Application of Various Rock Mass Classifications to Unsupported Openings at Mount Isa, Queensland: A Case Study

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SUMMARY: A number of published rock mass classification systems are applied to the assessment of unsupported openings within the dolomitic shales at the Mount Isa Mine. A statistical model for local variability in the intensity of fracturing within the shales serves as a basis for the structural data input. Results of the analysis are presented and limitations of the classification systems are discussed. Possible improvements in the systems are suggested. Past mining experience at the mine indicates that the classification systems yield conservative estimates for some rock mass parameters.

1. INTRODUCTION

One of the principal objectives of rock engineering is the estimate of the immediate and long-term stability of structures that are excavated in rock masses. This necessitates a quantitative evaluation of those physical and mechanical properties of rock masses which govern their strength and deformation characteristics.

The need for a relatively simple rock mass classification for practical engineering purposes has been long recognised and numerous proposals have been made over the last 40-50 years.

Ideally, a classification system suitable for mining of unsupported, open stopes should yield information on the permissible dimensions for such openings, strength of the rock mass to enable pillar design, modulus of the mass to permit prediction and interpretation of observed displacements during mining, and information for estimates of the effect of stress changes on each of the above parameters. This information is necessary for the optimum design of stopes that are to be extracted at progressively deeper levels within mines.

2. ROCK MASS CLASSIFICATION SYSTEMS

2.1 Scope of the Analysis

The aim of the present study is to assess the usefulness and limitations of a number of published classification systems.

Table I lists the rock mass classification systems included in the present assessment.

Table I

	Classification	Source
(i)	Rock Quality Designation (RQD)	Deere et al. (1966)
(ii)	Fissuration Factor (C)	Hansagi (1965)
(iii)	Rock Mass Rating (RMR)	Bieniawski (1973, 1976)
(iv)	Rock Mass Quality (Q)	Barton et al. (1974)
(v)	Modified Rock Mass Rating (Mod.RMR)	Laubscher and Taylor (1976)

2.2 Required Input Parameters

A detailed description of each system is outside the scope of this paper. However, to maintain clarity, the required input parameters are briefly listed in Table II.

Table II

System	Input Parameters
RQD-Index	Cumulative proportion of diamond drill core segments greater than 0.1 m within a selected depth of borehole.
C-Factor	Various parameters based on core diameter and lengths of recovered segments.
RMR	Unconfined compressive strength, RQD, spacing, orientation and condition of fractures, groundwater and limited number of excavation types.
Q	RQD, number of fracture sets, roughness and degree of alteration along weakest fractures, groundwater, rock stresses, excavation type.
Mod.RMR	A more detailed knowledge of parameters listed for RMR (with an associated different classification rating), plus adjustments for the effect of weathering field and mining induced stresses, and mining technique.

3. GEOLOGICAL INPUT FOR MOUNT ISA

The lead-zinc orebodies at Mount Isa Mine are essentially tabular and trend parallel to bedding. The average dip of bedding is 65° from horizontal. The ore is currently being mined by cut-and-fill and sub-level open stoping methods. The hanging-wall and footwall of stopes are defined by moderately to highly jointed and bedded shales.

The analysis is based on Orebodies 5, 7 and 11 within the dolomitic shales at the Mount Isa Mine. These are purposely selected to embrace the full range of ground conditions encountered in the lead-zinc orebodies.

3.1 Model for Fracture Orientation

Four principal fracture sets and several other locally common sets were differentiated for the dolomitic shales at the mine (Baczynski, 1974). The range of orientations for each set is represented on a lower hemisphere, equal area, stereographic projection plot of poles to fracture planes in Figure 1.

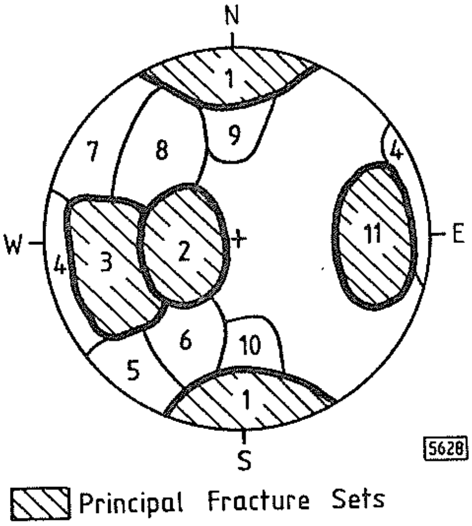

Figure 1 - Orientation of Fracture Sets at Mount Isa Mine.

