mines by ground-fall type between 2010–2019**

| Ground-fall type | Ground-fall accidents | Ground - fall deaths | Ground-fall disabilities | Ground-fall injuries | Non-fatal days lost from work | Days of restricted work activity |
|---|---|---|---|---|---|---|
| **Face** | 131 | 4 | 1 | 122 | 4,738 | 1,218 |
| **Highwall** | 77 | 6 | 0 | 20 | 881 | 68 |
| **Outburst** | 52 | 3 | 0 | 18 | 828 | 154 |
| **Rib fall** | 660 | 18 | 7 | 576 | 33,356 | 2,870 |
| **Roof fall** | 7,360 | 15 | 24 | 2,331 | 78,991 | 8,036 |
| **Roof and rib fall** | 6 | 0 | 0 | 4 | 229 | 0 |
| **Unclassified** | 17 | 0 | 1 | 11 | 488 | 87 |
| **All ground falls** | **8,303** | **46** | **33** | **3,082** | **119,520** | **12,433** |

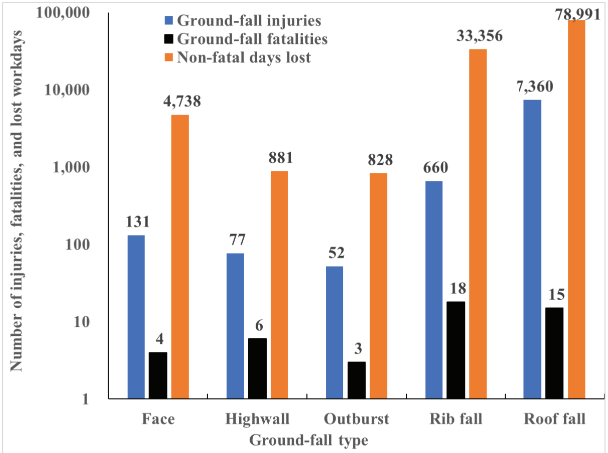



**Figure 2: Ground-fall injuries, fatalities, and non-fatal days lost from work associated with various ground-fall types in U.S. coal and metal/nonmetal mines between 2010 and 2019.**

Although the total number of rib-fall injuries shown in Table 2 is about 25% of the roof-fall injuries, rib falls resulted in more fatalities than roof falls between 2010 and 2019. Rib falls were responsible for 18 fatalities in coal and metal/nonmetal mines combined and roof falls were responsible for 15 fatalities. The non-fatal days lost from work due to rib falls is about 42% of the non-fatal days lost due to roof falls. The days of restricted work activity due to rib falls is about 36% of the days of restricted work activity due to roof falls.

## Ground-fall results in U.S. underground coal mines

The remainder of this paper focuses on ground-fall accidents in underground coal mines because most of the injuries, fatalities, and lost workdays between 2010 and 2019 occurred in underground coal mines particularly due to roof and rib falls. As shown in Table 3, between 2010 and 2019, roof-fall and rib-fall accidents in underground coal mines resulted in 25 fatalities representing 80% of the ground-fall fatalities, 31 permanent disabilities representing 94% of the ground-fall disabilities, 2,679 injuries representing 97% of the ground-fall injuries, 109,039 non-fatal days lost from work representing 96% of ground-fall non-fatal days lost from work, and 9,048 days of restricted work activities representing 97% of ground-fall days of restricted work activity.

**Table 3: Ground-falls summary in underground coal mines by ground-fall type between 2010–2019**

| Ground-fall type | Ground-fall accidents | Ground-fall deaths | Ground-fall permanent disabilities | Ground-fall injuries | Non-fatal days lost from work | Days of restricted work activity |
|---|---|---|---|---|---|---|
| **Face** | 63 | 3 | 1 | 57 | 3,001 | 259 |
| **Highwall** | 13 | 0 | 0 | 1 | 0 | 0 |
| **Outburst** | 22 | 3 | 0 | 8 | 441 | 0 |
| **Rib fall** | 575 | 14 | 7 | 523 | 32,283 | 1,615 |
| **Roof fall** | 7,059 | 11 | 24 | 2,156 | 76,756 | 7,433 |
| **Roof and rib fall** | 4 | 0 | 0 | 4 | 229 | 0 |
| **Unclassified** | 8 | 0 | 1 | 5 | 337 | 0 |
| **All ground falls** | **7,744** | **31** | **33** | **2,754** | **113,047** | **9,307** |

Table 4 summarizes ground-fall accidents in underground coal mines by year, and Figure 3 illustrates the year-to-year number of ground-fall accidents and the resulted injuries, non-fatal days lost, and days of restricted work activity. A downward trend exists in the number of both accidents and injuries (see the dotted lines in Figure 3a). The number of injuries from ground-falls decreased by 64%. However, the number of employee hours worked declined by 36% and the coal production reduced by 21%, indicating that the injury rate from ground-falls did not decrease as drastically from 2010 to 2019. Both injury and fatality rates will be discussed in detail in the following sections. The non-fatal days lost and days of restricted work declined by 42% and 82%, respectively (see Figure 3b).

**Table 4: Ground-fall accident frequency in underground coal mines by year**

| Year | Ground-fall accidents | Ground-fall injuries | Ground fall fatalities | Ground-fall permanent disabilities | Noninjury ground-fall accidents | Non-fatal days lost from work | Days of restricted work activity |
|---|---|---|---|---|---|---|---|
| **2010** | 1,568 | 437 | 6 | 4 | 1,125 | 14,692 | 1,644 |
| **2011** | 1,444 | 471 | 3 | 8 | 970 | 11,526 | 1,909 |
| **2012** | 935 | 353 | 4 | 2 | 578 | 13,201 | 1,334 |
| **2013** | 650 | 246 | 4 | 1 | 400 | 10,852 | 807 |
| **2014** | 729 | 274 | 3 | 4 | 452 | 12,541 | 1,103 |
| **2015** | 568 | 217 | 3 | 4 | 348 | 11,098 | 752 |
| **2016** | 438 | 150 | 2 | 0 | 286 | 8,265 | 599 |
| **2017** | 484 | 225 | 2 | 4 | 257 | 11,768 | 509 |
| **2018** | 488 | 211 | 1 | 4 | 276 | 10,630 | 354 |
| **2019** | 440 | 170 | 3 | 2 | 267 | 8,474 | 296 |
| **Total** | **7,744** | **2,754** | **31** | **33** | **4,959** | **11,3047** | **9,307** |

Over the ten-year period, ground-fall injuries involving more than 20 days lost from work were about 37% of all ground-fall injuries in underground coal mines and they resulted in 96% of the total non-fatal workdays lost for the whole underground coal mining industry. This indicates that these injuries were very severe.

