The MRMR Rock Mass Rating Classification System in Mining Practice

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ABSTRACT

The *in situ* rock mass rating system – IRMR - leading to the mining rock mass rating system - MRMR - for jointed rock masses has been used (and abused) in mining operations around the world for the past 27 years. Despite the recent development of elaborate design procedures and computer-aided design packages, MRMR remains one of the most versatile and practical mine design systems available.

It is important to realise that the rock mass classification system should not be replaced but rather complemented by more sophisticated and detailed design procedures. The classification system is not only the 'crude' method used for initial assessment (as described in some geotechnical literature) but also in many respects a very effective and practical engineering tool. MRMR could, and should be used during the entire stage of mine life as an integral part of the design process.

The objectives of this paper are to illustrate using practical case histories from the past decade, some of the pitfalls of the MRMR classification system, to clarify certain misconceptions in its application and update its mining application.

INTRODUCTION

In order to design a mining operation it is necessary to work with numbers, therefore, all mining investigations require that the rock mass be classified quantitatively. Unfortunately, geological features rarely conform to an ideal pattern of numerical classification and therefore require a certain amount of judgement and interpretation.

Several rock mass classification methods have evolved over the past 25 years and are commonly used all over the world. Despite the popularity of rating systems there is a growing concern in the mining community about their appropriateness and usefulness as a mine design tool. Some of the concerns are based on misunderstandings and misuse of the classification systems. It must be understood that a classification system can give the guidelines, but the geologist or engineer must interpret the finer details. The most important pitfall to avoid is the belief that the method is a rigorous analysis. However, the classification system(s) is not only the 'crude' method used for initial assessment (as described in some recent geotechnical literature) but also in many respects is an irreplaceable practical engineering tool, which could and should be used in conjunction with other tools during the entire stage of mine life.

It is important not to forget the complexity of the rock mass that cannot be 'just converted into a spreadsheet' without understanding the consequences. A disturbing trend observed in the industry is that with increasing numbers of decimal places in rock mass rating values there is a decreasing understanding of the reality. Quite often, more or less sophisticated statistical methods are being applied to the numbers obtained from the field, and important observations, critical to the understanding of the rock mass behaviour, are being 'averaged in' or rejected. This is not a weakness of the particular classification system; rather it reflects a failure of engineering judgment by the user.

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In this paper the authors illustrate, by using practical examples some of the pitfalls and consequences of the 'value averaging' in the context of the mining rock mass rating (MRMR) classification system Laubscher (1990) as well as comments on the recent update of the MRMR system.

PITFALLS AND UNCERTAINTIES

The basic functions of the MRMR classification system are to:

- subdivide (classify) the rock mass into zones, based on similar behaviour;
- provide a basis for communication between various mining disciplines; and
- formulate design parameters for the actual mine design.

The MRMR system is one of the methods to characterise the rock mass competency. It is important to understand that rock mass competency is not only influenced by its inherent geological parameters (material strength and quantity and strength of the defects), but also by the changes introduced by the mining activities (induced stress, blasting damage, exposure to weathering, relative orientation of the defects and excavations, water). These 'man made' changes often have detrimental effects on the rock mass competency and thus stability of the openings, and cannot be ignored.

The most common errors in classifying rock masses include:

- averaging values across geotechnical domains;
- mixing natural and mining induced defects (joints and fractures);
- mixing *in situ* rock mass rating (IRMR) and modified rock mass rating (MRMR) values;
- not considering the variability (distribution) of values of individual parameters;
- ignoring rock strength anisotropy and its orientation;
- averaging the intact rock strength (IRS) of weak and strong zones;
- averaging joint conditions for individual discontinuity sets;
- not considering discontinuities other than joints;
- ignoring the orientation of the structural irregularities (small- and/or large-scale joint expressions);
- ignoring or misusing the sampling error adjustment;
- wrongly adjusting for alteration;
- wrongly adjusting for weathering;
- not recognising internal rock defects such as discontinuous natural fractures, veins, foliation, cemented joints, schistosity, bedding, preferred mineral orientation and micro-fractures;
- applying mining adjustments without considering spatial relationship and time (eg weathering, blasting);
- mixing localised failures with caving; and
- altering the classification system to suite the local 'needs' and then using stability graphs and ground support tables based on original (unaltered) ratings.

It is not likely that there will be a universal system, which would be able to cater to all the possible situations and remain practical. However, understanding the uncertainties associated with data, collection and the limitations of the classification the MRMR system can be used successfully in mining practice. The sources of uncertainty may be divided into the following groups:

1. **Correctness of collected data** – In other words, how well the data represents the reality. Logger's error (eg logging mechanical fractures as natural) and sampling bias are the most obvious errors causing deviation from reality. The sampling bias could be significant if there are no data other than drill core. The continuity of the joints, and their large-scale expression are impossible to judge solely from core leaving a whole range of possibilities for rock mass behaviour. The discontinuities parallel to the core axis are invisible unless the holes are oriented in several directions.

2. **Fixed interval logging and grouping (averaging) the data** – If data are collected at fixed intervals (eg core logged on drilling runs) without consideration of lithological or geotechnical zones, important characteristics relevant to the design could be obscured (smoothed out). Drilling intervals cannot be expected to coincide with all highly fractured zones or with lithological boundaries. If data are averaged across broad intervals, the resulting wide distribution of the IRMR/MRMR values could lead to erroneous decisions. This is illustrated in Figure 1. Although an attempt should be made to zone the rock mass in order to simplify the spread of values, the zoning must be practical in its representation of important geological features.

3. **Strength and deformability calculations** – The classification is not a rigorous system and certain simplifications in determination the strength parameter will have an impact on the 'precision' of the results. The most commonly criticised areas are the lack of procedures for assessing the impact of veins and cemented joints and the calculation of the rock mass strength. Some of the issues are addressed in the new revised IRMR/MRMR classification system and discussed later.

