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Application of the volumetric joint count as a measure of rock mass jointing

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ABSTRACT

The volumetric joint count (Jv) is a useful measure of the degree of jointing given as number of joints in a unit volume of rock masses. It takes into account all the joints in a three-dimensional rock mass and is easily calculated from standard joint descriptions.

The paper describes the procedure how the (Jv) is calculated both from surface observations and from drill cores.

A classification of the (Jv) is shown and how it con be converted to RQD-values. The (Jv) can also be used to calculate the interblock size in jointed rock masses. A general diagram has been worked out to identify geo-materials (soils and rock masses).

1. Introduction

A standard description of a joint should take into account the following joint characteristics: (Ref. 8)

- joint orientation (strike and dip, or dip direction and dip)
- joint size (length, aperature/thickness)
- joint nature (roughness, character of joint walls and joint fillings)
- joint course (planarity, persistence)
- joint spacing (or number of joints in an area)

The influence of these parameters upon jointing is indicated on Fig. 1, which also shows the importance of the degree of jointing given as block size.

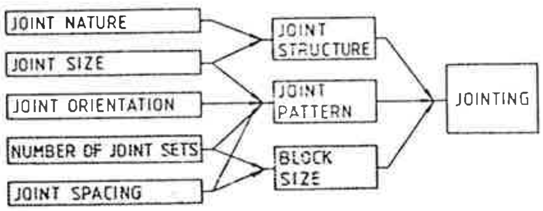

Fig. 1 The influence of the main joint parameters upon jointing

2. The volumetric joint count (Jv)

The volumetric joint count is a simple measure for the degree of jointing or the inter block size and it can therefore be used as an input in the description and classification of rock mass jointing. (Ref. 1 and 4).

One of the difficulties in working out a system for characterizing the degree of jointing, is its three-dimensional structure. The most commonly used system, namely joint spacing or joint frequency is a rouch, inaccurate measure based upon spacings of the dominating joint set. No rules exist, however, how to correct the measure where several joint sets are present.

Also the RQD-measure (Rock Quality Designation, Ref.5) give varying results for boreholes made perpendicular or parallell to the dominating joint set.

Fig. 2 shows a block diagram with three joint sets having spacings S_1, S_2 and S_3. The joint frequency (number of joints per unit length) for each set will be $1/S_1$, $1/S_2$ and $1/S_3$ respectively.

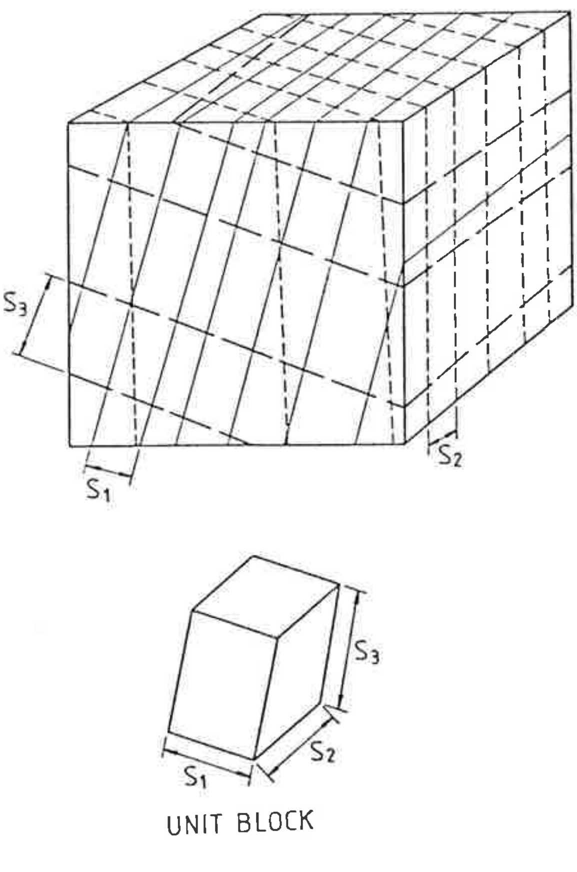

Fig. 2 Block diagram with 3 joint sets

The number of joints intersecting one unit of rock mass, is defined as the volumetric count

$$(Jv) = \frac{1}{S_1} + \frac{1}{S_1} + \frac{1}{S_1} \qquad \text{(eq.1)}$$

This definition of the degree of jointing (Jv) takes into account in an unambiguous way all the occuring joints in the rock mass.

