2. Measurement of discontinuity characteristics

General things about joint survey

- It is recommended to measure and record as many items as possible for the joints (discontinuities). Additional afterward survey for the missed items makes the survey inefficient and costly.
- Image processing technique for site investigation has been continuously developed but it has to still go further to catch up with human ability of observation. Ex.) Papers of image processing
- 150 ~ 350 discontinuities are known by experience to be reasonable for one sampling location. This means that 1,000 ~ 2,000 discontinuities are adequate for a site consisting of 5 ~ 15 sampling locations.
- Precise analysis is as important as precise joint survey.

Survey methods of rock mass

(1) Borehole sampling

- Advantage/application

① (Economically) applicable to the deep part of rock mass

② Borehole cores are available for RQD evaluation and various lab tests.

③ Joint orientation can be measured in borehole core (using a double tube core barrel) or wall

④ In-situ stress/deformability of rock mass (hydrofracturing, Goodman jack)

⑤ Ground water level/pressure and rock mass permeability

⑥ Evaluation of ore grade/geological structure

Survey methods of rock mass

- **Disadvantage/notes**

① Borehole TV is more convenient to measure the joint orientation with than borehole core

② Joint (trace) size is normally not able to be measured

③ Carefully differentiate the natural discontinuities from artificial ones.

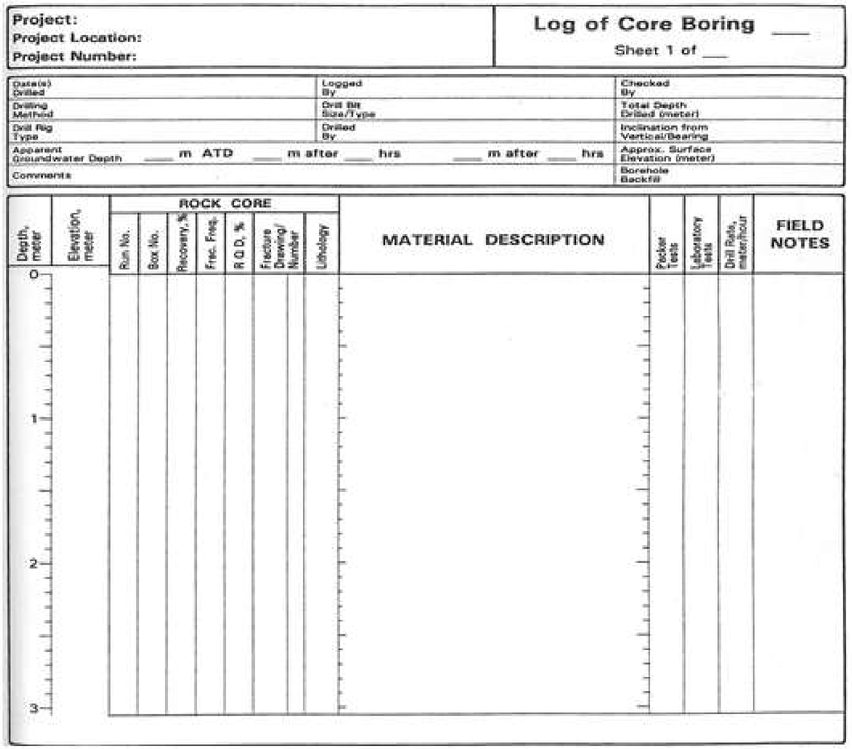
④ Infill materials can be easily disturbed / contaminated at core recovery.

- **Description/logging**

  Rock material, core barrel, RQD, comments on discontinuities, test results etc. (Fig.2.1)