4. **Strength anisotropy –** Similar to the laboratory specimen, the rock mass can, and usually does, exhibit anisotropy. Both intact rock strength and strength of the discontinuities may vary in different directions. The relationships between such strength anisotropies and the direction of the disturbing force (gravity or stress) should be tested. Ignoring the anisotropy could significantly underestimate or overestimate rock mass competency. An example of the joint anisotropy is illustrated in Figure 2.

5. **Distribution of values –** Each parameter used in the IRMR/MRMR calculations should be expressed as a distribution rather than a single (in many cases straight average only) figure. Rock masses are inherently heterogeneous and the values are usually widely spread. It is important to illustrate the spread and the position of the 'base case'. This has to be taken into account when formulating design criteria. The base case could be on different sides of the scale depending on whether stability or instability is investigated – (see Figure 3). Probability and risk are the keywords and it must be understood that mining design is *risk driven*.

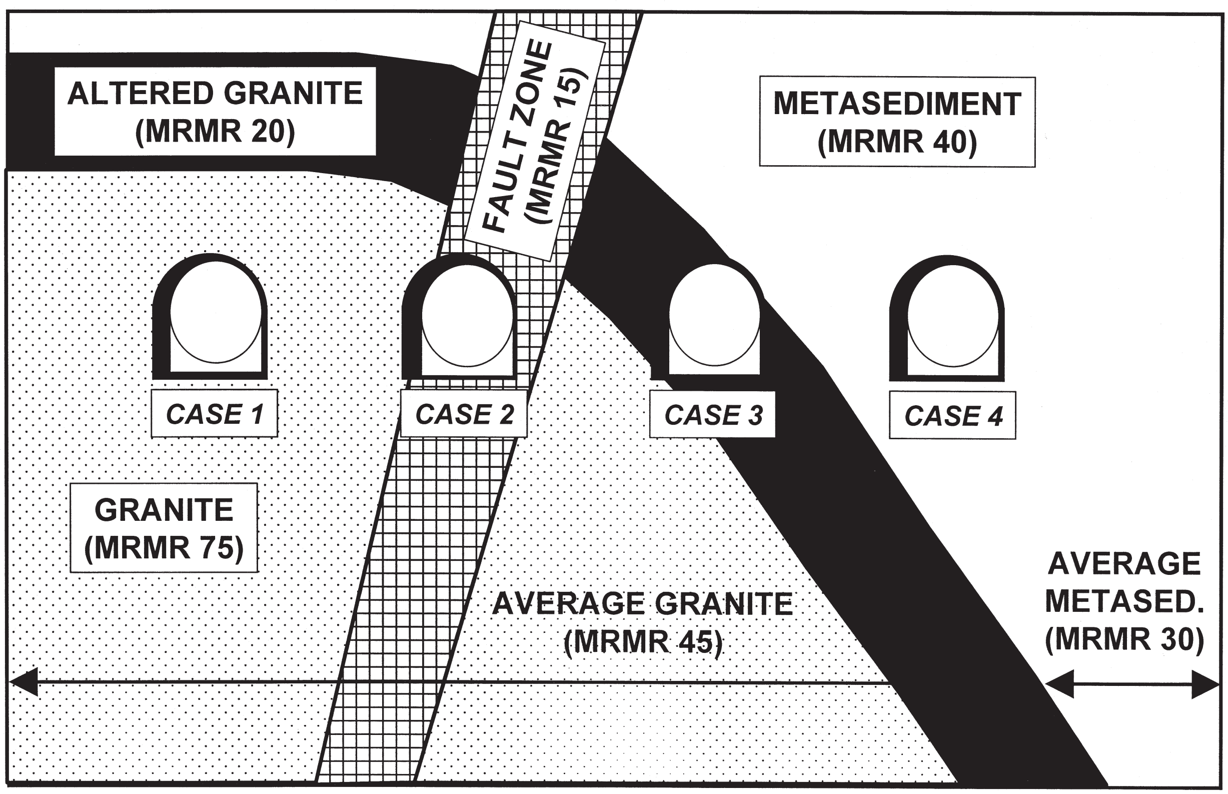
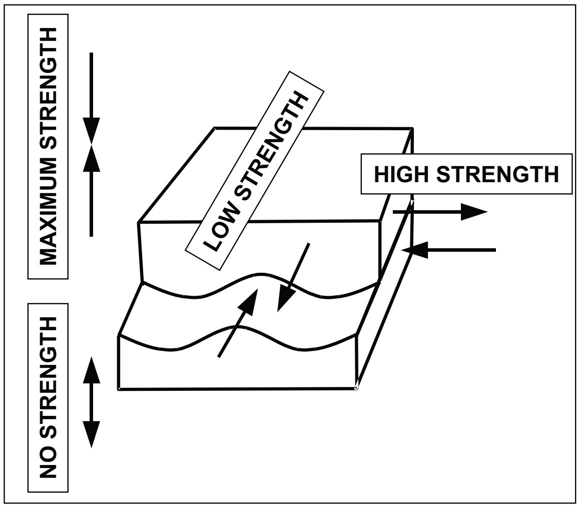


FIG 1 - An example of the hazards/risks in ignoring geotechnical zones. The mine was designed based on drill hole data. Two design domains were identified based on lithology and average MRMR values were assigned to each domain. The support for the tunnel in granite (case 1) was over-designed resulting in high mining costs. Tunnels developed in the fault and altered zones (cases 2 and 3) experienced severe stability problems because the support designed with a MRMR of 45 was inadequate. The tunnel developed in metasediment (case 4) was slightly over-designed.



