ROCK MASS CLASSIFICATION

Md. Abdul Malek
Lecturer
Dept. of Geology and Mining

Introduction

Rock mass classification systems are used for various engineering design and stability analysis.

These are based on empirical relations between rock mass parameters and engineering applications, such as tunnels, slopes, foundations, and excavatability.

The idea of classification is not to replace analytical studies, field observations, measurements or engineering judgment but to have a common basis for categorizing into different groups.

To identify parameters influencing the behaviour of a rock mass and correspondingly divide the particular rock mass formation into groups is one of the key objectives of classification.

Objectives

The objectives of rock mass classifications are (after Bieniawski 1989):

1. Identify the most significant parameters influencing the behaviour of a rock mass.
2. Divide a particular rock mass formulation into groups of similar behaviour – rock mass classes of varying quality.
3. Provide a basis of understanding the characteristics of each rock mass class
4. Relate the experience of rock conditions at one site to the conditions and experience encountered at others
5. Derive quantitative data and guidelines for engineering design
6. Provide common basis for communication between engineers and geologists

Benefits

The main benefits of rock mass classifications are included:

- ✓Improving the quality of site investigations by calling for the minimum input data as classification parameters.
- ✓Providing quantitative information for design purposes.
- ✓Enabling better engineering judgement and more effective way of communication on a project.
- ✓Provide a basis for understanding the characteristics of each rock mass.

List of rock mass classifications

There are various categories of rock mass classifications, included-

1. Terzaghi‟s rock mass classification or rock load classification method.
2. Stand-up time classification
3. Rock Quality Designation (RQD)
4. Rock Structure Rating (RSR)
5. Rock Mass Rating System (RMR)
6. CSIR classification of jointed rock mass
7. Q-System (NGI Tunneling Index)

Rock Quality Designation (RQD)

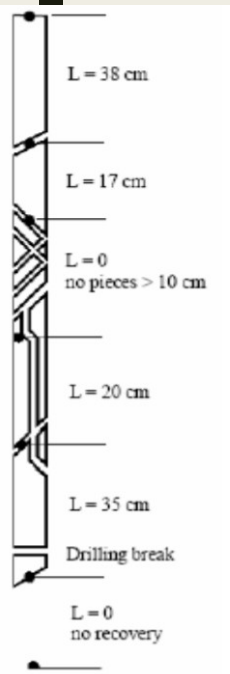
The Rock Quality Designing index (RQD) was developed by Deere in 1964 to provide a quantitative estimate of rock mass quality from drill core logs.

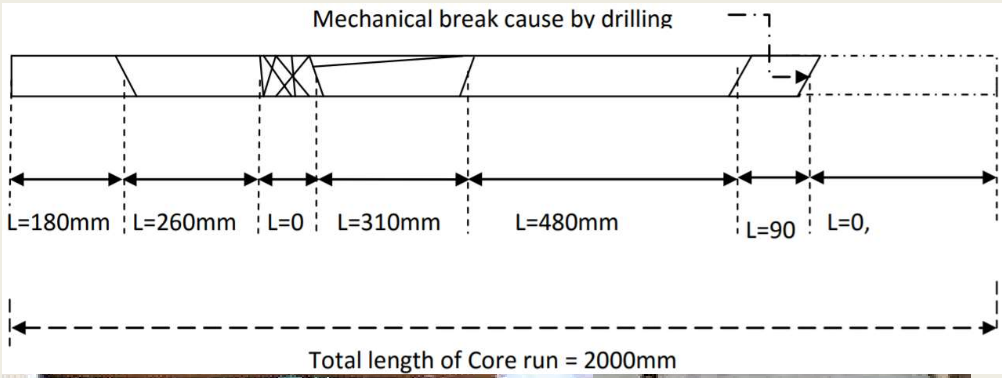
RQD is defined as the percentage of intact core pieces longer than 100 mm/10cm (4 inches) in the total length of core.

