Discontinuities

- **Discontinuity** is a general term for any mechanical discontinuity in a rock mass and represents a **plane of weakness** within the rock body.
- Most discontinuities are planes of separation and possess **little or no tensile strength** (The strength of a substance under tension).
- The most common discontinuities are **joints and bedding** planes. Other important discontinuities are planes of **faults, foliation, and unconformities**.
- Discontinuities vary in **size** from small microscopic fissures to huge faults.
- All types of discontinuities affect the **mechanical properties** of the **Foundation bed rocks or soils**.
- Discontinuities can **reduce or increase** the rock mass strength based on its orientation and type of filling material. Joints will normally reduce the rock mass strength by providing weakness planes in the rock mass . Accumulations of stronger material at joints surfaces such as quartz will increase the rock material strength
- Work must be done during field studies includes:
  - geological data collection including:
    - Sampling, identification and description of rocks.
    - Description and measurements of structures.
  - mapping of discontinuities
  - assessment of **rock mass conditions** from scan line surveys

- In general, the **main parameters of estimation** of a discontinuity type include:
  1. Number of sets
  2. Orientation (described in dip direction/dip)
  3. Spacing
  4. Persistence
  5. Roughness
  6. Aperture
  7. Filling
  8. Seepage
  9. Block size
  10. There are many other parameters can be considered depending on the type of discontinuity.
- For engineering purposes, the parameters of each discontinuity type in the foundation bed rocks must be :
  - described carefully.
  - Measured and represented as a **numerical values** to be used in the calculation of the **Rock Quality.**
- There are **certain techniques for estimation** of each of these parameters as numerical values.
- The estimated value of the **Rock Quality** is one of the essential parameters considered in **planning** of construction projects (e.g. dams, tunnels, roads, building constructions, …etc).

evaluation of Joints as a discontinuity

Joints are the most common discontinuity, and generally the most geotechnically important in rocks.

parameters to be evaluated for joints are:

1- **Number of sets**:

The number of joint sets is counted in the field for the joint system by careful observation in **three dimensions**; i.e. observations must be considered in the cross sectional and horizontal views.

For each joint set, the following parameters must be measured.

2- **Orientation**:

- The attitudes of joint planes present in each joint set are measured in the field from rock outcrops using **Brunton compass**. It is measured as strike, dip and direction of dip (or as dip/dip direction).
- Data are collected from chosen **stations**. In each station **all recorded joints** are measured.
- Collected data are plotted on a geological map by symbols and can be represented on orientation diagrams (**rose diagrams or point contour diagrams**).
- Determination of the orientation of the **line of intersection** of joint planes is important in the determination of ability of rock exposures for **wedge failure**.
- The determination of the **orientation of joint sets** is of prime importance in:
  - construction of dams and tunnels
  - quarrying and mining
  - construction of highways
  - slope stability determination.

3- **Spacing**:

- Spacing is the **perpendicular** distance between two adjacent joints.
- The spacing between two joints may **vary** from a few centimeters to more than a meter.
- Under the same stress, competent rocks will have **more joints and smaller spacing** than less-competent rocks.
- It is commonly observed that , a joint set has a relatively **constant spacing** between individual fractures.

4- **Frequency**:

The joint frequency is estimated as the **number of joints per meter** for a given joint set. It Is measured from rock outcrops in the field and also from cores of drill holes.

5- Persistence:

Persistence is the measure of the **continuous length** or area of the discontinuity

6- **Roughness**:

Roughness is the **waviness or small irregularities** of the joint surface. Quantitative evaluation of this parameter can be estimated by comparing the roughness observed on the joint surface with a certain table giving **the degree of roughness**.

7- **Aperture**:

Aperture is the **perpendicular distance between the joint walls**. In other words, it is the width of the joint opening. Apertures of many joints are wide open to allow large flow of water through them.

8- **<u>Filling</u>**:

The fill materials in a joint vary widely. Many joints that originated with considerable openings are tightly filled with veins or dyke minerals.

Filling with secondary silica or hydrothermal quartz completely **seals** the joint openings and considerably increase the hardness of the rock material. Filling by carbonates and loose materials such as clay, silt, and micas reduce the rock strength.

9- <u>Wall Strength</u> :

Is the Equivalent compression strength of the adjacent rock walls of a discontinuity. It may be lower than rock block strength due to weathering or alteration of the walls.

