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Rapid Rating Using Coal Mine Roof Rating to Provide Rapid Mine Roof Characterisation from Exploration Drilling

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RAPID RATING USING COAL MINE ROOF RATING TO PROVIDE RAPID MINE ROOF CHARACTERISATION FROM EXPLORATION DRILLING

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ABSTRACT: The Australian coal industry is currently experiencing rapid expansion with many companies fast tracking the development of new mines. In many cases, operators are collecting large quantities of exploration drilling data for pre-feasibility and feasibility studies as well as for operational start-up and mine expansion.

"Rapid Rating" is a new method for calculating the Coal Mine Roof Rating (CMRR). It has been designed to allow large quantities of exploration data to be processed quickly to provide a standardised indicator of geotechnical conditions. It is intended to make CMRR more readily available to mine operators. When the CMRR was first developed there was less core drilling conducted in the USA than is conducted in Australia today. So it was specifically designed to allow geotechnical information to be collected easily in the absence of core data. It was then modified to allow calculation from core. The method for calculating CMRR required a geologist to collect the inputs manually, and this may take between 1 – 4 hrs. The need to assess large quantities of drill core in very short time frames has only emerged relatively recently, and "Rapid Rating" has been developed to meet this need. "Rapid Rating" can calculate a CMRR from between 40 minutes and 5 minutes for a large data set. It can calculate CMRR over numerous possible bolt lengths for sensitivity studies on different bolting horizons and during the early stages of mine design when bolt length is still a variable. The "Rapid Rating" calculation method is automated which makes the results more repeatable and less subjective. The "Rapid Rating" system, is described, which explores the benefits and limitations of this technique for mine design and strata management.

WHAT IS CMRR

The Coal Mine Roof Rating is an empirical method for quantifying the engineering properties of mine roof. The CMRR (Mark and Molinda, 1994) weighs some of the geotechnical factors which may affect the competence of mine roof and combines them into a single rating on a scale from 0 to 100.

Rock mass classification systems (such as Bieniawski's "RMR" and Barton's "Q") have been used for many years in geotechnical engineering. These systems were not developed specifically for coal mine roofs and thus are less applicable to stratified layers (as a result of sedimentary geology). The bedding of coal mine roof is often an important parameter on the competence of the roof.

The RMR and Q systems tend to focus on the properties of joints rather than horizontal bedding. They also rate one unit at a time, whilst coal mine roofs typically consist of several layers. The CMRR has been developed specifically for coal mines based on a database from nearly 100 mines in every major coal field in the USA.

The CMRR makes it possible to compare ground control experience from different mines, coalfields, and countries. This makes it possible to collect a large database of case histories which can then be used to assist in the development of ground control strategies.

The CMRR can be calculated from roof rock exposures such as highwalls and overcasts or from exploration drill core. Colwell, 2003, describes the procedure to be used to calculate CMRR in Australia. The input parameters which are used to calculate CMRR from core are listed below with their approximate weighting (vary considerably depending on specific geology):

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- 70 % fracture spacing – the spacing of discontinuities such as bedding planes, joints and faults;
- 30 % UCS – uniaxial compressive strength of the intact rock;
- -20 % weak bedding planes – the number of weak bedding planes between units;
- -10 % moisture sensitivity – the propensity of the rock to degrade upon exposure to water;
- -20 % groundwater – the quantity of water flowing into workings;
- -5 % overlying weak rock – the presence of much weaker rock overlying the immediate roof.

While rock mass classification schemes such as the CMRR are appropriate for their original application, particularly within the limits of the case studies from which they were developed, considerable caution must be exercised when applying rock mass classifications to other rock engineering problems, or to cases which lie outside the database.

It is important to remember that CMRR is a Rock Mass Strength indicator as opposed to a Rock Mass Stability indicator. When using CMRR in determining mine or support design many other factors need to be considered in combination with CMRR to determine design specifications. The CMRR does not take into account pre-existing or mining induced stresses. It does not include mining geometry such as roadway span or orientation of workings. It does not include roof support. It does not include rib conditions. As such it should not be used on its own for the purpose of geotechnical design (e.g. roof support, roadway spans, cut-out distances, pillar design etc). Empirical design systems such as ALTSII, use CMRR to determine design parameters but do not rely solely on CMRR. They also include additional input factors such as stress and geometry in in the process.

METHODS OF CALCULATING CMRR

CMRR can be calculated from drill core or from roof rock exposures such as highwalls and overcasts. There are currently three methods which can be used to calculate CMRR from drill core.

