THE VOLUMETRIC JOINT COUNT AS A MEASURE OF ROCK MASS JOINTING

F³ CONF. IN JERUSALEM 1986

Arild Palmstrøm, engineering geologist
Ingeniør A. B. Berdal A/S
Kjørbovegen 25, 1300 Sandvika, Norway

ABSTRACT

The volumetric joint count (Jv) is a useful measure of the degree of jointing for practical purposes. It is given as the number of joints in a unit volume of rock masses and takes into account all the joints in a tree-dimensional rock mass. Standard joint descriptions can be used as input in estimating the (Jv).

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

Classification of the (Jv) is shown and how it can be converted to and from 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

Joints are discontinuities usually present in almost all rock masses. They form defects in the rocks having strength, permeability and deformation characteristics highly different from those of the intact rock. Depending upon origin and nature of the joints, their behaviour and structure can vary a lot. For the single joint itself, both its orientation, size and mechanical properties can have a great range of variations, Ref. (3), (7).

In addition the jointing pattern made up of the different joint sets form a complexity that makes an accurate description and classification of the various jointed rock masses difficult.

The volumetric joint count is a simple measure for the degree of jointing which is found accurate enough for most practical geo-engineering purposes. It can be used both as a a measure of the inter block size and as an input in Bieniawski's Geomechanical and Barton's Q-factor classification systems for estimating rock support.

2. THE VOLUMETRIC JOINT COUNT (Jv)

A measure for rock mass jointing should mainly be based on normal field description of joints. A recommended standard description by D. R. Piteau (Ref. 8) should take into account all the following joint characteristics:

- 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)

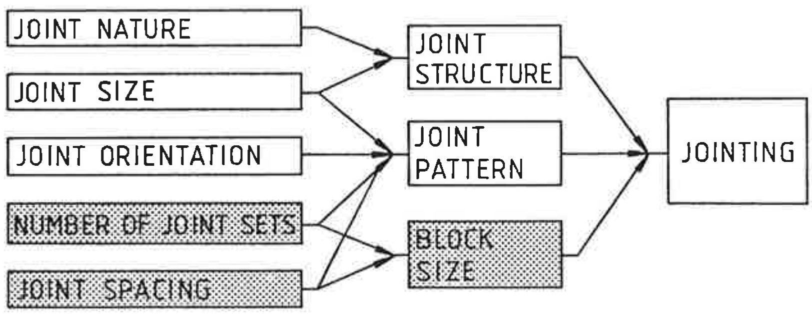

Fig. 1 The influence of the main joint parameters upon jointing

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

One of the difficulties in working out a system for characterizing the degree of jointing, is its three- dimensional structure. The most commonly used systems, namely the joint spacing and the joint frequency are rough, inaccurate measures based upon spacings of the most 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) gives quite different results made whether the borehole is perpendicular or parallell to the dominating joint set, especially whether the core lengths are shorter or longer than 10 cm.

For rock masses intersected by joint sets the (Jv) is defined as the number of joints intersecting a rock mass. It is therefore the sum of the joint frequencies for each of the sets. This is shown in Fig. 2 which 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, and hence the volumetric joint count will be:

$$(Jv) = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} \qquad \text{(eq.1)}$$

Thus the (Jv) by definition takes into account all the joint sets in a rock mass and not only the dominating set.

In cases where the jointing is not entirely made up of joint sets rough correction factors accurate enough for most practical descriptions are given in the chapter below.

