ROCK MATERIALS AND THEIR PROPOERTIES

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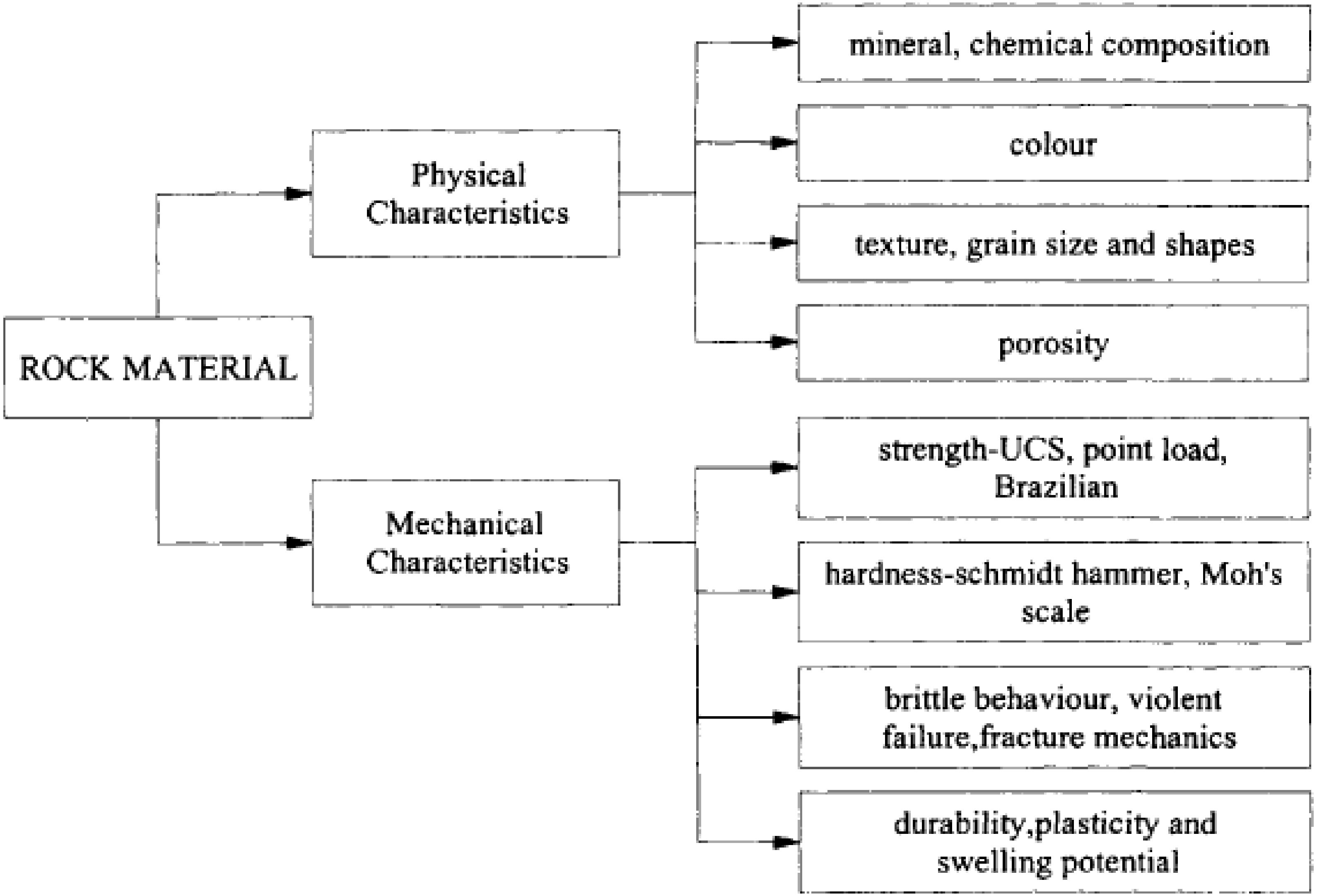
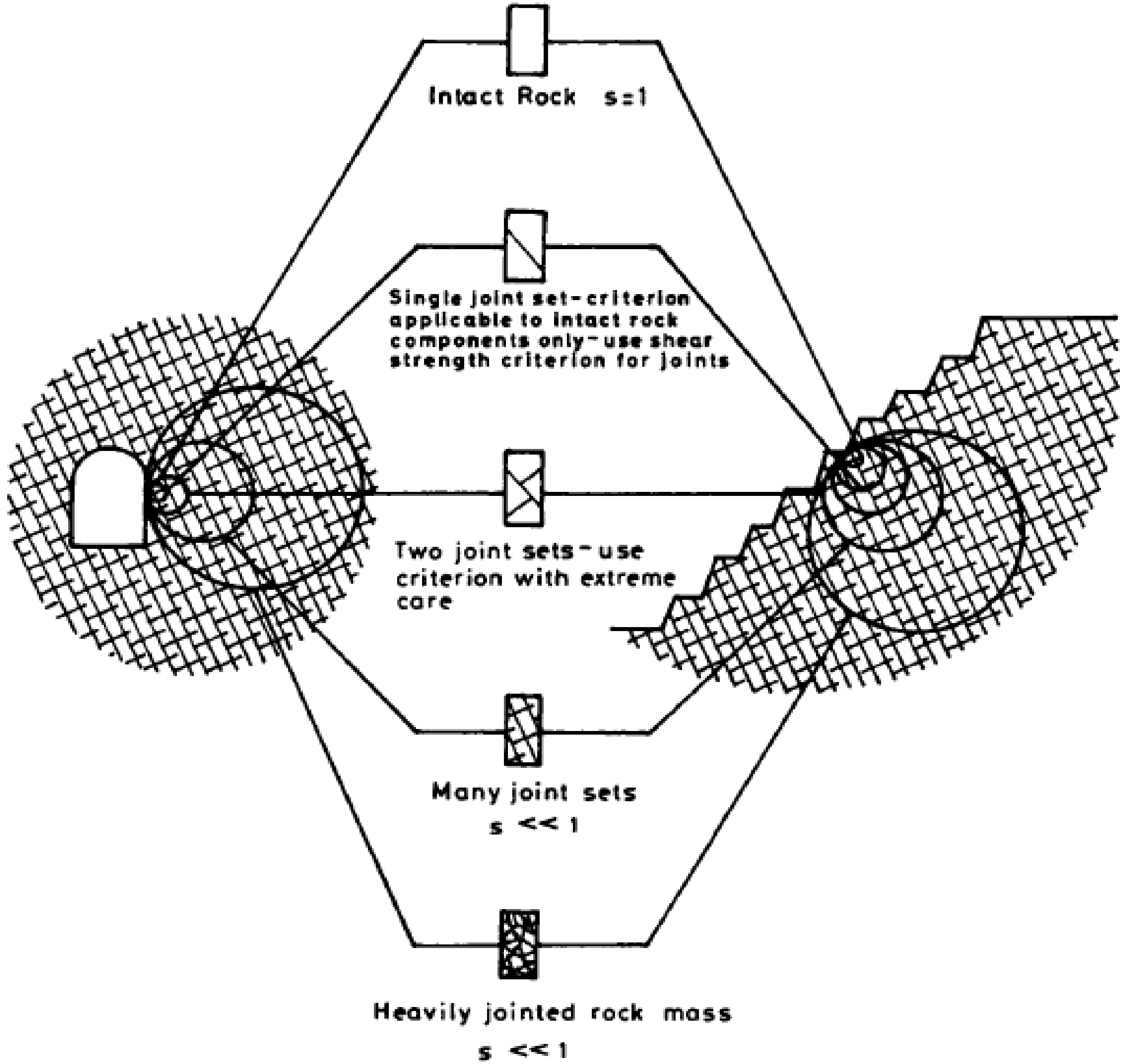
Rock Materials