Total Core Recovery

Korean logging form



ASCE recommended

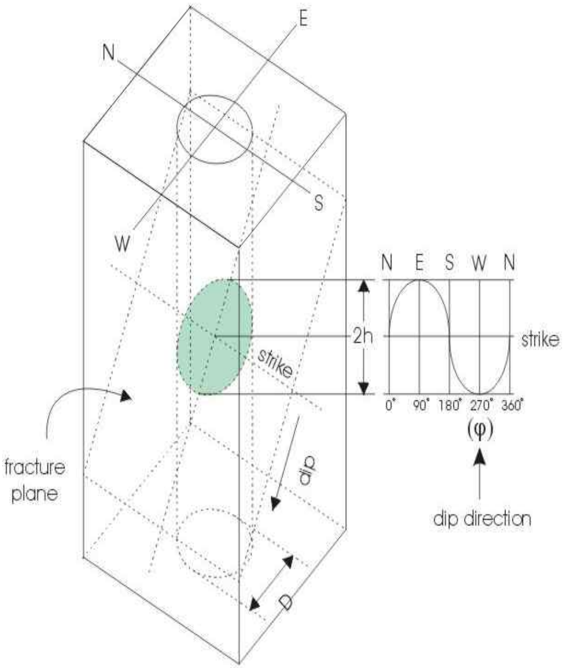
Survey methods of rock mass

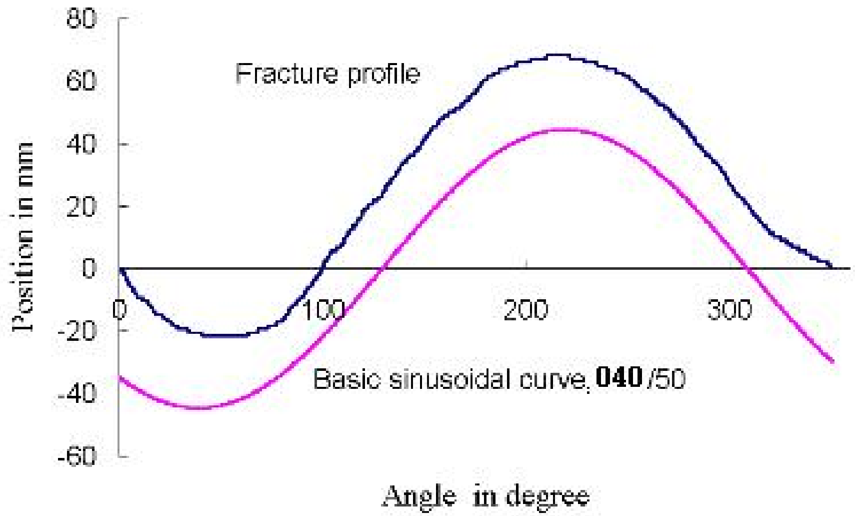
- **Measuring joint orientation : when the borehole is in vertical direction**

① With rock core (p.29)
② On borehole wall

- **Measuring joint roughness**

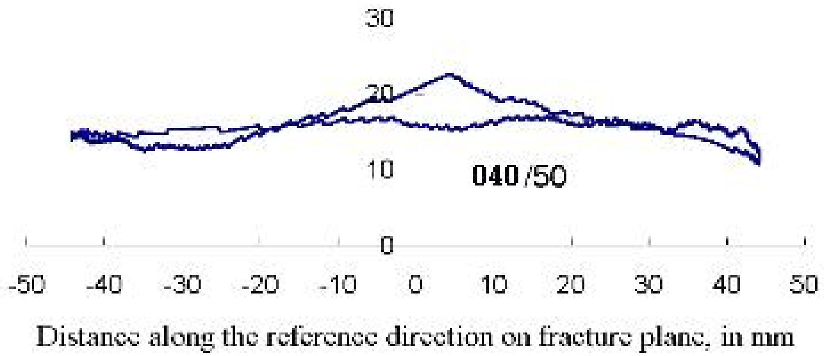
① With rock core
② On borehole wall (refer to next page)

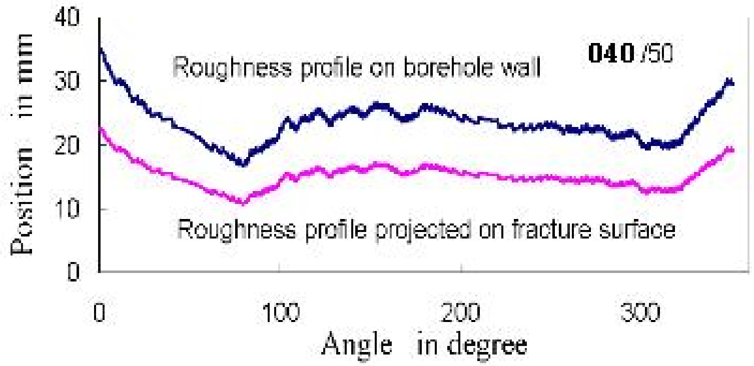




Application of borehole television

Joint trace on the borehole wall and
Its corresponding sine wave





Joint profile projected on a specially oriented plane

Joint roughness profile on borehole wall and another roughness profile projected on fracture surface