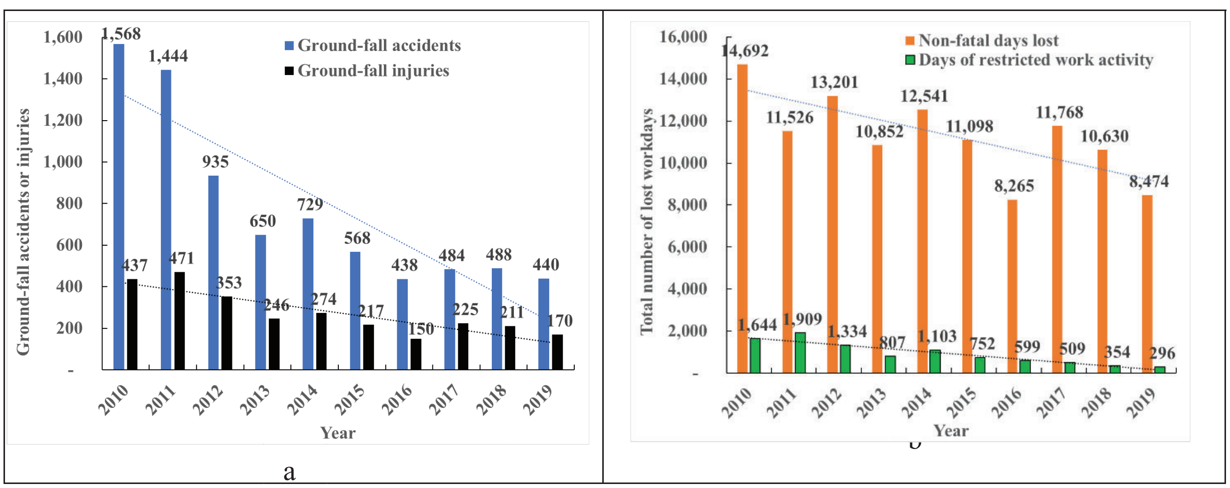



**Figure 3: Annual number of ground-fall accidents and the resulted injuries and total number of lost workdays in underground coal mines between 2010 and 2019.**

## Main causes for ground falls

The causes of ground falls can be described using the following three categories: geology (a rock mass failure), engineering (a support system failure), or direct human actions (induced by mining activity) (Biswas and Zipf, 2003). From 2010–2019, direct human actions account for 56% of ground-fall injuries; they include those triggered by human/machine interaction with rock or coal that occurred while drilling or bolting (44%), operating the continuous miner (8%), scaling or barring down (2%), setting timbers (1%), and mucking (1%), this result is based on 38% of mine worker activity data in the MSHA database because 62% of the mine worker activity was missing. Efforts to enhance the safety of mine worker activities connected with support installation (bolts/timbers) and scaling/mucking may be avenues for reducing ground-fall accidents.

**Effect of mining method on ground-fall frequency and production in underground coal mines**

The density of roof and rib support and the mining conditions in room-and-pillar mines are typically different from that observed in longwall mines. Additionally, the mining methods themselves are very different in terms of powered roof support at the mining face when considering pillar retreat. These differences could affect the number of injuries/fatalities and injury/fatality rates. One of the most definitive factors affecting roof-fall incident rates is the mining method (Pappas and Mark, 2012). Hence, to eliminate the confounding effect of mining method and to better understand its impact on injury and fatality rates, ground-fall accidents in underground coal mines were separated by the mining method into room-and-pillar and longwall mines.

A summary of ground-fall accidents in room-and-pilar mines and longwall mines is shown in Table 5. These ground-fall injuries correspond to four ground-fall categories (roof fall, rib fall, face fall, and rock outburst). Between 2010 and 2019, 71% of the ground-fall injuries and 78% of the noninjury ground falls occurred in room-and-pillar mines, while 29% of the ground-fall injuries and 22% of the noninjury ground fall occurred in longwall mines, 43% of underground coal production came from room-and-pillar mines, while 57% of the production came from longwall mines despite the underground employee working hours in room-and-pillar mines being about 1.5 times longwall mines. Although the total number of injuries between 2010 and 2019 in longwall mines (792 cases) is about 40% of the room-and-pillar mine injuries (1962 cases), the severity of longwall injuries is higher because 43% of the longwall injuries involved more than 20 days lost from work, while 34% of the room-and-pillar injuries involved more than 20 days lost from work.

From 2011–2019, there was a substantial 59% reduction in the number of room-and-pillar mines and a corresponding 41% reduction in coal production. On the other hand, the number of longwall mines increased by 7% from 2010 to 2014, then continually decreased until 2019. There was a 24% reduction in longwall mines associated with a 24% reduction in coal production in 2019 as compared to 2014.

