PRACTICAL EXPERIENCES WITH APPLICATION OF THE COAL MINE ROOF RATING (CMRR) IN AUSTRALIAN COAL MINES

By David Hill[1]

ABSTRACT

The Australian underground coal mining industry has made extensive use of the Coal Mine Roof Rating (CMRR) classification system for a diverse range of purposes in recent years. These include mining method selection, and coal pillar and roof support design. This paper outlines a series of case histories, from large-scale feasibility studies to local support design investigations, that collectively illustrate the broad applicability, advantages, and usefulness of the methodology, as well as some of the current limitations.

The key role of the CMRR in an overall hazard definition methodology is demonstrated for a major Australian project, and some ideas with regard to the future application of the CMRR, in the context of geotechnical risk management within a progressive, highly productive extractive industry, are put forward.

BACKGROUND

The Coal Mine Roof Rating (CMRR) is a measure of roof quality or structural competency for bedded roof types typical of underground coal mines. The CMRR was developed by the former U.S. Bureau of Mines (of which the health and safety research component was transferred to NIOSH) and has been widely applied in Australia since the mid-1990s. It was derived from the South African Council for Scientific and Industrial Research's Rock Mass Rating (RMR) system, which has been used in the mining and tunneling industries for over 30 years [Bieniawski 1974].

The CMRR was initially based on field observations at surface highwalls and portals, as well as underground air crossings and roof falls [Molinda and Mark 1994]. Later, a methodology was developed for assessing the CMRR from drill core, to assist where underground exposures were limited or unavailable [Mark and Molinda 1996]. The system was revised in 2003 to incorporate experiences gained since 1994 [Mark and Molinda 2003].

The CMRR considers the following factors:

- Thickness of the individual roof beds
- Shear strength properties of the bedding/planes of weakness
- Compressive strength of the rock material
- Moisture sensitivity of the rock material
- Number of different units (i.e., the degree of homogeneity of the roof)
- Presence of groundwater
- Presence of a particularly strong bed or weaker overlying beds

Essentially, the CMRR is calculated by deriving unit ratings for individual geotechnical units and then determining a weighted average for the bolted horizon. The CMRR is therefore specific to roof bolt length and can change, for example, if the bolt length is increased to anchor into an overlying relatively competent horizon or if a particularly incompetent unit in the immediate roof is cut down during drivage. Unit ratings can range from 0 to 100; the typical range encountered in Australia is 15–70.

Molinda and Mark [1994] suggest the following categorization of roof competency:

CMRR < 45	Weak roof
CMRR = 45–65	Moderate roof
CMRR > 65	Strong roof

At the time of the original U.S. research, 75% of the data fell into the "weak" or "moderate" categories, with an average CMRR of around 53. By contrast, Australian coal industry research in the late 1990s indicated a lower average CMRR for longwall mines of 50, with 86% of the data falling into the "weak" or "moderate" categories [Colwell 1998]. The issue of typically lower roof competencies in Australia will be explored later in this paper.

POSITIVE ASPECTS OF THE CMRR

With particular regard to the underground coal mining geotechnical environment, the CMRR system is considered to incorporate a number of positive technical features and to offer the rock mechanics engineer several practical advantages over alternative approaches.

The major positive technical aspect is that the CMRR system focuses on characterizing the structural competency of a bedded, sedimentary rock mass and effectively its propensity for deformation due to buckling under the action of horizontal stress, noting that in Australian collieries, this is the main cause of roof deterioration (see Figure 1). The propensity for roof buckling is a function of the excavation span, bed thickness, and the material stiffness properties. A roof that remains intact, without any