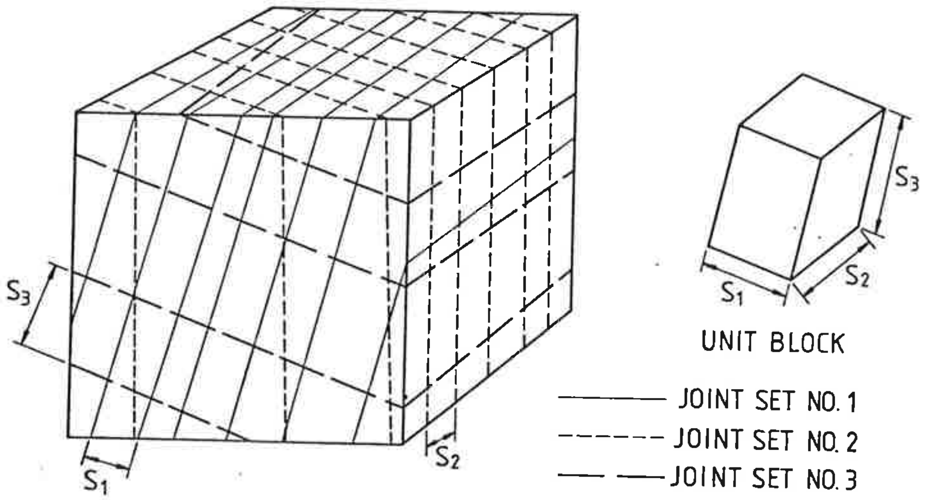

Fig. 2 Block diagram with 3 joint sets

3. CALCULATION OF (Jv) FROM SURFACE OBSERVATIONS

Even with equal distribution of joints a rough estimate shows that the numbers of joints intersecting a surface plane can vary about $\pm$ 25% at diffe-rent angles of the plane with respect to the joints. When more frequent joints occur along one or two directions, the number of joints in a surface plane can vary even more. This should be kept in mind when carrying out joint mapping either from surface observations or from drillcores.

From common surface observations where the jointing is mainly 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, however, normally vary within certain limits. By calculating the (Jv) from the closer and wider spacing for each set, the apparent maximum and minimum degree of jointing can be found. This is shown in Example 1. .

In the cases when mostly random or irregular joints occur the (Jv) can be found by counting all observed joints to be within a known surface area. By assuming that the jointing has a uniform distribution, the (Jv) can be estimated from the number of joints per unit area N_1 and multiplied by a factor K_1.

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

The factor K_1 will vary with the distribution of the joints. With an equal distribution in all three directions K_1 will mostly be 1.15 - 1.5 depending upon the orientation of the surface with respect to the joint planes. For unequal distributions the K_1 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 rough estimation. In this way the two-dimensional measurements are converted to three-dimensional, refer to Example 2.

If the angle (δ) between each of the joints and a surface plane is measured a more accurate (Jv) can be found using the formula

$$(Jv) = \sum \frac{1}{\sin\delta} \qquad \text{(eq.3)}$$

Small values of (δ) will highly influence the (Jv) value and accurate angle measurements in such cases are therefore recommended.

4. CALCULATION 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 also be estimated from core observations given either as RQD or as joint frequency.

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

$$(Jv) = K_2 \times N_2 \qquad \text{(eq. 4)}$$

The multiplying factor K_2 = approx. 1.65 - 3.0 for equally distributed joints. The variation is caused by different orientations of the borehole with respect to the joints. An average factor K_2 = 1,8-2,0 has been found to cover the most common jointing distribution. Refer to Example 3. 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 should if possible be adjusted up or down respectively for the actual situation.

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

RQD=115-3.3 x (Jv) (eq. 5 a)

(RQD=100 for Jv<4.5)

or

(Jv)=33-RQD/3.3 (eq. 5 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). By measuring the angles between the individual joints and the core, the more accurate (Jv) can be found using eq. 3 as described for surface observations, see Example 3.

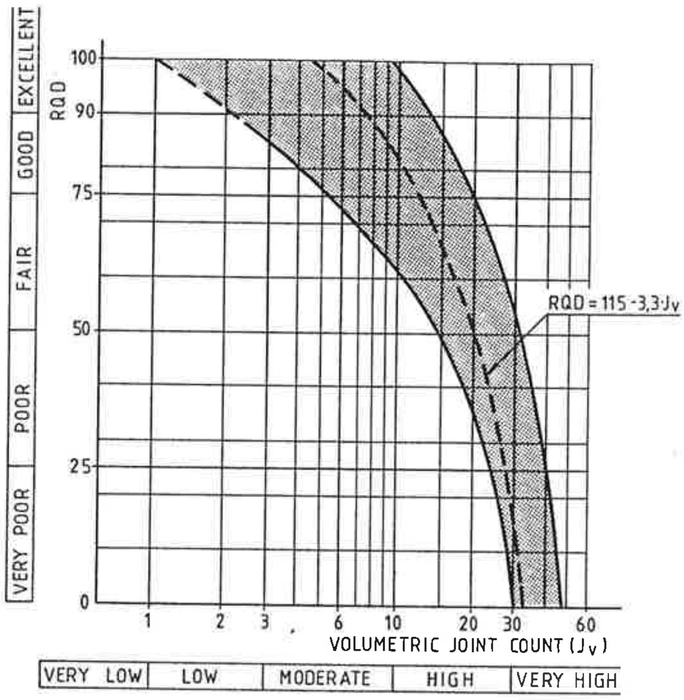

Fig. 3 Connection between RQD and (Jv)