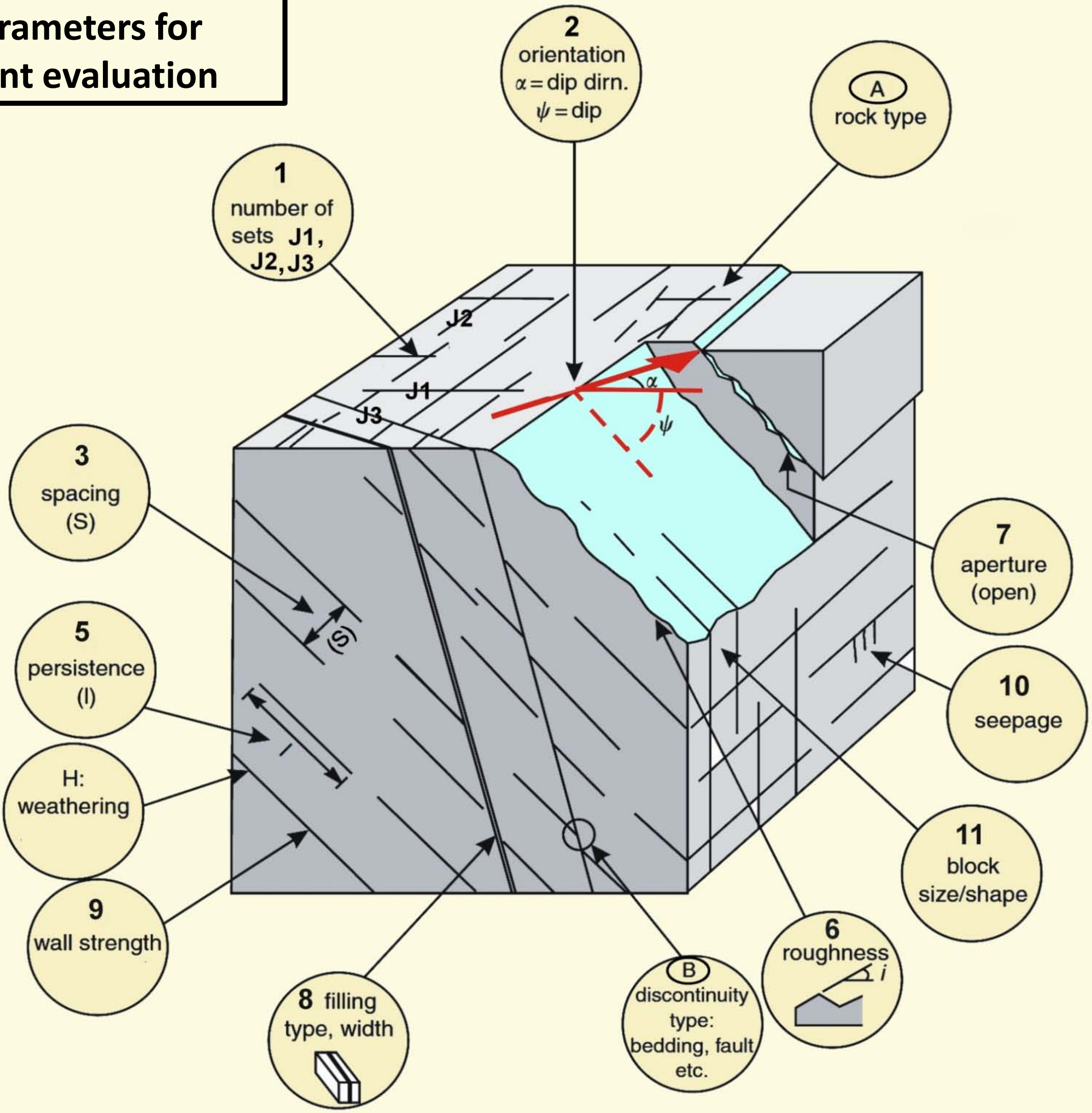
10- <u>Seepage</u> :

Is the Water flow and free moisture visible in individual discontinuities or in the rock mass as a whole.

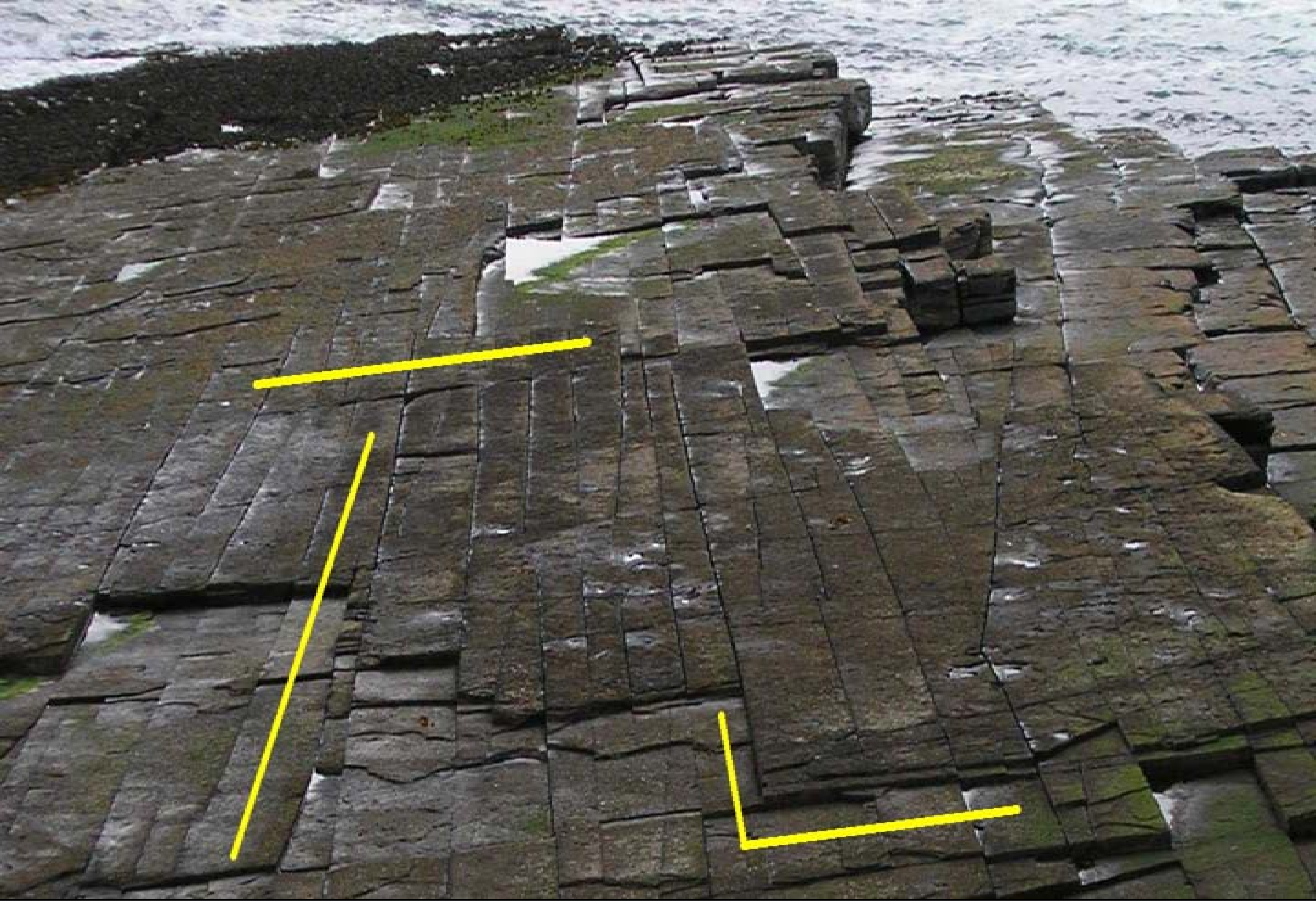
11- <u>Block Size</u> :

