Information Circular 9151

Roof and Rib Fall Accident and Cost Statistics: An In-Depth Study

By Deno M. Pappas

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. BuMines IC 9151	2.	3. PB90-266636

4. Title and Subtitle	5. Report Date
Roof and Rib Fall Accident and Cost Statistics: An In-Depth Study	1987
	6.

7. Author(s)	8. Performing Organization Rept. No.
Deno M. Pappas	

9. Performing Organization Name and Address	10. Project/Task/Work Unit No.
U.S. Bureau of Mines Washington, DC 20241	11. Contract(C) or Grant(G) No. (C) (G)

12. Sponsoring Organization Name and Address	13. Type of Report & Period Covered
Same	14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

The purpose of this Bureau of Mines study of U.S. roof and rib (roof-rib) accident statistics and related accident costs is to define current accident trends (1980–84) associated with fatal and nonfatal roof-rib fall accidents. Data were retrieved from a data base containing all recorded U.S. mining accidents, then sorted and normalized utilizing a computer software program. The statistics indicate that roof-rib accidents have significantly declined in the 5-yr study period. Moreover, they indicate that there have been increases and/or patterns of roof-rib accidents associated with specific mine characteristics such as seam height, mine size, geographic location, and seasonal variation. Also, roof-rib injury characteristics produced pattern changes involving worker activity, lost workdays, types of injury, and severity of injury. A conservative estimate indicates that there has been a 30% adjusted increase in the cost of a roof-rib accident over the 5-yr study period.

17. Document Analysis   a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited release	Unclassified	20
	20. Security Class (This Page)	22. Price
	Unclassified	

(See ANSI–Z39.18)   See Instructions on Reverse   OPTIONAL FORM 272 (4–77)
(Formerly NTIS–35)
Department of Commerce

CONTENTS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

h	hour	MMst	million short tons
in	inch	st	short ton
min	minute	yr	year

ROOF AND RIB FALL ACCIDENT AND COST STATISTICS: AN IN-DEPTH STUDY

By Deno M. Pappas[1]

ABSTRACT

The purpose of this Bureau of Mines study of U.S. roof and rib (roof-rib) accident statistics and related accident costs is to define current accident trends (1980-84) associated with fatal and nonfatal roof-rib fall accidents. Data were retrieved from a data base containing all recorded U.S. mining accidents, then sorted and normalized utilizing a computer software program. The statistics indicate that roof-rib accidents have significantly declined in the 5-yr study period. Moreover, they indicate that there have been increases and/or patterns of roof-rib accidents associated with specific mine characteristics, such as seam height, mine size, geographic location, and seasonal variations. Also, roof-rib injury characteristics produced pattern changes involving worker activity, lost workdays, types of injury, and severity of injury. A conservative estimate indicates that there has been a 30% adjusted increase in the cost of a roof-rib accident over the 5-yr study period.

[1]Research civil engineer, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

Underground coal mining has always been recognized as a hazardous occupation. Between 1931 and 1984, over 29,000 coal miners lost their lives in underground accidents. This represents an average of one fatality for every 100,000 h worked underground. Over 50% of these 29,000 fatalities were associated with roof-rib fall accidents; this is a greater amount than for any other class of accident. Although there have been articles written analyzing accident statistics, there has been very little written specifically on roof-rib fall accidents and costs. Such is the intent of this paper.

Before looking at the statistics, the term "roof-rib fall" needs to be defined. Whenever an entry is developed in a coal seam, the surrounding coal and rock mass of the opening are no longer in equilibrium. The rock mass in the roof has lost support from below, the floor rock no longer has an applied load from above, and the coal seam is no longer constrained along the sides (rib and face) of the opening $(\underline{1})$.[2] If the roof is not adequately supported, the surrounding rock and coal may collapse or fall into the entry and randomly strike underground workers. In cases where an accident results from the fall of the face, it will be considered a rib fall. Specifically, the failure of the roof or rib may be attributed to one or more of the following factors:

1. Geologic anomalies.--Occur in the roof or rib as faults, slips, joints, rolls, clay veins, kettlebottoms, and sand channels.

2. Effects of weathering.--Humidity or temperature changes may cause the roof to deteriorate, which leads to roof failure.

3. Stress conditions.--Stresses occurring within the strata because of the effects of the overburden or the effects of past geologic activity may result in a roof-rib fall. For example, bumps or bursts result in a sudden and violent rupture of the supporting coal pillars because the vertical unit loading of the pillar exceeds the bearing strength of the coal $(\underline{2})$. High horizontal stress is another stress condition that may cause a roof-rib fall. The horizontal stress may be in excess of the vertical stress, resulting in open cracks along the entries that may lead to failure of the roof.

4. Mining method.--The method employed may initiate roof-rib failure such as in longwall mining and retreat room-and-pillar mining.

5. Scaling.--The occurrence of roof failure caused by a worker barring down the roof. Although, the failure of roof was initiated by the worker, the accident is still classified as a roof fall.

Most often roof-rib fall accidents involve one or more of the preceding factors, coupled with the fact that the victim was under unsupported roof near the face. The working face area is the most hazardous area because the stresses are being actively redistributed and failure can occur instantly. Not included as roof-rib falls are accidents caused by haulage equipment knocking out roof support because it is the motion of the machinery that causes the accident. Therefore, roof-rib falls can be related to the unpredictable behavior of a rock mass in transition from one state of equilibrium to another and may be initiated by several factors.

---

[2]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

EVALUATION OF ROOF-RIB ACCIDENT STATISTICS

To evaluate the roof-rib accident data, it is first necessary to define the meaning of the term "accident." For this study, an accident is defined as any mishap that results in a fatal or nonfatal injury, including injuries that do not result in lost workdays. It is important to include nonfatal accidents data along with the fatal accidents to obtain a larger data base and a more complete picture of the extent of roof-rib fall accidents. For every roof-rib fatality, 30 nonfatal accidents occur that result in over 39,000 lost workdays (averaged) annually. Therefore, to get a more complete data base, the statistics include both fatal and nonfatal roof-rib fall accidents for the 1980-84 period, except where otherwise noted.

The following five types of accident rates were calculated to evaluate roof-rib accidents in U.S. underground coal mines. These rates normalize the accidents with respect to controlling factors such as hours worked underground, production, and size of work force, to give a more concise measure of roof-rib accidents.

1. Roof-rib fall accidents per 200,000 employee-hours worked underground. The 200,000-h figure approximates the number of hours worked by 100 full time miners per year.

2. Roof-rib fall accidents per million short tons of underground coal produced.

3. Roof-rib fall accidents per average total number of underground workers. This rate is actually a percentage of the average underground work force injured in these accidents.

4. Total number of lost workdays due to roof-rib accidents per 200,000 employee-hours worked underground. This rate is known as the nonfatal severity rate and indicates the seriousness of nonfatal accidents.

5. Total number of lost workdays due to roof-rib fatal, nonfatal, and permanently disabling accidents per 200,000 employee-hours worked underground. This rate is referred to as the overall severity rate. It is similar to the nonfatal severity rate except that it accounts for accidents resulting in a fatality or a permanent total disability. Permanently disabling and fatal injuries are each charged 6,000 days (3).

Raw data for this study were obtained with the use of the Health and Safety Analysis Center (HSAC) accident file (from the Mine Information Systems of the Denver Safety and Health Technology Center of the Mine Safety and Health Administration (MSHA)), which has on record all reported U.S. mining accidents, and was retrieved with the use of the Bureau's program (HDBSEL). The records for all roof-rib accidents that resulted in fatal or nonfatal injuries (degree 1 to 6) were retrieved and transferred to the RS/1 (Research Systems 1) software package designed by BBN Research Systems.[3] The use of RS/1 permitted the retrieved records to be tabulated, sorted, and graphed.

Certain factors may be related to the increase or decrease of accidents. However, an exact list of the factors influencing a pattern of roof-rib accidents is nearly impossible to compile. Equally

---

[3]Reference to specific products does not imply endorsement by the Bureau of Mines.

difficult is the task of proving unequiv-ocally that the factor is associated with the accident statistics. There are many hidden factors that may additionally af-fect the compiled data such as lengthy strikes, catastrophic disasters, and in-consistencies in recording accident in-formation. The accuracy of this study is only as accurate as the accident records entered into the data base. Consequent-ly, this study emphasizes accident rate trends that occurred over the 5-yr study period rather than specific accident num-bers or rates. Factors affecting acci-dent trends are suggested, but are not necessarily the only factors involved and, in most instances, cannot be definitely confirmed.