5. CALCULATION OF BLOCK SIZE FROM (Jv)

Because both the (Jv) and the block sizes in a 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 angles between the different joint sets and for the different block shapes. 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

$$V = V_o \times \frac{1}{\sin\alpha} \times \frac{1}{\sin\beta} \times \frac{1}{\sin\gamma} \quad \text{(eq. 6)}$$

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

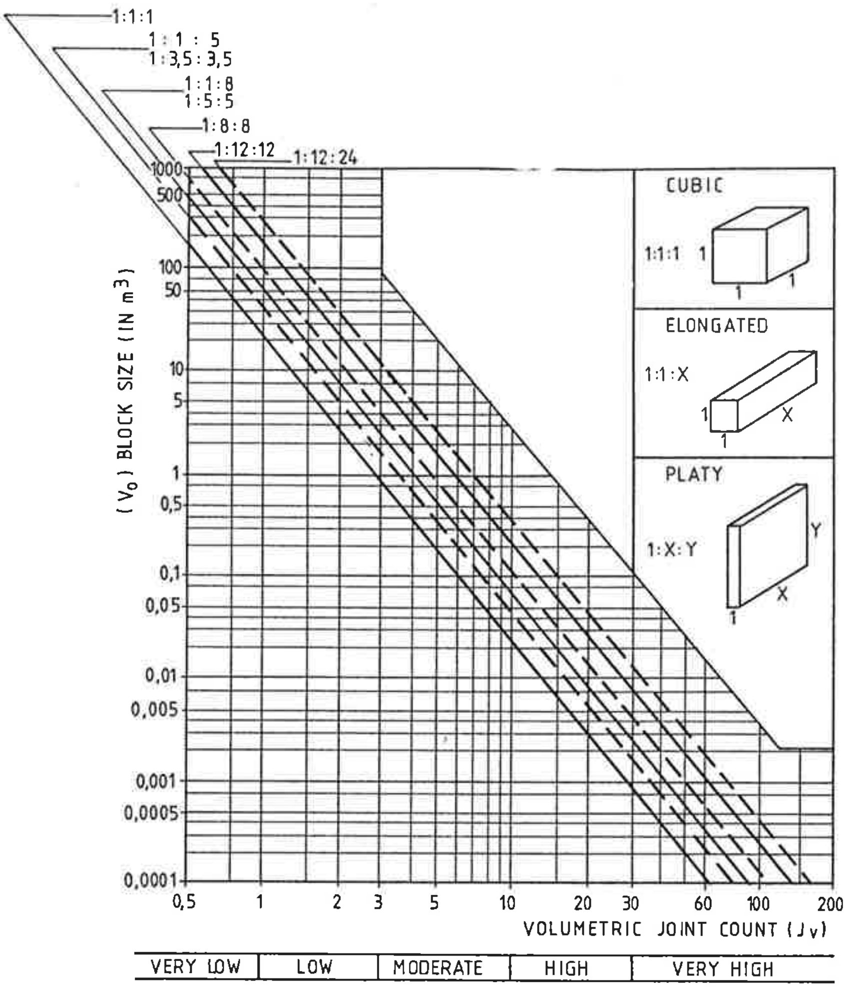

Fig. 4 Inter block size as a function of (Jv) and block shapes.

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

$V < 1.8\ Vo$

For most situations where an average block size is sufficiant:

$V = 1.25 \times V_o$ (eq. 7)

6. APPLICATION OF THE (Jv) FOR ROCK MASS DESCRIPTION

Equation 7 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 in Fig. 5 is regarded as an approximate limit for soil materials.