Survey methods of rock mass

- **Borehole TV logging system**

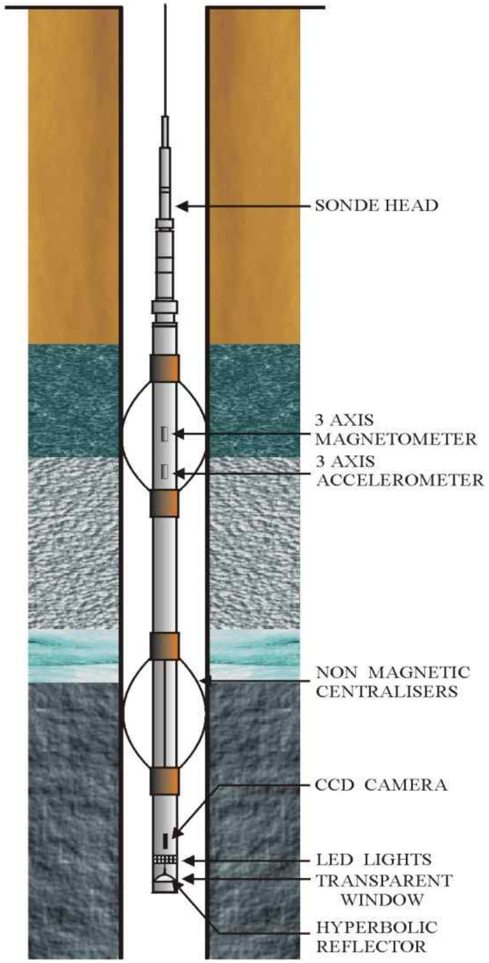
  - TV in "Borehole TV Logging System" is an abbreviation of two different words: television and televiewer. The former uses optical lenses while the latter uses ultra sonic waves to observe (survey) the borehole wall.

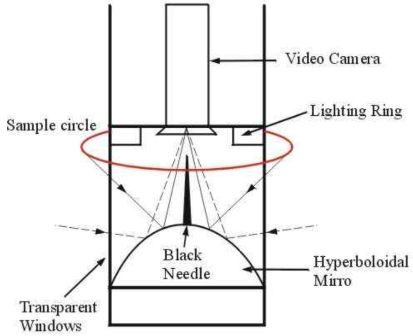
    The borehole television logging system is frequently referred to as "Borehole Image Processing System (BIPS)".

  - BIPS provides the direct view of a target with a straightforward mechanism. This enables BIPS to be applied to dry boreholes or cavities and to show ground water flow in borehole, while suspending materials in the water prevent it from observing water flow or borehole wall.

  - The borehole televiewer has a unit to detect the magnetic north (Zemmanek etc, 1969) as BIPS dose. The televiewer sends a stream of ultra sonic waves (thousands per second) towards the borehole wall as it is lifted up with rotation. The reflected sonic waves are continuously recorded. Through their amplitude and traveling time, we can measure borehole radius, joint orientation and mechanical properties of rock.

    The observed or analysed images are normally recorded with depth in digital formats. Both techniques/systems complement well each other.


SONDE HEAD
3 AXIS
MAGNETOMETER
3 AXIS
ACCELEROMETER
NON MAGNETIC
CENTRALISERS
CCD CAMERA
LED LIGHTS
TRANSPARENT
WINDOW
HYPERBOLIC
REFLECTOR


Video Camera
Lighting Ring
Sample circle
Black
Needle
Hyperboloidal
Mirro
Transparent
Windows