- The term "Rock Material" refers to the intact rock within the framework of discontinuities.
- In other words, this is the smallest element of rock block not cut by any fracture.
- There are always some micro fractures in the rock material but these should not be treated as fractures.
- Rock material' differs from 'rock mass' which refers to in-situ rock together with its discontinuities and weathering profile.
- Rock material has the following characteristics:


ROCK MATERIAL
Physical Characteristics
Mechanical Characteristics
mineral, chemical composition
colour
texture, grain size and shapes
porosity
strength-UCS, point load, Brazilian
hardness-schmidt hammer, Moh's scale
brittle behaviour, violent failure,fracture mechanics
durability,plasticity and swelling potential



Intact Rock s=1
Single joint set-criterion applicable to intact rock components only-use shear strength criterion for joints
Two joint sets-use criterion with extreme care
Many joint sets
s << 1
Heavily jointed rock mass
s << 1

CLASSIFICATION OF ROCK MATERIAL BASED ON UNCONFINED COMPRESSIVE STRENGTH (STAPLEDON AND ISRM)

Term for Uniaxial Compressive Strength	Symbol	Strength (MPa)	Ranges for some Common Rock Materials				
			Granite, Basalt, Gneiss, Quartzite, Marble	Schist Sandstone	Limestone, Siltstone	Slate	Con-crete
Extremely Weak	EW	0.25 - 1		**	**		
Very weak	VW	1 - 5		**	**	**	**
Weak	W	5 - 25		**	**	**	**
Medium Strong	MS	25 - 50	**		**	**	
Strong	S	50 - 100	**				
Very Strong	VS	100 - 250	**				
Extremely Strong	ES	>250	**				

The uniaxial compressive strength (UCS) can be easily predicted from point load strength index tests on rock cores and rock lumps right at the drilling site because ends of rock specimens need not be cut and lapped. UCS is also found from Schmidt's rebound hammer

Uniaxial Compression

Rock failure in uniaxial compression occurs in two modes:

- **(i)** Local (axial) splitting or cleavage failure parallel to the applied stress, and
- **(ii)** Shear failure.

- **Local cleavage fracture:**

  Local cleavage fracture characterizes failure initiation at 50 percent to 95 percent of the compressive strength and is continuous throughout the entire loading history.

- **Axial cleavage fracture:**

  Axial cleavage fracture is a local stress relieving phenomenon which depends on the strength anisotropy and brittleness of the crystalline aggregates as well as on the grain size of the rock.

- Local axial splitting is virtually absent in fine grained materials at stress levels below their compressive strength.

ROCK QUALITY DESIGNATION-RQD

- Rock quality designation RQD was introduced by D. U. Deere in 1964 as an index of assessing rock quality quantitatively. It is a more sensitive index of the core quality than the core recovery.
- The RQD is a modified per cent core-recovery which incorporates only sound pieces of corethat are 100 mm (4 inch.) or greater in length along the core axis,

$$RQD = \frac{\text{sum of core pieces} \geq 10\text{ cm}}{\text{total drill run}} \cdot 100, \quad \%$$

Methods of obtaining RQD

- 1. Direct Method

  For RQD determination, the International Society for Rock Mechanics (ISRM) recommends a core size of at least NX (size 54.7 mm) drilled with double-tube core barrel using a diamond bit.
- A slow rate of drilling will give better RQD.
- The relationship between RQD and the engineering quality of the rock mass as proposed by Deere (1968) is given in Table