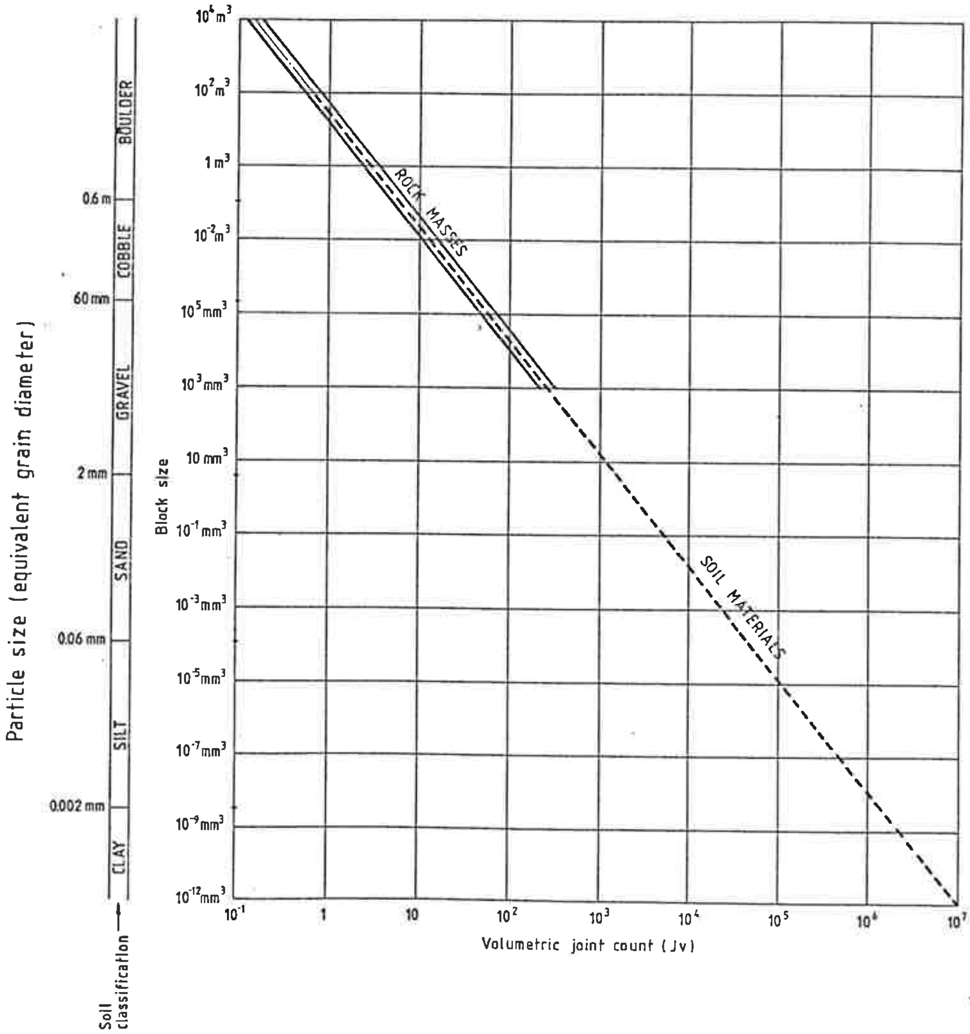

Fig. 5 Correlation between (Jv), block size in rock masses, and particle size in soils.

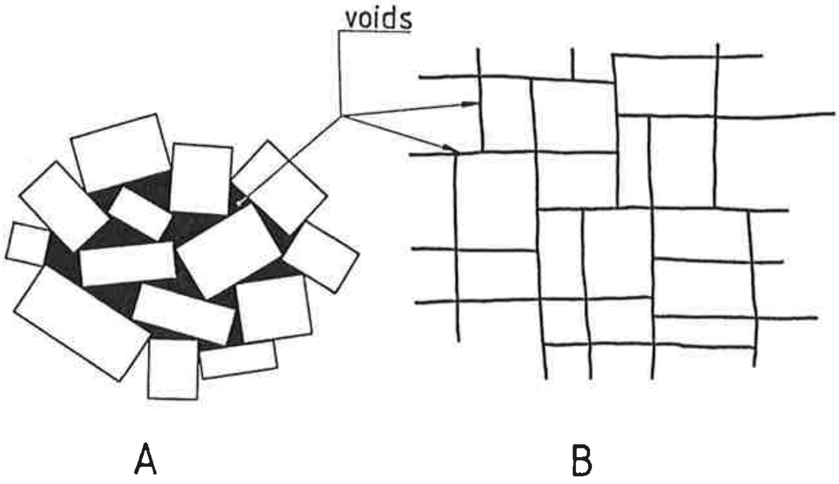

Fig. 6 Difference in structure and porosity of a soil (A) and a rock mass having the same size of particles/blocks caused by their different origin. In some fault zones the rock material may often have soil properties.

