The Influence of Seam Height on Lost-Time Injury and Fatality Rates at Small Underground Bituminous Coal Mines

Robert H. Peters, Barbara Fotta, and Launa G. Mallett
National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, Pittsburgh, Pennsylvania

Due to variations in the thickness of U.S. coal seams, there is great variability in the height of the roof where underground miners work. Restrictions imposed by low seam heights have important safety consequences. As the height of their workplace decreases, miners must stoop, duck walk, or crawl, and their vision, posture, and mobility become increasingly restricted. Low seam height also places important restrictions on the design of mobile equipment and other mining machinery. Using the employment and injury data reported to the Mine Safety and Health Administration (MSHA) from 1990 to 1996, small underground bituminous coal mines with less than 50 employees were stratified by average coal seam height according to the following categories: low (≤42″), medium (43″–60″), and high (≥61″). Injury rates for both nonfatal days lost and fatality cases were examined by seam height and leading type of injury incidents. The leading types of incidents associated with fatalities were roof falls and powered haulage equipment. In comparison to high-seam mines, miners working in low or medium seams are at higher risk of being killed by powered haulage equipment, roof bolting machines, and falls of unsupported roof. The leading types of incidents associated with nonfatal injuries were handling materials and powered haulage. As mining height decreases, miners are at increasingly higher risk of having a nonfatal injury from incidents involving roof bolting machines, load-haul-dump equipment, personnel carriers, and powered haulage conveyors. As mining height increases, miners are at increasingly higher risk of having a nonfatal injury from slips and falls and incidents involving shuttle cars and roof and rib falls. Knee injuries are a particularly severe problem in low-seam mines. The rate of injuries to miners while crawling or kneeling is 10 times higher in low seams than in high seams.

Keywords Mine Safety, Injury Data Analysis, Small Mines

Seam height can vary from as low as 20 inches to a height of 12 feet or more. Seam height effects not only mining method and equipment choices, but also the posture, mobility, and vision of the worker. The relationship between seam height and injury frequency is confounded by the effects of both mine size and mining method. Mines operating in thinner seams of coal (less than 43 inches high) tend to have fewer employees and are more likely to use continuous or conventional mining versus longwall mining methods.[1]

During the past three decades, several researchers have reported that small underground coal mines experienced significantly higher fatality rates than larger mines.[1–4] The National Academy of Sciences (NAS)[2] found that, during the period 1978–1980, the fatality rate for mines with 50 or fewer employees was about three times that of mines with over 250 employees, and almost twice that of mines with 51 to 250 employees. The NAS researchers examined the influence of several potential reasons for the strong correlation between mine size and fatality rates, including company ownership, union status, length of time the mine was in operation, and seam thickness. They concluded that none of these factors could account for the large disparity.

Of the 90 million hours worked by underground miners at bituminous coal mines in 1996, approximately half were worked in mines with an average seam height of five feet or less. In addition, 94 percent of mines operating in seams of 3.5 feet or less employed fewer than 50 people. Thin-seam or low coal mines are located almost exclusively within the southern Appalachian coal fields. And, in fact, 96 percent of small thin-seam mining operations are located in three states: Kentucky, West Virginia, and Virginia. The proportion of total U.S. underground bituminous coal being produced from thin-seam mines appears to have remained constant during recent years. However, as thick seams of underground coal are depleted, one might expect to eventually see a decline in the average height of the U.S. coal seams being mined.

The objective of this study is to identify and quantify the kinds of injuries associated with working in thin-seam mining operations. One advantage of using more recent data is that a much higher proportion of mines now report their seam height to the Mine Safety and Health Administration (MSHA). The NAS researchers reported that 78 percent of mines with 20 or fewer employees and 59 percent of mines with 21 to 50 employees failed to report seam heights during the period of their study (1975–1980). In the present study, information about seam height was available for 99 percent of all active U.S. coal mines.

