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MINE ROOF CONDITION AND THE OCCURRENCE OF ROOF FALLS IN COAL MINES[1]

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ABSTRACT. Mine roof fall characteristics of 250 falls in 5 different room-and-pillar coal mines, located in Pike, Martin, and Floyd counties, Kentucky, were investigated to determine the relationship of selected parameters associated with roof failure and the assumed condition of the mine roof before failure. The selected parameters used in the study included: presence of cracks and water before the occurrence of fall, sloughing of coal ribs, floor heave condition, type of roof support (resin or mechanical anchor bolts), distance to coal face, and time of occurrence of fall after initial coal extraction. In addition, 8 research hypotheses, utilizing multiple linear regression techniques, were generated to test the relationship among the selected parameters and mine roof condition.

The results indicated that the vast majority of falls portrayed some presence of water before the actual fall, occurred in less than 30 weeks after initial coal excavation, located usually greater than 30 m from nearest coal face, gave evidence of cracks in mine roof before occurrence of fall, generally portrayed a good roof condition before the fall, showed presence of sloughing of coal ribs, and gave no occurrence of floor heave before occurrence of fall. In terms of the characteristics of the original support systems in the mine roof falls studied, most roofs were either supported by mechanical-anchor bolts or resin or full-column bolts; very rarely did the roof appear to fail if supported by posts or cribs.

A detailed inspection of the hypothesis and model comparison results gave supporting evidence that the condition of the roof is not dependent on the usual indicators of potential failure, such as presence of cracks and moisture. In fact, in most cases of mine roof failure, the immediate roof condition was rated as good or better, which gives little or no indication of pending failure and collapse. Hence, a combination of factors that are not easily accessible to measurement, are the dominant factors in the determination of roof fall-potential areas.

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INTRODUCTION

Roof fall occurrence is a common ground control problem. In fact, roof falls are so common many mining operations consider it a part of the regularly computed downtime (Gaddy 1973, Peng 1978). In some instances, it may cost as much to clean up a fall as it does to mine actual coal. The loss of revenues associated with downtime is not the only tragedy involved but includes the loss of life. Roof falls have been shown to be the major cause of death in underground coal mines in the United States, accounting for over 50% of all fatalities in coal mines in the United States (Peng 1978). Nearly all roof failures can be traced to 2 major causes: (1) the interaction of stresses in the roof, pillars and floor exceeded the rupture of the roof rock strata; and (2) geologic disturbances in the immediate roof, such as slickenslides, channel sands, transition zones, rider coal seams, kettlebottoms, cracks and joints and the presence of water, are often associated with roof falls (Horne et al. 1978, Hylbert 1980, Moebs 1974, Pothini and Von Schonfeldt 1979).

In underground mines of the western United States, many roof falls are associated with localized defects in the immediate roof (Van Besien 1973). Factors

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contributing to roof falls include the type and thickness of the rock strata, slickenslides, plant material on bedding planes, burrowed and rooted zones, rider coal seams, kettlebottoms, cracks in the roof, and the presence of water. Dougherty (1971) found that roof falls occurred 7% of the time when the roof was sandstone, and 12% of the time when coal was left to protect the shales, while 80% of roof falls occurred when the roof consisted of unprotected shales.

The best quality roof consists of well consolidated graywacke sandstones which are generally about 3 m thick and laterally continuous for more than 600 m (Horne et al. 1978). However, sandstones also present roof control problems. Orthoquartzitic sandstones may provide the high quality roof rock needed, but this sandstone tends to react more brittlely than other sandstones or non-sandstones (Hylbert 1980, Moebs 1974). Usually orthoquartzitic sandstones are jointed and fractured producing the possibility of a severe roof fall (Horne et al. 1978).

In roofs where interbedded sandstones and shales or flaggy sandstones exist, roof competence depends on bed thickness (Horne et al. 1978, Hylbert 1980). When beds are less than 0.6 m thick, separation can occur along the bedding plane giving rise to a roof fall that can fall as a single unit. If beds become thicker than 3 m, slickenslide surfaces develop due to differential compaction giving rise to roof falls that may not fall as single units. Hylbert's (1980) study also indicated that lithified plant material on bedding planes is likely to contribute to the incidence of roof falls because it weakens the cohesiveness of the rock to the next bed. Therefore, the optimum bed thickness is approximately 0.6–3 m thick producing an optimum bridging strength of the material.