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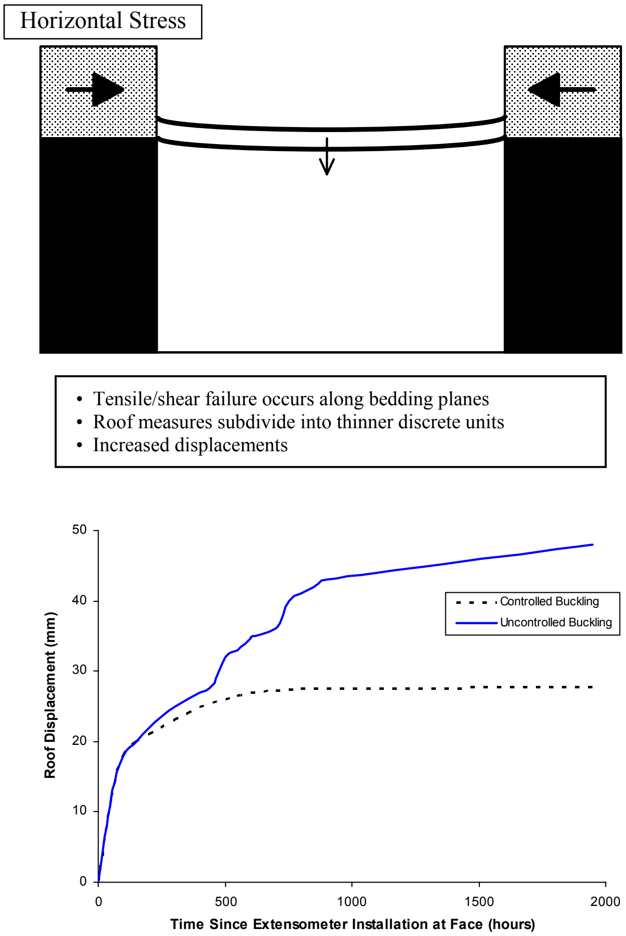

- Tensile/shear failure occurs along bedding planes
- Roof measures subdivide into thinner discrete units
- Increased displacements

Figure 1.—Schematic of roof buckling under the action of horizontal stress and typical roof displacement data.

appreciable delamination under the action of horizontal stress, can be referred to as "static."

The CMRR drill core methodology typically ascribes approximately two-thirds of the overall rating to the discontinuity rating, which is related directly to bed thickness and the potential for delamination (i.e., reducing bed thickness). This discontinuity rating is defined as the lower of two parameters: the discontinuity spacing rating (defined from RQD and/or the fracture spacing) and the diametral point load test (PLT) rating. The diametral point load testing aids in identifying a material that is prone to delamination (e.g., fissile), which may be otherwise unbroken in the core tray. The relatively humble diametral PLT on vertically orientated core is highly relevant to assessing the potential for roof buckling due to horizontal stress.

The practical advantages of the CMRR relate very largely to its widespread application and the extensive databases that link the parameter to a range of mining situations (i.e., the CMRR is used as a primary input in a number of coal pillar and roof support design scenarios). Over the last decade, the CMRR has effectively become a common universal language for engineering geologists and geotechnical engineers operating in the U.S. and Australian coal industries. This has come about by a process of technology transfer, which has been particularly aided by the emphasis on the part of NIOSH on publishing associated research outcomes, including the underpinning databases. This availability and transparency of data has enabled other practitioners to interrogate the empirical findings and rapidly develop experience and confidence in the associated applications. As with all empirical methodologies, understanding the limitations and nature of the underpinning database is vital. Extrapolating technical findings, such as regression relationships, beyond the limits of a database can be highly problematic, requiring both caution and wisdom.

In practice, engineers have been able to take published research outcomes, derive their own local data, and interrogate that data in the context of the published work. This aids in understanding the local situation, including the extent to which local circumstances may vary from those previously encountered elsewhere, with associated caveats on the confidence that can be placed in the analysis.

The position of the CMRR within the coal industry has become akin to that of Microsoft Windows within the software industry—there may be a better commonly available and applicable operating system, but the CMRR has become entrenched. Furthermore, as the use of the CMRR spreads, the barriers to entry of alternative methodologies increase at a disproportionate rate. In the medium term (the next 10 years), it considered highly unlikely that the CMRR will be displaced by any new innovation. A more likely outcome is that current technical initiatives will develop "calibrations" with the CMRR, such that the latter remains the lingua franca.

CURRENT ISSUES WITH USING THE CMRR

A number of issues associated with using the CMRR warrant mention, as they can influence the technical result and associated design outcomes.