METHODS

The data used for this study are a subset of the data collected annually by MSHA and recorded in its employment and accident databases for the U.S. coal industry. Data for bituminous coal were included, while anthracite was excluded due to differences in mineral stratification and mining methods utilized. The nonfatal days lost (NFDL) injuries were examined for a five-year period, 1992–1996. NFDL injuries were defined as those that resulted in a permanent disability and/or in days away from work or days of restricted work activity. Since the number of fatalities per year is much smaller than the number of nonfatal injuries, a seven-year period (1990–1996) was used in computations of fatality rates. We only included injuries and fatalities that occurred at underground locations. Injuries to workers at surface facilities such as preparation plants, shops, or offices were not included.

To reduce the confounding effects of mining method and mine size on injury rates, mines using longwall mining methods and mines employing an average of 50 or more underground workers were identified and *excluded* from analysis. This does not entirely eliminate the confounding effects of mining method. Although we were unable to identify all mines using conventional mining methods, we assume that there are relatively few of them. Using information from the injury database, we know that 9 percent of the injuries occurring in low-seam mines were associated with conventional mining methods. The corresponding percentages for medium- and high-seam mines were 3 percent and 1 percent, respectively. However, limitations to the MSHA employment database did not permit calculation of the corresponding number of hours worked at conventional mines.

During the most recent year we examined (1996), 704 small, underground, nonlongwall bituminous coal mines were in operation. Our calculation of nonfatal days lost injury rates, covering the period 1992–1996, is based on data from 1793 mines. Our calculation of fatality rates, covering the period 1990–1996, is based on data from 2461 mines. Mines were categorized by their average seam height as low (≤42″), medium (43″–60″), or high (≥61″). Mines with missing or unrealistic seam heights (e.g., seam height of one inch) were individually examined and corrections were made based on valid seam heights for the mine from previous and/or subsequent years. When such corrections could not be made, the mines were excluded from further analyses. The excluded mines accounted for less than 1 percent of underground exposure hours.

The method of acquiring seam height information differed depending on whether the injury under consideration was fatal or nonfatal. MSHA conducts detailed on-site investigations of all fatal incidents in the mining industry. Information about the actual height of the mine roof at the scene of the fatality is nearly always included in MSHA's fatal accident investigation reports. This was the source used to place the fatality cases into a seam height category. However, the information about the height of the mine roof at the location of *nonfatal* injuries is somewhat less precise. MSHA does not usually conduct on-site investigations of nonfatal injuries, and does not ask mine operators to record this information on their injury report. Instead, it requests mine operators to report their mine's average seam height. Consequently, we used the average seam height reported to MSHA during the year that the injury occurred, as a proxy measure of the approximate height of the roof at the location of an injury. The seam height at various locations within an underground coal mine can be somewhat variable. However, previous analyses[5] established that the mine's reported average seam height serves as an adequate proxy to the actual height of the mine's roof at locations where miners were injured.

Injury rates were computed using the reported total number of hours worked at underground locations as the measure of worker exposure for each mine. NFDL injury rates were calculated per 100 full-time equivalents (FTE). MSHA reports injury rates based on 200,000 hours of work, which is equivalent to 100 FTE. The fatality rate was based on 100,000 FTE, i.e., 200 million hours. Each FTE represents 2000 hours, assuming 40 hours of work/week for 50 weeks/year. The formulas were as follows:

1. NFDL Injury Rate = (Number of lost-time injuries/sum of hrs) * (200,000 hrs)
2. Fatal Injury Rate = (Number of fatalities/sum of hrs) * (2×10^8 hrs)

For this study, a decision was made to calculate fatality rates including cells with a small number of cases, e.g., 0, 1, or 2 cases. Because reporting of incidents to MSHA is required by law, this surveillance system captures all fatalities with a sensitivity of 100 percent. However, one must be cautious in interpretation of rates based on these numbers due to instability. Therefore, both the number of incidents and rates are presented in the results.

RESULTS

During the seven-year period, 1990–1996, 117 miners were fatally injured at small nonlongwall underground bituminous coal mines. Table I presents fatality rates broken down by type of incident and by seam height category. The overall fatality rate was 109.6 per 100,000 FTE. The three leading types of incidents responsible for fatalities are: 1) roof falls, 2) powered haulage, and 3) machinery.