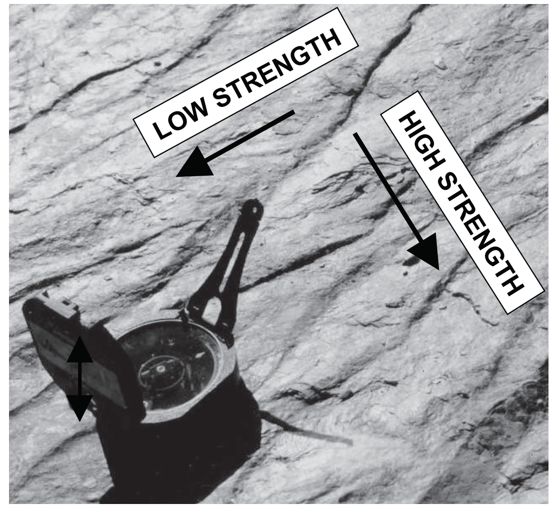


FIG 2 - An example of strength anisotropy of the joints.

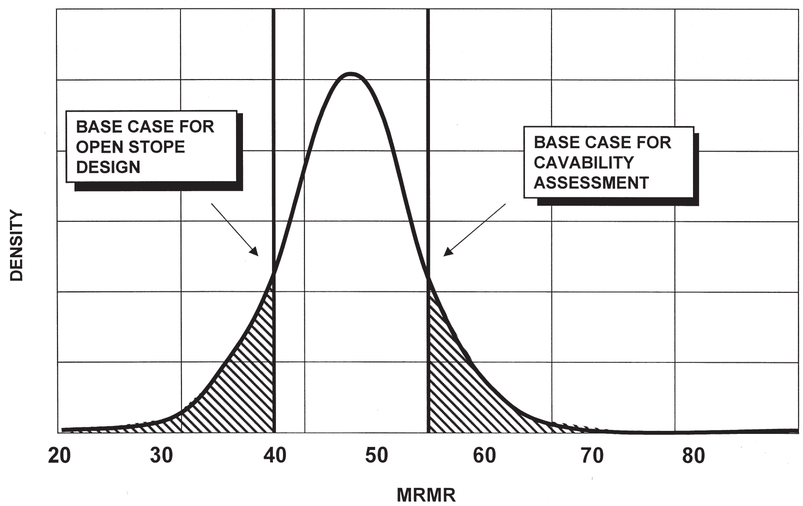


FIG 3 - Typical variation of MRMR values within the geotechnical zone and acceptable risk for various mining scenarios.

Of the five categories of sources of uncertainties only one (strength and deformability calculations) is a valid criticism of the classification system. The remaining four depend on the user and the classification system should not be blamed. Some of the issues were addressed in the revised IRMR/MRMR system and the following paragraph discusses the changes.

COMMENTS ON THE REVISED MRMR CLASSIFICATION SYSTEM

The revised MRMR classification system introduced several changes to the Laubscher's MRMR classification system as published prior to 1999. For details of the revised MRMR system please refer to the Laubscher and Jakubec (2000) paper and see Figure 4. The changes are as follows:

- introduction of rock block strength (RBS);
- introduction of 'cemented' joints adjustment;
- changes in joint condition rating (JC) adjustments; and
- expressing the water impact as an MRMR adjustment.

In order to avoid confusion with the Bieniawski RMR, the term IRMR is now used to indicate the rating of the *in situ* rock mass.

These changes were proposed as a direct result of the increased use of the classification system in the mining industry and are based on practical experiences in mines worldwide. The following case study is to illustrate the necessity of the different approach to the classification system.

There is a problem in classifying joints in primary rock where the structural features that have continuity and define potential rock blocks are cemented. In areas of bad blasting or high stress these features tend to open as the cement fails and are easily identified. Thus in a low stress area with good blasting very few open joints would be mapped and a rock mass rating of 60 would be the *in situ* rock mass rating value - IRMR, however in a high stress area the same rock would have a rating of 42, which, in fact, would be the modified rock mass rating value - MRMR with a stress adjustment factor of 70 per cent and not the IRMR. Neither example is providing the correct value, because, in the case of the IRMR of 60 the implication is that the joints are widely spaced, the primary fragmentation rock blocks are large,