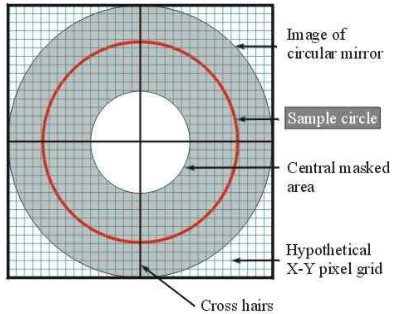


Image of
circular mirror
Sample circle
Central masked
area
Hypothetical
X-Y pixel grid
Cross hairs

BIPS

Survey methods of rock mass

- Logging with optical television

The optical television records the borehole view reflected by hyperbolic mirror attached to the probe. CCD camera continuously takes photos whose width is 5 *mm* and each photo consists 720 pixels. The camera is lifted up with a constant speed of about 0.5~1.5 *m/min*. The magnetic north is measured by a 3-axis magnetometer and recorded with photo images. Joint traces on the borehole wall show sinusoidal waves when their image is unrolled into a plane. By reference to the north, dip direction can be determined and the dip angle can be calculated by using the amplitude of joint trace and borehole radius.

Advantages of optical television

- Applicable to dry boreholes
- Ground water flow can be observed.
- Rock type variation, infilling materials, geological structure can be observed.
- Aperture of joints can be measured.
- No special software is needed for analysis.

Survey methods of rock mass

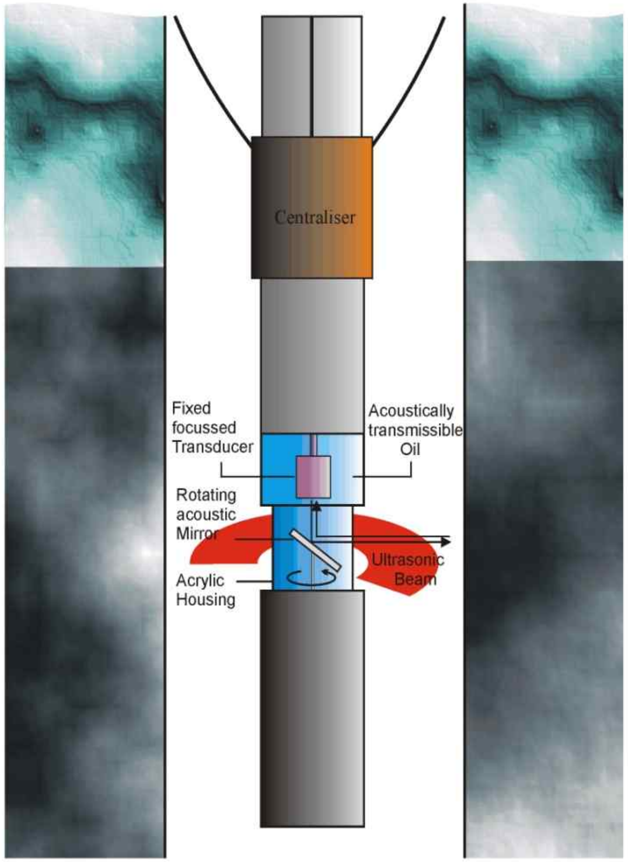
- Logging with televiewer

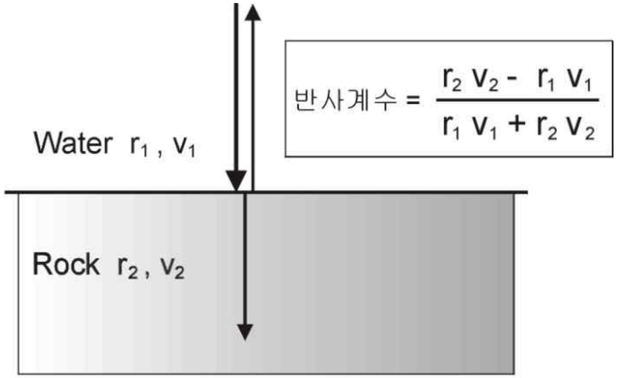
  The televiewer is said to be an acoustic borehole scanner which periodically shoots ultra sonic beam (1.5 MHz) to borehole wall and records its reflected waves for the energy (amplitude) and travel time.

