From Palmström A.: RMi – a rock mass characterization system for rock engineering purposes.
PhD thesis, Oslo University, Norway, 1995, 400 p.

Chapter 5

ROCK MASSES CHARACTERIZED BY THE RMi

> *"How convinced are we that the rock properties we feed into the design models actually describe the way the rock mass reacts to a perturbation like a tunnel or a cavern?"*
> Ulf E. Lindblom (1986)

RMi is an expression, which covers intact rock as well as the aggregates of rock blocks formed by joint planes. As RMi is tied to the resulting effect of interacting blocks, it is not meant to characterize single blocks or joints. Therefore, it is, from its definition and structure, only applicable in continuous volumes of rock masses. Ideally, such a volume should be homogeneous.

Where RMi is used as a general characterization of rock masses, the size of the 'sample' or the volume involved is not related or limited by the excavation constructed. Thus, the rock mass is considered continuous if the 'sample' size is not limited by geologic boundaries or other in situ features. For some types of rock masses with widely spaced joints such a 'sample' will, however, be of a considerable size.

The actual project and the specific calculation or engineering work connected with it, determines the size of the rock mass involved. In such cases the rock mass may be considered as continuous or discontinuous as described in the next section.

4.1 ON CONTINUOUS AND DISCONTINUOUS ROCK MASSES

When the 'sample' of a rock mass being considered is such that only a few joints are contained in this volume, its behaviour is likely to be highly anisotropic, and it is considered as *discontinuous*. If the sample size is many times the size of the individual fragments, the effect of the each particle (and hence the joints) is statistically levelled out, and the sample may be considered *continuous* (Deere et al., 1969). See Fig. 5-1.

This is the case when none of the discontinuities or joint sets is significantly weaker than any of the others within the volume of rock under consideration. If a discontinuity is very weak when compared to the others, as could be the case when dealing with a fault passing through a jointed rock mass, the rock mass may be characterized as continuous, and the fault must be characterized separately as a singularity if it is relatively small, or else as a weakness zone, as described in Appendix 2.

The volume required for a sample of a rock mass to be considered continuous is a matter of judgement. It depends on the range of block or particle sizes making up the 'sample' volume. This matter has been discussed by several authors:

- John (1962) suggests that a sample of about 10 times the average (linear) size of the single units may be considered a uniform continuum. It is clear that this will depend to a great extent on the uniformity of the unit sizes in the material or the uniformity of the spacings of the discontinuities. For a unit of 1 m^3 the size of the sample would be 10^3 = 1000 m^3.

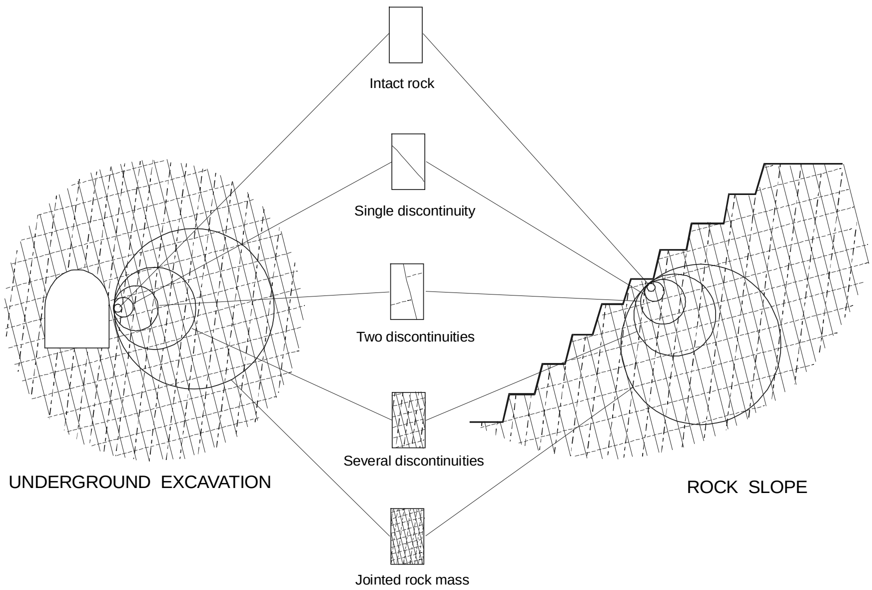

Fig. 5-1 Various volumes of rock masses involved in a 'sample'. Continuous rock masses are: 'intact rock', 'jointed rock mass', and possibly 'several discontinuities'. (From Hoek, 1983) The tunnel shown involves relatively few discontinuities, i.e. a discontinuous rock mass.

- Deere et al. (1969) have tied the 'sample' size to the size of a tunnel from its stability behaviour. Whereas the stability of a tunnel opening in a continuous material can be related to the intrinsic strength and deformation properties of the bulk material, stability in a discontinuous material depends primarily on the character and spacing of the discontinuities. In this connection they have found that the size of the 'sample' related to a tunnel should be considered discontinuous *"when the ratio of fracture spacing to a tunnel diameter is between the approximate limits of 1/5 and 1/100. For a range outside these limits, the rock may be considered continuous, though possibly anisotropic."* (See Fig. 5-2).

- Another approximate indication is based on the experience from large sample testing at Karlsruhe, Germany (see Appendix 6), where a volume containing at least $5 \times 5 \times 5 = 125$ blocks is considered continuous (Mutschler, 1993).

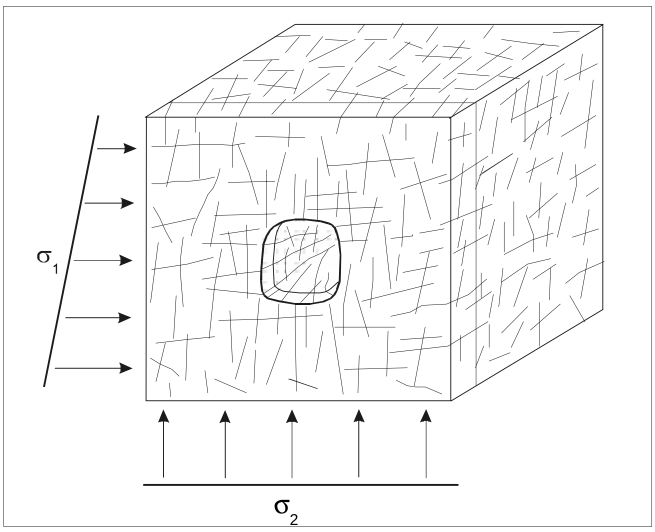

Fig. 5-2 The size for a 'sample' to be characterized as continuous for the actual tunnel. In this case the stability is governed by the blocks around the opening, i.e. the ground around the tunnel is discontinuous (modified from Barton, 1990).

