ROCK MECHANICS

Rock classification

Hasan Ghasemzadeh

Rock classification

- Terzaghi classification
- Goodman classification
- Total/Solid Core Recovery(TCR/SCR)
- Rock Quality Designation (RQD)
- Rock Structure Rating (RSR)
- Rock Mass Rating (RMR)
- Tunneling Rock Quality Index (Q)

Terzaghi classification (1946)

- Intact rock
- Stratified rock
- Moderately jointed rock
- Blocky & seamy rock
- Crushed rock
- Squeezing rock
- Swelling rock

Goodman classification(1980)

- Crystalline texture
- Clastic texture
- Very fine-grained rock
- Organic rock

Goodman classification(1980)

- Crystalline texture

Dolomite

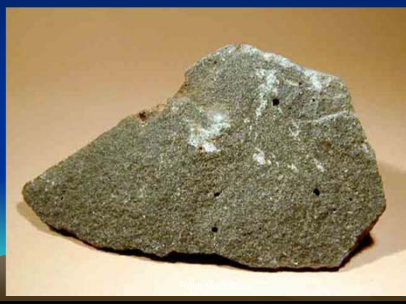
Goodman classification(1980)

- Crystalline texture

Gneiss

Goodman classification(1980)

- Very fine-grained rock



Basalt

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Goodman classification(1980)

- Very fine-grained rock

Slate

Rock Mechanics ٨

Goodman classification(1980)

- Very fine-grained rock

Rock Mechanics ٩

Goodman classification(1980)

- Organic rock

Coal

Rock Mechanics ١٠

Total Core Recovery(TCR)

Interbeds

- **Basalt Breccia**

$$TCR = \frac{l_{\text{sum of pieces}}}{l_{\text{tot core run}}} \times 100\%$$

Rock Mechanics ١١

Solid Core Recovery(SCR)

- **Vesicular Basalt**

$$SCR = \frac{l_{\text{sum of solid core pieces}}}{l_{\text{tot core run}}} \times 100\%$$

Rock Mechanics ١٢

Rock Quality Designation (RQD)

- Basalt interiors

$$RQD = \frac{l_{\text{sum of core pieces >10cm length}}}{l_{\text{tot core run}}} \times 100\%$$

Rock Mechanics ۱۳

RQD

(2m window: RQD = 20 to 50 …. May need to measure)

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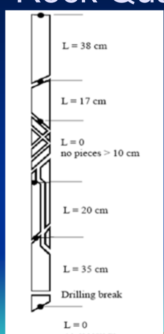
Rock Quality Designation (RQD)



Deere (1989)

مثال

total core length=200

$$RQD = \frac{l_{\text{sum of core pieces >10cm length}}}{l_{\text{tot core run}}} \times 100\%$$

$$RQD = \frac{38+17+20+35}{200} \times 100\% = 55\%$$

Rock Mechanics ۱۴

Rock Structure Rating (**RSR**)

نوع و سختی سنگ و ساختار زمین شناسی ؟

فاصله و جهت درزه ها ؟

جریان آب؟

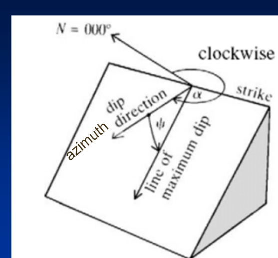
Rock Mechanics ۱۷

Rock Quality Designation (RQD)

RQD= {(core longer than 100mm)/(total core length mm)}*100

Rock quality	RQD
Very poor	0-25
Poor	25-50
Fair	50-75
Good	75-90
Excellent	90-100

Rock Mechanics ۱۵



dip direction (three digits)/dip (two digits)

035/70, 290/15

جهت درزه

آزیموت و شیب را میتوان با استفاده از قطب نما و شیب سنج اندازه گرفت

Azimuth=dip direction

Strike معمولا بین صفر تا ۱۸۰ درجه بیان می شود

$$strike = \alpha - 90 \pm (180)$$

Rock Mechanics ۱۸

Rock Structure Rating (**RSR**)

Vickham et al. (1972)

RSR=A+B+C=<100

A : General geology

	Basic Rock Type				Geological Structure			
	Hard	Medium	Soft	Decomposed	Massive	Slightly Folded or Faulted	Moderately Folded or Faulted	Intensively Folded or Faulted
Igneous	1	2	3	4				
Metamorphic	1	2	3	4				
Sedimentary	2	3	4	4				
Type 1					30	22	15	9
Type 2					27	20	13	8
Type 3					24	18	12	7
Type 4					19	15	10	6

Parameter A, Geology: General appraisal of geological structure on the basis of:

a. Rock type origin (igneous, metamorphic, sedimentary).
b. Rock hardness (hard, medium, soft, decomposed).
c. Geologic structure (massive, slightly faulted/folded, moderately faulted/folded, intensely faulted/folded).