REVIEW OF ACCIDENT FATALITIES, 1910-84

A review of accident fatalities (fig. 1) over the past 74 yr reveals a dramatic drop (approximately 96%) in the total un-derground fatalities as well as in roof-rib fall fatalities. Some of the major reasons for these decreases are as follows:

1. Decreases in accidents between 1920 and 1950 seem to coincide with drops in production due to slowdowns in the econo-my; e.g., the Great Depression of the 1930's, and the post-World War II reces-sion of the late 1940's.
2. Mechanization of the mining indus-try during the early 1950's, considerably improved productivity and required a smaller work force. As the number of employee-hours decreased, so did the num-ber of accidents (4).
3. The increased use of roof bolts starting in the 1950's.
4. Federal legislation, especially the 1952 Federal Coal Mine Act and the 1969 Coal Mine Health and Safety Act, which promoted underground federal inspections (4).
5. Bureau of Mines research efforts in developments of the ATRS (automated tem-porary roof support), FOPS [falling ob-ject protective structures (canopies)], methane drainage techniques, permissibil-ity criteria for explosives, etc.
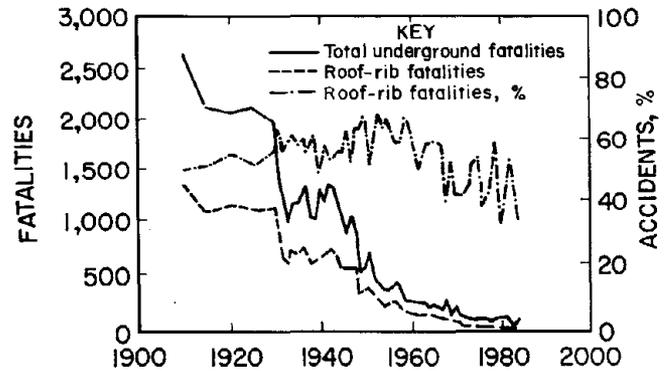
FIGURE 1.—Underground fatality statistics, 1910-84.
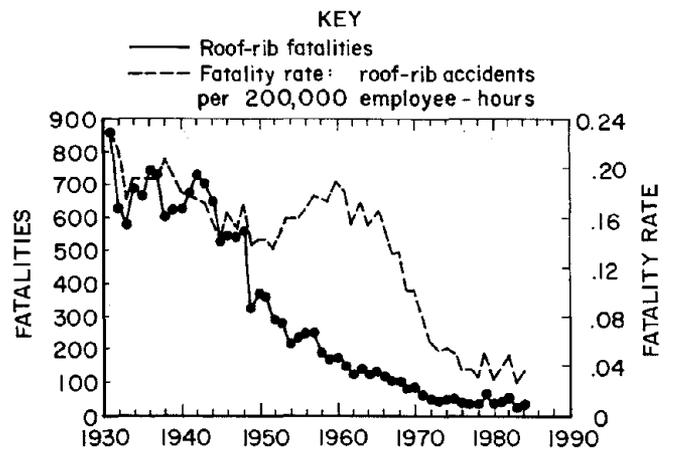
FIGURE 2.—Roof-rib fall fatality statistics, 1931-84.

6. A greater awareness of underground hazards promoted by mandated safety training and supplemented by the union and MSHA safety programs such as REAP (roof evaluation accident prevention).

To obtain a more accurate picture of the rate of roof-rib fall fatalitites, the data were normalized, based on the total employee-hours worked. From figure 2 it is quite clear that although the number of fall fatalities started to decrease in the 1940's, it was not until the 1960's that the fatality rate (based on employee-hours worked) actually started to drop. Examination of roof-rib accident percentages (fig. 1) shows that a consistently high percentage (50%-70%) of all the underground fatalities re-sulted from roof-rib falls. It was only recently that these percentages moderate-ly dropped. During the early 1980's, roof-rib fall fatalities averaged about

40% of all underground fatalities, which is still greater than any other type of accident.

U.S. ACCIDENT RATES

Reviewing the various U.S. accident rates (fig. 3) illustrates that roof-rib accidents have consistently decreased over the last 5 yr, hitting a new low rate in 1983 and rebounding somewhat in 1984. These accident rates all confirm that a decrease in roof-rib accidents occurred: Accidents per million short tons mined dropped 42%, accidents per 200,000 employee-hours worked decreased 17%, and accidents per average number of workers dropped 15%.

A probable reason for the decrease may be due to the fact that between 1980 and 1984 there was a 28% decrease in the average number of employees working underground (5). Even though the rates are normalized linearly, the effects of a smaller work force may have a disproportional effect in decreasing the number of roof-rib accidents. Possibly, the mining companies elected to keep their more experienced employees, which may have resulted in a higher concentration of safety orientated miners.

It is interesting to note that although the number of workers decreased 28%, underground coal production (short tons produced per year) has increased 6.3% and underground coal productivity (short tons produced per 8-h shift) has increased 41% over the same time span (5). Recently, Spokes (6) found a correlation between declining accident rates and increasing productivity. However, this does not necessarily mean that increasing the productivity will definitely cause fewer accidents; there are many other factors intertwined.

Examining the severity rates in figure 4 does not show any definite trends except that both severity rates have erratically increased over the 5-yr study period. The overall severity rate increased approximately 30%, and the nonfatal severity rate increased less than 7%. This is a possible indication that the seriousness of injuries resulting from roof-rib fall accidents is on the increase.

FIGURE 3.—U.S. roof-rib fall accident rates, 1980-84. A, accidents per million short tons of underground coal mined; B, accidents per 200,000 employee-hours worked; C, accidents per average total number of underground workers.
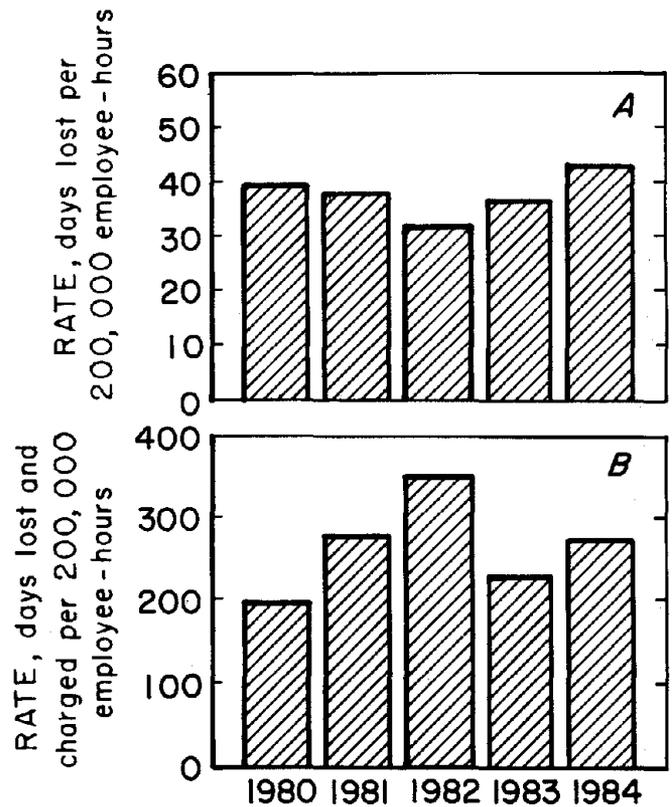
FIGURE 4.—U.S. roof-rib severity rates, 1980-84. A, number of days lost (related to nonfatal accidents) per 200,000 employee-hours worked; B, number of days lost and days charged (related to fatal and permanent total disability accidents) per 200,000 employee-hours worked.

STATE ACCIDENT RATES

Examination of equivalent accident rates by State points out some regional differences. Figures 5 and 6 show the roof-rib fall accident rates for the top 10 underground coal producing States. The following comparisons were drawn from these figures and are compared with the national rate.

Most noticeable in all of the bar charts are the considerably higher roof-rib fall accident rates in the Western States of Utah and Colorado. On the average, 1.8% of Utah's and Colorado's work force was injured in roof-rib fall accidents alone, as compared with the national average of 0.9% (fig. 5c). This may be due to several factors uniquely associated with western coal mines. These include abnormal seam characteristics (deeper, thicker, and pitching seams) and a less experienced work force. In the east, the State of Virginia also had fairly high accident rates (fig. 5). However, there was a downward trend in these higher accident rate States.

During the early part of the study, Kentucky had the lowest roof-rib fall accident rates in the country but, by the end of the study period, Tennessee, Alabama, and Pennsylvania had equal or somewhat lower accident rates. Figure 5 indicates that Kentucky's accident rates were gradually approaching the national rate, while rates of most other States were on the decline.

Between these two extremes of accident rates were Alabama, Illinois, Tennessee, and West Virginia, which hovered around the national rate (fig. 5). It is interesting to note that West Virginia's accident rates closely followed the national rates. Pennsylvania's and Ohio's accident rates, which were fairly high initially, dropped consistently after 1982 (fig. 5).