3. Calculation of (Jv) from surface observations

From common surface joint observations where the jointing is made up of joint sets, the volumetric joint count can easily be calculated since it is based upon joint spacings as shown above (eq.1). The individual spacing for a joint set will normally vary within certain limits. By calculating the (Jv) from the closer and wider spacing for each set, the maximum and minimum degree of jointing can be found. This is shown on Example 1.

In the cases when mostly random or irregular joints occur the (Jv) can be found by counting all the observed joint within a known surface area. By assuming that the jointing has a uniform idstribution, the (Jv) can be found by calculating the number of joints per unit area N_1 and multiplying this with a factor K.

$$(Jv) = K_1 \times N_1 \qquad \text{(eq.2)}$$

The factor K_1 will vary with the distribution of the joints. With an equal distribution in all three directions K_1 will be 1.15 - 1.5 depending upon the orientation of the surface with respect to the joint planes. For unequal distributions the K will have a greater range of variations. Under most common conditions, however, it has been found that K_1 = 1.25 - 1.35. A factor of K_1 = 1.3 is recommended for estimation. In this way the two-dimensional measurements are converted to three-dimensional, refer to Example 2.

4. Calulation of (Jv) from drillcores.

As mentioned above the volumetric joint count (Jv) is originally based upon mapping either in a tunnel/cavern or on the earth surface. In cases where no surface observations are available the (Jv) can be found using core observations either as RQD or as the joint frequency.

For the joint frequency N_2 (number of joints per meter borehole) the transition from one-dimensional (in a borehole) to three-dimensional is:

$$(Jv) = K_2 \times N_2 \qquad \text{(eq. 3)}$$

The multiplying factor K_2 = 1.65 - 3.0 for equally distributed joints. The variation is caused by orientations of the borehole with respect to the joint sets. An average factor K_2 = 2.0 has been found to cover the most common jointing distribution. If the borehole is orientated parallel or perpendicular to a dominating joint set, the factor K_2 will have a greater range than indicated above and must be adjusted up or down respectively for the actual situation, Refer to Example 3.

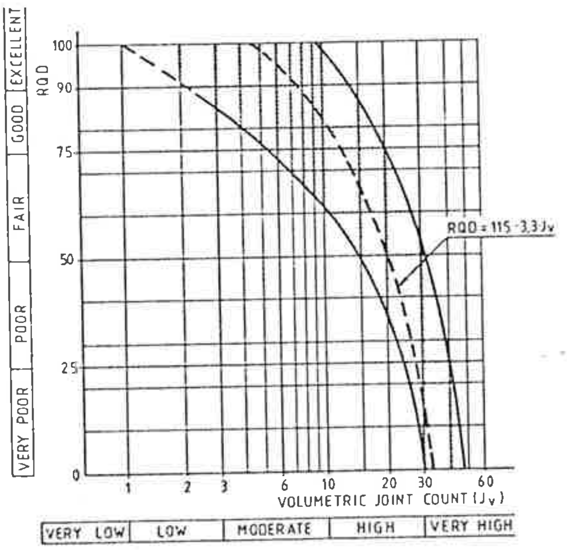

Fig. 3 Connection between RQD and (Jv)

Between the RQD and the (Jv) there is a theoretical correlation:

$$RQD = 115 - 3.3 \times (Jv) \qquad \text{(eq. 4 a)}$$

(RQD=100 for Jv<4.5)

or

$$(Jv) = 33 - RQD/3.3 \qquad \text{(eq. 4 b)}$$

(RQD= 0 for Jv>35)

as shown in Fig. 3.

The limitations in the RQD assessment, (where for example the RQD=100 if the core pieces are 11 cm long and 0 if they are 9 cm) causes often a rough correlation between RQD and (Jv).

5. Calculation of block size from (Jv)

Because both the (Jv) and the block size of the rock mass vary according to the degree of jointing, a linear correlation exists between them. The (Jv) is, however, dependent upon the jointing pattern which means that the block size must be adjusted for both the angels between the different joint sets and for the block shape. In Fig. 4 the block size for the three main different block shapes, namely the cubic, the elongated and the platy type is given. The diagram is based on joints intersecting each other at right angles. At other angles the volume must be a adjusted by the formula

$$V = V_o \times \frac{1}{\sin\alpha} \times \frac{1}{\sin\beta} \times \frac{1}{\sin\gamma}$$

where α, β and γ are the angels between the joint sets, see Example 1.