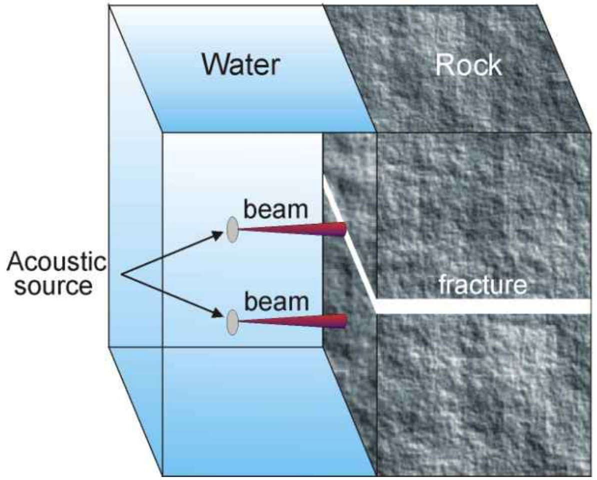
  The magnitude of energy of the reflected wave depends on reflection coefficient which is a function of material density and traveling velocity as shown in the figure below. When the acoustic beam reflects from a joint plane its energy is dispersed on the surface and impeded by joint infilling materials resulting in a weak signal to the sensor. Open joints make the acoustic wave travel farther than in-filled joints do. This helps to confirm the existence of a joint.

  A joint trace is shown as a sine curve on the borehole wall. By the magnetic north stored in televiewer record, the scanning data is arranged according to orientation: N-E-S-W-N. Dip direction and dip angle of the joint can be obtained from the joint trace, borehole size and the information of north.

  The televiewer record includes the amplitude of reflected waves, travel time and location of sensor. The wave amplitude is affected by discontinuities and rock strength. The travel time is used to measure the borehole radius or to correct the measurement. The sensor location can be determined by depth which is measured by a depth counter attached to winch and orientation which is measured by 3 axis magnetometer and 3 axis clinometer.







Principle of televiewer logging

Survey methods of rock mass

Advantages of televiewer

- **Young's modulus of rock can be estimated.**
- **Applicable even in unclean water**
- **Less chance to incorrectly identify the rock type due to not relying on surface observation**
- **The amount of record is smaller than that of BIPS.**
- **Variation of borehole radius can be detected.**

(2) Exposed rock face sampling

- Pros and Cons

① Relatively larger sampling area is available.
② Lower cost
③ Not applied to the area that is unexcavated, damaged by blasting/weathering or covered with bush/plants

- Scanline sampling

Standard regulation/rule for sampling is not set up yet.

1) Selection of sampling area

- Place(s) representing the site
- Large enough to include 150 ~ 350 joints (50% of joints should have one or two endpoints within the sampling area)
- Safety: safe from rock failure, ground water flow and traffic)

2) Installation of scanlines

- Length: 2 m ~ 30 m
- Orientation: Parallel to the strike or dip of the sampling plane
- Reducing sampling bias: select a sampling plane perpendicular to the previous ones
- Close to the face: make the scanline close to the rock face (required to measure short joint traces).
- Splitting a scanline: when a scanline deviates from a straight line more than 20°
- Photographing: photos from several view points with scales

  ex.) markers attached to the scanline at 1*m* interval (Fig. 2.4).

  Different distance between camera and surface points of sampling area makes its image distorted (Fig. 2.5).

  → a) Long focal length lens/tilt shift lens (hardware solution)

  b) Photogrammetry: image matching and orientation with scale information gives 3D coordinates of every point on the image

3) Recording joint intersection points

- Origin point: measurement starts from zero at either end of the scanline and the intersecting points are recorded in order of location.
- Target: natural joints
- Fracture zone: record the extent, location and nature of the zone.
- Closely spaced/sub-parallel joints: record representative measurements, extent and count

4) Joint orientation

- Measuring point: intersection points of joints and a scanline
- Tool: clinocompass (clinometer + magnetic compass + spirit level (Fig. 2.7, Fig. 2.8)
- Representation: dip direction/dip, strike/dip
- Error: ±10° for dip direction and ±5° for dip angle.