Severity rates in Tennessee, Virginia, and the Western States were very high initially, but then dropped or stabilized (fig. 6). In a reverse situation, Kentucky's rates were fairly low initially, but then increased significantly above the national average (fig. 6). Kentucky's high overall severity rate in 1984 is due in part to the disproportionate number of roof-rib fatalities (20 fatalities) that occurred that year. The remaining States fall close to or below the national severity rate.

CHARACTERISTICS OF U.S. ROOF-RIB FALL ACCIDENTS

The analysis of the compiled statistics included detailed examination of roof-rib accident characteristics related to the time of occurrence, to specific mine attributes, and to the accident victim. Within each grouping, all available data on each roof-rib accident were compiled and evaluated. The data measured frequency or rate of occurrence to emphasize particular trends within each category.

SEASONAL PATTERNS

Data on the occurrence of roof-rib falls with respect to time of year were compiled to determine if seasonal patterns such as fluctuations in temperature, barometric pressure, and humidity might affect the frequency of roof-rib falls. Figure 7 displays the average number of roof-rib fall accidents (between 1980 and 1984) with respect to month of accident. Data from 1981 were omitted because it was a strike year and monthly accident results were biased. Also, roof-rib accidents that occurred in mines of the Western United States (Utah, Colorado, New Mexico, and Wyoming) were omitted because these areas are mostly arid climates and experience minimum fluctuations in humidity.
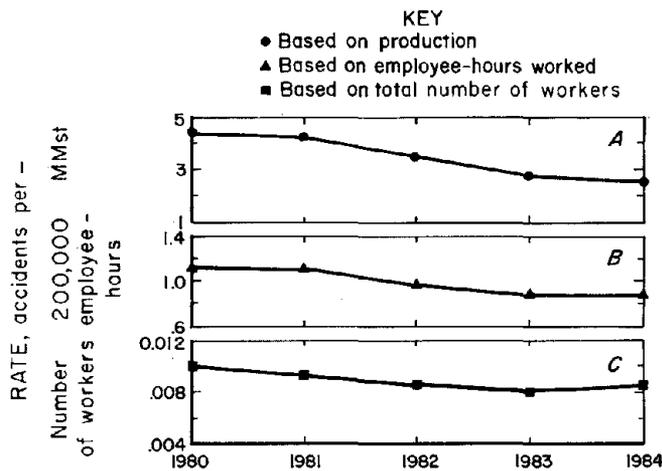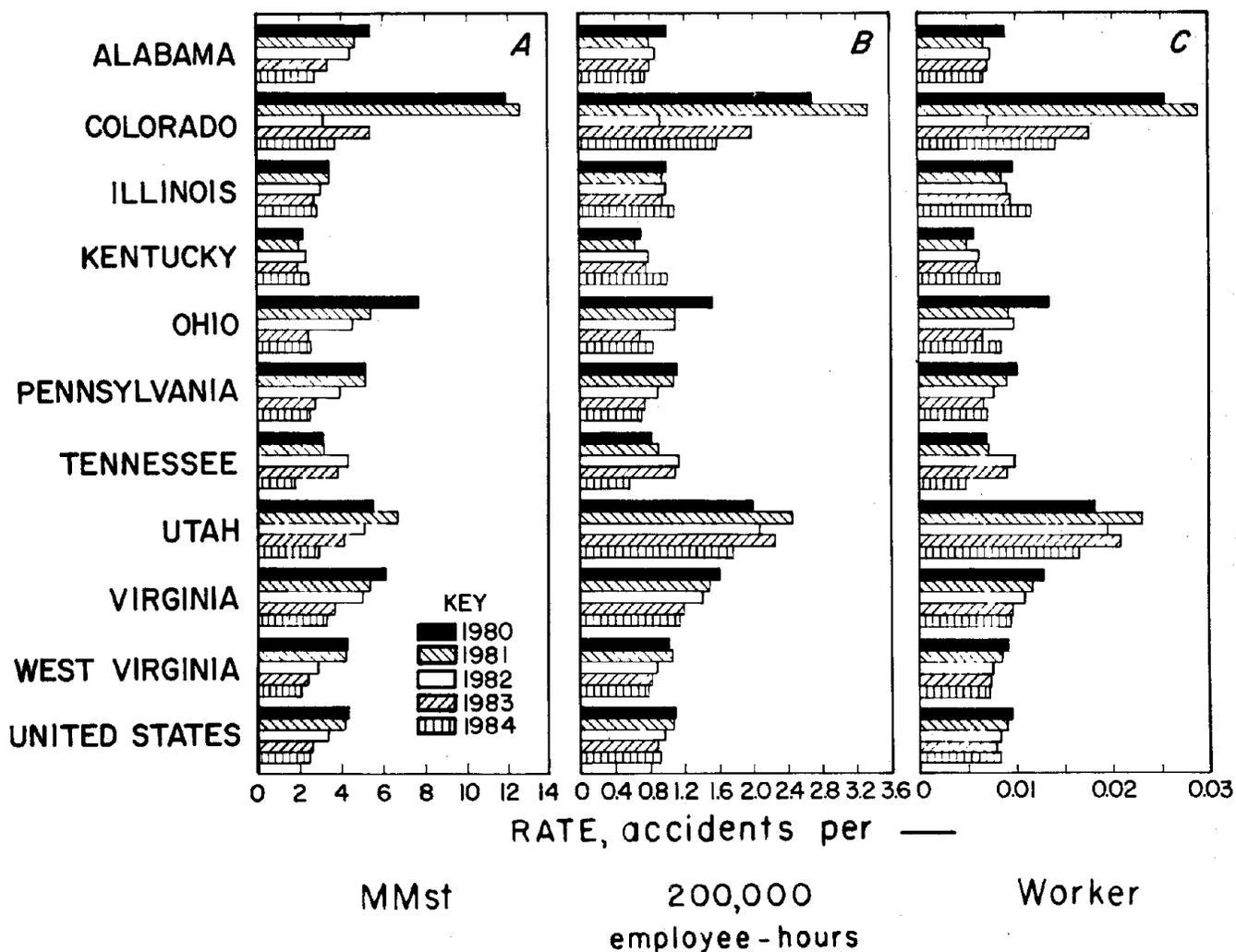
FIGURE 5.—Roof-rib accident rates, by State. A, accidents per million short tons of underground coal mined; B, accidents per 200,000 employee-hours worked; C, accidents per average total number of underground workers.

