# ROCK ENGINEERING

## ECG533

## Rock Mass Classification

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## Learning Outcome

- *The student should be able to apply rock mass classification system to quantify quality of rock mass*
- *To determine the suitable rock support system of rock mass*

## Introduction

Rock mass classifications were developed to create some order out of the chaos in site investigation procedures. They were not intended to replace analytical studies, field observations, measurements or engineering judgement.

And main benefits of rock mass classifications:

- Improving the quality of site investigations by calling for the minimum input data as classification parameters.
- Providing quantitative information for design purposes.
- Enabling better engineering judgement and more effective communication on a project.

# Introduction

List of rock mass classifications

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

# 1. Terzaghi's rock mass classification

- *Intact* rock
- *Stratified* rock
- *Moderately jointed* rock
- *Blocky and seamy* rock
- *Crushed*
- *Squeezing* rock
- *Swelling* rock

# 1. Terzaghi's rock mass classification

- *Intact* rock contains neither joints nor hair cracks. Hence, if it breaks, it breaks across sound rock. On account of the injury to the rock due to blasting, spalls may drop off the roof several hours or days after blasting. This is known as a *spalling* condition. Hart, intact rock may also be encountered in the *popping* condition involving the spontaneous and violent detachment of rock slabs from the sides or roof.
- *Stratified* rock contains of individual strata with little or no resistance against separation along the boundaries between the strata. The strata may or may not be weakened by transverse joints. In such rock the spalling condition is quite common.
- *Moderately jointed* rock contains joints and hair cracks, but the blocks between joints are locally grown together or so intimately interlocked that vertical walls do not require lateral support. In rocks of this type, both spalling and popping conditions may be encountered

# 1. Terzaghi's rock mass classification

- *Blocky and seamy* rock contains of chemically intact or almost intact rock fragments, which are entirely separated from each other and imperfectly interlocked. In such rock, vertical walls may require lateral support.
- *Crushed* but chemically intact rock has the character of crusher run. If most or all of the fragments are as small as fine sand grains and no recementation has taken place, crushed rock below the water table exhibits the properties of a water-bearing sand.
- *Squeezing* rock slowly advances into the tunnel without perceptible volume increase. A prerequisite for squeeze is a high percentage of microscopic and sub-microscopic particles of micaceous minerals or clay minerals with a low swelling capacity.
- *Swelling* rock advances into the tunnel chiefly on account of expansion. The capacity to swell seems to be limited to those rocks that contain clay minerals such as montmorillonite, with a high swelling capacity.

## 2. Stand-up time classification

The stand-up time for an unsupported span is related to the quality of the rock mass in which the span is excavated (Lauffer, 1958)

The main significance of this method is that an increase in tunnel span leads to a major reduction in the stand up time.

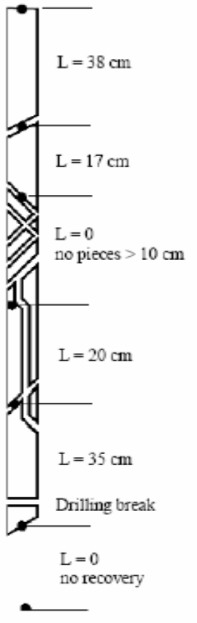
## 3. Rock quality designing index (RQD)

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

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

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

# 3. Rock quality designing index (RQD)




Total lengths of core run = 200 cm

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

$$RQD = \frac{38 + 17 + 20 + 35}{200} \times 100 = 56\%$$

# 3. Rock quality designing index (RQD)

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

$$RQD = 115 - 3.3 \, Jv$$

*where* Jv *is the sum of the number of joints per unit length for all joint (discontinuity) sets known as the volumetric joint count.*

## 3. Rock quality designing index (RQD)

- RQD is a directionally dependent parameter and its value may change significantly, depending upon the borehole orientation.
- RQD is intended to represent the rock mass quality in situ. When using diamond drill core, care must be taken to ensure that fractures, which have been caused by handling or the drilling process, are identified and ignored when determining the value of RQD.
- When using Palmstrom's relationship for exposure mapping, blast induced fractures should not be included when estimating Jv.

## 3. Rock quality designing index (RQD)

**Rock Mass Classification Based on RQD**

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

## 4. Rock Structure Rating (RSR)

**Rock Structure Rating** (RSR) is a quantitative method for describing quality of a rock mass and then appropriate ground support.

There are considered two general categories:

- geotechnical parameters:
  - rock type; joint pattern; joint orientations; type of discontinuities; major faults; shears and folds; rock material properties; weathering or alteration. and
- construction parameters:
  - size of tunnel; direction of drive; method of excavation.

