

❖ Rock mass quality

Rock mass classification (or rock mass rating) is an empirical system, developed from previous surface and underground excavation, and utilized for design of excavations in rock.

It has been in use for centuries by miners on a rather crude basis. Rock was classified as being hard rock, crumbly bad rock, squeezing ground, black mud, etc. all which describe a major geotechnical parameter governing the rock's performance. However, this is insufficient for an engineering design.

In 1968 Deere introduced the concept of Rock Quality Designation (RQD). This classification was simply the percentage of core pieces greater than twice the core diameter over a fixed length interval. However, rock reinforcement was recommended, and often predicated, on these values.

In 1973, Bieniawski introduced a system of Rock Mass Rating based on:

- intact rock strength (uniaxial compressive strength);
- RQD (rock quality designation);
- joint frequency (number of natural occurring fractures or discontinuities per length);
- joint conditions (joint infill, persistence, and roughness);
- ground water conditions (water pressure)

This was followed in 1974 by Barton's Q system (occasionally called the NGI Q system or simply Q system) which includes most of the same input parameters but with the important differences that the system is logarithmic instead of linear (as is the RMR scale) and that it includes a load carrying capacity term, the Stress Reduction Factor (SRF). Transformation equations have been developed between the Barton's Q and Bieniawski's RMR systems and may be found in any number of rock mechanics texts.

Both of these classification systems were developed within the civil engineering field on civil excavations. They were therefore not strictly applicable to mining as the openings utilized for creating the classification schemes were too large, open too long, and over-supported from a mining perspective.

In 1977 Laubscher proposed the Mining Rock Mass Rating (MRMR) system. This system was a modification of Bieniawski's system but was devoted exclusively to mining. It has since been applied and modified, based on additional experience in mines around the world.

➤ RMR statistics

All rock mass rating values, whatever system is utilized, can be dealt with statistically (RMR will be utilized generically to denote ANY rock mass rating system). Generally, RMR is collected over a natural logging interval. Thus, the interval lengths will vary. To properly account for this, the RMR intervals should be discretized, or broken into uniform lengths. Anywhere from 0.1 - 0.5m is the normal range for these uniform length intervals.

RMR is a strange beast in that it is generally dealt with as a scalar quantity but in fact is determined by many vector variables. Fracture frequency is orientation dependent and is one of the variables included in the RMR value. Differing logging orientations will provide different RMR values. Infill too, is often structure set dependent. As the orientation of logging determines which structures are intersected, this value too, is somewhat a vector quantity. While all of the ills of the RMR system cannot be addressed in this short document, some of the pitfalls are at least mentioned, which allows the user to compensate for the inaccuracies in some fashion.

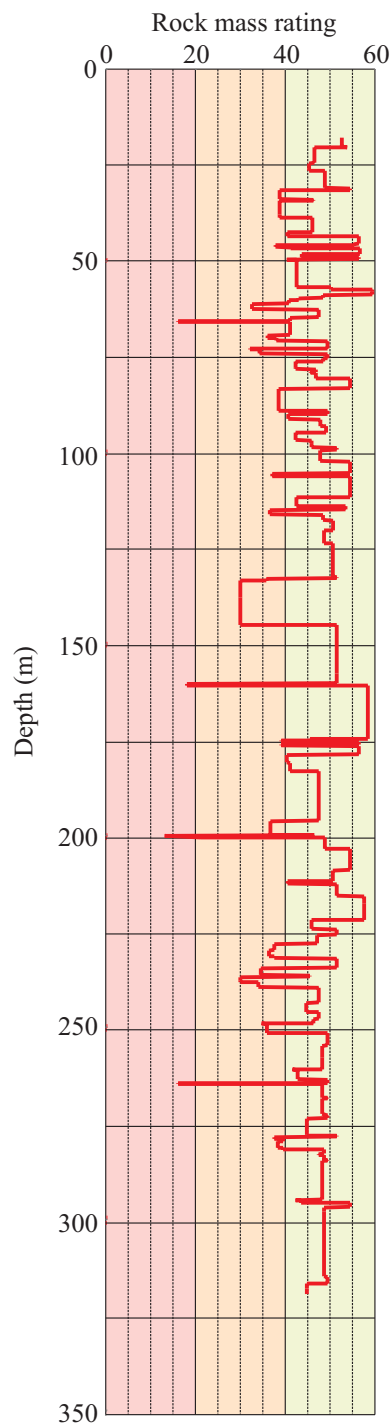
RMR systems also allow for "adjustments" based on the excavation type, stress conditions, weathering, water, etc. These adjustments, too, are empirical. As such, they are somewhat vague. Once again, a statistical treatment of the adjusted values is proper, and generally warranted as it provides a better evaluation of the range of possible design values.