Discontinuous sandstone bodies, such as sandstone channels, often rank as one of the more troublesome roof control problems (Custer and Gaddy 1981, Moebs 1974). The bodies also frequently cut out coal beds, are involved in roof falls and can start water problems. These associated problems with discontinuous sandstones are due to: the abrupt change of lithologies, such as the change from shale to sandstone; and differential compaction of sediments along the boundary of the sandstone deposit. These 2 factors create the shears and/or slumps which cause natural zones of weakness and an excellent place for roof control problems to develop (Hylbert 1980, McCulloch and Duel 1973). The ways to recognize these problem areas include the presence of fractures and/or steeply dipping coal beds, slickenslide surfaces becoming more numerous and the observation of a rise in the floor elevation (Custer and Gaddy 1981, McCabe and Pascue 1978). However, the occurrence of a sandstone channel is at best difficult to predict.

Hence, the condition of the immediate mine roof is extremely important in forecasting the occurrence of mine roof falls. The objective of this research is to investigate the relationship of the visible condition of the roof before the occurrence of failure to the actual occurrence of a mine roof fall.

All of the coal seams used in the present study are part of the Breathitt Formation in the Lower and Middle Pennsylvanian Series. It is generally accepted that the deposition of these coals and their associated sandstones, shales, and underclays took place on deltas and delta lobes with the source area to the northwest and sediment transportation to the east and southeast (Englund 1964, Ferm 1974, Hylbert 1980). Deposition of these deltas and delta lobes took place within the Pocahontas Basin which is a smaller basin within the larger Appalachian Basin (Hylbert 1980).

The 4 different coal seams that were examined included: the Broas, the Peach Orchard (Coalburg), and the Pond Creek (Lower Elkhorn), all in Martin Co., the Pond Creek again in Pike Co., and the Fire Clay coal seam in Floyd Co. The intervals between coal seams are cyclic, either a coarsening upward or fining upward sequence (Hylbert 1980). This cyclic sequence is a key stratigraphic relationship that permits the use of several coal seams.

METHODS AND MATERIALS

Cooperation by 4 mining companies allowed the investigation and data collection of mine roof falls in 5 different mines (fig. 1) to determine the relationship among condition of roof to selected parameters associated with failure. The parameters studied included: presence of cracks and water before the occurrence of fall, sloughing of coal ribs, floor heaving, type of roof support (resin or mechanical anchor bolts), distance to coal face, and time of occurrence of fall after initial coal extraction. A total of 250 roof falls from the counties of Pike, Martin, and Floyd in eastern Kentucky were measured and used as the basis for this study. However, due to the sensitive nature of the information contained in the present study, the coal companies involved requested that the exact locations of their mines and associated roof fall statistics be withheld.

Multiple linear regression analysis techniques (McNeil et al. 1976) were performed, via SPSS (Statistical Package for the Social Science) and DPLINEAR (Double Precision Linear Regression), to test 8 hypotheses relating the condition of the roof before the fall to selected parameters associated with failure. The Newman and Fry (1973) method for adjusting alpha for multiple comparison was also employed. In addition, a combination of the computer software packages of SPSS and PLOTALL, a computer-graphics software to generate frequencies and visual profiles, were used to display distributions of selected parameters associated with the recorded falls.

RESULTS

Table 1 illustrates the summary of frequency counts, relative frequencies, and cumulative frequencies for the various parameters. Fig. 2 displays the distribution of the assumed condition of the mine roof before failure. Tables 2 and 3 summarize the result of the hypothesis testing of selected parameters with assumed condition as the criterion.

DISCUSSION

As evident from an inspection of table 1, the vast majority of falls portrayed some presence of water before the actual fall (78.0%), occurred in less than 30 weeks after initial coal excavation (71.3%), located usually greater than 30 m from nearest coal face (70.4%), gave evidence of cracks in mine roof before occurrence of fall (75.2%), generally portrayed a good roof condition before the fall (60.8%) (fig. 2), showed presence of sloughing of coal ribs (48.8%), and no occurrence of floor heave (88.0% no sloughing) before occurrence of fall. In terms of the characteristics of the original support systems in the mine roof falls studied, most roofs were either supported by mechanical-anchor bolts (57.2%) or resin or full-column bolts (38.8%); very rarely did the roof appear to fail if supported by posts (0.4%) or cribs (1.2%). Of course, this result may be due to the extremely popular use of roof bolts.