Rock Structure Rating (**RSR**)

B : Joint pattern

	Strike ⊥ to Axis					Strike ‖ to Axis		
	Direction of Drive					Direction of Drive		
	Both	With Dip		Against Dip		Either direction		
	Dip of Prominent Joints [a]					Dip of Prominent Joints		
Average joint spacing	Flat	Dipping	Vertical	Dipping	Vertical	Flat	Dipping	Vertical
1. Very closely jointed, < 2 in	9	11	13	10	12	9	9	7
2. Closely jointed, 2-6 in	13	16	19	15	17	14	14	11
3. Moderately jointed, 6-12 in	23	24	28	19	22	23	23	19
4. Moderate to blocky, 1-2 ft	30	32	36	25	28	30	28	24
5. Blocky to massive, 2-4 ft	36	38	40	33	35	36	24	28
6. Massive, > 4 ft	40	43	45	37	40	40	38	34

[a] Dip: flat: 0-20°; dipping: 20-50°; and vertical: 50-90°

Rock Structure Rating (**RSR**)

C : Ground water, joint condition

	Sum of Parameters *A + B*					
	13 - 44			45 - 75		
Anticipated water inflow	Joint Condition [b]					
gpm/1000 ft of tunnel	Good	Fair	Poor	Good	Fair	Poor
None	22	18	12	25	22	18
Slight, < 200 gpm	19	15	9	23	19	14
Moderate, 200-1000 gpm	15	22	7	21	16	12
Heavy, > 1000 gp	10	8	6	18	14	10

Parameter C: Effect of groundwater inflow and joint condition on the basis of:

a. Overall rock mass quality on the basis of A and B combined.
b. Joint condition (good, fair, poor).
c. Amount of water inflow (in gallons per minute per 1000 feet of tunnel).

[b] Joint condition: good = tight or cemented; fair = slightly weathered or altered; poor = severely weathered, altered or open

Gpm=3.785 liter per minute

Rock Mass Rating (RMR)
Geomechanics classification

Bieniawski (1976-1989)

Numerous amendments since 1976 For assessing the stability of rock slopes

- strength of the intact rock
- RQD
- Groundwater

Discontinuities

- Spacing, length, roughness
- Aperture width, infill, weathering

RMR=A1+A2+A3+(A4 or E)+A5+B=<100

ROCK MASS RATING (**RMR**)

Bieniawski (1989)

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Range of values						
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 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 discontinuities		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125		
		(Joint water press)/(Major principal σ)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

ROCK MASS RATING (**RMR**)

Bieniawski (1989)

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)						
Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	
C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS						
Rating		100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number		I	II	III	IV	V
Description		Very good rock	Good rock	Fair rock	Poor rock	Very poor rock
D. MEANING OF ROCK CLASSES						
Class number		I	II	III	IV	V
Average stand-up time		20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)		> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)		> 45	35 - 45	25 - 35	15 - 25	< 15

ROCK MASS RATING (**RMR**)

Bieniawski (1989)

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions					
Discontinuity length (persistence) Rating	< 1 m 6	1 - 3 m 4	3 - 10 m 2	10 - 20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1 - 1.0 mm 4	1 - 5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Ratings	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**			
Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	Fair	

Rock Mechanics ۲۵

Rock Mass Rating (**RMR**)

Rock mass class	Excavation	Rock bolts (20 mm diameter, fully grouted)	Shotcrete	Steel sets
I - Very good rock *RMR*: 81-100	Full face, 3 m advance.	Generally no support required except spot bolting.		
II - Good rock *RMR*: 61-80	Full face , 1-1.5 m advance. Complete support 20 m from face.	Locally, bolts in crown 3 m long, spaced 2.5 m with occasional wire mesh.	50 mm in crown where required.	None.
III - Fair rock *RMR*: 41-60	Top heading and bench 1.5-3 m advance in top heading. Commence support after each blast. Complete support 10 m from face.	Systematic bolts 4 m long, spaced 1.5 - 2 m in crown and walls with wire mesh in crown.	50-100 mm in crown and 30 mm in sides.	None.
IV - Poor rock *RMR*: 21-40	Top heading and bench 1.0-1.5 m advance in top heading. Install support concurrently with excavation, 10 m from face.	Systematic bolts 4-5 m long, spaced 1-1.5 m in crown and walls with wire mesh.	100-150 mm in crown and 100 mm in sides.	Light to medium ribs spaced 1.5 m where required.
V – Very poor rock *RMR*: < 20	Multiple drifts 0.5-1.5 m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting.	Systematic bolts 5-6 m long, spaced 1-1.5 m in crown and walls with wire mesh. Bolt invert.	150-200 mm in crown, 150 mm in sides, and 50 mm on face.	Medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if required. Close invert.

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RMR for slopes or tunnels

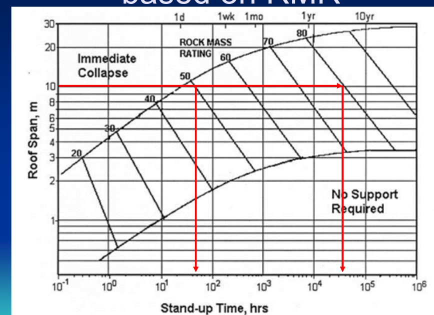
Additional factors applied to RMR_{basic}:

- Accounts for excavation method
- Accounts for joint orientation
- "Stand up time" for various tunnel spans based on RMR
- Modified RMR for Mining
  - -MRMR (Laubscher)
  - -MBR (Cummings et al)

طبقه بندی اصلاح شده RMR جهت در نظر گرفتن تنش برجا و تنش های ایجاد شده در اثر حفاری و همچنین در نظر گرفتن تاثیرات انفجار و هوازدگی

Rock Mechanics ۲۷

Evaluation of Tunnels based on RMR



Example: 10 m span RMR = 80 Stand up time > 4 years
RMR = 50 Stand up time ≈ 2 days

Rock Mechanics ۲۸

Q system
(Rock tunnelling quality index)

Initial data base was 212 cases of nominally unlined tunnels and caverns

50 rock types were initially represented

Numerous shear zones and faults containing clay

Numerous shear zones and faults containing clay

A larger number of igneous and metamorphic rocks

Rock Mechanics ۲۹

Q system
(Rock tunnelling quality index)

$$Q = \frac{RQD}{J_n} \frac{J_r}{J_a} \frac{J_w}{SRF}$$

block size

frictional

Active stress and water effect

$$0.001 \le Q \le 2000$$

Rock Mechanics ۳۰

Q system
(Rock tunnelling quality index)

$$Q = \frac{RQD}{J_n} \frac{J_r}{J_a} \frac{J_w}{SRF}$$

$$0.001 \le Q \le 1000$$

structure of the rock mass

- RQD Rock quality designation (10-100)
- J_n = joint set number (0.5 – 20)
- The ratio RQD/Jn ~ **block size**

Rock Mechanics

Q system

J_n

(3 to 4m window)

Jn = 15 (at least!)

