Application of coal mine roof rating (CMRR) to extended cuts

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Introduction

On July 15, 1997, four coal miners were killed in the United States by roof falls in three separate incidents. This tragic coincidence was a dramatic reminder that roof falls remain the single greatest hazard faced by underground coal miners.

One reason that roof falls have proven to be a stubborn problem is that mines are not built of manmade materials, such as steel or concrete, but rather are built of rock, just as nature made it. The structural integrity of a coal mine's roof is greatly affected by the natural weaknesses, including cracks, small faults and layering. To make matters more difficult, the geologic processes that formed it have varied in space and time, so engineering properties of the roof can change dramatically from mine to mine and even within individual mines.

Engineers have had difficulty obtaining quantitative data on the strength of rock masses for design. Traditional geologic reports contain valuable descriptive information but seldom include engineering properties. On the other hand, laboratory strength test results are inadequate, because the strength of a small rock sample is only indirectly related to the strength of the rock mass.

To help quantify the engineering properties of a mine roof, the coal mine roof rating (CMRR) was proposed (Molinda and Mark, 1994). The CMRR weighs the geotechnical factors that determine roof competence and combines them into a single rating on a scale of zero to 100. The CMRR integrated 20 years of research on geologic hazards in mining and utilized the worldwide experience with rock mass classification systems. In developing the CMRR, field data were

Abstract

Since first introduced, the coal mine roof rating (CMRR) has been widely accepted as a tool for geologic characterization and mine planning. This paper discusses the application of the CMRR to another practical ground-control problem: extended cuts. Extended cuts, i.e., cuts greater than 6 m (20 ft) in length, are commonly used with remote-control continuous miners. Extended cuts can greatly increase productivity, but they have been associated with a number of fatal roof-falls. When extended cuts are attempted in weak roof material, the roof may collapse before it can be bolted. Until now, it has not been possible to predict where conditions may not be suitable for extended cuts. In this study, data on the CMRR and extended-cut experience were collected at 36 mines in seven of the United States. It was found that, when the CMRR was greater than 56, deep cuts were routine in nearly every case. When the CMRR was less than 37, extended cuts were almost never taken, and, when the CMRR was between 38 and 56, extended cuts were sometimes, but not always, feasible. The data also show that extended cuts are less likely to be stable if either the entry span or the depth of cover increases.

collected from nearly 100 mines in every major coalfield in the United States. Cost-sharing cooperative research agreements were signed with the Cyprus, Ziegler and Peabody coal companies to support the research.

The CMRR can be calculated from underground exposures such as roof falls and overcasts (Molinda and Mark, 1994), or the CMRR can be calculated from exploratory drill core (Mark and Molinda, 1996). In either case, the main parameters measured are:

- the uniaxial compressive strength of the intact rock,
- the spacing and persistence of discontinuities such as bedding planes and slickensides,
- the cohesion and roughness of the discontinuities, and
- the presence of groundwater and moisture sensitivity of the rock.

Simple index tests and observations are used to rate each of these parameters. In the case of drill core, point load tests (PLTs) are used to estimate the compressive strength and the cohesion. The CMRR is obtained by summing the ratings for the individual parameters. Detailed procedures for calculating the CMRR have been published elsewhere (Molinda and Mark, 1994; Mark and Molinda, 1996).

The CMRR makes three significant contributions:

- It focuses on the specific engineering characteristics of coal measure rock.
- It applies to all US coalfields and allows for a meaningful comparison, even where lithologies are quite different.

- And it provides a methodology for geotechnical data collection.

The CMRR has found numerous applications in ground-control design. A study conducted at 44 longwall mines found that tailgate performance was largely determined by the CMRR and the ALPS pillar-stability factor (Mark and Chase, 1994). Significant correlations between the CMRR and the entry width (Fig. 1) and between CMRR and the intensity of roof support were also found. Another study determined that yielding pillar gate entry designs have only been successful when the CMRR was greater than 50 and the pillar's width-to-height ratio was less than five (DeMarco, 1994).