Is Rock **block dimensions** resulting from **the intersecting joint sets**, and resulting from the spacing of the individual discontinuities.

Parameters for joint evaluation



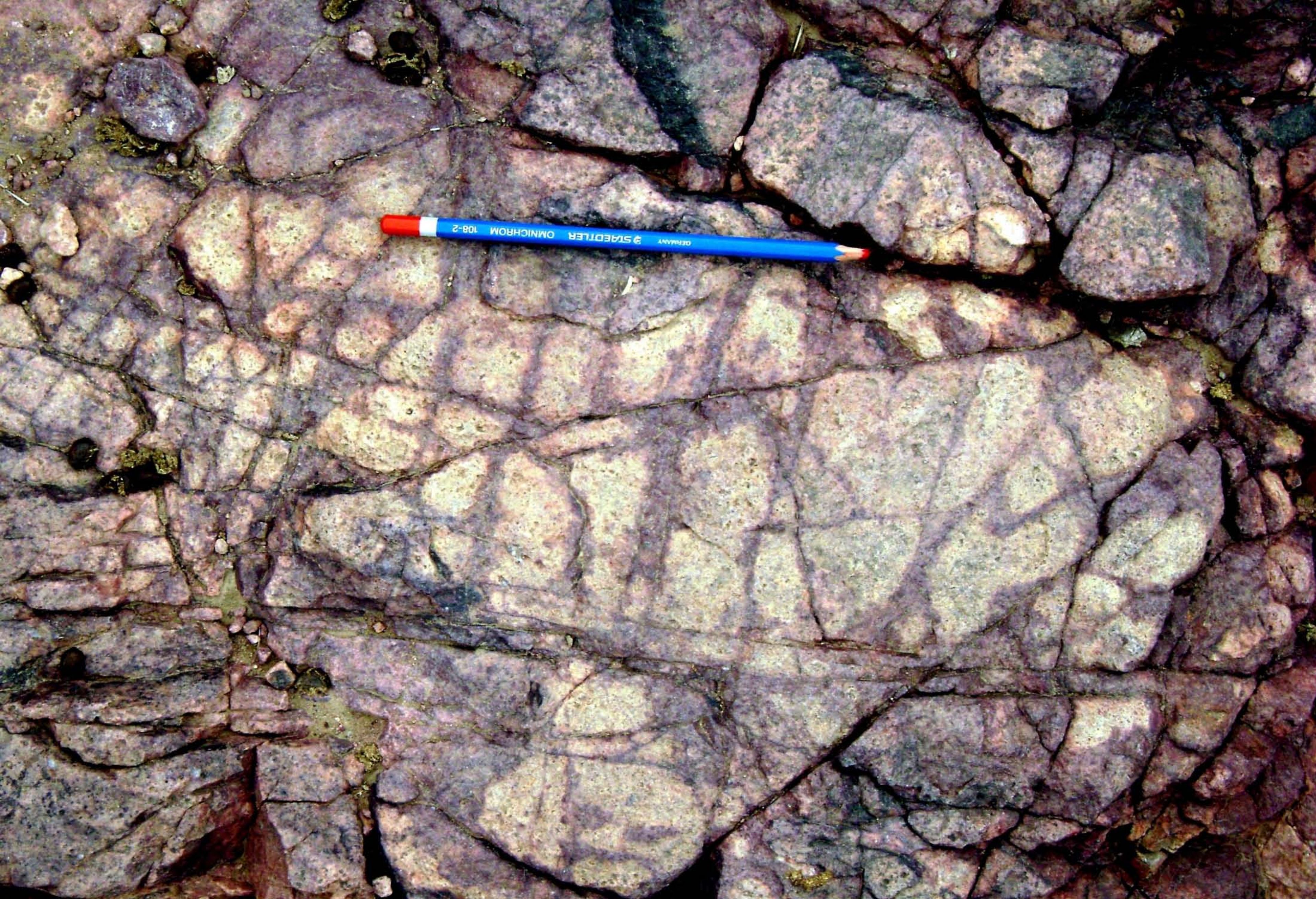
Three sets of joints in chert layer. The previously mentioned parameters must be evaluated for each set.