Standard Method

This is the most comprehensive and time consuming method for calculating CMRR. The Geologist or Engineer inspects the core and divides it into units which have similar geotechnical properties such as uniaxial compressive strength, bedding and discontinuities. The properties of each unit are determined including fracture spacing, RQD, diametral point load testing, uniaxial compressive strength from rock testing or axial point load testing or sonic log, moisture sensitivity, weak unit contacts, and the presence of overlying weak rock. The units and their properties are then entered into the CMRR spreadsheet (provided with Colwell, 2003 or from NIOSH www.cdc.gov/niosh/mining/topics/ groundcontrol/groundcontrol.htm) and the individual unit ratings and overall CMRR is calculated. Each CMRR calculation is done separately. The CMRR data is collected and entered manually. This is the best method to use when drill core needs to be assessed on a relatively infrequent basis, or only a small number calculations need to be made at one time. The calculation can only be done on a maximum of five separate units which tends to limit the CMRR calculation to a 2 m length of core.

Rapid Rating

This is the quickest and most efficient method of calculating CMRR values on large quantities of drilling data. The geological data, comprising the digital Lithology log fracture log, geophysical logs, core photos, and rock testing results is imported into the Rapid Rating Program. The Rapid Rating program analyses the data to automatically create geotechnical unit and calculate their properties, the unit ratings and the CMRR. The logic and calculations used by Rapid Rating are exactly the same as those in the Colwell spreadsheet (Colwell 2003). The CMRR data used is the normal geological data collected for each drill core so the core does not need to be inspected or tested separately to calculate CMRR. The data for many holes is imported and CMRR is calculated at the same time, and without separate calculation. Calculating CMRR on a set of geological data using Rapid Rating requires a standard setup time for each data set, and the processing time is similar whether there are 10 or 20 holes. Each CMRR can in theory have an infinite number of units and an infinite length although there are practical/geotechnical limitations to the number of units and CMRR length which can be used.

Hole Log Unit Rating

This is the quickest method of calculating unit ratings (rather than CMRRs – as the unit ratings have to be combined to create a CMRR). A similar approach is used as described above in rapid rating, except that the unit ratings are done on lithological units rather than by identifying discrete geotechnical units. These ratings can be calculated more quickly than the Rapid Rating CMRR and are useful to include on a hole composite log to highlight variations in rock mass strength between lithological units. They cannot be used to calculate full CMRRs and they cannot be compared with other full CMRR results or in the CMRR design tools such as ALTSII or other empirical design approaches which use CMRR values.

RAPID RATING METHODOLOGY

Rapid Rating automates the process of:

- identifying lithological and structural units,
- identifying moisture sensitive units,
- calculating fracture spacing within units,
- calculating average UCS for units,
- identifying weak contacts,
- calculating strong bed adjustments,
- calculating unit ratings, and
- calculating CMRR values.

The Rapid Rating system calculates CMRR as described below:

1. Create UCS Units – Sonic data is imported into the program. Inferred UCS is calculated for each sonic depth. The difference between each UCS value is calculated. The program then analyses the data and identifies where gradient changes in the UCS plot occur and where steep gradients occur. The program identifies patterns in the gradients and picks out bumps. A UCS unit is defined by the start and end of the bump. The program identifies plateau changes, where the UCS steps up or down. In this case the UCS unit is split in the middle of the change section. (See Figure 1).

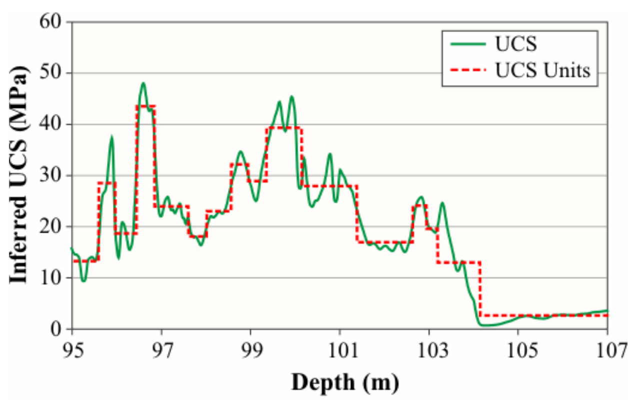

Fig 1: UCS units overlaid on UCS plot.

2. Create Lithology Units – Lithology data is imported into the program. The lithology dictionary is used to convert the data to text. CMRR lithology units are created with a lithological description and are given a moisture sensitivity deduction.
3. Create CMRR units – The program compiles the UCS units and the lithological units. If there are a number of UCS units within one lithological unit, the lithological unit is split up by the UCS units and vice versa. If a UCS unit start or end depth is similar but not exactly the same as a lithological unit, the CMRR will use the UCS unit depth. If a CMRR unit encompasses more than one lithological unit, the description used will be that of the largest lithological component. Units which are 5 cm thick or less are removed and joined to adjacent units. Units which are 15 cm thick or less are removed and joined to adjacent units if the UCS difference is not significant. (See Figure 2).
4. Calculate Average UCS for each CMRR Unit – The program collects the individual UCS values over the length of each CMRR unit and averages them.