Methodology Aspects

Firstly and probably most significantly, it should be noted that the three published and accepted methodologies (i.e., the original exposure observation method, the initial drill core method, and the revised drill core procedures) can yield very different outcomes in specific circumstances. An extreme example is the massive conglomerate roof that is typical of the Great Northern Seam in the Lake Macquarie (Newcastle Coalfield) area of New South Wales. The original observation method would be guided by the general lack of discontinuities within the unit and would produce a rating of around 90. By contrast, both the original and revised drill core procedures would recognize the moderate strength of the material (commonly ≤60 MPa and controlled by the nature of the cementation of the matrix between the pebbles), resulting in a typical unit rating of 60–65. In practice, the Teralba Conglomerate will typically span ≥50 m practically indefinitely, unsupported and with localized skin failures only.

In this case, the variance in the CMRR has no appreciable operational impact, as in the prevailing geotechnical environment (and in an Australian regulatory framework), even a CMRR of 60 will result in effectively minimum design outcomes (i.e., in this case, it does not particularly matter if the roof is better than suggested by a CMRR of 60). However, it does have negative implications in that it can reduce confidence in the reliability of the technique and hinder effective communication (i.e., it is unhelpful to categorize a unit as "moderate" if, for all practical purposes, it behaves as "strong"). Furthermore, the variance would be operationally significant if the CMRR were to be used as a guide to cavability, in which case vastly different expectations would tend to be associated with a CMRR of 60 as opposed to 90.

Also, the old and current drill core methods tend to produce different outcomes. The current method is considered an overall improvement in that it more systematically accounts for the influence of bedding and jointing, such that structurally affected areas are less likely to be overrated (essentially, the original method defaulted to the diametral PLT strength rating and ignored the discontinuity rating). However, in the current system, the maximum discontinuity spacing rating has been downgraded significantly from 70 to 48 (22 points). This tends to reduce the significance in the rating system of thickly bedded/massive sandstones and conglomerates, such that more conservative results are obtained.

Obviously, such a major change in a rating system requires careful consideration, as these systems are only useful in the context of their derived databases. Adjusting the input to these databases necessarily alters the outcomes in terms of the relationships between parameters and the derived equations. The impact of the changes is reduced in this case by the fact that the underpinning NIOSH CMRR databases are derived very largely from underground observations as opposed to drill core.

In fact, the use of the CMRR in the United States is understood to be based largely on underground observations, whereas in Australia the drill core method is most commonly applied. This change in emphasis also needs to be understood, as it materially impacts the way in which the CMRR is applied. As an example, a number of major Australian coal projects have used the CMRR to investigate spatial variations in roof competency across resource areas in recent years, which is only viable given the availability of adequate exploration borehole data.

Since the revision of the drill core method in 2003, Strata Engineering has on several occasions cross-checked the results obtained using the various published procedures. An example is illustrated in Figure 2, which summarizes the outcomes of a CMRR survey based on 30 drill cores across the resource area for a major longwall project in New South Wales. The following comments are made with regard to the results:

1. On average, the CMRR values obtained using the revised procedure were reduced by 10% compared to those obtained using the old drill core method (i.e., a slightly more conservative result was generally obtained).
2. 50% of the data points varied within only ±10%.
3. The percentage variation trend line crossed zero at a CMRR value of 45, which, as noted, marks the category transition from "weak" to "moderate" roof. Practically, the revised procedure tended to have limited overall effect for CMRR values of <55.
4. A variation of >20% was only noted in two circumstances. Firstly, in fault-affected areas, the revised procedure was more sensitive to jointing, with reduced CMRR values (note the three outlying data points in Figure 2). This was considered an improved, more realistic outcome. Secondly, the impact of reducing the maximum discontinuity rating from 70 to 48 was most pronounced in cases where the original methodology would generate particularly high CMRR values (>65).