Rock Mechanics

Q system

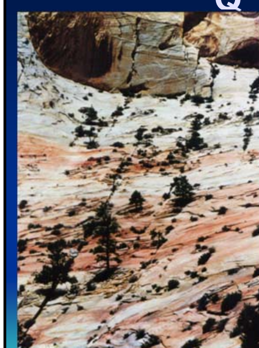
1. Rock Quality Designation		RQD
A	Very poor	0 - 25
B	Poor	25 - 50
C	Fair	50 - 75
D	Good	75 - 90
E	Excellent	90 - 100

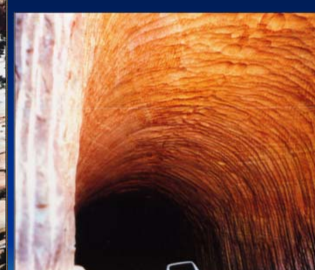
Note: i) Where RQD is reported or measured as ≤ 10 (including 0), a nominal value of 10 is used to evaluate Q.
ii) RQD intervals of 5, *i.e.*, 100, 95, 90, *etc.*, are sufficiently accurate.

2. Joint Set Number		J_n
A	Massive, no or few joints	0.5 - 1.0
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

Note: i) For intersections, use ($3.0 \times J_n$)
ii) For portals, use $2.0 \times J_n$)

Q system





Jn = 2 ⟶3)

Rock Mechanics

Q system

RQD J_n

Very poor	0-25
Poor	25-50
Fair	50-75
Good	75-90
Excellent	90-100

One joint set	2
Two joint sets	4
Two joint set + random	6
Three joint sets	9

Rock Mechanics

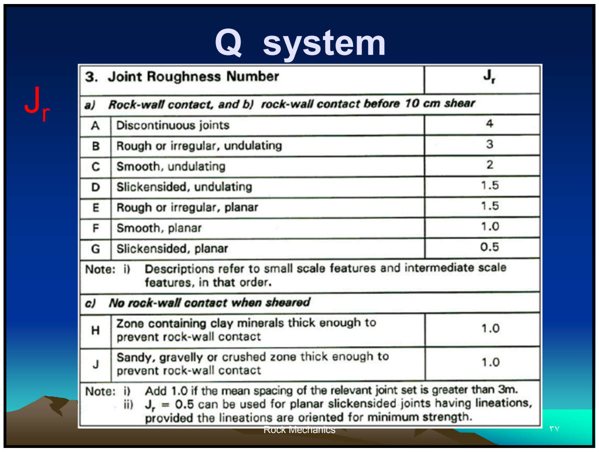
Q system

$$Q = \frac{RQD}{J_n} \frac{J_r}{J_a} \frac{J_w}{SRF}$$

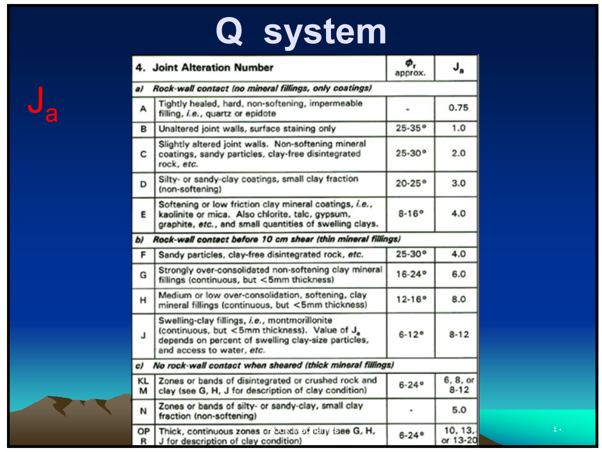
roughness and frictional characteristics

- J_r = joint roughness number (0.5 -5)
- J_a = the joint alteration number (0.75 – 20: hard to soft filling)
- The ratio J_r/J_a ~ joint roughness & friction