Data has also been presented that relate the incidence of roof falls to the CMRR and intersection span (Fig. 2). These were based on observations at five underground mines (Mark et al., 1994). The CMRR has recently been incorporated into guidelines for multiple seam mine design (Luo et al., 1997), hazard analysis and mapping (Wuest et al., 1996), tailgate support selection (Harwood et al., 1996) and feasibility studies (Beerkircher, 1994). The US Mine Safety and Health Administration has used the CMRR in fatal accident investigations, and at least three major coal companies have recently taken steps to integrate the CMRR into their exploration programs.

Stability of extended cuts

Extended (deep) cut mining is where the continuous miner advances the face more than 6 m (20 ft) beyond the last row of permanent supports. The development of remote-control, spray fan systems and flooded-bed scrubbers provided the technology to enable continuous miners to take deep cuts and still comply with mining regulations. Since 1989, the number of mines with approvals for extended cuts has increased from 206 to 399 (Grau and Bauer, 1997). About 75% of all underground labor hours are worked at mines with extended-cut permits.
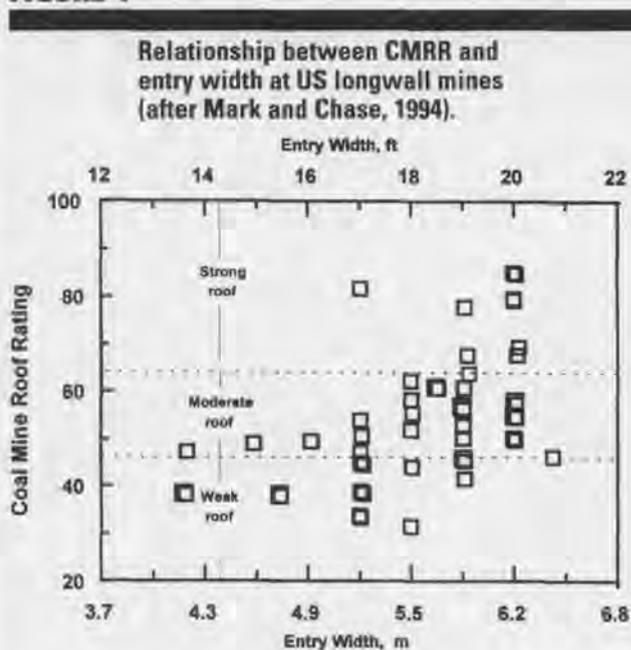
In practice, many mines with permits only take extended cuts when conditions allow for them. Where the roof is competent, extended cuts are routine. At the other extreme, when the roof is very poor, miners may not even be able to complete a 6-m (20-ft) cut before the roof collapses.

Because mining personnel should never be beyond the roof supports, falls of unbolted roof should not be a major hazard. Yet, between 1988 and 1995, extended cuts may have been a factor in 26% of all roof-fall fatalities in underground coal mines (Grau and Bauer, 1997). The ability to identify areas where extended cuts might collapse prematurely could be very useful to mine planners and regulators.
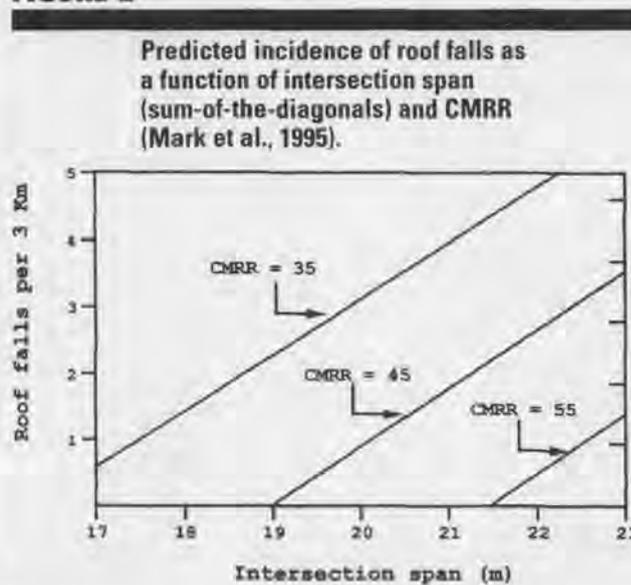
An extended cut in a coal mine is actually a special case of an unsupported span. The stand-up time of unsupported spans is one of the fundamental issues in rock engineering. The following basic relationships that governs stand-up time were originally formulated by Austrian tunneling engineers (Bieniawski, 1989):