**Table 5: Summary of ground-fall frequency in room-and-pilar mines and longwall mines from 2010-2019.**

| | Year | Number of mines* | Ground-fall injuries | Ground-fall deaths | Ground-fall permanent disabilities | Roof-fall accidents | Roof-fall injuries | Roof-fall deaths | Roof-fall permanent disabilities | Rib-fall accidents | Rib-fall injuries | Rib-fall deaths | Rib-fall permanent disabilities | Employee working hours |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Room-and-pillar mines** | 2010 | 458 | 355 | 5 | 4 | 1,257 | 295 | 3 | 3 | 70 | 58 | 2 | 1 | 60,491,632 |
| | 2011 | 467 | 380 | 2 | 7 | 1,103 | 309 | 0 | 5 | 75 | 69 | 2 | 2 | 67,008,334 |
| | 2012 | 446 | 267 | 3 | 1 | 702 | 224 | 1 | 1 | 44 | 42 | 2 | 1 | 60,775,471 |
| | 2013 | 349 | 171 | 3 | 1 | 446 | 141 | 2 | 0 | 30 | 26 | 0 | 1 | 53,015,549 |
| | 2014 | 295 | 181 | 3 | 2 | 493 | 150 | 1 | 0 | 32 | 30 | 0 | 0 | 48,375,750 |
| | 2015 | 257 | 145 | 2 | 3 | 362 | 114 | 1 | 3 | 28 | 27 | 1 | 0 | 39,819,561 |
| | 2016 | 211 | 102 | 2 | | 255 | 83 | 0 | 0 | 22 | 16 | 2 | 0 | 28,755,975 |
| | 2017 | 201 | 138 | 1 | 2 | 276 | 112 | 1 | 1 | 24 | 23 | 0 | 0 | 32,208,542 |
| | 2018 | 202 | 126 | 1 | 3 | 266 | 99 | 0 | 3 | 27 | 25 | 1 | 0 | 34,211,037 |
| | 2019 | 193 | 97 | 2 | 2 | 244 | 73 | 0 | 2 | 30 | 24 | 2 | 0 | 33,867,699 |
| **Total** | | | **1,962** | **24** | **25** | **5,404** | **1,600** | **9** | **18** | **382** | **340** | **12** | **5** | **458,529,550** |
| **Longwall mines** | 2010 | 39 | 82 | 1 | 1 | 204 | 57 | 0 | 0 | 22 | 18 | 1 | 0 | 33,811,529 |
| | 2011 | 41 | 91 | 1 | 0 | 232 | 65 | 1 | 1 | 22 | 22 | 0 | 0 | 37,511,479 |
| | 2012 | 42 | 86 | 1 | 1 | 156 | 58 | 1 | 1 | 22 | 21 | 0 | 0 | 38,363,297 |
| | 2013 | 42 | 75 | 1 | 0 | 133 | 46 | 0 | 0 | 22 | 22 | 0 | 0 | 37,517,458 |
| | 2014 | 42 | 93 | 0 | 2 | 172 | 66 | 0 | 1 | 24 | 24 | 0 | 1 | 36,400,091 |
| | 2015 | 39 | 72 | 1 | 1 | 145 | 48 | 0 | 0 | 21 | 20 | 0 | 1 | 30,771,116 |
| | 2016 | 35 | 48 | 0 | 0 | 145 | 36 | 0 | 0 | 9 | 9 | 0 | 0 | 22,696,987 |
| | 2017 | 34 | 87 | 1 | 2 | 155 | 63 | 0 | 2 | 17 | 17 | 0 | 0 | 25,879,112 |
| | 2018 | 33 | 85 | 0 | 1 | 167 | 60 | 0 | 1 | 19 | 19 | 0 | 0 | 26,332,214 |
| | 2019 | 32 | 73 | 1 | 0 | 146 | 57 | 0 | 0 | 15 | 11 | 1 | 0 | 26,423,705 |
| **Total** | | | **792** | **7** | **8** | **1,655** | **556** | **2** | **6** | **193** | **183** | **2** | **2** | **315,706,988** |

### Effect of mining method on average incidence rates in underground coal mines

Figure 5 illustrates the annual numbers of ground-fall injuries and injury rates for room-and-pillar mines and longwall mines. In room-and-pillar mines, a downward-moving trend in the number of injuries from ground falls exists from 2010 to 2019, such that the number of injuries decreased by 73%. While this decrease seems dramatic, the number of underground employee-hours in the same time period also declined by 44%, making the apparent decline in room-and-pillar injury rate less impressive; the injury rate in room-and-pillar mines in 2019 is about 50% less than that of 2010. The average injury rate in the five-year period between 2010 and 2014 was about 0.92, while it was about 0.72 between 2015 and 2019. Improvements in roof control technology, including the widespread use of cable bolts particularly in the intersections, a persistent educational campaign organized by MSHA (Mark and Gauna, 2017; Mark et al., 2004; Zhang et al., 2019 ), and the reduction in mine worker exposure to hazardous areas are generally considered among the main reasons for reduced accidents and injuries in room-and-pillar mines.

For longwall mines, the number of injuries fluctuates between 48 and 93 with an average value of 79. There is no noticeable improvement in the injury rate between 2010 and 2019. The injury rate in 2010 was 0.48, while it was 0.55 in 2019. The average injury rate in five-year period between 2010 and 2014 is about 0.47, while it was 0.55 between 2015 and 2019. Between 2017 and 2019, the number of underground employee-hours is significantly lower than the rest of the ten-year period, making the injury rates significantly higher in these three years. A single injury has a much greater effect on injury rate with smaller number of employee working hours.

For the ten-year period between 2010 and 2019, the average injury rate in room-and-pillar mines was about 0.82, while it was about 0.51 in longwall mines, The average injury rate in room-and-pillar mines was getting closer to that of longwall mines. In 2010 the injury rate in room-and-pillar mines was 2.42 times that of longwall mines, while in 2019 there was insignificant difference between the injury rate of room-and-pillar mines and longwall mines that indicates a significant improvement in ground-control safety in room-and-pillar coal mines.