Although it was not possible to normalize the results based on employee-hours, there did seem to be a seasonal trend. The number of roof-rib accidents peaked in the months of August through October and then dropped off during the months of November through February. This trend may be due to an increase in coal production during the late summer for winter stockpiling, resulting in an increase in underground exposure time and subsequently more accidents. Because monthly
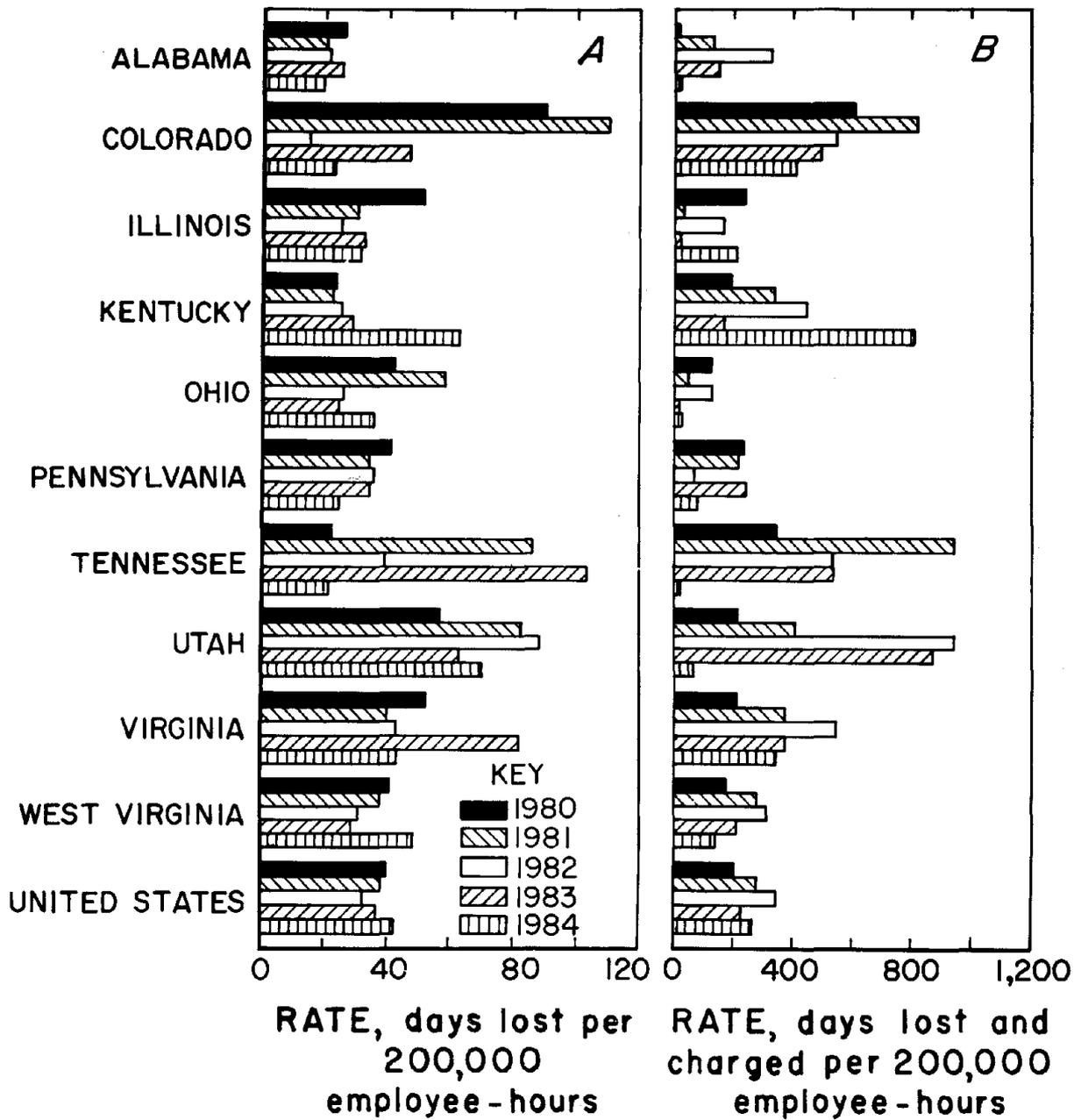
FIGURE 6.—Severity rates for roof-rib accidents, by State. *A*, days lost (related to nonfatal accidents) per 200,000 employee-hours worked; *B*, days lost and days charged (related to fatal and permanent total disability accidents) per 200,000 employee-hours worked.
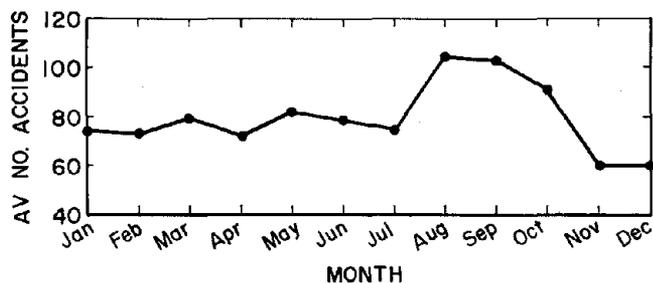
FIGURE 7.—Average number of roof-rib accidents with respect to month of occurrences (excludes Western States).

FIGURE 8.—Average number of roof-rib accident occurrences with respect to time of day.

production figures are unavailable, this speculation could not be verified.

However, a similar seasonal trend of roof falls was reported by Stateham and Radcliffe (7), who found that humidity has a strong influence on roof fall occurrence rates. Using cubic regression techniques, they correlated humidity and roof fall statistics over a 3-yr period and found that their best-fit curves almost coincided in sinusoidal cycles. The roof fall occurrence rate curve followed the humidity curve by about 14 days. Their results indicated that the probability of a roof fall is greatest in August and least in February. Their study also indicated that the barometric pressure was not related to roof falls.

Another study by Haynes (8) found that the effect of temperatures and temperature changes on rock around mine openings has a negligible effect on roof stability. Consequently, it appears that the only climate condition that may play a part in the occurrence of roof-rib falls is humidity.

DAILY PATTERNS

Another time-related parameter focuses on the approximate hour at which the roof-rib fall accident occurred. Figure 8 shows the number (5-yr average) of roof-rib accidents within 30-min intervals during a 24-h period. The peak number of accidents occurred between 10:00 and 10:30 a.m., 1:00 and 1:30 p.m., and 6:00 and 6:30 p.m. The 10:00-10:30 a.m. peak may coincide with the ap-proximate time of day miners are in full operation at the face; however, by noon the number of accidents has dropped by half,

probably because of the lunch break. The 1:00-1:30 p.m. peak may signify full operation after lunch, and the 6:00-6:30 p.m. peak may be due to the evening shift in full operation. These peaks may indicate a pattern of more accidents occurring in the second and third hour into the respective shifts and also after the lunch break.

Theodore Barry and Associates (9) found a similar pattern in a study conducted in the late 1960's. This study speculated that the higher number of roof falls in this period was due to lack of adequate testing of the roof at the start of a shift, since the miners, having just started their daily tasks, were not focusing enough attention on the behavior of the roof. Figure 8 shows a low number of roof-rib accidents at the start and end of each shift, probably because the workers were in transition and away from the face areas. These accident trends can probably be related more to human factors than to the occurrence of roof-rib falls.

MINE ATTRIBUTES

According to the Department of Energy (10), there were over 1,760 underground coal mines operating in the United States in 1984. Although no two mines are identical, it was thought that common mine characteristics such as seam height, mine size, underground location mining method, etc., may be associated with the frequency of roof-rib fall accidents.

10

Seam Height

One of the obvious mine characteristics that was considered was the seam height. A scan of Figure 9A shows that roof-rib accidents occur at a higher rate for thin seams (<36 in) and for very thick seams (>120 in). Examination of the fatality rates (fig. 9B) also shows higher rates for thin seams; however, the higher rates do not extend to the thick seams. Figure 9 shows that accident and fatality rates for mines with intermediate seam thicknesses (37-120 in) are fairly low. Data for these figures cover only the 1983-84 period because the seam height was inconsistently reported for the other years.

The somewhat higher accident rates for thick-seam mines, although not reflected in the fatality rates, may possibly be due to the higher roof, which allows any falling material to gain more velocity and thereby cause more serious injuries. Possibly, the more extensive use of canopies on mining equipment in thicker seams may limit the occurrences of a fatal roof-rib accidents.

The higher accident rates for thinner seams (<36 in) may be due, in part, to the extremely confined work area. The low head room makes assessment of the roof difficult and inhibits escape from an impending roof fall. The thinner seams also limit the type of mining that can be used; for example, the use of longwall mining, which may provide better protection from roof-rib falls, is precluded. Another possible explanation given by MSHA (11) is the lack of cabs and canopies on low-coal mining face equipment, resulting in less protection and a higher frequency of accidents due
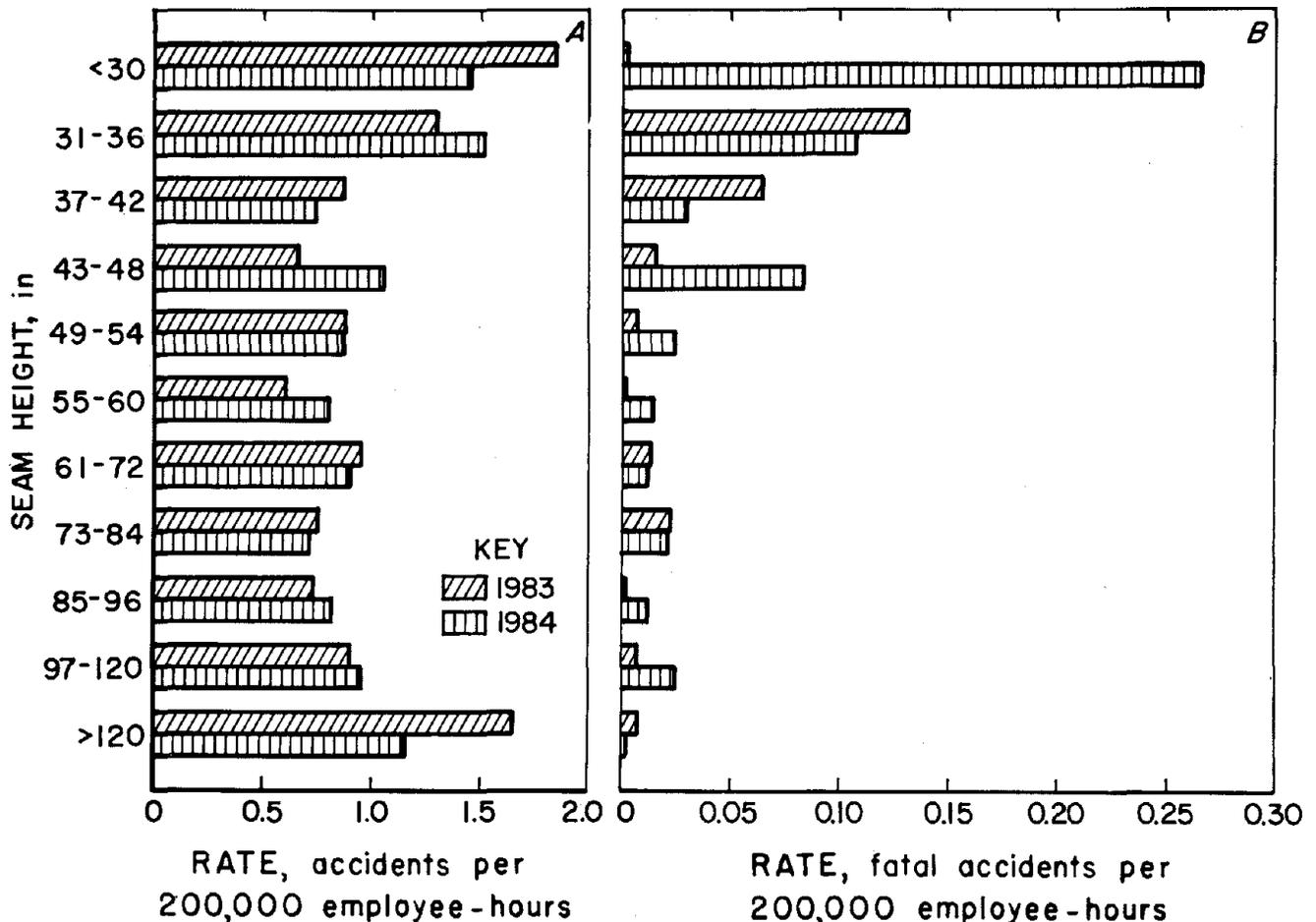