## 4. Rock Structure Rating (RSR)

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

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

*Parameter B, Geometry:* Effect of discontinuity pattern with respect to the direction of the tunnel drive on the basis of:

- Joint spacing.
- Joint orientation (strike and dip)
- Direction of tunnel drive.

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

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

# 4. Rock Structure Rating (RSR)

PARAMETER "A"

| | BASIC ROCK TYPE | | | | GEOLOGIC 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 |

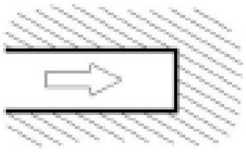
# 4. Rock Structure Rating (RSR)

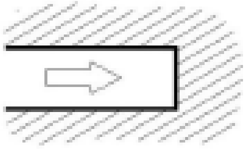
PARAMETER "B"

| | 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 closed joint, < 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 |

Dip of Prominent Joints
→ flat : 0 – 20 $^{o}$
→ dipping : 20 – 50 $^{o}$
→ vertical : 50 – 90 $^{o}$

# 4. Rock Structure Rating (RSR)




DIRECTION OF DRIVE

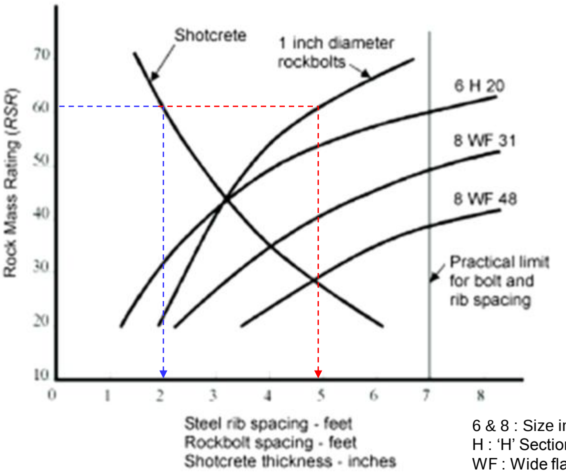
# 4. Rock Structure Rating (RSR)

PARAMETER “C”

| Anticipated water inflow gpm/1000 ft of tunnel | Sum of Parameter A + B | | | | | |
|---|---|---|---|---|---|---|
| | 13 - 44 | | | 45 - 75 | | |
| | Joint Condition | | | | | |
| | 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 gpm | 10 | 8 | 6 | 18 | 14 | 10 |

Joint condition
→ good : tight or cemented
→ fair : slightly weathered or altered
→ poor : severely weathered, altered or open

# 4. Rock Structure Rating (RSR)




6 & 8 : Size in inch
H : 'H' Section
WF : Wide flange 'I' section
20,31 & 48 : weight in lb/foot

# 5. Rock Mass Rating System (RMR)

Proposed by Bieniawski (1976)

The following six parameters are used to classify a rock mass using the RMR system

- → Uniaxial compressive strength of rock material.
- → Rock quality designation (RQD).
- → Spacing of discontinuities.
- → Condition of discontinuities.
- → Groundwater conditions.
- → Orientation of discontinuities.

# 5. Rock Mass Rating System (RMR)

| A. CLASSIFICATION PARAMETER 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 | | |

| **B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS** (see F) | | | | | | |
|---|---|---|---|---|---|---|
| Strike and dip orientations | | Very favourable | Favourable | Fair | Unfavourable | Very Unfavourable |
| Rating | Tunnel & 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 | 30min 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 |
| **E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions** | | | | | | |
| Discontinuity length (persistence)<br>Rating | | < 1 m<br>6 | 1 – 3 m<br>4 | 3 – 10 m<br>2 | 10 – 20 m<br>1 | > 20 m<br>0 |
| Separation (aperture)<br>Rating | | None<br>6 | < 0.1 m<br>5 | 0.1 – 1.0 mm<br>4 | 1 – 5 mm<br>1 | > 5 mm<br>0 |
| Roughness<br>Rating | | Very rough<br>6 | Rough<br>5 | Slightly rough<br>3 | Smooth<br>1 | Slickensided<br>0 |
| Infilling (gouge)<br>Rating | | None<br>6 | Hard filling < 5 mm<br>4 | Hard filling > 5 mm<br>2 | Soft filling < 5 mm<br>2 | Soft filling < 5 mm<br>0 |
| Weathering<br>Rating | | Unweathered<br>6 | Slightly weathered<br>5 | Moderately weathered<br>3 | Highly weathered<br>1 | Decomposed<br>0 |

# 5. Rock Mass Rating System (RMR)

| F. EFFECT OF DISCONTINUITY STRIKE AND DIP OREINTATION 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 | |

# 5. Rock Mass Rating System (RMR)

| **RMR** | **Rock quality** |
|---|---|
| 0 - 20 | Very poor |
| 21 - 40 | Poor |
| 41 - 60 | Fair |
| 61 - 80 | Good |
| 81 - 100 | Very good |