The core should be at least 54.7 mm or 2.15 inches in diameter and should be drilled with a double tube core barrel.

$$Core\ Recovery = \frac{\sum Length\ core\ pieces}{Total\ length\ of\ core\ run} \times 100 \qquad Core\ Recovery = \frac{18 + 26 + 31 + 48 + 9}{200} \times 100$$

$$RQD = \frac{\sum (Length\ core\ pieces > 10cm)}{Total\ length\ of\ core\ run} \times 100 \qquad RQD = \frac{18 + 26 + 31 + 48}{200} \times 100 = 61.5\%$$





Palmstrom (1982) suggested that, when no core is available but discontinuity traces are visible in surface exposures or exploration adits, the RQD may be estimated from the number of discontinuities per unit volume. The suggested relationship for clay-free masses is:-

$$RQD = 115 – 3.3\ J_v$$

Where, J_v *is the sum of number of joints per unit length for all joints sets known as the volumetric joint count.*

According to Merritt (1972), the RQD system has limitations in areas where the joints contain clay fillings.

The clay fillings would reduce the joint friction and the RQD would be high despite the fact that the rock is unstable.

The RQD is not a good parameter in the case of a rock mass with joint distances near 100 mm.

If the distance between continuous joints is 105 mm (core length), the RQD value will be 100%.

If the distance between continuous joints is 95 mm, the RQD value will be 0%.

Rock mass classification based on RQD

RQD	Rock Quality Classification
<25%	Very Poor
25-50%	Poor
50-75%	Fair
75-90%	Good
90-100%	Excellent

CSIR classification of jointed rock mass

Bieniawski, at the South African **Council of Scientific and Industrial Research** (CSIR) suggested that a classification for jointed rock mass should-

Divide the rock mass into groups of similar behaviour;

Provide a good basis for understanding the characteristics of the rock mass;

Facilitate the planning and the design of structures in rock by yielding quantitative data required for the solution of real engineering problems; and

Provide a common basis for effective communication among all persons concerned with a geomechanics problem.

The aims should be fulfilled by ensuring that the adopted classification is simple and meaningful in term, and based on measurable parameters which can be determined quickly and cheaply in field. In this regards, Bieniawski originally proposed the "Geomechanics Classification" should incorporate the following parameters:

- Rock Quality Designation (RQD),
- State of weathering,
- Uniaxial compressive strength of intact rock,
- Spacing of joints and bedding,
- Strike and dip orientations,
- Separation of joints,
- Continuity of joints, and
- Ground water inflow

Table – DEERE AND MILLER‟S CLASSIFICATION OF INTACT ROCK STRENGTH

Description	*Uniaxial Compressive Strength*			*Example of rock types*
	Lbf/in²	*kgf/cm²*	*MPa*	
Very low strength	150 – 3500	10 – 250	1 – 25	Chalk, rocksalt.
Low strength	3500 – 7500	250 – 500	25 – 50	Coal, siltstone, schist.
Medium strength	7500 – 15000	500 – 1000	50 – 100	Sandstone, slate, shale.
High strength	15000 – 30000	1000 – 2000	100 – 200	Marble, granite, gneiss.
Very high strength	> 30000	> 2000	> 200	Quartzite, dolerite, gabbro, basalt

Table – DEERE‟S CLASSIFICATION FOR JOINT SPACING

Description	Spacing of joints		*Rock mass grading*
Very wide	> 3 m	> 10 ft	Solid
Wide	1 m to 3 m	3 ft to 10 ft	Massive
Moderately close	0.3 m to 1 m	1 ft to 3 ft	Blocky/seamy
Close	50 mm to 300 mm	2 in to 1 ft	Fractured
Very close	< 50 mm	< 2 in	Crushed and shattered