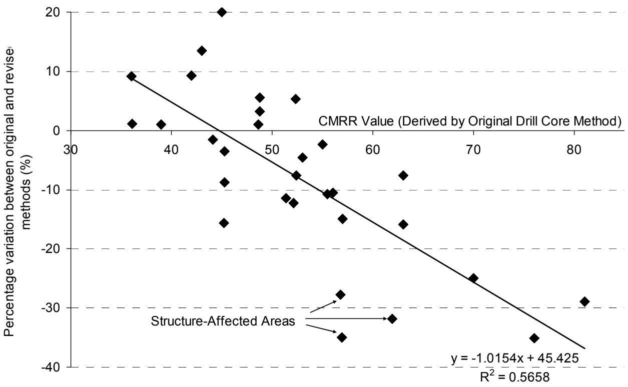

Figure 2.—Example of the effect of the revision to CMRR drill core procedures.

Other surveys and comparisons have produced similar results, although it is common to find that there is still some reduction in the unit ratings between the old and current methodologies, even in the CMRR<40 range. In practice, experience suggests that it is virtually impossible to obtain a CMRR of >70 with the revised drill core procedure.

It is important to note that that the great bulk of the Australian coal mining industry is currently operating at CMRRs of 35–55. This is the area of greatest significance for mine design and operational practice. It is also the zone of closest agreement between the various CMRR procedures, such that the impact of any discrepancies is reduced. Also, Australian experience suggests that roof behavior tends to become generally benign and insensitive to CMRR fluctuations at values of ≥55 (i.e., these values tend to be associated with static roof behavior, which is essentially self-supporting and the most stable roof condition attainable). Therefore, the disparities between the CMRR methodologies in stronger roof types tend to have minimal practical consequence.

Overall, the variances are currently tolerated, given that the modified procedures tend to be more conservative (in the case of areas of geological structure, appropriately so). However, in a different geotechnical environment or industry, the discrepancies could potentially be of more concern.

Coal Roof

Approximately 50% of the Australian longwall mining industry operates under a roof wholly or at least partly composed of coal. Australian coals tend to be weak, bedded, and cleated (jointed), resulting in low CMRR values (typically 30–40). Nevertheless, in the absence of persistent, weak partings (commonly associated with thin mudstone or tuff bands), these coal roof units tend to perform relatively well, for example, under tailgate loading conditions. Historically, this has tended to be attributed largely to the low modulus of the material attracting reduced levels of horizontal stress (i.e., a specific gravity of 1.3–1.5, versus typically 2.5 for adjacent strata).

As a consequence, it has become common to apply adjustment factors to coal ratings. Although there is no generally agreed adjustment process, these adjustment factors typically range up to an additional 20% of the raw rating, depending on the extent to which the unit is clean (i.e., the prevalence of thin "dirt" bands), as well as the practical experiences of mining under the given roof type.

Human Error

Although the CMRR is considered a relatively straightforward and uncomplicated system of rock mass classification, the potential for human error remains. A common error is the failure to distinguish between geological and geotechnical units. This is particularly true for gradational roof types (e.g., dark gray mudstone grading upward into gray siltstone, or bands of fine alternating with medium-grained sandstone). It is common for a roof material that visually is reasonably uniform to be logged by a geologist as a single lithological unit, whereas in practice the structural competency of the unit can vary markedly. This is especially true over short distances directly relevant to ground behavior (i.e., the first 2 m of roof). Unless the individual conducting the geotechnical logging is aware of the need to gather sufficient detail to define the homogeneity of a particular unit, valuable information can be lost.

When using the drill core method in the absence of visibly distinct roof units, PLTs (diametral plus axial) at a maximum of a 0.5-m spacing in the bolted interval will normally generate sufficient data to enable a reasonable analysis. Evaluation of a combined RQD, fracture spacing, and PLT data set then often facilitates subdivision of preliminary roof units, producing a more meaningful overall CMRR outcome.

Horizontal Stress

A common feature of the Australian coal mining geotechnical environment is a level of horizontal stress that is much higher than the vertical, often with appreciable stress anisotropy. Major principal horizontal stresses two to four times the vertical stress are typical, along with minor horizontal stresses one to three times the vertical. Elevated horizontal stress magnitudes and stress field rotation can be associated with major geological structures, such as reverse faults. The stress regime often manifests itself in roof behavior that is strongly directionally dependent (i.e., an unfavorable roadway orientation with respect to the major horizontal stress is frequently associated with increased roof displacement).

