

**CVG4184 / 6305: Rock Mechanics
Winter 2020**

**Chapter 4: Rock Mass
Classification**

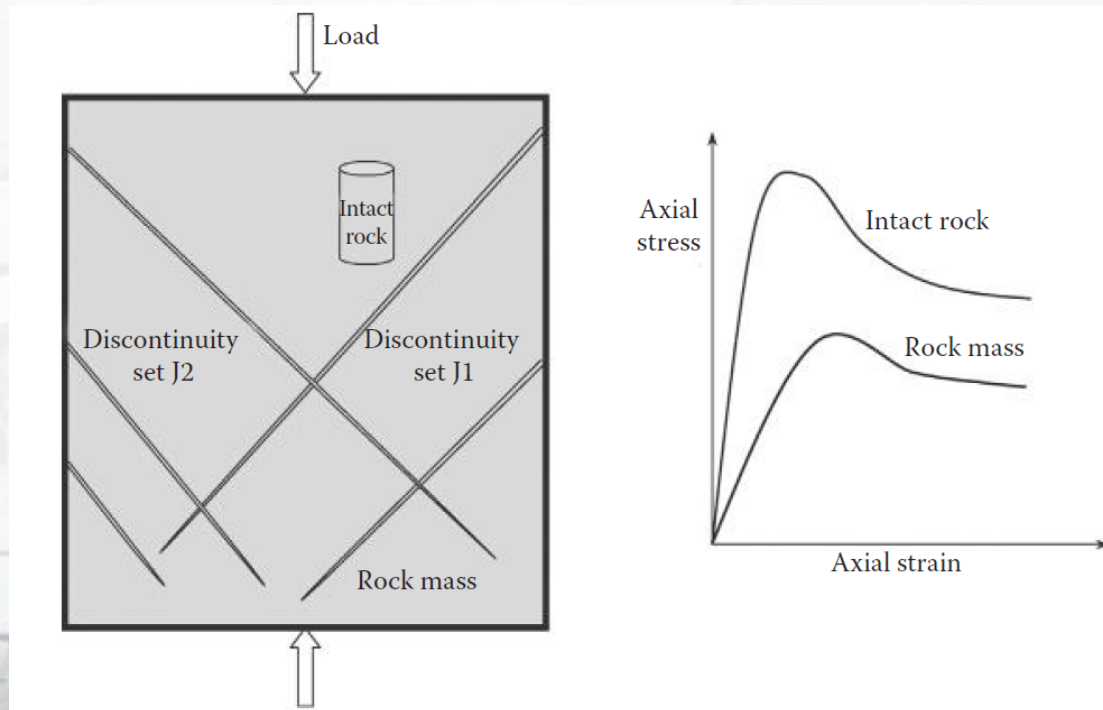
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Introduction

- The engineering properties of the **intact rock (e.g., UCS, mineral composition)** supply only a portion of the key parameters used in classifying the rock mass.
- The **in-situ rock mass** may have one or more sets of discontinuities that can have a significant influence on strength, stiffness, permeability and stability.
- Additional properties associated with the **discontinuities in the rock mass** (e.g., orientation, spacing, etc.), are relevant in rock mass classification.
- The pattern of discontinuities is evident in the **cored sections** obtained during the site exploration studies, as well as in the **exposed faces** and rock outcrops.

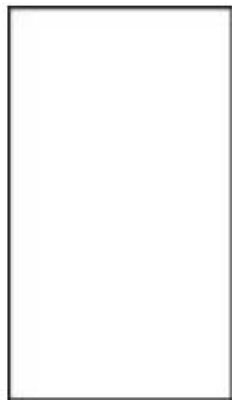
Intact rock and rock mass

- The **rock mass** is generally characterized based on:
 - properties of the **intact rock**;
 - **size** of the rock pieces (blocks) between joints;
 - **frictional characteristics** of joints (roughness, type and quality of the infill material).

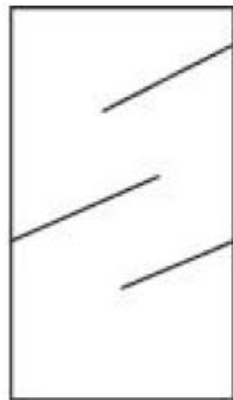


Joints and joint sets

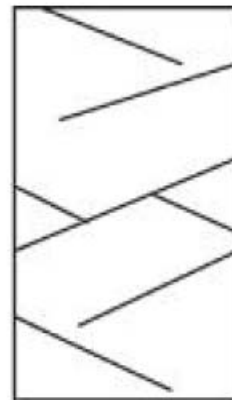
- The rock mass can have any number of joints.
 - When there are **no joints**, the rock mass and the intact rock have the same properties.
 - An **increasing number of joints** and joint sets make the rock mass more fragmented and the block sizes become smaller.



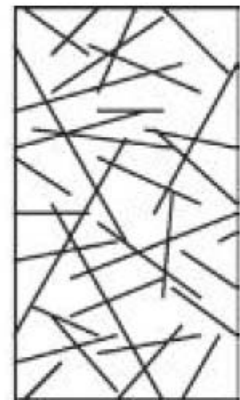
Intact rock



One joint set



Two joint sets



Many joint sets

Discontinuity characterization

- There are several parameters that are used to describe discontinuities:

- Orientation
- Spacing
- Persistence
- Roughness
- Wall strength
- Aperture
- Filling
- Seepage
- Number of joint sets
- Block size and shape

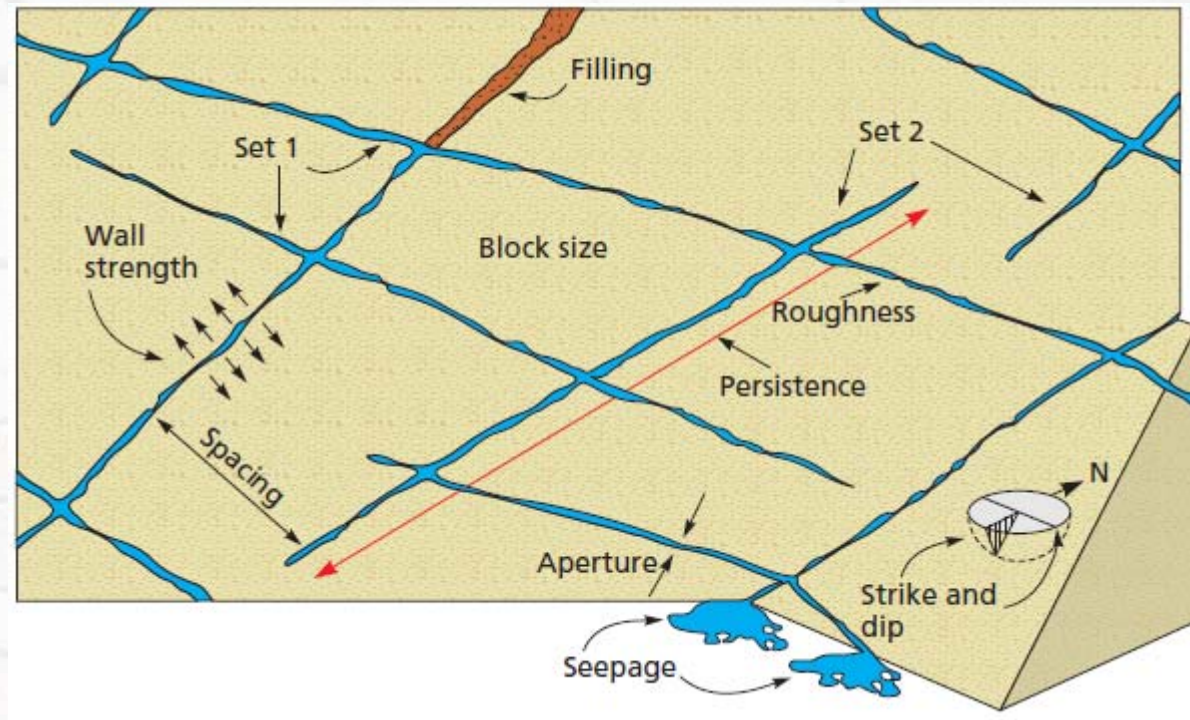


Diagram of the geometric properties of discontinuities (Hudson, 1989)

Discontinuity characterization

- **Orientation:** measured by the dip and dip direction; critical to the stability of the rock mass.
- **Spacing:** the perpendicular distance between two adjacent discontinuities of the same set; affects the hydraulic conductivity of the rock mass and the failure mechanism.