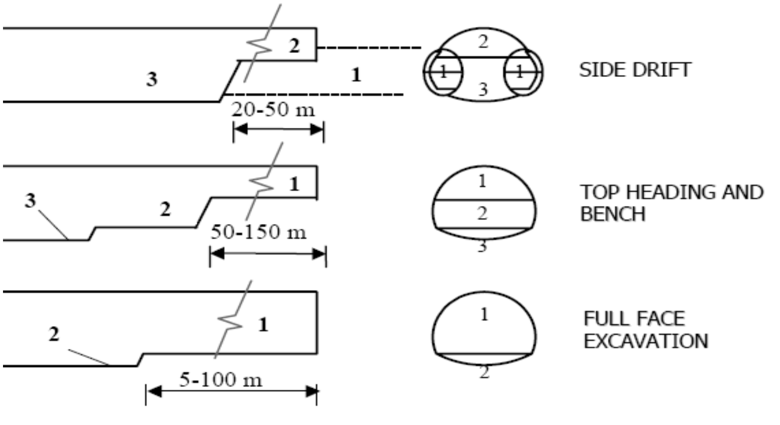
# 5. Rock Mass Rating System (RMR)

Guidelines for excavation and support of 10 m span rock tunnels in accordance with the RMR System (After Bieiniawski 1989)

| 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. Commerce 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. Closed invert. |

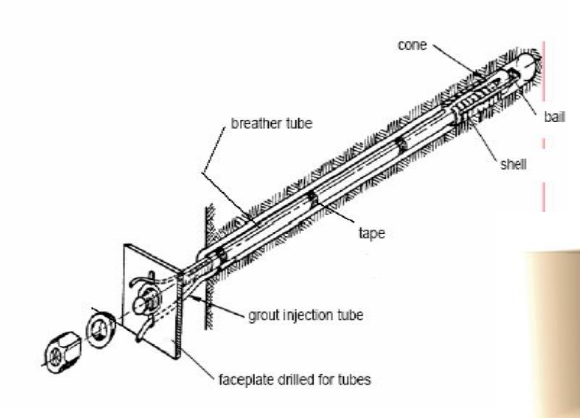
# 5. Rock Mass Rating System (RMR)

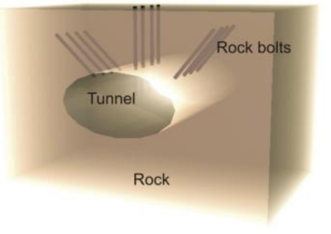
## EXAMPLES OF EXCAVATION



# 5. Rock Mass Rating System (RMR)

EXAMPLES OF ROCKBOLT




# 5. Rock Mass Rating System (RMR)

EXAMPLES OF SHOTCRETE

## 5. Rock Mass Rating System (RMR)

PRACTICAL EXAMPLE

A tunnel is to be driven through a slightly weathered granite with a dominant joint set dipping at 60º against the direction of the drive. Index testing and logging of diamond drilled core give typical Point- load strength index values of 8 MPa and average RQD values of 70%. The slightly rough and slightly weathered joints with a separation of < 1 mm, are spaced at 300 mm. Tunneling conditions are anticipated to be wet.

## 5. Rock Mass Rating System (RMR)

SOLUTION

The RMR value is determined as follows:

| Table | Item | Value | Rating |
|---|---|---|---|
| A.1 | Point load index | 8 MPa | 12 |
| A.2 | RQD | 70% | 13 |
| A.3 | Spacing of discontinuities | 300 mm | 10 |
| E.4 | Condition of discontinuities | Note 1 | 22 |
| A.5 | Groundwater | Wet | 7 |
| B | Adjustment for joint orientation | Note 2 | -5 |
| | | Total | **59** |

*Note 1: For slightly rough and altered discontinuity surfaces with a separation of < 1 mm, Table A.4 gives a rating of 25. When more detailed information is available, Table E can be used to obtain a more refined rating. Hence, in this case, the rating is the sum of: 4 (1-3 m discontinuity length), 4 (separation 0.1-1.0 mm), 3 (slightly rough), 6 (no infilling) and 5 (slightly weathered) = 22.*

*Note 2: Table 4.4.F gives a description of 'Fair' for the conditions assumed where the tunnel is to be driven against the dip of a set joints dipping at 60o. Using this description for 'Tunnel and Mines' in Table 4.4.B gives an adjustment rating of –5.*