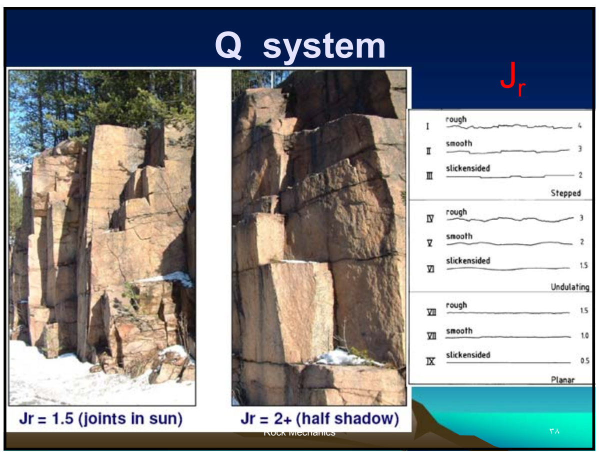
Rock Mechanics

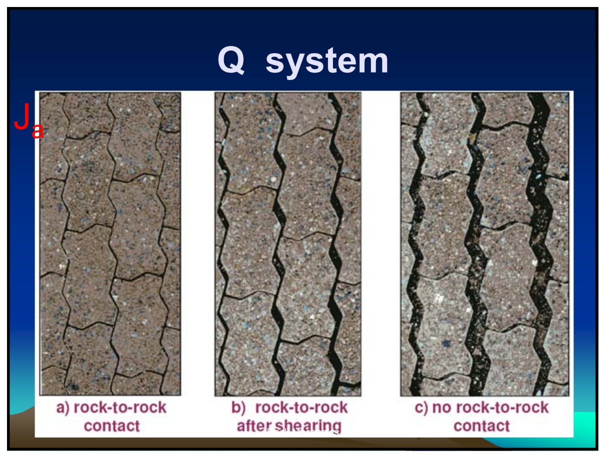


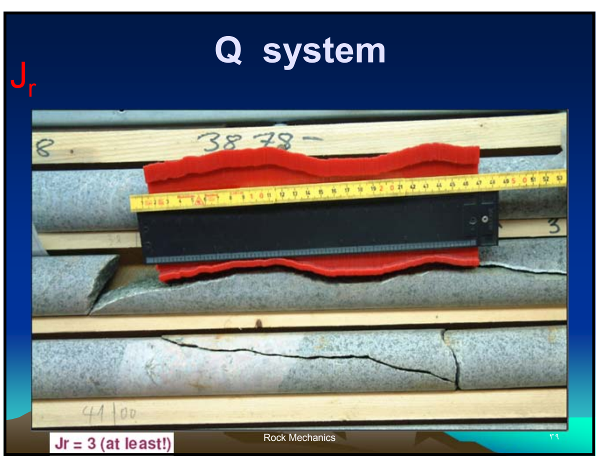
3. Joint Roughness Number		J_r
a) Rock-wall contact, and b) rock-wall contact before 10 cm shear		
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slickensided, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slickensided, planar	0.5
Note: i) Descriptions refer to small scale features and intermediate scale features, in that order.		
c) No rock-wall contact when sheared		
H	Zone containing clay minerals thick enough to prevent rock-wall contact	1.0
J	Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact	1.0
Note: i) Add 1.0 if the mean spacing of the relevant joint set is greater than 3m. ii) J_r = 0.5 can be used for planar slickensided joints having lineations, provided the lineations are oriented for minimum strength.		

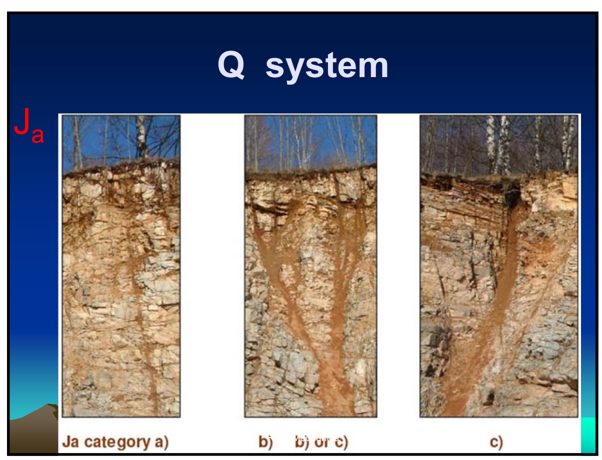


4. Joint Alteration Number		ϕ_r approx.	J_a
a) Rock-wall contact (no mineral fillings, only coatings)			
A	Tightly healed, hard, non-softening, impermeable filling, *i.e.*, quartz or epidote	-	0.75
B	Unaltered joint walls, surface staining only	25-35°	1.0
C	Slightly altered joint walls. Non-softening 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 <5mm thickness)	16-24°	6.0
H	Medium or low over-consolidation, softening, clay mineral fillings (continuous, but <5mm thickness)	12-16°	8.0
J	Swelling-clay fillings, *i.e.*, montmorillonite (continuous, but <5mm thickness). Value of J_a depends on percent of swelling clay-size particles, and access to water, *etc.*	6-12°	8-12
c) No rock-wall contact when sheared (thick mineral fillings)			
KL 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
OP R	Thick, continuous zones or bands of clay (see G, H, J for description of clay condition)	6-24°	10, 13, or 13-20









Q system

J_r/J_a

PRESUMED SUB-SURFACE FAULT

Jr/Ja = 1/8

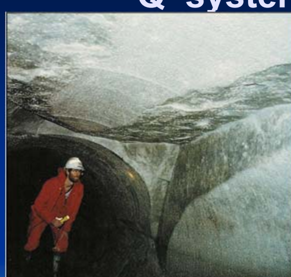
Q system

5. Joint Water Reduction Factor		approx water pres. (kg/cm²)	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

Note: i) Factors C to F are crude estimates. Increase J_w if drainage measures are installed.
ii) Special problems caused by ice formation are not considered.