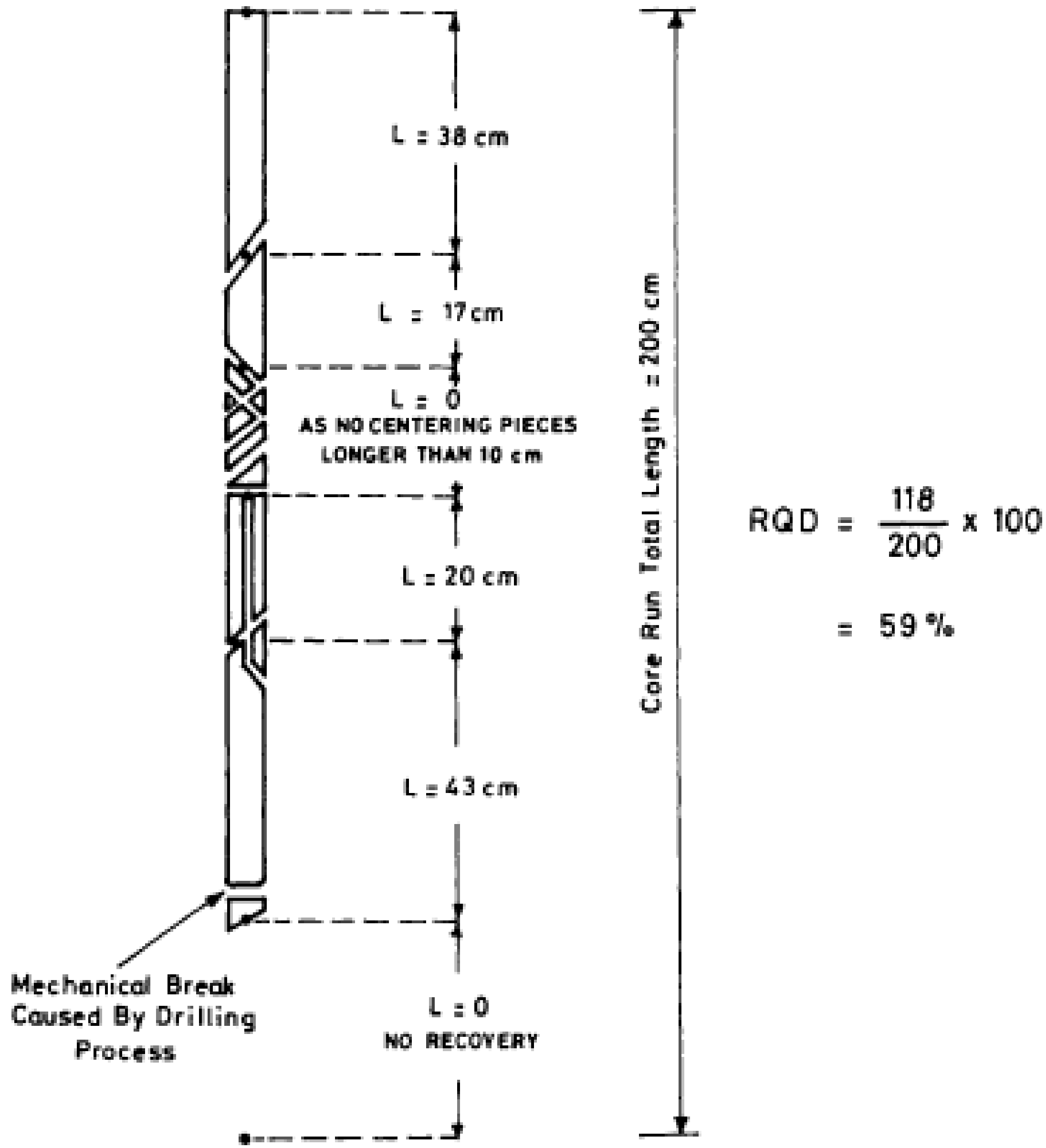


Figure 4.1: Procedure for measurement and calculation of rock quality desgination RQD (Deere, 1989)

RQD and Rock Quality

CORRELATION BETWEEN RQD AND ROCK MASS QUALITY

S. No.	RQD (%)	Rock Quality
1	<25	Very poor
2	25-50	Poor
3	50-75	Fair
4	75-90	Good
5	90-100	Excellent

Methods of obtaining RQD

2.Indirect Methods

a. *Seismic approach*

- The seismic survey method makes use of the variation of elastic properties of the strata that affect the velocity of the seismic waves travelling through them, thus providing useful information about the subsurface strata.
- This method has the advantages of being relatively cheap and rapid to apply and helps in studying large volume of rock masses.

- The effect of discontinuities in rock mass may be estimated by comparing the in-situ compressional wave velocity with laboratory sonic velocity of intact drill core obtained from the same rock mass.
- RQD(%)=Velocity ratio

$$=(V_F/V_L).100$$

where V_F is insitu compressional wave velocity, and V_L. is compressional wave velocity in intact rock core.

b. Volumetric Joint Count approach

When cores are not available, RQD may be estimated from number of joints (discontinuities) per unit volume J_v. A simple relationship which may be used to convert J_v, into RQD for clay-free rock masses is (Palmstrom, 1982),

RQD = 115 - 3.3 J_v

where J_v represents the total number of joints per cubic meter or the volumetric joint count

- J_v is a measure for the number of joints within a unit volume of rock mass defined by

$$J_v = \sum_{i=1}^{J} \left(\frac{1}{S_i}\right)$$

- S_i is the average joint spacing in metres for the *i*th joint set and J is the total number of joint sets except the random joint set

- RQD is a simple and inexpensive index, BUT, when considered alone it is not sufficient to provide an adequate description of a rock mass because it disregards joint orientation, joint condition, type of joint filling and stress condition.

ROCK MASS CLASSIFICATIONS

- Hoek and Brown (1980), Goodman (1993) and Brown (2003), among others, have reviewed the considerable number of rock mass classification schemes that have been developed for a variety of purposes.
- Two of these schemes, the **NGI tunnelling quality index (*Q) developed by Barton et al. (1974)*** *and the* ***CSIR goemechanics or Rock*** **Mass Rating (RMR) scheme developed by Bieniawski (1973, 1976),** are currently widely used in civil engineering and in mining practice.
- The more recent system, ***GSI system introduced by Hoek (1994)*** and developed further by Marinos and Hoek (2000)

Bieniawski's geomechanics classification

- Bieniawski (1973, 1976) developed his scheme using data obtained mainly from civil engineering excavations in sedimentary rocks in South Africa.
- Bieniawski's scheme uses **five classification parameters**

1 **Strength of the intact rock material. The uniaxial compressive strength of the** intact rock may be measured on cores as described in section 4.3.2. Alternatively, for all but very low-strength rocks, the point load index (section 4.3.9) may be used.