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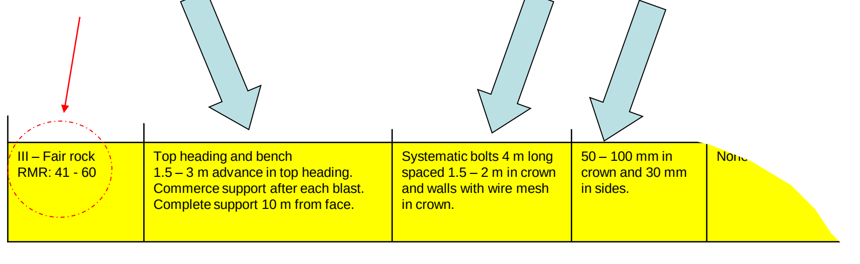
# 5. Rock Mass Rating System (RMR)

With RMR = 59, Table suggests that a tunnel could be excavated by top heading and bench, with a 1.5 to 3 m advance in the top heading. Support should be installed after each blast and the support should be placed at a maximum distance of 10 m from the face.

Systematic rock bolting, using 4 m long 20 mm diameter fully grouted bolts spaced at 1.5 to 2 m in the crown and walls, is recommended. Wire mesh, with 50 to 100 mm of shotcrete for the crown and 30 mm of shotcrete for the walls, is recommended.



## 6. Rock Tunneling Quality Index, Q

The Q-system of rock mass classification was developed in Norway in 1974 by Nick Barton, Lien, R., and Lunde, J at NGI (Norwegian Geotechnical Institute).

The system was developed on the basis of an analysis of 212 tunnel case histories from Scandinavia. It is a quantitative classification system and is an engineering system facilitating the design of tunnel supports

## 6. Rock Tunneling Quality Index, Q

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

where

| | |
|---|---|
| RQD | is the Rock Quality Designation |
| $J_n$ | is the joint set number |
| $J_r$ | is the joint roughness number |
| $J_a$ | is the joint alteration number |
| $J_w$ | is the joint water reduction factor |
| SRF | is the stress reduction factor |

# 6. Rock Tunneling Quality Index, Q

CLASSIFICATION OF INDIVIDUAL PARAMETERS

| DESCRIPTION | VALUE | NOTES |
|---|---|---|
| 1. ROCK QUALITY DESIGNATION | RQD | |
| A. Very poor | 0 – 25 | 1. Where RQD is reported or measured as ≤ 10 (including 0), a nominal value of 10 is used to evaluate Q |
| B. Poor | 25 – 50 | |
| C. Fair | 50 - 75 | |
| D. Good | 75 – 90 | 2. RQD intervals of 5, i.e. 100, 95, 90 etc. are sufficiently accurate. |
| E. Excellent | 90 – 100 | |
| 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 | 3 | |
| D. Two joint sets | 4 | |
| E. Two joint sets plus random | 6 | |
| F. Three joint sets | 9 | 1. For intersections use (3.0 x $J_n$ ) |
| G. Three joint sets plus random | 12 | |
| H. Four or more joint sets, random, Heavily jointed, 'sugar cube', etc. | 15 | 2. For portals use (2.0 x $J_n$) |
| I. Crushed rock, earthlike | 20 | |

# 6. Rock Tunneling Quality Index, Q

CLASSIFICATION OF INDIVIDUAL PARAMETERS

| DESCRIPTION | VALUE | | NOTES |
|---|---|---|---|
| 3. JOINT ROUGHNESS NUMBER<br>**a. Rock wall contact**<br>**b. Rock wall contact before 10 cm shear** | Jr | | |
| A. Discontinuous joints | 4 | | |
| B. Rough and irregular, undulating | 3 | | |
| C. Smooth undulating | 2 | | |
| D. Slickensided undulating | 1.5 | | 1. Add 1.0 if the mean spacing of the relevant joint set is greater than 3 |
| E. Rough or irregular, planar | 1.5 | | |
| F. Smooth, planar | 1.0 | | |
| G. Slickensided, planar | 0.5 | | 2 Jr = 0.5 can be used for planar, slikensided joints having lineations, provided that the lineations are oriented for minimum strength. |
| **c. No rock wall contact when sheared** | | | |
| H. Zones containing clay minerals thick enough to prevent rock wall contact | 1.0 (nominal) | | |
| I. Sandy, gravely or crushed zone thick enough to prevent rock wall contact | 1.0 (nominal) | | |
| 4. JOINT ALTERATION NUMBER<br>**a. Rock wall contact** | $J_a$ | Ør degrees (approx.) | |
| A. Tightly healed, hard, non-softening, impermeable filling | 0.75 | | 1. Values of Ør, the residual friction angle, are intended as an approximate guide to the mineralogical properties of the alteration products, if present. |
| B. Unaltered joint walls, surface staining only | 1.0 | 25 - 35 | |
| C. Slightly altered joint walls, non-softening mineral coatings, sandy particles, clay free disintegrated rock, etc. | 2.0 | 25 - 30 | |
| D. Silty-, or sandy-clay coatings, small clay-fraction (non-softening) | 3.0 | 20 – 25 | |
| E. Softening or low-friction clay mineral coatings, i.e. kaolinite, mica. Also chlorite, talc, gypsum and graphite etc., and small quantities of swelling clays. (Discontinuous coatings, 1 – 2 mm or less) | 4.0 | 8 – 16 | |