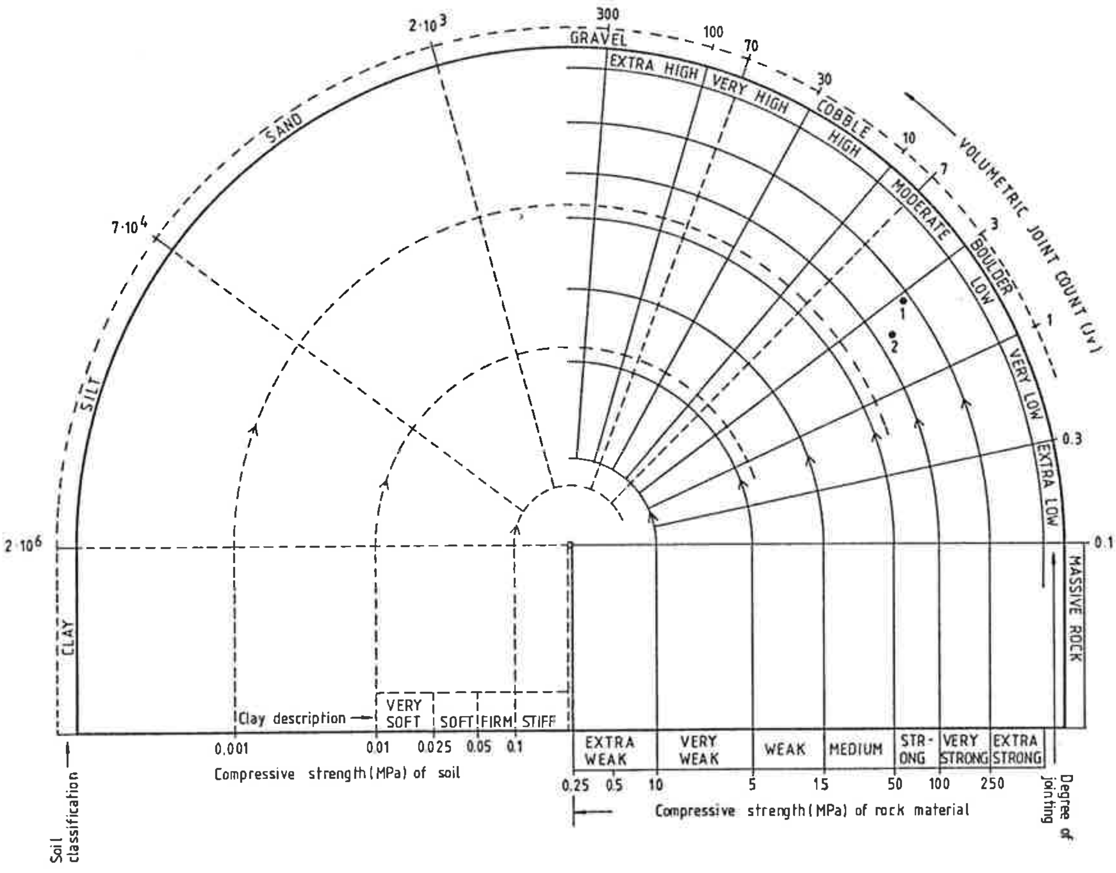

Fig. 7 Identification of soil and rock masses from particle/block size and compressive strength. The area covered by soil materials is given as dotted lines while rock masses is within the area for contineous lines.

Between about volumes of 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 mainly due to the dilantancy of the rock masses. It is therefore important to indicate on the diagram whether the material is a soil or a rock mass.

Based on the connection between soil and rock masses in Fig. 5 a suggested diagram covering most 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 little less than half the diagram while the soil materials cover about two thirds of it. Results from example 1 and 2 is plotted on the diagram.

Fig. 8 shows the main principles of the development of the main groups of rocks from molten rocks (magma) or from surface deposits through diagenesis and metamorphism. This development in the geological circle is applied in Fig. 9 which proves that most of the earth materials can be covered in the identification diagram (Fig. 7).

Jointing - which highly decreases the mechanical properties of rocks - is in Fig. 8 and 9 regarded as the first step in the weathering process of rock desintegration which transform the rocks to loose materials (soils).