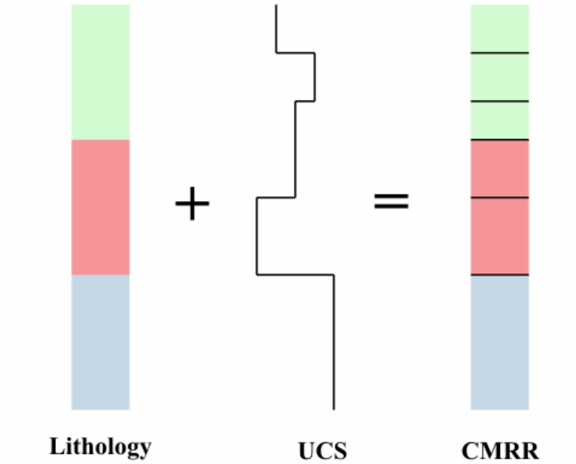

Fig 2: Lithological and UCS units are combined to create CMRR units.

5. Calculate Fracture Spacing, RQD, Diametral Strength – Fracture spacing, RQD and Diametral data is imported into the program. An average depth is calculated for each fracture by averaging the 'from' and 'to' depths. The fracture spacing is calculated at each fracture as the distance between it and the previous fracture. The fracture spacing for each CMRR unit is calculated by averaging the fracture spacings which occur within the CMRR unit. For example the fracture spacing for the unit depicted below would be (FS1+FS2+FS3+FS4)/4. (See Figure 3).

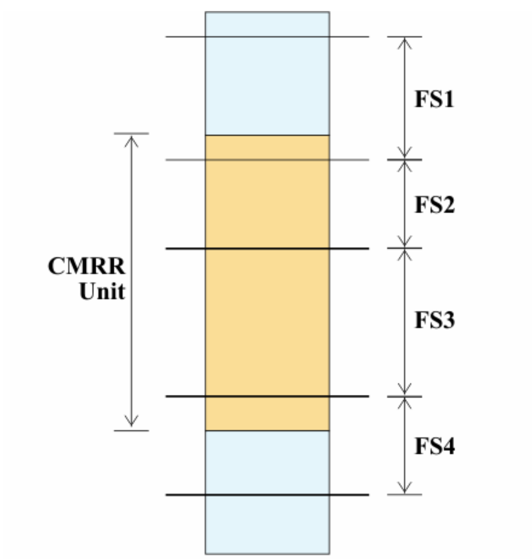

Fig 3: Fracture spacing is the average of the spacings between fractures which occur in the CMRR Unit.

6. The program calculates the UCS rating, Discontinuity Rating and the Unit Rating.
7. The program identifies the location of weak bedding planes where lithological changes occur and one of the two lithologies has some form of potentially "slippery" mineralogy component such as coal, clay, tuff, claystone, mudstone etc.
8. The depths and horizons which CMRR results are required for the input. If groundwater is present, the groundwater adjustment is input. The data is reviewed and surcharge is allocated against the effected horizons.

9. The program calculates the Strong Bed adjustment, weak contacts adjustment and the thickness weighted average rating for each depth and horizon. Then it adds the adjustments, the rating, the groundwater adjustment and the surcharge adjustment to create a CMRR result.

GEOTECHNICAL ASSESSMENT AND DESIGN WITH CMRR

The CMRR is best used as part of a holistic approach to geotechnical characterisation and mine design (see Figure 4). By focusing on collecting and analysing a base level of essential geotechnical data an accurate and reliable set of rock properties can be established. This includes rock testing analysis, fracture data, geophysical log analysis, acoustic scanner structural analysis, borehole breakout stress mapping and composite log analysis. Quality base data will reduce the risks of inappropriate design to operational implementation.