CLASSIFICATION PARAMETERS AND THEIR RATINGS

PARAMETER			RANGES OF VALUES						
1.	Strength of intact rock material	Point load strength	> 8 MPa	4 – 8 MPa	2 – 4 MPa	1 – 2 MPa	For this low range uniaxial compressive test is preferred		
		Uniaxial compressive strength	> 250 MPa	100 – 250 MPa	50 – 100 MPa	25 -50 MPa	10 – 25 MPa	3 – 10 MPa	1 – 3 MPa
	Rating		15	12	7	4	2	1	0
2.	Drill core quality RQD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3.	Spacing of joints		> 3 m	1 – 3 m	0.3 – 1 m	50 – 300 mm	< 50 mm		
	Rating		30	25	20	10	5		
4.	Condition of joints		Very rough surfaces Not continuous No separation Hard joint wall rock	Slightly rough surfaces Separation < 1 mm Hard joint wall rock	Slightly rough surfaces Separation < 1 mm Soft joint wall rock	Slickensided surfaces or Gough < 5 mm thick or Joint open 1 – 5 mm Continuous joints	Soft gouge > 5 mm thick or Joints open > 5 mm Continuous joints		
	Rating		25	20	12	6	0		
5	Ground water	Inflow per 10 m tunnel length	None Or 0 Or Completely dry		< 25 litres/ min Or 0.0 – 0.2 Or Moist only (interstitial water)	25 – 125 litres/ min Or 0.2 – 0.5 Or Water under moderate pressure	> 125 litres/ min Or > 0.5 Or Severe water problems		
		Ratio: Joint water pressure/ major principal stress							
		General conditions							
	Rating		10		7	4	0		

RATING ADJUSTMENT FOR JOINT ORIENTATIONS

Strike and dip orientations of joints		Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
Rating	Tunnel	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	-60

ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 – 81	80 – 61	60 – 41	40 – 21	< 20
Class no.	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

MEANING OF ROCK MASS CLASSES

Class no.	I	II	III	IV	V
Average stand –up time	10 years for 5 m span	6 months for 4 m span	1 week for 3 m span	5 hours for 1.5 m span	10 min for 0.5 m span
Cohesion of the rock mass	> 300 kPa	200 – 300 kPa	150 – 200 kPa	100 – 150 kPa	< 100 kPa
Friction angle of the rock mass	> 45°	40° – 45°	35°– 40°	30° – 35°	< 30°

THE EFFECT OF JOINT STRIKE AND DIP ORIENTATIONS IN TUNNELING

Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		Dip 0° – 20° irrespective of strike
Drive with dip		Drive against dip				
Dip 45° – 90°	Dip 20° – 45°	Dip 45°– 90°	Dip 20°– 45°	Dip 45°– 90°	Dip 20° – 45°	
Very favourable	Favourable	Fair	Unfavourable	Very unfavourable	Fair	Unfavourable

Q-System (NGI Tunneling Index)

The Q-system is a classification system for rock masses with respect to stability of underground openings. The Q-system of rock mass classification was developed in Norway in 1974 by Nick Barton, Lien, R., and Lunde, J at NGI (Norwegian Geotechnical Institute).

It is a quantitative classification system and is an engineering system facilitating the design of tunnel supports.

It expresses the quality of the rock mass in the so-called Q-value, on which are based design and support recommendations for underground excavations.

The Q-value is determined with, $Q = \frac{RQD}{J_n} \text{ x } \frac{J_r}{J_a} \text{ x } \frac{J_w}{SRF}$

The Q-value is determined with, $Q = \frac{RQD}{Jn} \text{ x } \frac{Jr}{Ja} \text{ x } \frac{Jw}{SRF}$

Where RQD	- Rock Quality Designation
J_n	- Joint set number
J_r	- Joint roughness number
J_a	- Joint alteration number
J_w	- Joint water parameter
SRF	- Stress reduction factor

The first term RQD divided by J_n (joint set number) is related to the size of the intact rock blocks in the rock mass. The second term J_r (joint roughness number) divided by J_a (joint alteration number) is related to the shear strength along the discontinuity planes and the third term J_w (joint water parameter) divided by SRF (stress reduction factor) is related to the stress environment on the intact rock blocks and discontinuities around the underground excavation.