- for a given rock mass, a tunnel's stand-up time decreases as the roof span becomes wider, and
- for a given roof span, a tunnel's stand-up time decreases as the rock-mass quality becomes poorer.

Relationship between CMRR and entry width at US longwall mines (after Mark and Chase, 1994).

Predicted incidence of roof falls as a function of intersection span (sum-of-the-diagonals) and CMRR (Mark et al., 1995).

Using data collected from numerous tunnels and mines, Bieniawski (1989) was able to quantify this relationship (Fig. 3). Bieniawski used the rock mass rating (RMR) as the measure of rock quality. His data indicate that an unsupported 4.3-m- (14-ft-) wide tunnel would be expected to collapse immediately if the roof's RMR was less than 33. If the tunnel was 6-m (20-ft) wide, immediate collapse would be expected if the RMR was less than 41. The following equation expresses the relationship for this range of tunnel spans (approximately the range encountered in underground coal mining)

$$RMR = 13 + 1.4\,W_e \quad (1)$$
where
W_e is the entry width, ft.

Because roof bolting normally takes place within

several hours of mining, the collapse of an extended cut may be considered "immediate."

The CMRR was developed to represent the unique characteristics of layered coal measure rock, while the RMR is more appropriate for jointed hard rock. However, the CMRR was designed to be equivalent to the RMR, so that the CMRR/unsupported span/stand-up time relationship should be nearly the same in both systems (Molinda and Mark, 1994).

The fundamental relationships among rock quality, span and stability were apparent in two of the studies reported earlier. As Fig. 1 shows, longwall mines with poor-quality roof have "naturally" gravitated to narrower entries. Similarly, Fig. 2 shows that the incidence of roof falls increases either as the span increases or as the CMRR decreases. Extended cuts provide an opportunity to evaluate the stand-up time of coal mine roof without the influence of roof bolts.

Research results

The stability of extended cuts was investigated at 36 mines in seven states between 1994 and 1997. In eight mines, different roof conditions were encountered in different areas within the mine, resulting in a total of 44 case histories. The CMRR was calculated from underground observations in each case. Usually, the entry width was determined as the mean of at least ten underground measurements, but, in others, it was the nominal width supplied by the mine. The typical cut is the permitted deep cut, except where reduced by "conditions." The depth of cover is typical of the area studied.

Mine officials were asked to rate how often they were able to achieve a full extended cut. Responses such as "always" and "almost every time" were grouped in Class 1 ("always stable"). Class 2 ("sometimes stable") included responses such as "about half the time." Cases where it was "rarely" possible to complete an extended cut or where company policy limited cut depths when certain conditions were encountered, were grouped in Class 3 ("never stable"). In one case, the roof was reported to collapse as soon as the box cut was mined, reducing the effective roof span to 4.3 m (14 ft). The "never-stable" class also included two mines that had not

applied for an extended-cut permit, because they felt their roof was too weak. Several other mines that had not applied for other reasons, such as methane control, were not included in the table.

The data are shown in Table 1. All eight cases where the CMRR was less than 36 fell into the "never-stable" class. Only two "never-stable" cases had a CMRR greater than 36. Of the 12 "sometimes-stable" cases, eight occurred where the CMRR was less than 46. Where the CMRR was greater than 56, every case was "always stable."

The multivariate statistical technique of logistic regression was employed to quantify other relationships within the data. Logistic regression is used where the outcome variable is "dichotomous" (has two levels). When asked to discriminate between the "never-stable" group and the other two groups, the only significant variable was the CMRR. For CMRRs greater than 38, only two immediate collapses are misclassified.