Still much work remain to develop the (Jv) system. First more work should be done to study the importance of joint distribuion with regard to surface planes and boreholes to find out possible methods for calculating more accurate (Jv) values from observations. Secondly the importance of different joint types or joint features should be further studied, i.e. joint size (length, width), joint frictional properties (undulation, joint coatings etc.) to develop estimates of the compressive strength of jointed rock masses. Fig. 10 shows an example of this based on the identification diagram Fig. 7 and on work done by E. Hoek (Ref. 10) using the formula

$$\sigma_1' = (s \times \sigma_c^2)^{\frac{1}{2}} \qquad \text{(eq. 8)}$$

where

σ_1' is the compressive strength of a rock mass
σ_c is the uniaxial compressive strength of the intact rock material
s is an empirical constant varying with (Jv) and joint properties.

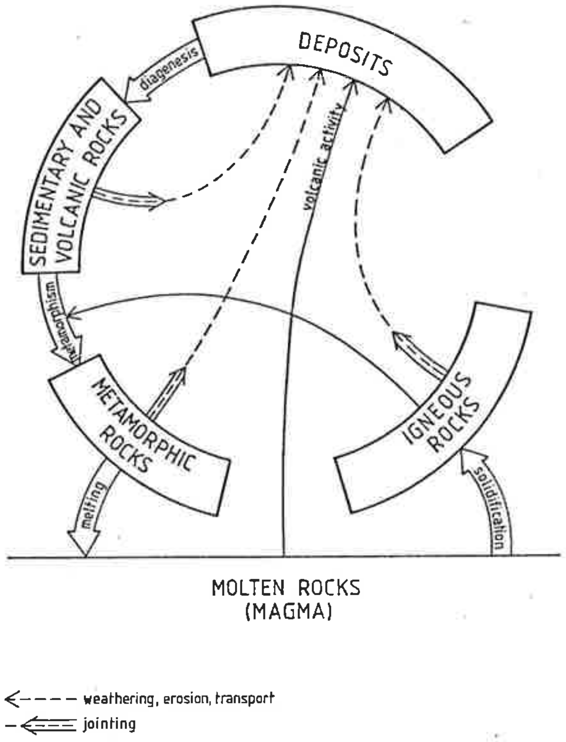

Fig. 8 The geological circle showing the development of the main rock groups.