TABLE I

Fatalities in small underground bituminous coal mines by seam height and type of incident, 1990–1996

	Seam height					
	Number of fatalities			Fatalities/100,000 FTE		
Type of incident	Low ≤42″	Medium 43″–60″	High ≥61″	Low ≤42″	Medium 43″–60″	High ≥61″
Roof falls	23	24	7	46.0	64.1	36.3
Supported roof	10	16	5	20.0	42.7	25.9
Unsupported roof	13	8	2	26.0	21.4	10.4
Rib falls	0	0	2	0	0	10.4
Powered haulage	8	10	2	16.0	26.7	10.4
Personnel carriers	1	2	0	2.0	5.3	0
Load-haul-dumps	2	3	0	4.0	8.0	0
Conveyors	1	2	2	2.0	5.3	10.4
Shuttle cars	4	3	0	8.0	8.0	0
Machinery	7	5	4	14.0	13.4	20.7
Roof bolters	3	1	0	6.0	2.7	0
Continuous miners	4	3	4	8.0	8.0	20.7
All other	14	1	10	28.0	2.7	51.8
Totals	52	40	25	104.1	106.8	129.6

Table II presents NFDL injury rates broken down by type of incident and by seam height category. During the five-year period, 1992–1996, there were a total of 7825 underground NFDL injuries resulting in lost time or days of restricted activity. The overall NFDL injury rate was 11.24 per 100 FTE. The six leading types of incidents responsible for these injuries are: 1) handling materials, 2) machinery, 3) powered haulage, 4) slip or fall of person, 5) roof falls, and 6) nonpowered hand tools.

Overall Rates

The overall fatality rate is highest for high-seam mines. However, one must be cautious in interpreting the overall fatality rate findings because they are based on a relatively small number of incidents. An explosion at the South Mountain mine, which killed eight miners, had a large impact on the fatality rate for high-seam mines. If this multiple-fatality disaster at a high-seam mine had not happened, medium-seam mines would have had the highest fatality rate (104.2), and the rates for low- and high-seam mines would have been nearly identical (76.0 and 77.8, respectively). The overall rates of NFDL injuries for each seam height category are nearly identical.

When we broke the injury data down by both seam height category and type of incident, some important differences in the types of factors primarily responsible for miners' injuries and fatalities became apparent.

Roof Falls

Rates of *nonfatal* days lost injuries caused by roof falls increase as seam height increases. Conversely, the rate of *fatalities* caused by roof falls is lowest in seam heights above 60 inches. One reason fatality rates are higher at lower seam heights may be that MSHA regulations permit mines operating in heights of less than 42 inches to apply for exemption from the requirement that all underground mobile equipment have overhead canopies to protect the operator. Of the 54 miners killed by roof falls in small mines during 1990–1996, seven were operating equipment without a canopy.

Twenty-three of these 54 miners (43%) were under unsupported roof, and 31 were under supported roof. (The miners killed by falls of unsupported roof had all gone beyond the last row of roof bolts at the time the roof fell on them.) In comparison to seams above 60 inches, the rate of fatalities caused by falls of unsupported roof in lower seams is twice as high. A variety of potential explanations have been suggested to account for this difference.[6] One factor that may be contributing to this difference in fatality rates is that, when one must crawl to move about, it may be tempting to take shortcuts through areas of unsupported roof. Another factor that may contribute to the higher rate of fatalities caused by falls of unsupported roof in lower seams is that it is more difficult for miners to get a good look at the roof when crawling or stoop walking as opposed to standing in an upright posture. There appears to be no relation to seam height for fatalities caused by falls of *supported* roof. Based on their analysis of injuries to West Virginia's roof bolter operators caused by roof falls, Grayson et al.[7] noted that the amount of lost time per injury was much greater at small mines than at large mines (97.2 days vs. 13.8 days per injury). Grayson et al. attributed this difference to better equipment in large mines.