# 6. Rock Tunneling Quality Index, Q

CLASSIFICATION OF INDIVIDUAL PARAMETERS

| DESCRIPTION | VALUE | NOTES |
|---|---|---|
| **4. JOINT ALTERATION NUMBER** | $J_a$ | Ør degrees (approx.) |
| **b. Rock wall contact before 10 cm shear** | | |
| F. Sandy particles, clay-free, disintegrating rock etc. | 4.0 | 25 – 30 |
| G. Strongly over-consolidated, non-softening clay mineral fillings (continuous < 5 mm thick) | 6.0 | 16 – 24 |
| H. Medium or low over-consolidation, softening clay mineral fillings (continuous < 5 mm thick) | 8.0 | 12 – 16 |
| J. Swelling clay fillings, i.e. montmorillonite, (continuous < 5 mm thick). Values of $J_a$ depend on percent of swelling clay – size particles and access to water. | 8.0 – 12.0 | 6 – 12 |
| **c. No rock wall contact when sheared** | | |
| K. Zones or bands of disintegrated or crushed | 6.0 | |
| L. rock and clay (see G,H and J for clay | 8.0 | |
| M. conditions) | 8.0 – 12.0 | 6 – 24 |
| N. Zones or bands of silty- or sandy-clay, small clay fraction, non-softening | 5.0 | |
| O. Thick continuous zones or bands of clay | 10.0 – 13.0 | |
| P. & R. (see G,H and J for clay conditions) | 6.0 – 24.0 | |

# 6. Rock Tunneling Quality Index, Q

CLASSIFICATION OF INDIVIDUAL PARAMETERS

| | | | |
|---|---|---|---|
| 5. JOINT WATER REDUCTION | $J_w$ | approx. water pressure (kgf/cm²) | |
| A. Dry excavation or minor inflow i.e. < 5 1/m locally | 1.0 | < 1.0 | |
| B. Medium inflow or pressure, occasional outwash of joint fillings | 0.66 | 1.0 – 2.5 | |
| C. Large inflow or high pressure in competent rock with unfilled joints | 0.5 | 2.5 – 10.0 | 1. Factors C to F are crude estimates; increase $J_w$ if drainage installed |
| D. Large inflow or high pressure | 0.33 | 2.5 – 10.0 | |
| E Exceptionally high inflow or pressure at blasting Decaying with time | 0.2 – 0.1 | > 10 | 2. Special problems caused by ice formation are not considered. |
| F. Exceptionally high inflow or pressure | 0.1 – 0.55 | > 10 | |

| | | |
|---|---|---|
| 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) | 10.0 | 1. Reduce these values of SRF by 25 – 50% but only if the relevant shear zones influence do not intersect the excavation |
| B. Single weakness zones containing clay, or chemically distegrated rock (excavation depth < 50 m) | 5.0 | |
| C. Single weakness zones containing clay, or chemically distegrated rock (excavation depth > 50 m ) | 2.5 | |
| D. Multiple shear zones in competent rock (clay free), loose surrounding rock (any depth) | 7.5 | |
| E. Single shear zone in competent rock (clay free). (depth of excavation < 50 m) | 5.0 | |
| F. Single shear zone in competent rock (clay free). (depth of Excavation > 50 m) | 2.5 | |
| G. Loose open joints, heavily jointed or 'sugar cube', (any depth) | 5.0 | |