Q-logging ratings for RQD, Jn , Jr , Ja , Jw ……… and SRF (Barton, 2002)

1. Rock Quality Designation		RQD (%)
A	Very poor	0-25
B	Poor	25-50
C	Fair	50-75
D	Good	75-90
E	Excellent	90-100

Notes:

i) Where RQD is reported or measured as £ 10 (including 0), a nominal value of 10 is used to evaluate Q.

ii) RQD intervals of 5, i.e., 100, 95, 90, etc., are sufficiently accurate.

2. Joint set number		J_n
A	Massive, no or few joints	0.5-1
B	One joint set	2
C	One joint set plus random joints	3
D	Two joint sets	4
E	Two joint sets plus random joints	6
F	Three joint sets	9
G	Three joint sets plus random joints	12
H	Four or more joint sets, random, heavily jointed, 'sugar-cube', etc.	15
J	Crushed rock, earthlike	20

Notes:

i) For tunnel intersections, use (3.0 × Jn).

ii) For portals use (2.0 × Jn).

3. Joint roughness number		J_r
a) Rock-wall contact, and b) Rock-wall contact before 10 cm shear		
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slickensided, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slickensided, planar	0.5
b) No rock-wall contact when sheared		
H	Zone containing clay minerals thick enough to prevent rock-wall contact.	1.0
J	Sandy, gravely or crushed zone thick enough to prevent rock-wall contact	1.0

Notes:

Descriptions refer to small-scale features and intermediate scale features, in that order.

Add 1.0 if the mean spacing of the relevant joint set is greater than 3 m.

Jr = 0.5 can be used for planar, slickensided joints having lineations. τ (where $\tau \approx \sigma n \tan^{-1}$ (Jr /Ja).

	4. Joint alteration number	Φ_r approx.	J_a
a) Rock-wall contact (no mineral fillings, only coatings)			
A	Tightly healed, hard, non-softening, impermeable filling, i.e., quartz or epidote.	--	0.75
B	Unaltered joint walls, surface staining only.	25-35°	1.0
C	Slightly altered joint walls. Non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc.	25-30°	2.0
D	Silty- or sandy-clay coatings, small clay fraction (non-softening).	20-25°	3.0
E	Softening or low friction clay mineral coatings, i.e., kaolinite or mica. Also chlorite, talc, gypsum, graphite, etc., and small quantities of swelling clays.	8-16°	4.0

b) Rock-wall contact before 10 cm shear (thin mineral fillings).			
F	Sandy particles, clay-free disintegrated rock, etc.	25-30°	4.0
G	Strongly over-consolidated non-softening clay mineral fillings (continuous, but < 5 mm thickness).	16-24°	6.0
H	Medium or low over-consolidation, softening, clay mineral fillings (continuous, but < 5 mm thickness).	12-16°	8.0
J	Swelling-clay fillings, i.e., montmorillonite (continuous, but < 5 mm thickness). Value of J_a depends on per cent of swelling clay-size particles, and access to water, etc.	6-12°	8-12
c) No rock-wall contact when sheared (thick mineral fillings)			
K,L & M	Zones or bands of disintegrated or crushed rock and clay (see G, H, J for description of clay condition).	6-24°	6, 8, or 8-12
N	Zones or bands of silty- or sandy-clay, small clay fraction (non-softening).	--	5.0
O,P & R	Thick, continuous zones or bands of clay (see G, H, J for description of clay condition).	6-24°	10, 13, or 13-20

	5. Joint water reduction factor	approx. water pres. (kg/cm^2)	J_w
A	Dry excavations or minor inflow, i.e., < 5 l/min locally.	< 1	1.0
B	Medium inflow or pressure, occasional outwash of joint fillings.	1-2.5	0.66
C	Large inflow or high pressure in competent rock with unfilled joints.	2.5-10	0.5
D	Large inflow or high pressure, considerable outwash of joint fillings.	2.5-10	0.33
E	Exceptionally high inflow or water pressure at blasting, decaying with time.	> 10	0.2-0.1
F	Exceptionally high inflow or water pressure continuing without noticeable decay.	> 10	0.1-0.05

Notes:

i) Factors C to F are crude estimates. Increase Jw if drainage measures are installed.

ii) Special problems caused by ice formation are not considered.

iii) For general characterization of rock masses distant from excavation influences, the use of J_w=1.0, 0.66, 0.5, 0.33 etc. as depth increases from say 0-5m, 5-25m, 25-250m to >250m is recommended, assuming that RQD/J_n is low enough for good hydraulic connectivity.