TABLE II
Nonfatal days lost injuries in small underground bituminous coal mines by seam height and type of incident, 1992–1996

	Seam height					
	Number of injuries			Injuries/100 FTE		
Type of incident	Low ≤42″	Medium 43″–60″	High ≥61″	Low ≤42″	Medium 43″–60″	High ≥61″
Roof falls	470	441	263	1.45	1.82	2.03
Rib falls	34	48	56	.10	.20	.43
Powered haulage	708	389	147	2.18	1.61	1.14
Personnel carriers	160	75	20	.49	.31	.15
Load-haul-dump	268	101	32	.83	.42	.25
Conveyors	102	41	11	.31	.17	.09
Shuttle cars	112	141	70	.34	.58	.54
Machinery	552	409	162	1.70	1.69	1.25
Roof bolters	409	294	108	1.26	1.21	.83
Continuous miners	75	73	27	.23	.30	.21
Handling materials	1102	938	433	3.39	3.87	3.35
Nonpowered hand tools	283	187	104	.87	.77	.80
Slip or fall of person	203	223	204	.62	.92	1.58
Stepping or kneeling on an object	101	33	20	.31	.14	.15
All other	167	102	46	.51	.42	.36
Totals	3620	2770	1435	11.14	11.44	11.09

Rib Falls

The sides or walls of the tunnels created by extracting the coal are referred to as "ribs." As expected, the rate of nonfatal days lost injuries caused by material falling from the ribs increases substantially as mining height (and the height of the rib) increases. The two fatalities resulting from falls of rib both occurred in high-seam mines.

Powered Haulage

The rate of nonfatal days lost injuries associated with powered haulage decreases substantially as seam height increases. This trend is particularly evident for nonfatal days lost injuries involving personnel carriers (such as man trips), load-haul-dumps (mostly scoops), and conveyors (includes mobile bridges). One reason the rate of injuries involving shuttle cars is actually *lower* in thin-seam mines may be that proportionately fewer shuttle cars are used in low seam mines as compared to medium- or high-seam mines. Continuous haulage systems and battery powered scoops tend to be used in place of shuttle cars in thin-seam conditions. In spite of the tendency to use alternatives to shuttle cars in thin-seam conditions, fatalities involving this type of equipment are more prevalent in lower seams. All seven fatalities involving shuttle cars occurred in low- and medium-seam mines.

Based on their microanalysis of injuries to West Virginia's small mine shuttle car operators during 1993, Grayson et al.[7] state that "the real problem with accidents occurring to shuttle car operators is in small mines.... All aspects of performing this job are a problem, but the largest impact with respect to lost workdays is in operation of the vehicle. Most of the problem lies in tramming the machine, which is a seam thickness phenomenon."

A consistently decreasing trend is not observed across seam height for rates of fatalities involving various types of powered haulage equipment. However, the lowest rates usually occur in high seams. In fact, of the 20 miners killed in powered haulage incidents, only two were in high seams.

A contributing factor to the higher rates of injuries observed in low and medium seams involving powered haulage incidents is the low clearance of the mine roof. As the mining height decreases, the mine roof, as well as installed roof bolts and plates, become additional sources of injury to the miner. Necks, backs, heads, and shoulders are the body parts most frequently injured when miners contact the mine roof. Of the 210 incidents in which the source of injury was reported to be the mine roof, 32 percent involved load-haul-dumps, 19 percent involved man trips, and 9 percent involved shuttle cars. According to the injury narratives, these miners were injured when the haulage equipment they were operating ran over a bump or hole or rock on the mine bottom, causing them to be thrown into the roof. In medium-seam heights miners are similarly injured when they are thrown up into the protective canopy on the equipment they are operating.

The mobile equipment used in underground coal mines is not typically equipped with seat belts, and there is little or no foam padding on the seats or the underside of the overhead canopy. Another factor that may contribute to injuries caused by powered haulage in low seams is the operator's restricted field of vision. Due to the low profile design of equipment used in thin seams, the operator is often in an almost fully reclined posture while driving mobile equipment.

