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THE WEIGHTED JOINT DENSITY METHOD LEADS TO IMPROVED CHARACTERIZATION OF JOINTING

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SUMMARY
The weighted joint density (wJd) method offers better characterization of the degree of jointing and the block size than the common methods in use today. It can be applied in drill core logging as well as in surface registration of jointing. A rating factor (f_i) is used for each of four intervals for the intersection angle between the joint and the observation plane (or bore hole). As common angles have been applied, the measurement for wJd is quickly performed.

1. INTRODUCTION

The orientation of a joint compared to an observation surface or a bore hole influences the number of joints observed (Franklin et al., 1971; Terzaghi, 1965). Joints perpendicular to the surface plane or the bore hole will be more frequently intersected than other joints. This effect frequently bias the observations. For this reason Hudson and Priest (1983) recommend, where drillings are applied, to perform three bore holes in different directions for obtaining information on the 3-dimensional jointing in a rock mass. Such solutions are, however, costly and time-consuming.

Considering the high costs for core drilling it is remarkable that so little has been done to refine the conventional surface observation and core logging methods, for enabling better information of the jointing to be obtained.

2. THE PRINCIPLE OF THE WEIGHTED JOINT DENSITY METHOD

The weighted joint measurement method is developed to achieve better information from bore hole and surface observations. In principle, it is based on the measurement of the angle between each joint and the surface or the bore hole. Its definition is

- for measurements in rock surfaces:

$$\mathbf{wJd = (1/\sqrt{A})\ \Sigma(1/\sin\delta)} \qquad \text{eq. (1)}$$

- for measurements along a drill core or scanline:

$$\mathbf{wJd = (1/L)\ \Sigma(1/\sin\delta)} \qquad \text{eq. (2)}$$

Here δ is the intersection angle, i.e. the angle between the observation plane or bore hole and the individual joint.
A is the size of the observed area in m^2, see Fig. 1
L is the length of the measured section along the core or scanline, see Fig. 1

A similar idea has earlier been published by R. Terzaghi (1965) who suggested to take into account the orientation of the joints and the probability for them to be cut by the observation plane or the drill hole.

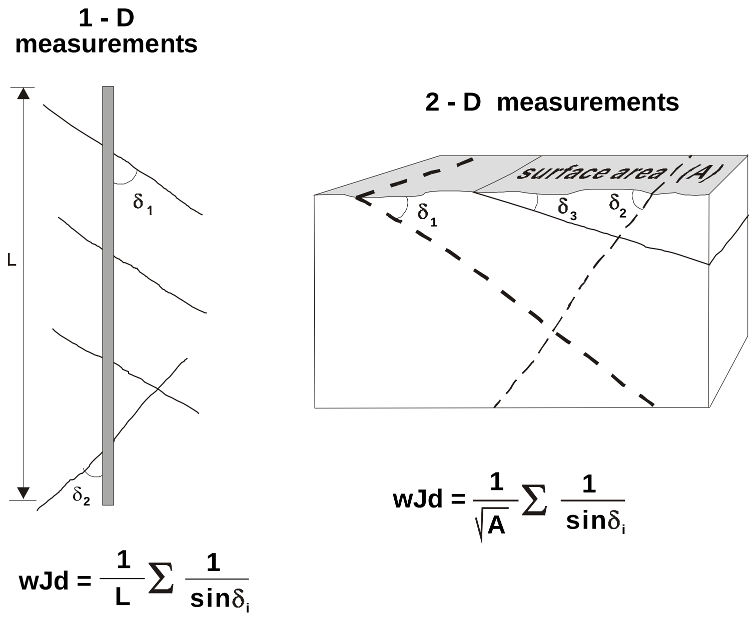

Fig. 1 The intersection between joints and a drill core hole (left) and between joints and a surface (right) (from Palmström, 1995).

Terzaghi stresses the problem of correcting for small values of δ because, in these cases, the number of intersections will be significantly affected by local variations in spacing and continuity. *"Further, no correction whatsoever can be applied if δ is zero. Hence N_{90} would fail to correctly indicate the abundance of horizontal and gently dipping joints in a horizontal observation surface."* Thus, a single joint may easily disturb the measurement.