The hypothesis testing results (tables 2 and 3) indicated that the condition of the

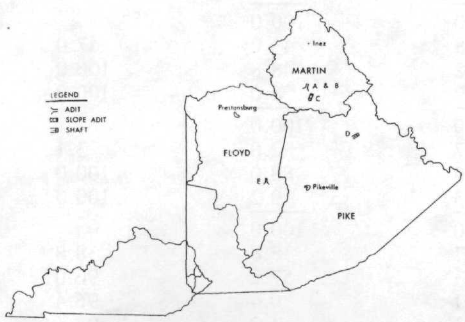

FIGURE 1. Location of Kentucky coal mines used in the present study. The letters symbolize the coal seams present at each mine site: (A) Peach Orchard, (B) Broas, (C) and (D) Pond Creek, and (E) Fire Clay.

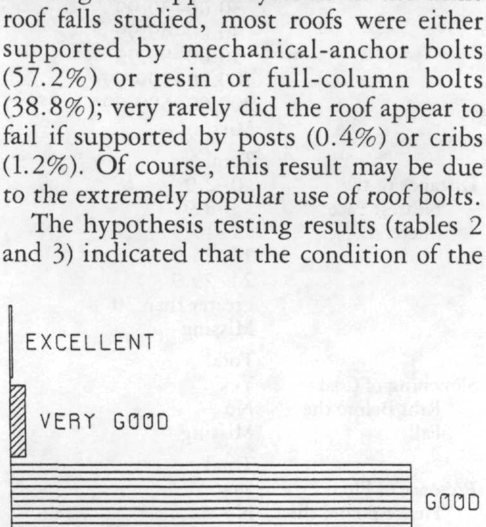

FIGURE 2. Computer generated histogram of assumed condition of mine roof before occurrence of actual roof fall.

TABLE 1

Summary of frequency counts, relative frequencies, and cumulative frequencies for support systems and associated physical parameters.

Parameter	Value Label	Absolute Frequency	Relative Frequency (%)	Adjusted Cumulative Frequency (%)*
Cracks in Roof Before Fall	Yes	188	75.2	85.1
	No	33	13.2	100.0
	Missing	29	11.6	100.0
	Total	250	100.0	
Assumed Condition of the Roof Before the Fall	Excellent	1	0.4	0.4
	Very Good	6	2.4	2.8
	Good	152	60.8	63.6
	Poor	79	31.6	95.2
	Very Poor	12	4.8	100.0
	Total	250	100.0	
Presence of Water Before the Fall	Yes	195	78.0	78.0
	No	55	22.0	100.0
	Total	250	100.0	
Time of Roof Fall After Coal Excavation (weeks)	0.00–0.99	23	9.2	10.0
	1.00–1.99	23	9.2	20.0
	2.00–2.99	16	6.4	27.0
	3.00–3.99	9	3.6	30.9
	4.00–4.99	25	10.0	41.7
	5.00–9.99	19	7.6	50.0
	10.00–19.99	22	8.8	59.1
	20.00–29.99	28	11.2	71.3
	30.00–39.99	10	4.0	75.7
	40.00–49.99	7	2.8	78.7
	50.00–99.99	23	9.2	88.7
	100.00–199.99	16	6.4	95.7
	200.00–599.99	10	4.0	100.0
	Missing	20	8.0	100.0
	Total	250	100.0	
Distance to the Nearest Face (meters)	0–2.9	16	6.4	7.0
	3–8.9	4	1.6	8.7
	9–15.9	3	1.2	10.0
	16–23.9	14	5.6	16.6
	24–29.9	15	6.0	23.1
	greater than 30	176	70.4	100.0
	Missing	21	8.4	100.0
	Total	250	100.0	
Slouching of Coal Ribs Before the Fall	Yes	108	43.2	47.0
	No	122	48.8	100.0
	Missing	20	8.0	100.0
	Total	250	100.0	
Presence of Floor Heave Before the Fall	Yes	7	2.8	3.1
	No	220	88.0	100.0
	Missing	23	9.2	100.0
	Total	250	100.0	
Type of Support Before the Fall	Resin Bolts	97	38.8	38.8
	Anchor Bolts	143	57.2	96.0
	Post	1	0.4	96.4
	Cribbs	3	1.2	97.6
	Not Supported	6	2.4	100.0
	Total	250	100.0	

*Adjusted for missing data

TABLE 2

Result of the general hypothesis testing discriminative relationships among assumed condition of the roof before the fall and associated failure parameters, using the full and restricted model concepts of multiple regression.