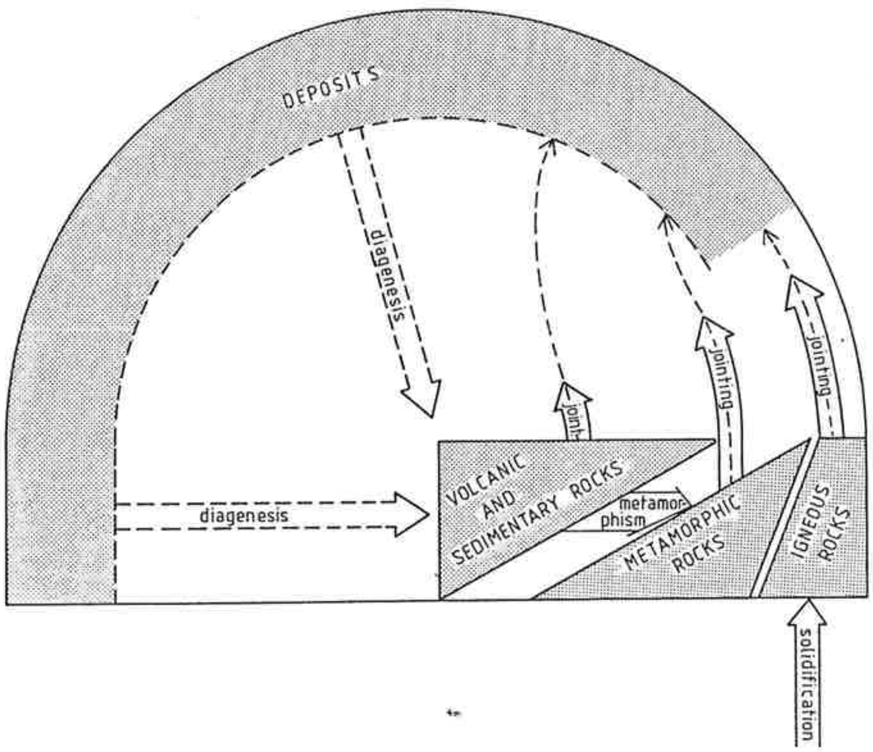

Fig. 9 The geological circle applied to the indentification diagram in Fig. 7

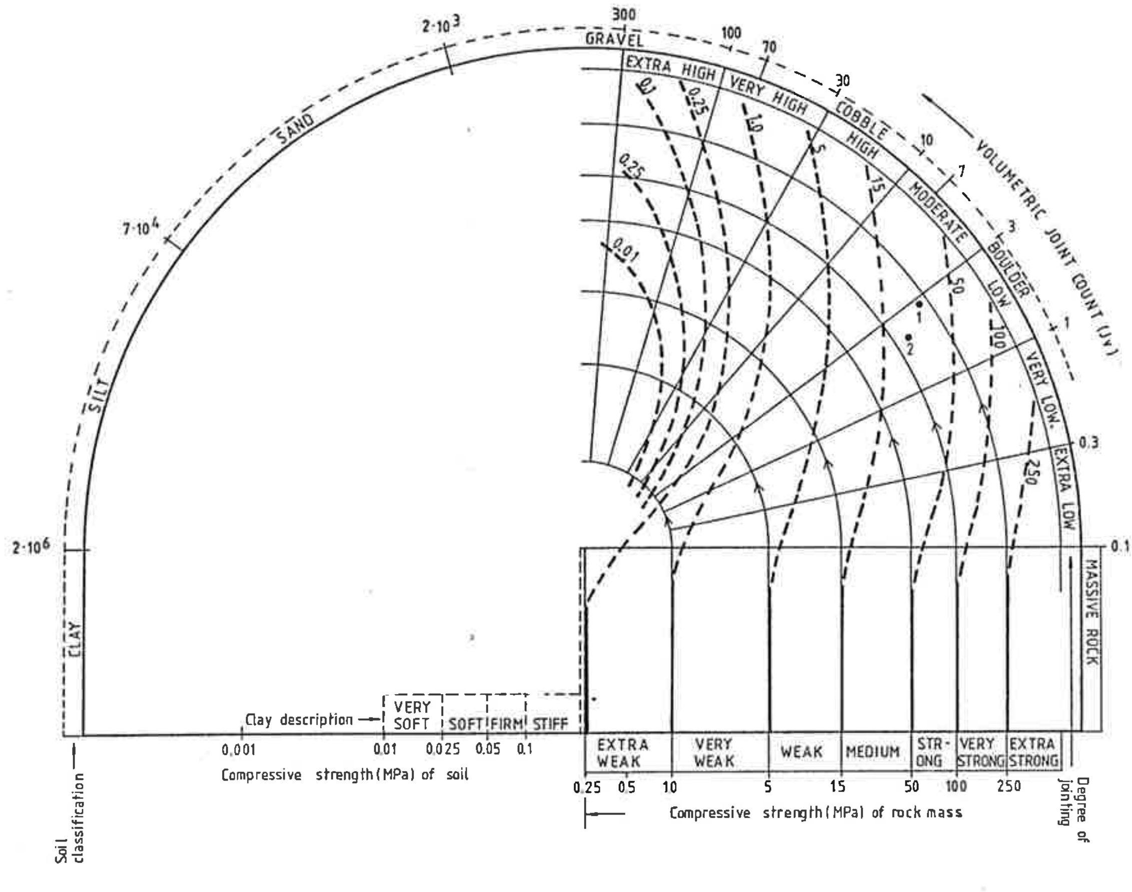

Fig. 10. Approximate compressive strength of clay-free jointed rock masses as a function of the (Jv) and the compressive strength of the intact (massive) rock. A similar diagram can be made for joints with clay fillings or clay coating.

7. 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. 11 a mean (Jv) = 2.8 is found, which can be classified as low to moderate.

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

ORIENTATION STRIKE	ORIENTATION DIP	SPACING	NO OF JOINTS	JOINT SET FREQUENCY	(Jv) VOLUMETRIC JOINT COUNT
i^g	i^g	m	no	no / m	no / m^3
30	100	0.5 - 1		2 - 1	1.95 - 3.7
150	100	1 - 2		1 - 0.5	
90	10 NW	2 - 4		0.5 - 0.25	
80	30 NW		2 (random)	0.2 *)	

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

Fig. 11 Joint observations, example 1. Eq 1 is used for estimating the (Jv)

The angles between the three joint sets can be found using Wulff's stereographical net. As shown on Fig. 12 they are 95^g and 82^g which gives V ~ Vo = 1,5 m3

In Fig. 10 it is found that - provided clay-free joints - the compressive strength of the rock masses is approx. 35 MPa, which is a little less than 1/3 of the intact rock.