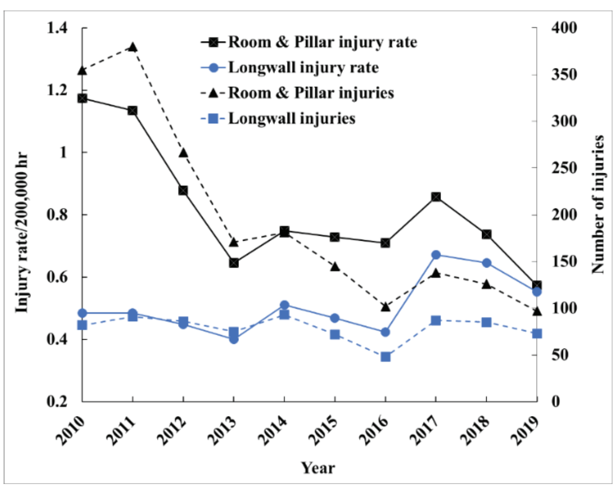



**Figure 5: Ground-fall injuries and injury rates in room-and-pillar and longwall mines from 2010–2019.**

About 52% of ground-fall injuries in longwall mines occurred during the development stage as shown in Table 6. About 73% of these injuries occurred due to roof falls, while 24% occurred due to rib falls. Additionally, 3% occurred due to face falls and combined roof and rib falls as shown in Table 7.

**Table 6: Number and % of longwall injuries occurring during development stage between 2010 and 2019.**

| Year | Number of ground-fall injuries in longwall mines | Number of ground-fall injuries in longwall mines at development stage | % injuries at development stage |
|---|---|---|---|
| **2010** | 82 | 42 | 51 |
| **2011** | 91 | 46 | 51 |
| **2012** | 86 | 45 | 52 |
| **2013** | 75 | 38 | 51 |
| **2014** | 93 | 54 | 58 |
| **2015** | 72 | 37 | 51 |
| **2016** | 48 | 25 | 52 |
| **2017** | 87 | 39 | 45 |
| **2018** | 85 | 43 | 51 |
| **2019** | 73 | 43 | 59 |

**Table 7: Distribution of longwall injuries at development stage by ground-fall type**

| Ground-fall type | Number of longwall injuries at development stage |
|---|---|
| **Face** | 7 |
| **Rib fall** | 101 |
| **Roof and rib fall** | 3 |
| **Roof fall** | 301 |

Figure 6 illustrates the average fatality rates for room-and-pillar and longwall mines between 2010–2019. The authors did not calculate annual fatality rates because the number of fatalities in longwall mines was either 0 or 1 yearly, while it was 5 or less in room-and-pillar mines. The average fatality rate in room-and-pillar mines was 2.36 times that in longwall mines.

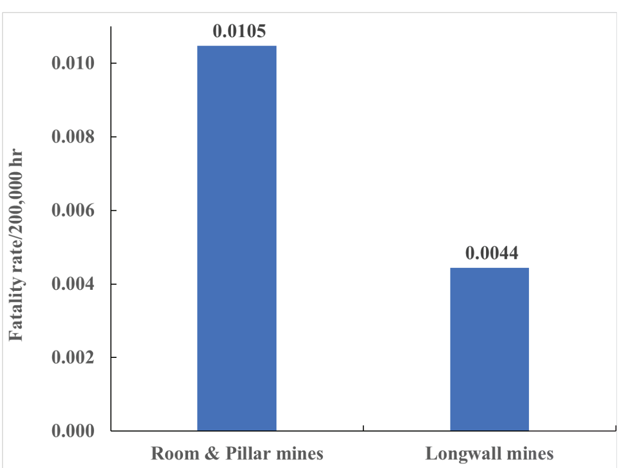



**Figure 6: Average fatality rates in room-and-pillar and longwall mines between 2010-2019.**

## Effect of mining method on roof and rib incidence rates and severity of injuries

Since most of the injuries and fatalities in underground coal mines are connected to the fall of roof and rib (see Table 3 and 5), more focus is directed in this section to roof- and rib-fall injury and fatality rates. Figure 7 illustrates the roof-fall and rib-fall injury rates in room-and-pillar mines and longwall mines between 2010 and 2019. Rib-fall injury rates have almost plateaued around 0.14 and 0.12 for room-and-pillar and longwall mines, respectively.

The average roof-fall injury rate for the ten-year period between 2010 and 2019 was 0.66 and 0.36 for room-and-pillar mines and longwall mines, respectively. Before 2013, the roof-fall injury rate in room-and-pillar mines was substantially higher than the roof-fall injury rate in longwall mines. However, after 2013 the roof-fall injury rates in room-and-pillar mines and longwall mines have been getting closer, and in 2019 roof-fall injury rate in room-and-pillar mines was almost identical to that of longwall mines. One potential reason for this is that many coal mines operating in difficult ground conditions have been forced to close. It is likely that this resulted in better ground conditions on average with the remaining mines in operation. Longwall mines are much more productive and presumably have not experienced this same phenomenon.

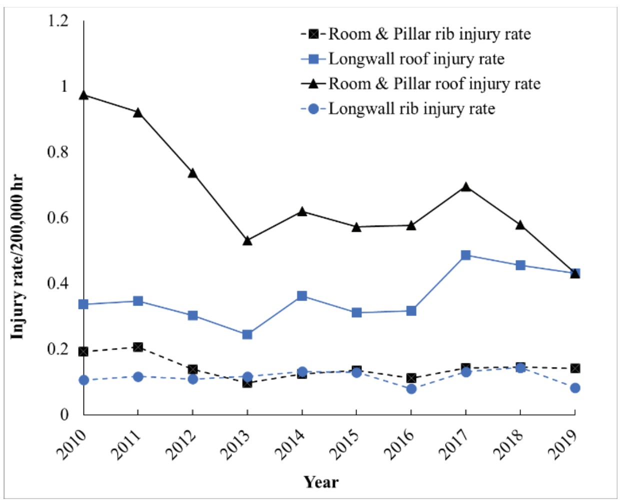



**Figure 7: Roof-fall and rib-fall injury rates by mining method between 2010 and 2019.**

Figure 8 illustrates the average fatality rate due to roof and rib falls in room-and-pillar mines and longwall mines between 2010 and 2019. The data indicates that the average fatality rates in room-and-pillar mines are significantly higher than that of longwall mines. The rib-fall fatality rate in room-and-pillar mines was 4.1 times that of longwall mines, and the roof-fall fatality rate in room-and-pillar mines was 3.4 times that of longwall mines. Additionally, the average fatality rate due to rib falls was higher than that of roof falls. In room-and-pillar mines the fatality rate due to rib falls was 1.54 times that of roof falls, while it was 1.27 in longwall mines. With the reduction of roof-fall fatalities, the spotlight has more recently been turned to shine a light on rib-fall fatalities.