5) Semi-trace length

- **Definition: distance between a joint-scanline intersection and either end of the joint trace. The counting points of joint traces should be within the same part of the sampling plane :**

  ex.) left (right) or upper (lower) part of the scanline.
- **Uncertainty : The average length of semi-trace is half of the mean joint trace length, which means there is uncertainty in estimation of the complete trace length especially when the sample size is small.**
- **Advantage over complete trace length measurement: Simple and rapid**
- **Terms for filtering:**

  ① trimming - excluding traces shorter than a lower limit

  ② curtailment - excluding traces longer than a upper limit

  ③ truncation - not recording the number of excluded traces

  ④ censoring - recording the number of excluded traces

- **Window sampling**

1) Pros and cons

- Pros:

a) Joints parallel to scanline or sampling window are not observed. In case of window sampling only the joints with a specific orientation are missed in the window.

b) More joints can be sampled from the same region than by the scanline

- Cons:

a) There are more joint traces in the sampling window than in the scanline, which means the window sampling requires more time to count and record joints.

→ automated process is useful - photogrammetry,
laser profiling (hard to find joint trace),
radar, seismo-acoustic (resolution problem).

b) The number of observed joint traces decreases as the joint size decreases. The decreasing rate is lower in case of window sampling.

2) Classification of joint traces according to the no. of end points in a window

① Contained trace (양끝내포선) - both ends are in the window

② dissecting trace (한끝내포선) - either end is in the window

③ transecting trace (양끝외포선) - both ends are out of the window

- **Application of geostatistics to discontinuity analysis**

  - A kind of applied statistics dealing with varied spatial data sets.
  - Variogram: a measure of the continuity of spatial phenomena expressed as an average squared difference at different locations (Fig.2.10).

$$\gamma\left(h\right)=\frac{1}{2n}\sum_{i=1}^{n}\left[p(x)-p(x+h)\right]^2$$

- Kriging: a stochastic interpolation technique based upon a generalized least square algorithm using variograms as weighting functions. With the least square algorithm, the estimate becomes unbiased and its variance becomes minimized.
- Difficulty in application: As for the joints it is usual to analyze their features for each joint set such as size and spacing. As the investigation area is extended, however, the joint orientation and accordingly the definition of set change. This makes it difficult to analyse the joint set features with variogram or Kriging.

- **Rock mass classification**

1) RMR/Q system

- RMR (Bieniawski, 1973), Q-system (Barton et al, 1974): Providing guidelines of support, excavation method and strength and deformability of rockmass. Quantitative and simple description of rock mass is provided.
- Somewhat subjective and qualitative factors involved: Description of discontinuity condition (RMR and Q) - very (slightly) rough, slightly (highly) weathered, rough or irregular, smooth, undulating...
- Lack of statistical information of joints and relevant analysis technique: Rock mass classification schemes was developed in 1970's and has proceeded independently of research on discontinuity sampling and analysis.

2) RQD

- Fundamental factor of rock mass classification: 20/100 in RMR, 100 in Q:

$$Q = \frac{RQD(100)}{J_n(20)} \frac{J_r(5)}{J_a(20)} \frac{J_w(1)}{SRF(400)}$$

- Relation with spacing: closely and most directly related with spacing or linear frequency. It shows, however, similar values for the joints having more than 30*cm* of spacing.
- Dependence on the orientation of a scanline or borehole: RQD may change significantly by the scanning orientation in the site where only 1~2 joint sets are dominant. RMR/Q are not careful about this problem.

2) RMi (Rock Mass index)

- Suggested by Palmstrom (1995).
- Factors: Joint roughness, alteration, size/termination, density, uniaxial compressive strength
- Feature: No consideration of stress and joint orientation → assuming rock mass as an isotropic material. RMi indicates a rock mass strength. Subjective judgment may intervene in the evaluation process.

The Rock Mass index (RMi)

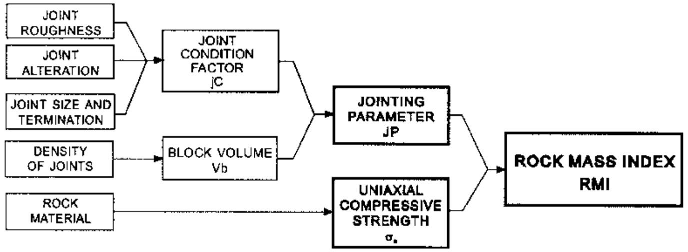


Figure 1 The main inherent parameters in the rock mass are applied in the RMi (from Palmström, 1995).