Three sets of joints dividing the rock mass into rectangular blocks

Three sets of joints filled with secondary material of higher competency than the rock mass

Two sets of joints filled with secondary material of higher competency than the rock mass



Joints in sandstone stained with iron solutions

ROCK MASS CLASSIFICATION systems

- ❖ The purpose of **rock mass classification is to evaluate the quality of a particular rock mass** (or part of a rock mass) by assigning rating values to a **set of rock parameters**.
- ❖ There are several methods for the geomechanical classification of rock masses in order to evaluate the quality of a rock mass for construction.
- ❖ The difference between these methods is the parameters used in rock quality determination and the weight of each parameter in the rock quality equation.

❖ Rock mass classification Systems for tunneling: Quantitative

- Rock Mass Rating (RMR)
- Q-system (Rock Tunnelling Quality Index)
- Mining rock mass rating (MRMR)

❖ Rock mass classification Systems for slope engineering

- Slope Mass Rating (SMR) and Continuous Slope Mass Rating
- Q-slope
- Rock mass classification system for rock slopes
- Slope Stability Probability Classification (SSPC)

❖ Other Rock mass classification systems:

- Rock Mass Structure Rating (RSR)
- Geological Strength Index (GSI)

Rock mass rating (RMR)

- Among the rock mass classification techniques is the **Rock mass rating (RMR)** method. Most of the applications of *RMR* is in the field of tunnelling but also in the stability analysis of slope foundations. and different kinds of mining openings.
- **Rock mass rating (RMR)** classification divides the quality of a rock mass into five classes **(very good, good, fair, poor, and very poor),** based on assigning rating values for the following factors:

  1. **RQD** (rock-quality designation)
  2. intact rock strength
  3. joint spacing
  4. Joints Conditions including : aperture, roughness, Infilling, and weathering.
  5. groundwater inflow
  6. joint orientation

- Each factor has its **own weight** in the equation of RMR. It is evaluated in the field and given a numerical value based on certain limitation tables. The sum of these values indicates the RMR.

❖ Rock-quality designation:

is the percentage of core recovery obtained in core pieces of 10 cm (or more) in length out of the total length of the drill hole run in rock. Thus,

$$RQD\ (\%) = \frac{\sum of\ core\ pieces\ >\ 10\ cm}{total\ length\ of\ the\ core\ run} \times 100$$

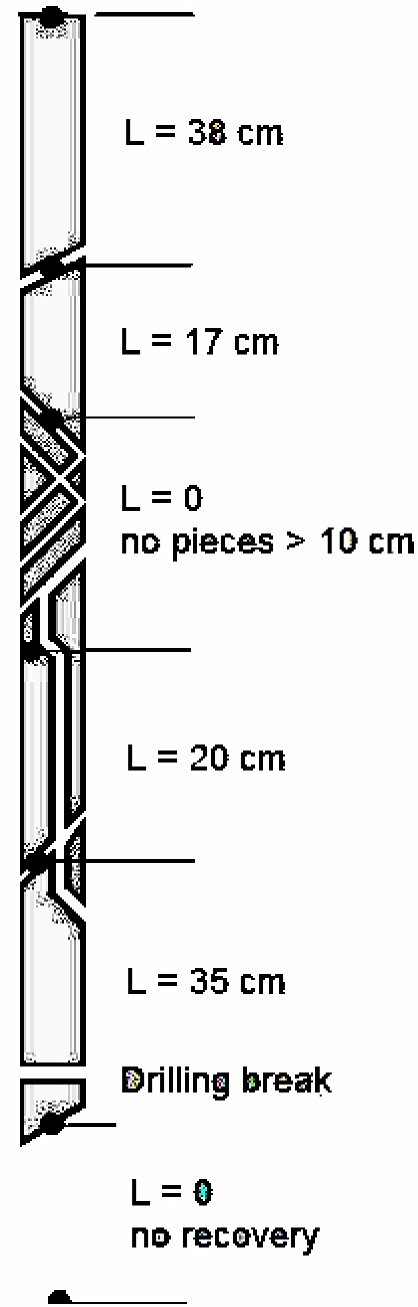
The core should be at least 54.7 mm or 2.15 inches in diameter.

Example:

Total length of core run = 200 cms

$$RQD = \frac{\sum \text{Length of core pieces} > 10 \text{ cm length}}{\text{Total length of core run}} \times 100$$

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



❖ The weights of the different parameters in the RMR equation

	Parameter	Maximum rating in RMR
1	RQD (rock-quality designation)	20
2	Intact rock strength	15
3	Joint spacing	20
4	Joints Conditions including : aperture, roughness, Infilling, weathering.	30
5	Groundwater inflow	15
	Total Sum	100
6	Joint orientation	-12

❖ The RMR equation

- The first five parameters (1-5) represent the basic parameters in the RMR equation. The sum of their ratings is the **(RMR_{basic})**. The sixth parameter is treated separately because the influence of discontinuity orientations depends upon engineering applications.
- All the ratings are algebraically summed for the five first parameters and then adjusted depending on the sixth parameter as shown in the following equations.

$$RMR_{basic} = \Sigma \text{ of ratings of parameters } (1+2+3+4+5)$$

$$RMR = RMR_{basic} + \text{rating of the sixth parameter (joint orientation)}$$

Geomechanics classification of rock masses RMR (after Bieniawski, 1989)

