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SIZE AND SHAPE OF SPACE FILLING BLOCKS IN A QUARRY

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ABSTRACT

A rock mass divided by natural fractures looks like a set of space filling blocks (polyhedra). In order to characterise the structural design of a rock mass located in the quarries of Comblanchien (Côte d'Or, France), size and shape of block convex hulls outlined on horizontal benches are computed using five size parameters [A (area), B (perimeter), R_C and R_I (radii of circles C and I : largest contained in and smallest containing the polygon) and DF (Feret Diameter)] and six shape factors [$IA_m = R_C/R_I$, $CB_m = 32A/(\pi B^2)$, CB_d is the CB_m shape factor for the dynamic equivalent ellipse of the polygon, DCI, DCG and DIG are ratios of distances between centres (centres of circles C/ I and G : centre of gravity) to DF]. With such a set of parameters we suggset a classification of blocks, and their size and shape are related to the geological history of the rock mass.

KEYWORDS : geology, jointed and faulted rock mass, size, shape, space filling Bbocks.

INTRODUCTION

The knowledge of the tectonic division of a rock massif is of greatest geotechnical importance to enable quantitative assessments of fracturing, relevant to the mechanical and hydraulical behaviour of rock masses. A rock mass divided by natural fractures looks like a set of space filling polyhedra, their faces, edges and corners being respectively distinct individual sub-planar fractures and intersections of two or three of them. In this paper we present the joint geometry of a rock mass located in the quarries of Comblanchien (Côte D'Or, France). As fractures are quite vertical, polyhedra become prisms and joint geometry is characterised by analysing the size and the shape of two dimensional polygons outlined on two partially superimposed horizontal benches (vertically 2.4 m apart). Data acquisition (orientation and position) consists in a systematic manual in situ survey of fracture traces ; co-ordinates of a set of points distributed on traces were measured with reference to an arbitrary orthogonal system (Gervais, 1993). Then 564 and 1531 traces were surveyed on 912 and 2075m^2 area surfaces ; densities B_A of fracture traces are respectively 0.92 and 1.06 m/m^2 (Gervais *et al*, 1993). Blocks are defined as closed domains outlined by fracture traces ; if any ending part of a trace exists in such a domain, it is cancelled. Finally we have 126 and 275 blocks (Fig. 1). Principal orientations of polygon edges are reflecting the regional geological history : N020° E, N040°E, N110-115°E, N145-150°E and N060-080°E.

CONVEX HULLS OF THE 2D BLOCKS

Since natural fractures are sub-planar, their intersections with horizontal planes fluctates around

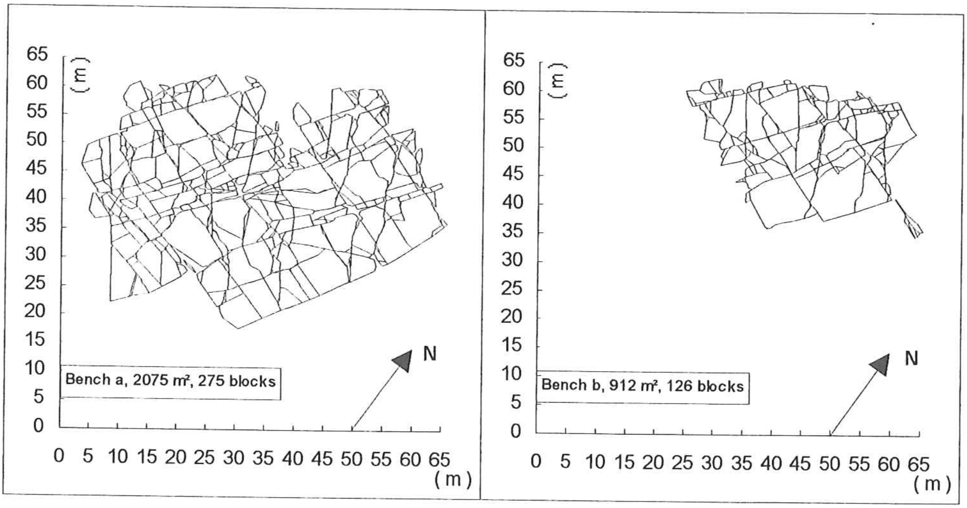

Fig. 1. Closed domains outlined on benches a (left) and b (rigth ; b is the upper one).

their mean geological direction ; that, associated with the finite length of fractures, leads to a pattern of non convex polygons. Among 401 blocks, 96 (24%) are naturally convex and 305 are not. Looking at the convex hulls of these 305 blocks shows that less than 10% increasing values of area appears for 87% of them and less than 10% decreasing values of perimeter for all of them (Table 1). Total area of original blocks and final area of convex hulls are respectively 2356 and 2455 m² giving rise to an increasing surface area of 4% (similarly less than 1% perimeter decreasing). Thus we assume that the geometrical characteristics of the rock mass is not biased when studying size and shape of convex hulls. From a stereological point of view it is noticeable that this transformation leads to a number of edges per polygon distribution (Table 1, Fig. 2) that looks like that of cells or grains at equilibrium (Williams, 1972 ; Riss, 1988) ; it is asymmetric, with mode, median and mean values between 6 and 7 edges.