3.2 Model for Fracture Spacing

Model for the variability in the intensity of fractures within the mine shales is based on the "zonal" concept for the spatial distribution of fractures in rock. The writer describes the basis for this model elsewhere (Baczynski, 1980). The mean intensity for each fracture set is indicated below.

Table III

Mean in situ Intensity and Corresponding Spacing

Set No.	Intensity (m/m^2)	Spacing (m)
1	2.17	0.46
2	2.17	0.46
3	1.12	0.89
4	0.24	4.2
5	0.12	8.3
6	0.28	3.6
7	0.05	20.0
8	0.23	4.3
9	0.15	6.7
10	0.12	8.3
11 (5 Orebody)	6.0	0.17
11 (7 Orebody)	5.2	0.19
11 (11 Orebody)	15.6	0.06

Field investigations suggest that there is no correlation between the intensity of bedding plane partings (Set No. 11) and other fracture sets within the shales.

3.3 Model for RQD-Index

As this parameter was not determined during field mapping, it was necessary to establish a correlation between fracture frequency and RQD-index rating on basis of diamond drill core data.

A literature survey on the topic indicates marked differences between the various published correlations. The mean trends adapted from Deere et al (1966) for a metamorphic rock type and proposed by Barton et al (1975) for essentially igneous rock types, by Priest and Hudson (1976) for sedimentary rocks, and by Kulhawy (1978) from theoretical considerations, are illustrated in Figure 2.

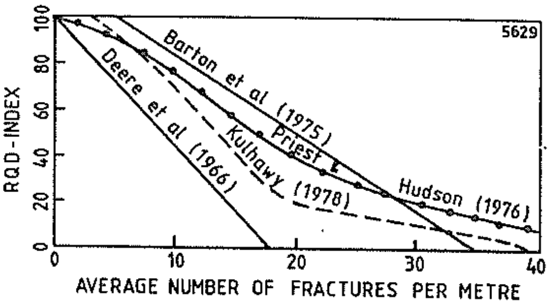

Figure 2 - Summary of Published RQD-Fracture Frequency Correlations.

It is apparent from these results that no single method can be considered to have universal application.

Figure 3 illustrates the correlation established for the dolomitic shales at the mine. This relationship is in extremely good accord with the results of Priest and Hudson (1976), especially for fracture frequencies less than 20 per metre. The trend at higher fracture frequencies is poorly defined because of lack of appropriate data.

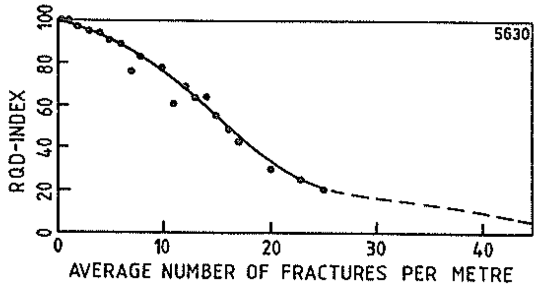

Figure 3 - Relationship Between Fracture Frequency and RQD for Dolomitic Shales at Mount Isa Mine.

It is interesting to note that both the Mount Isa and Priest and Hudson (1976) trends were established for sedimentary strata. These results suggest that one of the governing factors in the observed relationships is rock type. However, more evidence is necessary to confirm this suggestion.

3.4 Model for C-Factor Index

This index was not determined from diamond drill cores, but was derived on the basis of transformations between RQD and C-Factor published by Granstrom (1969) and later by Roberts (1977). The relationship between fracture frequency, RQD and C-Factor for the present study is summarized in Table IV. Non-tabulated values may be approximated by linear interpolation.

Table IV

Relationship Between RQD and C-Factor for Mount Isa

Fracture Frequency/m	RQD	C-Factor
0.0	100	1.00
3.0	95	0.79
5.5	90	0.65
7.0	85	0.56
8.5	80	0.50
9.5	75	0.45
24.0	22	0.13
56.0	0	0.00

3.5 Model for Strength and Modulus

The mean unconfined compressive and tensile strengths of the intact rock cores are assumed to be 180 MPa and 20 MPa, respectively.

The mean Young's modulus of the cores is 100 GPa.

3.6 Model for Condition of Fractures

The relative frequency per metre of core of bedding plane partings (Set No. 11) that may be classed as "planar fractures with slickensided, graphitic surfaces" may be described by means of a normal probability density function with mean of 0.42 and standard deviation of 0.26.