<table>
<tr><td colspan="10">A: Classification Parameters</td></tr>
<tr><td rowspan="3">1</td><td rowspan="2">Strength of intact rock (MPa)</td><td>Point load PLI_{50}</td><td>>10</td><td>10–4</td><td>4–2</td><td>2–1</td><td colspan="3">PLI_{50} Not applicable</td></tr>
<tr><td>UCS</td><td>>250</td><td>250–100</td><td>100–50</td><td>50–25</td><td>25–5</td><td>5–1</td><td><1</td></tr>
<tr><td colspan="2">Rating</td><td>15</td><td>12</td><td>7</td><td>4</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td rowspan="2">2</td><td colspan="2">RQD</td><td>90–100%</td><td>75–90%</td><td>50–75%</td><td>25–50%</td><td colspan="3"><25%</td></tr>
<tr><td colspan="2">Rating</td><td>20</td><td>17</td><td>13</td><td>8</td><td colspan="3">3</td></tr>
<tr><td rowspan="2">3</td><td colspan="2">Spacing of discontinuities</td><td>>2 m</td><td>0.6–2 m</td><td>0.2–0.6 m</td><td>60–20 mm</td><td colspan="3"><60 mm</td></tr>
<tr><td colspan="2">Rating</td><td>20</td><td>15</td><td>10</td><td>8</td><td colspan="3">5</td></tr>
<tr><td rowspan="2">4</td><td colspan="2">Condition of discontinuities</td><td>Very rough, impersistent, no aperture, unweathered.</td><td>Sl. rough, aperture <1 mm, sl. weathered</td><td>Sl. rough, aperture <1 mm, highly weathered</td><td>Slicken-sided or gouge <5 mm or aperture 1–5 mm, continuous</td><td colspan="3">Soft gouge >5 mm thick, separation > 5 mm, continuous</td></tr>
<tr><td colspan="2">Rating</td><td>30</td><td>25</td><td>20</td><td>10</td><td colspan="3">0</td></tr>
<tr><td rowspan="4">5</td><td rowspan="3">Groundwater</td><td>Inflow per 10 m tunnel length</td><td>None</td><td><10 litres/min</td><td>10–25 litres/min</td><td>25–125 litres/min</td><td colspan="3">>125 litres/min</td></tr>
<tr><td>Joint water pressure/ major principal stress, σ_1</td><td>0</td><td>0–0.1</td><td>0.1–0.2</td><td>0.2–0.5</td><td colspan="3">>0.5</td></tr>
<tr><td>General conditions</td><td>Completely dry</td><td>Damp</td><td>Wet</td><td>Dripping</td><td colspan="3">Flowing</td></tr>
<tr><td colspan="2">Rating</td><td>15</td><td>10</td><td>7</td><td>4</td><td colspan="3">0</td></tr>
</table>

Rating of Discontinuity Conditions, Bieniawski, 1979

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

Source: Bieniawski, 1979.

From: Engineering Rock Mass Classification-Bhawani Singh-2011

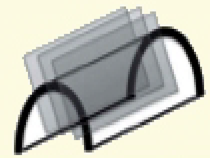
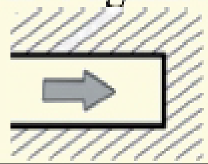
Rating of Discontinuity Conditions, Bieniawski, 1993

Parameter*	Ratings				
Discontinuity length (persistence/ continuity)	<1 m	1–3 m	3–10 m	10–20 m	>20 m
	6	4	2	1	0
Separation (aperture)	None	<0.1 mm	0.1–1.0 mm	1–5 mm	>5 mm
	6	5	4	1	0
Roughness of discontinuity surface	Very rough	Rough	Slightly rough	Smooth	Slickensided
	6	5	3	1	0
Infillings (gouge)		Hard filling		Soft filling	
	None	<5 mm	>5 mm	<5 mm	>5 mm
	6	4	2	2	0
Weathering discontinuity surface	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
	6	5	3	1	0

Source: Bieniawski, 1993. From: Engineering Rock Mass Classification-Bhawani Singh-2011

B: ***Rating adjustment for joint orientations***

Guidelines for assessment of adversity of discontinuities

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

Rating adjustments for RMR

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
Rating	Tunnels and mines	0	–2	–5	–10	–12

Rock mass classes in Rock Mass Rating (RMR)

Based on the calculated value of the RMR the rock mass quality is subdivided into the following five classes:

C: *Rock mass classes*

Class	I	II	III	IV	V
Description	Very good	Good	Fair	Poor	Very poor
Rating	100–81	80–61	60–41	40–21	<20