FIGURE 9.—Roof-rib accident rates with respect to seam height of the mine. A, fatal and nonfatal roof-rib accidents per 200,000 employee-hours worked; B, only fatal roof-rib accidents per 200,000 employee-hours worked.

due to roof falls. The higher accident rate may not be totally attributed to the seam height, it may also be interrelated with other factors such as the large number of low-coal mines that are small mines. And as the succeeding section explains, smaller coal mines have higher roof-rib accident rates.

Mine Size

The size of the mine was reviewed on the assumption that larger mines have larger technical staffs and more capital to deal with ground control problems. Small mines have a minimal technical staff (if any), little capital, and are sometimes located in unusual seams with difficult ground control problems. Consequently, the smaller mines may have a higher accident rate, as documented in accident studies conducted by the National Academy of Science and National

Research Council (12-13). Their studies, which included all types of accidents, found a strong correlation between mine size and fatal injuries.

Since the size of a mine can be quantified by the magnitude of its work force, this Bureau study normalized all roof-rib accidents and fatal accidents based on the annual average total number of employees (fig. 10). Examination of the accident rates (fatal and nonfatal) in figure 10A shows that, initially, intermediate-size mines (51 to 150 employees) had high accident rates, but by 1983 these rates had dropped considerably. Over the same period, accident rates in small mines (1 to 20 employees) increased above all the other mine size categories. Even more pronounced is the fatal accident rate (fig. 10B), which shows that small mines have a significantly higher fatality rate than all other groups. It is interesting to note from both graphs
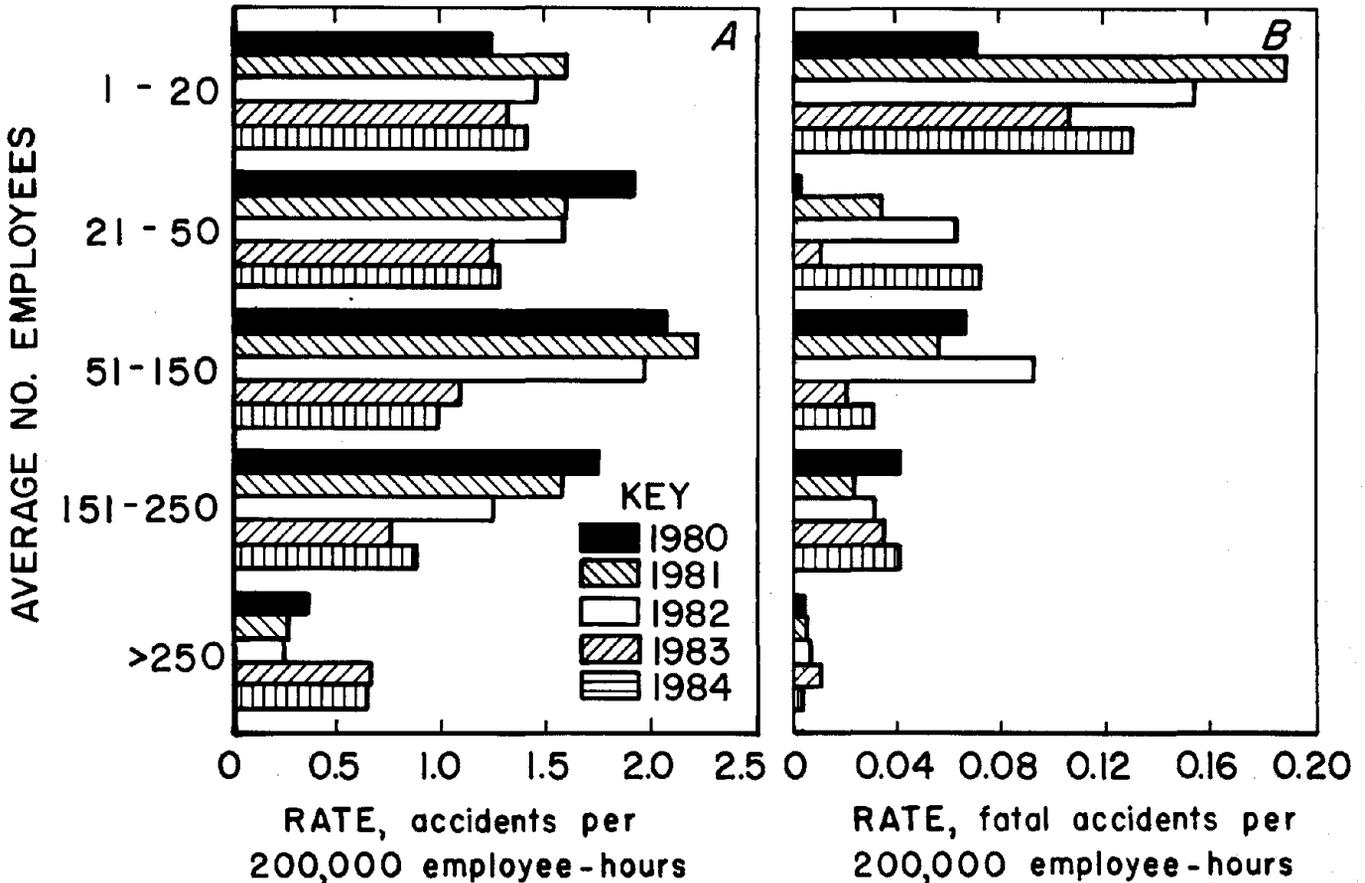
FIGURE 10.—Roof-rib accidents rates with respect to mine size based on the average number of mine employees. A, fatal and nonfatal roof-rib accidents per 200,000 employee-hours worked; B, only fatal roof-rib accidents per 200,000 employee-hours worked.

that very large mines (greater than 250 employees) have the lowest roof-rib accident rates of all categories, especially for fatal accidents.

Underground Location

The location of the roof-rib fall accident was another factor studied. Figure 11 shows that approximately 61% of roof-rib fall accidents occur at the working face, 12% at an intersection, and the remaining portion at various other or undefined locations. These results seem reasonable since most miners work at the face. At the face, the miners are often under temporarily supported or unsupported roof, where there is a much greater risk of a roof fall. No trends from year to year were detectable with respect to location.

Mining Method

Further examination of mine attributes involved the mining method employed at the location where the accident occurred. Longwall mining is becoming a popular method of mining, which is evident by a 100% increase in the number of working longwall faces in the United States between 1974 and 1986 (14-15). The rapid growth in use of the longwall method may be attributed to a higher recovery rate and safer working climate, since the miners are almost always under the protection of the longwall shields.

Figure 12 is a compilation of the number of roof-rib accidents based on the mining method used at the section where the accident occurred. The bar chart shows accidents decreasing for the conventional and continuous mining methods, with the number of longwall accidents increasing slightly with time. This slight increase is most likely due to the increased number (approximately 59 panels) of longwall panels started in the 5-yr period.