SIZE AND SHAPE OF CONVEX HULLS

Five size parameters are computed for each polygons: area (A), perimeter (B), radii (R_C, R_I) of the largest/smallest circle contained in or containing the polygon and Feret Diameter (DF) Table 2 and Fig. 3 show statistical results about these parameters except DF oftently equal to

Table 1. Relative variations of number of edges, area and perimeter of blocks.

Number N of polygons having lost ΔN edges			Number and proportion of polygons with increasing area.			Number and proportion of polygons with decreasing perimeter.		
N		ΔN	N	N%	ΔA/A	N	N%	ΔB/B
96	24%	0	101	25%	≤ 0.00%	124	31%	≤0.00%
80	20%	1	167	42%	≤ 1.00%	300	75%	≤1.00%
52	13%	2	211	53%	≤ 2.00%	367	92%	≤2.00%
48	12%	3	246	61%	≤ 3.00%	383	96%	≤3.00%
35	09%	4	274	68%	≤ 4.00%	390	97%	≤4.00%
24	06%	5	301	75%	≤ 5.00%	395	99%	≤5.00%
138	24%	>5	360	90%	≤10.00%	401	100%	≤9.29%
			389	97%	≤20.00%			
			401	100%	≤ 40.14%			

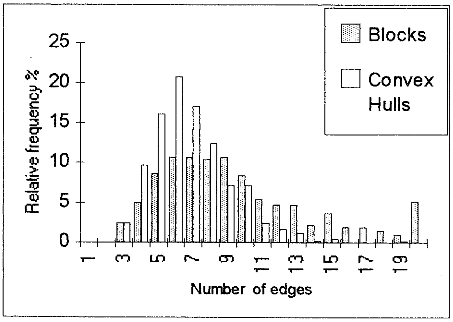

Fig. 2. Number of edges per block.

2.R_C (160 cases) and next because it is used to create shape parameters (see lower). In order to classify blocks in coherent groups, histograms allow us to define four subsets:

- Group I and II with 27 large and 4 very large blocks: $A \geq 18.0$ m² and $B \geq 17.0$ m and $R_C \geq 3.25$ m and $R_I \geq 1.70$ m.
- Group III (267 not too large blocks): group IIIa (170 blocks) when $2.0 \leq A < 18.0$ m² and $5.8 \leq B < 17.0$ m and $1.10 \leq R_C < 3.25$ m and 0.50 m$\leq R_I < 1.70$ m. Group IIIb corresponds to 97 blocks that fullfill one at least of the four previous criteria.
- Group IV with 103 small and very small blocks : $A < 2.0$ m² and $B < 5.8$ m and $R_C < 1.10$ m and $R_I < 0.50$ m.

Shape parameters $IA_m = R_I/R_C \in [0, 1]$ and $CB_m = 32A/(\pi B^2) \in [0, 8/\pi^2]$ were first computed (Table 3). Some blocks, on the left lower part the $\{IA, CB_m\}$ diagram (Fig 4) are obviously elongated shapes but a majority of them is concentrated on the middle upper part. Looking at the lower IA and CB_m limits for blocks belonging to groups I and II we find IA = 0.407 and $CB_m = 0.521$. As an example, Fig. 5 shows the 175 (64%) blocks from bench a having both IA > 0.407 and $CB_m > 0.521$. Then it is clear that even if these blocks are somewhat isometric and massive they are not looking alike ; because IA and CB_m are global parameters they can't take into account the spatial distribution of the mass (surface area) within its boundary (perimeter). Nevertheless we propose a classification based on IA and CB_m values:

- Class A (290 blocks) with IA>0.407 or $CB_m > 0.521$ with subsets A_1 (244 blocks, IA>0.407 and $CB_m > 0.521$), A_2 (7 blocks, IA<0.407 and $CB_m > 0.521$) and A_3 (39 blocks, IA>0.407 and $CB_m < 0.521$).
- Class B (111 blocks) with IA < 0.407 and $CB_m < 0.521$ with subsets B1 (65 blocks) and B2 (46 blocks, $CB_m < 0.420$ and IA<0.262).

Because this classification is not sufficient we have analysed four other shape parameters: $\{CB_d$, DCI, DCG and DIG$\}$. CB_d is the CB_m shape factor for the dynamic equivalent ellipse (Medalla, 1970) of the polygon, DCI, DCG and DIG are ratios of distances between two given centres among the three (C, I and G : centre of gravity) to DF. Then this set of six shape factors (Table 3) allows a principal component analysis working with the correlation matrix ; table 4 shows the eigenvalue matrix.