D: Meaning of rock mass classes

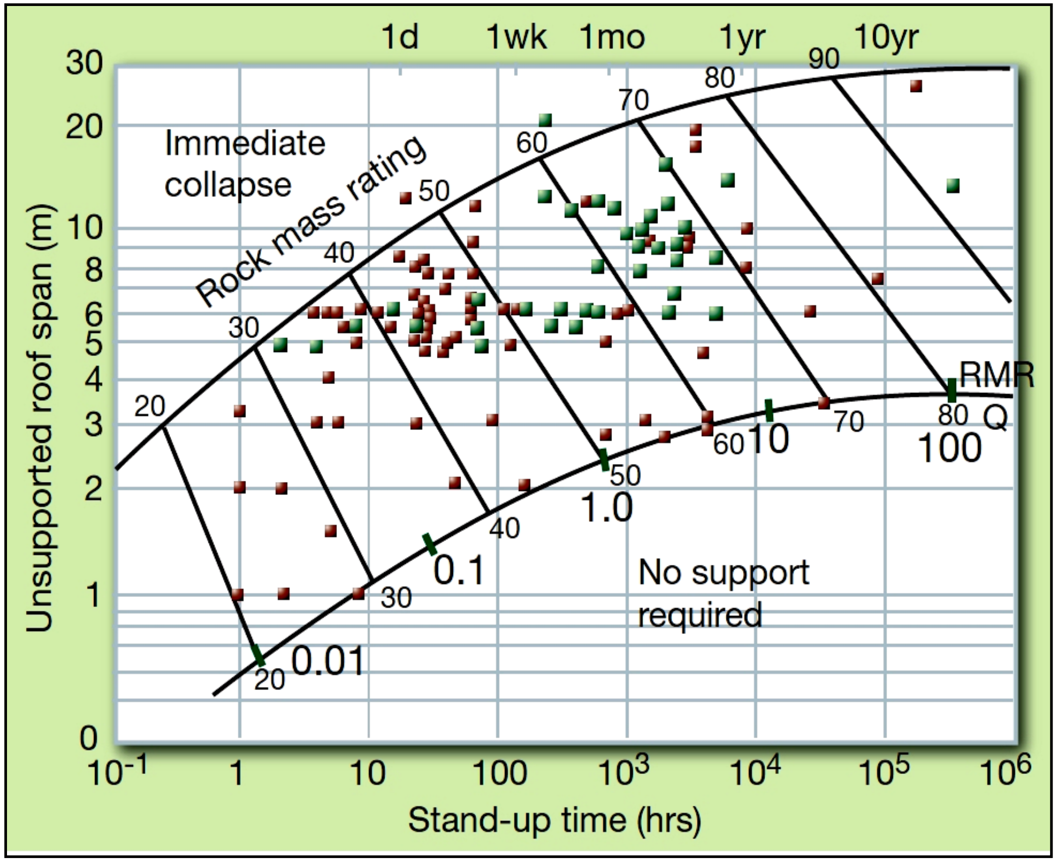
Class	I	II	III	IV	V
Average stand-up time	10 years for 5 m span	6 months for 4 m span	1week for 3 m span	5 hours for 1.5 m span	10 hours for 0.5 m span
Cohesion of rock mass	> 300 kPa	200–300 kPa	150–200 kPa	100–250 kPa	< 100 kPa
Friction angle of rock mass	> 45°	45°–90°	35°–40°	30°–35°	< 30°

<u>Stand-up time</u> :

is how long a rock mass will safely stand by itself without failure from the roof of a tunnel. This indicates the maximum period of time available to install supports for the tunnel.

Stand-up time data versus RMR from case histories after Bieniawski, 1989

- ❖ All the data in the diagram represent the study of historical cases.
- ❖ <u>In the diagram :</u>
- Each point represents the stand-up time for an unsupported tunnel span in a case history at failure.
- the two curves represent the limiting boundaries of the RMR values bounding the historical cases.
- The black straight lines represent the boundary values between RMR fields.



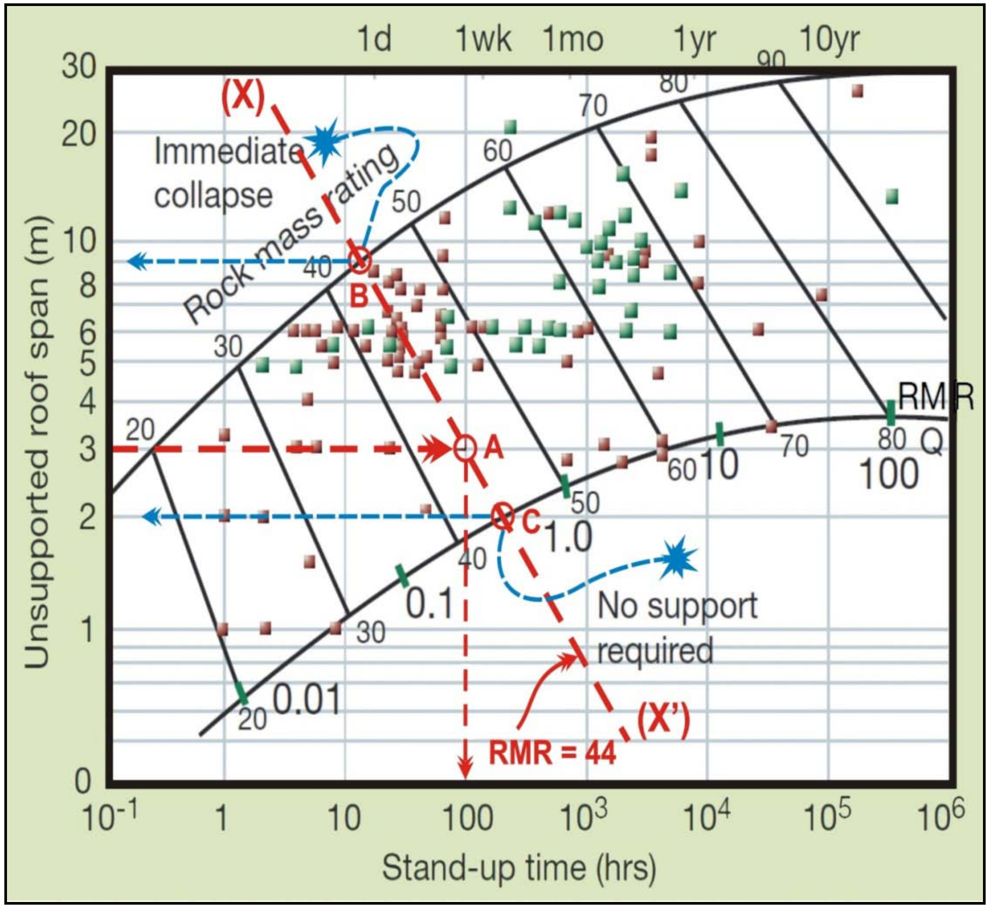
- In the region above the upper RMR curve, immediate collapse occurs, and immediate support is required.
- In the region below the lower RMR curve, no collapse occurs and no support is required.