From this it is clear that it is important to determine whether a material should be considered continuous or discontinuous in a particular case. Accordingly, the type of behaviour of the material may be predicted, from which suitable theories and methods of design may be employed.

In this connection it may also be mentioned that the current approach to modelling engineering projects in a jointed rock mass is to treat the rock as a discontinuum (controlled by individual joints) in the near field of an opening, and as a continuum in the far field (when the volumes are significantly larger).

5.2 ZONING OF ROCK MASSES INTO STRUCTURAL REGIONS

To facilitate the characterization of the variation of rock masses within a region or along a borehole, it is often necessary and convenient to distinguish a number of *structural regions* (Piteau, 1973), wherein the rock and joints have similar composition. Each part selected can then be considered and treated individually for its particular characteristics. ISRM (1980) has applied the term *zoning of rock masses* for such division into structural regions in their proposed method for basic geotechnical description (BGD) of rock masses. Designation of a structural region implies that the *detailed jointing* (Selmer-Olsen, 1964) within the region selected is similar, assuming that the individual joint sets have the same characteristics, as the joint sets most likely - at least on a local basis - have been developed under similar conditions of stress (Piteau, 1973).

A zone may include differing volumes of rock masses, such as interbedded layers of sedimentary or volcanic formations exhibiting the same geotechnical characteristics (ISRM, 1980). In the case of rock masses which vary continuously from place to place, for example due to weathering, ISRM advises delineating arbitrary zone boundaries in such a way that the properties of each zone may be considered relatively uniform. Generally, it is found that structural regions of similar jointing will juxtapose at major geological structures. The boundaries of a zone will therefore often be defined by faults, dykes and rock boundaries.

As the RMi expresses the inherent characteristics, it is well suited to be applied in the zoning. The input data from the survey is then, manually or by the use of a computer, utilized to find the rock mass quality values for each of the structural regions.

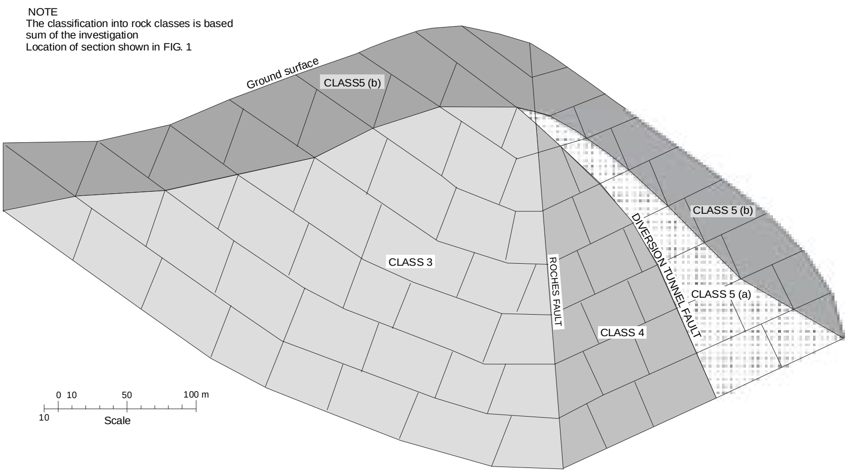

Fig. 5-3 Example of zoning into rock classes in a profile (from Chappell, 1990)

Chappell (1990) has, through zoning of rock masses into structural regions (Fig. 5-3), arrived at models where strength characteristics and deformational response of the intact rock material are combined with associated discontinuity parameters.

5.3 PRINCIPLES IN CHARACTERIZING THE VARIATIONS IN ROCK MASSES

In spite of a zoning of the rock volumes into structural regions of similar characteristics, the various parameters of the rock mass within a zone may still show variations, refer to Fig. 5-4. As described in Chapter 4 the parameters selected has been divided into three main groups:

- the intact rock features,
- the features contributing to the size and shape of rock blocks, and
- the features connected to the joints and their condition.

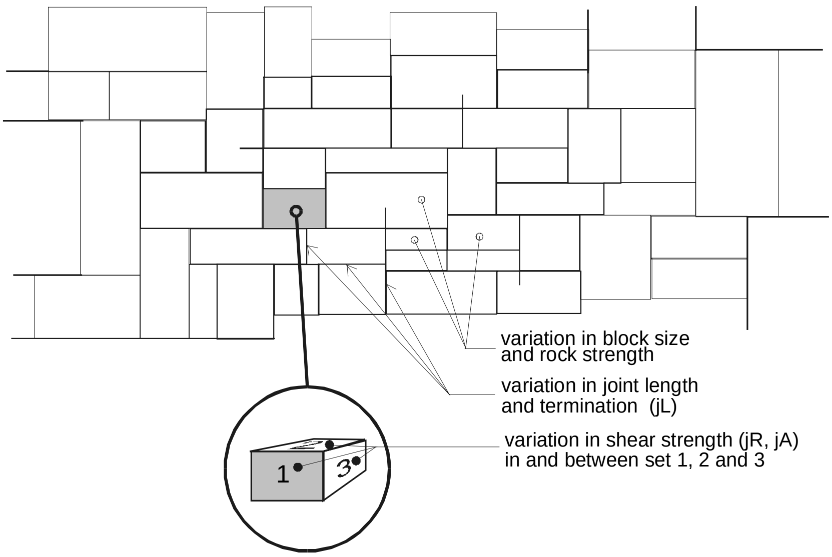

Fig. 5-4 Sketch showing possible variations in rock mass parameters.

The numerical characterization of these parameters is described in Appendix 3 where different methods of finding their values are described. As many or all of the parameters may show variations within the actual zone or rock mass volume, their conditions may be compared and their values determined from evaluation and judgement based on understanding of the geological setting. A short description of the rock mass may help to a clearer knowledge of the site conditions.

5.3.1 Variations in the rock material

The distribution of rocks in a location is generally determined from field observations based on geological classification. Within the same type of rock strength (σ_c) and anisotropy may vary, which may be caused by variation(s) in the following features:

- composition/structure;
- texture; and/or
- weathering/alteration.

In addition folding and alternation between different rocks may contribute to the variation in σ_c values in the location. The range of some of these features can be found from the tests or assessments described in Appendix 3 on numerical determination of input parameters to the RMi. Some of the variations in the rock properties may sometimes be viewed in connection with the jointing features as described in Appendix 1.