The weighted joint density is according to Palmström (1995):

- for surfaces **wJd = $(1/\sqrt{A})\ \Sigma(1/\sin\delta) = (1/\sqrt{A})\ \Sigma f_i$** eq. (3)
- for bore holes **wJd = $(1/L)\ \Sigma(1/\sin\delta) = (1/L)\ \Sigma f_i$** eq. (4)

Here f_i is a rating factor.

To solve the problem of small intersection angles and to simplify the observations, the angles have been divided into intervals for which a rating of f_i has been selected as shown in Section 3. The selection of the intervals and the rating of f_i has been determined from a simulation as described in the following.

3. DEVELOPMENT OF THE wJd METHOD

The difficulty in obtaining reliable information on the joint distribution creates a problem when investigating methods for measuring joint density. This problem can be omitted analysing a known distribution of joints, which have been simulated in a computer. A line can be used to represent a bore hole (or scanline) which cuts the simulated joint model, and in the same way in the same way a plane constitutes an outcrop surface on which the simulated number of joints can be found. By this simulation, results from different types of jointing along a "bore hole" or on a "surface" can be easily investigated. As the density and pattern of joints are known, reasonable comparisons can be carried out between various ratings of the f_i as well as the various angle intervals.

The simulation was carried out using a computer spreadsheet where the jointing was represented by three joint sets at right angles to each other. The spacing of the joint sets could be varied so that different joint patterns could be loaded into the spreadsheet.

A total of 640 trials were made including:

- Joint patterns, which varied from equidimensional to very long and very flat blocks.
- Variation in joint density between 0.001 m^3 and 1000 m^3 block volumes.
- Angles between the plane of observation (or bore hole) and intersecting joints varying between:
  10^o and 85^o for surface planes;
  5^o and 80^o for bore holes.

The same intervals and ratings of f_i were selected for both the surface and the borehole registrations. Various ratings of f_i (= 1/sinδ) and various limits of the angle intervals have been investigated. The best fit for f_i is given in Table I.

TABLE I ANGLE INTERVALS AND RATINGS OF THE FACTOR f_i

Angle (δ) between joint and surface or bore hole	**Rating of the factor f_i**
> 60^o	1
31 - 60^o	1.5
16 - 30^o	3.5
< 16^o	6

Each joint is given a rating f_i depending on the actual angle interval. It is easy to be familiar with the intervals in Table I after some training as common angles have been selected.

3.1 The wJd found from surface observations

The "joint observations" were made on surface planes corresponding to a 75 m^2 observation area. The angle between the plane and each joint was recorded an the weighted joint density found. As seen in Fig. 2, there is a good correlation within approximately ± 30% between the calculated wJd and the volumetric joint count (Jv) (reference Palmström, 1982), except for the lower values of Jv (i.e. large blocks). This is mainly due to the fact that some joints are not recorded within the observation area because of the large spacing of joints and small angles between joint and observation plane. Therefore, the calculated wJd will be lower than the real value for such situations.