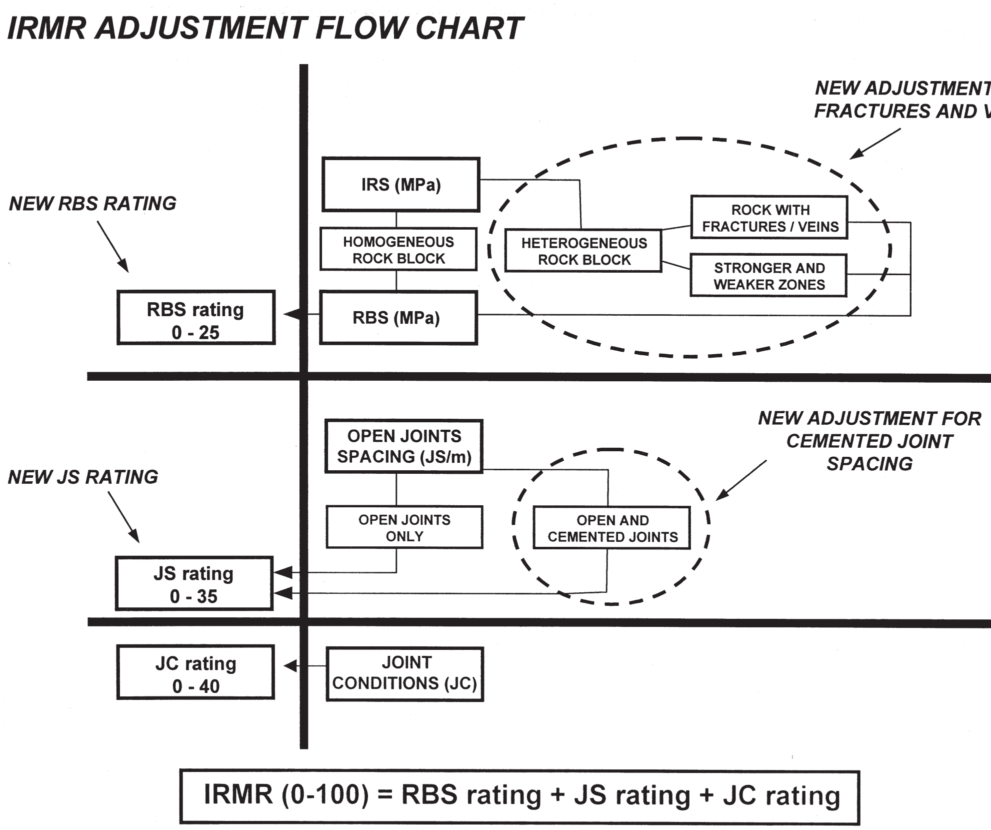


FIG 4 - *In situ* Rock Mass Rating (IRMR) adjustment flowchart. Illustrates the changes and additions to all previous versions RMR classification that predate Laubscher and Jakubec (2000).

and the cave fragmentation would be coarse owing to the strength of the rock blocks. This is dangerously misleading, because the rock blocks contain cemented joints that may fail under stress. The number of joints and the quality of the cement must be noted. A procedure has been formulated to adjust the combined joint spacing and condition ratings to account for cemented joints. Another approach would be to work with the rock block strength rather than the IRS and in this way veins and fractures are taken into consideration. By providing these avenues for cemented joints, fractures and veins there is no need for the mapper or logger to force cemented joints into the open joint category.

The following geological parameters will reduce the *in situ* rock mass competency (IRMS) and are discussed in details in the following paragraphs.

- material strength;
- quantity of defects (discontinuities); and
- strength of the defects (discontinuities).

Material strength

Depending on the scale, the following material strength is recognised:

- Intact rock strength (IRS),
- Rock block strength (RBS), and
- Rock mass strength (RMS).

The weakening defects that may have an effect on the individual strength categories are illustrated in Figure 5.

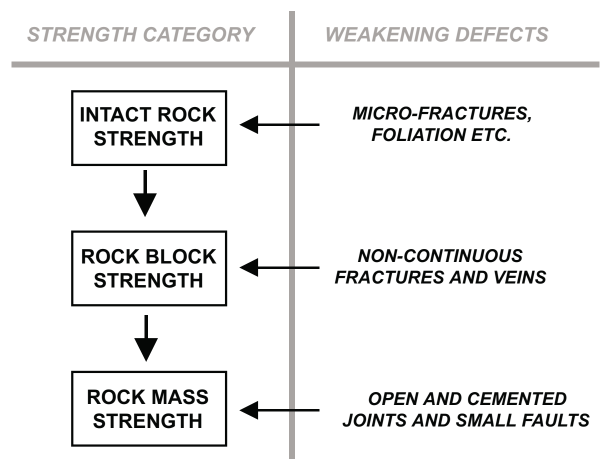


FIG 5 - Strength category and potential weakening defects.

Intact rock strength (IRS)

Intact rock strength is defined as the unconfined compressive strength (UCS) of the rock specimen that can be directly tested, including all internal defects apart from discontinuities. The problem is that the core samples commonly are 'selected' and represent the stronger material in the rock mass. Although the intact rock sample is taken from the core between fractures, cemented joints and veins it could include internal defects that influence the strength of the material (see Figure 6). Such defects include, but are not limited to: microfractures, foliation, weaker mineral clasts, etc. Although most defects will decrease the IRS, there are cases where the defects can have a strengthening effect on the rock mass (eg silicification).

Rock block strength (RBS)

Rock block strength is defined as the strength of the primary rock block (bounded by joints), corrected for non-continuous fractures and veins. In order to arrive at a value for the RBS, the measured IRS value must be adjusted for sample size, such that the conversion from core or hand specimen to rock block is approximately 80 per cent of the IRS. For example, where the intact rock strength (IRS) is 100 MPa, the rock block strength (RBS) is 80 MPa, in the absence of fractures and veins. Where such discontinuities are present, a further adjustment is required to more accurately determine the RBS. The strength of closed structures, and their frequency, is used to determine this adjustment.

The strength of closed structures is difficult to estimate and extra caution must be exercised in its determination. A procedure utilising the Moh's hardness number and fracture (or vein) frequency was developed as a guideline to adjust for the relative weakness within the rock block, and is described in Laubscher and Jakubec (2000).

Discontinuities

One of the weaknesses of most classification systems is that cemented joints are not accounted for, and they are forced into the open joint category or sometimes they are ignored. It is clear that in the first case the rock mass strength was underestimated and in the second case the rock mass strength is overestimated. If the stability of an open stope design, for example is investigated and cemented joints are counted as open joints the design will be conservative, which could be acceptable. If however, the cavability is investigated and cemented features are counted as open, the rock mass strength could be underestimated resulting in an incorrect cavability assessment. The new category of cemented joints was therefore introduced to rectify that problem and procedures for adjusting the overall joint rating were developed.

Discontinuities – joint spacing adjustment (JS)

In previous papers, one had the option of using the Rock Quality Designation (RQD) and joint spacing or Fracture Frequency per metre (FF/metres). However, the fracture/vein frequency and their condition is now part of the rock block strength calculation and therefore cannot be counted twice. It is for this reason that the joint spacing (JS) rating is reduced to 35 and refers only to open joints. Whilst there are situations where there are more than three joint sets, for simplicity they should be reduced to three sets. These adjustments differ slightly from the previous ratings chart in that the ratings for one and two sets are proportionately higher.