2 Rock Quality Designation (*RQD)* as described before

3 Spacing of joints. In this context, the term joints is used to describe all discontinuities.

4 **Condition of joints. This parameter accounts for the separation or aperture of** discontinuities, their continuity or persistence, their surface roughness, the wall condition (hard or soft) and the nature of any in-filling materials present.

5 **Groundwater conditions. An attempt is made to account for the influence of** groundwater pressure or flow on the stability of underground excavations in terms of the observed rate of flow into the excavation, the ratio of joint water pressure to major principal stress, or by a general qualitative observation of groundwater conditions.

NGI Q-System

This classification was developed by Barton *et al. (1974) as a means estimating* support requirements for hard rock tunnels in Scandinavia as a function of an index of rock mass quality, defined as,

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

- **RQD is the Rock Quality Designation** discussed before
- **Jn is the Joint Set Number** which represents the number of joint sets in the rock mass, varying from 0.5 for a massive rock mass with no or few joints to 20 for crushed or diaggregated rock;
- **Jr is the Joint Roughness Number** which represents the roughness of the structural features in the rock mass, varying from 0.5 for slickensided, planar surfaces to 5 for non-persistent structures with spacings larger than 3 m;

- **Ja is** the Joint AlterationNumberrepresenting the condition or degree of alteration of the structures in the rock mass, varying from 0.75 for wall-wall contact in unaltered rock or for joints containing tightly healed, hard, non-softening, impermeable filling to 20 for structures with thick fillings of clay gouge;
- **Jw is the Joint Water Reduction Factor** representing the groundwater conditions, varying from 0.05 for exceptionally high inflows or for water pressure continuing without noticeable decay to 1.0 for dry conditions or minor inflows; and
- **SRF is the Stress Reduction Factor** which is a coefficient representing the effect of stresses acting on the rock mass, varying from 0.5 for high stress but tight structure conditions in good quality rock to 400 for heavy squeezing rock pressures or heavy rock burst conditions and immediate dynamic deformations in massive rock.