The relatively high levels of horizontal stress are a cause for prudence in applying any empirical relationships involving the CMRR and parameters related to stress (e.g., depth) derived from the U.S. coal mining industry, which does not seem to experience the phenomena described previously (at least not to the same degree).

An example is the use of the CMRR as a guide to the probability of stability of extended cuts (i.e., temporarily unsupported heading lengths of greater than 6 m) in "cut-and-flit" (place-changing) development operations, based on U.S. research [Mark 1999]. There are at least two known Australian cases of the failure of extended-cut drivage systems in strongly anisotropic horizontal stress fields due to instability of the unsupported cut in the unfavorable roadway direction.

USE OF THE CMRR IN AUSTRALIA: PRACTICAL EXAMPLES

Drivage Method Selection

Following directly from the comments made in the "Horizontal Stress" section above, it is useful to consider the Australian experience of cut-and-flit mining in the context of the overall knowledge base. The relationship between the CMRR, depth, and stability of extended cuts taken during cut-and-flit operations is shown in Figure 3 [Mark 1999], together with the Australian data.

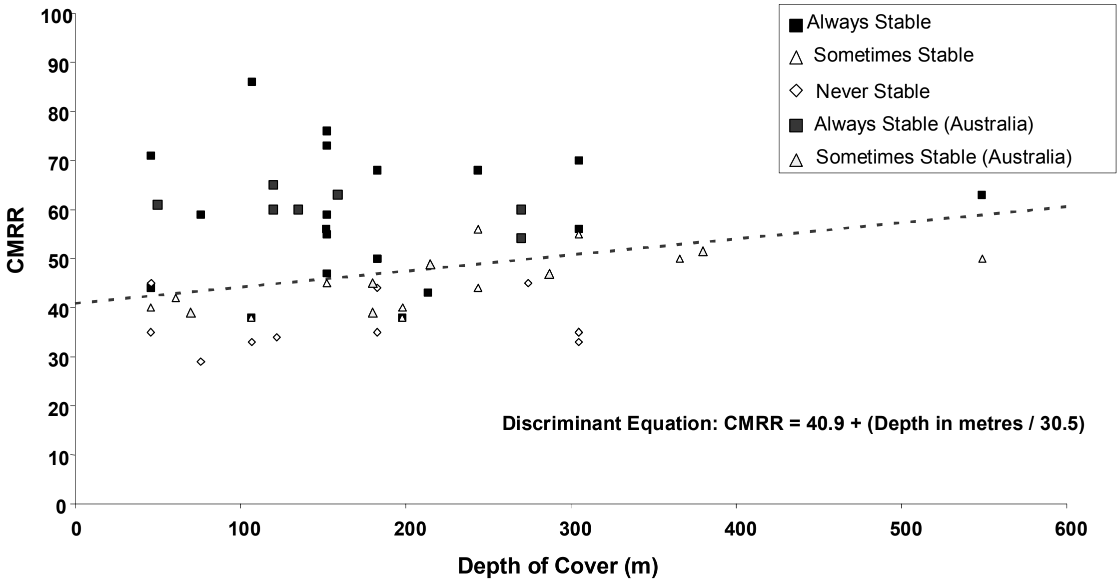

Figure 3.—CMRR extended-cut database.

The U.S. database derives from a survey of place-changing operations requesting mine operators to rank their experiences with regard to extended-cut stability. Also shown in Figure 3 is the discriminant equation trend line derived by Mark [1999], which is the line that best splits the "always stable" from the "sometimes stable/never stable" cases.

The line of the discriminant equation is given by

$$CMRR = 40.9 + H/30.5 \tag{1}$$

where H is the depth of cover (m).

Effectively, the higher the CMRR, the more likely place-changing is to be a success and the more likely the roof is to retain static behavior, depending in part on depth of cover (and the associated levels of in situ stress).

The following comments are made with regard to Figure 3:

1. It is evident that Australian cut-and-flit experience is generally consistent with that of the United States in terms of the distribution of the data with respect to the discriminant equation.
2. The Australian "always stable" cases are characterized by CMRRs of >50 and depths of <300 m.
3. The transition from "always" to "sometimes stable" is commonly marked by a progressive increase in the severity of skin failure (i.e., detachment of the first 0.5 m of roof in the unsupported cut, often associated with a bed with a low unit rating in the immediate roof), as opposed to massive roof failure.
4. The "sometimes stable" Australian case at a 380-m depth was characterized by directionally dependent roof behavior.
5. The two "sometimes stable" Australian cases involving CMRRs of 39 both involved a coal roof.