If cemented joints are present and the cement is weaker than the strength of the host rock, the additional adjustment to the JS rating is applied.

Discontinuities – joint strength adjustment (JC)

The IRMR system is revised to account for cemented joints and to have water as a mining adjustment. The joint condition rating remains at 40, but the joint condition adjustments have been changed based on recent experience.

The strength of the least favourable joint set (orientation of the joint with regards to the disturbing force) should be taken into consideration. If that is uncertain, than the procedure favouring weaker joints should be used. The procedure is described in Laubscher and Jakubec (2000) paper and provides more realistic results than a weighted average.

It should also be recognised that a joint's strength may vary under different confinement pressures/stress.

Mining adjustments

The objective of the mining adjustment is to account for the disturbance of the rock mass caused by mining activities. Usually the 'man made' impact has a detrimental effect on the surrounding rock mass, and the mining adjustment provides a more realistic assessment of the rock mass competency for the particular mining situation.

The authors realise that the mining adjustment numbers are somewhat more difficult to define and are therefore commonly ignored. In other cases, the mining adjustment numbers are liberally applied 'in a spreadsheet', without consideration of the particular mining scenario, resulting in unrealistically

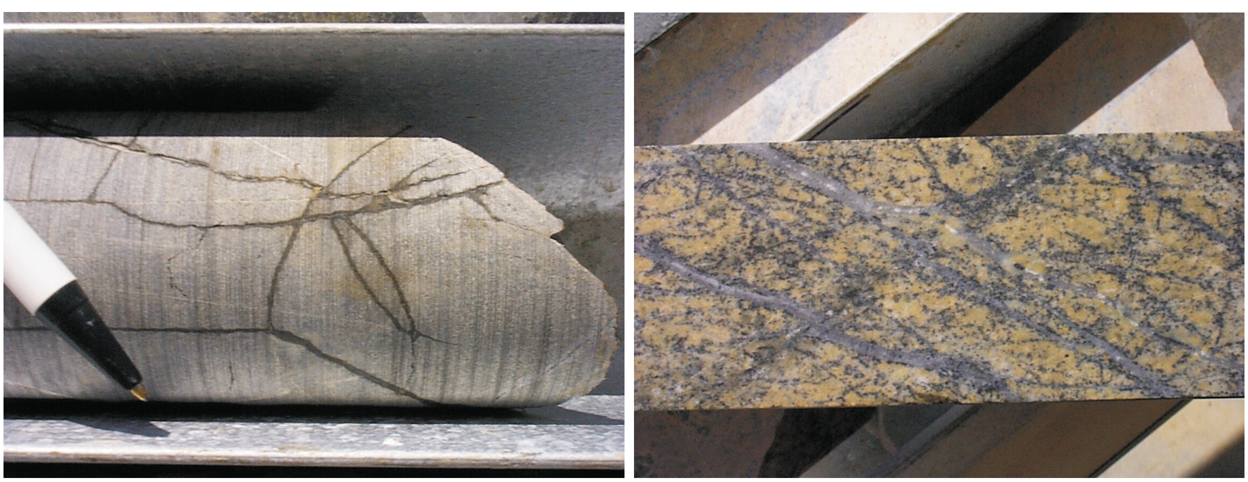


FIG 6 - Defects in the hand specimen. Microfractures enhanced by trapped moisture (on left) significantly decreased the IRS while quartz veins in a silicified zone (right) actually increased the IRS of the particular rock unit.

conservative figures. Clearly, ignoring or overestimating the mining impact could have significant consequences on the design. At the same time understanding the potential impact of the mining activities on the rock mass (reflected by the changing values of IRMR into MRMR) could reveal the need for better mining practices (eg cautious blasting or protection of excavations against weathering).

The following points summarise the proposed mining adjustments:

- the adjustments to the IRMR reflect the impact of mining activities on the competency of the rock mass;
- the values of the adjustments are time and space dependent (see Figure 7); and
- the impact of the adjustments can be minimised by good mining practices.

The following mining phenomena impacts on the rock mass competency:

- exposure to weathering;
- blasting damage;
- induced stress softening or strengthening impact;
- joint orientation with respect to the mining excavations and/or principal stress; and
- water and ice.

The following are field observations, which were incorporated into the revised MRMR classification.

Weathering

- the strength of the rock decreases if weathered;
- the more jointed or fractured a rock mass the more easily it will weather;
- rate of weathering depends on the climate (temperature variation and moisture content);
- rate of weathering depends on the mineralogy (clays and other phylosilicates); and
- weathering usually impacts only on areas close to the exposed rock faces and decreases into the rock mass.

Blasting

- blasting will decrease the strength of the rock mass by creating new fractures and by decreasing the strength of the existing ones;
- highly jointed rock is more susceptible to blasting damage than a massive rock mass;
- blasting damage decreases from the source; and
- blasting damage decreases with increasing confinement of the rock mass.

Water and ice

- water generally decreases rock mass strength;
- ice generally increases rock mass strength;
- rock mass strength increases with lower ice temperatures; and
- ice in the rock mass could cause creep.

Stress/discontinuity orientation

- if the principal stress is perpendicular to the major discontinuity set it can strengthen the rock mass;
- if the principal stress is at an angle to the discontinuity it will weaken the rock mass; and
- stress/rock mass strength ratio is more important than the absolute value of the stress.

In the following paragraphs the individual adjustments are discussed in the greater detail.