For a more accurate assessment of accident trends, the data needed to be normalized based on annual tonnage per mining method. Table 1 shows the accident rates of the longwall method versus all other methods (conventional, continuous,
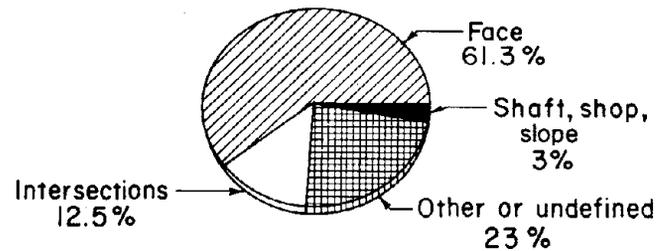
FIGURE 11.—Roof-rib accident locations.
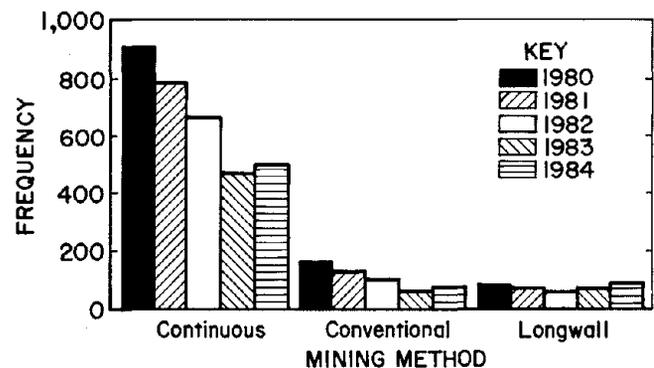
FIGURE 12.—Frequency of roof-rib accidents with respect to type of mining method.

and hand loading) grouped together and normalized with production figures from 1978 and 1983, since these are the only years for which longwall production figures were published (10, 16). However, these rates are somewhat biased since longwalls are considerably more productive than other mining methods and the number of accidents that the longwall rate is based upon is considerably less than the number of accidents for the other rate, which may affect the accuracy.

Both longwall and the other mining methods show a substantial accident rate drop over the 5-yr time span (from 3.5 to 1.48 accidents per million short tons for longwalling and 4.88 to 2.98 accidents for all other methods) reflecting the overall drop in roof-rib accidents. Yet, the percentage difference in roof-rib accident rates between the longwall method and all other methods widened from 28% in 1978 to 50% in 1983 (table 1).

Although these data are somewhat biased, they may indicate that longwalls provide a safer working environment, as was found in an equivalent accident study conducted by Peake (17). Peake's study,

TABLE 1. - Roof-rib accident rates, longwall versus all other mining methods

	1978	1983
Production, st:		
Longwall......................	11,981,000	47,257,000
Other methods..................	217,094,592	244,885,378
Number of roof-rib accidents:		
Longwall......................	42	70
Other methods.................	1,061	731
Accident rate:[1]		
Longwall......................	3.50	1.48
Other methods.................	4.88	2.98
Difference[2]..............%..	28	50

[1]Accidents per million short tons mined.
[2]Percentage by which roof-rib accident frequency for all other mining methods exceeded that for longwall mining in the United States.

conducted in 1985, examined all types of accidents for 13 longwall and nonlongwall working faces and the data were normalized based on employee-hours worked instead of production. Peake's study found that the nonlongwall mining method accident rate exceeded the longwall rate by 53%.

THE ACCIDENT VICTIM

One of the more important concerns in compiling these statistics was to evaluate the characteristics and effects that a roof-rib accident has on the victims and their families. Various factors evaluated include the victim's activity at the time of the roof-rib accident, the number of lost workdays, and the type of injury resulting from the accident.

Worker Activity

The types of activities that the victims were pursuing at the moment the roof-rib fall occurred were evaluated. Tables 2 and 3 show the top 10 worker activities, with the highest accident and fatality rates based on employee-hours worked (5-yr average). Handling supplies, barring down the roof-rib, and roof bolting had the highest accident rates (table 2). Examination of the fatality rates in table 3 shows almost the same worker activities as table 2 except in a different order, possibly indicating

TABLE 2. - Worker activity roof-rib accident rates, averages for 1980-84, accidents per 200,000 employee-hours

Rank	Worker activity	
1...	Handling supplies or material	0.088
2...	Bar down......................	.081
3...	Roof bolter, other...........	.070
4...	Set, remove, relocate props..	.061
5...	Continuous miner..............	.060
6...	Walking, running..............	.050
7...	Idle..........................	.050
8...	Machine maintenance, repair..	.045
9...	Timbering.....................	.043
10..	Move power cable..............	.035

TABLE 3. - Worker activity roof-rib fatality rates, averages for 1980-84, fatalities per 200,000 employee-hours

Rank	Worker Activity	
1...	Continuous miner............	0.0035
2...	Timbering...................	.0025
3...	Observe operations..........	.0022
4...	Roof bolter, inserting bolt	.0022
5...	Handling supplies...........	.0021
6...	Supervise...................	.0021
7...	Set, remove, relocate props	.0019
8...	Roof bolter, other..........	.0018
9...	Bar down....................	.0017
10..	Walking, running............	.0014

which activities are more prone to result in a fatal accident. Operating the

continuous miner, timbering, and observing operations had the highest fatality rates. Although many of the activities listed in table 3 correspond to activities that usually occur at the working face, several of the activities were merely observing operations, supervising, walking, or idle time. These data emphasize the randomness at which a roof-rib fall can occur.

Lost Workdays

Most of the attention associated with roof-rib accidents is focused on the fatalities, and rightly so. However, out of the average 1,100 roof-rib accidents that occur each year, less than 4% of these accidents are fatalities. Whereas, over 50% of these accidents are severe enough to result in 10 or more lost workdays, as shown in table 4, which gives a cumulative percentage of days lost.

MSHA defines days lost as the number of full calendar days that the injured employee is unable to work as a result of a temporary disability (3). This does not include lost workdays from an accident resulting in a permanent total disability. Consequently, the statistics offer a relative indication of the seriousness of roof-rib accidents in terms of the number of lost workdays.

Data from figure 13 indicate that the average length of time away from work because of a roof-rib fall accident has increased from 35 to 44 days over the 5-yr study period. This indicates that the victim is requiring a longer recuperation period, and one reason may be that roof-rib accidents are becoming more severe, as was noted with the severity rates. A

TABLE 4. – Distribution of roof-rib accidents with respect to days lost, averages for 1980-84

Days lost	Av No. of accidents	Cumulative percentage
>499................	2	0.2
249 to 499.........	19	1.9
143 to 249.........	42	5.7
99 to 143..........	42	9.5
88 to 99...........	18	11.2
66 to 88...........	49	15.6
44 to 66...........	90	23.9
22 to 44...........	155	37.9
10 to 22...........	160	52.5
4 to 10............	176	68.5
1 to 4.............	157	82.9
0..................	148	96.3
0[1]...............	40	100.0
Total.........	1,098	NAp

NAp Not applicable.
[1]Fatal and other accidents resulting in permanent total disability.

tally of the total workdays lost between 1980 and 1984 yields almost 200,000 days or 1.6 million employee-hours lost because of roof-rib accidents alone (These figures do not include workdays lost from an accident resulting in a permanent total disability.)

Type of Injury

Analysis of the types of injuries sustained by roof-rib fall victims shows that 17% of the victims suffer injuries to multiple parts of their bodies. Multiple injuries are most often linked with severe or fatal injuries. Following multiple injuries, the most frequent injuries are to the back and the
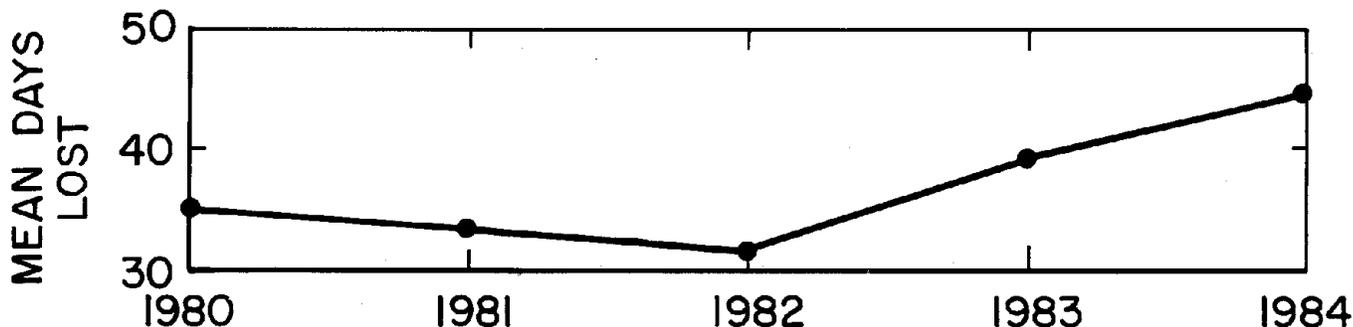

FIGURE 13.—Average number of lost workdays due to roof-rib accidents.

extremities (finger, foot, hand, and leg). These injuries are usually less sever than multiple injuries. The parts of the body injured in roof-rib accidents seem fairly well represented because fall material injures susceptible areas of the body such as the back, extremities, etc. In many instances, injuries affect more than one area.

Roof-rib accidents not only affect the victim physically but also financially. This introduces a new factor: What economic effects do roof-rib accidents have on their victims, as well as on the mining industry?