The three quotients in Q-equation may be taken to represent the

block size = $\left(\frac{RQD}{J_n}\right)$

the inter-block frictional shear strength = $\left(\frac{J_r}{J_a}\right)$

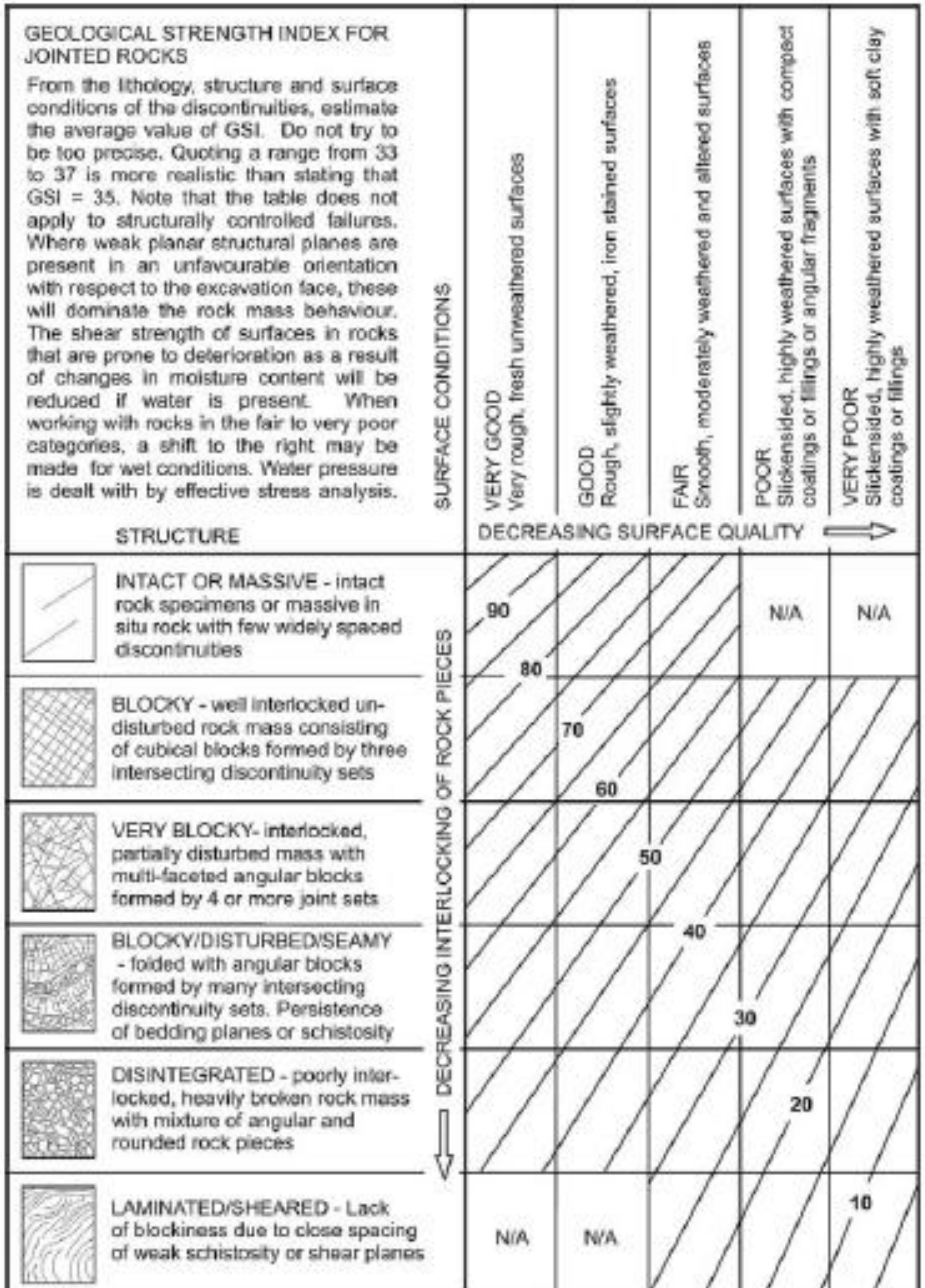
and the "active stress" = $\left(\frac{J_w}{SRF}\right)$

respectively

Geological Strength Index (GSI)

- Hoek (1994) and Hoek *et al. (1995) introduced a new rock mass classification scheme known as* the Geological Strength Index (GSI).

- The GSI was developed to overcome some of the deficiencies that had been identified in using the RMR scheme with the rock mass strength criterion
- GSI is for strength and deformability of rock


GEOLOGICAL STRENGTH INDEX FOR JOINTED ROCKS
From the lithology, structure and surface conditions of the discontinuities, estimate the average value of GSI. Do not try to be too precise. Quoting a range from 33 to 37 is more realistic than stating that GSI = 35. Note that the table does not apply to structurally controlled failures. Where weak planar structural planes are present in an unfavourable orientation with respect to the excavation face, these will dominate the rock mass behaviour. The shear strength of surfaces in rocks that are prone to deterioration as a result of changes in moisture content will be reduced if water is present. When working with rocks in the fair to very poor categories, a shift to the right may be made for wet conditions. Water pressure is dealt with by effective stress analysis.
STRUCTURE
SURFACE CONDITIONS
VERY GOOD Very rough, fresh unweathered surfaces
GOOD Rough, slightly weathered, iron stained surfaces
FAIR Smooth, moderately weathered and altered surfaces
POOR Slickensided, highly weathered surfaces with compact coatings or fillings or angular fragments
VERY POOR Slickensided, highly weathered surfaces with soft clay coatings or fillings
DECREASING SURFACE QUALITY
INTACT OR MASSIVE - intact rock specimens or massive in situ rock with few widely spaced discontinuities
BLOCKY - well interlocked un-disturbed rock mass consisting of cubical blocks formed by three intersecting discontinuity sets
VERY BLOCKY- interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint sets
BLOCKY/DISTURBED/SEAMY - folded with angular blocks formed by many intersecting discontinuity sets. Persistence of bedding planes or schistosity
DISINTEGRATED - poorly inter-locked, heavily broken rock mass with mixture of angular and rounded rock pieces
LAMINATED/SHEARED - Lack of blockiness due to close spacing of weak schistosity or shear planes
DECREASING INTERLOCKING OF ROCK PIECES
90
80
70
60
50
40
30
20
10
N/A
N/A
N/A
N/A