MKAJ 1073 ENGINEERING ROCK MECHANICS

ROCK MASS RATING (RMR)

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Classification of rocks based on geological aspects are subjective: igneous, sediment & metamorphic.

For design & construction, objective classification (numerical values) is more appropriate – classification of rock based on prevailing weakness planes, number of joint set, & engineering properties like strength, weathering grade & permeability.

The objectives of rock mass classification:

- **Identify the most important parameters influencing the rock mass**
- **Divide a rock mass formation into groups of similar behaviour**
- **Derive quantitative data and guidelines for engineering design**
- **Provide common basis for communication between geologist and engineers**

Rock Mass Rating, RMR:

Also called geomechanics classification, based on the work of Bieniawski (1973)

The system includes 'stand-up time' of an unsupported excavation' & 6 other parameters:
- **uniaxial compressive strength of intact rock material, UCS**
- **Rock quality designation, RQD**
- **Joint or discontinuity spacing**
- **Conditions of discontinuity (infilling, persistence)**
- **Conditions of groundwater**
- **Orientation of discontinuity (strike & dip angle).**

Collection of field data for RMR:

The rating of 6 parameters of the RMR are given in Table 1 to 6.

For eliminating doubts due to subjective judgments, the rating for different parameters should be given a range in preference to a single value.

(1) Uniaxial compressive strength of intact rock material (UCS)

The strength of the intact rock material should be obtained from rock cores, the ratings based on uniaxial compressive strength (preferred) & point-load strength as shown in Table 1.

Qualitative description	Compressive Strength (MPa)	Point-load strength (MPa)	Rating
Exceptionally strong	> 250	8	15
Very strong	100 – 250	4 – 8	12
Strong	50 – 100	2 – 4	7
Average	25 – 50	1 – 2	4
Weak	10 – 25	Use of uniaxial compressive strength is preferred	2
Very weak	2 – 10	- do -	1
Extremely weak	1 – 2	- do -	0
Note: At compressive strength less than 0.6 MPa, many rock material would be regarded as soil			

Table 1: Strength of intact rock material (Bieniawski, 1989)

(2) Rock Quality Designation (RQD)

RQD should be determined as previously discussed and rating are given in Table 2.

Qualitative description	RQD (%)	Rating
Excellent	90 - 100	20
Good	75 - 90	17
Fair	50 - 75	13
Poor	25 - 50	8
Very poor	0 - 25	3

Table 2: Rock Quality Designation RQD (Bieniawski, 1989)

(3) Spacing of discontinuities

The term discontinuity includes joints, beddings or foliations, shear zones, minor faults, or other weakness planes. The linear distance between two adjacent discontinuities should be measured for all sets of discontinuities & the rating should be obtained from Table 3 for the most critical discontinuity.