Rock classification based on the spacing of discontinuities

<i>Description</i>	<i>Spacing (mm)</i>
Extremely close spacing	<20
Very close spacing	20–60
Close spacing	60–200
Moderate spacing	200–600
Wide spacing	600–2000
Very wide spacing	2000–6000
Extremely wide spacing	>6000

Source: ISRM, *Int. J. Rock Mech. Min. Sci. Geomech. Abstr.*, 15, 319, 1978.

Discontinuity characterization

- Spacing

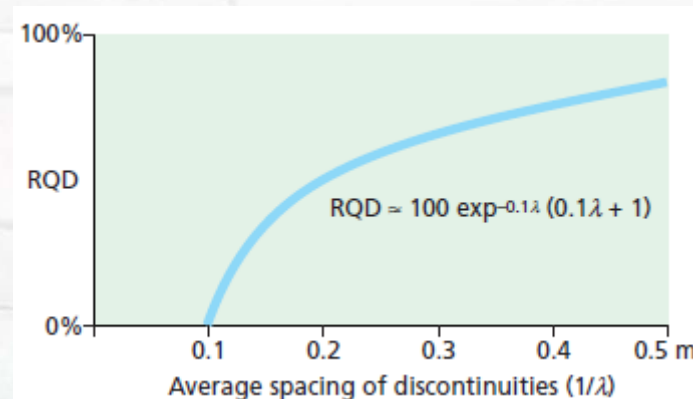
- In the absence of measurements of joint spacing, the joint **frequency** (and thus the joint spacing) can be estimated from the RQD:

$$RQD = 100 e^{-0.1\lambda} (0.1\lambda + 1)$$

Where:

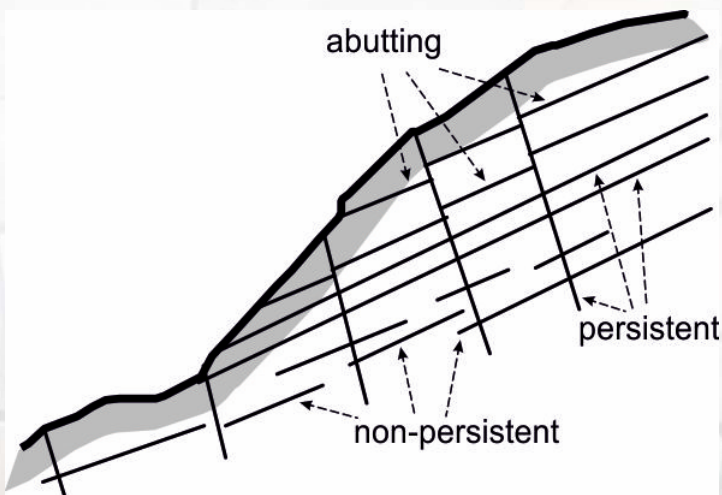
λ = number of joints per m (i.e., joint frequency).

RQD is in %.



Discontinuity characterization

- **Persistence**: determines the possibilities of relative movement along a discontinuity in a rock mass.
 - **Persistent** discontinuity: a continuous plane in a soil or rock mass.
 - **Non-persistent** discontinuity: ends in intact rock.
 - **Abutting** discontinuity: abuts against another discontinuity.



Description for persistence

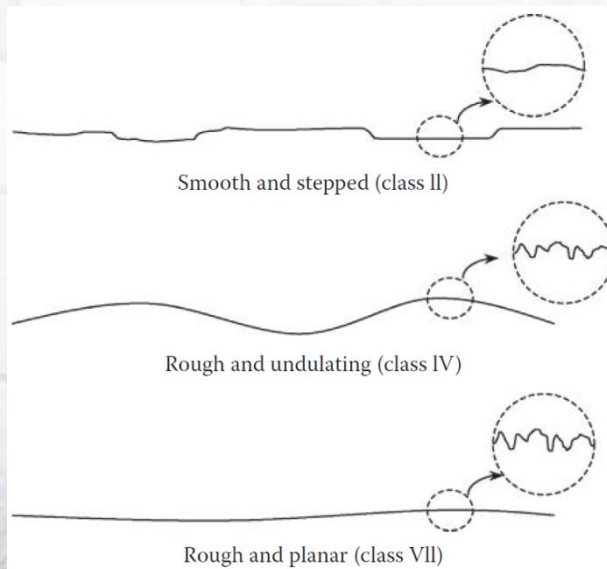
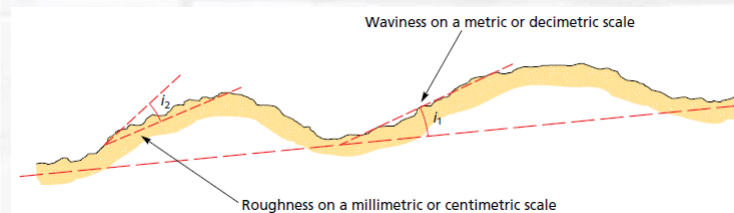
<i>Description</i>	<i>Trace length (m)</i>
Very low persistence	<1
Low persistence	1–3
Medium persistence	3–10
High persistence	10–20
Very high persistence	>20

ISRM, *Int. J. Rock Mech. Min. Sci. Geomech. Abstr.*, 15, 319, 1978.

Discontinuity characterization

- Roughness:**

- large-scale surface undulations (waviness) observed over several meters;
- small-scale unevenness of the two sides relative to the mean plane, observed over several centimeters.



Roughness classification

Class	Unevenness and undulations	J_r
I	Rough, stepped	4 ^a
II	Smooth, stepped	3 ^a
III	Slickensided, stepped	2 ^a
IV	Rough, undulating	3
V	Smooth, undulating	2
VI	Slickensided, undulating	1.5
VII	Rough, planar	1.5
VIII	Smooth, planar	1
IX	Slickensided, planar	0.5

Increasing roughness ⇕

Source: ISRM, *Int. J. Rock Mech. Min. Sci. Geomech. Abstr.*, 15, 319, 1978.