The results were more enlightening when the "never-stable" and "sometimes-stable" groups were combined and compared with the "always-stable" group. Now, both the CMRR and the depth of cover (H) were identified as statistically significant. An overall accuracy of 87% (6 misclassifications) was achieved with the equation

$$CMRR_{crit} = 40.9 + (H/100) \quad (2)$$
where
$CMRR_{crit}$ is the CMRR value below which instability may start to occur and
H is the depth of cover, ft.

Figure 4 plots the CMRR against the depth of cover, along with Eq. (2). The most likely explanation for the trend towards less-stable extended cuts as the cover increases is the greater stress level. The vertical stress increases in proportion with the depth, and studies have shown that the horizontal stress typically increases twice as rapidly as the vertical (Mark and Mucho, 1994).

Figure 5 plots entry width against the CMRR for the data set. The statistics indicated that entry width was less significant than depth of cover in predicting the performance of extended cuts. The best equation with CMRR and the entry width (W_e) is a as follows (85% overall accuracy and seven misclassifications)

$$CMRR_{crit} = 19.2 + 1.64 \, W_e \quad (3)$$

Note that Eq. (3) is very similar to the one calculated from Bieniawski's data (Eq. (1)), which is also plotted on Fig. 5. There is a difference of about six CMRR points in the intercept because Eq. (3) separates the "sometimes-stable" from the "always-stable" groups, while Eq. (1) corresponds to "always immediate collapse." Most of the "never-stable" group falls below the Bieniawski line, as predicted.

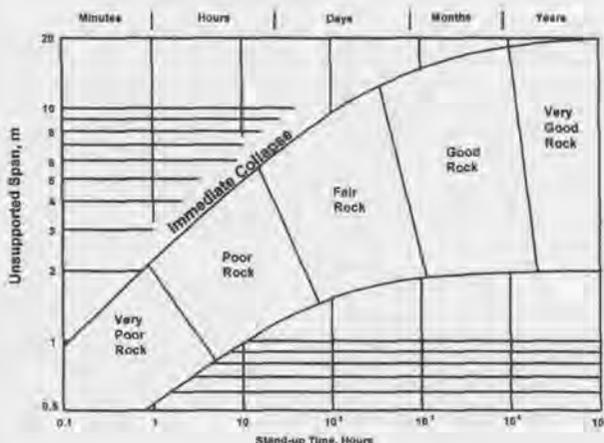The best equation that combines the effects of both depth and span is

$$CMRR_{crit} = 18.6 + (H/100) + (1.2 \, W_e) \quad (4)$$

Conclusions

The study confirms that the stability of extended cuts is determined primarily by the roof quality, of which

FIGURE 3

Relationship between RMR, tunnel span, and stand-up time (Bieniawski, 1989).
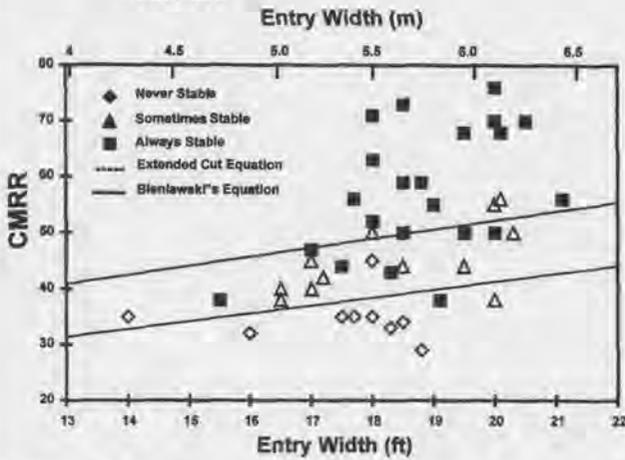
TABLE 1

Extended cuts at US coal mines.