Full Model:

Condit = 3.72512 (U) − 0.07979 (Supporb) − 0.00149 (Distance) − 0.11329 (Cracks) + 0.14439 (Floor) − 0.18151 × 10 − 4 (Time) − 0.02407 (Water) − 0.21200 (Slough) + E

R^2Full	df_n/df_d	Alpha	F-Ratio	Probability	Significance
0.04358	7/187	0.05	1.21738	0.2951	NS

Restricted Model:

Condit = 3.72512 (U) + E

R^2 Restricted 0.0

Hypothesis 5: The variables Supporb, Distance, Cracks, Floor, Time, Water, and Slough account for a statistically significant amount of variance in discriminating the assumed condition of the roof before the roof fall (Condit).

Note. NS and S denote statistical significance for a nondirectional, two-railed test at the 0.05 alpha model. R^2 indicates the amount of variance explained by the model. The term df_n/df_d denotes degrees of freedom-numerator, degrees of freedom-denominator.

TABLE 3

Summary of F-ratios, probability levels, R^2 for both the full and restricted models, degrees of freedom-numerator, degrees of freedom-denominator, and significance for each research hypothesis testing discriminative relationships among mine roof condition before the fall and associated failure parameters.

Parameter(s)	R^2 Full	R^2 Restr.	df_n/df_d	F-Ratio	Probability	Significance
Slough, Floor, Cracks, Water, Distance, Time, Supporb	0.04358	0.0	[a]1/187	1.21738	0.2951	NS
Slough	0.03007	0.0	[b]1/193	5.98440	0.0153	NS*
Floor	0.00004	0.0	[b]1/193	0.00722	0.0324	NS
Cracks	0.00263	0.0	[b]1/193	0.50876	0.4765	NS
Water	0.00025	0.0	[b]1/193	0.04818	0.8265	NS
Distance	0.00138	0.0	[b]1/193	0.26711	0.6059	NS
Time	0.00172	0.0	[b]1/193	0.33302	0.5646	NS
Supporb	0.01938	0.0	[b]1/193	3.81489	0.0522	NS*

Note. An F-test was utilized to test for significant relationships among assumed condition of the roof before fall and selected physical parameters. The assigned alpha level of 0.05 for two-tailed, nondirectional test was considered statistically significant. However, the employment of a correction for multiple comparisons was necessary, using the Newman and Fry (1973) method. The corrected alpha level of 0.007 was used before any specific research hypothesis was considered significant.

*Approaching significance at the 0.05 level

The power for the hypothesis using a medium effect size is as follows:

[a]0.99

[b]0.995

roof is not dependent on the usual indicators of potential failure such as presence of cracks and moisture. In fact, in most cases of mine roof failure, the immediate roof condition was rated as good or better, which gives little or no indication of pending failure and collapse. Hence, a combination of factors that are not easily accessible to measurement, are the dominant factors in the determination of roof fall-potential areas.

Many geologic factors influence the thickness, continuity, quality, and mining conditions of coal. Some of these geologic features formed during or near peat accumulation, while other factors developed long after deep burial and coalification. The recognition of the nature of these features, whether affecting the entire coal field or only locally, is important in mining operations. The nature of the overlying and underlying rocks in a coal mine may be a significant factor in the minability of the coal seam. The material in the first few meters above the coal must be strong enough to remain stable for the required time period when it is supported by bolts, timbers, cables, or combinations of roof support systems.

Since the behavior of a rock mass subjected to changes in stress induced by mining activities is governed by both the mechanical properties of the intact rock material and the number and nature of the geological discontinuities present in the rock mass, the first step in preventing mine roof falls is to characterize the condition of the immediate mine roof and its relationship to potential failure zones. As shown in this study, there is no adequate warning to failure and eventual collapse of roof based on an initial assessment of mine roof by experienced mining personnel.

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