Discontinuity characterization

- **Wall strength:** compressive strength of the rock that makes up the walls of the discontinuity.
 - Governs the shear strength and deformability of rock mass.
 - **Joint wall compressive strength (JCS)** is a measure of wall strength (Barton, 1973).

$$JCS = UCS \quad \text{-unaltered joints}$$

$$JCS = 0.25UCS \quad \text{- weathered joint surface}$$

$$\log_{10} JCS \text{ (MPa)} = 0.00088\gamma R + 1.01$$

Where:

γ = unit weight of rock (kN/m³)

R = Schmidt hammer rebound number on the joint surface

Discontinuity characterization

- Wall strength and friction angle

➤ The friction angle of a rough discontinuity surface has two components:

- basic friction angle of the rock material, ϕ_b
- roughness angle, i .

$$\tau = \sigma_n \tan(\phi_b + i) \quad \phi_b + i \leq 50^\circ$$

$$i \text{ (degrees)} = JRC \log \left(\frac{JCS}{\sigma_n} \right) \quad \frac{JCS}{\sigma_n} = 3 \text{ to } 100$$

$$\phi_b \approx \phi_r$$

Where:

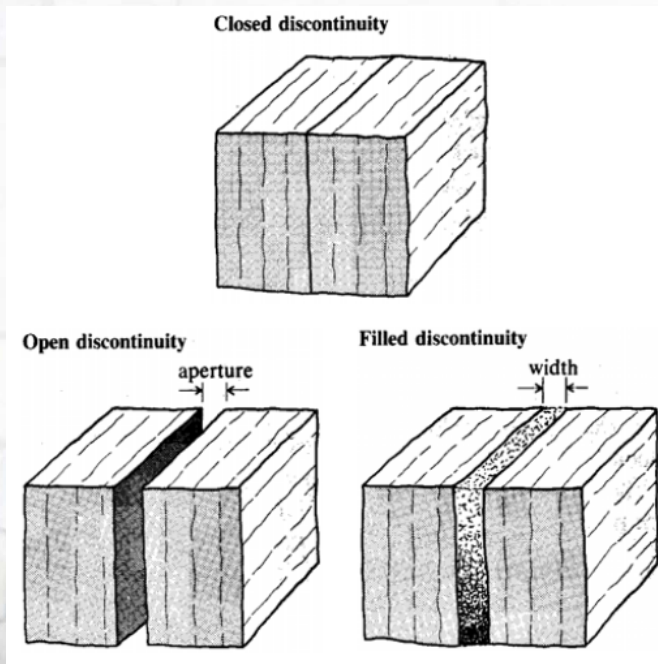
σ_n = effective normal stress on the discontinuity plane (kN/m²)

ϕ_r = residual friction angle of rock (typically 25° - 35°, but as low as 15° for weathered joint walls).

JRC = joint roughness coefficient

Discontinuity characterization

- **Aperture**: the perpendicular distance between the two adjacent rock walls of an open discontinuity, where the space is filled by air or water.
- When the space between the walls is filled with sediments, the term "**width**" of the infill is used instead of aperture.



Descriptions associated with apertures

Aperture (mm)	Description
<0.1	Very tight
0.1–0.25	Tight
0.25–0.5	Partly open
0.5–2.5	Open
2.5–10	Moderately wide
>10	Wide
10–100	Very wide
100–1000	Extremely wide
>1000	Cavernous

ISRM, *Int. J. Rock Mech. Min. Sci. Geomech. Abstr.*, 15, 319, 1978.

Discontinuity characterization

- **Filling:** the material (e.g. calcite, chlorite, clay and silt) that occupies the space between the adjacent rock walls of a discontinuity.
 - A complete description of the filling may include the **width, mineralogy, grain size, water content, permeability and strength.**
 - Affects the permeability and the deformability of the rock mass.
- **Seepage:** mainly through discontinuities (secondary permeability), as the permeability of the intact rock (primary permeability) is generally very low.
 - ISRM has separate ratings from I (no seepage) to VI (heavy flow) for unfilled and filled discontinuities.

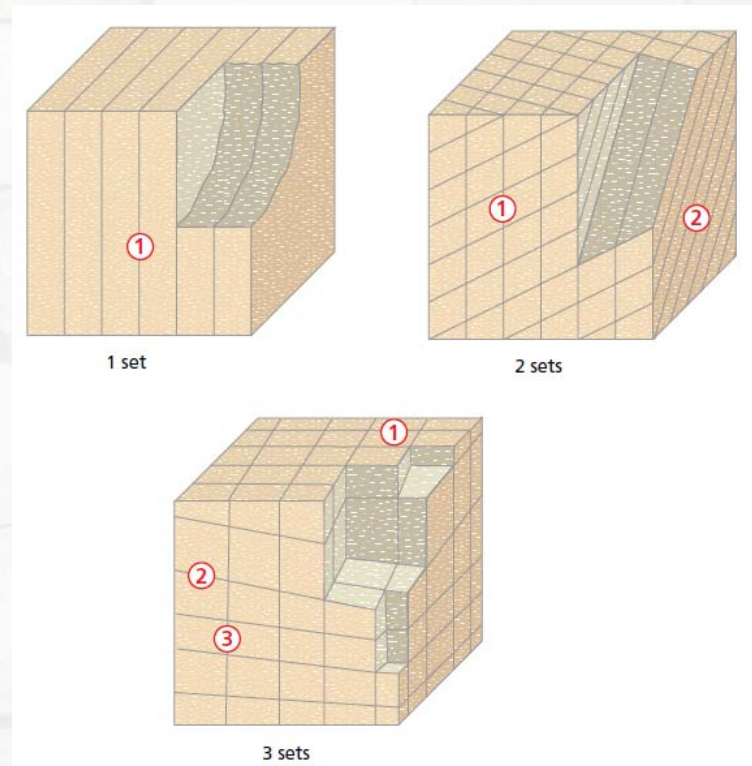
Discontinuity characterization

- **Number of joint sets:** determines the ability of the rock mass to sustain deformation without any failure within the intact rock.

Classification based on number of joint sets

Group	Joint sets
I	Massive, occasional random joints
II	One joint set
III	One joint set plus random
IV	Two joint sets
V	Two joint sets plus random
VI	Three joint sets
VII	Three joint sets plus random
VIII	Four or more joint sets
IX	Crushed rock, similar to soils

ISRM, *Int. J. Rock Mech. Min. Sci. Geomech. Abstr.*, 15, 319, 1978.



Discontinuity characterization

- **Block size:** depends on the number of discontinuity sets, spacing and persistence that separates the blocks.
 - The **block size and the shear strength** along the discontinuities play a **key role in the stability** of the rock mass in rock slopes and underground openings.
 - **Block size** is a key parameter in rock mass classification.
 - **Block size** is defined as the average diameter of an equivalent sphere of the same volume.
 - Quantified by a block size index (I_b) or volumetric joint count (J_v).

Discontinuity characterization

- **Block size index, I_b** : the average dimension of a block.
- **Volumetric joint count, J_v** : the total number of joints intersecting a unit volume of rock mass.
- For an orthogonal joint system of three sets with spacing of S_1 , S_2 and S_3 :

$$I_b = \frac{S_1 + S_2 + S_3}{3}$$

$$J_v = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3}$$

$$RQD = 115 - 3.3J_v$$

Block sizes and J_v values

J_v (joints/m ³)	Description
<1	Very large blocks
1–3	Large blocks
3–10	Medium-sized blocks
10–30	Small blocks
30–60	Very small blocks
>60	Crushed rock

ISRM, *Int. J. Rock Mech. Min. Sci. Geomech. Abstr.*, 15, 319, 1978.

Where S_1 , S_2 and S_3 are in m, and J_v is in joints/m³.

For $J_v < 4.5$, $RQD=100\%$; and for $J_v > 30$, $RQD=0\%$.

Discontinuity characterization

Example 1

A rock mass consists of four joint sets. The following joint counts are made normal to each set:

- joint set 1 = 12 per 10 m,
- joint set 2 = 17 per 5 m,
- joint set 3 = 16 per 5 m,
- joint set 4 = 13 per 10 m.