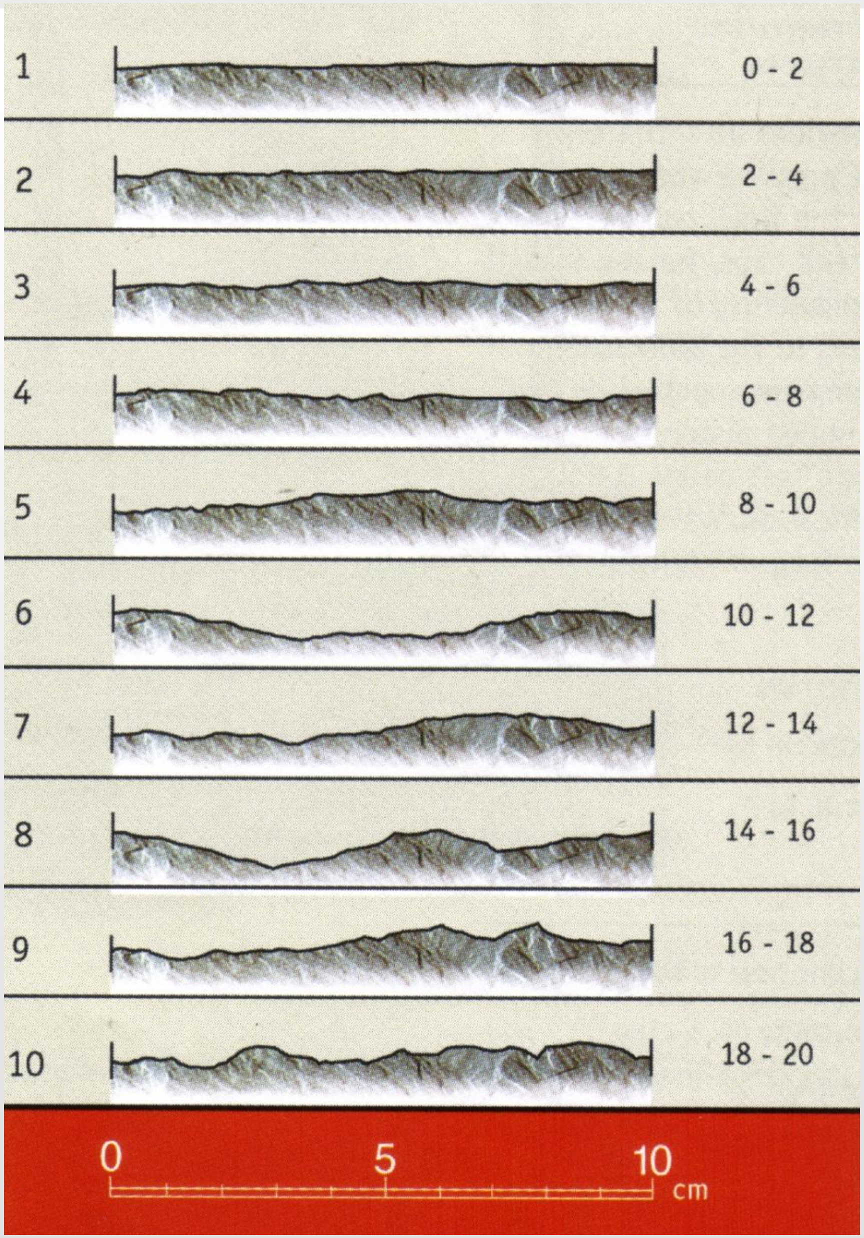
Description	Spacing (m)	Rating
Very wide	> 2	20
Wide	0.6 – 2	15
Moderate	0.2 – 0.6	10
Close	0.06 – 0.2	8
Very close	< 0.06	5
Note: If more than one discontinuities sets are present and the spacing of discontinuities of each set varies, consider the set with the lowest rating		

Table 3: Spacing of discontinuities (Bieniawski, 1989)

(4) Condition of discontinuity

This parameter includes roughness of discontinuity surfaces, their separation (aperture or opening), length or continuity, weathering of the discontinuity surfaces, and infilling (gouge) material. The details of rating are given in Table 4.