The remainder of the partings and all other fractures (i.e., Set Nos. 1-10) may be broadly classed as "discontinuous fractures with slightly rough surfaces which have a separation of less than 1 mm and hard wall rock" (Barton et al, 1974 and Bieniawski, 1973).

Although the broad classification cannot be considered to be universally applicable, it was necessary to characterize the fractures within a particular class for purposes of the analysis.

The analysis does not extend to mine areas where major, gouge-infilled faults are present.

3.7 Model for Stress Field

Three principal stresses are assumed to be 36 MPa, 26 MPa and 16 MPa, respectively; with the major principal stress acting normal to bedding.

3.8 Model for Groundwater and Weathering

Both parameters are assumed to be negligible for purposes of the analysis.

3.9 Mining Techniques

A classification of just below "good conventional blasting" as designated in Laubscher and Taylor (1976) is assumed for the mine.

4. METHOD OF ANALYSIS

Both the RQD-Index and C-Factor ratings were determined directly from the statistical model for local variability in the intensity of fracturing within the mine shales.

A simple computer program based on the "Monte Carlo" method (Hammersley and Handscomb, 1964) was written and used to statistically assess the ranges of RMR-, Q- and Mod.RMR-index ratings for the hangingwall shales of the orebodies investigated. Statistical probability density function for classification ratings was derived on the basis of a sample of 1000 randomly generated test blocks with respect to each selected block dimension.

The aim of the analyses was to evaluate the local variability in ground conditions within single stopes as well as the overall variability in mean ground conditions between stopes within particular orebodies.

All results are expressed in terms of means and ranges of values within 2 standard deviations about the mean. This range accounts for 95 per cent of values that may be anticipated within the hangingwall shales. The probability that poorer conditions exist is 0.025.

5. PRESENTATION AND DISCUSSION OF RESULTS

5.1 Rock Mass Strength

The ranges of unconfined compressive and tensile rock mass strengths deduced for the three orebody hangingwalls on the basis of the strength reduction factor proposed by Hansagi (1965) are summarized in Table V. Estimates of rock mass friction angles based on Bieniawski (1976) are also indicated in this table.

The estimates appear to be in reasonable accord with the values commonly assumed at the mine for design purposes.

The estimate of the mean pillar unconfined compressive strength for Orebody No.7 on the basis of the C-Factor is 87 MPa. This compares well with the 90 MPa suggested by Brady (1977) from back-analysis of experimental stoping in that orebody.

Although the results permit the construction of simple Mohr-envelopes for the rock mass, it must be emphasized that the shape of the resulting envelopes is directly related to the magnitude of the values assumed for the mean strengths of intact rock cores.

The use of the C-Factor method should be restricted to rock masses with similar ground conditions to those studied by Hansagi (1965).

5.2 Rock Mass Modulus

Rock mass modulus estimates based on RQD, as derived by Coon and Merritt (1970) and Cording et al. (1971), as well as estimates on basis of RMR-rating proposed by Bieniawski (1975) are also summarized in Table V.

Both methods yield similar modulus values. However, the results based on RQD display a greater range of values for local variability. Similar ranges may also be achieved by the use of the RMR-

Table V

Estimates of Rock Mass Properties

Rock Mass Property	Orebody	Local Variability Within Stope		Variability Between Stopes	
		Mean	Range	Mean	Range
Compressive Strength (in MPa) on basis of Hansagi (1965).	5	68	30-131	68	54-83
	7	74	37-135	74	61-93
	11	35	11-130	35	19-74
Tensile Strength (in MPa) on basis of Hansagi (1965).	5	8	3-15	8	6-10
	7	8	5-15	8	7-11
	11	4	1-15	4	2-8
Friction Angles on basis of Bieniawski (1976).	5	40	36-44	40	38-42
	7	40	36-44	40	38-42
	11	36	32-41	36	34-40
Modulus (in GPa) on basis of RQD-Index Rating.	5	19	14-80	19	17-35
	7	20	15-80	20	18-40
	11	14	11-70	14	12-19
Modulus (in GPa) on basis of RMR-rating, Bieniawski (1975).	5	22	18-39	22	19-26
	7	23	19-39	23	20-28
	11	18	15-29	18	15-24

Table VI

Estimate of Hangingwall Spans (in Metres) on Basis of Various Rock Classifications

Orebody	Rock Mass Classification System					
	Bieniawski		Laubscher and Taylor		Barton et al.	
	Mean	Range	Mean	Range	Mean	Range
5	11	7-16	25	17-33	28	16-48
7	11	7-16	25	18-34	28	16-48
11	6	3-15	15	7-32	11	4-26

relationship published in Bieniawski (1978b). The latter values are not tabulated in this paper.