	6. Stress Reduction Factor	SRF
	a) Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated	
A	Multiple occurrences of weakness zones containing **clay** or chemically disintegrated rock, very loose surrounding rock (any depth).	10
B	Single weakness zones containing **clay** or chemically disintegrated rock (depth of excavation ≤ 50 m).	5
C	Single weakness zones containing **clay** or chemically disintegrated rock (depth of excavation > 50 m).	2.5
D	Multiple shear zones in competent rock (**clay-free**), loose surrounding rock (any depth).	7.5
E	Single shear zones in competent rock (**clay-free**), (depth of excavation ≤ 50 m).	5.0
F	Single shear zones in competent rock (**clay-free**), (depth of excavation > 50 m).	2.5
G	Loose, open joints, heavily jointed or 'sugar cube', etc. (any depth)	5.0

Notes:

i) Reduce these values of SRF by 25-50% if the relevant shear zones only influence but do not intersect the excavation. This will also be relevant for characterization.

	b) Competent rock, rock stress problems	σ_c/σ_1	σ_φ/σ_c	SRF
H	Low stress, near surface, open joints.	> 200	< 0.01	2.5
J	Medium stress, favourable stress condition.	200-10	0.01-0.3	1
K	High stress, very tight structure. Usually favourable to stability, may be unfavourable for wall stability.	10-5	0.3-0.4	0.5-2
L	Moderate slabbing after > 1 hour in **massive** rock.	5-3	0.5-0.65	5-50
M	Slabbing and rock burst after a few minutes in **massive** rock.	3-2	0.65-1	50-200
N	Heavy rock burst (strain-burst) and immediate dynamic deformations in **massive** rock.	< 2	> 1	200-400

Notes:

i) For strongly anisotropic virgin stress field (if measured): When $5 \leq \sigma_1 / \sigma_3 \leq 10$, reduce σ_c to 0.75 σ_c. When $\sigma_1 / \sigma_3 > 10$, reduce σ_c to 0.5 σ_c, where σ_c = unconfined compression strength, σ_1 and σ_3 are the major and minor principal stresses, and σ_θ = maximum tangential stress (estimated from elastic theory).

Notes (continue):

ii) Few case records available where depth of crown below surface is less than span width. Suggest an SRF increase from 2.5 to 5 for such cases (see H).

iii) Cases L, M, and N are usually most relevant for support design of deep tunnel excavations in hard massive rock masses, with RQD /Jn ratios from about 50 to 200.

iv) For general characterization of rock masses distant from excavation influences, the use of SRF = 5, 2.5, 1.0, and 0.5 is recommended as depth increases from say 0-5m, 5-25m, 25-250m to >250m. This will help to adjust Q for some of the effective stress effects, in combination with appropriate characterization values of Jw. Correlations with depth - dependent static deformation modulus and seismic velocity will then follow the practice used when these were developed.

c) Squeezing rock: plastic flow of incompetent rock under the influence of high rock pressure		$\sigma_\varphi / \sigma_c$	SRF
O	Mild squeezing rock pressure	1-5	5-10
P	Heavy squeezing rock pressure	> 5	10-20

Notes:

vi) Cases of squeezing rock may occur for depth $H > 350\ Q^{1/3}$ according to Singh 1993. Rock mass compression strength can be estimated from SIGMA cm $\approx 5\ \gamma\ Q_c^{1/3}$ (MPa) where γ = rock density in t /m^3, and $Q_c = Q \times \sigma_c /100$, Barton, 2000.

d) Swelling rock: chemical swelling activity depending on presence of		SRF
R	Mild swelling rock pressure	5-10
S	Heavy swelling rock pressure	10-15