Q system

J_r/J_a



(125 years old Beaumont Tunnel)

TBM TUNNELLING

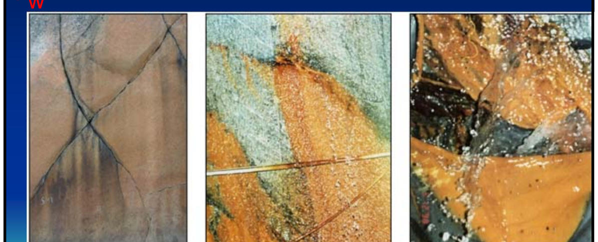
Jr = 1, Ja = 1

frictional strength = 1/1 = 1

IF THERE WAS WEATHERING:
Ja ► 2 ►3 ►4 ►6 ►8 ......
(Maybe the block/wedge fell when Ja was reduced to 2)
Jr/Ja ► 0.5, 0.33, 0.25, 0.17, 0.13

Q system

J_w



Jw = 1 or 0.66 Jw = 0.5 Jw = 0.2

Q system

$$Q = \frac{RQD}{J_n} \frac{J_r}{J_a} \frac{J_w}{SRF}$$

Active stress

- J_w = joint water reduction factor (1 – 0.05: dry to water under pressure)
- SRF = the stress reduction factor (0.5 – 400: low stress & favourable orientation to high stress)

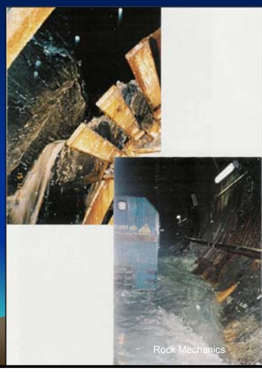
Q system

J_w

Jw = 0.66 Jw = 0.1 or 0.2

Q system

J_w



Most of tunnel was Jw < 0.5

Q system

SRF

Multiple faults (at least two): SRF = 10

Q system

SRF

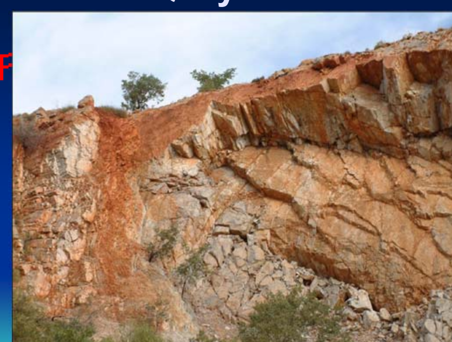
FAULTING

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 ≤ 50m)	5
C	Single weakness zones containing ***clay*** or chemically disintegrated rock (depth of excavation > 50m)	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 ≤ 50m)	5.0
F	Single shear zones in competent rock (***clay-free***) (depth of excavation > 50m)	2.5
G	Loose, open joints, heavily jointed or "sugar cube", *etc.* (any depth)	5.0

Note: i) Reduce these values of SRF by 25-50% if the relevant shear zones only influence but do not intersect the excavation.

Q system

SRF

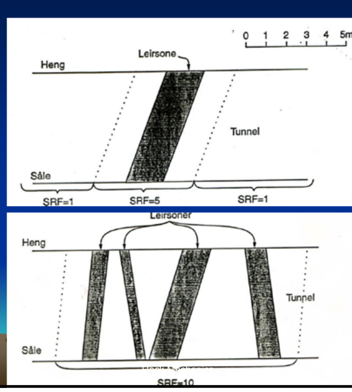


PRESUMED SUB-SURFACE FAULT

SRF = 2.5 or 5 according to depth

Q system

SRF



Q system

SRF

STRESS FRACTURING IN (mostly) MASSIVE ROCK

6. Stress Reduction Factor				SRF
b)	***Competent rock, rock stress problems***	σ_c/σ_1	σ_θ/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

Note: ii) For strongly anisotropic virgin stress field (if measured): when $5 \le \sigma_1/\sigma_3 \le 10$, reduce σ_c to $0.75\sigma_c$. When $\sigma_1/\sigma_3 > 10$, reduce σ_c to $0.5\sigma_c$, 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).

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

Q system

Determination of the Stress Reduction Factor in Highly Stressed *Jointed* Rock (Warren Peck, 2000)

- SRF = $34(\sigma_c / \sigma_1)^{-1.2}$

(when not particularly anisotropic stresses)

- SRF = $31(\sigma_1 / \sigma_3)^{0.3} (\sigma_c / \sigma_1)^{-1.2}$

(when strongly anisotropic stresses)

Both the above for category σ_c / σ_1 from 10 to 1.5

Rock Mechanics

Q system

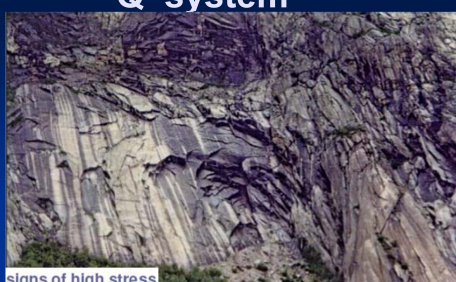
SRF

6. Stress Reduction Factor			SRF
c)	***Squeezing rock: plastic flow of incompetent rock under the influence of high rock pressure***	σ_θ / σ_c	SRF
O	Mild squeezing rock pressure	1-5	5-10
P	Heavy squeezing rock pressure	>5	10-20
Note:	iv) Cases of squeezing rock may occur for depth $H > 350 Q^{1/3}$ (Singh *et al.*, 1992). Rock mass compression strength can be estimated from $q \approx 7 \gamma Q^{1/3}$ (MPa) where γ = rock density in gm/cc (Singh, 1993).		
d)	***Swelling rock: chemical swelling activity depending on presence of water***		
R	Mild swelling rock pressure		5-10
S	Heavy swelling rock pressure		10-15