| DESCRIPTION | VALUE | | | NOTES |
|---|---|---|---|---|
| **6. STRESS REDUCTION FACTOR** | | | SRF | |
| **b. Competent rock, rock stress problems** | | | | |
| | $\sigma_c/\sigma_1$ | $\sigma_t/\sigma_1$ | | 2. For strongly anistropic virgin stress field (if measured): when $5 \le \sigma_1/\sigma_3 \le 10$, reduce $\sigma c$ to $0.8\sigma_c$ and $\sigma t$. When $\sigma_1/\sigma_3 > 10$, reduce $\sigma c$ and $\sigma t$ to $0.6\sigma_c$ and $0.6\sigma_t$, where $\sigma_c$ = unconfined compressive strength, and $\sigma_t$ = tensile strength (point load) and $\sigma 1$ and $\sigma 3$ are the major and minor principal stresses. |
| H. Low stress, near surface | > 200 | > 13 | 2.5 | |
| J. Medium stress | 200 – 10 | 13 – 0.66 | 1.0 | |
| K. High stress, very tight structure (usually favourable to stability, may be unfavourable to wall stability) | 10 – 5 | 0.66 – 0.33 | 0.5 – 2 | |
| L. Mild rockburst (massive rock) | 5 – 2.5 | 0.33 – 0.16 | 5 – 10 | |
| M. Heavy rockburst (massive rock) | < 2.5 | < 0.16 | 10 – 20 | 3. 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). |
| **c. Squeezing rock, plastic flow of incompetent rock under influence of high rock pressure** | | | | |
| N. Mild squeezing rock pressure | | | 5 – 10 | |
| O. Heavy squeezing rock pressure | | | 10 – 20 | |
| **d. Swelling rock, chemical swelling activity depending on presence of water** | | | | |
| P. Mild swelling rock pressure | | | 5 - 10 | |
| R. Heavy swelling rock pressure | | | 10 - 15 | |

**ADDITIONAL NOTES ON THE USE THESE TABLES**

When making estimates of the rock mass Quality (Q), the following guidelines should be followed in addition to the notes listed in the tables:

1. When borehole core is unavailable, RQD can be estimated from the number of joints per units volume, in which the number of joints per metre for each joint set are added. A simple relationship can be used to convert this number to RQD for the case of clay free rock masses: RQD = 115 – 3.3 $J_v$ (approx.), where $J_v$ = total number of joints per $m^3$ ($0 < RQD < 100$ for $35 > J_v > 4.5$).
2. the parameter $J_n$ representing the number of joint sets will often affected by foliation, schistosity, slaty cleavage or bedding etc. If strongly developed, these parallel 'joints' should obviously be counted as a complete joint set. However, if there are few 'joints' visible, or if only occasional breaks in the core are due to these features, then it will be more appropriate to count them as 'random' joints when evaluating $J_n$.
3. The parameters $J_r$ and $J_a$ (representing shear strength) should be relevant to the weakest significant joint set or clay filled discontinuity in the given zone. However, if the joint set or discontinuity with the minimum value of $J_r/J_a$ is favourably oriented for stability, then a second, less favourably oriented joint set or discontinuity may sometimes be more significant, and its higher value of $J_r/J_a$ should be used when evaluating Q. The value of $J_r/J_a$ should in fact relate to the surface most likely to allow failure to initiate.
4. When a rock mass contains clay, the factor SRF appropriate to loosening loads should be evaluated. In such cases the strength of the intact rock is of little interest. However, when jointing is minimal and clay is completely absent, the strength of the intact rock may become the weakest link, and the stability will then depend on the ratio rock-stress/rock-strength. A strongly anistropic stress field is unfavourable for stability and is roughly accounted for as in note 2 in the table for stress reduction factor evaluation.
5. The compressive and tensile strength ($\sigma_c$, $\sigma_t$) of the intact rock should be evaluated in the saturated condition if this is appropriate to the present and future in situ conditions. A very conservative estimate of the strength should be made for those rocks that deteriorate when exposed to moist or saturated conditions.

# 6. Rock Tunneling Quality Index, Q

Equivalent Dimension, De

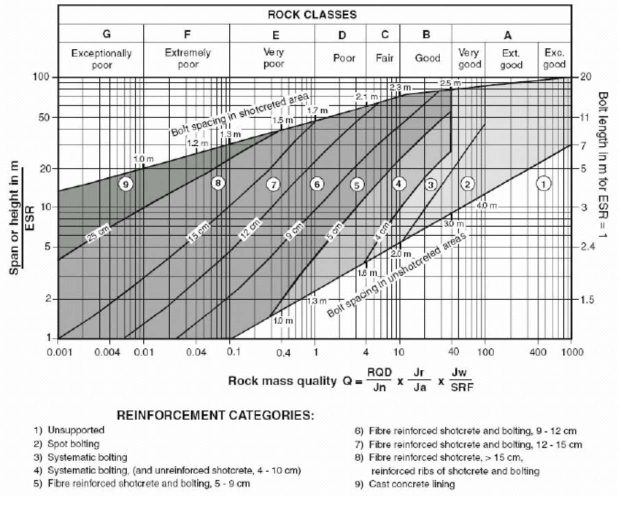
$$D_e = \frac{\text{Excavation span, diameter or height (m)}}{\text{Excavation Support Ratio } ESR}$$