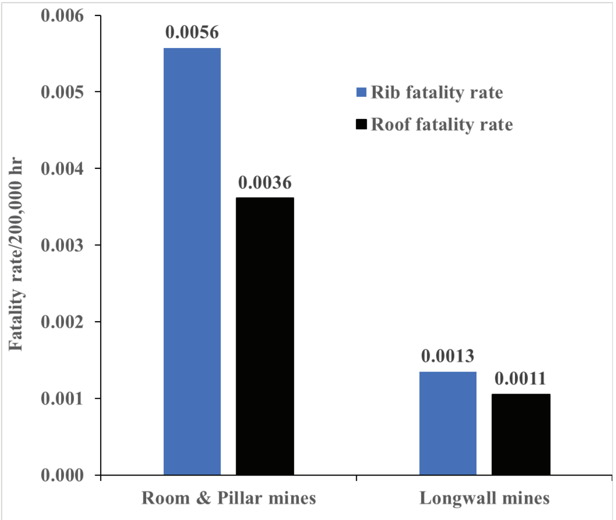



**Figure 8: Average fatality rates for roof and rib falls in room-and-pillar and longwall mines between 2010 and 2019.**

The ratio of rib-fall injuries to roof-fall injuries is about 21% in room-and-pillar mines, while it is about 33% in longwall mines (see Table 5). The ratio of non-fatal days lost due to rib-fall injuries to roof-fall injuries is about 40% in room-and-pillar mines, while it is about 44% in longwall mines (see Figure 9). The data would indicate that rib-fall injuries are more severe than roof-fall injuries. The non-fatal days lost due to rib-fall injuries in room-and-pillar mines are about 2.0 times that for longwall mines, while the non-fatal days lost due to roof fall in room-and-pillar mines are about 2.2 that of longwall mines.

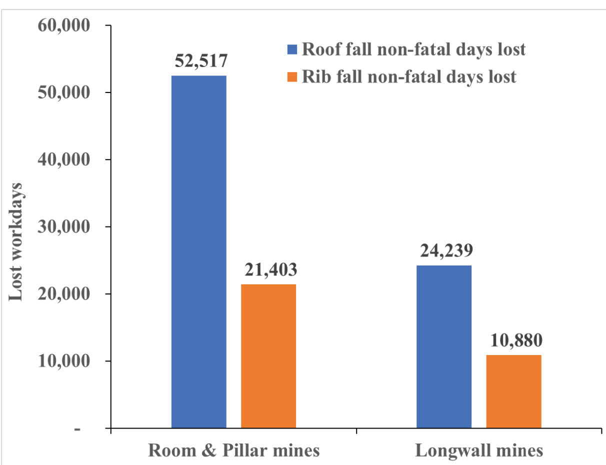



**Figure 9: Lost workdays due to roof and rib falls in room-and-pillar mines and longwall mines.**

Generally, rib injuries involving more than 20 days lost from work accounted for about 51% of all rib-fall accidents with injuries in underground coal mines, while roof-fall accidents with injuries with more than 20 days lost from work accounted for about 33%. This indicates a need for more research to find out why rib fall injuries are more severe that could help identify better strategy to protect mines and an ongoing need to improve rib control practices in underground coal mines.

**Effect of coal-seam thickness on average injury/fatality rates**

Mining height affects the selection of not only mining method and equipment, but also mine-worker posture, mobility, vision, and performance. Coal-seam height is not necessarily the mining height, which sometimes includes roof and floor rock that is often removed due to equipment size, particularly when the seam thickness is small. Obtaining the actual mining height of a mine at the scene of the injury would be ideal. However, this information is not usually available unless a fatality occurs. Determining how seam thickness affects the average injury and fatality rates at underground coal mines would increase our understanding of how the underground mining environment affects the risk of injury/fatality to mine workers.

The coal-seam thickness in room-and-pillar mines and longwall mines was stratified into four groups based on previous studies (Fotta and Mallett, 1997; Pappas and Mark, 2012): 1) Very low seam heights are less than 43 in., 2) Low seam heights range from 43 to 60 in., 3) Medium seam heights range from 60 to 72 in., and 4) High seam heights exceed 72 in. The mining height varies by region. In Central Appalachia for example, it is typically 5-6 feet regardless of the coal seam height. In Pennsylvania, most of room and pillar mining is done inseam without mining neither the roof nor the floor, the mining height of some of these mines is very low.

Table 8 summarizes the ground-fall frequency and injury/fatality rates associated with coal-seam thicknesses in room-and-pillar mines and longwall mines. The proportion of the number of room-and-pillar mines are roughly evenly distributed among the four coal-seam thickness categories. However, 93% (54 mines out of 58) of the longwall mines fall in the “High” coal-seam category. No longwall mines exist in the “Very low” coal-seam category, and only one longwall mine exists in the “Low” category.

Despite room-and-pillar mines in the “High” coal-seam thickness category having about 1.75 times higher injuries than the “Low” coal seam thickness, there was a slight difference in their injury rates because the “High” coal seam thickness mines have the highest amount of employee working hours. The injury rate for thick seams in room-and-pillar mines was about 0.884, while it was 0.463 for longwall mines. Hence, the injury rate for thick seams in room-and-pillar mines is almost double that of the longwall mines. A single injury has a substantial effect on the injury rate in categories where total employee working hours are very low. This is why a “Low” coal-seam thickness longwall mine that only experienced two injuries has a very high injury rate (1.7091). Taken out of context, a value such as this appears to be very high when in fact the average rate for all longwall mines is much lower (see Table 8).