Such variation in the compressive strength should, as recommended by the ISRM (1978), be given as a range. *In rocks where the strength varies with direction of the testing, the lowest value should be applied for* σ_c *as input to RMi.*

The requirements for the quality of the geo-data to be applied and the actual type of engineering will indicate whether the different rocks in a location may be characterized as separate volumes or not.

5.3.2 Variations in the jointing

Jointing is generally much more complex in its variation and influence in rock mass behaviour than the intact rock. In most types of observations and measurements the joints are characterized and not the blocks they delineate. In Appendix 3 methods to asses the block size from such measurements are shown.

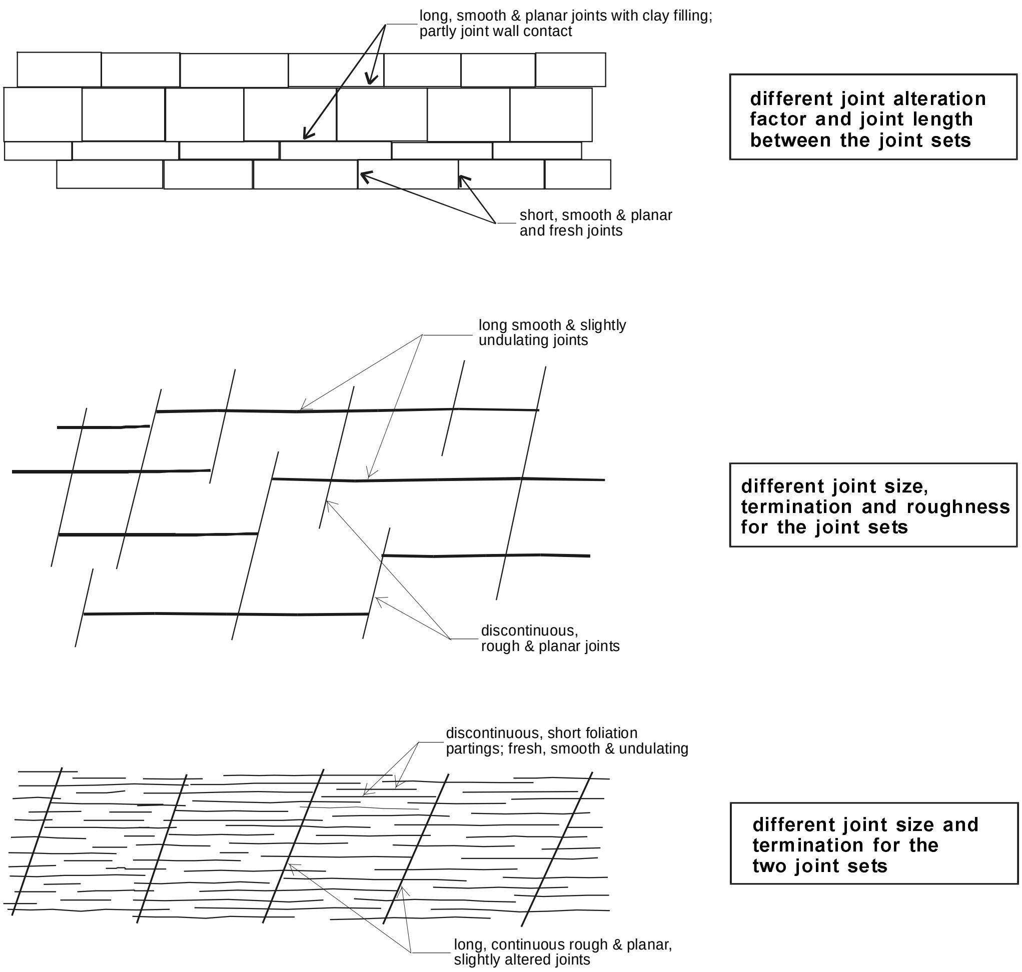

Fig. 5-5 Some examples of variations in jointing.

The detailed jointing may constitute the various patterns by which joint spacings determine the block sizes and their variation. Jointing can be divided into the following:

1. Common types of jointing mainly consisting of tectonic joints:
   - Mainly joint sets and few random joints (often with one of the joint sets along the bedding or the foliation).
   - Few joint sets plus many random joints.
   - Mostly random joints (i.e. irregular jointing).
2. Special types of jointing which can make up a smaller or larger part of the jointing:
   - Foliation jointing in anisotropic (schistose) rocks.
   - Columnar jointing in basalts.
   - Cleavage jointing in some granites.
   - Sheet jointing (exfoliation jointing) caused by stresses near the surface.
   - Desiccation jointing in sedimentary mudstones.
   - Jointing in the zone of weathering.
   - Jointing in tectonic zones (crushed zones).

Some examples of variations in rock masses are given in Fig. 5-5.

The variations in one or more of these factors result in that, in reality, regular geometric shapes are the exception rather than the rule. Jointing in sedimentary rocks usually produces the most regular block shapes.

There are so many variations in jointing that it has not been possible to work out one single method to characterize all these in a common jointing parameter. Therefore, different methods are shown, and it is up to the user to select the method that is best for the actual case.

5.3.2.1 The block size (Vb)

The block size and its variation depend on the density of the jointing influenced also by the number of joint sets and the spacings in these sets. In addition random joints may contribute, especially where irregular jointing occurs.

The variation in block size may be graphically shown in a sieve curve similar to that shown in Fig. A3-21 or in Fig. 4-8. This variation can be measured and reported in different ways, depending on the number of joint registrations and the accuracy required of the measurements. One possible method is, - based on the efforts required and the availability of measurements, - to use Vb_{25} and Vb_{75} as the range (see Fig. A3-21), similar to what is used in soil mechanics.

The block size, which is another measure for the quantity of joints, can be found from several types of measurements by using the relations described in Section 3 in Appendix 3.

A . Block volume found from joint spacing or joint density measurements

Spacing may be given as a range (S_{min} and S_{max}) for each joint set. The minimum block volume is found from the minimum values for each set $Vb_{min} = S1_{min} \times S2_{min} \times S3_{min}$ provided the joint sets intersect at right angles. The maximum block volume is found accordingly.

Example 5-1: Block volume determined from joint spacings.

The following joint spacings have been observed in a location:

joint set 1, spacing $S1 = 0.3 - 0.5$ m
joint set 2, spacing $S2 = 0.5 - 1$ m
joint set 3, spacing $S3 = 1 - 3$ m

Provided the joints intersect at right angles the block volume is

$Vb_{min} = 0.3 \times 0.5 \times 1 = 0.15\ m^3$, $Vb_{max} = 0.5 \times 1 \times 3 = 1.5\ m^3$

Example 5-2: Block volume found from 1) the quantity of joints, and 2) from the joint spacings.