Roughness


1
0 - 2
2
2 - 4
3
4 - 6
4
6 - 8
5
8 - 10
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10 - 12
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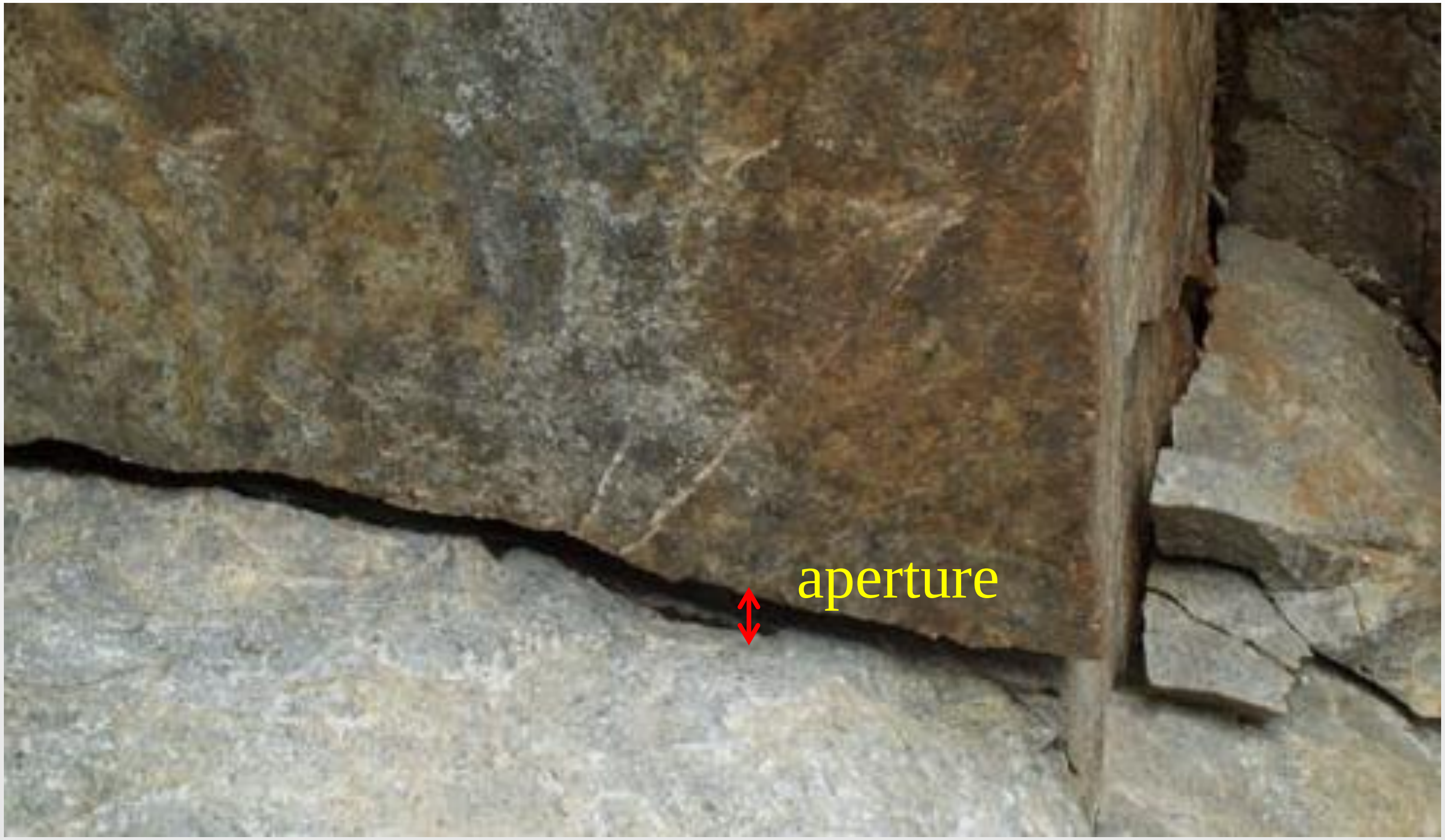


Aperture

Infilling

Description	Rating
Very rough and weathered, wall rock tight and discontinuous, no separation	30
Rough and slightly weathered, wall rock surface separation < 1 mm	25
Slightly rough and moderately to highly weathered, wall rock surface separation < 1 mm	20
Slickensided wall rock surface or 1 – 5 mm thick gouge or 1 – 5 mm wide continuous discontinuity	10
5 mm thick soft gouge, 5 mm wide continuous discontinuity	0

Table 4: Condition of discontinuities (Bieniawski, 1989)

(5) Ground water condition

In the case of tunnel, the rate of inflow of ground water in litres per minute per 10 m length of the tunnel should be determined, or general condition can be described as completely dry, damp, wet dripping & flowing.

If actual water pressure data is available, these should be stated & expressed in terms of the ratio of the seepage pressure to the major principal stress.

The ratings as per the water condition are given in Table 5.