Machinery

The rates of nonfatal days lost injuries involving machinery incidents are higher in low and medium seams than in high seams. This trend persists for incidents involving roof bolting operations, which accounted for 71 percent of machinery nonfatal incidents and 4 of the 16 fatal machinery incidents (see Figure 1). All 4 fatal incidents occurred in low or medium seams. Additional information about injuries involving roof bolting operations can be obtained by looking at the actual source of the injury. For nonfatal days lost injuries, the specific source of the injury is coded as the mining machine itself at twice the rate in low seams as in high seams. All four fatalities resulted from crushing injuries involving the roof bolting machine. Turin et al.[8] contains several recommendations about the prevention of fatalities involving roof bolters. An additional source of nonfatal injuries is roof bolts. The rate of injuries involving roof bolts is four times higher in low seams than in high seams. As noted by Grayson et al.,[7] one reason that injuries involving bolts are more prevalent in low coal seams may be that miners frequently must bend and unbend roof bolts to install them into the roof.

Incidents involving continuous mining machines accounted for only 16 percent of nonfatal days lost injuries but 70 percent of the fatal injuries. Seam height does not appear to be related to the rate of injuries associated with continuous mining machines.

Handling Materials

The highest rate of nonfatal days lost injuries is associated with the "handling materials" injury category. Most of these injuries involve musculoskeletal sprains or strains, particularly of the back. The rate of injuries does not appear to vary much with seam height. The highest rate is found in the medium-seam height category. Medium seams also have the highest rates of back injuries overall, the highest rates of injuries resulting in strains or sprains, and the highest rates of injuries resulting from all types of over-exertion (lifting objects, pulling or pushing objects, and wielding or throwing objects). This may reflect the fact that miners in 43- to 60-inch seams cannot stand fully erect when lifting and transporting materials, and they may experience difficulty in using their leg muscles to do as much of the lifting. Additionally, these miners are often stressing their backs with continual stooping and duck walking.

Nonpowered Hand Tools

Rates of nonfatal days lost injuries resulting from incidents involving nonpowered hand tools do not vary substantially with changes in seam height.

FIGURE 1
Coal miner operating roof bolter machine in a low-seam mine.

Slips and Falls

As expected, the rates of nonfatal days lost injuries due to slips or falls increases substantially as seam height increases.

Stepping or Kneeling on Object

The rates of nonfatal days lost injuries due to stepping or kneeling on an object are substantially higher in low seams than in either medium or high seams. The activity of the miner is usually described as crawling or kneeling at the time of the injury. As expected, rates of injuries to miners while crawling or kneeling were strongly related to seam height. The rate is 10 times higher in low seams than in high seams. About 75 percent of these injuries were to the knee. Articles on miners' knee disorders have been published in the research and medical literature for many years.[9] Miners in low-seam conditions often work on hard and uneven surfaces, pushing their joints to extreme ranges of motion with static stress. Prolonged kneeling can adversely affect the skin, bursae, and knee joints, resulting in cuts and scrapes, bursitis, laxity of the knee joint, or torn menisci. As expected, when the rates of knee injuries for different seam height categories were compared, substantial differences were found. Overall, rates of knee injuries decreased as seam height increased. About 23 percent of the knee injuries in low seams were the result of crawling or working on the knees for extended periods of time. This percentage dropped to 9 percent in medium seams and less than 5 percent in high seams. Grayson et al.[7] report that, in comparison to large mines, miners in small mines experience a much greater number of lost workdays because of problems associated with crawling, including cysts from wearing knee pads and damage to nerves in the hands.

All other

Of the 25 fatalities due to all other causes, 14 happened in low seams, one in medium, and 10 in high seams. Methane gas explosions caused 13 fatalities. Seven others were caused by electrocution. Very few of the total NFDL injuries fall in the "all other" category—less than 1 percent.

CONCLUSIONS

For mine operators and government agencies to receive the greatest return on their investments in miners' safety, it is important that they have a good understanding of the types of hazards faced by workers at different types of mines. This study shows that the types of factors posing the greatest threat to coal miners' safety vary substantially with seam height. The findings from this study should help guide mine safety professionals who are seeking to improve safety at thin-seam mining operations.