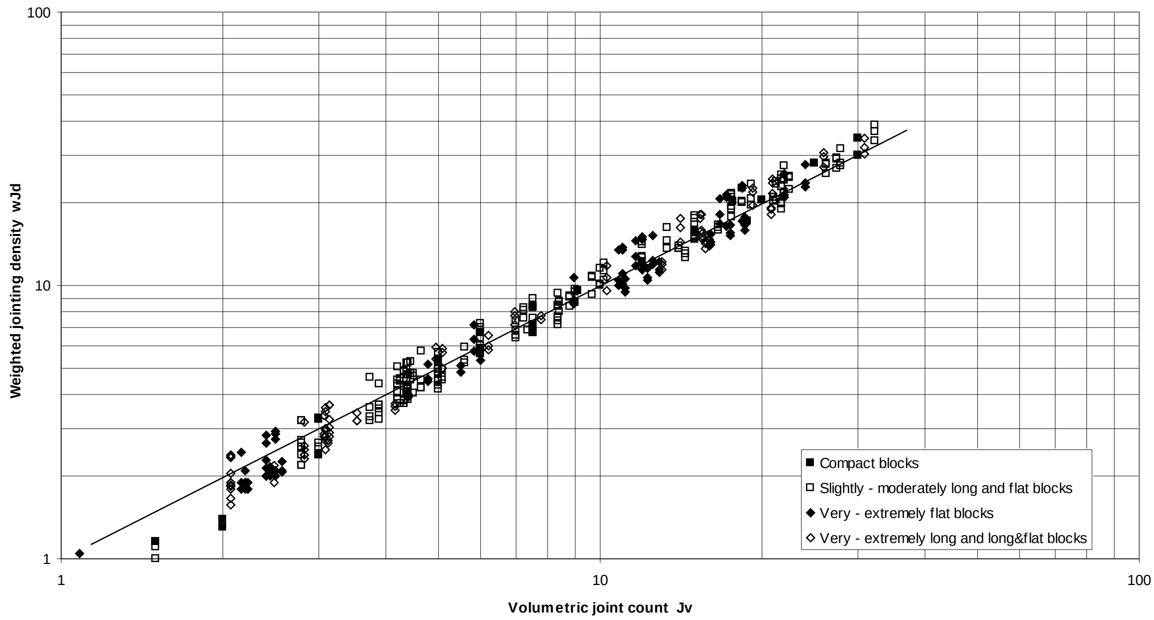

Fig. 2 The correlation between (known) volumetric joint count (Jv) and weighted 2-D joint density measurement (wJd) made in 'surfaces' (from Palmström, 1995).

3.2 The wJd found from core logging

In these simulations an observation length of 10 m along a bore hole was chosen. The wJd obtained from the various simulations is compared with Jv in Fig. 3. As expected, there is a poorer correlation for this (1-D) type of jointing measurement, which have an inaccuracy of between approximately +35% and - 50% for Jv > 2 (Fig. 3) compared with the surface (2-D) type of measurements (Fig. 2). Also, the poorest correlation was again obtained at the lowest values of Jv (Jv < 2), probably because some of the joints were not encountered in the 10 m long sections in the "bore holes".

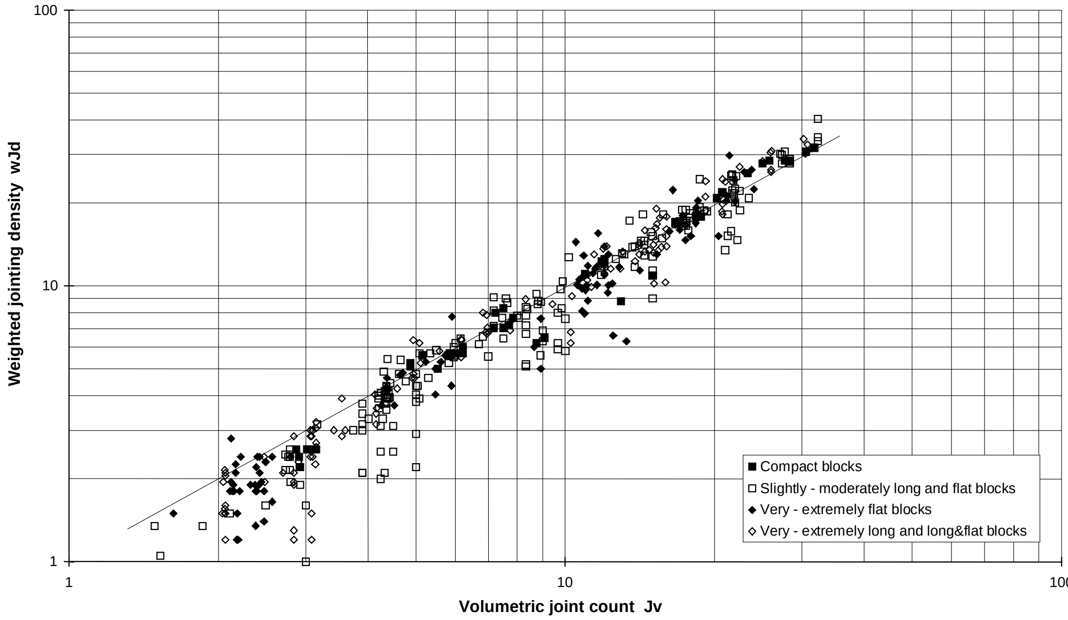

Fig. 3 The correlation between (known) volumetric joint count (Jv) and weighted 1-D joint density measurement (wJd) made in "bore holes" (from Palmström, 1995).