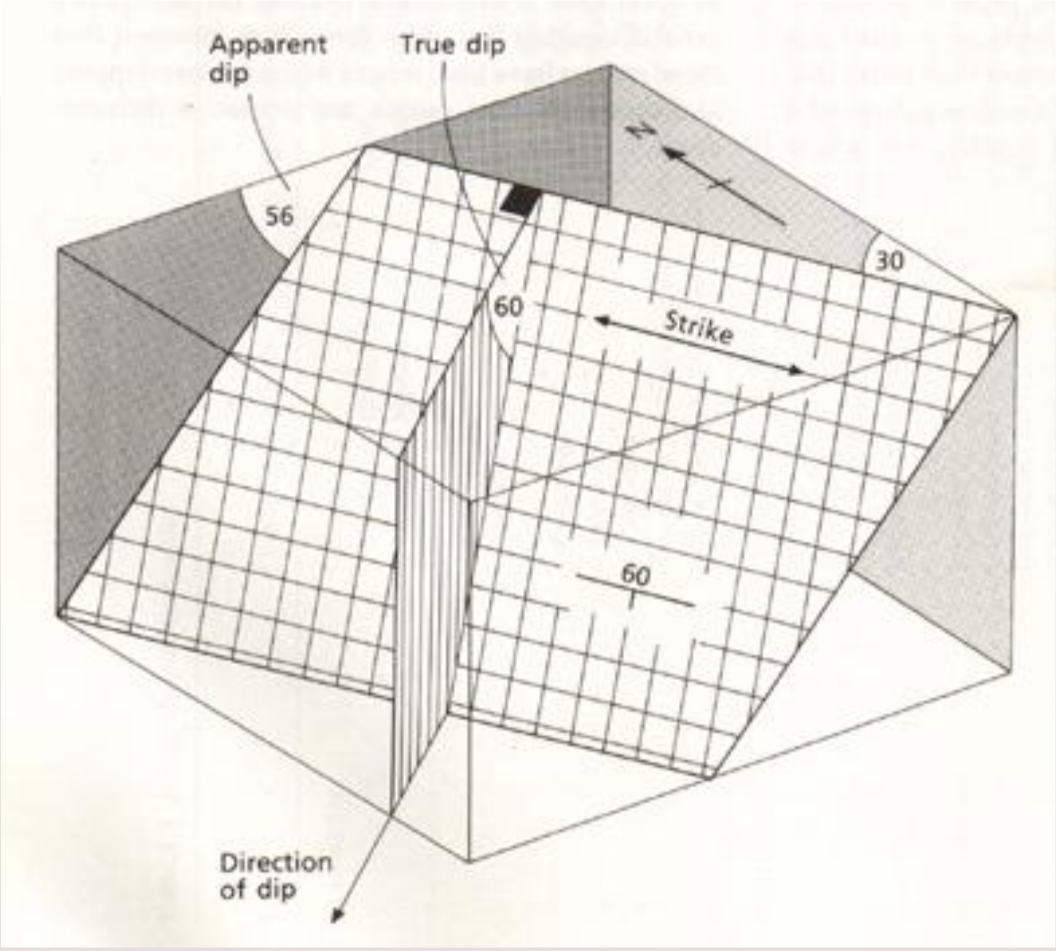
Inflow per 10m tunnel length (litre/min)	**None**	**< 10**	**10 – 25**	**25 – 125**	**> 125**
Joint water pressures / major principal stress	**0**	**0 – 0.1**	**0.1 – 0.2**	**0.2 – 0.5**	**> 0.5**
General description	**Completely dry**	**damp**	**wet**	**dripping**	**flowing**
Rating	**15**	**10**	**7**	**4**	**0**

Table 5: Ground water condition (Bieniawski, 1989)

Rating of the above 5 parameters (Table 1 to Table 5) are added to obtain what is called the basic rock mass rating - RMR_{basic}

- uniaxial compressive strength of intact rock material, UCS
- Rock quality designation, RQD
- Joint or discontinuity spacing
- Conditions of discontinuity (infilling, persistence)
- Conditions of groundwater
- Orientation of discontinuity (strike & dip angle).