The CMRR extended-cut relationship has been used, in conjunction with cover depth data, to delineate areas of potential cut-and-flit development as part of the planning process for new mines. However, cut-and-flit has never been the preferred method of gate road drivage in Australia, and the use of this process has declined since the 1990s.

More recently, the CMRR extended-cut relationship has been used as a guide as to the likely transition point from static to buckling roof behavior when using conventional cut-and-bolt (or "in-place") drivage techniques. This transition point is associated with a marked increase in roof support requirements and a need to restrict the unsupported span at the face, which even with conventional development can vary between 2 and 15 m, depending on the configuration of the miner bolter.

Therefore, although a mine may not be contemplating using cut-and-flit, use can be made of the fact that the successful application of this technique depends on the roof behaving in a largely self-supporting fashion (such that cuts >6 m will tend to stand unsupported, often for extended periods prior to bolting). This has ramifications for continuous miner selection, particularly regarding the distance from the face at which bolts are installed.

Roof Characterization

The support system designer is required to have an appreciation of expected ground conditions in an area to be mined, as well as the likely range of ground conditions (e.g., the propensity for zones of poor roof). In this regard, characterization of likely roof competency at the planning stage, backed up with hazard mapping during subsequent mine development, are key components of the strata management process.

New projects place increased emphasis on mapping roof competency using drill core data and, in particular, the CMRR. The information generated is usually combined with the available knowledge of the in situ stresses and geological structure in the area of interest to arrive at initial estimates of ground conditions and likely associated ground support needs. At the operational stage, this information is combined with mapping of geological structure and roof behavior to produce composite hazard plans, which are progressively extrapolated into adjacent mining areas.

Increasingly, the focus of these activities is not on drawing copious "lines on plans," but on producing color-coded hazard information (e.g., green – yellow – red) that can be readily assimilated by mining personnel.

An example of CMRR contouring for planning purposes is shown in Figure 4. This particular plan is based on 50 CMRR results from an area of approximately 16 km^2 (an exploration borehole spacing of around 500 m). Subsequent mining has borne out the general strength trends depicted in the example.

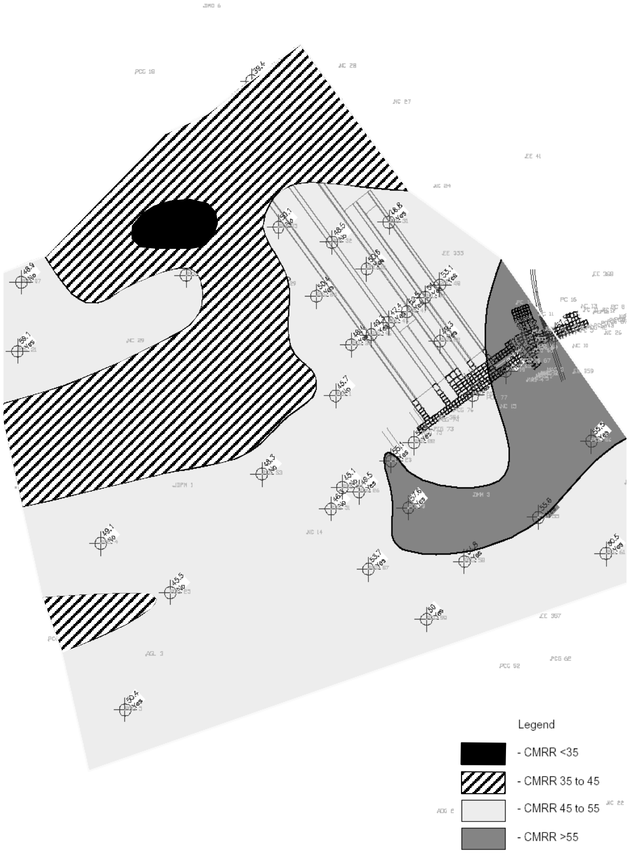

Figure 4.—Example of CMRR contouring.