4. EXAMPLES

4.1 Surface observations

Two examples of jointing seen on a surface are shown in Fig. 4.

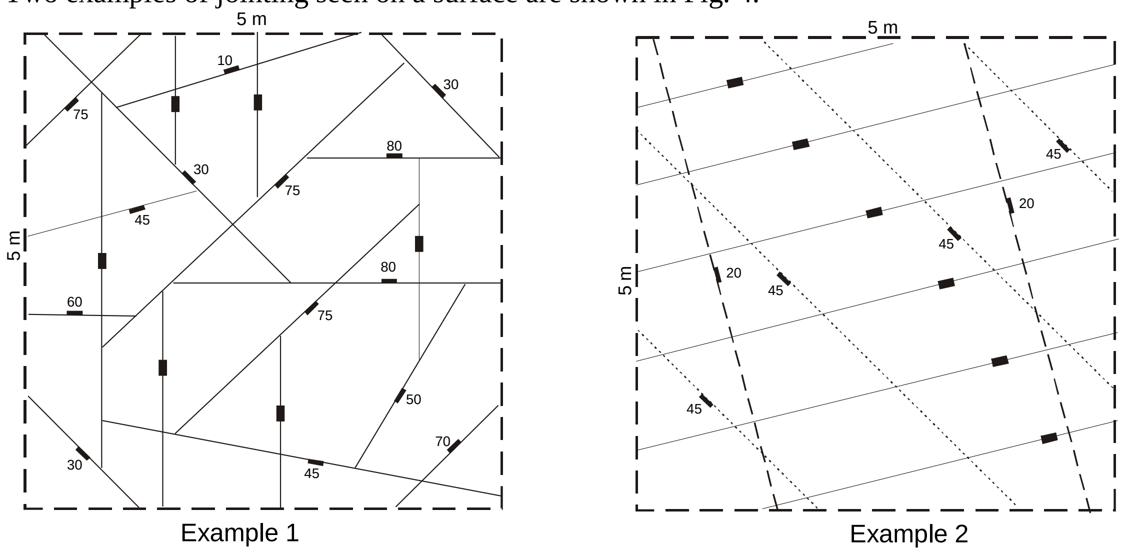

Fig. 4 Two examples of jointing on a surface

The observation area in both examples is 25 m^2, and the results from the observations are given in Table II. In the second example all the joints belong to joint sets. Thus, it is possible to calculate the volumetric joint count (Jv = 3.05) from the spacings (which are 0.85 m, 1 m, and 1.1 m). As seen, the weighted joint density measurement gives here values, which are somewhat higher than the (known) value for the volumetric joint count.

TABLE II THE CALCULATION OF THE WEIGHTED JOINT DENSITY FROM ANALYSIS OF JOINTING SHOWN FOR THE SURFACES IN FIG. 4

Location	Area A	Number of joints (n) within each interval				Total number of joints	Number of weighted joints	wJd = $(1/A^{0.5})N_w$	Jv
	m^2	> 60^o	31 - 60^o	16 - 30^o	< 16^o	(from Fig. 4)	$N_W = \Sigma$ **n x f$_i$**		
Example1	25	12	4	3	1	20	34.5	6.9	
Example 2	25	6	4	2	0	12	19	3.8	3.05
Rating of f_i =		1	1.5	3.5	6				

4.2 Bore hole observations

An example from core logging is shown in Fig.5. The 5 m long part of the core has been divided into the following 3 sections with similar density of joints: 50.0 - 52.17 m, 52.17 - 53.15 m, and 53.15 - 55.0 m. For each section the number of joints within each angle interval has been counted and the results are shown in Table III.