For room-and-pillar mines, 54% (13 out of 24) of the ground-fall fatalities occurred in the “High” coal-seam heights with an average fatality rate of 0.0149. For longwall mines, it was expected that most of the fatalities would occur in “High” coal seam heights because 91% of the longwall mines are operating in that coal height category (see Table 8). About 47% of the fatalities in the “High” coal-seam heights occurred due to rib falls in room-and-pillars mines and longwall mines combined, while 26% of the “High” coal seam fatalities occurred due to roof falls.

**Table 8: Ground-fall frequency and average injury/fatality rate by coal-seam thickness and mining method for ten-year period between 2010 and 2019**

| Mining method | Coal-seam thickness category | Ground-fall injuries | Ground-fall fatalities | Employee hours | Injury rate | Fatality rate | Number of mines | Days lost from work | Ground-fall fatality cases |
|---|---|---|---|---|---|---|---|---|---|
| Room-and-pillar mines | V-low | 201 | 2 | 54,826,260 | 0.7332 | 0.0073 | 258 | 9,370 | 1 rib & 1 roof |
| | Low | 444 | 4 | 102,193,260 | 0.8689 | 0.0078 | 285 | 16,419 | 2 rib & 2 roof |
| | Medium | 524 | 5 | 127,247,047 | 0.8236 | 0.0079 | 203 | 18,233 | 2 rib & 3 roof |
| | High | 770 | 13 | 174,262,983 | 0.8837 | 0.0149 | 271 | 30,208 | 7 rib & 3 roof & 3 outburst |
| Longwall mines | Low | 2 | 0 | 234,035 | 1.7091 | 0.0000 | 1 | 0 | ----- |
| | Medium | 144 | 1 | 38,596,586 | 0.7462 | 0.0052 | 3 | 7,208 | 1 face |
| | High | 641 | 6 | 276,876,367 | 0.4630 | 0.0043 | 54 | 30,686 | 2 face & 2 rib & 2 roof |

**Effect of coal-seam thickness on roof-fall and rib-fall injury rates**

The relationship between roof-fall and rib-fall incidence rates with coal-seam thickness is investigated in this section. Since there is no wide distribution of seam heights in longwall mines—91% of the longwall mines are operating in "High" seam heights—only data from room-and-pillar mines will be examined in this section. The expectation was that the injury rate due to rib falls would increase as coal-seam height increases, but surprisingly, room-and-pillar mines with "High" coal-seam heights show lower rib-fall injury rates compared to "Medium" and "Low" coal-seam height as shown in Figure 10. This is likely because of high employee working hours at these mines and the fact that more of these mines routinely use rib support.

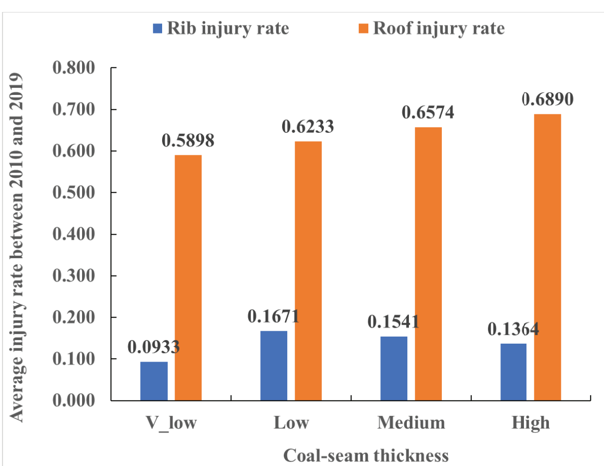



**Figure 10: Average rib-fall and roof-fall injury rates between 2010 and 2019 in room-and-pillar mines.**

In room-and-pillar mines, 50% of ground-fall fatalities occurred due to rib falls and 37% occurred due to roof falls. Surprisingly, one of the two fatalities that occurred in the very low coal-seam category was due to a rib fall, and 50% of the ground-fall fatalities that occurred in low coal seam category were due to rib falls. This means that rib fatalities in room-and-pillar mines are not limited to thick coal seams (see Table 8). One potential reason for this is that the mining height could be significantly higher than the seam thickness.

**Effect of mine size on injury/fatality rates**

Mine size is defined as the total number of underground employee working hours. Three categories of mine sizes were defined: <50 employees (small size); 50–149 employees (medium size); and >149 employees (large size). No small-size longwall mines exist in the U.S., and 97% of U.S. longwall mines belong to the large-mine size category. As shown in Figure 11 and Table 9, small-size room-and-pillar mines tend to extract thinner seams, while large-size room-and-pillar mines tend to extract thicker seams.