From the stand-up time diagram you can predict the probable stand-up time for a certain roof span in a rock mass of known RMR.

To determine the stand-up time in a rock mass of RMR = 44 for tunnel span = 3 m :

1. Draw the line (x-x’) representing the RMR value = 44.
2. Draw a line at the level of 3 m span, that intersects (x-x’) at point (A).
3. **Point (A)** indicates the value of stand-up time on the horizontal axis = 100 hrs.

- **Point (B)** indicates that, for a rock mass of RMR=44, immediate collapse occurs in tunnel spans greater than 9 m, and immediate support is required.
- **Point (C)** indicates that, for a rock mass of RMR=44, no collapse occurs in tunnel spans smaller than 2 m, and no support is required.



Design Parameters and Engineering Properties of Rock Mass

S. No.	Parameter/ properties of rock mass	RMR (rock class)				
		100–81 (I)	*80–61 (II)*	*60–41 (III)*	*40–21 (IV)*	*<20 (V)*
1	Classification of rock mass	Very good	Good	Fair	Poor	Very poor
2	Average stand-up time	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
3	Cohesion of rock mass (MPa)*	>0.4	0.3–0.4	0.2–0.3	0.1–0.2	<0.1
4	Angle of internal friction of rock mass	>45°	35–45°	25–35°	15–25°	<15°
5	Allowable bearing pressure (T/m^2)	600–440	440–280	280–135	135–45	45–30
6	Safe cut slope (°) (Waltham, 2002)	>70	65	55	45	<40

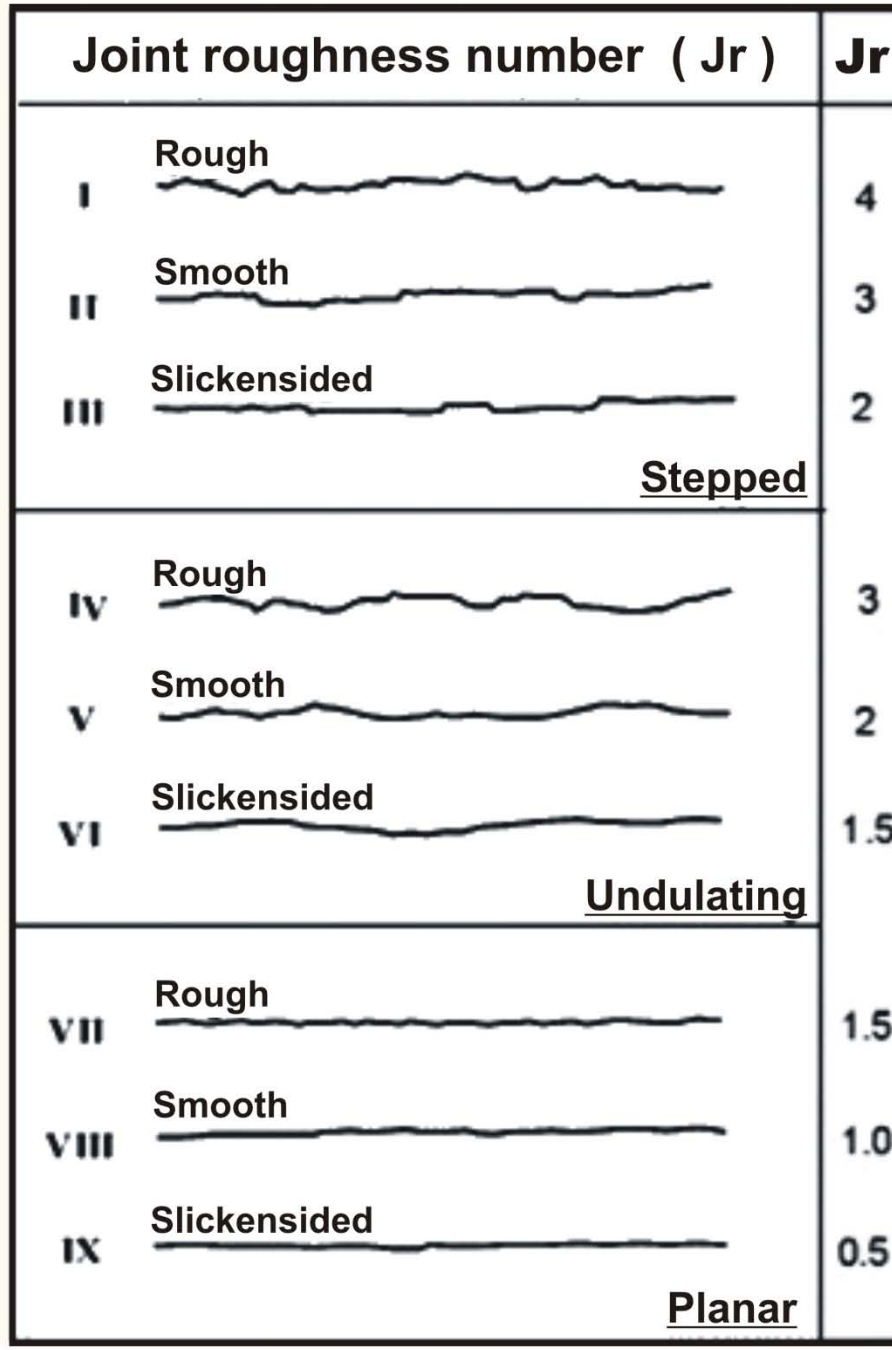
During earthquake loading, the above values of allowable bearing pressure may be increased by 50% in view of rheological behavior of rock masses (see Chapter 20).