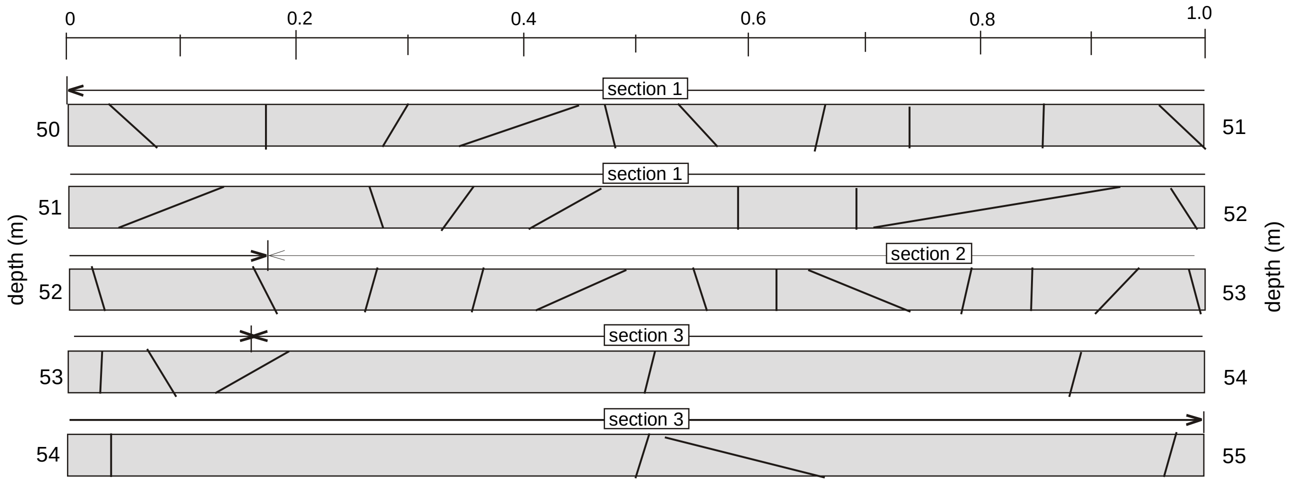

Fig. 5 Example of jointing along part of a bore hole

TABLE III THE CALCULATION OF THE WEIGHTED JOINT DENSITY FROM REGISTRATION OF JOINTING IN THE BOREHOLE IN FIG. 5

Depth	Length L	Number of joints (n) within each interval				Total number of joints	Number of weighted joints	wJd = $(1/L)N_w$
m	m	> 60^o	31 - 60^o	16 - 30^o	< 16^o	(from Fig. 5)	$N_W = \Sigma$ **n x f$_i$**	
50 - 52.17	2.17	11	6	2	1	20	33	15
52.17 - 53.15	0.98	9	3	2	0	14	20.5	20.9
53.15 - 55.0	1.85	5	0	1	0	6	8.5	4.6
Rating of f_i =		1	1.5	3.5	6			

5. CONCLUSION

The weighted joint density method offers a relatively quick and simple way to measure the joint density. It reduces the inaccuracy caused by the attitude of joints and thus leads to a better characterization of the rock mass. This may in turn lead to a reduction in the number of bore holes required for investigations.

The evaluation of weighted joint density requires only small additional effort over currently adopted logging practices. The only additional work is to determine which angle interval the intersection between the observation plane (or bore hole) and each joint belongs. The angles chosen for the intervals between joint and bore hole should be familiar to most people and this should make the observations for wJd quick. The use of only five intervals makes the registration simple and easy.

The intervals for intersection angle and assigned ratings eliminate the strong influence of the smallest angles, i.e. angles parallel or nearly parallel to the observation plane or bore hole.

Simulations have been used to select appropriate ratings based on a comparison with the volumetric joint count (Jv). (Palmström, 1982). Therefore, where accurate measurements have been performed, the wJd should be similar to the volumetric joint count (wJd $\approx$ Jv).

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