COST ANALYSIS OF ROOF-RIB FALL ACCIDENTS

To evaluate the economic effects that roof-rib fall accidents cause, the computer software package ACIM (accident cost indicator model) was utilized. This cost analysis program, developed under contract for the Bureau, was mathematically modeled to incorporate information gathered from mine inspection offices, workmen's compensation agencies, insurance companies, and major medical centers. Output from the program estimates the tangible costs, both total cost and cost per accident, for a specified type and degree of accident. The costs are broken down into the following categories (18-19):

1. The cost of the accident to the mining industry.--This includes the cost of cleanup after the accident and associated production losses, the cost of State Worker Compensation Benefits, the cost of the medical treatment, the cost of the union death-disability benefits, and the cost of the mining industry's investigation of the accident.

2. The cost of the accident to the victim and victim's family.--Cost due to lost wages during recuperation or the lost wages for the remaining portion of the victim's career if the accident results in a fatality or permanent (total) disability. Lost wages are adjusted to account for compensation wages received from benefits.

3. The cost of the accident to the public sector.--This includes the cost of benefits (Federal Social Security) paid out to the victim and victim's family and the cost of the public investigation conducted by MSHA.

These costs are based on cost data for a particular year and are not adjusted for inflation unless otherwise stated. Also excluded are costs of lawsuits; costs of hiring and training replacement workers; costs of resarch to prevent or reduce accidents; and most costs related to lost profit, sales, or equipment idled by an accident (18).

It should be emphasized that the ACIM program does not use the actual costs associated with each accident but rather a random generator to approximate the accident costs. Therefore, these costs should be used cautiously since they are only estimated costs of roof-rib accidents. This is especially true for fatal accidents, where no true cost can be placed on the loss of human life.

TOTAL ACCIDENT COSTS

The software program approximates the total cost of all roof-rib accidents between 1980 and 1984 at $215 million or about 27% of the cost of all underground accidents. A breakdown of the groups of individuals economically affected by roof-rib accidents (averaged 1980-84) is shown in the pie chart in figure 14. The major costs of these accidents between 1980 and 1984 are carried by the mining industry (approximately 47% or $100 million), the victim and victim's family (approximately 32%, or $70 million), and public agencies (approximately 21% or $45 million). Also shown in figure 14 is the breakdown of the cost percentage involved within each grouping. The major roof-rib accident costs result from production losses ($37 million), lost wages ($70
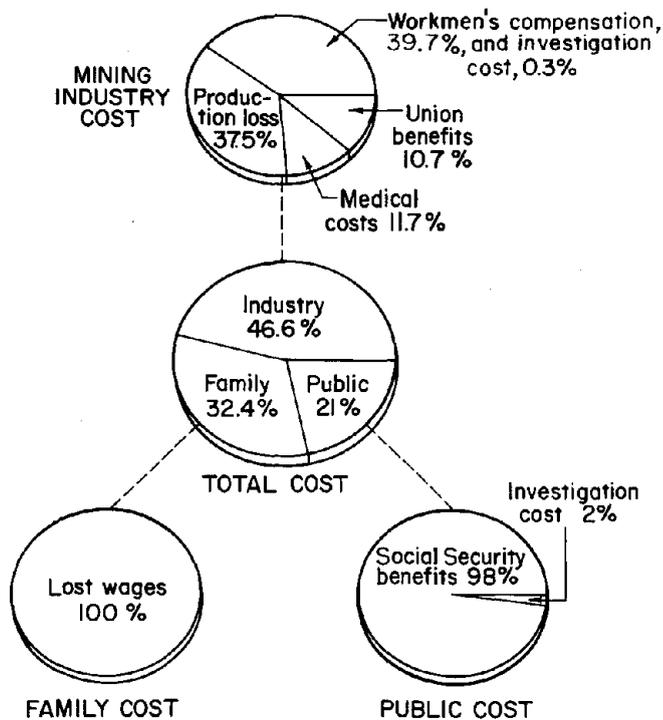
FIGURE 14.—Pie chart of roof-rib accident cost percentages, averages for 1980-84.

million), and benefits, such as Social Security, union, and worker's compensation ($95 million).

COST PER ACCIDENT

To obtain a more accurate approximation of accident costs, the program normalizes the data in the form of cost per accident. Table 5 illustrates the wide gap that exists between the cost per accident of roof-rib fall accidents versus all other accident types. In 1984, the cost per roof-rib fall accident was estimated at $52,000 while the cost per accident of all other underground accidents was estimated at $16,600.

As table 5 shows, roof-rib accidents are over three times as costly as all other underground accidents. Specifically, these large roof-rib costs can be traced to the cost of production losses (6.2 times more costly per accident), the cost of all benefits (1.3-4.1 times more costly per accident), and the cost of lost wages (3.9 times more costly per accident). The higher production loss costs may be related to a longer shutdown period of the mine because of cleanup of the fallen material and resupport of the roof-rib fall area. The higher union, Federal, and workmen's compensation benefit costs and wage losses may be due to the greater severity of injuries caused by roof-rib fall accidents requiring a longer recuperation. Thus, the roof-rib accident victim loses more wages and subsequently increases the cost of the benefits that are paid by the mining industry and public sectors. Consequently, these large increases in cost per accident substantiates the negative impact that

TABLE 5. —Comparison of roof-rib accident costs and all other types of accidents for 1984, cost per accident

	Roof-rib accidents	All other mining accidents	Ratio
Mining industry:			
Workers' compensation[1]	$6,929	$5,322	1.30
Production losses	10,917	1,746	6.25
Medical expenses	774	611	1.27
Union benefits[1]	2,144	514	4.17
Investigation	63	13	4.85
Total mining industry	20,827	8,206	2.54
Family:			
Lost wages (total cost to family)	21,324	5,488	3.88
Public:			
Social Security benefits[1]	9,714	2,860	3.40
MSHA investigation	231	45	5.13
Total cost to public	9,945	2,905	3.42
Total cost per accident	52,096	16,599	3.14

[1]Benefits.

roof-rib accidents have on various sectors of the economy.

To evaluate cost trends over the 5-yr period, the ACIM program was modified such that all the costs were in 1983 dollars. This eliminated the effects of inflation over the time period and allowed the data to be equitably compared. Figure 15A shows that roof-rib accidents as well as all other types of accidents have erratically increased in cost (approximately 30%) over the time period. Therefore, all types of accidents are becoming increasingly more expensive, even with the effects of inflation eliminated.

COMPARISON OF ACCIDENT COSTS BASED ON DEGREE OF INJURY

Figures 15B and 15C display the approximate cost ranges of roof-rib accidents with varying degrees of injury. Figures 15B and 15C illustrates that the degree

FIGURE 15.—Comparison of costs per accident. A, roof-rib accidents versus all other types of accidents (adjusted for inflation); B, fatal roof-rib accidents versus permanent partial or total disabling accidents; C, roof-rib accidents resulting in days lost injuries versus no days lost injuries.

of injury dramatically dictates the cost of a roof-rib accident (based on cost per accident in 1983 dollars). For instance, the cost per fatal accident (degree 1) is around $1 million per accident, but the cost of an accident resulting in a permanent partial or total disability (degree 2) is around $300,000; while the cost of an accident resulting in lost workdays is close to $6,000, and the cost of an accident with no lost workdays is about $500.

For actual cost comparisons of various degrees of injury, roof-rib accident costs for 1983 were examined as shown in table 6. Comparison of the fatal accidents (degree 1) versus accidents resulting in permanent disabilities (degree 2), which are the two most costly types of accidents, yields some interesting information. The estimated cost per accident resulting in a permanent disability is about 40% of the cost of a fatal accident. The lower costs of degree 2 accidents result from considerably lower production losses, lost wages, and benefit costs (table 6). Whenever a fatal accident occurs, it forces the whole mine to shutdown for one or more workdays, while with degree 2 accidents only the affected mine section may be closed. Consequently, degree 2 accidents have lower production losses than occur with fatal accidents.

Another comparison was made from table 6, contrasting fatal accidents (degree 1) with accidents resulting in injuries with lost workdays (degrees 3-4) and injuries with no workdays lost (degrees 5-6). These comparisons are even more noteworthy. The degree 1 accident cost averaged $955,000 per accident while the degrees 3 and 4 accident cost averaged $6,123 per accident (150 times less than degree 1 accident costs) and the degrees 5 and 6 accident cost averaged $517 per accident (1,800 times less than degree 1 accident costs).