Rock Mechanics

Q system

SRF

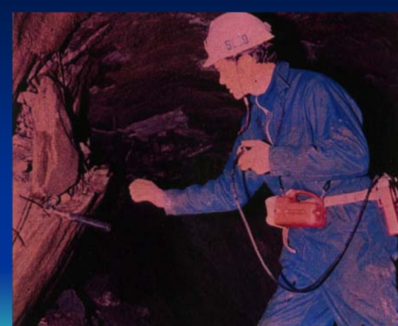


signs of high stress

Rock Mechanics

Q system

SRF

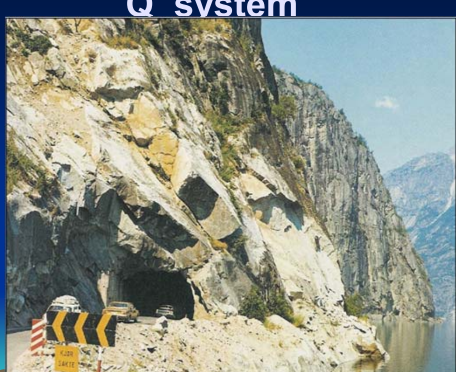


Hydrothermally altered granite containing montmorillonite (SRF = 15, or higher? - extreme tunnel closure of 4m!)

Rock Mechanics

Q system

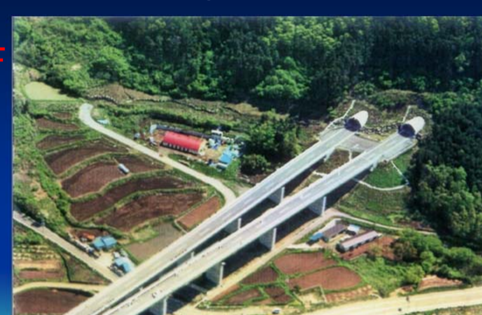
SRF



Near-surface example of high tangential stresses.

Q system

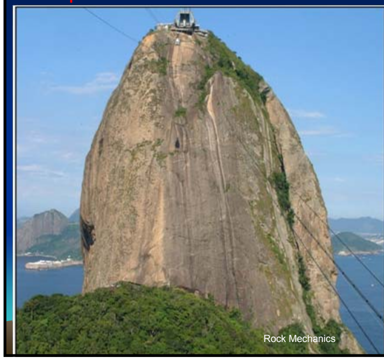
SRF



ANTICIPATED SQUEEZING. MOTORWAY UP-AND-DOWN LANES DIVERGED BY ABOUT 3 (OR 4?) TUNNEL DIAMETERS (SRF = 20 ?)

Q system

Example

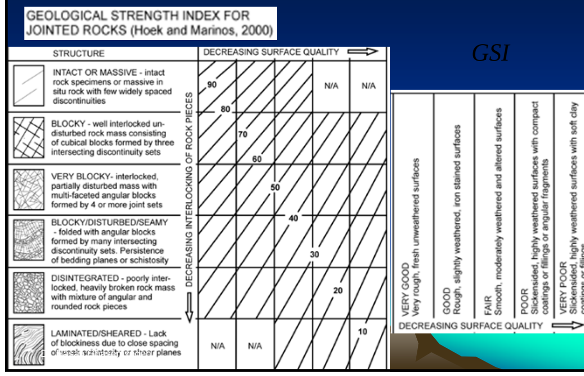


Q = 1000 (or better)

Q = 100/0.5 x 4/0.75 x 1/1

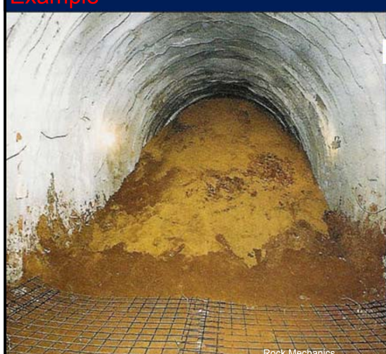
Rock Mechanics

NGI system



Q system

Example

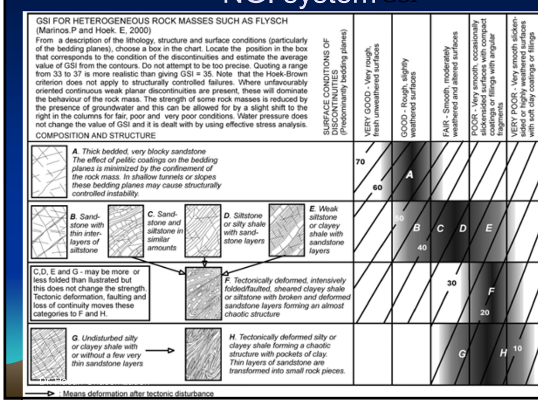


Q = 0.001 (or worse)

Q = 10/20 x 1/8 x 0.5/ 20

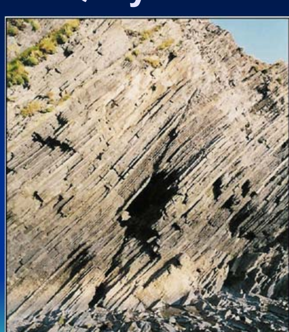
Rock Mechanics

NGI system GSI



Q system

Example



A shear (minor fault) without clay.

$$Q = \frac{20-60}{3} \times \frac{1.0}{0.75-1} \times \frac{1}{2.5} = 2.7 - 10.7$$

Q RMR comparison

RMR – ROCK MASS RATING

(MPa)	(%)	(m)	(-)	(-)
$= \sigma_C$ +	RQD +	S +	$J_{condition}$ +	Water
(0 – 15)	(3 – 20)	(5 – 20)	(0 – 30)	(0 – 15)