Since the angles between joint sets, are seldom less than 50^g, the block size will be:

$$V < 1.8\ Vo$$

For most situations where average the block size is sufficiant

$$V = 1.25 \times V_o \qquad \text{(eq. 5)}$$

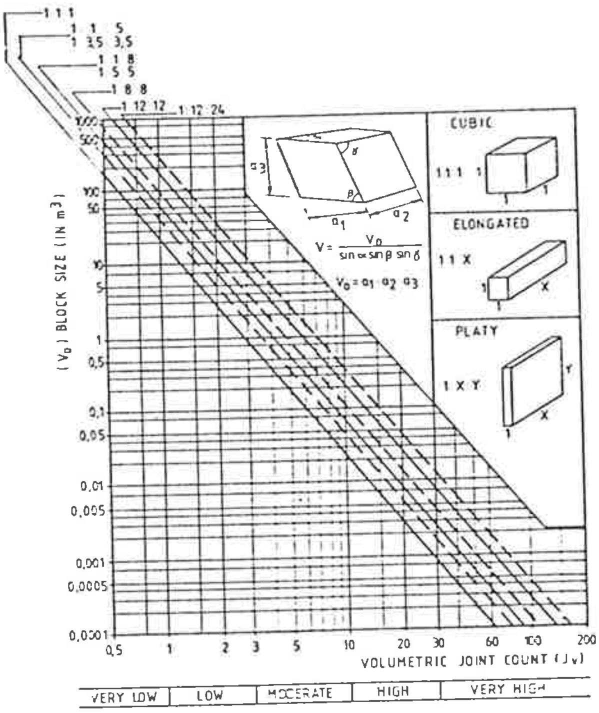

Fig. 4 Inter block size as a function of (Jv) and joint pattern

Equation 5 is used in Fig. 5 to show the most common correlation between the volumetric joint count (Jv) and the block size. Here is also the relation to the grain size of soil materials indicated. Since it is very seldom that the joint spacing in a rock mass is less than about 10 mm - which gives a (Jv) of about 300 - this is regarded as the limit for the degree of jointing. Similar it is utmost seldom to have larger blocks in loose materials than about 100 m3 which here is regarded as a limit for soil materials.

Between about 10^3 mm3 and 10^2 m3 the materials can therefore be either soil or rock masses. The different structure of the two types of materials in, Fig. 6, causes the great differences in their mechanical behaviour.

Based on the connection between soil and rock masses in Fig. 5 a suggested diagram covering all geo materials is shown on Fig. 7. In addition to block or particle size the compressive strength is used as a material parameter. As shown the rock masses cover a little less than half the diagram while the soil materials cover about three quarters of it.

Example 1 and 2 is plottet on the diagram.