The lower accident cost of degrees 3 and 4 is due to zero production losses (more than likely a minuscule amount of production losses did occur), lower benefit costs, and less lost wages. With a less severe accident injury, the mine is not closed and therefore production
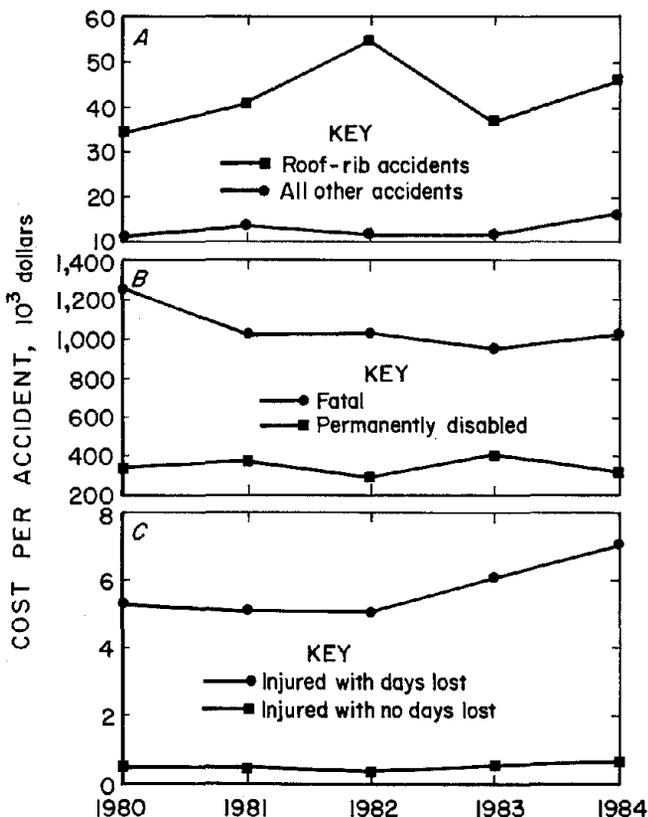
TABLE 6. - Comparison of costs per roof-rib accident based on degree of injury for 1983, cost per accident

Cost factors	Degree 1: Fatal	Degree 2: Permanently disabled	Degrees 3-4: injured with lost workdays	Degrees 5-6: Injured with no lost workdays
Mining industry:				
Workers compensation[1].....	$126,668	$179,838	$3,023	0
Production losses.........	229,302	9,415	0	0
Medical costs..............	0	1,048	825	$517
Union benefits[1]...........	55,117	22,124	32	0
Investigation..............	1,640	0	0	0
Total mining costs.....	412,727	212,425	3,880	517
Family:				
Lost wages (total family costs)...................	263,953	85,023	1,940	0
Public:				
Social Security benefits[1].	273,301	103,329	303	0
Investigation..............	5,079	0	0	0
Total public costs.....	278,380	103,329	303	0
Total cost per accident	955,060	400,777	6,123	517
Total accident cost[2]...	21,966,400	3,606,998	3,968,407	62,535

[1]Benefits.

[2]Total estimated cost of roof-rib accidents for all degrees of injury in 1983 = $29,604,340.

losses do not occur. Also, lost wages and benefit costs drop because of less severe injuries and shorter recuperation time. Costs of accidents with injuries of degrees 5 and 6 are reduced even further, almost to zero, except for the medical costs involved. Therefore, as the severity of the injury decreases the cost per accident decreases exponentially and considerably reduces the financial burden of the mining industry, the family, and the public.

The total estimated cost of all roof-rib accidents in 1983, which was the lowest annual cost of the five years studied, was calculated at approximately, $29,600,000 (table 6). Although these costs are only estimates, they are a monetary incentive for the mining industry to provide a safer underground environment and to instill in its workers safe working habits for reducing the risk of roof-rib fall accidents.

SUMMARY

The effects of roof-rib accidents are extensive, ranging from the economic loss of equipment and production to the fatal and nonfatal injuries that result in lasting physical and financial impairments suffered by the victims and their families. Although roof-rib falls will probably never be totally eliminated, the statistics show that the following problem areas need further attention:

- High accident rates in Virginia, Colorado, and Utah.

- Fairly high severity rates in Utah and Kentucky.

- Increased risk of roof falls in August through October because of higher humidity.

- More accidents seem to occur in the second and third hour of each shift and after the lunch break.

- High accident rates in mines with very thin coal seams (<36 in) and with very thick seams (>120 in).

- High fatality rates in mines with very thin coal seams (<36 in).

- High fatality rates at small mines with average annual work force of less than 20.

- Several worker activities seem more prone to accidents, such as operating continuous miners and roof bolting.

- Increasing number of days away from work after a serious injury.

Underlining the effects of roof-rib fall accidents are the accident costs, which have been estimated at $52,000 per roof-rib fall accident as opposed to $16,600 for all other types of accidents. Also, as the degree of injury resulting from a roof-rib accident becomes more severe, the cost of the accident increases exponentially. These high costs impact the mining industry, the injured workers and their families, and indirectly the public sector.

These compiled roof-rib statistics also indicate the following encouraging areas that should be maintained:

- U.S. roof-rib accident rates have consistently dropped in the last 20 yr, especially in recent years.

- A lower probability of accidents exists in mines with coal seam thicknesses of 37 to 120 in.

- Mines employing more than 250 workers have a lower probability of accidents.

- Longwall mining appears to be a safer mining method.

While these statistics may not be absolute, they do offer a current profile of U.S. roof and rib accidents and related accident costs, which reinforces the need for continued ground control research.

REFERENCES

1. Peng, S. S. Coal Mine Ground Control. Wiley, 1978, 200 pp.

2. Thrush, P. W. A Dictionary of Mining, Mineral, and Related Terms. BuMines Spec. Publ., 1968, p. 151.

3. U.S. Mine Safety and Health Administration (Dep. Labor). Summary of Selected Injury Experience and Worktime for the Mining Industry in the United States, 1931-1977. 1984, 69 pp.

4. Schlick, D. P., R. Peluso, and K. Thirumalai. U.S. Coal Mining Accidents and Seam Thicknesses. Paper in Proceedings of Symposium on Thick Seam Mining by Underground Methods (Queensland, Australia, 1976). Australasian Inst. Min. and Metall., Symp. Ser. No. 14, Aug. 1976, pp. 61-74.

5. U.S. Mine Safety and Health Administration (Dep. Labor). Mine Injuries and Worktime, Quarterly: Closeout Editions 1980-84. 119 pp.

6. Spokes, E. M. New Look at Underground Coal Mine Safety. Min. Eng. (Littleton, CO), v. 26, No. 4, 1986, pp. 266-270.

7. Stateham, R. M., and D. E. Radcliffe. Humidity: A Cyclic Effect in Coal Mine Roof Stability. BuMines RI 8291, 1978, 19 pp.

8. Haynes, C. D. Effects of Temperature and Humidity Variations on Coal Mine Roof Stability. Paper in Proceedings of a Symposium on Underground Mining (Louisville, KY, Oct. 21-23, 1975). Natl. Coal Assoc., Washington, DC, v. 2, 1975, pp. 120-126.

9. Theodore Barry and Associates. Accident Prediction Investigation Study (contract S0122023). BuMines OFR 38-73, 1972, 174 pp.: NTIS PB 221000.

10. U.S. Energy Information Administration (Dep. Energy). Coal Production 1984. DOE/EIA-0118, 1985, 144 pp.

11. U.S. Mine Safety and Health Administration (Dep. Labor). Comparison of Injury Hazards in Different Coal Seams Heights. 1981, 22 pp.

12. National Academy of Sciences. Fatalities in Small Underground Coal Mines (contract J010014-5). BuMines OFR 124-83, 1983, 20 pp.

13. National Research Council. Toward Safer Underground Coal Mines. Natl. Acad. Press, 1982, 190 pp.

14. Loxley, T. E., D. B. Lull, and J. O. Rasor. Self-Advancing Roof Supports for Longwall and Shortwall Mining, October 1974 Census, U.S. Naval Surface Weapons Center, Apr. 1975, 113 pp.

15. Sprouls, M. W. Longwall Census '84. Coal Min. and Process., v. 21, Dec. 1984, pp. 39-53.

16. U.S. Energy Information Administration (Dep. Energy). Bituminous Coal and Lignite Productions and Mine Operations. DOE/EIA-0118(78), 1980, 80 pp.

17. Peake, C. V. Longwall Output Continues to Rise. Coal Age, v. 91, No. 8, 1986, pp. 58-60.

18. Chi, D. N., and D. G. Di Canio. Mine Accident Cost Data Bases and Some Implications. Pres. at 1983 Am. Min. Congr. Min. Conv., San Francisco, CA, Sept. 11-14, 1983, 5 pp., available from D.N. Chi, BuMines, Pittsburgh, PA.

19. Di Canio, D. G., and A. H. Nakata. Accident Cost Indicator Model To Estimate Costs to Industry and Society From Work-Related Injuries and Deaths in Underground Coal Mining, Volume I. Development and Application of Cost Model (contract J0255031, FMC Corp.). BuMines OFR 39(1)-77, 1976, 202 pp.; NTIS PB 264 438.