+ orientation adjustment (0 to *minus* 12) for tunnels
(0 to *minus* 60) for slopes

Theoretical range of RMR ≈ 5 to 100

$$Q = RQD/Jn \times J_r/J_a \times J_w/SRF$$

RQD%	Joint roughness	Water
number of sets	Joint alteration	Stress/Strength

10 to 100 (actual)	0.5 to 5	0.05 to 1.0
0.5 to 20	0.75 to 20	0.5 to 400

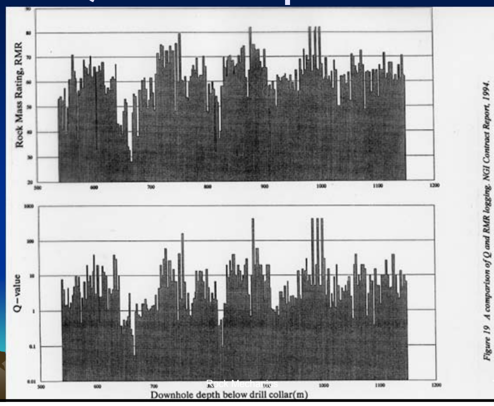
Theoretical range of Q ≈ 0.001 to 2000

Note that 'σ_c' and 'S' (spacing) do not occur in the Q-value estimate, only indirectly in stress/strength (SRF) and in RQD

Note that 'Jn' (number of sets) and 'stress' do not occur in RMR

Rock Mechanics

Q RMR comparison



Tunnels and the Q rating

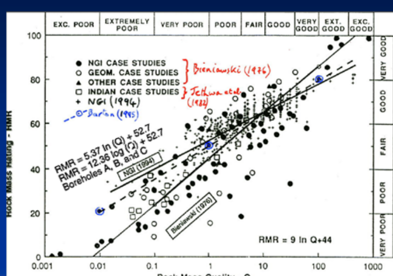
- Require ESR and D_e
  - D_e = equivalent dimension

$$D_e = \frac{\text{Excavation span or height}}{\text{ESR}}$$

  - ESR = excavation support ratio
  - ESR is a function of the tunnel use and acceptable level of risk

Rock Mechanics

Q RMR comparison



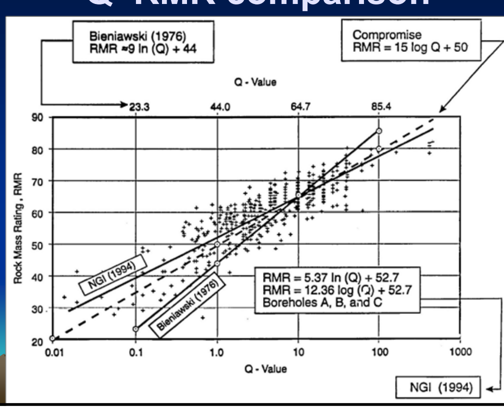
RMR ≈ 9 lnQ+44 (Bieniawski, 1989)	$Q \approx e^{\frac{(RMR-44)}{9}}$	1
RMR ≈ 15 logQ+50 (Barton, 1995)	$Q \approx 10^{\frac{(RMR-50)}{15}}$	2

ESR Values (Barton et al 1974)

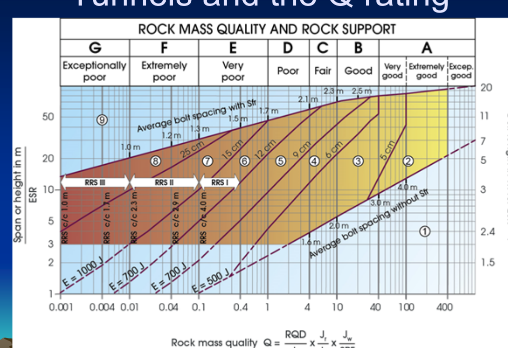
Temporary mine openings	3 - 5
Permanent mine openings, water tunnels for hydro power, etc.	1.6 - 2
Power stations, **major road & railway tunnels**, etc.	1
Underground nuclear power stations, railway stations, etc.	0.8

Rock Mechanics

Q RMR comparison



Tunnels and the Q rating



Rock Mechanics

Tunnels and the Q rating

1) Unsupported
2) Spot bolting
3) Systematic bolting
4) Systematic bolting, (and unreinforced shotcrete, 4 - 10 cm)
5) Fibre reinforced shotcrete and bolting, 5 - 9 cm
6) Fibre reinforced shotcrete and bolting, 9 - 12 cm
7) Fibre reinforced shotcrete and bolting, 12 - 15 cm
8) Fibre reinforced shotcrete, > 15 cm, reinforced ribs of shotcrete and bolting
9) Cast concrete lining

Rock Mechanics

Evaluation of Tunnels based on Q rating

Example:
- 10 m span & ESR = 2
- Q= 40

Requires rock bolts at 3 m spacing, 2.4 m long

- 10 m span & ESR = 1
- Q= 40

Requires rock bolts at 3 m spacing, 3 m long

Rock Mechanics

Evaluation of Tunnels based on Q rating

Example:

1)
- 10 m span & ESR = 2
- Q= 40

2)

10 m span & ESR = 1
- Q= 40

Rock Mechanics

Rock Bolts- Q system

CT Bolts

- Rock bolt lengths are for an ESR of 1.0 (conservative)