**These values are applicable to slopes only in saturated and weathered rock mass.*

Source: Bieniawski, 1993.

From: Engineering Rock Mass Classification-Bhawani Singh-2011

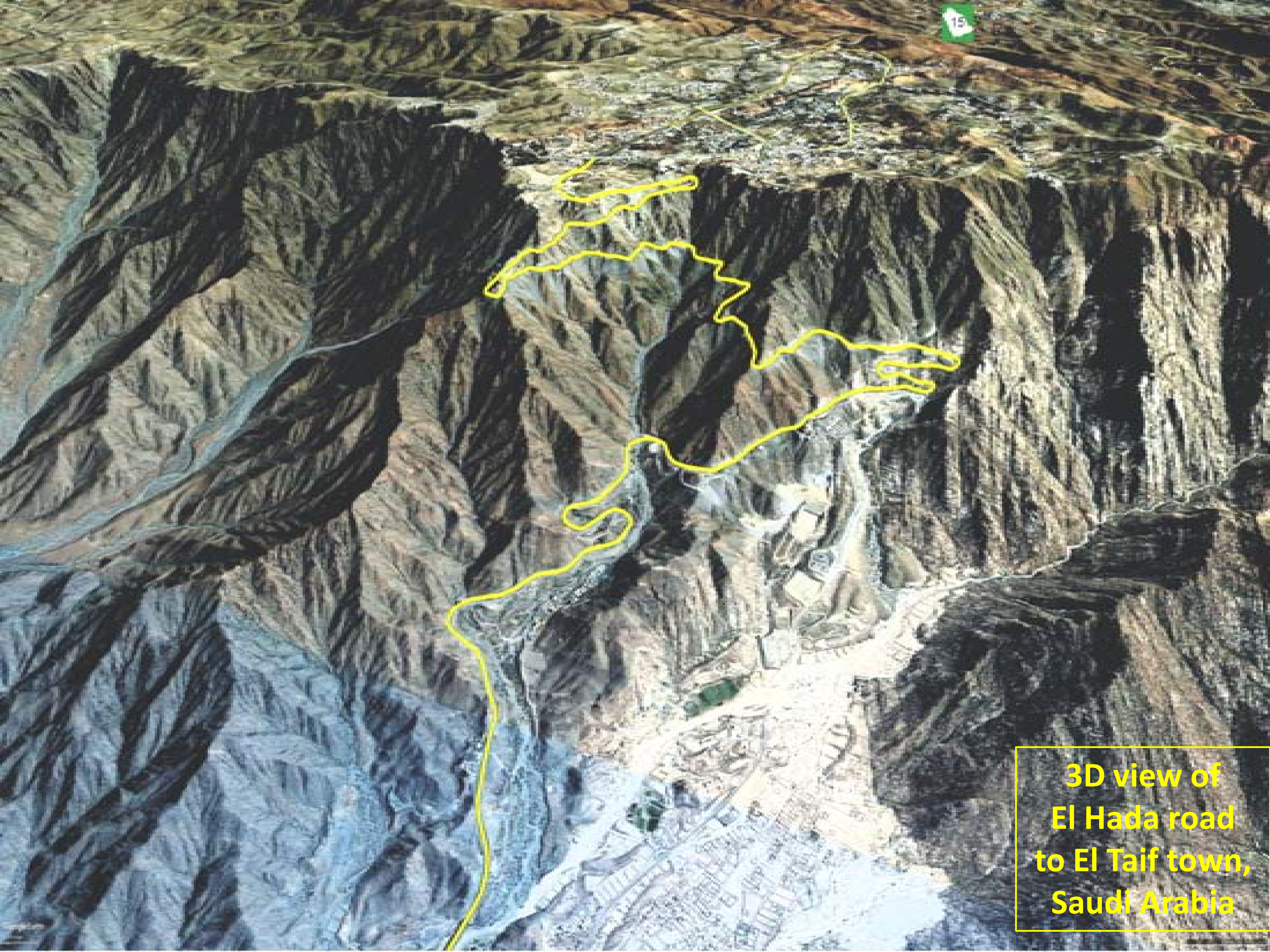
Table for the evaluation of joint roughness number (Jr)



Photos showing some engineering problems

Slope stability problem

Slope stability problem



3D view of El Hada road to El Taif town, Saudi Arabia

Part of El Hada road to El Taif town, Saudi Arabia

Part of El Hada road to El Taif town, Saudi Arabia

Part of El Hada road to El Taif town, Saudi Arabia

Part of El Hada road to El Taif town, Saudi Arabia

Closer view of the previous photo


Probable wedge failure


MARKLINE
Permanent Marker

- **<u>Tables, diagrams, some photos and definitions of scientific terms are used after the following references for teaching purpose.</u>**

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