From Australian experience, the following refinement of the CMRR classification is considered appropriate. This particularly focuses on the CMRR 35–55 rating zone, which is of most practical interest:

CMRR < 35	Very weak roof
CMRR ≥ 35, but < 45	Weak roof
CMRR ≥ 45, but < 55	Moderate roof
CMRR ≥ 55, but < 65	Strong roof
CMRR ≥ 65	Very strong roof

It is understood that less success has been had in the United States regarding the development of spatial trends of roof strength, although the exercises known to date [Mark et al. 2004] have involved significantly greater borehole spacings (i.e., typically >2 km).

The successful application of this technique in Australia in recent years has generally been based on the following:

1. Exploration borehole spacings of ≤ 500 m.
2. Drawing interpretations also from complementary geological data sets (e.g., structure and sedimentology information).
3. Adoption of a pragmatic approach as to the quality of the information generated versus practical project needs.
4. An example of the interpretation of a CMRR data set is given in Figure 5. Although there is no overall trend linking the CMRR to depth, if the northwestern area (bounded by a seam convergence zone and characterized by a distinct thickening of the seam) is isolated, then it is apparent that over the major part of the resource area, roof quality improves gradually with depth. Within this area, it is not necessary or appropriate to attempt to define the CMRR to two decimal places for a given depth; it is enough to be aware that very weak roof can be expected at depths of <150 m, with weak/moderate roof at greater depths.

Spatial trends for the CMRR can be used in conjunction with other relevant information and parameters (e.g., structural and sedimentology data, depth, and drivage orientation with respect to the major horizontal stress) to produce preliminary hazard plans. The plans are then progressively refined as actual mining information becomes available. An example of a preliminary hazard plan for a major mining project is shown in Figure 6.

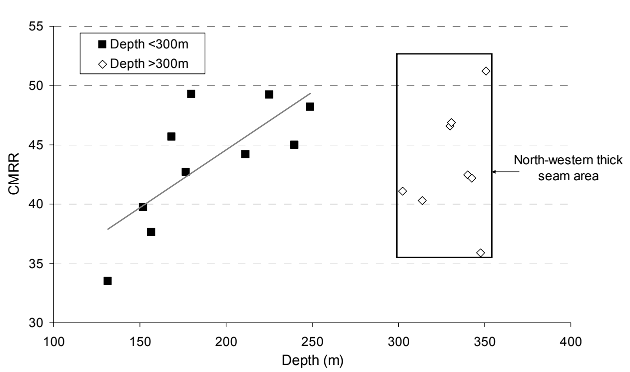

Figure 5.—Example of spatial trends from a CMRR data set.

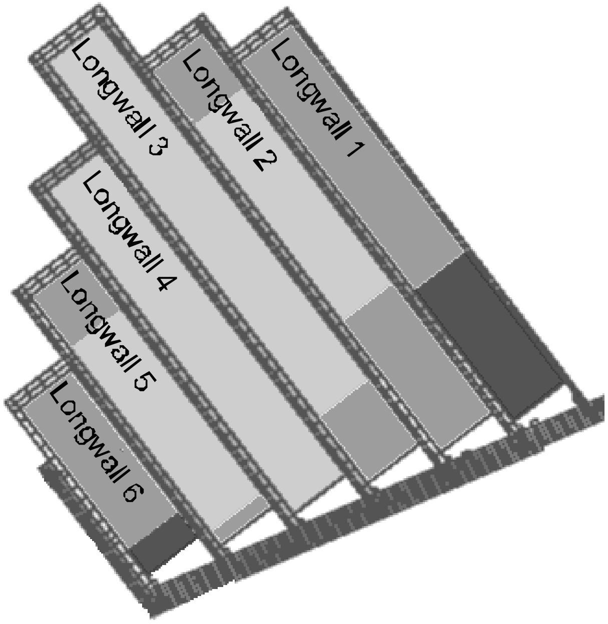

Figure 6.—Preliminary hazard plan for a major mining project.