RMi is based principally on the reduction in strength of a rock caused by jointing [1] and is expressed as:

$$RMi = \sigma_c \times JP \qquad \text{eq. (1)}$$

where σ_c = the uniaxial compressive strength of intact rock measured on 50 mm samples;
JP = the jointing parameter which is a reduction factor representing the block size and the conditio of its faces as represented by their friction properties and the size of the joints.

$$JP = 0.2\sqrt{jC} \times Vb^{D} \qquad \text{eq. (2)}$$

where Vb is given in m^3, and $D = 0.37\, jC^{-0.2}$ has the following values:

for jC =	0.1	0.25	0.5	0.75	1	1.5	2	2.5	3	4	6	9	12	16	20
D =	0.586	0.488	0.425	0.392	0.37	0.341	0.322	0.308	0.297	0.28	0.259	0.238	0.225	0.213	0.20

The joint condition factor is expressed as $jC = jL\ (jR/jA)$ where jL, jR and jA are factors for respectivel joint length and continuity, joint wall roughness, and joint surface alteration.

Table 4. Classification of RMi (from Palmström, 1995)

TERM for RMi	TERM related to rock mass strength	RMi VALUE
Extremely low	Extremely weak	< 0.001
Very low	Very weak	0.001 - 0.01
Low	Weak	0.01 - 0.1
Moderate	Medium	0.1 - 1
High	Strong	1 - 10
Very high	Very strong	10 - 100
Extremely high	Extremely strong	> 100

Table 1. The ratings of the joint roughness factor, (jR, found from smoothness and waviness (from Palmström, 1995) (The ratings of jR are similar to Jr in the Q-system)

small scale smoothness of joint surface	large scale waviness of joint plane: planar	slightly undulating	strongly undulating	stepped	interlocking (large scale)
very rough	3	4	6	7.5	9
rough	2	3	4	5	6
slightly rough	1.5	2	3	4	4.5
smooth	1	1.5	2	2.5	3
polished	0.75	1	1.5	2	2.5
slickensided*)	0.6 - 1.5	1 – 2	1.5 – 3	2 – 4	2.5 – 5
	For filled joints: jR = 1		For irregular joints a rating of jR = 5 is suggested		

*) For slickensided joints the value of jR depends on the presence and appearance of the striations; the highest value is used for marked striations.

Table 2. Characterization and rating of the joint alteration factor, jA, (from Palmström, 1995) (jA is similar to Ja in the Q-system, except for the grade of alteration)

A. CONTACT BETWEEN THE TWO ROCK WALL SURFACES

TERM	DESCRIPTION	jA
Clean joints		
-Healed or "welded" joints	Softening, impermeable filling (quartz, epidote etc.)	0.75
-Fresh rock walls	No coating or filling on joint surface, except for staining	1
-Alteration of joint wall:		
· 1 grade more altered	The joint surface exhibits one class higher alteration than the rock	2
· 2 grades more altered	The joint surface shows two classes higher alteration than the rock	4
Coating or thin filling		
-Sand, silt, calcite etc.	Coating of friction materials without clay	3
-Clay, chlorite, talc etc.	Coating of softening and cohesive minerals	4

B. FILLED JOINTS WITH PARTIAL OR NO CONTACT BETWEEN THE ROCK WALL SURFACES

TYPE OF FILLING MATERIAL	DESCRIPTION	Partial wall contact thin fillings (< 5 mm*)) jA	No wall contact thick filling or gouge jA
-Sand, silt, calcite etc.	Filling of friction materials without clay	4	8
-Compacted clay materials	"Hard" filling of softening and cohesive materials	6	10
-Soft clay materials	Medium to low over-consolidation of filling	8	12
-Swelling clay materials	Filling material exhibits clear swelling properties	8 - 12	12 - 20

*) Based on joint thickness division in the RMR system (Bieniawski, 1973)

Table 3. The joint size and continuity factor, jL, (from Palmström, 1995).