Weathering adjustment

It is often the practice to adjust for weathering every time weathered rock is encountered. This is incorrect and it should be emphasised that only weathering which can be defined as 'degradation of the rock mass strength within the project life' should be adjusted for. Lower IRS or JC should cater for weathering that occurred before the drilling or before the excavation.

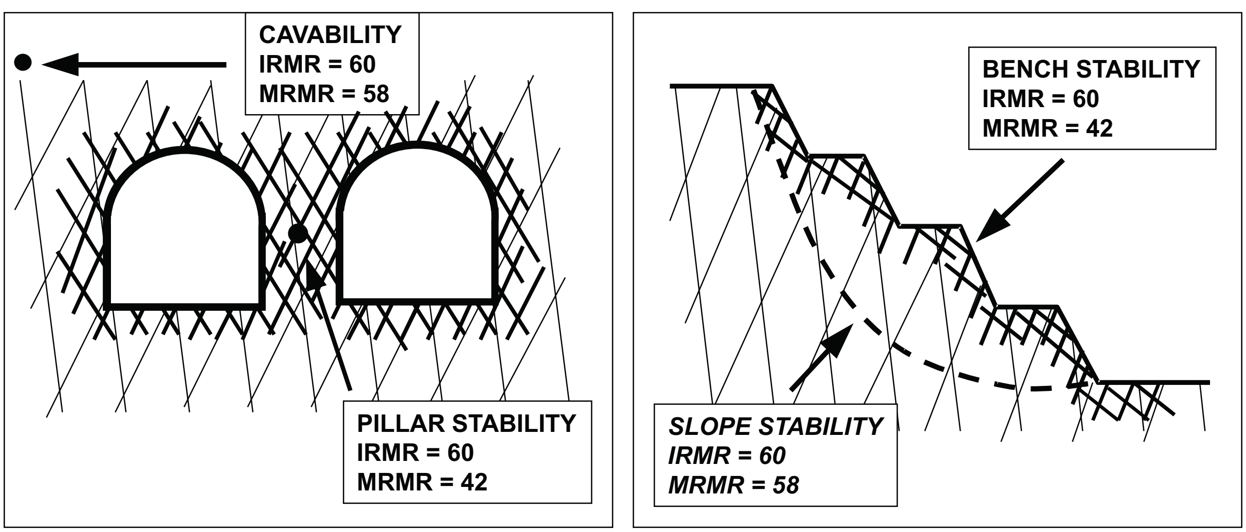


FIG 7 - Space dependency of blasting adjustment. Whilst investigating bench or pillar stability, blasting could significantly reduce the rock mass strength. On the other hand the rock mass strength is not likely to be affected deeply in the open pit slope.

The following terminology is used:

- **Intact rock weathering susceptibility** is an inherent property of the rock reflecting the potential of the rock to degrade in strength due to its mineralogical composition.
- **Rate of weathering** is the rate at which the rock strength degrades. It could depend on exposure to moisture, wetting and drying or freezing and thawing cycles.
- **Rock mass weathering** is a function of the rock mass surface exposure and weathering susceptibility. Blasting damage (induced fractures) and open joints will accelerate the rock mass weathering by increasing the surface exposed to weathering and opening pathways for moisture.

In conclusion the rock mass weathering adjustment is a function of:

- exposure time - (longer exposure leads to a larger adjustment);
- rate of intact rock weathering, which is dependent on the climatic conditions and on the mineralogical composition of the rock;
- surface exposure (blasting damage and/or higher open joint frequency results in a higher rate of weathering); and
- location (if bench or tunnel stability is investigated, weathering will play a major role; when deep seated pit slope instability or cavability is investigated, then it is unlikely that weathering will impact on design).

Possible methods for estimating the rate of weathering could be as follows:

- measurement of the rock degradation against pegs installed into the walls of the excavation (intact rock weathering);
- accelerated weathering of the core through repeated wetting and drying or freezing and thawing (intact rock weathering);
- profile survey of the excavated benches (rock mass weathering); and
- slake durability laboratory tests.

The total weathering adjustment is a combination of both rock mass weathering and exposure time adjustments.

The weathering impact can be minimised by sealing the exposed surface after excavation (through shotcrete, polyurethane, asphalt, etc) or by pressure grouting prior to excavation.

Blasting adjustment

Blasting creates new fractures and loosens the rock mass and/or causes movements along the existing joints thus reducing the rock mass strength.

Similar to the weathering adjustment, the blasting impact is space dependent (see Figure 7). For example the blasting adjustment could be very high if bench stability is investigated but will have a minimal effect on the overall pit slope stability. Similarly the blasting damage to the apex pillar could severely impact on the drawpoint stability but will not impact on cavability.

The amount of blasting damage will depend on the proximity to the open face and on the stress (confinement). Highly jointed rock masses are also susceptible to blasting damage

One method of estimating the blasting impact could be to compare rock block strength before (eg drill core) and after the blasting. The method is illustrated in the following example. Logging of the core revealed the following:

- Intact rock strength of the rock is 100 MPa. There are no natural veins or fractures besides the jointing thus the rock block strength (RBS) rating is 23.
- The natural discontinuities counted in the core yield two open joints/m and four cemented joints/m. The combined rating is 22.
- Joint condition (JC) rating is 24.

In situ rock mass rating is a combination of the individual ratings thus IRMR = 67. Mapping of the underground tunnel revealed that there are six new blast induced cracks per metre and four cemented joints are open as a result of blast damage. Rock block strength will be lower and using the technique described in Laubscher and Jakubec, 2000 the resulting RBS rating is now 19. The open joint rating decreased to 20 and the final adjusted MRMR is now 63, indicating 94 per cent adjustment due to blasting.

Water and ice adjustment

Water will generally reduce the strength of the rock mass by reducing the friction across the structures and/or by reducing the effective stress.