Measured on the outcrop of approximately 25 m^2 shown in Fig. 5-6, the following number of joints have been found:

7 joints with length > 5 m (= na1);
6 joints with length approx. 3 m (= na2); and
45 small joints with length approx. 1.5 m (= na3).

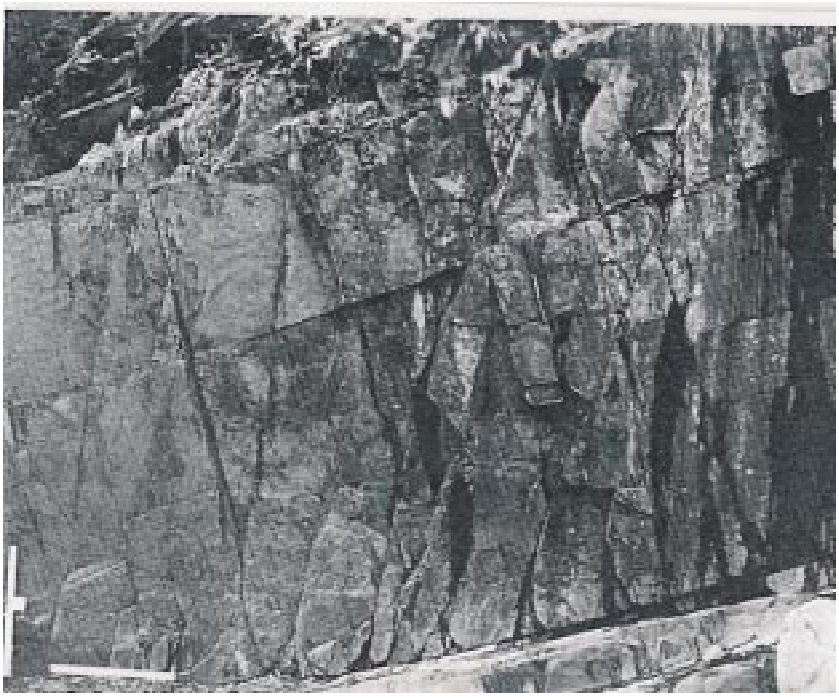

Fig. 5-6 Jointed Ordovician mudstone. The rulers shown are 1 m long (from Hudson and Priest 1979).

1) Block volume found from the quantity of joints. Most joints are shorter than the dimension of the observation area and their quantity should therefore be adjusted using eq. (A3-32a) $na^* = na \times Lj / \sqrt{25}$ (see Appendix 3, Section 3). This gives

$na1^* = 1$, $na2^* = 3.6$ and $na3^* = 13.5$

The density of joints is then $Na = (na1^* + na2^* + na3^*) / \sqrt{25} = 4.8$ joints/m. As it is not known how the surface is oriented with respect to the main joint set an average value of $ka = 1.5$ is applied to find the volumetric joint count (see eq. (A3-32) and Fig. A3-25):

$Jv = Na \times ka \approx 7.2$ joints/m^3.

Assuming that the blocks are mainly compact (equidimensional) with a shape factor of $\beta = 30$ the average block volume is found as (eq. (A3-27):

$Vb = \beta \times Jv^{-3} = 0.08\ m^3$

2) Block volume found from the following spacings roughly measured in Fig. 5-6:
set 1: S1 = 1.3 - 2.2 m (average = 1.75 m)
set 2: S2 = 0.8 - 1.8 m (average = 1.3 m)
set 3: S3 = 1.2 - 2 m (average = 1.4 m)
In addition 45 random joints can be seen within the observation area of 25 m^2. These joints are mainly short (approximately 1.5 m long), therefore their number has been adjusted according to eq. (A3-32a) $na^* = 45 \times 1.5 / \sqrt{25} = 13.5$. The density of random joints is then

$$Na = 13.5 / \sqrt{25} = 2.7 \text{ joints/m}$$

An average value of ka = 1.5 has been chosen to find the contribution of random joints to Jv:
$Jv_{random} = Na \times ka = 4$ joints/m^3

The resulting average volumetric joint count is found as

$$Jv = (1/1.75) + (1/1.3) + (1/1.4) + Jv_{random} = 6.05 \text{ joints/m}^3$$

Using $\beta = 30$ the block volume is

$$Vb = \beta \times Jv^{-3} = 30 \times 6.05^{-3} = 0.13 \text{ m}^3$$

The second method (the combined spacing and joint density method) gives block volume 60% larger than the first method. This may be explained by the very approximate joint spacing in method no. 2.
(A rough estimate from the photo indicates an average block volume of
Vb = 0.2 m^3 for compact (equidimensional) blocks).

B. Probability calculations to determine the variation in block volume

As the joint spacings generally are independent random variables, probability calculations may be applied to determine the range of the block volume from the variations in spacings for each joint set. Suppose the three joint sets intersect at right angles, then the block volume is

$$Vb = S1 \times S2 \times S3$$

where S1, S2, S3 are the joint spacings for the three sets.

Within each set the spacing varies within certain limits. In the derivations below it is assumed that the minimum value of the spacing corresponds to

mean value - α standard deviations

and the maximum value to

mean value + α standard deviations.

The expression above for the block volume can be written as

$$\ln Vb = \ln S1 + \ln S2 + \ln S3 \qquad \text{eq. (5-1)}$$

Assume that the joint spacings have a log-normal distribution. This is often the case for jointing as shown in Section 5 in Appendix 1. Then eq. (5-1) can be expressed by its
mean ln value

$$\mu_{\ln Vb} = \mu_{\ln S1} + \mu_{\ln S2} + \mu_{\ln S3} \qquad \text{eq. (5-2)}$$

and the standard deviation as

$$\sigma_{\ln Vb} = \{(\sigma_{\ln S1})^2 + (\sigma_{\ln S2})^2 + (\sigma_{\ln S3})^2\}^{½} \qquad \text{eq. (5-3)}$$

where $\mu_{\ln S1} \approx (\ln S1_{min} + \ln S1_{max})/2$ (and similar for $\mu_{\ln jR}$ and $\mu_{\ln jA}$) eq. (5-4)

$$\sigma_{\ln S1} \approx (\ln S1_{max} - \ln S1_{min})/2\alpha \qquad \text{eq. (5-5)}$$

Applying α standard deviations from the mean ln-value ($\mu_{\ln Vb}$) and a log-normal distribution, the block volume will be

$$Vb_{low} \approx e^{(\mu_{lnVb} - \alpha\sigma_{lnVb})} \qquad \text{eq. (5-6)}$$

and

$$Vb_{high} \approx e^{(\mu_{lnVb} + \alpha\sigma_{lnVb})} \qquad \text{eq. (5-7)}$$

For practical purposes α = 1 standard deviation may be applied.