Although Bieniawski (1978a) indicates that the RMR-method yields a lower degree of scatter of values about the mean, there is no conclusive evidence to suggest that this method is more reliable. The similarities between both sets of results indicate that either method may be used to estimate the mean rock mass modulus.

Moreover, both indices are, to varying extents, an indirect estimate of the total intensity of fracturing within the mass.

The RQD rating is not only governed by the total fracture intensity, but is also a function of the spatial relationship between fractures. Where fracture clustering occurs, a higher RQD rating is achieved and hence a higher modulus is estimated. For example, the same fracture frequencies per metre of core at Mount Isa yield a scatter of 30 per cent in RQD estimates.

On the other hand, estimates of the RMR-index incorporate parameters that have little or no effect on modulus.

This problem is best illustrated by means of a simple example. If the "unconfined compressive strength" and "spacing of fractures" parameters of the RMR-classification are considered, then similar rating reductions could be achieved for two different rock mass conditions. In the first instance, a mass with no fractures and strength of 3-10 MPa would contribute 31 points out of a possible 45 towards the total rating. In the second case, a mass with fractures spaced 0.3-1.0 m and an unconfined compressive strength in the range 100-200 MPa would contribute 32 points. In brief, both masses contribute a similar point score towards the cumulative RMR rating. However, both masses should have different modulus reduction factors. In the first case, this factor should be close to unity since there are no fractures in the mass and the modulus of intact cores should reflect the modulus of the mass. In the second example, the reduction factor will be governed by the stiffness of the fractures and its value will be less than unity, possibly 0.7 or lower.

It is apparent from the above discussion that there are real difficulties associated with each method. Neither method can be expected to yield anything more than an approximate estimate of rock mass modulus.

However, as the RQD-index is far easier to derive in the field, the writer would recommend its use over the more complicated RMR geomechanics classification rating for modulus determinations.

5.3 Stable Spans for Hangingwall of Stopes

Stable hangingwall spans have been estimated on the basis of the RMR-, Q- and Mod.RMR-index ratings. The results are summarized in Table VI.

The results indicate that Bieniawski's RMR classification system yields conservative estimates for unsupported spans, especially since stopes with hangingwall spans in excess of 30 metres have been mined in 5 and 7 Orebodies at the mine.

However, it must be appreciated that the RMR system was basically designed for the evaluation of near surface structures and was never intended to embrace mining situations. Its principal applications are to permanent engineering structures within rock masses that are subjected to relatively low stresses. With respect to these structures, the classification provides an excellent system which is no more conservative than any of the others.

For example, on the basis of Barton's ESR value of 1.0 for "major road and rail tunnels", the mean and range of unsupported spans determined for the 5 Orebody structural environment are 5.5 and 2.0-10.0m respectively. These values are even more conservative than those derived by the RMR-system for the upper limit of applicability.

The following three main factors confound the application of Bieniawski's RMR-system to mining situations:

(i) The system does not provide for the incorporation of stress effects on stability.

(ii) Although the system attempts to determine stand-up time which could then be indirectly related to stability in mining situations, the proposed times appear to be conservative with respect to past experience at the mine.

(iii) There is an upper limit of 20 metres for the maximum permissible span dimension. This value is extremely conservative.

It is considered by the writer that none of the above factors can be resolved without considerable redesigning of the existing system. This prospect makes the RMR-classification unacceptable to open stoping situations.

Both Laubscher and Taylor's Mod.RMR-system and Barton's Q-index yield similar estimates for stable unsupported spans. The values again appear to be conservative. However, the results are considerably better than those derived on the basis of Bieniawski's RMR-classification. Moreover, the derived spans for 5 and 7 Orebodies are probably within 30 per cent of the average values suggested by past mining experience.

It is apparent from the input parameters in Table II that both systems were proposed for or extended to embrace mining situations. In fact, Laubscher and Taylor's classification was designed specifically for mine assessments.

Each of the two systems permits stress effects to be incorporated into the analysis. This provides an opportunity for assessment of stope stability at various stress levels expected in the mine workings.