In the case of the presence of ice in a permafrost situation the rock mass could be significantly strengthened. This will depend mainly on the amount of ice and on the temperature of ice. Because of creep behaviour of the ice, the strength usually decreases with time.

Joint orientation adjustment

Joint orientation adjustment discounts the RMR value as a result of gravity. Since the disturbing force (gravity) is vertical the adjustment value depends on the number of faces of the rock block inclined from the vertical (see Figure 8). The discontinuity strength expressed as joint condition (friction) is also considered. This adjustment should not be used if significant stress is present, as the stress adjustment will take preference.

Stress adjustment

The stress adjustment caters for the magnitude and orientation of the principal stress. Beside the magnitude of the stress (strength/stress ratio) it is also important to know the orientation of discontinuities with respect to the principal stress. Mining induced stresses are the redistribution of field or regional stresses as a result of the geometry and orientation of the excavations. The orientation, magnitude and ratio of the field stresses should be known either from stress measurements or from published stress distribution diagrams.

The maximum principle stress can cause spalling, crushing of pillars, deformation and plastic flow of soft zones and result in cave propagation. The deformation of soft zones leads to the failure of hard zones at low stress levels. A compressive stress at a large angle to structures will increase the stability of the rock mass and inhibit caving (seen Figures 9 and 10).

The following factors should be considered in assessing the mining induced stresses:

- drift induced stresses;
- interaction of closely spaced drifts;
- location of drifts/tunnels close to large stopes/excavations;
- abutment stresses, particularly with respect to the direction of advance and orientation of field stresses (an undercut advancing towards the maximum stress ensures good caving but creates high abutment stresses and *vice versa);*
- uplift as the undercut advances;
- column loading from caved ground caused by poor draw control;
- removal of restraint to sidewalls and apexes;

- increase in mining area and changes in geometry;
- massive wedge failures;
- influence of structures not exposed in the excavation but which increase the probability of high toe stresses or failures developing in the back; and
- presence of intrusives that may retain high stresses or shed stress into the surrounding more competent rock.

The final stress adjustment is a combination of the stress orientation adjustment and the stress/rock mass strength ratio (see Figures 9 and 10).

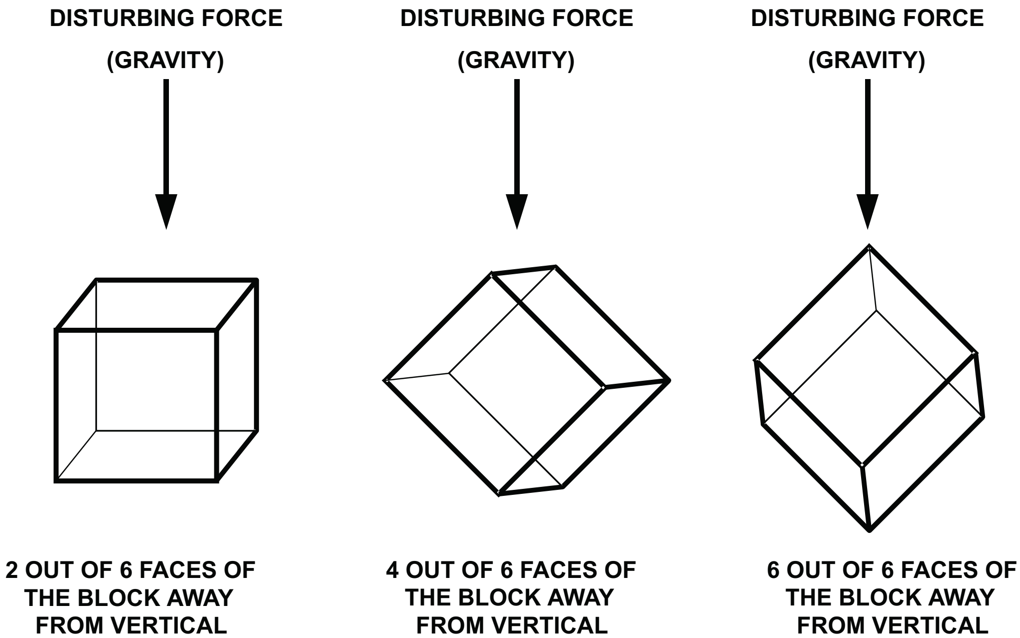


FIG 8 - An example of rock block formed by three sets of joints. The block on the left is the most stable since the two out of three sets are vertical, so the adjustments for gravity is only 90 per cent.

