Safety Challenges at Thin Seam Mines

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Small underground coal mines have historically experienced higher fatality rates than larger mines (National Academy of Sciences, 1983; Peters and Fotta, 1994). By "small", we mean mines that have fewer than 50 underground employees. Although various ideas have been presented about what factors might be responsible for this difference, researchers have had a difficult time establishing the specific causes. Mine size is highly correlated with seam height. Smaller mines tend to operate in significantly thinner coal seams than large mines. Mining height is usually equal to the height of the coal seam, and can vary from as low as 20 inches to a height of 12 feet or more. Because there are several reasons to expect that differences in mining height are related to differences in injury rates for particular types of accidents, additional statistical analyses have been performed to examine this issue (see Fotta and Mallett, 1997). 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. Additionally, 94% 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 Appalachian coal fields. And, in fact, 96% 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 article is to continue to identify and quantify the kinds of injuries associated with working in thin seam mining operations. An analysis of these injuries may help us to identify the hazards associated with working in low-seam conditions that place miners at greater risk of injury than their counterparts who work in high-seam conditions.

Method. Using the mine-level employment and injury data reported to MSHA, mines were stratified by average coal seam height as low (less than 43 inches), medium (43-60 inches), or high (greater than 60 inches). 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.[1] During the five-year period from 1992-96, there were roughly 700 nonlongwall mines in operation that employed fewer than 50 underground miners. While most of these mines utilized continuous miners in their operations, an estimated 10-15% employed conventional mining methods. These 700 mines accounted for a total of 139 million employee hours, almost half of which were worked in seam heights less than 43 inches. The rates of nonfatal injuries were computed for the five- year period from 1992-96. Since the number of fatalities per year is much smaller than the number of nonfatal injuries, a seven-year period (1990-96) was used in computations of fatality rates.

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[1]This does not entirely eliminate the confounding effects of mining method. Researchers were unable to identify all mines using conventional mining methods. However, using information from the injury database, 9% 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% and 1%. However, limitations to the MSHA employment database did not permit calculation of the corresponding number of hours worked at conventional mines.

Results. Figure 1 shows the number of nonfatal and fatal injuries for the major types of accidents. Table 1 gives rates of nonfatal and fatal lost time injuries for each of the three seam height categories.

Roof Falls. Rates of *nonfatal* 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 1990-96, seven were operating equipment without a canopy.

Twenty-three of these 54 miners (43%) were under unsupported roof, and 31 were under supported roof. 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 (see Holmes Safety Bulletin, December 1994, pp. 4-9). One factor that may be contributing to this difference in fatality rates 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.

Rib Falls. As expected, the rate of nonfatal injuries caused by rib falls 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 injuries associated with powered haulage decreases substantially as seam height increases. This trend is particularly evident for the rates of nonfatal injuries involving personnel carriers (such as mantrips), 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. Although a consistently decreasing trend is not observed across seam height for the rates of fatal injuries, the lowest rates consistently occur in high seams. And, 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 or top, 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% involved load-haul-dumps, 19% involved mantrips, and 9% shuttle cars. According to the accident narratives, these miners were injured when they hit 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. 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 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% of machinery nonfatal incidents and four of the 16 fatal machinery incidents. All four 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 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 fatals resulted from crushing injuries involving the roof bolting machine. 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. One reason that injuries involving bolts are more prevalent in low coal seams may be that miners frequently must bend and unbend roof bolts in order to install them into the roof.

Incidents involving continuous mining machines accounted for only 16% of nonfatal injuries but 70% 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 injuries is associated with the "handling materials" accident 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, 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 injuries resulting from incidents involving nonpowered hand tools do not vary substantially with changes in seam height.

Slips and falls. As expected, the rates of injuries due to slips or falls increases substantially as seam height increases.

Stepping or kneeling on object. The rates of 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 ten times higher in low seams than in high seams. About 75% of these injuries were to the knee. Articles on miners' knee disorders have been published in the research and medical literature for many years (Bruchal, 1995). 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% 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% in medium seams and less than 5% in high seams.

Conclusions The working height of an underground coal mine can directly affect safety in a number of ways. As the working height decreases to the extent that miners must stoop, duck walk, or crawl, the miners' 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 proportionally for thinner coal seams, the height restriction makes it infeasible 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 in order 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 (Gallagher et al. 1995). 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. 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.

Human factors research has been performed to try to address some of the hazards associated with working in low seam mines. Studies have been performed on the following:

personal protective equipment (e.g., knee pads, gloves, reflectorized outer garments)
design recommendations for underground mobile equipment operator compartments
recommendations for improving the maintainability design of underground equipment
software for evaluating the adequacy of the equipment operator's field of vision, given the size of the operator and various dimensions of the operator's compartment

software for evaluating the adequacy of illumination systems on mobile equipment
reduction of shocks and jolts through the incorporation of viscoelastic foams and other features to improve shuttle car seating
recommendations for the design of controls on roof bolting machines
procedure for bending bolts in low coal
recommendations for keeping miners away from unsupported roof
preventing back injuries
various materials handling devices and procedures

Please contact the authors if you would like more information about these topics.