JOINT LENGTH	TERM	TYPE	jL continuous joins	jL discontinuous joints**)
< 0.5 m	very short	bedding/foliation partings	3	6
0.1 - 1.0 m	short/small	joint	2	4
1 - 10 m	medium	joint	1	2
10 - 30 m	long/large	joint	0.75	1.5
> 30 m	very long/large	(filled) joint, seam*) or shear*)	0.5	1

*) Often occurs as a single discontinuity, and should in these cases be treated separately. **) Discontinuous joints end in massive rock

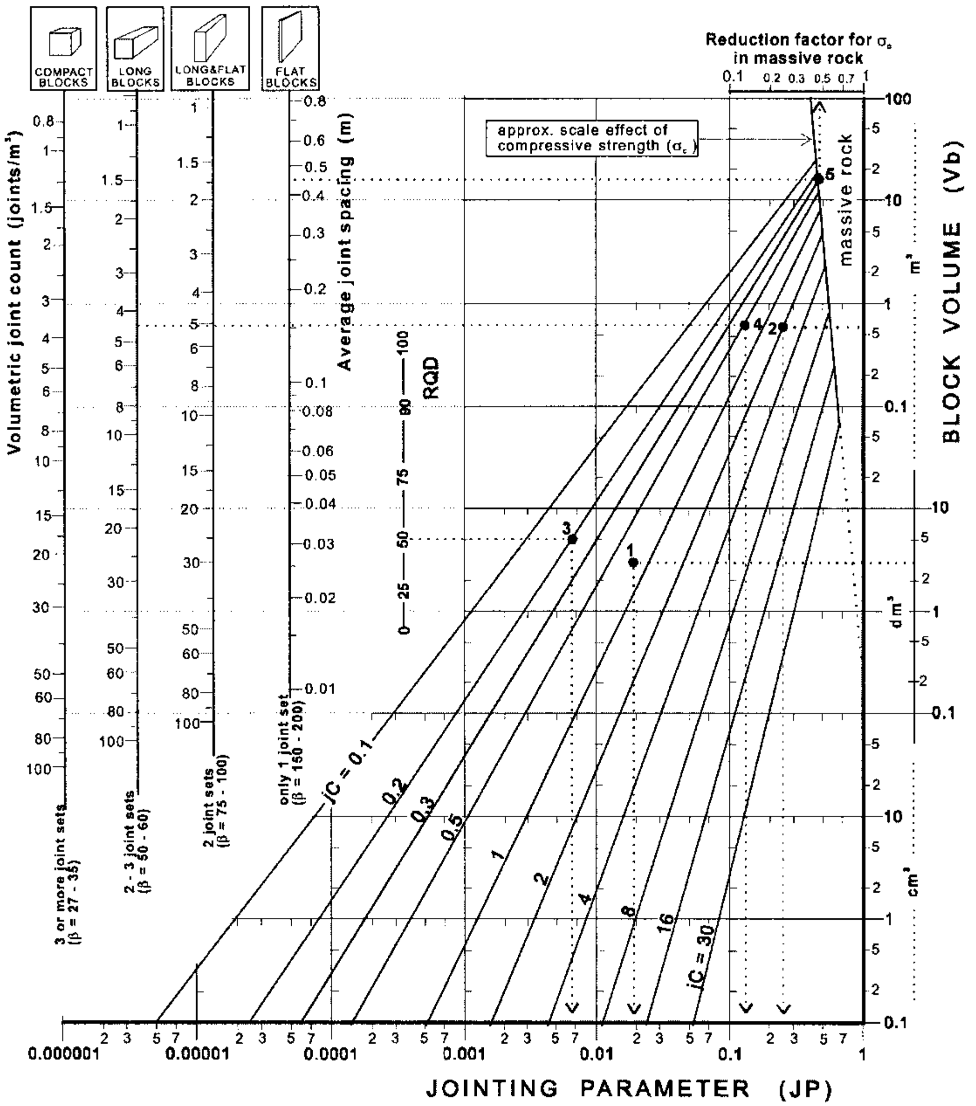


Figure 3. The jointing parameter (JP) found from the joint condition factor (jC) and various measurements of jointing intensity (Vb, Jv, RQD). The determination of JP from Vb (or RQD or Jv) in the examples are indicated (from Palmström, 1995).