<u>Example 5-3:</u> <u>The variation range of block volume found from joint spacings</u>.

The following spacings have been measured:

- joint set 1, spacing S1 = 1 - 2 m (ln S1 = 0 - 0.693)
- joint set 2, spacing S2 = 2 - 3 m (ln S2 = 0.693 - 1.099)
- joint set 3, spacing S3 = 3 - 4 m (ln S3 = 1.099 - 1.386)

For α = 1 standard deviation the mean ln values of the spacings and the volume are found as

$$\mu_{\ln S1} = ½ (0.693) = 0.347$$
$$\mu_{\ln S2} = ½ (0.693 + 1.099) = 0.896$$
$$\mu_{\ln S3} = ½ (1.099 + 1.386) = 1.243$$
$$\mu_{\ln Vb} = 0.347 + 0.896 + 1.243 = 2.486$$

The standard deviation is:

$$\sigma_{lnS1} = (0.693)/2 = 0.347$$
$$\sigma_{lnS2} = (1.099 - 0.693)/2 = 0.203$$
$$\sigma_{lnS3} = (1.386 - 1.099)/2 = 0.144$$
$$\sigma_{lnVb} = (0.347^2 + 0.203^2 + 0.144^2)^{½} = 0.427$$

This gives

$$Vb_{low} \approx e^{(2.486 - 0.427)} = 7.84 \text{ m}^3$$
$$Vb_{high} \approx e^{(2.486 + 0.427)} = 18.40 \text{ m}^3$$

and

$$Vb_{mean} \approx e^{\mu \cdot lnVb} = 12.0 \text{ m}^3$$

(If the lowest, mean, and highest values for all spacing had been chosen
$Vb_{min} = 6$ m^3, $Vb_{mean} = 13.13$ m^3, $Vb_{max} = 24$ m^3)

As mentioned in Appendix 1, there may be cases where only one joint set or two joint sets occur, hence no blocks are delineated which means that the block volume is infinite. In other cases most of the joints terminate in solid rock so that blocks are not clearly delimited. An example of this is schists in which foliation joints and partings are the only joints present. In such situations the length of the joints may be applied for calculating the effect of the jointing. A useful method is shown in Example 5-7.

5.3.2.2 The joint condition factor (jC)

The joint condition factor (jC) is composed of 4 variables: the smoothness, waviness, size and alteration of each joint in the actual volume of rock mass. Thus jC may show significant variations, and it may be difficult to estimate its range of variation.

Ideally the value of jC for each of the joints or joint sets should be used in RMi. As it was found impossible to include the jC value for all joints and at the same time maintain the simple structure of RMi, this factor is only represented as one number (or range). This means that where there are different conditions for the various joint sets, some simplifications have to be made to combine them as shown in the following:

A. jC determined for <u>one joint or joint set</u> where the parameters involved in it vary

Alt.1.

The variation range of jC is found from combination of the parameter values so that the minimum value and the maximum value is found for the actual joint or joint set

$jC_{min} = jL_{min} \times jR_{min} / jA_{max}$ eq. (5-8)

$jC_{max} = jL_{max} \times jR_{max} / jA_{min}$ eq. (5-9)

<u>Example 5-4</u>: <u>jC determined from variations in joint characteristics.</u>

The following values have been found for a joint set:

- the joint wall surface is smooth to slightly rough, jw = 1 - 1.5
- the waviness is slightly to strongly undulating, js = 1.5 - 2
- silty coating on the joint wall, part wall contact, jA = 3
- the continuous joints vary between 0.5 - 5 m in length, jL = 1 - 1.5

From this the roughness factor is found as

$jR = jw \times js = 1.5 - 3$

and the minimum and maximum joint condition will be (from the lowest and highest value of jR and jL)

$jC_{min} = 0.5, \quad jC_{max} = 1.5$

Alt. 2.

The variation range of jC is found from *probability calculations* similar to that described for block volume, provided the three parameters in the joint condition are independent random variables. The joint condition factor is $jC = jL \times jR/jA$

Each parameter varies within certain limits. The expression above can be written as

$\ln jC = \ln jL + \ln jR - \ln jA$ eq. (5-10)

Assuming that the joint condition parameters have a log-normal distribution, eq. (5-10) has the following mean ln-value:

$\mu_{\ln jC} = \mu_{\ln jL} + \mu_{\ln jR} - \mu_{\ln jA}$ eq. (5-11)

where $\mu_{\ln jL} \approx (\ln jL_{min} + \ln jL_{max})/2$ eq. (5-12)

(and similar for $\mu_{\ln jR}$ and $\mu_{\ln jA}$)

Applying ±1 standard deviations from this mean ln-value, $\mu_{\ln jC}$, the standard deviation is

$\sigma_{\ln jC} = \{(\sigma_{\ln jL})^2 + (\sigma_{\ln jR})^2 + (\sigma_{\ln jA})^2\}^{½}$ eq. (5-13)

where $\sigma_{\ln jL} \approx (\ln jL_{max} - \ln jL_{min})/2$ eq. (5-14)

(and similar for $\sigma_{\ln jR}$ and $\sigma_{\ln jA}$)

For a log-normal distribution of $\mu_{\ln jC}$ the joint condition will be

$jC_{low} \approx e^{(\mu_{\ln jC} - \sigma_{\ln jC})}$ eq. (5-15)

and

$jC_{high} \approx e^{(\mu_{\ln jC} + \sigma_{\ln jC})}$ eq. (5-16)

B. The <u>resulting</u> jC or JP for the rock mass when jC varies for each joint or joint set

Alt. 1. Where the joint sets have approximately the same spacings:
Use the average value for jC for all sets.

Alt. 2. Where the spacings are different for the joint sets:

a. Simply apply the (assumed) average jC for all the joint sets.

b. Use the joint set with the most unfavourable value for jC.
This method is applied in the Q system. Also ISRM (1980) suggests that *"when joint sets show different shear strength, the set which shows the smallest mean angle of friction should be adopted, unless specific circumstances warrant otherwise. A record of the angles of friction corresponding to other fracture sets may prove of interest."*

c. Sometimes one joint set is significantly more important than the others. In such cases the data for this set may be applied directly.

d. Carry out an assessment of jC or JP as shown for the following two main cases:

Case 1
For every joint set with its jC and spacing it is assumed that the effect of jC varies with the size (area) of the joint plane. As the area of joint planes in a volume depends on the spacing (see Fig. 5-7), it is assumed that jC depends on the second power of the spacing.