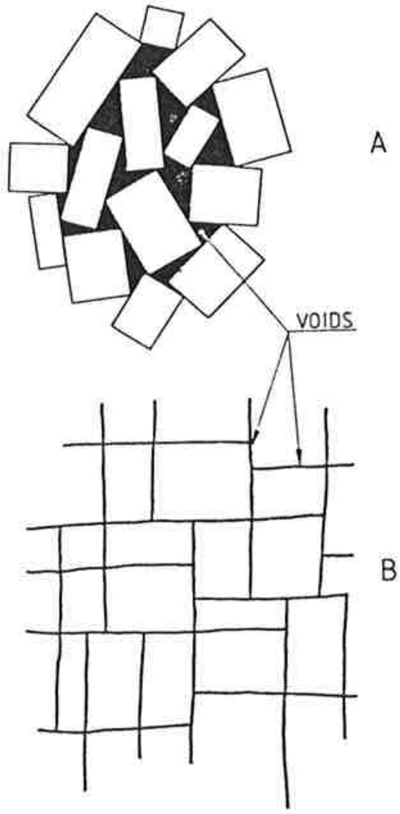

Fig. 6 Difference in porosity in a soil (A) and a rock mass

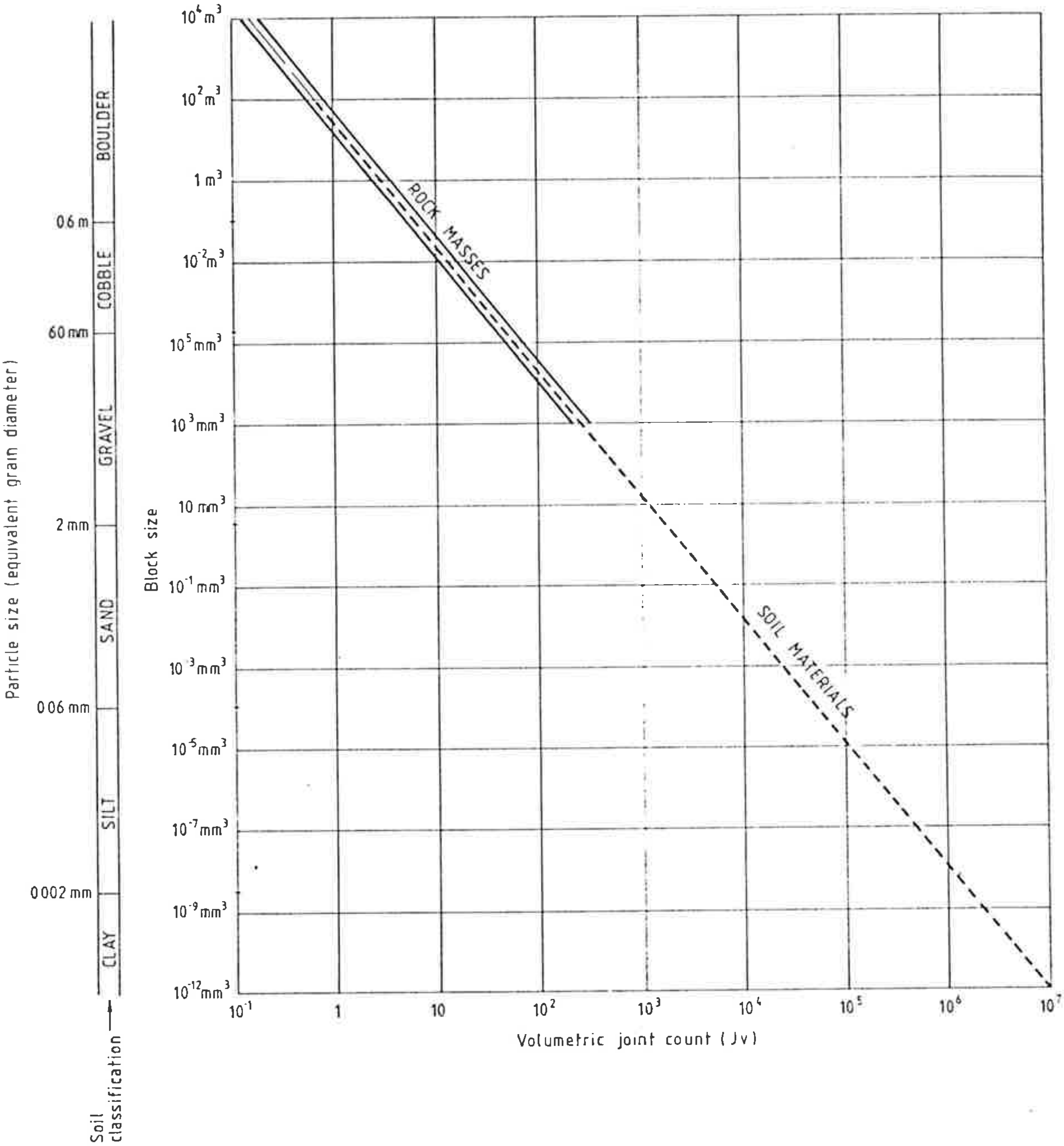

Fig. 5 Correlation between (Jv), block size in rock masses, and particle size i soils