Table 1. Nonfatal and fatal injury rates (injuries per 200,000 employee hours) by type of incident and seam height in small underground bituminous coal mines (<50 underground employees).

Incident Type	Nonfatal Lost Time Injury Rates, 1992-96			Fatal Injury Rates, 1990-96		
	Low seams	Medium seams	High seams	Low seams	Medium seams	High seams
Roof falls	1.45	1.82	2.03	.046	.064	.036
Supported roof	NA[1]	NA	NA	.020	.043	.026
Unsupported roof	NA	NA	NA	.026	.021	.010
Rib falls	.105	.198	.433	-	-	.010
Powered haulage	2.18	1.61	1.14	.016	.027	.010
Personnel carriers	.493	.310	.155	.002	.005	-
Load-haul-dumps	.825	.417	.247	.004	.008	-
Conveyors	.314	.169	.085	.002	.005	.010
Shuttle cars	.345	.582	.541	.008	.008	-
Machinery[2]	1.62	1.57	1.14	.014	.013	.021
Roof bolting machines	1.18	1.11	.75	.006	.003	-
Continuous miners	.231	.289	.193	.008	.008	.021
Handling materials	3.39	3.87	3.35	-	-	-
Nonpowered hand tools	.871	.772	.803	-	-	-
Slip or fall of person	.625	.921	1.58	-	-	-
Stepping/kneeling on object	.311	.136	.155	-	-	-

[1]Information concerning whether miners were under supported or unsupported roof is not coded in the MSHA database.

[2]Excludes those injuries resulting from falls of roof or rib during roof bolting or continuous miner operation.

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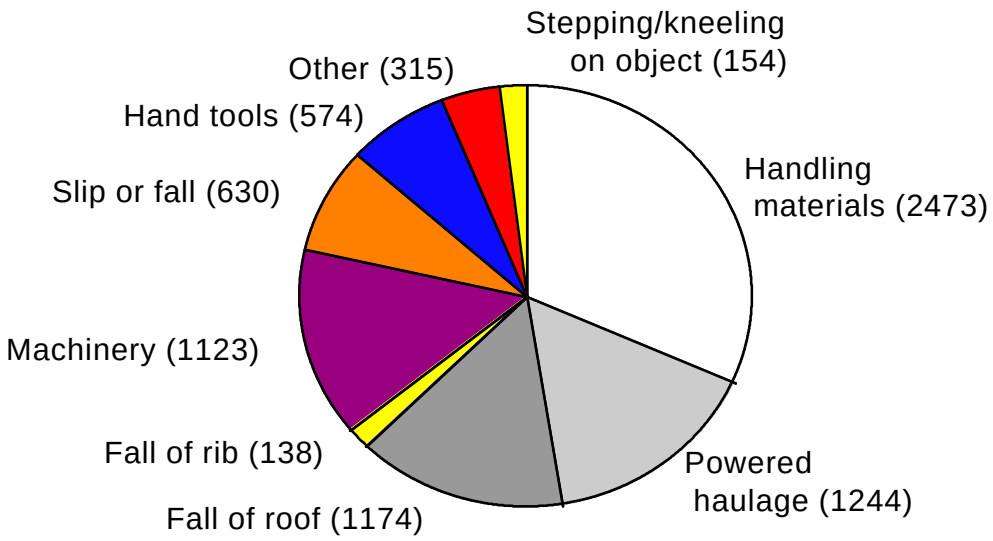
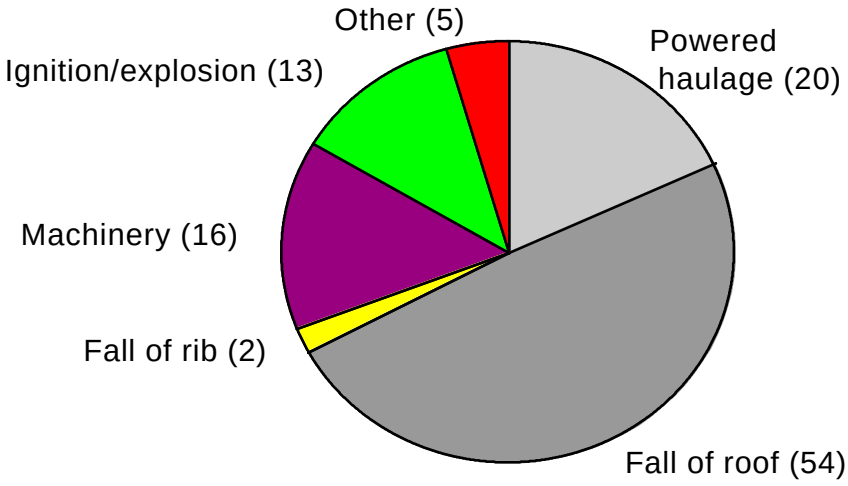
Figure 1.



Number of nonfatal lost time injuries
by type of incident, 1992-96.



Number of fatal injuries
by type of incident, 1990-96.