State	Coal seam	Entry width, ft	CMRR	Cut depth, ft	Cover, ft	Cut status*
AL	Blue Creek	20.5	70	30	1,000	1
	Blue Creek	20.3	50	25	1,800	2
	Mary Lee	21.1	56	35	500	1
IL	Herrin No. 6	15.5	38	30	650	1
	Herrin No. 6	18	71	40	150	1
	Herrin No. 6	24	86	40	350	1
	Herrin No. 6	16.5	38	35	650	2
	Herrin No. 6	18	45	40	150	3
	Herrin No. 6	16	33	20	350	3
	Springfield No. 5	19.5	50	40	600	1
IN	Springfield No. 5	18.8	59	40	250	1
	Springfield No. 5	18.8	29	15	250	3
KY	Cedar Grove	18.5	50	40	600	1
	Harlan	18	63	40	1,800	1
	Kentucky No. 11	17.2	42	–	200	2
	Kentucky No. 11	18.3	33	14	1,000	3
	Kentucky No. 9	17.5	44	40	150	1
	Kentucky No. 9	19.1	38	30	350	1
	Kentucky No. 9	20	38	36	350	2
	Kentucky No. 9	17.5	35	20	150	3
	Kentucky No. 9	18	35	17	1,000	3
	Pond Fork	19	55	30	500	1
KY	Pond Fork	18	45	30	900	3
OH	Freeport (L)	19.5	68	40	600	1
	Freeport (L)	19.5	44	20	600	3
PA	Kittanning (L)	17	47	40	500	1
	Kittanning (L)	20	50	30	600	1
	Kittanning (L)	17	45	40	500	2
	Kittanning (L)	14	35	15	600	3
	Pittsburgh	16.5	40	30	650	2
	Pittsburgh	17	40	30	150	2
	Sewickley	18.5	44	30	800	2
UT	"D"	20	55	–	1,000	2
	Hiawatha	20	70	40	1,500	1
WV	Coalburg	18.5	73	40	500	1
	Coalburg	20	76	40	500	1
	Dorothy	18.5	59	40	500	1
	Eagle	17.7	56	37	1,000	1
	Eagle	20.1	68	40	800	1
	Eagle	20.1	56	40	800	2
	Eagle	17.7	35	10	1,000	3
	Pocahontas No. 3	18	50	25	1,200	2
	Powellton	18.5	34	17	400	3
WY	Hanna	18.3	43	40	700	1

*Extended cut status: 1 = always stable; 2 = sometimes stable; 3 = never stable.

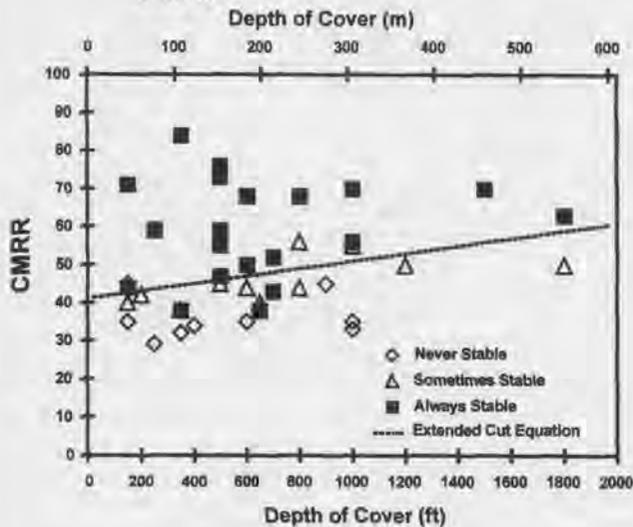the CMRR is an accurate indicator. The entry width and the depth of cover are secondary factors. The results pro- vide some simple guidelines for predicting the perfor- mance of extended cuts. When the CMRR is less than 38, it is unlikely that extended cuts will be feasible. When the CMRR is above 56, extended cuts should be routine. For intermediate roof conditions, extended cuts are more likely to be troublesome as the roof span widens or as the cover deepens. Equation (4) can be used to predict when problems are likely to be encountered. ∎

FIGURE 4

Relationship between CMRR and depth of cover for the extended-cut data set.

FIGURE 5

Relationship between CMRR and entry width for the extended-cut data set.

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