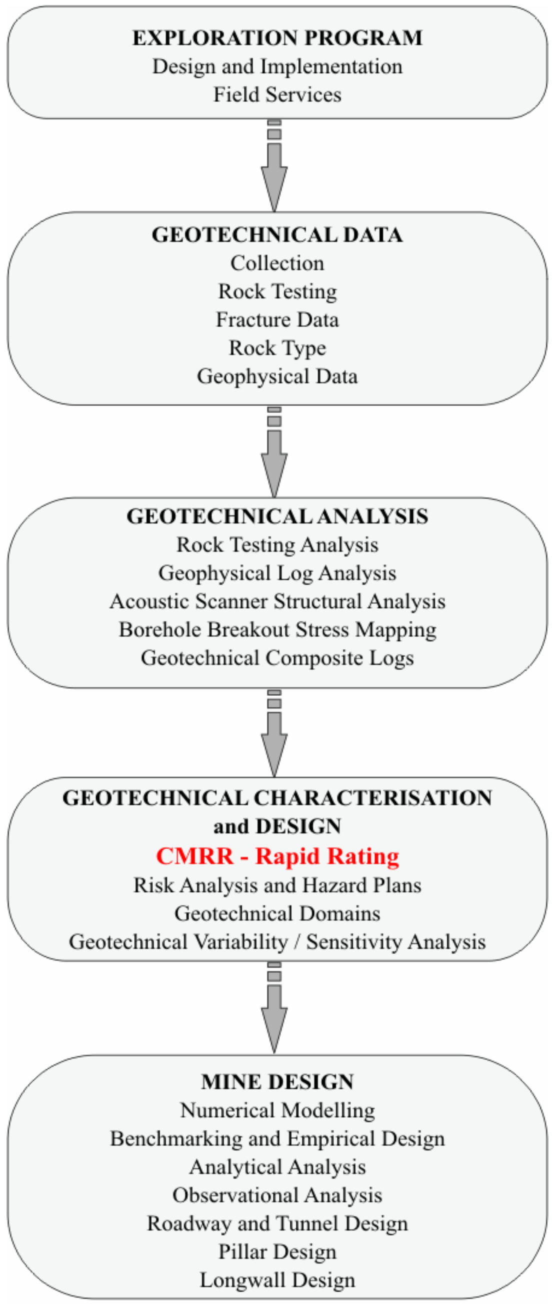

Fig 4: Geotechnical assessment and design with CMRR.

Quality geotechnical data and analysis can then be used to conduct geotechnical characterisation, that is, to calculate CMRR, identify geotechnical domains, conduct geotechnical sensitivity analysis and create hazard plans.

Robust geotechnical characterisation can be utilised in a comprehensive design approach which may include numerical modelling, empirical design and benchmarking, analytical design, and observational analysis. It is preferable to use at least two design approaches together, if possible, as each design tool has its own limitations.

Design is undertaken using a risk based approach which allows the operator to consider a range of potential operational approaches to manage the geotechnical risks whilst taking into account the implications of different approaches.

BENEFITS OF USING CMRR

There are many benefits of using CMRR:

- It allows numerous complex rock properties to be combined into one quantitative rock mass strength indicator in a consistent manner.
- It allows site geology to be displayed simply on a single plan using CMRR contours rather than requiring a number of plans such as uniaxial compressive strength, lithology, rock quality designation (RQD) to be overlaid.
- It allows better communication of geotechnical conditions between geologists and engineers and the workforce in general.
- It can be used to highlight areas of rock mass strength variability and to identify geotechnical domains.
- It can be used to compare ground control experiences between sites and allow benchmarking and empirical design.
- In conjunction with other geotechnical data, it can be used to indicate the potential for extended cuts.
- It can be used in ALTSII (Colwell, Hill, Frith, 2003) in conjunction with other geotechnical data to indicate tailgate standing support requirements.
- It can be used in conjunction with other geotechnical data to indicate primary support requirements.
- It can be used in conjunction with other geotechnical data in Strata Control Management Plans and in trigger response action plans.

RAPID RATING BENEFITS

- Results are generated much faster than the standard method.
- CMRR can be calculated over any horizon and with an unlimited number of units. CMRR can be calculated on numerous bolt lengths and horizons for sensitivity analysis.
- Improved repeatability of a CMRR calculation and reduced human errors.
- CMRR can be calculated from standard exploration data and does not require re-logging.
- Data is imported digitally, not manually entered, reducing double handling and errors.
- The Rapid Rating Program identifies discrete geotechnical units, calculates unit ratings and CMRR values automatically.
- Recalculations can be done quickly and easily.

RAPID RATING LIMITATIONS

The Rapid Rating system is designed to handle large quantities of data, and is not as cost effective to use on a small number of holes (eg. to calculate one 2 m CMRR).

Currently Rapid Rating is not a commercially available software package, which means that calculations using Rapid Rating can only be done by SCT Operations Pty Ltd. It would be quite possible to build a user friendly commercial software package if the need is present in the industry.