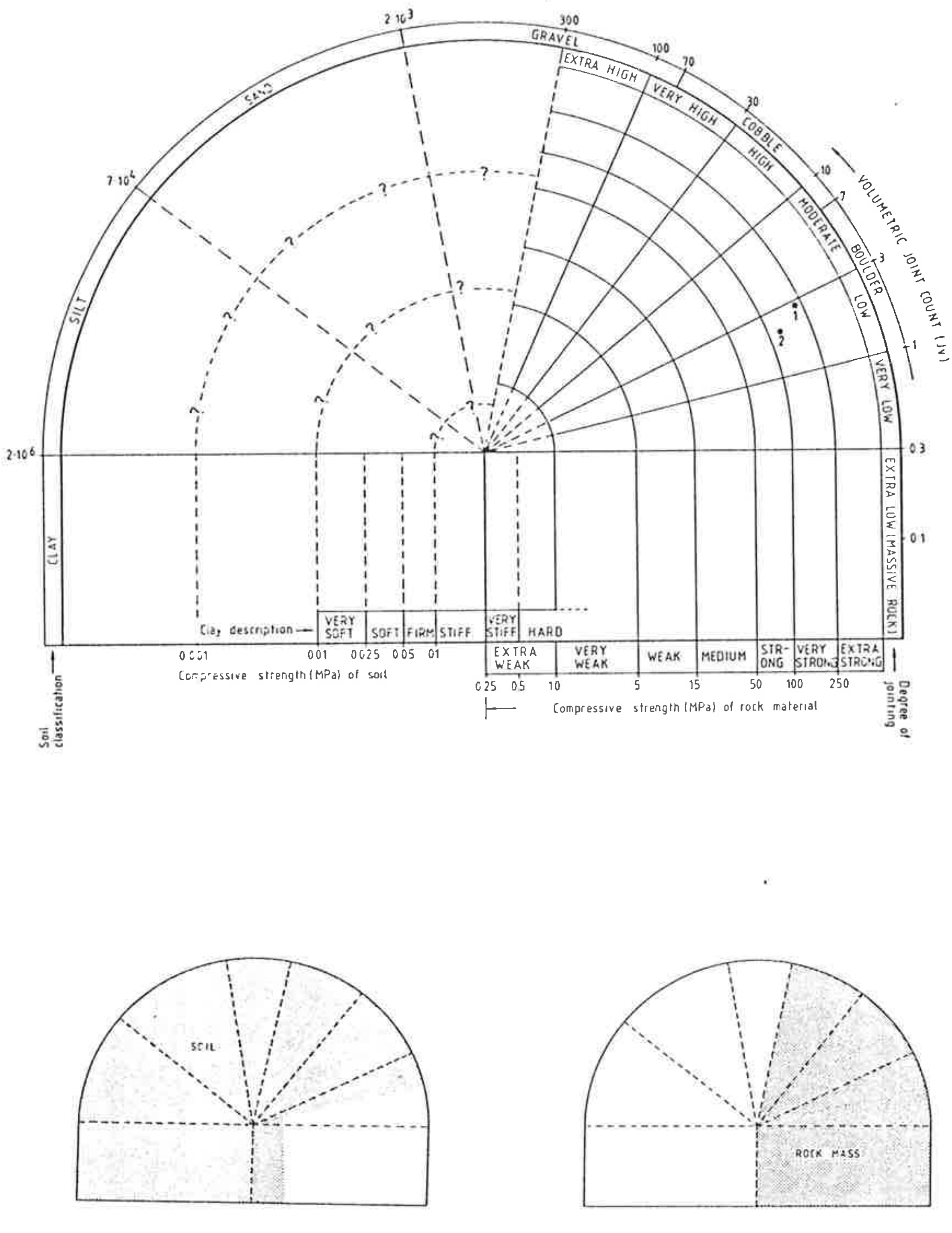

Fig. 7 Identification of soil and rock masses from particle/block size and compressive strength

6. Examples

Example 1

In a granite with compressive strength σ_c = 200 MPa three joint sets occur and a few random joints. As shown on Fig. 8 a mean (Jv) = 2.9 is found, which can be classified as low to moderate.

From the mean joint spacings the shape of the block is 1:2:2 (elongated) which from Fig. 4 gives a block size Vo = 1.5 m3.

	ORIENTATION		SPACING	NO OF JOINTS	JOINT SET FREQUENCY	(Jv) VOLUMETRIC JOINT COUNT
	STRIKE	DIP				
	^{g}	^{g}	m	no	no / m	no / m^3
1.	30	100	0.3 - 2		3 - 0.5	1.5 - 4.9
2	150	100	1 - 3		1 - 0.3	
3	90	10 W	1.5 - 2		0.7 - 0.5	
	80	30 NW	-	2 (random)	0.2 *)	

*) For random joints a joint frequency of 0.2 is used for the calculations.

