APPLICATION OF THE COAL MINE ROOF RATING (CMRR) TO EXTENDED CUTS

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ABSTRACT

Since it was 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 (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 fall accidents. When extended cuts are attempted in weak roof, the roof may collapse before it can be bolted, causing hazardous conditions. 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 7 states. It was found that when the CMRR was greater than 55, deep cuts were routine in nearly every case. When the CMRR was less than 37, extended cuts were almost never taken. Between 38 and 55, extended cuts were feasible sometimes but not others. The data also shows that extended cuts are less likely to be stable if either the entry span or the depth of cover increases.

INTRODUCTION

On July 15, 1997, four coal miners were killed 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 proved so stubborn a problem is that mines are not built of man-made materials like steel or concrete, but rather of rock just as nature made it. The structural integrity of coal mine roof is greatly affected by natural weaknesses including cracks, small faults, and layering. To make matters more difficult, the geologic processes that formed it 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 small rock samples are only indirectly related to the strength of the rock mass.

To help quantify the engineering properties of mine roof, the Coal Mine Roof Rating (CMRR) was proposed (Molinda and Mark, 1994). The CMRR combined 20 years of research on geologic hazards in mining with worldwide experience with rock mass classification systems. Field data was collected from nearly 100 mines in every major U.S. coalfield. Cost-sharing cooperative research agreements were signed with the Cyprus, Ziegler, and Peabody coal companies to support the research.

The CMRR weighs the geotechnical factors that determine roof competence, and combines them into a single rating on a scale from 0 to 100. The CMRR makes four significant contributions:

- Focuses on the characteristics of bedding planes, slickensides, and other discontinuities that weaken the fabric of coal measure rock;
- Applies to all U.S. coalfields, and allows meaningful comparison even where lithologies are quite different;
- Concentrates on the ability of the immediate roof to form a stable structure, and;
- Provides a methodology for geotechnical data collection.

Originally, the data for the CMRR was collected at underground exposures like roof falls and overcasts. To make it more generally useful, procedures were developed for determining the CMRR from drill core (Mark and Molinda, 1996). In addition, more than 2000 point load strength tests were conducted on samples of common coal measure rocks (Molinda and Mark, 1996). The samples were classified according to the popular pictorial rock core numbering system developed by John Ferm (Ferm et al., 1981).

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). Guidelines for sizing longwall pillars based on the CMRR have since been widely implemented. The same study found significant correlations between the CMRR and both entry width (figure 1) and the intensity of roof support. 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 5 (DeMarco, 1994).

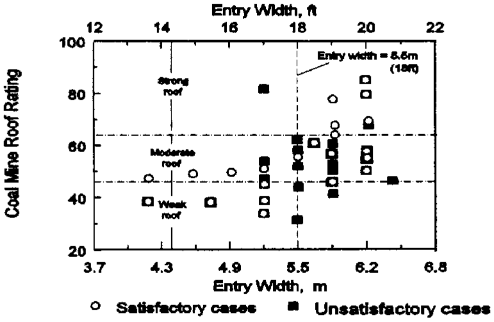

Figure 1. Relationship Between CMRR and Width at U.S. Longwall Mines (after Mark and Chase, 1994).

Data have also been presented that relate the incidence of roof falls to the CMRR and intersection span (figure 2). These were based on observations at five underground mines (Mark et al., 1994). The CMRR has lately 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 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.

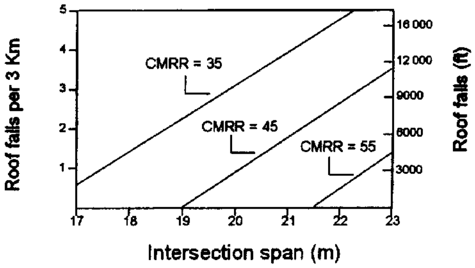

Figure 2. Predicted Incidence of Roof Falls as a Function of Intersection Span (Sum-of-the-diagonals) and CMRR (Mark et al., 1995).

STABILITY OF EXTENDED CUTS

Extended (deep) cut mining is where the continuous miner advances the face more than 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 man hours are worked at mines with extended cut permits.

In practice, many mines with permits only take extended cuts when conditions allow 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 20 ft cut before the roof collapses. Since mining personnel should never be beyond 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 the fundamental issues in rock engineering. The basic relationship that governs stand-up time was 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.

Using data collected from numerous tunnels and mines, Bieniawski (1989) was able to quantify this relationship (figure 3). Bieniawski used the Rock Mass Rating (RMR) as the measure of rock quality. His data indicates that an unsupported 14 ft wide tunnel would be expected to collapse immediately if the roof's RMR was less than 33. If the tunnel was 20 ft wide, immediate collapse would be expected if the RMR was less than 41. Equation (1) expresses the relationship **for this range of tunnel spans** (approximately the range encountered in underground coal mining):

$$RMR = 13 + 1.4\,W_e \qquad (1)$$

Where W_e is the entry width (ft).