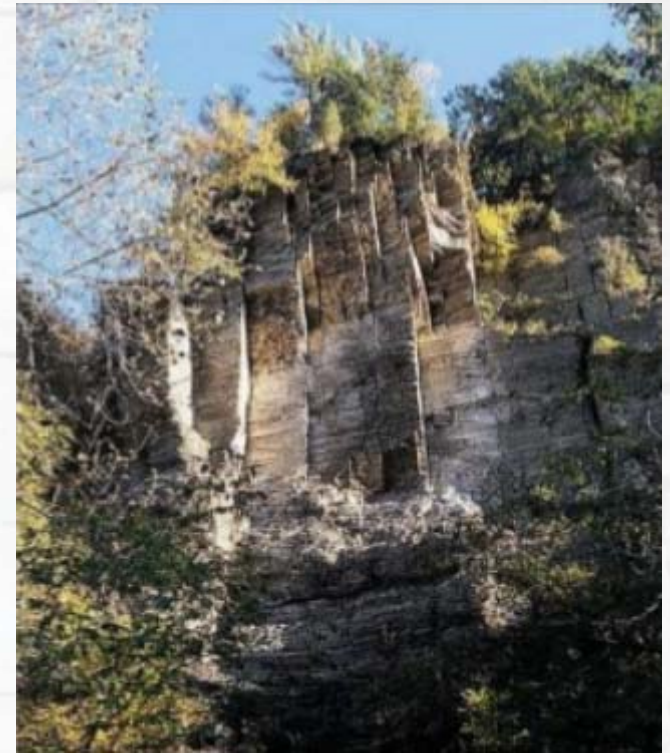
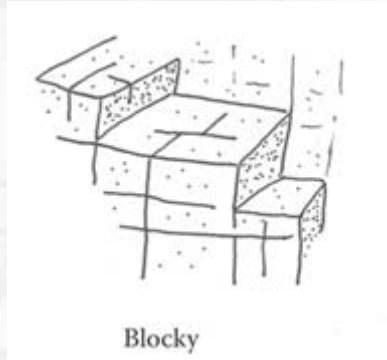
Find the volumetric joint count. How would you describe the block size? Estimate the *RQD*.

Discontinuity characterization

- **Description of the rock mass:** use one of the following adjectives reflecting the block size and shape (ISRM, 1978).
 - **Massive** – few joints or very wide spacing;
 - **Blocky** – approximately equidimensional;
 - **Tabular** – one dimension considerably smaller than the other two;
 - **Columnar** – one dimension considerably larger than the other two;
 - **Irregular** – wide variations of block size and shape;
 - **Crushed** – heavily jointed to sugar cubes.

Discontinuity characterization

- Description of the rock mass



Discontinuity characterization

- **Methods of measurement** of the 10 discontinuity characterization parameters and their relative merits:

Methods of measurements of discontinuity parameters				
<i>Parameter</i>	<i>Method of measurement</i>	<i>Core</i>	<i>Borehole via TV camera</i>	<i>Exposure</i>
Orientation	Compass-inclinometer	M	G	G
Spacing	Measuring tape	G	G	G
Persistence	Measuring tape	B	B	G/M
Roughness	Against reference chart	M	B	G
Wall strength	Schmidt hammer	M	B	G
Aperture	Scale or feeler gauge	B	M	G
Filling	Visual	B	B	G
Seepage	Timed observations	B	B/M	G
Number of sets	Stereographic projections	M	G	G
Block size	3D fracture frequency	B	B	G

G = Good, M = Medium, B = Bad.

Source: Hudson, J.A., *Rock Mechanics Principles in Engineering Practice*, Butterworths, London, 1989.

Rock mass classification

- A rock mass is **classified** on the basis of three factors:
 - **Intact rock properties:**
 - Strength (UCS);
 - Stiffness (Young's modulus).
 - **Joint characteristics:**
 - Frictional resistance along the joints between the adjacent blocks (number of joint sets, orientation, spacing, aperture, surface roughness, weathering and alteration, infilling).
 - **Boundary conditions:**
 - In-situ stresses within the rock mass;
 - Groundwater conditions.

Rock mass classification

- **Objectives** of rock mass classification:
 - To group rocks of similar engineering properties and behaviour;
 - To describe rock mass without any ambiguity.
- Some of the common rock mass classification systems are as follows:
 - **Classification by UCS;**
 - **Classification by RQD;**
 - **Rock mass rating (RMR);**
 - **Q-system;**
 - **Geological strength index (GSI).**

Rock classification - UCS

- **Classification** of rocks on the basis of the **UCS** (ISRM, 1978):

Classification of rock strengths				
Grade	Description	Field identification	σ_c (MPa)	Rock types
R0	Extremely weak rock	Indented by thumbnail.	0.25–1.0	Stiff fault gouge
R1	Weak rock	Crumbles under firm blows with point of geological hammer; can be peeled by pocketknife.	1–5	Highly weathered or altered rock
R2	Weak rock	Can be peeled by a pocketknife with difficulty; shallow indentations made by firm blow with a point of geological hammer.	5–25	Chalk, rock salt, potash
R3	Medium strong rock	Cannot be scraped or peeled with a pocketknife; specimen can be fractured with a single firm blow of a geological hammer.	25–50	Claystone, coal, concrete, schist, shale, siltstone
R4	Strong rock	Specimen requires more than one blow by geological hammer to fracture it.	50–100	Limestone, marble, phyllite, sandstone, schist, shale
R5	Very strong rock	Specimen requires many blows of geological hammer to fracture it.	100–250	Amphibolite, sandstone, basalt, gabbro, gneiss, granodiorite, limestone, marble, rhyolite, tuff
R6	Extremely strong rock	Specimen can only be chipped by a geological hammer.	>250	Fresh basalt, chert, diabase, gneiss, granite, quartzite

Source: Hoek, E. and Brown, E.T., *Int. J. Rock Mech. Min. Sci. Geomech. Abstr.*, 34, 1165, 1997.

Rock mass classification - RQD

- **Classification** of rock mass on the basis of the **RQD** (Deere, 1964)
 - RQD has been widely accepted as a measure of **fracturing degree** of the rock mass.
 - It **does not account** for the **strength** of the rock or **properties of the joints** and only partially reflects the rock mass quality.

RQD	Rock Mass Quality
< 25	Very poor
25 – 50	Poor
50 – 75	Fair
75 – 90	Good
99 – 100	Excellent

Rock mass classification - RMR

- **Rock mass rating (RMR)**: also known as the Geomechanics Classification System, was originally proposed by Bieniawski in 1973.
- Assigns a rating (0-100), based on the following five parameters:
 - **Strength of intact rock** – 15 points max.
 - **RQD** – 20 points max.
 - **Mean spacing of the discontinuities** – 20 points max.
 - **Condition of discontinuities** – 30 points max.
 - **Groundwater conditions** – 15 points max.
- The ratings of all parameters are added to make up the RMR.

Rock mass classification - RMR

- Rating Increment Tables

Rating increments for uniaxial compressive strength		
Point load strength index, $I_{s(50)}$ (MPa)	UCS (MPa)	Rating
Not applicable; use UCS only	<1	0
	1–5	1
	5–25	2
1–2	25–50	4
2–4	50–100	7
4–10	100–250	12
>10	>250	15

Source: Bieniawski, Z.T., *Engineering Rock Mass Classification*, Wiley

Rating increments for RQD					
RQD (%)	<25	25–50	50–75	75–90	90–100
Rating	3	8	13	17	20

Source: Bieniawski, Z.T., *Engineering Rock Mass Classification*, Wiley

Rock mass classification - RMR

- Rating Increment Tables

Rating increments for joint spacing

Spacing (mm)	<60	60–200	200–600	600–2000	>2000
Rating	5	8	10	15	20

Source: Bieniawski, Z.T., *Engineering Rock Mass Classification*, Wiley

Rating increments for the joint condition

<i>Condition of joint</i>	<i>Rating</i>
Open joint infilled with soft gouge >5 mm thickness OR separation >5 mm, and continuous extending several metres	0
Smooth surfaces OR 1–5 mm gouge infilling OR 1–5 mm aperture, and continuous joint extending several metres	10
Slightly rough surfaces, aperture <1 mm, and highly weathered walls	20
Slightly rough surfaces, <1 mm separation, slightly weathered walls	25
Very rough surfaces, not continuous joints, no separation, unweathered wall	30

Source: Bieniawski, Z.T., *Engineering Rock Mass Classification*, Wiley

Rock mass classification - RMR

- Rating Increment Tables

Guidelines for classifying the condition of discontinuity					
Persistence (m)	<1	1–3	3–10	10–20	>20
Rating	6	4	2	1	0
Aperture (mm)	None	<0.1	0.1–1.0	1–5	>5
Rating	6	5	4	1	0
Roughness	Very rough	Rough	Slightly rough	Smooth	Slickensided
Rating	6	5	3	1	0
Infilling (gouge)	None	Hard filling <5 mm	Hard filling >5 mm	Soft filling <5 mm	Soft filling >5 mm
Rating	6	4	2	2	0
Weathering	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
Rating	6	5	3	1	0

Source: Bieniawski, Z.T., *Engineering Rock Mass Classification*, Wiley

Rock mass classification - RMR

Example 2

Determine the rating increment for the following joint conditions:

- a. A joint with slightly rough and weathered walls has a separation less than 1 mm.
- b. A joint has a persistence = 2 m, aperture = 0.1–0.5 mm, roughness = slightly rough, infilling = none, weathering = slight.