Design Optimization

Information regarding spatial trends of the CMRR has been used in a number of recent Australian projects to optimize the design of the layout and/or ground support system. An example is tapered longwall chain pillars (Figure 7), which were first used at the South Bulga Mine in New South Wales in 2001. A tapered pillar design is feasible wherever the mining layout is unconstrained by existing development and there is a reasonably consistent change in one or more variables, such as the CMRR or depth, from one end of a panel to the other. The dimensions of the longwall block itself do not change, such that the panel will be rotated by a fractional amount (the "splay" angle is typically <1°, which is practically imperceptible underground). Gate road drivage savings of several kilometers have been achieved by optimizing pillars widths using this approach.

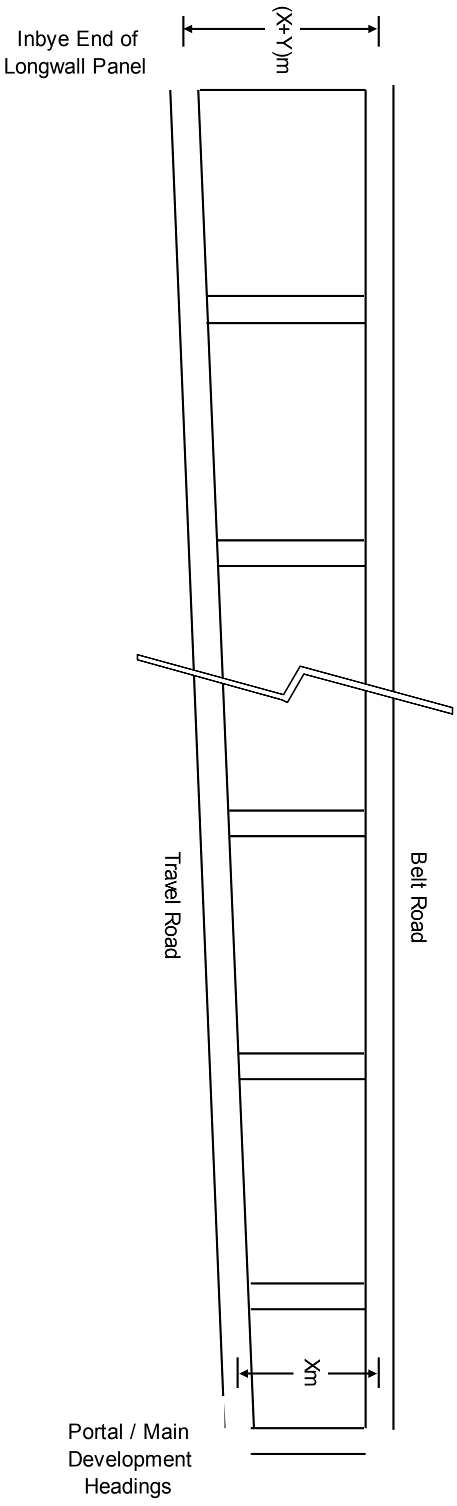

Figure 7.—Splayed chain pillar concept.

CONCLUDING REMARKS

A number of applications of the CMRR in Australia have been outlined. Although the CMRR is not considered a perfect rock mass classification system (several current issues have been highlighted), it is generally well suited to the Australian coal mine geotechnical environment and practical ground control issues facing the industry. Accordingly, the CMRR is increasingly accepted and its applications continue to extend, such that the scope and potential for the use of alternative systems is restricted.

It should not be implied, however, that the CMRR is used exclusively. There are several technical areas, mainly in the design of ground support, in which the CMRR and its associated empirical relationships are very commonly used in conjunction with other methodologies, including alternative rock mass classification schemes (specifically, Q and RMR), as well as numerical, analytical, and experiential approaches. This is most evident at the feasibility stage of a mining project. In the absence of meaningful local experience, design outcomes pertaining to alternative methodologies are often compared and cross-checked; inconsistencies can then be scrutinized.

It is expected that, in Australia at least, there will be an increasing focus on the use of the CMRR for defining spatial roof strength trends across resource areas, as this is an area in which the geotechnical engineer can add considerable value to a mining project, provided that the data are used rationally.

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