Rock Mechanics

Tunnels and the Q rating

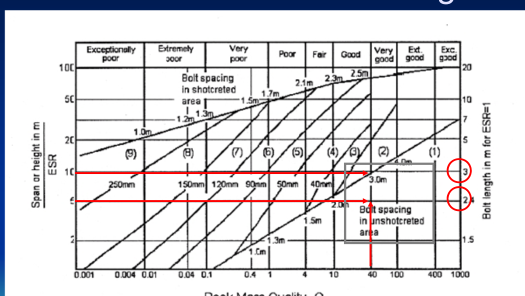


Figure 1. The Q system Tunnel Reinforcement Design Chart (Barton[7], 1996)

Example: 10 m span ESR = 2 Q= 40 10 m span ESR = 1 Q= 40

Rock Mechanics

Tunnels based on Q rating

Final Example:
- 10 m span & ESR = 1
- Q= 10

  Requires rock bolts at 2.3 m spacing, 3 m long in 40 mm shotcrete

Rock Mechanics

Tunnels and the Q rat

Example:
10 m span ESR = 1
Q= 10

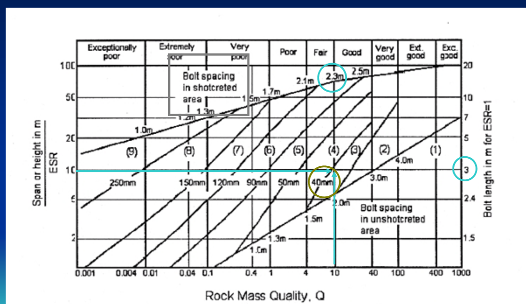


Figure 1. The Q system Tunnel Reinforcement Design Chart (Barton[7], 1996)

Rock Bolts- Q system

Lengths (L) can be stimated based on the excavation span (B) :

$$L = (2 + 0.15\,B) / ESR$$

- maximum unsupported span can be estimated from:

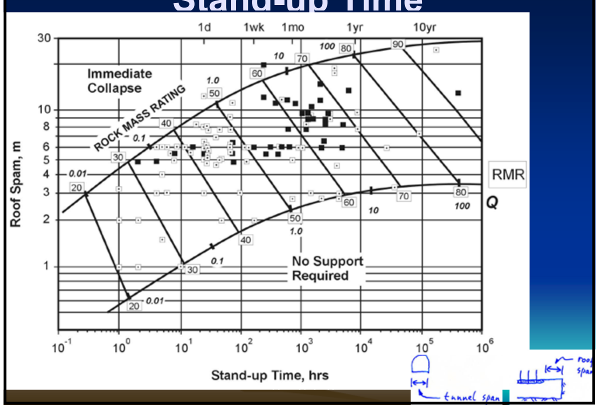
$$B_{max} = 2\,(ESR)\,(Q)^{0.4}$$

- relationship between the value of *Q* and the permanent roof support pressure (P_{roof}) (Grimstad and Barton ,1993)

$$P_{roof} = \frac{2\sqrt{Jn}\,Q^{-\frac{1}{3}}}{3Jr}$$

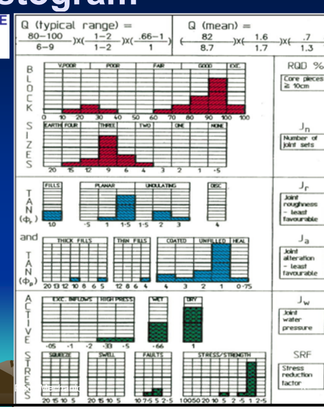
Rock Mechanics

Stand-up Time



Histogram

HISTOGRAM LOGGING TO CAPTURE VARIATION …….. AND TO SPEED LOGGING

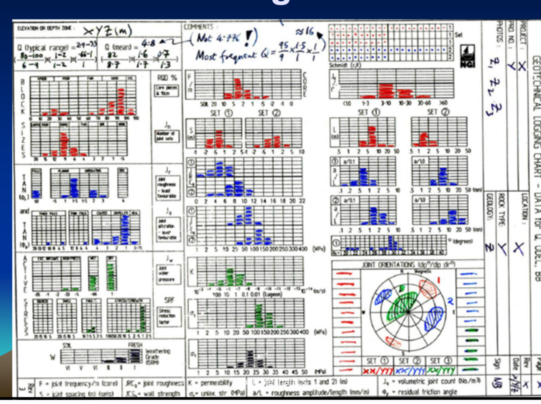


Note

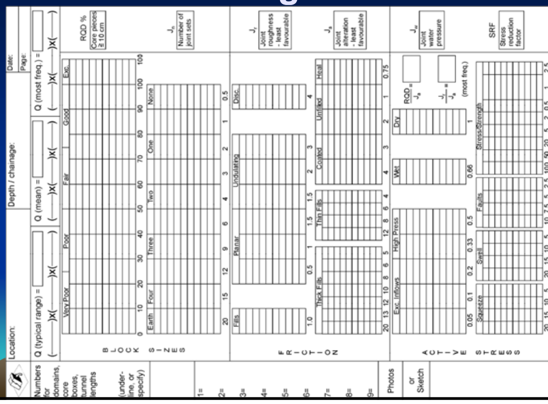
- blasting damage will result in the creation of new joints, can be accounted for by reducing the *RQD* value for the blast damaged zone (Loset, 1992)
- it is appropriate to give a range of values to each parameter in a rock mass classification and to evaluate the significance of the final result.

Rock Mechanics

Histogram



Histogram



KEY POINTS

- Rock mass rating systems are a useful way of forming **an** evaluation of rock masses
- The Q or NGI system was based on tunnelling
- The RMR (CSIR) system is more commonly used for slope stability
- The strength of rock masses can be judged from these sytems

Rock Mechanics