Fig. 8 Joint observations, example 1

The angles between the three joint sets can be found using Wulff's stereographical net. As shown on Fig. 9 they are 85^g, 90^g which gives V ~ Vo = 1,5 m3

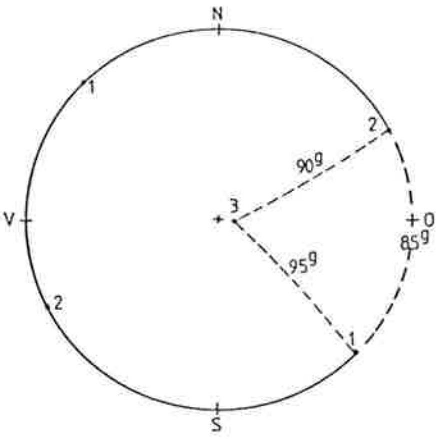

Fig. 9 The poles of the three joint sets in example 1 plotted in Wulff's stereographic net

Example 2

A hornfels (σ_c = 150 MPa) is mostly cut by irregular, single/random joints , which means that it is difficult to find the joint spacings. The number of joints in a given area has been measured at 3 observation points.

It is here assumed that the joints are about equally distributed in all three dimensions. A factor K_1 = 1.3 is therefore used to calculate the (Jv) as given in Fig. 10.

By further assuming that the blocks mostly have a cubic shape (and right angles) the block size is V = 1.3-2.0 m3.

OBSERVATION POINT	ORIENTATION			SPACING	NO OF JOINTS	N_1 JOINT FREQUENCY	(Jv) VOLUMETRIC JOINT COUNT
POINT	AREA	STRIKE	DIP				
NO	m^2	^{g}	^{g}	m	no	no / m^2	no / m^3
1	6				10	1.7	2.2
2	8				15	1.9	2.5 } 2.4
3	4				9	2	2.6

Fig. 10 Joint observation, example 2

Example 3

The joint frequency has been measured from dril core logging.

The (Jv) has been calculated using a factor k=2.0. It is assumed an even distribution of the joints in the rock mass and cubic blocks.

OBSERVATIONS			CALCULATIONS		
DEPTH (m)		JOINT FREQUENCY	(Jv)	RQD	BLOCK SIZE (m3)
a	0-10	15	30	16	0.001
b	10-20	12	24	36	0.02
c	20-30	8	16	62	0.06

7. References

(1) Barton, N., Lien, R., Lunde, J. (1974)
Engineering classification of rock masses for the design of tunnel support.
Rock Mech. 6, 1974

(2) Bergman, S.G.A. (1975)
Funksjonell bergklassifisering. (Functional classification of rock masses) (in Swedish).
IVA meddelande nr. 142 pp. 115-128.

(3) Beyer, F. (1982)
Zum mittleren Kluftabstand aus der Anzahl von Kluftanschnittlinien (in German).
Rock Mechanics 14 pp. 235-251

(4) Bieniawski, Z.T. (1973)
Engineering classification of jointed rock masses. The Civil Engineers in South Africa, July 1974.

(5) Deere, D.U. Monsees, J.E., Peck, R.B., Schmidt, B. (1969)
Design of tunnel liners and support systems. Office of High Speed Ground Transportation, U.S. Department of Transportation, Washinton.

(6) Franklin, J. A., Broch, E., Walton, G. (1971)
Logging the mechanical character of rock. Trans. Instn Min. Metall. (Sect. A: Min. industri) 80, 1971.

(7) Hudson, J.A., Priest, S.D., (1979)
Discontinuties and rock mass geometry.
Int. J. Rock Mech. Min. Sci., 1979 No. 6.

(8) Piteau, D.R. (1973)
Characterizing and extrapolating rock joints properties in engineering practice.
Rock Mechanics, Suppl. 2, 1973.

(9) International Society for Rock Mechanics, Commission of Standardization of Laboratory and Field Tests (Bartory, N., coord.) (1978). Suggested methods for the quantitative description of discontinuities in rock masses.
Int. J. Rock Mech. Min., Sci Vol 15 pp 319-368.

(10) Palmstrøm, A., (1982)
The volumetric joint count, a simple and useful measure of the degree of jointing.
4th Intn. Congr. IAEG, New Dehli.