If the spacing and the joint condition factor for the joint sets are S1, S2, S3 and jC1, jC2, jC3 respectively, the resulting jC may be expressed as

$$jC = \Sigma\{(1/S_i)^2 \times jC_i\} / \Sigma(1/S_i)^2 \qquad \text{eq. (5-17)}$$

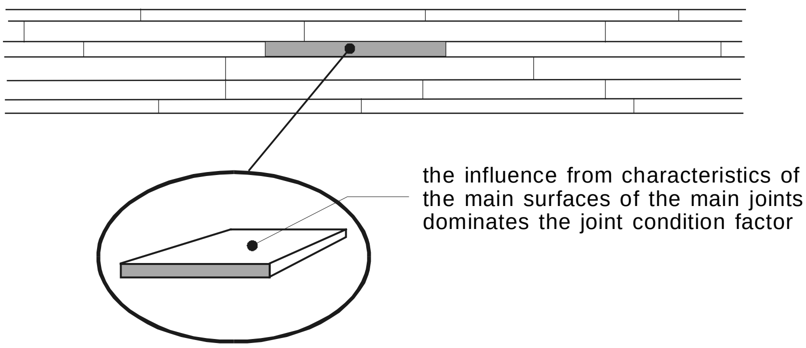

Fig. 5-7 The joint set with smallest spacing has the largest area in the block surface and hence the greatest impact on the jC.

or where joint frequencies are measured; for 2-D measurements

$$jC = \Sigma\{(Na_i)^2\, jC_i\} / \Sigma(Na_i)^2 \qquad \text{eq.(5-18)}$$

And for 1-D measurements

$$jC = \Sigma\{(Nl_i)^2\, jC_i\} / \Sigma(Nl_i)^2 \qquad \text{eq. (5-19)}$$

Here, Na will give more accurate values than Nl because it is adjusted for the length of the joints.

Example 5-5 Finding the average jC representative for all joint sets.
The observed data on joint spacings and joint conditions are given in Table 5-1.

TABLE 5-1 OBSERVATION DATA ON JOINT SPACING AND JOINT CONDITION

Joint set no.	Spacing	Average spacing Si	Joint condition factor	Average joint condition factor jC	$1/Si^2$	$(1/Si^2)$ jC
1	0.5 - 1.5	1	1 - 2	1.5	1	1.5
2	1 - 2	1.5	0.25 - 0.5	0.35	0.44	0.15
3	2 - 3	2.5	2 - 3	2.5	0.16	0.4

$$\Sigma 1/Si^2 = 1.6 \qquad \Sigma(1/Si^2)\ jC = 2.05$$

In this case eq. (5-17) may be used. From the values in Table 5-1 the resulting joint condition factor for all joint sets is then

$$jC = \Sigma(1/Si)^2\, jCi\ /\ \Sigma(1/Si)^2 = 2.05/1.6 = 1.3$$

Example 5-6: jC found from various joints and joint conditions in an outcrop.
Though one joint set may be seen (vertical), the jointing pattern in Fig. 5-8 may be characterized as irregular.

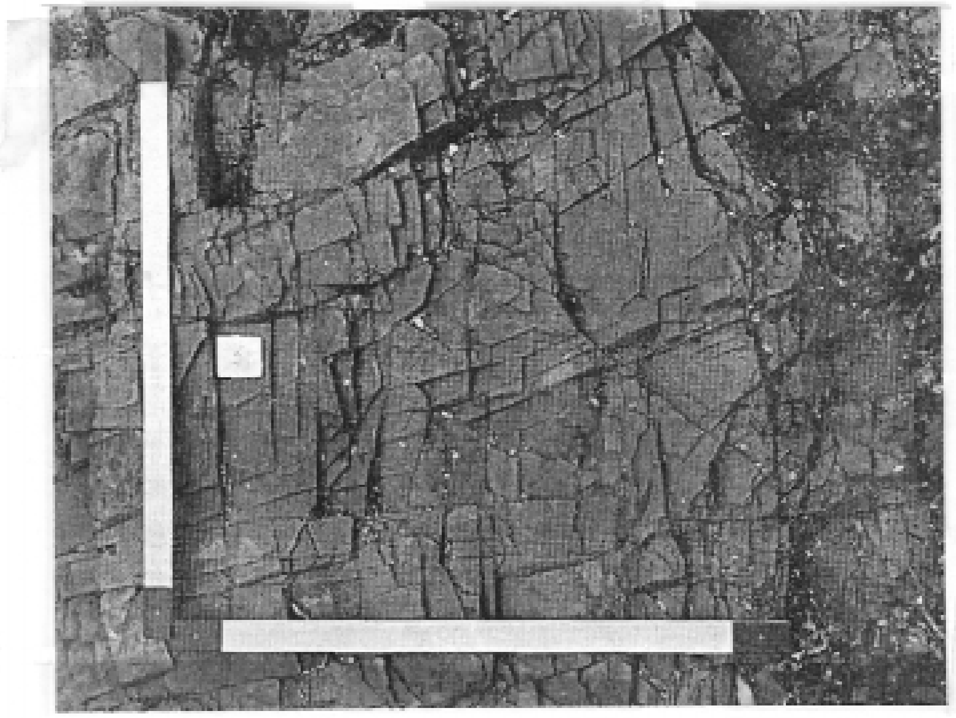

Fig. 5-8 Jointed outcrop of Carboniferous sandstone (from Hudson and Priest 1979). The rulers shown are 1 m long

It is assumed that all joints are fresh, slightly rough and planar. This means that jR = 1.5 and jA = 1. Most joints are continuous, i.e. terminate against each other. Because they have different size, jC will vary as given in the table on next page for a measurement area of 1 m^2.

As many of the joints are smaller than the length of the dimension of the observation area (1 m^2), their quantity has been adjusted in Table 5-2 using eq. (5-18).

TABLE 5-2 'OBSERVATIONS' MADE ON FIG. 5-9. THE JOINT CONDITION FACTORS HAVE BEEN ASSUMED.

'Observed' joints (na)	Approx. joint length	Average joint length (Lj)	Adjusted number of joints $Na^* = na \cdot Lj/\sqrt{A}$	Assumed joint condition factor(jC)	$(Na^*)^2$	$jC(Na^*)^2$
1	> 1.5 m	>1.5 m	1	1.5	1	1.5
5	0.5 - 1 m	1 m	5	2.5	25	62.5
20	0.2 - 0.5 m	0.3 m	6	4	36	144
40	< 0.2 m	0.15 m	6	6	36	216
			$\Sigma Na^* = 18$		$\Sigma(Na^*)^2 = 98$	$\Sigma jC(Na^*)^2 = 424$

The total amount of adjusted joints is Na* = 18 joints/m. Using ka = 1.5 in eq. (A3-32b) and $Jv = Na \times ka = 27$ joints/m^3, the estimated block volume is

$$Vb \approx \beta \times Jv^{-3} = 50 \times 27^{-3} = 2.5 \text{ dm}^3$$

(The blocks seem to mainly to be flat; therefore $\beta = 50$ is assumed.)