Unfortunately, practical difficulties are encountered in application of stress factor adjustments to ratings.

The basis for Laubscher and Taylor's stress criterion is poorly defined. Only a range of permissible adjustment ratios is indicated without any discussion or formula by which the appropriate ratio may be ascertained. This limits the usefulness of their system.

Barton's stress reduction factor (SRF) appears to offer considerable scope. However, a degree of personal judgement is permitted, especially in the case of extreme ground conditions. Thus, a likelihood exists that personal bias may enter and distort an analysis. It should be noted that small differences in the SRF-value will yield markedly different ratings and span estimates. This occurs because the Q-index is extremely stress sensitive.

The main disadvantage of the Q-system is its failure to include the effect of fracture orientation in the assessment procedure. All engineering structures are presumed to be already orientated in the most favourable direction with respect to geological structure. This situation does not commonly exist in mining where orientation of stopes is basically governed by economic geology and not entirely by structural considerations.

It is considered by the writer that the effectiveness and sensitivity of Barton's classification would be improved by the incorporation of the following three parameters in the assessment procedure:

(i) Adjustment factor (GEO) for orientation of geological structures with respect to geometry of the excavation.

(ii) Use of a "blockiness reduction factor (BRF)". The blockiness of a rock mass is a function of the number of fracture sets, as well as their intensity and continuity. As the intensity of these fractures increases, the same relative degree of blockiness or complete block isolation will exist, even with lower mean fracture continuity. Thus for a given rock mass, the value of the BRF-parameter is largely governed by the total intensity and mean continuity of fractures. The overall rock mass rating could be reduced by some ratio proportional to the BRF-value.

(iii) Use of an "orthogonal fracture factor (OFF)". In situations where fractures are essentially orthogonal with respect to the effective stress field, normal forces acting on the planes will be proportional to this field. These forces contribute towards interlock between fracture surfaces and thus act to stabilize the mass. Rock mass rating should be increased by some ratio which is directly, or possibly logarithmically, proportional to the relative frequency of othogonal fractures within the mass.

5.4 Correlation Between Classification Ratings

The following linear relationships were established between RMR-, Q- and Mod.RMR-ratings for the dolomitic shales at the mine. The trends are based on a SRF-value of 2.0 with respect to the Q-index.

(i) $\mathrm{RMR} = 7.5 \ \mathrm{Log}_n Q + 42$

(ii) $\mathrm{Mod.RMR} = 7.5 \ \mathrm{Log}_n Q + 19$

(iii) $\mathrm{RMR} = 0.93 \ \mathrm{Mod.RMR} + 25$

The analysis is based on a sample of 2000, statistically generated rock mass blocks for 7 and 11 Orebodies. Correlation coefficients between RMR, Mod.RMR and $\mathrm{Log}_n Q$ are in the range of 0.8 - 0.9.

The first equation is in close agreement with the trend proposed by Bieniawski (1976):

$$\mathrm{RMR} = 9 \ \mathrm{Log}_n Q + 44$$

However, it must be strongly emphasized that the correlations are stress dependent. The relationship will be significantly altered if, for example, different SRF-values are assumed in the determination of Barton's Q-rating. It is therefore important that any relationship for the transformation from one classification rating to another is not assumed to have universal application.

6. CONCLUSIONS

There are certain difficulties associated with the application of each rock mass classification system to unsupported openings such as the lead-zinc orebodies at the Mount Isa Mine. Moreover, none of the published systems appear to be completely satisfactory. However, a number are considered to be potentially useful classifications which could be modified to suit local mining requirements.

Aspects of the following rock mass classifications appear to be potentially useful with respect to underground mining:

Table VII

Rock Mass Parameter	Classification System
Unsupported Spans	(i) Barton's Q-index, or (ii) Laubscher and Taylor's Modified RMR-index.
Strength	(i) Hansagi's C-Factor in conjunction with Bieniawski's RMR-index.
Modulus	(i) Deere's RQD-index, or (ii) Bieniawski's RMR-index.

Overall, Barton's Q-index appears to be the most promising classification for the determination of stable spans within the dolomitic shales at Mount Isa Mine. However, the system needs to be modified to suit the structural environment at the mine.

Use of the "Monte Carlo" method for the generation of statistically valid input for geological structure and possibly some of the other input parameters, offers a technique by which it is possible to make a rapid assessment of the ranges of ground conditions that are likely to be encountered during mining.

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