Rock mass classification - RMR

- Rating Increment Tables

- The presence of **groundwater** in the joints can severely influence the shear strength and the deformability of the rock mass.
- The **general condition** of the joint can be determined qualitatively from the drill cores and borehole logs.

Rating increments for groundwater conditions

<i>Inflow (L/min) per 10-m tunnel length</i>	<i>Joint water pressure/major principal stress</i>	<i>General conditions</i>	<i>Rating increment</i>
>125	>0.5	Flowing	0
25–125	0.2–0.5	Dripping	4
10–25	0.1–0.2	Wet	7
<10	<0.1	Damp	10
None	0	Completely dry	15

Source: Bieniawski, Z.T., *Engineering Rock Mass Classification*, Wiley Interscience, New York, p. 251, 1989.

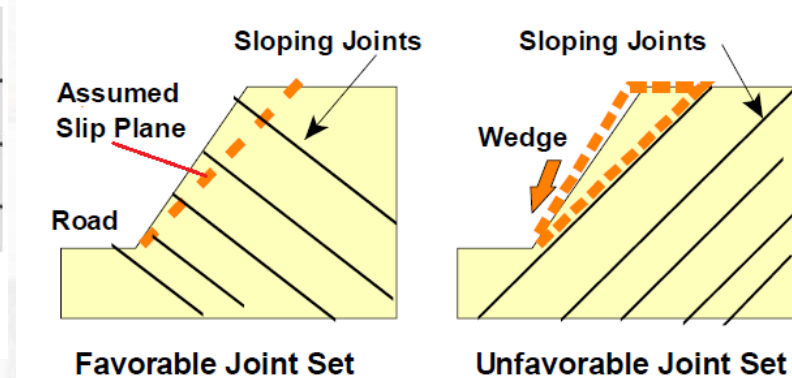
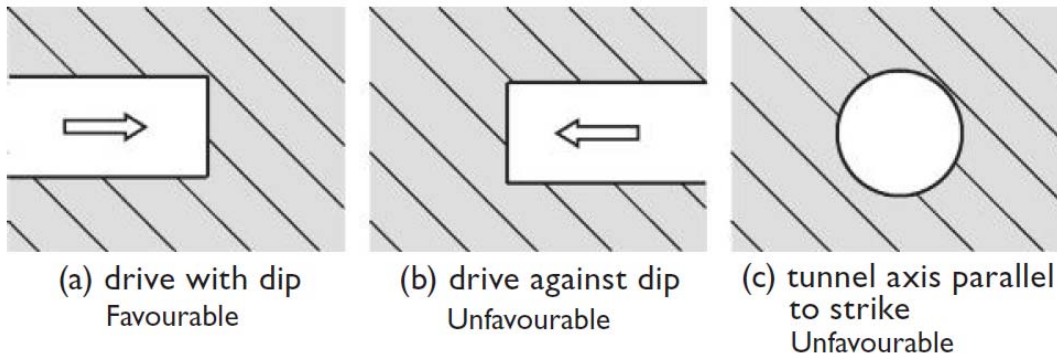
Rock mass classification - RMR

- Rock mass rating (RMR) adjustment
 - RMR is adjusted considering how **favourable or unfavourable** the joint orientations are with respect to the **project**.
 - The adjustment values are negative (0 to –60), and are different for tunnels, foundations and slopes.

Rating adjustments for discontinuity orientations			
Orientation of joints with respect to the project	Rating increments		
	Tunnels and mines	Foundations	Slopes
Very unfavourable	–12	–25	–60
Unfavourable	–10	–15	–50
Fair	–5	–7	–25
Favourable	–2	–2	–5
Very favourable	0	0	0

Rock mass classification - RMR

- Rock mass rating (RMR) adjustment



Effects of discontinuity orientation in tunnelling

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	Fair

Rock mass classification - RMR

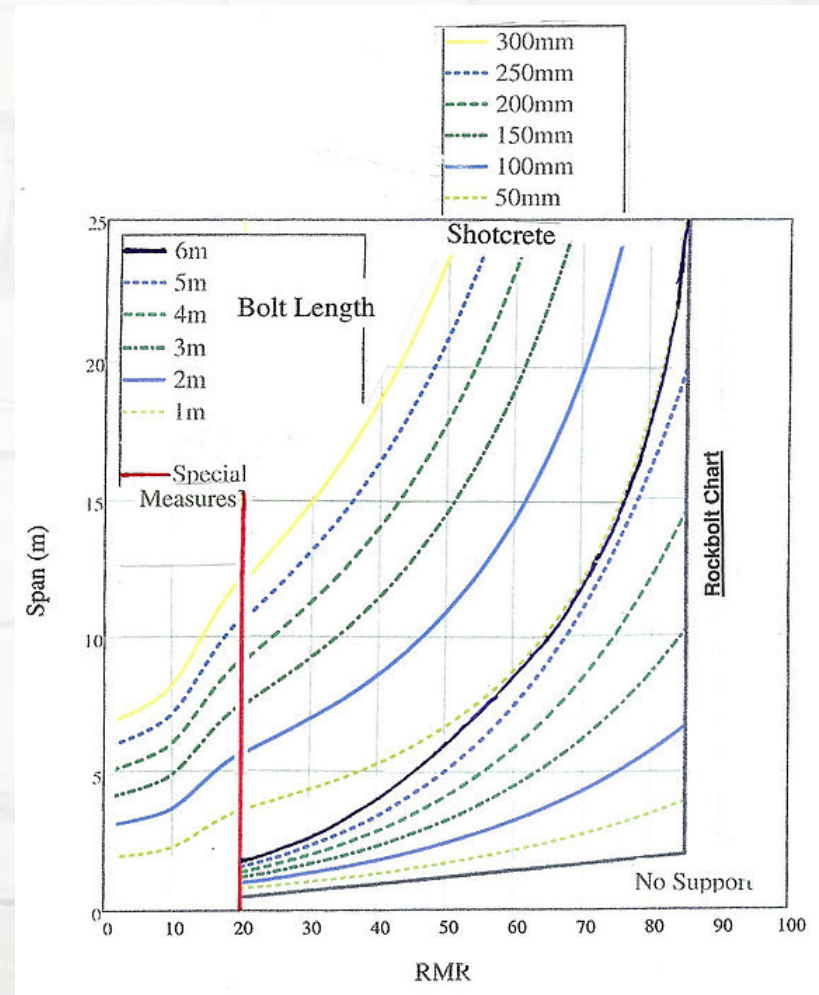
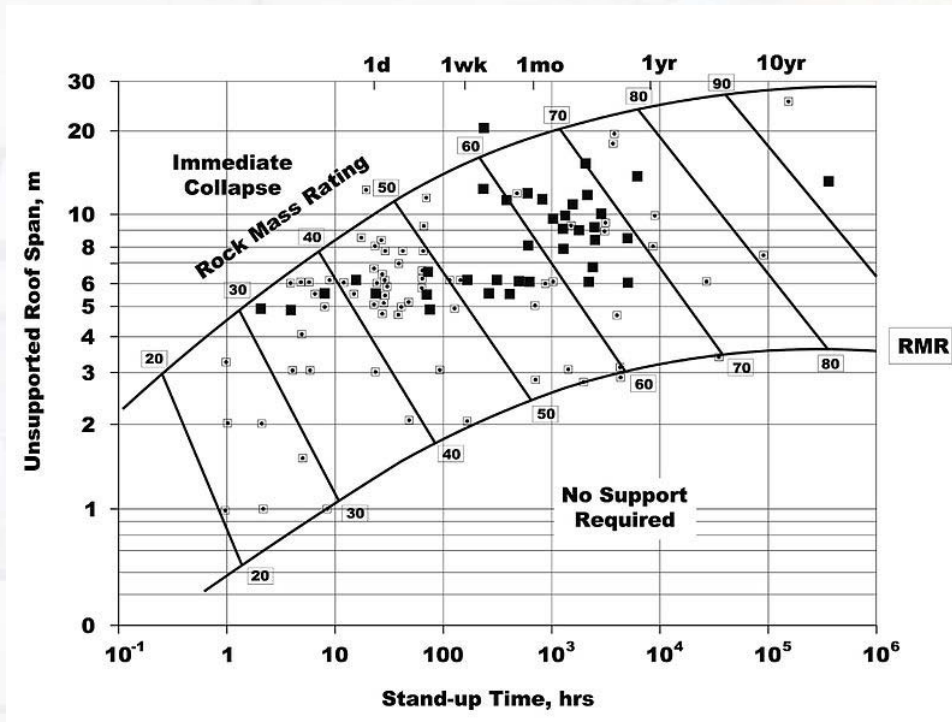
- Applications of Rock mass rating (RMR)
 - Selection of excavation and support procedures (e.g., rock bolt spacing, shotcrete, mesh) for underground openings.