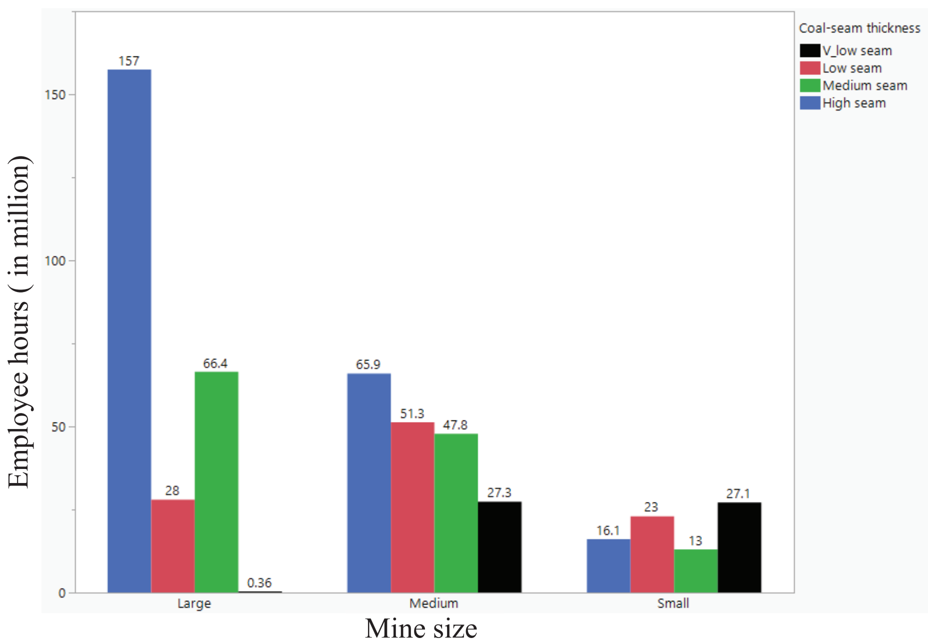



**Figure 11: Employee hours versus mine size at different coal-seam thickness in room-and-pillar mines between 2010 and 2019.**

As shown in Table 9, the average non-fatal days lost from work per injury decreases as the mine size increases, indicating that either the severity of injuries or risk usually declines as the mine size increases or the smaller mines may be less likely to report the less severe injuries. Also, the average fatality rate decreases as the mine size increases irrespective of the coal-seam thickness. An elevated ground-fall fatality rate in small mines was also identified in previous studies (Pappas and Mark, 2000).

**Table 9: Injury/fatality rates by coal-seam thickness in room-and-pillar mines between 2010 and 2019**

| Mine size | Coal-seam classification | Employee hours | Number of mines | Number of injuries | Number of fatalities | Injury rate | Average injury rate | Average fatality rate | Non-fatal days lost | Average non-fatal days lost per injury |
|---|---|---|---|---|---|---|---|---|---|---|
| **<50 workers** | V-low seam | 27,128,761 | 211 | 104 | 1 | 0.7741 | 0.8833 | 0.0148 | 5,239 | 47.5 |
| | Low seam | 22,962,745 | 174 | 111 | 1 | 0.9668 | | | 5,434 | |
| | Medium seam | 13,018,748 | 107 | 51 | 2 | 0.7835 | | | 2,254 | |
| | High seam | 16,059,929 | 126 | 81 | 1 | 1.0087 | | | 3,632 | |
| **50-149 workers** | V-low seam | 27,335,703 | 46 | 93 | 1 | 0.6804 | 0.8267 | 0.0111 | 4,131 | 39.1 |
| | Low seam | 51,284,500 | 93 | 198 | 2 | 0.7722 | | | 7,477 | |
| | Medium seam | 47,786,173 | 72 | 190 | 1 | 0.7952 | | | 6,179 | |
| | High seam | 63,452,170 | 107 | 336 | 8 | 1.0591 | | | 14,026 | |
| **>149 workers** | V-low seam | 36,1796 | 1 | 3 | 0 | 1.6584 | 0.8544* | 0.0072 | 0 | 24.0 |
| | Low seam | 2,794,6015 | 18 | 135 | 1 | 0.9661 | | | 3,508 | |
| | Medium seam | 66,442,126 | 24 | 283 | 2 | 0.8519 | | | 9,800 | |
| | High seam | 94,750,884 | 38 | 353 | 4 | 0.7451 | | | 12,550 | |

*The injury rate associated with v_low seam was ignored because these injuries are associated with zero days lost from work

A comparison of the ground-fall fatality rate in room-and-pillar mines between 2010–2019 and 1999–2008 is illustrated in Figure 12; there is a drastic reduction in the 2010–2019 fatality rates compared to 1999–2008 such that the fatality rates declined by 62% for mines of size < 50 workers, 33% for mines of size between 50-149 worker, and 55% for mines of size > 149 workers.

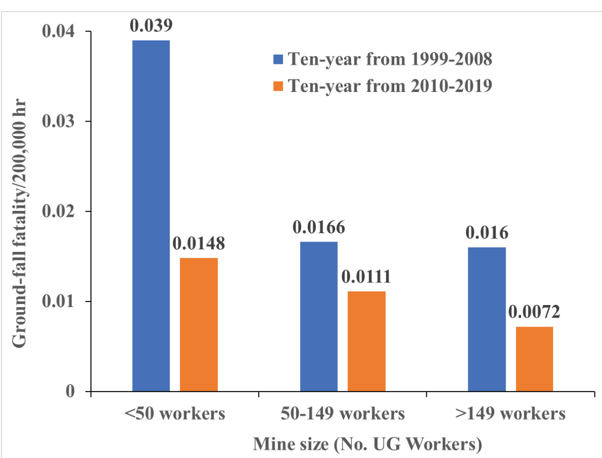



**Figure 12: Ground-fall fatality rates between 2010–2019 versus 1999–2008**

## Effect of seasonal change on roof-fall and rib-fall injuries

Previous studies have found that the seasonal change can affect the occurrence of roof fall and rib fall because of the seasonal fluctuations in temperature, pressure, and humidity (Pappas and Mark, 2012; Bajpayee et al., 2014), 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. The monthly roof-fall and rib-fall injuries between 2010 and 2019 were evaluated to determine if seasonal fluctuations in temperature, pressure, and humidity would affect roof-fall and rib-fall injuries. Figure 13 summarizes the roof-fall and rib-fall injuries in room-and-pillar mines between 2010 and 2019. For both room-and-pillar mines and longwall mines, about 30% of the roof-fall and rib-fall injuries occurred in the three months of summer (June, July, and August). Previous studies have found similar seasonal patterns. Those results indicated that the probability of a roof fall is greatest in August and lowest in February.