(6) Orientation of discontinuities
Orientation of discontinuities means the DIP and STRIKE of discontinuities (weakness planes).



Joint measurement using BRUNTON COMPASS

The value of the dip and strike should be recorded as shown in Table 6, the orientation of tunnel axis or slope face or foundation alignment should also be recorded.

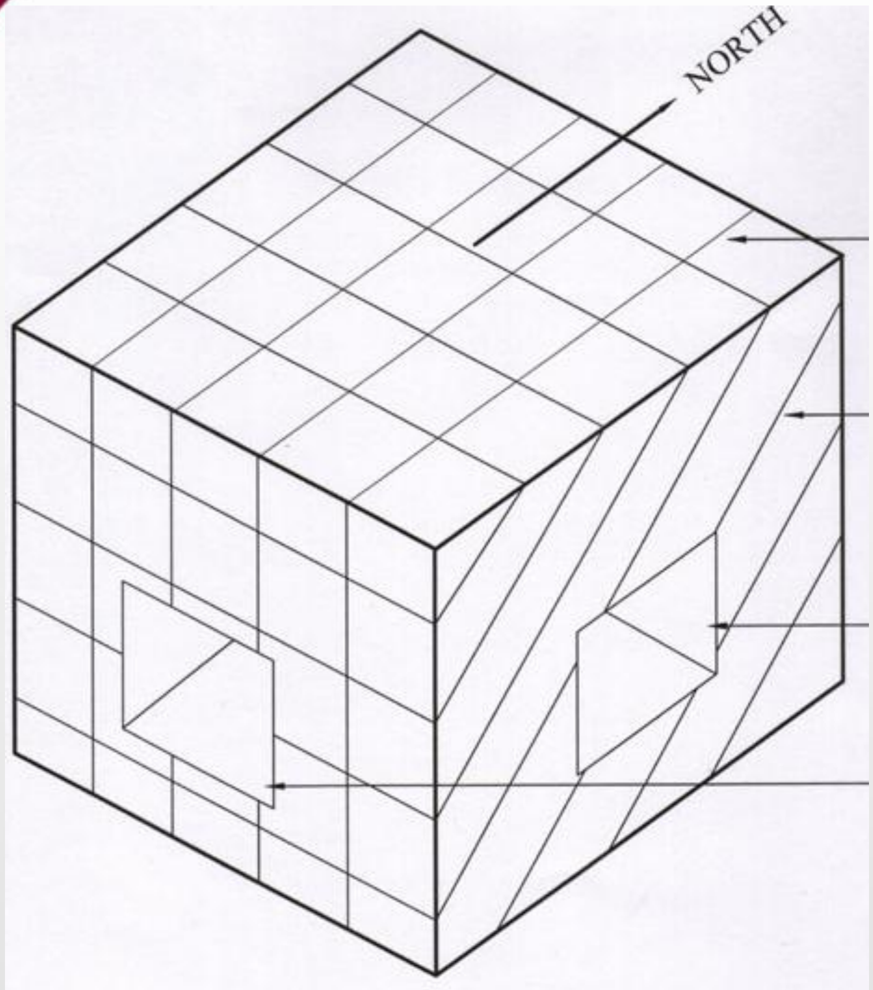
A. Orientation of tunnel/slope/foundation axis: ....
B. Orientation of discontinuities **Set-1 Average strike: ..... (from ..... to .....) Dip .....** **Set-2 Average strike: ..... (from ..... to .....) Dip .....** **Set-3 Average strike: ..... (from ..... to .....) Dip .....**

Table 6: Orientation of discontinuities

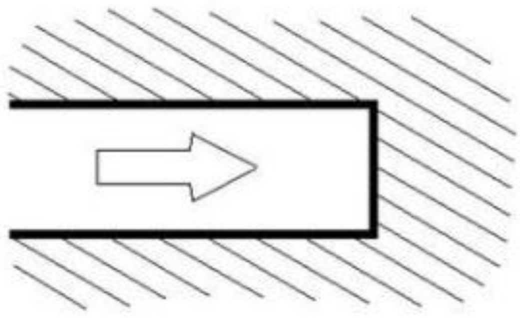
(6) Orientation of discontinuities
The influence of the strike & dip of the discontinuities is considered with respect to the direction of tunnel drive or slope face orientation or foundation alignment.