# 6. Rock Tunneling Quality Index, Q

| Excavation category | | *ESR* |
|---|---|---|
| A | Temporary mine openings. | 3-5 |
| B | Permanent mine openings, water tunnels for hydro power (excluding high pressure penstocks), pilot tunnels, drifts and headings for large excavations. | 1.6 |
| C | Storage rooms, water treatment plants, minor road and railway tunnels, surge chambers, access tunnels. | 1.3 |
| D | Power stations, major road and railway tunnels, civil defence chambers, portal intersections. | 1.0 |
| E | Underground nuclear power stations, railway stations, sports and public facilities, factories. | 0.8 |

# 6. Rock Tunneling Quality Index, Q

**ESTIMATED SUPPORT CATEGORIES**



# 6. Rock Tunneling Quality Index, Q

PRACTICAL EXAMPLE

A 15 m span crusher chamber for an underground mine is to be excavated in a norite at depth of 2,100 m below surface. The rock mass contains two sets of joints controlling stability. These joints are undulating, rough and unweathered with very minor surface staining. RQD values range from 85% to 95% and laboratory tests on core samples of intact rock give an average uniaxial compressive strength of 170 MPa. The principal stress directions are approximately vertical and horizontal and the magnitude of the horizontal principal stress is approximately 1.5 times that of the vertical principal stress. The rock mass is locally damp but there is no evidence of flowing water.

# 6. Rock Tunneling Quality Index, Q

| Parameter | Description | Value |
|---|---|---|
| RQD | → 85% to 95% | → 90 (average) |
| Jn | → for two joint sets | → 4 |
| Jr | → rough or irregular which are undulating | → 3 |
| Ja | → unaltered joint wall with surface staining only | → 1 |
| Jw | → excavation with minor inflow | → 1 |
| SRF | → $\sigma c / \sigma 1$ < 2.5 (competent rock) | → 15 (average) |

*For a depth below surface of 2,100 m the overburden stress will be approximately 57 MPa (2100 m2 x 27kN/m3 = 57 MPa)*
*→1.5 x 57 = 85 MPa (the major principal stress $\sigma 1$)*

*Given, the uniaxial compressive strength of the norite is approximately 170 MPa, this gives a ratio of $\sigma c / \sigma 1 = 2$.*

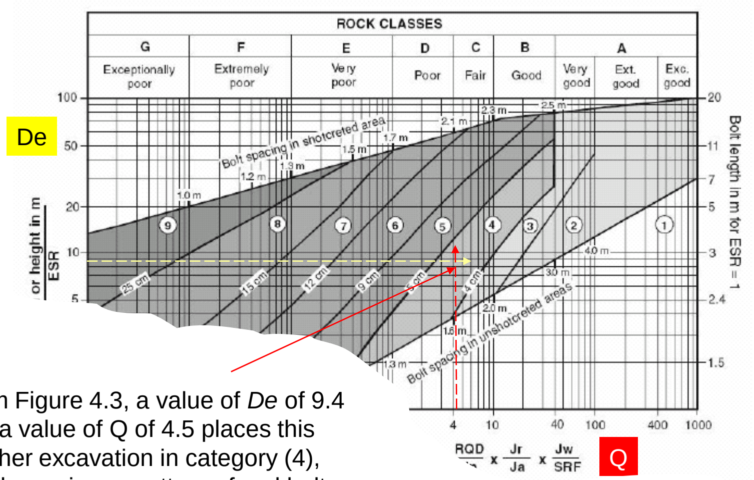
$$Q = \frac{90}{4} \times \frac{3}{1} \times \frac{1}{15} = 4.5$$

# 6. Rock Tunneling Quality Index, Q

| | **Description** | **Value** |
|---|---|---|
| ESR | → permanent mine opening | → 1.6 |

for an excavation span of 15 m, the equivalent dimension, *De* = 15/1.6 = 9.4.

# 6. Rock Tunneling Quality Index, Q




From Figure 4.3, a value of *De* of 9.4 and a value of Q of 4.5 places this crusher excavation in category (4), which requires a pattern of rockbolts (spaced at 2.3 m) and 40 to 50 mm of unreinforced shotcrete.

## 6. Rock Tunneling Quality Index, Q

ADDITIONAL (Barton et al, 1980)

Length of rockbolt, $L = 2 + \frac{0.15B}{ESR}$

Maximum span (unsupported) = $2\,ESR\;Q^{0.4}$

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

## 7. CSIR Classification for jointed rock

Bieniawski suggested that a classification for jointed rock mass should:

- divide the rock mass into groups of similar behaviour;
- provide a good basis for understanding the characteristics of the rock mass;
- facilitate the planning and the design of structures in rock by yielding quantitative data required for the solution of real engineering problems; and
- provide a common basis for effective communication among all persons concerned with a geomechanics problem.

## 7. CSIR Classification for jointed rock

These aims should be fulfilled by ensuring that the adopted classification is

- simple and meaningful in term; and
- based on measurable parameters which can be determined quickly and cheaply in the field.