The resulting joint condition factor may be found from eq. (A3-32a) using the adjusted joint densities :

$$jC = \Sigma(Na_i^*)^2\, jC_i \,/\, \Sigma(Na_i^*)^2 = 4.3$$

The jointing parameter is $JP = 0.2\,\sqrt{jC}\; Vb^D = 0.08$ $\quad (D = 0.37\, jC^{-0.2} = 0.276)$

Case 2

Consider that the rock mass is composed of (flat) blocks formed by only of one of the joint sets having its jointing parameter JP1. JP1 can be regarded as the strength of the material in the blocks formed by joint set 2 for which the JP2 can be found. The same principle can be applied for the remaining joint sets as is described below:

⇒ Find the jointing parameter JP1 related to joint set 1 (with spacing S1 and average length L1) from its jC and volume $Vb_1 = S1 \times L1^2$.

⇒ The same procedure is carried out also for the other joint sets and block volumes.

⇒ The resulting jointing parameter JP is the product of the jointing parameters found for each set: $JP = JP1 \times JP2 \times JP3$

<u>Example 5-7 JP found for various joint spacings and joint conditions.</u>

In Fig. 5-9 the jointing consists mainly of joints and partings along the foliation of a mica schist. There are mainly two types of these joints:

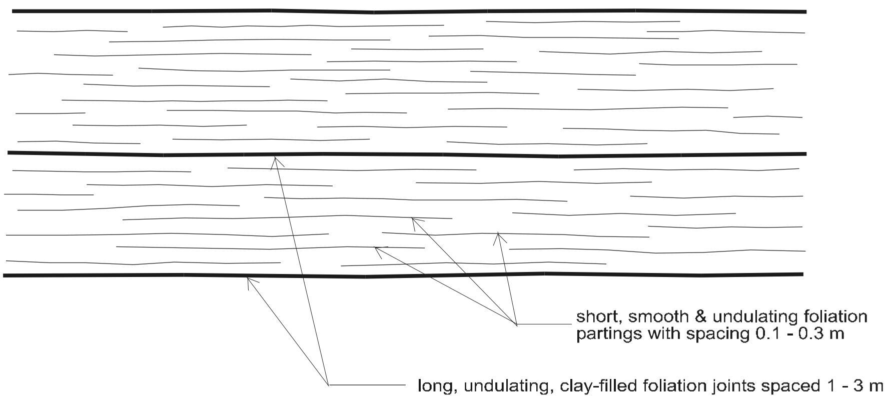

Fig. 5-9 Large foliation joints and small foliation partings

⇒ Foliation partings (set 1a). These are small (L_{1a} = 0.1 - 1.5 m long) and discontinuous joints, with spacing S_{1a} = 0.1 - 0.3 m (average 0.2 m) with:
- joint smoothness factor, js = 1.5 (slightly rough
- joint waviness factor, jw = 2 (strongly undulating)
- joint alteration factor, jA = 1 (fresh joint walls)
- joint length and continuity factor, jL = 4.

The joint condition factor for this set is $jC_{1a} = js \times jw \times jL/jA = 12$

⇒ Foliation joints (set 1b); these are pervasive joints (L_{1b} > 5 m) with spacing S_{1b} = 2 - 3 m (average 2.5 m) having:
- joint smoothness factor, js = 1 (smooth)
- joint waviness factor, jw = 2 (strongly undulating)
- joint alteration factor, jA = 2 (slightly altered rock in the joint wall; one grade more than the rock)
- joint length and continuity factor, jL = 0.7.

The joint condition factor for this set is $jC_{1b} = js \times jw \times jL/jA = 0.7$.

It is difficult to apply the method outlined in case 1 as the joints do not delineate defined blocks. A possible way to characterize this type of ground is to consider that it is composed of two sorts of blocks formed by the two types of joints. The jointing parameter is found as the product of the jointing parameter for each of the two types of blocks as is shown in the following:
- For joint set 1a - the foliation partings - the average block volume is determined by the spacing and length of the joints
  $Vb_{1a} = S_{1a} \times L_{1a}^2 = 0.13\ m^3$

With jC_{1a} = 12 the jointing parameter for this set is JP_{1a} = 0.44.
- Similarly, for joint set 1b the block volume[1] $Vb_{1a} = S_{1b} \times 4^2 = 40\ m^3$

and the jointing parameter JP_{1b} = 0.72 based on jC_{1b} = 0.7.

The resulting jointing parameter for the rock mass is $JP = JP_{1a} \times JP_{1b} = 0.32$.
(If the method shown in case 1 had been applied, the jointing parameter would be JP = 0.43, because the effect of the foliation joints (set 1b) will not be fully included.)

Also for *bedding joints* with variation in spacings and joint characteristics the same method as shown for foliation joints may be applied. Where both bedding joints and cross joints occur this method may be useful.

5.3.3 Singularities and weakness zones

Singularities, i.e. seams or filled joints and small weakness zones, should be mapped and considered separately where they occur as single features, see Fig. 5-9. If they occur in a kind of pattern spaced less than about 5 m, they may sometimes be included in the detailed jointing measurement.

The type and thickness of the filling is generally a main characteristic of singularities.

[1] Here the length L = 4 m has been applied as outlined in Section 3.2.3 in Appendix 3

TABLE 5-3 ASSUMED APPROXIMATE RANGE OF JP AND/OR RMi VALUES FOR THE MAIN TYPES OF WEAKNESS ZONES. THE VALUES DO NOT INCLUDE THE EFFECT OF SWELLING.