To facilitate a decision whether the strike & dip are favourable or not, reference should be made to Table 7 & Table 8 which provide a quantitative assessment of critical joint orientation effect with respect to tunnels & dams foundation respectively.

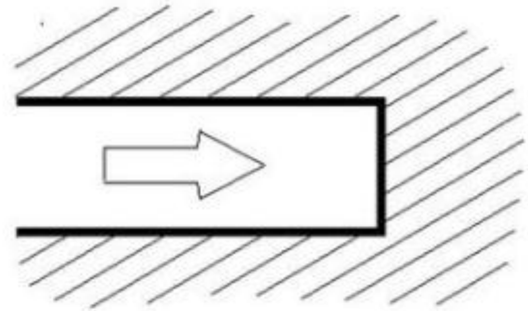
Once the ratings for the effect of the critical discontinuity are known, as shown in Table 9 an arithmetic sum of the joint adjustment rating in and the RMRbasic is obtained. This number is called the final rock mass rating RMR.


NORTH


KJØR
SAKTE



Drive with dip



Drive against dip

Strike perpendicular to tunnel				Strike parallel to tunnel axis	
Drive with dip		Drive against dip			
Dip 45^0 - 90^0	Dip 20^0 - 45^0	Dip 45^0 - 90^0	Dip 20^0 - 45^0	Dip 20^0 - 45^0	Dip 45^0 - 90^0
Very favourable	Favourable	Fair	Unfavoura-ble	Fair	Very un-favourable

Table 7: Assessment of joint orientation effect on tunnels (dips are apparent dips along tunnel axis) (Bieniawski, 1989)

Dip 0^0 - 10^0	Dip 0^0 - 10^0		Dip 30^0 - 60^0	Dip 60^0 - 90^0
	Dip direction			
	Upstream	Downstream		
Very favourable	Unfavourable	Fair	Favourable	Very Unfavourable

Table 8: Assessment of joint orientation effect on stability of dam foundation (Bieniawski, 1989)

Joint orientation assessment for:	Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Tunnels	0	-2	-5	-10	-12
Raft foundation	0	-2	-7	-15	-25
Slopes	0	-5	-25	-50	-60

Table 9: Adjustment for joint orientation (Bieniawski, 1989)

Estimation of RMR:

The rock mass rating is an algebraic sum of ratings for all the parameters in Table 1 to 5 & Table 9, after the adjustments for orientation of discontinuities given in Table 7 and 8.

The sum of ratings for 4 parameters in Table 2 to Table 5 is called Rock Condition Rating (RCR) which discounts the effect of strength (σ_c) of intact rock material & orientation of joints.

Heavy blasting creates new fractures, hence it is suggested that 10 points should be added to get RMR for undisturbed rock masses (e.g. excavation by TBM & road headers), and 3 to 5 points may be added depending upon the quality of the controlled blasting.

On the basis of RMR values for a given engineering structure, the rock mass is classified in 5 classes (see Table 10) as:

Group I:	**Very good**	**RMR 100 – 81**
Group II:	**Good**	**RMR 80 – 61**
Group III:	**Fair**	**RMR 60 – 41**
Group IV:	**Poor**	**RMR 40 – 21**
Group V:	**Very poor**	**RMR < 20.**

Separate RMR should be obtained for tunnels of different orientations after taking into account the orientation of tunnel axis with respect to the critical joint set (Table 6).

In terms of quality & mass strength, group I rock is more suitable for excavation of tunnel compared to groups with lower RMR, the tunnel also requires less support.