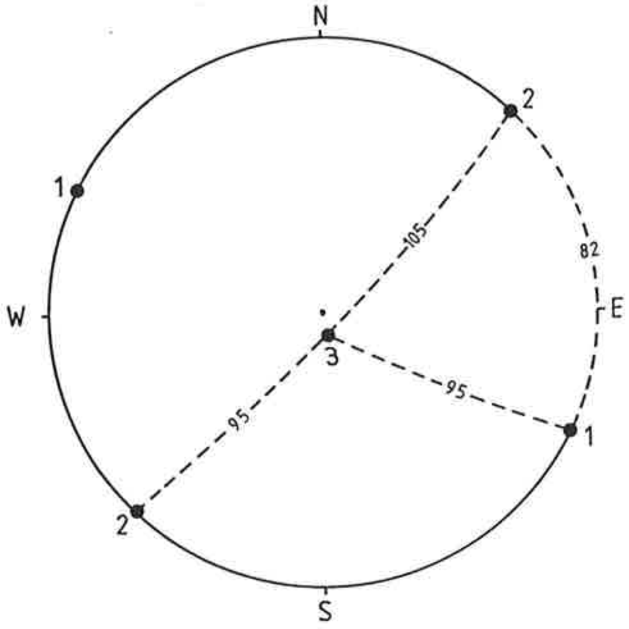

Fig. 12 The poles of the three joint sets in example 1 plotted in Wulff's stereographic net

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 sets and 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. 13.

By further assuming that the blocks mostly have a cubic shape, (and right angles) the block size is V = 1.3-2.0 m3. The compressive strength of the rock masses, Fig. 10, is approx. 25 MPa for clay-free joints.

OBSERVATION POINT		ORIENTATION		SPACING	NO OF	N_1 JOINT	(Jv) VOLUMETRIC
POINT	AREA	STRIKE	DIP		JOINTS	FREQUENCY	JOINT COUNT
NO	m^2	i^g	i^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				8	2	2.6

Fig. 13 Joint observations, example 2. Eq 2 is used for estimating the (Jv)

Example 3

A core hole has been drilled through the granite mentioned in Example 1. The orientation of the borehole is 190/60 (strike 90^g West of North, plunge 60^g). From the cores the following observations have been done:

DEPTH (m)	AVERAGE RQD	NO OF JOINTS (N_2)	ANGLE (δ) BETWEEN JOINTS AND CORE
30-40	100	14	11 joints 60^g 3 " 15^g
40-50	100	14	12 joints 60^g 2 " 15^g
50-60	100	12	9 joints 60^g 2 " 15^g 1 " 10^g

The following calculations have been carried out:

DEPTH	AVERAGE VALUES OF (Jv)	
(m)	from eq. 4	from eq. 3
30-40	(14x1.9) 1/10 = 2.7	(11/sin 60 + 3/sin 15) 1/10 = 2.6
40-50	(14x1.9) 1/10 = 2.7	(12/sin 60 + 2/sin 15) 1/10 = 2.3
50-60	(12x1.9) 1/10 = 2.3	(9/sin 60 + 2/sin 15 + 1/sin 10) 1/10 = 2.6

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, Washington.

(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) Watkins, M. D. (1971)
Terminology for describing the spcing of discontinuities of rock masses.
Q. J. Enging. Geol. Vol. 3 1970.

(10) Hoek, E. (1983)
Strength of jointed rock masses.
Geotechnique 33 No. 3, 1983.

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

(12) Palmstrøm, A (1985)
Application of the volumetric joint count as a measure of rock mass jointing.
Int. conf. on Fundamentals of rock joints, Bjørkliden, Sweden, 1985.

(13) International Society for Rock Mechanics, Commission of Standardization of Laboratory and Field Tests (Barton , 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.

(14) International Society for Rock Mechanics, Commission on Classification of Rocks and Rock Masses (1980). Basic geotechnical description of rock masses.
Int. J. Rock Mech. Min. Sci. Vol. 18, pp 85-110.

(15) The Norwegian Rock Mech. Group 1985.
Handbook, engineering geology of rock masses. (in Norwegian)
Tapir 1985.

apl/mn15r