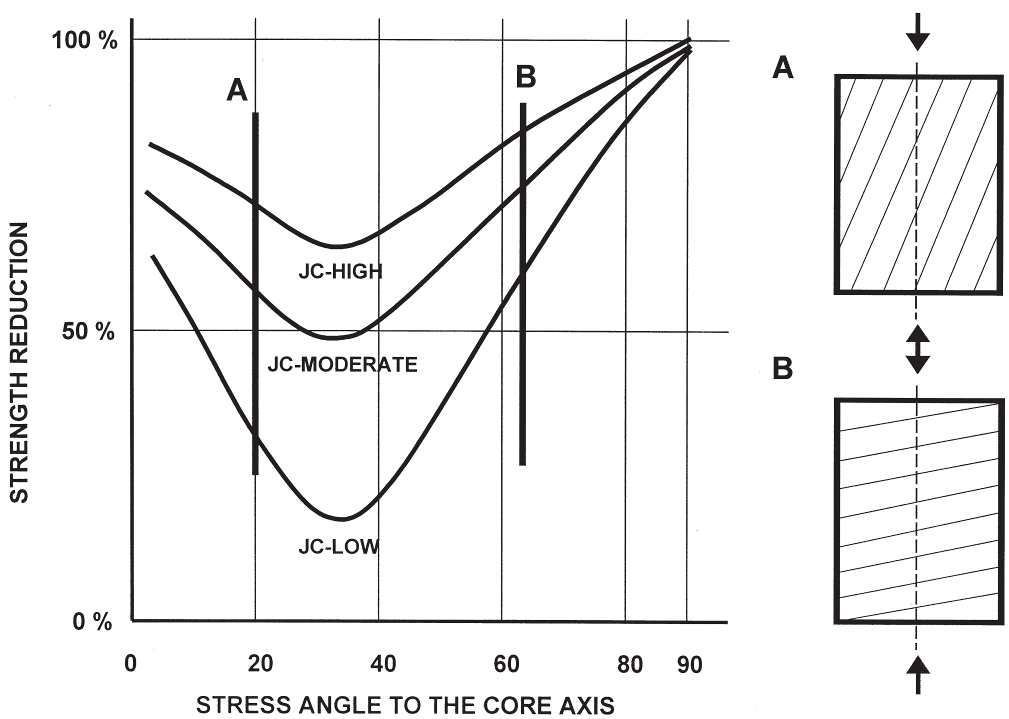


FIG 9 - Example of the strength reduction of the hand specimen related to the discontinuity/principal stress orientation.

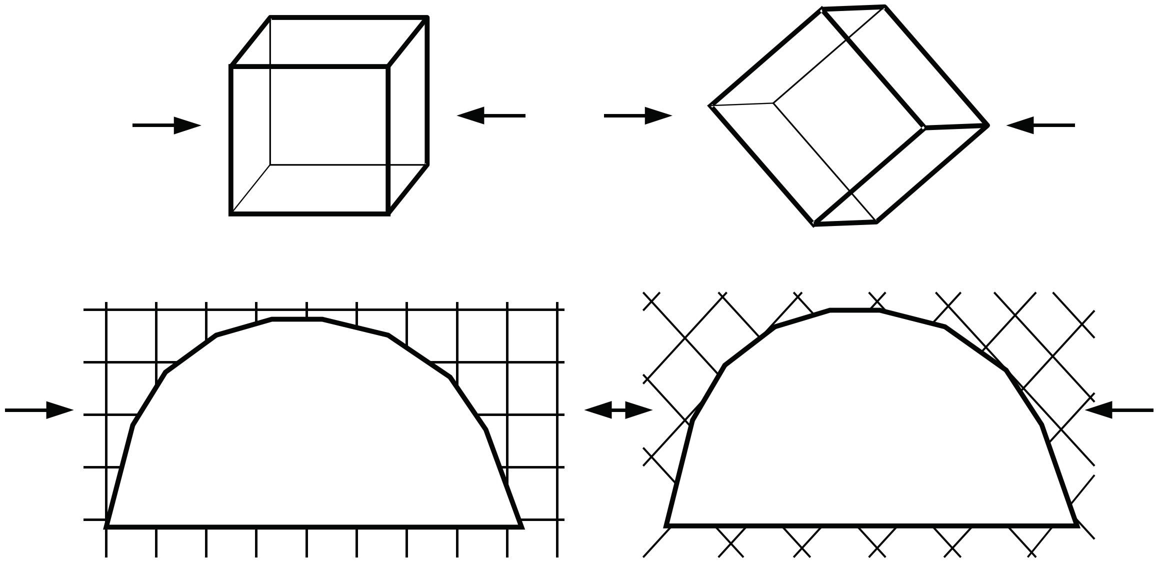


FIG 10 - Example of the 'clamping' effect of the horizontal stress if the stress is perpendicular to the major joint set (left). The diagram on the right showing a less stable configuration. Arrows indicating the orientation of major principal stress.

CONCLUSIONS

Although the MRMR system was initially developed for caving operations, over the past decade it has spread into all aspects of mining. The MRMR classification is now used on many large mining projects all over the world. Although it is relatively easy to use at the same time it can easily be abused. The system is not a rigorous analysis and it is designed as a guideline to be used together with engineering judgment. This could be seen as a problem by some but it is difficult to foresee that such a complex and complicated issue such as a rock mass could be properly assessed by a single computerised rigorous expert system. Attention to the real rock mass has to be paid at all times. The use of spreadsheets greatly enhance our ability to quickly calculate and illustrate results but without 'touching' the rocks and using engineering judgement conclusions based on such computerised processes could not only be misleading but dangerous.

One has to be realistic about the rock mass characterisation and to 'calculate' MRMR values to three decimal points is ridiculous. Attempts should be made to zone the rock mass in order to narrow down the spread of the values, then select the base case and apply sensitivities to test the robustness of the model. It is better to be roughly right than precisely wrong.

In practical terms one has to understand why the particular parameter is collected and how it is going to impact on design and stability. It is not necessary to do detailed three metre interval logging of the 1000 metre drill core if the orebody is 800 m deep and will be mined by an open stoping method. In that case 'high resolution' logging could be executed in the vicinity of the future excavation and the rest could be only broadly characterised. At the same time if a caving method is considered then the relevant lithologies must be characterised in terms of competency, fragmentation and cavability.

The classification system has to be transparent and IRMR and MRMR numbers have to be 'de-codeable'. The individual parameters collected for IRMR could be used in other, more detailed analyses.

It is important that all the critical parameters influencing the rock mass behaviour are catered for. Ignoring strength reduction due to micro-fractures or ignoring the presence of cemented joints could lead to great economic losses. Rather than ignoring the issues it is better to use a simplistic method as it is better to be roughly right than precisely wrong. Where the system has been properly applied (in combination with engineering judgment) it has proved to be a valuable tool in planning and communication.

REFERENCE

Laubscher, D H and Jakubec, J, 2000. The IRMR/MRMR Rock Mass Classification System for Jointed Rock Masses, SME 2000.