TYPE OF WEAKNESS ZONE	Jointing parameter **JP**	Rock mass index **RMi**
Zones of weak materials		
• *Layers of soft or weak minerals*, such as:		
- clay materials [1]..	**	0.01 - 0.05
- mica, talc, or chlorite layers and lenses [2]...........	**	0.05 - 5
- coal seams..	0.04 - 0.1	0.6 - 3
• *Zones of weak rocks or brecciated rocks,* such as:		
- some dolerite dykes [3].......................................	0.005 - 0.05	*
- some pegmatites, often heavily jointed..............	0.005 - 0.05	*
- some brecciated zones and layers which have not been "healed".....................................	0.005 - 0.05	*
• *Weathered surface or near surface deposits*..........	0.005 - 0.05	0.05 - 3
Faults and fault zones		
• *Tension fault zones*		
- feather joints and filled zones, such as:		
> clay-filled zones [1]..	**	0.01 - 0.05
> calcite-filled zones [2]....................................	**	0.5 - 5
• *Shear fault zones*		
- coarse-fragmented, crushed zones......................	0.01 - 0.1	*
- small-fragmented, crushed zones.......................	0.001 - 0.02	*
- sand-rich crushed zones....................................	0.0005-0.005	0.0005 - 0.005
- clay-rich, crushed zones, such as:		
> simple, clay-rich zones................................	0.001 - 0.015	*
> complex, clay-rich zones.............................	0.0005 - 0.01	*
> unilateral, clay-rich zones............................	0.002 - 0.02	*
- foliation shears [4]		
• *Altered faults*		
- altered, clay-rich zones......................................	0.005 - 0.05	0.006 - 3.5
- altered, leached (crushed) zones........................	0.002 - 0.02	0.003 - 2
- altered veins/dykes...	0.01 - 0.1	0.0003 - 0.3
Recrystallized and cemented/welded zones	It is difficult to assume general numerical values for these types of zones	

* Varies with the type of rock
** Massive rock is assumed(a scale factor of 0.5 has been applied for the compressive strength of rock)
1) The clay is assumed very soft - firm
2) No strength data found. The values given are assumed
3) Assumed that the joints are without clay
4) When occurring alone the foliation shear is probably a singularity; else probably a simple or complex clay-rich zone

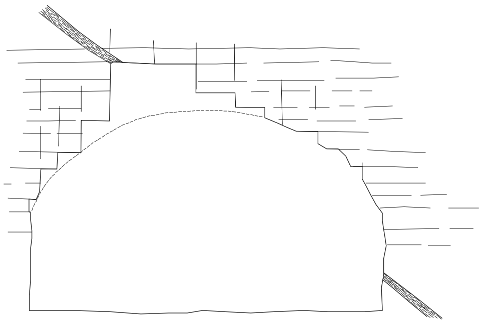

Fig. 5-9 Example of the influence from a singularity on stability (from Cecil, 1970)

Large and moderate *weakness zones* should, as previously mentioned, be characterized as one type of rock mass having its own RMi value. In Appendix 3 the various features of weakness zones and faults are further described. Not only the central part is of importance in the behaviour of the zone, but also the transitional part and the composition of the surrounding rock masses should be identified and given numerical values based on observation of block volume, joint condition and rock material.

In many weakness zones most of the discontinuities are filled. Thus, the properties of the filling material may dominate the behaviour of the zone.
Approximate RMi or JP values for weakness zones are shown in Table 5-3.

5.3.4 Summary of the possibilities and methods to determine the block volume or the jointing parameter where the jointing characteristics vary

A summary of the possibilities for characterizing different joint condition parameters in various types of rock masses is shown in Table 5-4.

TABLE 5-4 VARIOUS TYPES OF JOINTING AND JOINT CONDITION INDICATING THEIR SUITABILITY TO BE CHARACTERIZED IN THE RMi

TYPE OF JOINTING - consisting of	JOINT CONDITION FACTOR (jC)			
	SAME jC FOR ALL JOINTS	DIFFERENT jC		
		between the sets only	between the joints in the sets	between the single joints
Regular jointing				
- mainly of joint sets	x	x	(x)	-
- columnar jointing	x	(x)	?	-
Mixed jointing				
- joint sets + random joints	x	x	:	:
Irregular jointing				
- mainly random or irregular joints	x	-	-	:
Foliation jointing				
- long joints + short partings	x	x	(x)	?
Bedding jointing				
- long joints + short cross joints	x	x	(x)	-

x Well suited for RMi characterization; i.e. jC can be used directly from field registrations
(x) Can be characterized satisfactorily; i.e. jC is assessed according to the method described
: Can be roughly characterized; i.e. jC may be estimated provided simplifications are made
? This type of jointing occurs seldom
\- This type of jointing does not occur

The value of jC, which is connected to the different types of joints or joint sets, forms a vital part of geo-data acquisition. It is, therefore, important that the observations are carried out by experienced persons with knowledge of the geological conditions, and that the selection of parameters is tied to well defined classes.
A verbal description of the joint condition is of great help here as additional information. This is further explained in Appendix 3 in connection with 'translation' of descriptions into numerical values.

Table 5-5 shows a summary of the methods to determine the block volume and joint condition factor where the joint characteristics and joint spacings vary.

TABLE 5-5 SOME OF THE METHODS AND EXAMPLES TO DETERMINE THE VALUE OF INPUT PARAMETERS TO RMi ON JOINTING

Variations in the block size (Vb)

A. The block volume found from joint spacing or joint density measurements

Example 5-1 shows how the block volume can be determined from joint spacings.

Example 5-2 outlines how the block volume can be found from 1) the quantity of joints, and 2) from joint spacings.

B. Probability calculations to determine the variation in block volume

Example 5-3 shows a method to determine the variation range of block volume from joint spacings.

Variations in the joint condition factor (jC)

A. The jC determined for <u>*one joint or joint set*</u> *where its parameters vary*

Alt.1. The variation range of the jC is found from combination of the parameter values so that the minimum value and the maximum value is found for the actual joint or joint set.

Example 5-4: The jC determined from variations in joint characteristics.

Alt. 2. The variation range of jC is found using a *probability calculation* similar to example 5-3.

B. The <u>*resulting*</u> *jC or JP for the rock mass when jC varies for each joint or joint set*

Alt. 1. Where the joint sets have approximately the same spacings: Use the average value of jC for all sets.

Alt. 2. Where the spacings are different for the joint sets:

a. Simply apply the (assumed) average jC for all the joint sets.
b. Use the joint set with the most unfavourable value for jC.
c. Sometimes one joint set is significantly more important than the others. In such cases the data for this set may be applied directly.
d. Carry out an assessment of jC as described in the following two cases:

Case 1 For every joint set with its jC and spacing it is assumed that the effect of jC varies with the size (area) of the joint plane.

Example 5-5 shows how the average jC representative for all joint sets can be found.

Example 5-6: The jC found from various joints and joint conditions in an outcrop.

Case 2 Consider that the rock mass is composed of (flat) blocks formed by only one of the joint sets with its own jointing parameter (JP). The resulting JP for the rock mass is the product of the jointing parameters found in the same way for each of the joint sets: $JP = JP1 \times JP2 \times JP3 \times ...$

Example 5-7: Determination of JP for various joint spacings and joint characteristics.