Diametral point load testing is not routinely conducted with coring. The benefit of Rapid Rating is that it is quicker and cheaper than the standard method and this is partly due to the fact that the core does not need to be relogged and retested. Unfortunately this means that CMRR generally has to be calculated by Rapid Rating without diametral point load testing data. There are some circumstances where the core is weakly bedded but unfractured. In these situations the fracture spacing and RQD ratings can be quite high whereas the diametral PLT would be low and so in its absence, may lead to a high CMRR which is unrepresentative. It may be possible in future to correlate diametral point load results with bedding (identified visually or in geophysical logging) to enable this error to be reduced. Currently, the results are ground truthed and qualified if there is a possibility of the error being present in a result.

Rapid Rating makes it possible to calculate CMRR over any core length (e.g. 0.5 m, 1 m, 2 m, 4 m, 8 m or 100 m) as the number of units is not limited in the calculation process. However, CMRR is an empirical system and was specifically developed to be used over a length of around 2 m. As such the weightings, equations and methodology can not be assumed to be useful for other lengths. It may be useful to calculate CMRR on the 0.5m horizon to indicate the potential need for roof skin control such as mesh, or to indicate the extent of longwall dilution for a given roof horizon. It may be useful to calculate CMRR on the 4 m and 8 m horizons to indicate the potential need for long tendon support. So whilst it may be interesting to calculate CMRRs on other horizons and start to build a database for these horizons, until such time as significant research is conducted into the validity of applying CMRR to the other horizons, and until substantial empirical databases are developed for the other horizons the results should be used with extreme caution.

FUTURE DEVELOPMENTS

If a correlation between diametral point load tests and visible bedding, geophysical logs and fracture spacing can be developed then the limitations on calculating CMRR retrospectively and using exploration data which was not obtained with CMRR in mind can be significantly reduced. This has enormous potential to decrease the cost of developing a CMRR database for a site and potential to significantly increase the amount of CMRR data which can be generated.

Similarly, if a reasonable indication of discontinuity rating can be developed by correlating fracture spacing and diametral point load tests with geophysical logs (even if only on a site to site basis) the possibility of determining CMRR from non core holes may be realised. This would have an even larger impact on the cost of developing an extensive CMRR database and amount of CMRR data which can be generated.

There are possibly valuable applications of the development of CMRR databases of other horizons such as 3-8m roof horizon to indicate the need for long tendon reinforcement, the 0.2-0.5 m horizon to indicate roof skin conditions and longwall dilution, and the floor horizon (with adjustments to ratings and methodology) to indicate floor conditions.

CONCLUSIONS

The CMRR is an extremely valuable geotechnical characterisation tool which can significantly simplify and enhance the identification and communication of different geotechnical regimes. Rapid Rating is a new method of calculating CMRR from exploration drilling data which significantly reduces the cost and time to calculate CMRR on large quantities of data. It increases the flexibility in CMRR calculations and reduces human error as well as ensuring a consistent approach in identifying units and their properties.

As CMRR becomes more widely adopted in the Australian mining industry it is important for mining professionals to remember that it is a rock mass quality (strength) indicator and not a roof stability indicator. As such it needs to be considered in combination with all of the other geotechnical design factors such as stress, geometry, roadway use, structure. It should be used in combination with other design approaches to determine mine design parameters such as support patterns.

The benefits to the industry from improving the CMRR will increase if the results can be made simpler to obtain more geological information such as pre-existing drilling data and non core holes can be used. This will allow larger site CMRR databases to be created with a higher spatial density of geotechnical information and lead to increased safety and reduced operational costs through more appropriate geotechnical design.

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REFERENCES

Colwell, M, 2003. A Manual for Assessing the Coal Mine Roof Rating (CMRR), Colwell Geotechnical Services.

Colwell, M G, Hill, D J and Frith, R C, 2000. ALTS II - A Longwall Gateroad Design Methodology for Australian Collieries *in proceedings of the 1st Australasian Ground Control in Mining Conference: Ground Control in Mining: Technology & Practice*: Sydney 10 - 13 November 2003, pp 123-135.

Mark, C, 1999. Application of the Coal Mine Roof Rating (CMRR) to Extended Cuts. *Mining Engineering*, pp. 52-56.

Mark, C and Molinda, G M, 1994. Coal Mine Roof Rating (CMRR): A Practical Rock Mass Classification for Coal Mines, US Bureau of Mines IC 9387.

Mark, C and Molinda, G M, 1996. Rating the Strength of Coal Mine Roof Rocks, US Bureau of Mines IC 9444.

Mark C and Molinda, G M, 2005. The Coal Mine Roof Rating (CMRR) - A Decade of Experience. *Int. J. of Coal Geology,* Vol 64/1-2, pp. 85-103.