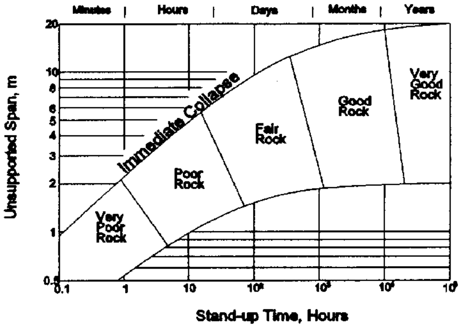

Figure 3. Relationship Between RMR, Tunnel Span, and Stand-up Time (Bieniawski, 1989).

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 relationship between rock quality, span, and stability was apparent in two of the studies reported earlier. As figure 1 shows, longwall mines with poor quality roof have "naturally" gravitated to narrower entries. Similarly, figure 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 7 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 10 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 like"always" and "almost every time" were grouped in class 1 ("Always Stable"). Class 2 ("Sometimes Stable") included responses like "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 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 is shown in table 1. All 8 cases where the CMRR was less than 36 fell into the "Never Stable" class. Only 2 "Never Stable" cases had a CMRR greater than 36. Of the 12 "Sometimes Stable" cases, 8 occurred where the CMRR was less than 46. Where the CMRR was greater than 56, every case was "Always Stable."

The multi-variate 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 CMRR>38, only 2 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:

$$\text{CMRR} = 40.9 + (H/100) \qquad (2)$$

Figure 4 plots the CMRR against the depth of cover, along with equation (2). The most likely explanation for 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).

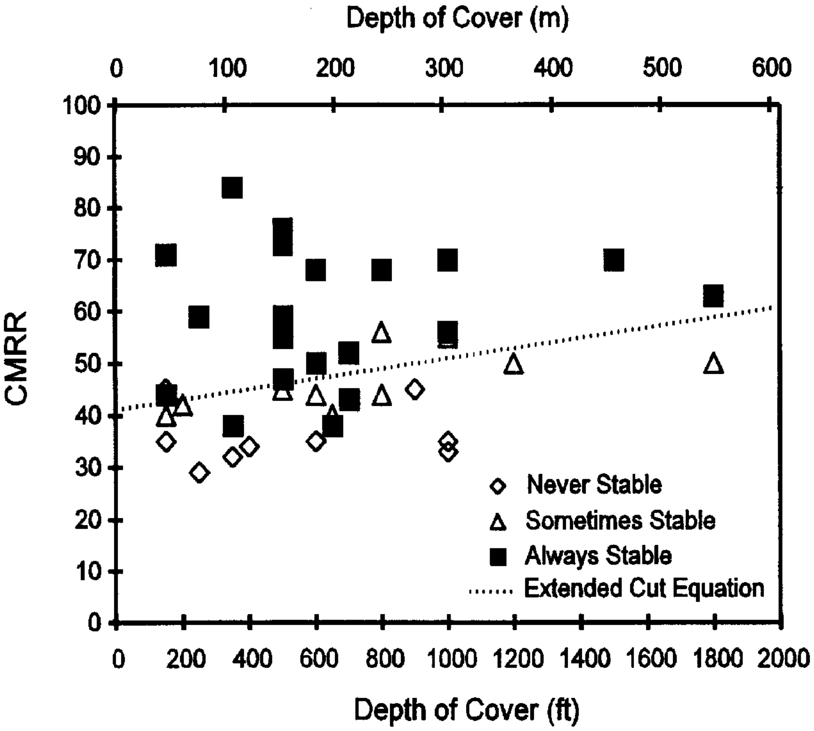

Figure 4. Relationship Between CMRR and Depth of Cover for Extended Cut Data Set.

Table I. Extended Cuts at U.S. Coal Mines

State	Coal Seam	Entry width (ft)	CMRR	Cut Depth (ft)	Cover (ft)	Cut Status[1]
AL	Blue Creek	20.5	70	30	1000	1
AL	Blue Creek	20.3	50	25	1800	2
AL	Mary Lee	21.1	56	35	500	1
IL	Herrin No. 6	15.5	38	30	650	1
IL	Herrin No. 6	18	71	40	150	1
IL	Herrin No. 6	24	86	40	350	1
IL	Herrin No. 6	16.5	38	35	650	2
IL	Herrin No. 6	18	45	40	150	3
IL	Herrin No. 6	16	33	20	350	3
IL	Springfield No. 5	19.5	50	40	600	1
IN	Springfield No. 5	18.8	59	40	250	1
IN	Springfield No. 5	18.8	29	15	250	3
KY	Cedar Grove	18.5	50	40	600	1
KY	Harlan	18	63	40	1800	1
KY	Kentucky No. 11	17.2	42		200	2
KY	Kentucky No. 11	18.3	33	14	1000	3
KY	Kentucky No. 9	17.5	44	40	150	1
KY	Kentucky No. 9	19.1	38	30	350	1
KY	Kentucky No. 9	20	38	36	350	2
KY	Kentucky No. 9	17.5	35	20	150	3
KY	Kentucky No. 9	18	35	17	1000	3
KY	Pond Fork	19	55	30	500	1
KY	Pond Fork	18	45	30	900	3
OH	Freeport (L)	19.5	68	40	600	1
OH	Freeport (L)	19.5	44	20	600	3
PA	Kittanning (L)	17	47	40	500	1
PA	Kittanning (L)	20	50	30	600	1
PA	Kittanning (L)	17	45	40	500	2
PA	Kittanning (L)	14	35	15	600	3
PA	Pittsburgh	16.5	40	30	650	2
PA	Pittsburgh	17	40	30	150	2
PA	Sewickley	18.5	44	30	800	2
UT	"""D"""	20	55		1000	2
UT	Hiawatha	20	70	40	1500	1
WV	Coalburg	18.5	73	40	500	1
WV	Coalburg	20	76	40	500	1
WV	Dorothy	18.5	59	40	500	1
WV	Eagle	17.7	56	37	1000	1
WV	Eagle	20.1	68	40	800	1
WV	Eagle	20.1	56	40	800	2
WV	Eagle	17.7	35	10	1000	3
WV	Pocahontas No. 3	18	50	25	1200	2
WV	Powellton	18.5	34	17	400	3
WY	Hanna	18.3	43	40	700	1