Some examples of the RMR data reduction process are given in the attached figures. Figure N1 depicts the drillhole RMR as logged. Figure N2 shows a cumulative density function of the RMR after discretization and adjustment.

➤ **Rock mass strength**

Rock mass strength is the strength of the inhomogeneous mass in which the excavation will be placed. Rock mass strength, as most other parameters in rock mechanics, is scale dependent. For example, failure in a small slope in a hard, competent, quartz diorite would be controlled by discontinuities, not by the inherent strength of the rock mass. However, if the slope height was increased and zones of varying strength material were included in the quartz diorite, then failure could conceivably pass through intact rock. Similarly, failure could occur, without following discontinuities, in a small slope composed of heavily altered rock. Zones which will allow failure through intact rock, and, equally important, those zones which will not, are areas which must be identified through determination of rock mass strength.

Rock mass strengths may be determined using rock mass ratings. This technique is based on combining compressive strength indices, discontinuity characteristics (length, intensity, orientation, infill conditions), weathering characteristics, etc. to arrive at a numerical rating.. Strengths are assigned to this equivalent material based on experience in rock masses in materials exhibiting similar numerical ratings. Once experience has been obtained in the area being classified, the system can be calibrated to more accurately reflect the rock mass strength. An example of an RMR determined strength envelope is given as Figure N3.

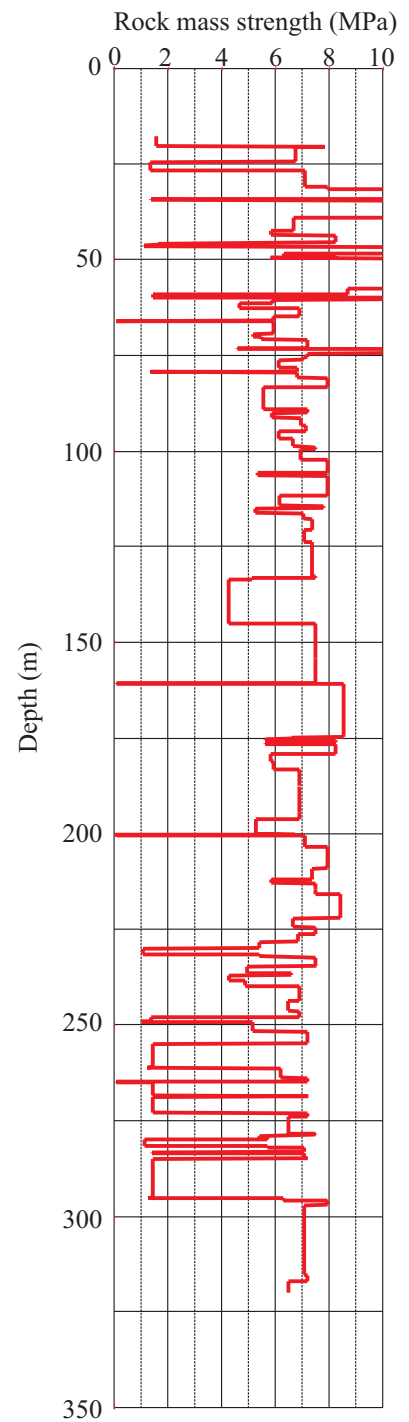


Rock mass rating statistics

Mean	46.816
Standard Error	0.128
Median	48.300
Mode	48.300
Standard Deviation	7.031
Variance	49.442
Kurtosis	0.901
Skewness	-0.761
Range	46.450
Minimum	13.050
Maximum	59.500
Sum	141151.139
Count	3015.000
Confidence Level(0.950000)	0.251

Rock mass strength statistics (MPa)

Mean	6.634
Standard Error	0.052
Median	6.958
Mode	1.440
Standard Deviation	2.840
Variance	8.066
Kurtosis	3.198
Skewness	0.618
Range	19.545
Minimum	0.065
Maximum	19.610
Sum	20001.992
Count	3015.000
Confidence Level(0.950000)	0.101