Parameters & properties of rock mass	Rock Mass Rating (Rock Class)				
	100-81 (I)	80-61 (II)	60-41(III)	40-21 (IV)	< 20 (V)
Classification of rock mass	Very good	Good	Fair	Poor	Very poor
Average stand-up time	10 years for 15 m span	6 months for 8 m span	1 week for 5 m span	10 hours for 2.5 m span	30 min.for 1 m span
Cohesion of rock mass (MPa)*	> 0.4	0.3 – 0.4	0.2 – 0.3	0.1 – 0.2	< 0.1
Angle of internal friction of rock mass	> 45^0	35^0 – 45^0	25^0 – 35^0	15^0 – 25^0	15^0
Note * These values are applicable to slopes only in saturated and weathered rock mass					

Table 10: Design parameters & engineering properties of rock mass (Bieniawski, 1989)

Separate RMR should be obtained for tunnels of different orientations after taking into account the orientation of tunnel axis with respect to the critical joint sets (Table 6).

RMR can be used for estimating many useful parameters such as the unsupported span, the stand-up time (bridging action period) & the support pressure for an underground opening.

It can also be used for selecting a method of excavation & permanent support system for underground excavation in rock (Bieniawski, 1976).

Deformation modulus & allowable bearing pressure may also be estimated.

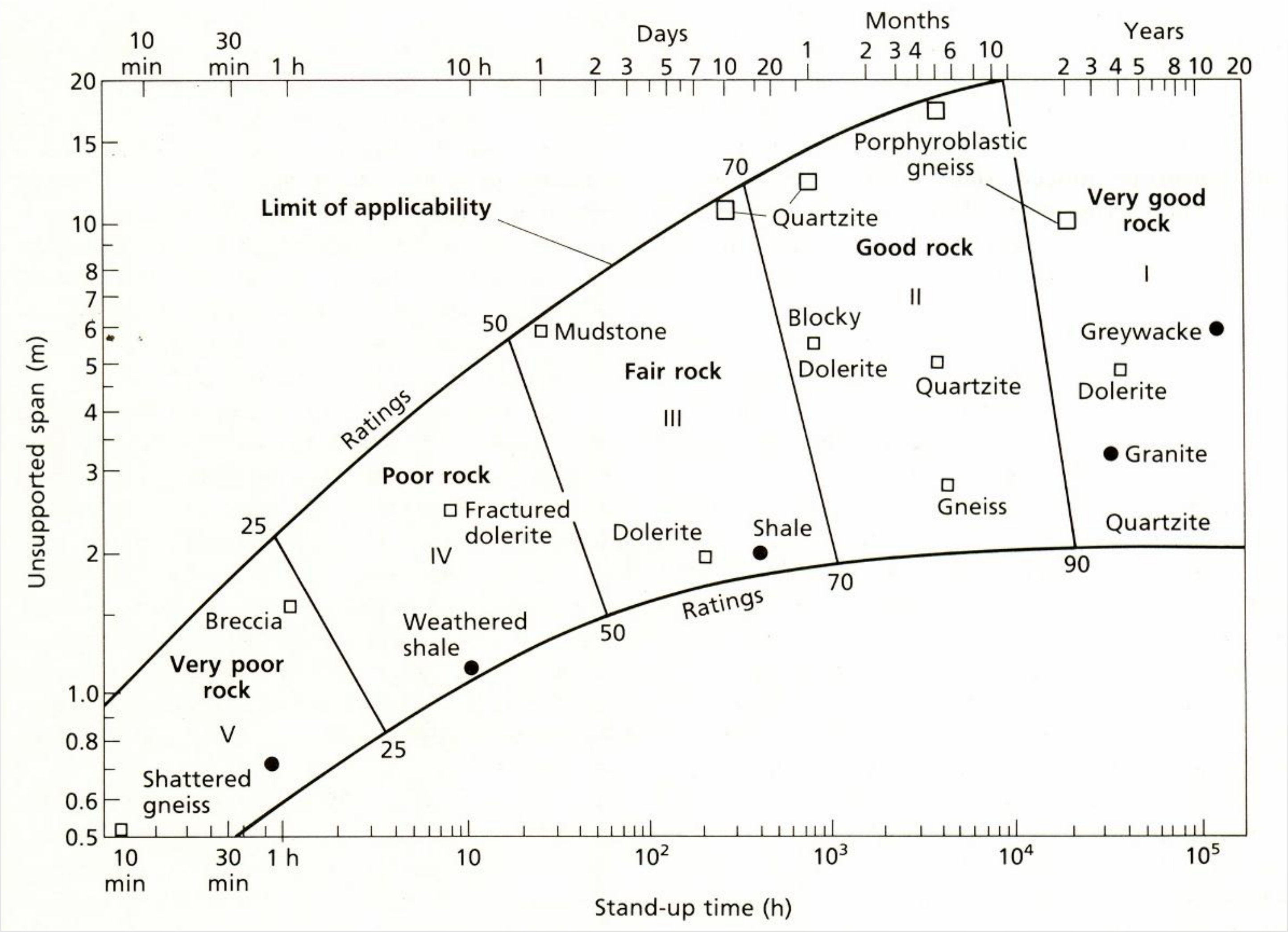
Application of RMR:

(1) Average stand-up time for arched roof:

The stand-up time depends upon effective span of the opening which is defined as the width of the opening or the distance between the tunnel face and the last support, whichever is smaller. For arched openings the stand-up time would be significantly higher than that for a flat roof.

Controlled blasting will further increase the stand-up time as damage to the rock mass is decreased.

It is important not to delay supporting of the roof in the case of rock with high stand-up time, as this may lead to deterioration in the rock which ultimately reduces the stand-up time.



Relationship between RMR rating, stand-up time & Unsupported span (Bieniawski, 1989)

Bieniawski (1989) provides a comprehensive guidelines for selection of tunnel stabilisation methods. This is applicable to tunnels excavated with conventional drill & blast method.

These guidelines depend upon factors like depth below surface (in situ overburden stress) tunnel size & shape & method of excavation. The stabilisation measures are the permanent and not temporary (or primary) support.

Excavation shape: horseshoe; width: 10m; vertical stress: 25MPa; construction method drill and blast				
Rock Mass	**Excavation**	**Support**		
Rating		Rock bolts (20mm dia. fully bonded)	Shotcrete	Steel sets
Very good rock (I) RMR: 81-100	Full face 3m advance	Generally, no support required except for occasional spot bolting		
Good rock (II) RMR: 61-80	Full face 1.0-1.5m advance. Complete support 20m from face.	Local bolts in crown 3m long, spaced 2.5m with occasional wire mesh.	50mm in crown where required	None
Fair rock (III) RMR: 41-60	Top heading and bench 1.5 - 3m in advance top heading. Commence support after each blast. Complete support 10m from face.	Systematic bolts 4m long, spaced 1 - 2m in crown and walls with wire mesh in crown.	50 - 100mm in crown and 100mm in sides	None
Poor rock (IV) RMR 21-40	Top heading and bench 1.0 - 1.5m advance in top heading. Install support concurrently with excavation 10m from face.	Systematic bolts 4 - 5m long, spaced 1 - 1.5m in crown and walls with wire mesh.	100 - 150mm in crown and 100mm in sides	Light to medium ribs spaced 1.5m where required
Very poor rock (V) RMR < 20	Multiple drifts. 0.5 - 1.5m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting.	Systematic bolts 5 - 6m long, spaced 1 - 1.5m in crown and walls with wire mesh. Bolt invert	150 - 200mm in crown, 150mm in sides and 50mm on face	Medium to heavy ribs spaced 0.75m with steel lagging and forepoling if required

Table 11: RMR guide for excavation & stabilisation methods in rock tunnel (Bieniawski, 1989)

Reference:

1. **Bieniawski, 1989. Engineering Rock Mass Classification. John Wiley & Sons. Canada**