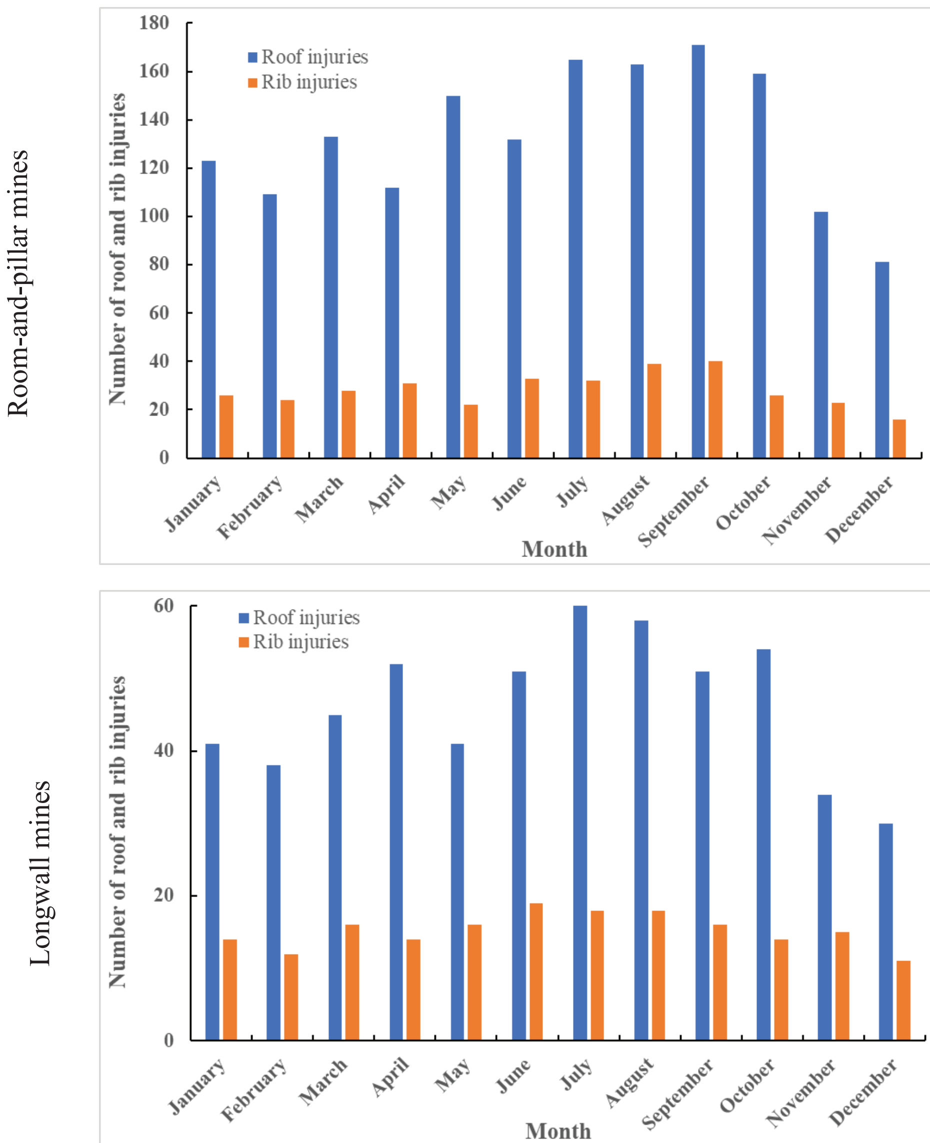



**Figure 13: Roof-fall and rib-fall injuries in room-and-pillar mines and longwall mines by month**

Pappas and Mark (2012) found a similar pattern, and they provided a reasonable explanation for an increase in the number of ground-fall accidents in the summer with the following: "the 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." Laswel (1999) reported that a reduction in the long-term roof falls occurred in an underground coal mine when the mine used an air conditioning system to control the temperature between May 1st and October 1st.

**Summary and conclusion**

The ground-fall statistics and trends discussed in this paper provide an update to previously published studies with the most current data on ground falls in the United States. This study provides the basis for identifying new areas for additional research as well as improving existing projects by establishing the burden and need currently experienced by the mining industry. Future research, using this study as a guide, will provide the potential for increased impact on mine worker safety and health. Ground-falls in U.S. mines, particularly in underground mines, are a major source of both fatal and non-fatal injuries, as well as lost workdays. This study conducted a comprehensive statistical analysis of ground-fall accidents and injuries from 2010 to 2019. This included the classification of over 8,000 incident narratives that include 46 fatalities, 33 permanent disabilities, 3,082 injuries, 119,520 non-fatal days lost, and 12,433 days of restricted work activities. The majority of these ground-fall injuries occurred in underground coal mines, and additional analysis was directed to evaluate roof-fall and rib-fall incident trends in underground coal mines due to the mining method, coal-seam thickness, mine size, seasonal effects, and the amount of experience of the injured or fatality victim.

During this decade, injury rates in underground mines have decreased significantly. This is particularly evident in underground room-and-pillar mines, where the roof-fall injury rate in 2019 was nearly half what it was in 2010. On the other hand, roof-fall injury rates in longwall coal mines have slightly increased over this same time. Additionally, rib-fall injury rates in both room-and-pillar and longwall mines have remained relatively consistent. There exist multiple potential explanations for these trends.

During this period many coal mines were forced to close, particularly those mining in difficult ground conditions where significantly more roof support was required. It is likely that this resulted in better ground conditions on average with the remaining mines in operation leading to a reduction in roof-fall related injuries. Longwall mines, on the other hand, are much more productive than room-and-pillar mines and likely have not experienced this same phenomenon. Finally, with the reduction of roof-fall fatalities, the spotlight has more recently been turned to shine a light on rib-fall fatalities. Rib falls fatally injured more miners than roof falls between 2010 and 2019. Additionally, the severity of rib-fall injuries tends to be higher than that of roof-fall injuries. This represents an area for improvement with additional ground control research being conducted with the aim of preventing rib-fall injuries and fatalities.

**Disclaimer**

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

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