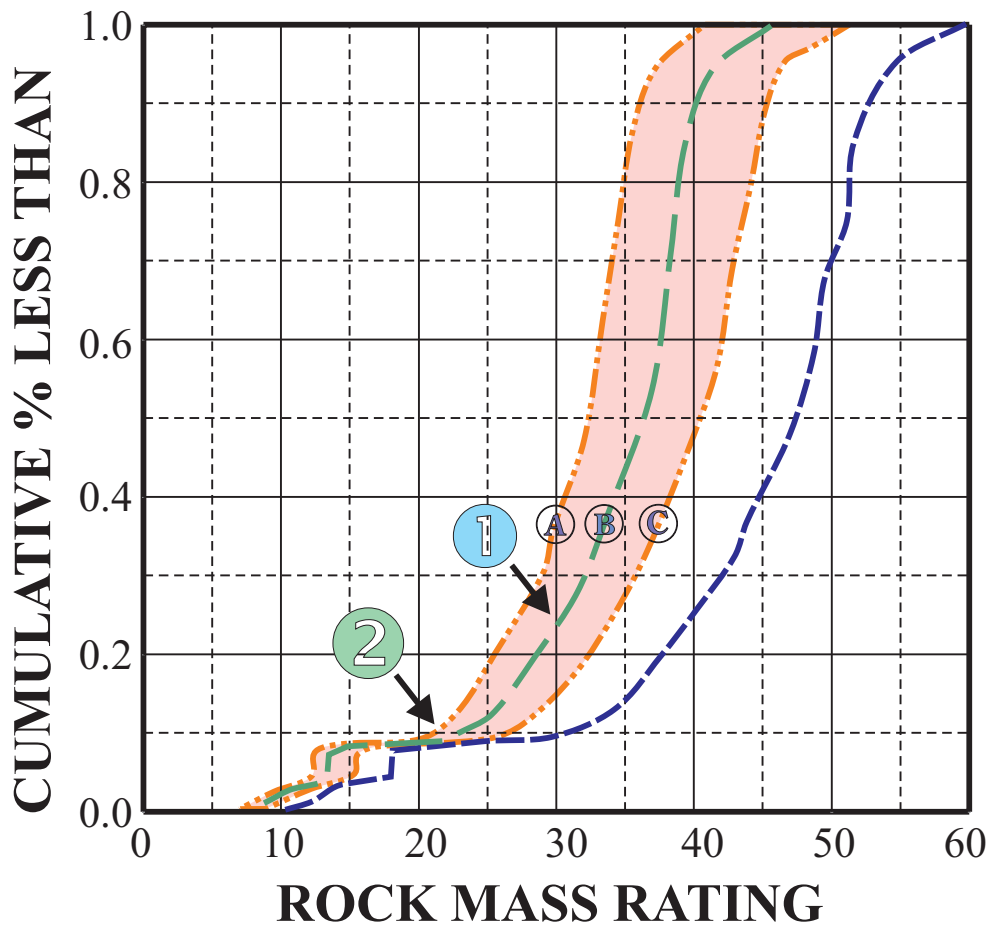


Rock mass rating classification

- 0-20 = very poor rock
- 20-40 = poor rock
- 40-60 = average rock
- 60-80 = good rock
- 80-100 = excellent rock

FIGURE N1





Unadjusted RMR - all lithologies	
Mean	43.790
Standard Error	0.175
Median	47.500
Mode	51.500
Standard Deviation	10.652
Variance	113.455
Kurtosis	1.752
Skewness	-1.490
Range	49.200
Minimum	10.300
Maximum	59.500
Sum	161410.048
Count	3686.000
Confidence Level(0.950000)	0.344

Adjusted RMR - all lithologies - design	
Mean	33.499
Standard Error	0.134
Median	36.338
Mode	39.398
Standard Deviation	8.148
Variance	66.397
Kurtosis	1.752
Skewness	-1.490
Range	37.638
Minimum	7.880
Maximum	45.518
Sum	123478.687
Count	3686.000
Confidence Level(0.950000)	0.263

Adjusted RMR Range (approximate)

RMR design values (after adjustments)

- B** mean = 33
- C** maximum = 37
- A** minimum = 30
- 1** Robertson/Olsen handled RMR mean = 28
- 2** Robertson/Olsen RMR recommended design mean = 22