Rock mass classes based on RMR					
RMR	81–100	61–80	41–60	21–40	0–20
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock
Average stand-up time of tunnel	20 years for 15-m span	1 year for 10-m span	1 week for 5-m span	10 hours for 2.5-m span	30 minutes for 1-m span
Cohesion of rock mass (kPa)	>400	300–400	200–300	100–200	<100
Friction angle of rock mass (°)	>45	35–45	25–35	15–25	<15

Source: Bieniawski, Z.T., *Engineering Rock Mass Classification*, Wiley

Rock mass classification - RMR

- Applications of Rock mass rating (RMR)



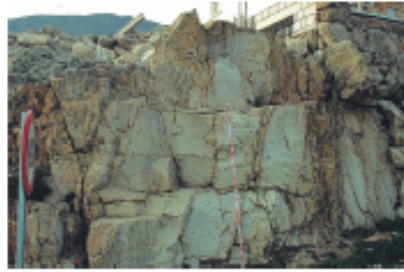
Rock mass classification - RMR

- Applications of Rock mass rating (RMR)

Class I (RMR = 81-100) and Class II (RMR = 61-80) rock masses

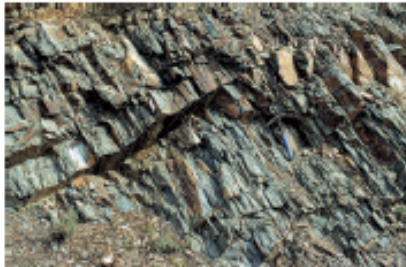


Cretaceous dolomite. Very good quality. Two main sets of discontinuities.



Granite. Good quality. Several sets of weathered discontinuities.

Class III rock masses (RMR = 41-60)

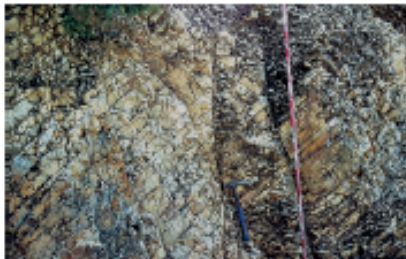


Ordovician slate. Fair quality. High fracturing degree. Weathering degree: III.



Ordovician quartzite. Fair quality. High fracturing degree. Very hard intact rock.

Class IV (RMR = 21-40) and Class V (RMR ≤ 20) rock masses



Ordovician quartzite. Poor quality. Weathered and heavily jointed rock mass.



Palaeozoic slate. Very poor quality. Heavily jointed. Degree of weathering: V.

Examples of classes of rock mass
(González de Vallejo and Ferrer, 2011)

Rock mass classification - RMR

Example 3

Determine the RMR value for tunneling work in a rock formation with the following details:

- The point load strength index $I_{s(50)} = 6 \text{ MPa}$
- $RQD = 80\%$
- Mean spacing of discontinuities = 500 mm
- Joint walls had slightly rough and weathered surfaces, with less than 1mm separation
- Groundwater condition = Damp
- Discontinuity orientation with respect to the project = Fair

Rock mass classification - RMR

Example 4

A highly fractured siltstone rock mass is found to have 2 joint sets and many random fractures, average *RQD* is 41%, joints appears continuous observed in tunnel, joint surfaces are slickensided and undulating, and are highly weathered, joint has a separation of about 3-5 mm, filled with clay, average rock material uniaxial compressive strength is 65 MPa, inflow per 10 m tunnel length is observed at approximately 50 l/min, with considerable outwash of joint fillings. The tunnel axis is parallel to the strike and the dip is 30°. Determine the RMR value.

Rock mass classification – Q-System

- Tunneling Quality Index: Q-System
- Developed by Barton et al. (1974) to characterize the rock mass and determine the tunnel support system.
- Based on the following six parameters:
 - *RQD* (0–100)
 - Number of joint sets in the rock mass, J_n (1–20)
 - Joint roughness number, J_r (1–4)
 - Joint condition (alteration) number, J_a (1–20)
 - Joint water reduction factor, J_w (0.1–1.0)
 - Stress reduction factor, *SRF* (1–20)

Rock mass classification – Q-System

- **Tunneling Quality Index: Q-System**

- The individual parameters are assigned values and the complete rating is calculated from:

$$Q = \left(\frac{RQD}{J_n} \right) \left(\frac{J_r}{J_a} \right) \left(\frac{J_w}{SRF} \right)$$

Measure of block size in cm ←

↓

Measure of shear strength = $\tan \phi_r$

→ Measure of "active stress"

- The value of Q ranges on a logarithmic scale from 0.001 to 1000+.
- The higher the value of Q , the better the rock mass quality.

Rock mass classification – Q-System

- Parameter values for the Q-System

RQD values in Q-system					
Class	A	B	C	D	E
Designation	Very poor	Poor	Fair	Good	Excellent
RQD	0–25	25–50	50–75	75–90	90–100

Source: Barton, N.R., et al., *Rock Mech.*, 6, 189, 1974.

Notes: (1) When RQD < 10, use 10 in computing Q; (2) RQD rounded off to 5 (i.e. 80 and 85) is adequate.

Joint set number J_n for Q-system		
Class	Description	J_n
A	Massive; none 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 cubes etc.	15
J	Crushed rock; earth-like	20

Source: Barton, N.R., et al., *Rock Mech.*, 6, 189, 1974.

Notes: (1) For tunnel intersections, use $3.0 \times J_n$; (2) for portals, use $2.0 \times J_n$.

Rock mass classification – Q-System

- Parameter values for the Q-System

Joint roughness number J_r		
Class	Description	J_r
(a) Rock–wall contact, and (b) Rock–wall contact before 10 cm of 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
(c) No rock–wall contact when sheared		
H	Zone containing clayey 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

Source: Barton, N.R., et al., *Rock Mech.*, 6, 189, 1974.