As the working height decreases to the extent that a miner must stoop, duck walk, or crawl, the miner's vision, posture, and mobility become increasingly restricted. The physical demands placed on the miner generally increase as seam height is reduced. Additionally, as mining height decreases, the mine roof increasingly becomes an additional source of injury to the miner. Although equipment is sized to fit in thinner coal seams, the height restriction makes it more difficult to use protective canopies. It also puts limitations on the placement of operator compartments, which affects what and how much an operator can see while in the cab. Lower mining heights can also make tasks more difficult to perform, such as requiring a roof bolter operator the added effort of bending and unbending roof bolts to insert them into the mine roof.

A safety concern at medium-seam operations is posture. Miners working at these heights cannot lift using the traditionally advocated safe lifting procedures based on unrestricted height. Laboratory studies of the effects of lifting materials using different postures (e.g., kneeling, stooping, etc.) suggest that working heights in the 48- to 72-inch range are more stressful on the back than working heights which require a person to remain kneeling or which allow a person to stand.[10]

Reduced mobility is another concern in lower seam heights. Miners who must duck walk or crawl from place to place within their work area may be moving more slowly and with greater expenditure of energy than miners who are free to walk upright. Miners' decreased ease of movement and restricted view of the roof are two factors which may contribute to the finding that miners are twice as likely to be killed by falls of unsupported roof in seams below 60 inches as compared to higher seams.

It appears that visibility, limits to mobility, and posture restrictions may all affect miners' safety. However, further investigations are needed to gain a better understanding of the exact processes by which low-seam height contributes to injuries, and to identify better strategies for injury prevention in this very challenging work environment. This study strongly suggests that seam height is an important factor in understanding the reasons for injuries at small mines. However, further research is needed to determine what other factors may also be responsible for the differences.

ACKNOWLEDGMENT

The authors thank Larry Layne for his many excellent suggestions on earlier drafts of this manuscript.

REFERENCES

1. National Research Council: Toward Safer Underground Coal Mines. National Research Council, Washington, DC (1982).
2. National Academy of Sciences: Fatalities in Small Underground Coal Mines. Contract No. J0100145, USBM Open File Report No. 124-83. National Academy of Sciences, Washington, DC (1983).
3. Winn, G.L.; Grayson, R.L.; Elliott, G.D.: The Problem of Small-Mine Safety in West Virginia. Prof Safety 39(5):41–44 (1994).
4. Peters, R.H.; Fotta, B.: Statistical Profile of Accidents at Small Underground Coal Mines. USBM Special Publication 18-94. In: Improving Safety at Small Underground Mines, R.H. Peters, Ed. pp. 5–14. NIOSH, Pittsburgh, PA (1994).
5. Fotta, B.; Mallett, L.G.: Effect of Mining Height on Injury Rates in U.S. Underground Nonlongwall Bituminous Coal Mines, National

Institute for Occupational Safety and Health Information Circular Report 9447. NIOSH, Pittsburgh, PA (1997).

6. Peters, R.H.; Fotta, B.: A Review of Recent Data Concerning Accidents Caused by Falls of Unsupported Roof. In: Proceedings of the 25th Annual Institute on Coal Mine Safety and Health Research, pp. 129–137. Virginia Polytechnic Institute and State University, Blacksburg, VA (1994).
7. Grayson, R.L.; Althouse, R.C.; Winn, G.L.; Klishis, M.J.: A New Injury Analysis Methodology for Developing Prioritized Workplace Intervention Strategies. Appl Occup Environ Hyg 13(1):41–52 (1998).
8. Turin, F.C.: Human Factors Analysis of Roof Bolting Hazards in Underground Coal Mines. USBM Report of Investigations 9568. NIOSH, Pittsburgh, PA (1995).
9. Bruchal, L.: Occupational Knee Disorders: An Overview. In: Advances in Industrial Ergonomics and Safety VII, A. Bittner and P. Champney, Eds., pp. 89–93. Taylor and Francis, Philadelphia (1995).
10. Gallagher, S.; Hamrich C.; Cornelius, K.M.; Redfern, M.: The Effects of Vertical Space Restriction on the Movement Experienced by the Lumbar Spine. In: Proceedings of 1997 American Industrial Hygiene Conference, Dallas, TX, p. 19 (1997).