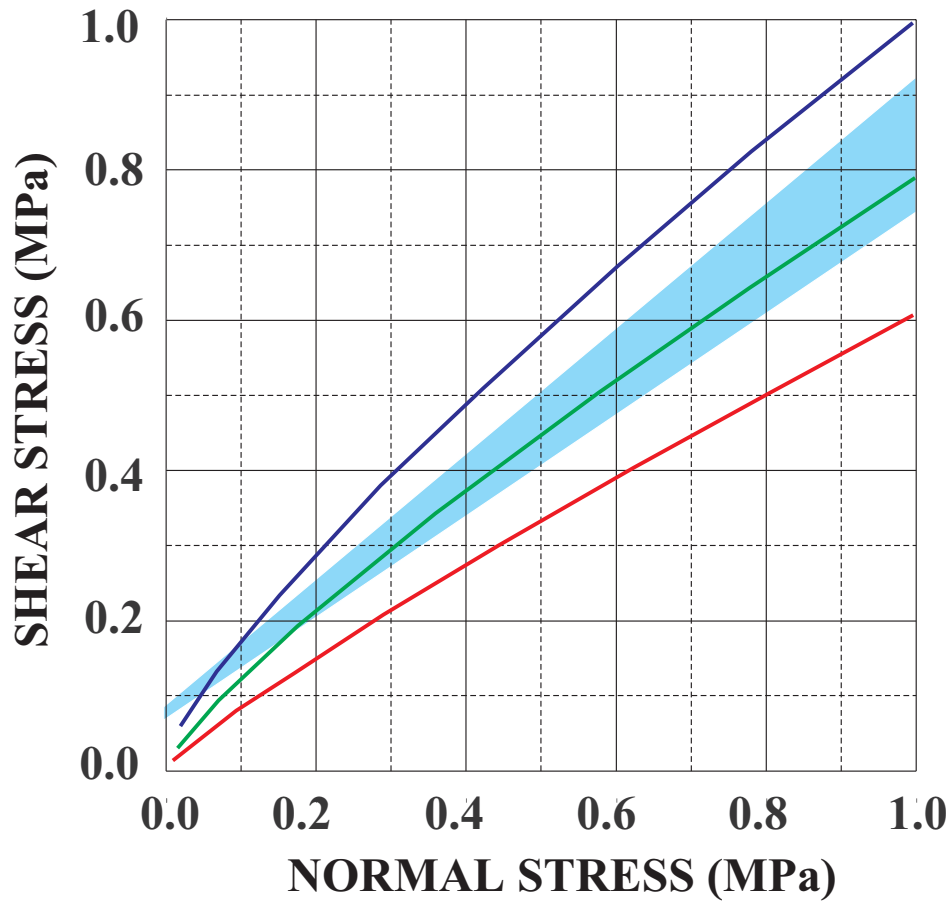
Note:
All drillhole data was composited into 0.3m intervals before compilation and plotting.

FIGURE N2



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— Upper strength bound equivalent material model
 — Mean strength equivalent material model

— Lower strength bound equivalent material model



Robertson/Olsen RMR strength assessment for pit slopes
 RMR range 35-40; friction angle = 40 degrees; cohesion = 86kPa
 RMR range 25-30; friction angle = 34 degrees; cohesion = 69kPa
 (values from Island Copper Mine, B.C., Canada. See text for derivation of design RMR values for methodology)

Applicable strength range		Equivalent material rock strength									
		20% rock		25% rock		35% rock		40% rock		50% rock	
from (MPa)	to (MPa)	friction angle	cohesion (kPa)	friction angle	cohesion (kPa)	friction angle	cohesion (kPa)	friction angle	cohesion (kPa)	friction angle	cohesion (kPa)
0	0.1	36.8	10.1	38.4	15.0	46.0	21.5	48.5	32.1	53.0	38.9
0.1	0.2	33.4	19.1	34.8	23.9	41.3	38.0	44.5	48.8	48.2	63.2
0.2	0.3	31.7	27.6	33.5	34.5	39.2	51.5	42.0	66.2	46.1	79.9
0.3	0.4	30.7	35.1	32.3	42.4	37.6	65.9	40.0	84.8	44.0	102.5
0.4	0.5	30.0	41.9	31.4	51.0	36.6	77.0	38.6	101.7	43.7	106.0
0.5	0.6	29.6	47.2	30.7	59.0	35.6	89.5	37.7	115.0	41.5	139.3
0.6	0.7	29.2	53.3	30.2	66.6	34.9	101.2	37.0	127.6	40.5	157.7
0.7	0.8	28.8	59.0	29.8	73.8	34.3	112.3	36.2	142.0	39.7	175.2
0.8	0.9	28.5	64.5	29.4	80.6	33.8	122.9	35.5	158.0	39.0	192.0
0.9	1	28.2	71.5	29.0	88.3	33.3	134.8	34.8	173.3	38.5	205.5

ROCK MASS STRENGTH - PROBABILISTIC STRENGTH MODEL
FIGURE N3