Notes: (1) Add 1.0 if the mean spacing of the relevant joint set is greater than 3 m and (2) $J_r = 0.5$ for planar slickensided joints having lineations if the lineations are favourably oriented.

Rock mass classification – Q-System

- Parameter values for the Q-System

Joint alteration number J_a			
Class	Description	ϕ_r (°)	J_a
(a) Rock–wall contact (no mineral fillings, only coatings)			
A	Tightly healed, hard, nonsoftening, 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, nonsoftening mineral coatings, sandy particles, clay-free disintegrated rock etc.	25–30	2.0
D	Silty- or sandy-clay coatings, small clay fraction (nonsoftening)	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 overconsolidated nonsoftening clay material fillings (continuous but <5-mm thickness)	16–24	6.0
H	Medium or low overconsolidation, 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 % 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 crushed rock and clay (see G, H and 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 (nonsoftening)	—	5.0
O, P, R	Thick continuous zones or bands of clay (see G, H and J for description of clay condition)	6–24	10, 13 or 13–20

Source: Barton, N., *Int. J. Rock Mech. Min. Sci.*, 39, 185, 2002.

Rock mass classification – Q-System

- Parameter values for the Q-System

Joint water reduction J_w			
Class	Description	Approx. water pressure (kPa)	J_w
A	Dry excavation or minor inflow (i.e. <5 L/min locally)	<100	1.0
B	Medium inflow or pressure, occasional outwash of joint fillings	100–250	0.66
C	Large inflow or high pressure in competent rock with unfilled joints	250–1000	0.5
D	Large inflow or high pressure, considerable outwash of joint fillings	250–1000	0.33
E	Exceptionally high inflow or water pressure at blasting, decaying with time	>1000	0.2–0.1
F	Exceptionally high inflow or water pressure, continuing without noticeable decay	>1000	0.1–0.05

Source: Barton, N., *Int. J. Rock Mech. Min. Sci.*, 39, 185, 2002.

Notes: (1) C to F are crude estimates; increase J_w if drainage measures installed; (2) special problems formed by ice formation are not considered.

Rock mass classification – Q-System

• Parameter values for the Q-System

Stress reduction factor SRF

(a) Weakness zones intersecting excavations, which may cause loosening of rock mass when tunnel is excavated

Class	Description	SRF
A	Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock (any depth)	10
B	Single-weakness zone containing clay or chemically disintegrated rock (depth of excavation ≤ 50 m)	5.0
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

(b) Competent rock, rock stress problems

Class	Description	σ_c/σ_1	σ_0/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 to wall stability	10–5	0.3–0.4	0.5–2
L	Moderate slabbing after > 1 h 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	0.65–1.0	50–200
N	Heavy rock burst (strain-burst) and dynamic deformations in massive rock	< 2	> 1	200–400

(c) Squeezing rock: plastic flow of incompetent rock under the influence of high rock pressure

Class	Description	σ_0/σ_c	SRF
O	Mild squeezing rock pressure	1–5	5–20
P	Heavy squeezing rock pressure	> 5	10–20

(d) Swelling rock: chemical swelling activity depending on presence of water

Class	Description	SRF
R	Mild swelling rock pressure	5–10
S	Heavy swelling rock pressure	10–15

Source: Barton, N., *Int. J. Rock Mech. Min. Sci.*, 39, 185, 2002.

Source: Barton, N.R., et al., *Rock Mech.*, 6, 189, 1974.

Notes: (1) σ_0 = maximum tangential stress (estimated from elastic theory), σ_c = unconfined compressive strength, σ_1 = major principal stress. (2) Reduce SRF by 25–50% if relevant shear zones only influence but do not intersect the excavation. (3) Barton et al. (1974) have maximum SRF of 20. (4) In strongly anisotropic stress fields (when measured), when $\sigma_1/\sigma_3 = 5$ to 10, reduce σ_c by 25%, and for $\sigma_1/\sigma_3 > 10$, reduce σ_c by 50%.

Rock mass classification – Q-System

- Applications of the Q-system

- Selection of excavation and support procedures for underground openings.

Rock mass classification for tunnelling based on Q-system

Q-value	Class	Rock mass quality
400–1000	A	Exceptionally good
100–400	A	Extremely good
40–100	A	Very good
10–40	B	Good
4–10	C	Fair
1–4	D	Poor
0.1–1.0	E	Very poor
0.01–0.1	F	Extremely poor
0.001–0.01	G	Exceptionally poor