[1] Extended Cut Status: 1=Always Stable 2=Sometimes Stable 3=Never Stable

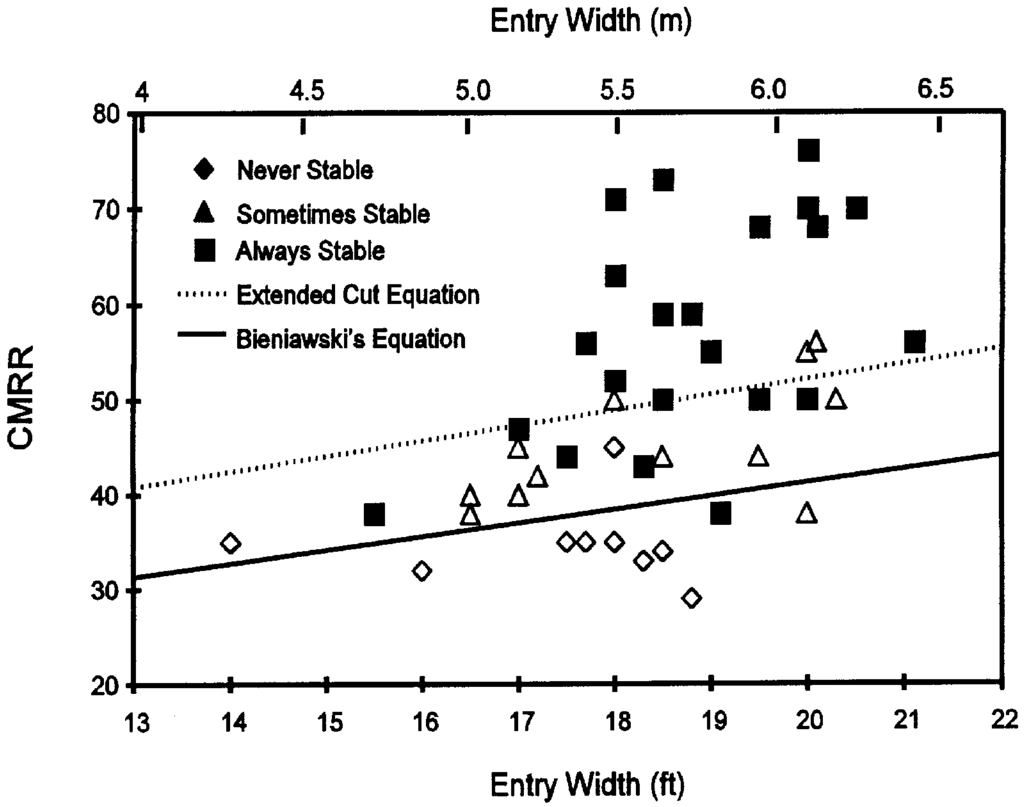

Figure 5. Relationship Between CMRR and Entry Width for Extended Cut Data Set.

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) was equation 3 (85% overall accuracy, 7 misclassifications):

$$CMRR = 19.2 + 1.64\ W_e \qquad (3)$$

Note that this equation is very similar to the one calculated from Bieniawski's data (equation 1), which is also plotted on figure 5. There is a difference of about 6 CMRR points in the intercept because equation (3) separates the "Sometimes Stable" from the "Always Stable" groups, while equation (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 was:

$$CMRR = 18.6 + (H/100) + (1.2\ W_e) \qquad (4)$$

CONCLUSIONS

The study confirmed that the stability of extended cuts is determined primarily by the roof quality, as measured by the CMRR. The entry width and the depth of cover are secondary factors.

The results provide some simple guidelines for predicting the performance of extended cuts. When the CMRR is less than 38, it is unlikely that extended cuts will be feasible. When the CMRR is above 55, 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 the when problems are likely to be encountered.

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