## 7. CSIR Classification for jointed rock

In order to satisfy these requirements, Bieniawski originally proposed that his “Geomechanics Classification” should incorporate the following parameters:

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

# 7. CSIR Classification for jointed rock

The five classification parameters then became:

- *Strength of intact rock material* → table 3
- *Rock Quality* Designation
- *Spacing of joints* → table 4
- *Condition of joints*
- *Ground water conditions*

# 7. CSIR Classification for jointed rock

Table 3 – DEERE AND MILLER'S CLASSIFICATION OF INTACT ROCK STRENGTH

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

Table 4 – DEERE'S CLASSIFICATION FOR JOINT SPACING

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

# 7. CSIR Classification for jointed rock

Table 5

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

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

# 7. CSIR Classification for jointed rock

Table 5

B. RATING ADJUSTMENT FOR JOINT ORIENTATIONS

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

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

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

D. MEANING OF ROCK MASS CLASSES

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

# 7. CSIR Classification for jointed rock

TABLE 6 – THE EFFECT OF JOINT STRIKE AND DIP ORIENTATIONS IN TUNNELING

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

# 7. CSIR Classification for jointed rock

PRACTICAL EXAMPLE

Consider the example of a granitic rock mass in which a tunnel is to be driven. The classification has been carried out as follows:

| Classification Parameters | Value or Description | Rating |
|---|---|---|
| 1. Strength of intact material | 150 MPa | 12 |
| 2. RQD | 70 % | 13 |
| 3. Joint spacing | 0.5 m | 20 |
| 4. Condition of joints | Slightly rough surfaces<br>Separation < 1 mm.<br>Hard joint wall rock | 20 |
| 5. Ground water | Water under moderate pressure | 4 |
| | Total score | 69 |

# 7. CSIR Classification for jointed rock

PRACTICAL EXAMPLE

The tunnel has been oriented such that the dominant joint set strikes perpendicular to the tunnel axis with a dip of 30° against the drive direction. From Table 6,

→this situation is described as unfavourable for which a rating adjustment of –10 is obtained from Table 5B.

→Thus the final rock mass rating becomes 59 which places the rock mass at the upper end of Class III with a description of fair.

→Figure 6 gives the stand-up time of an unsupported 3 metre tunnel in this rock mass as approximately 1 month.

# 7. CSIR Classification for jointed rock

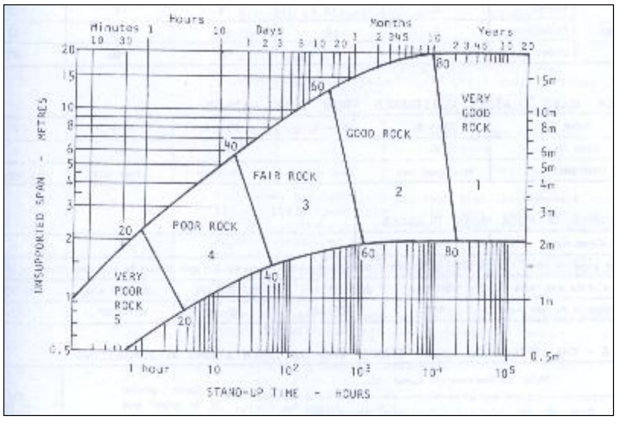



Figure 6: relationship between the stand-up time of an unsupported underground excavation span and the CSIR Geomechanics Classification proposed by Bieniawski

http://www.geoconsol.com/page
s.php?page=a

# 7. CSIR Classification for jointed rock

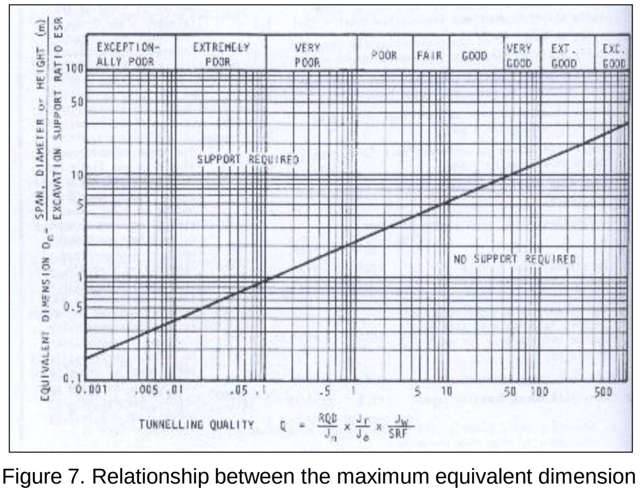



Figure 7. Relationship between the maximum equivalent dimension De of an unsupported underground excavation and the NGI tunneling quality index Q. (After Barton, Lien and Lunde1).