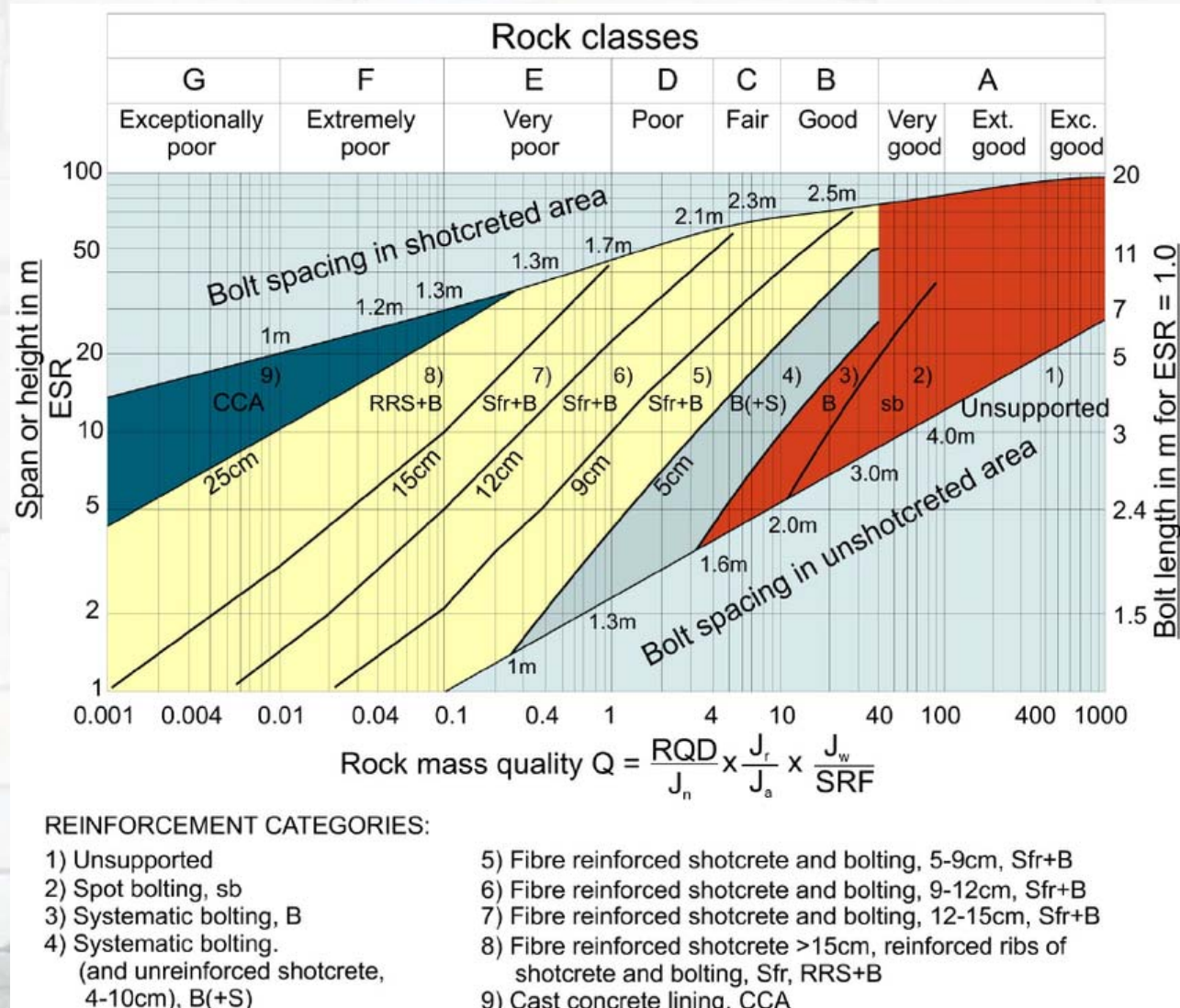
- Relating the RMR and the Q-system

$$RMR \approx 9 \ln Q + 44 \quad \text{Bieniawski (1976, 1989)}$$

$$RMR \approx 15 \ln Q + 50 \quad \text{Barton (1995)}$$

Rock mass classification – Q-System

• Applications of the Q-system



Rock mass classification – Q-System

Example 5

It is proposed to construct an underground tunnel 500 m below the ground. The drilled cores have an *RQD* of 85% and the number of joint sets is estimated to be 2. The joints are rough, undulating and unweathered with minor surface staining. The average uniaxial compressive strength of the cores is 190 MPa. The major principal stress acts horizontally and is twice the vertical stress. The unit weight of the rock is approximately 30 kN/m³. The excavation is relatively dry, with some dampness and negligible inflow. Estimate the Q-value.

Rock mass classification – Q-System

Example 6

It is proposed to construct an underground tunnel in a sandstone rock mass, fractured by 2 joint sets plus random joints, average RQD is 70%, average joint spacing is 0.11 m, joint surfaces are slightly rough, highly weathered with stains but no clay found on surface, joints are generally in contact with apertures generally less than 1 mm, average rock material uniaxial compressive strength is 85 MPa. The tunnel is to be excavated at 80 m below ground level and the groundwater table is 10 m below the ground surface. The unit weight of the rock is approximately 27 kN/m³. Estimate the Q-value.

Rock mass classification - GSI

- **Geological Strength Index (GSI)**
- GSI was introduced by Hoek (1994) with a heavy reliance on geological observations, and less on numerical values.
- GSI ranges from about 10 for extremely poor-quality rock mass to 100 for very strong unjointed rock mass.
- GSI is one of the parameters used in assessing the strength and deformability (stiffness) of the rock mass using the Hoek–Brown failure criterion.
- Based on the following two parameters:
 - **surface condition of the discontinuity;**
 - **interlocking among the rock blocks.**

Rock mass classification - GSI

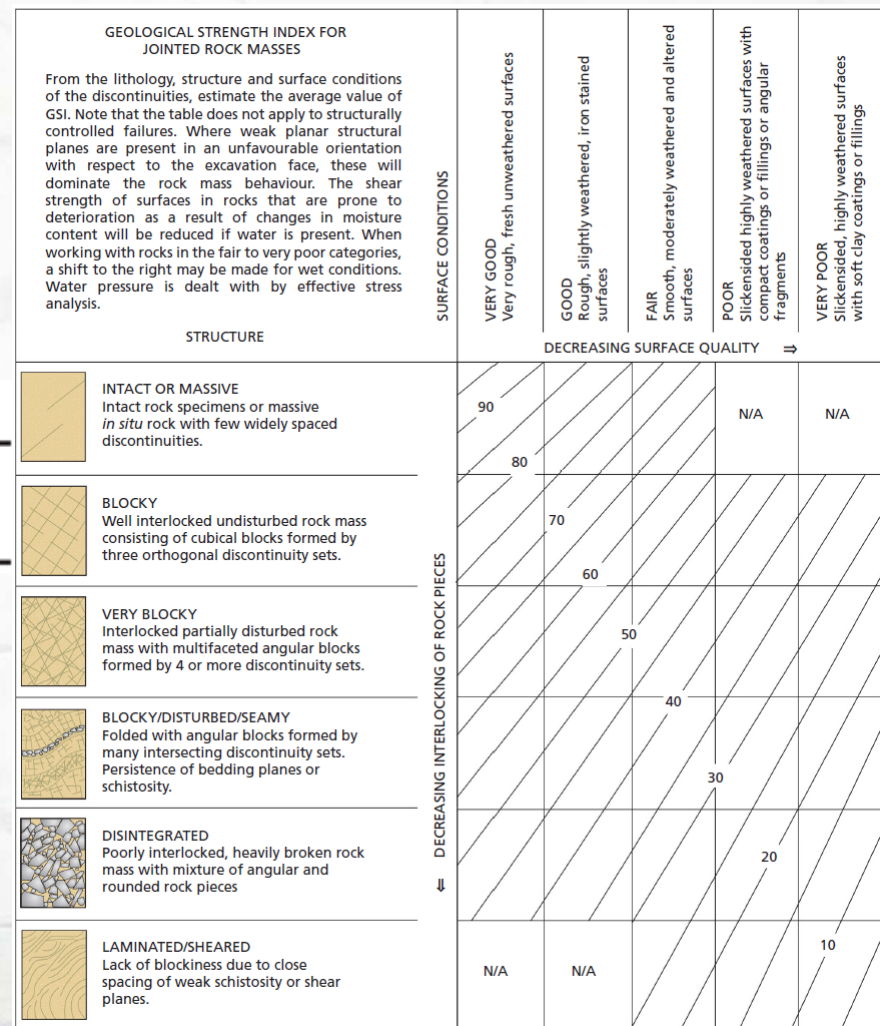
- Geological Strength Index (GSI) application

➤ Tool to estimate rock mass strength with the Hoek-Brown failure criterion.

Rock mass quality and GSI

GSI	<20	21-40	41-55	56-75	76-95
Rock mass quality	Very poor	Poor	Fair	Good	Very good

Chart for GSI estimates from geological observations (Hoek and Marinos, 2000).



Rock mass classification - GSI

- Relating the GSI to RMR

$$GSI \approx RMR - 5 \quad \text{Bieniawski (1989)}$$

Where RMR is determined assuming dry conditions at the excavation (rating increment = 15), with no adjustment for discontinuity orientations with respect to the project (very favourable; rating adjustment = 0).

- Relating the GSI to the Q-system

$$Q' = \left(\frac{RQD}{J_n} \right) \left(\frac{J_r}{J_a} \right) \quad \text{Hoek et al. (2005)}$$

Where Q' is calculated assuming dry excavation ($J_w = 1$) and medium stress with favorable stress condition ($SRF = 1$).

$$GSI = 9 \ln Q' + 44$$

Rock mass classification - GSI

Example 7

A granite rock mass has three joint sets, an *RQD* of 85%, and average joint spacing of 250 mm. Joint surfaces are stepped and rough, unweathered with some stains, and have no separation. The average uniaxial strength of the intact rock cores is 190 MPa, and the excavation area is slightly damp. The excavation is at a depth of 200 m where no unusual in-situ stresses are expected. Find the *RMR*, *Q* and *GSI* values. Assume a rock unit weight of 28 kN/m³, very favourable joint orientation and that the vertical in-situ stress is the major principal stress.

Rock mass classification – Other Systems

- Rock Mass Number (N)

$$N = \left(\frac{RQD}{J_n} \right) \left(\frac{J_r}{J_a} \right) (J_w)$$

Where N is determined as the rock mass quality Q-value when *SRF* is set at 1 (i.e., normal condition, stress reduction is not considered).

- Rock Mass Index (RMi)

$$RMi = \sigma_c J_p$$

Where :

σ_c = uniaxial compressive strength of the intact rock material;

J_p = jointing parameter accounting for 4 joint characteristics, namely, joint density (or block size), joint roughness, joint alteration and joint size.

J_p is in fact a reduction factor representing the effects of jointing on the strength of rock mass ($J_p = 1$ for intact rock, $J_p = 0$ for crushed rock masses).