Correlations between shape parameters and factors of the component analysis (Fig. 6, Table 5) show that F1 positive (225 blocks 56%) will be interpreted as relating to high IA, CB_m and CB_d values and small DCI and DIG values and F2 positive as relating to DCG high values and CB_m small values. Figure 7 shows blocks of the bench a belonging to each of the four F1F2 quadrats. First quadrat (F1>0, F2<0) is the location of the more isotropic blocks that are possible to find in regard of the geological history : blocks are mainly parallelograms generated by the two primary families of fractures (N 040°E , N 110°115°E) ; keeping F2<0 but having F1<0 (quadrat n°2) we have blocks identically generated as the former one but with a specific elongation and in some cases an eccentricity of the inner circle centre in regard to the outer circle and gravity centres. F2>0 corresponds to truncated blocks because of the N145°E family of fractures. Depending on the position where initial parallelograms were truncated, they become or remain elongated (F1<0, quadrat 3) or quite massive (F1>0, quadrat 4) but with in some cases an eccentricity of the outer circle centre in regard of the inner circle and gravity centres.

Table 2. Statistical results for A, B, R_C and R_I.

401 blocks	A	B	R_C	R_I
Mean	6.1228	8.8521	1.7800	0.8581
Variance	83.3823	28.4979	1.0611	0.4153
Standard deviation	9.1314	5.3383	1.0301	0.6445
Maximal value	70.8510	32.6710	6.5140	4.0650
Minimal value	0.0360	0.9960	0.2360	0.0640
Median	2.5540	7.1240	1.4910	0.6510

Table 3. Statistical results for the shape parameters.

	IA	CBm	CBd	DCI	DCG	DIG
Mean	0.4673	0.5392	0.6774	0.1533	0.0715	0.0969
Variance	0.0178	0.0114	0.0161	0.0066	0.0015	0.0054
Maximum	0.7810	0.7390	0.8100	0.4320	0.1790	0.3930
Minimum	0.0770	0.1430	0.1340	0.0170	0.0040	0.0070
Median	0.4770	0.5630	0.7170	0.1430	0.0660	0.0730
Correlations						
IAm	1.0000	0.9278	0.9230	-0.6424	-0.2329	-0.6336
CBm		1.0000	0.8669	-0.6180	-0.3590	-0.4993
CBd			1.0000	-0.6033	-0.0767	-0.6655
DCI				1.0000	0.4842	0.8493
DCG					1.0000	0.0106
DIG						1.0000

Table 4. Variance-Covariance matrix after diagonalisation of the correlation matrix.

	F1	F2	F3	F4	F5	F6
Variance Σ=6	3.993	1.086	0.767	0.076	0.058	0.020
% total	66.55%	84.65%	97.43%	98.70%	99.67	100.00%

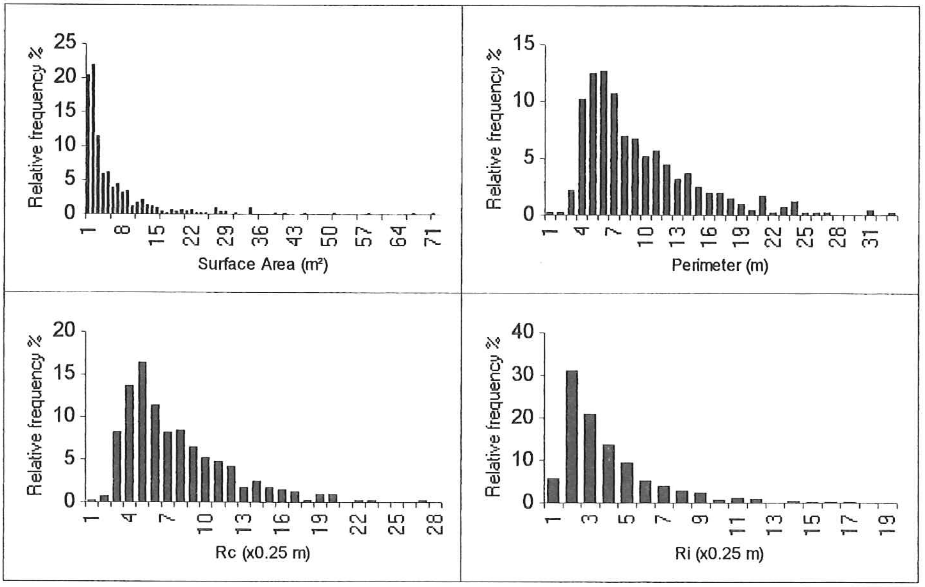

Fig. 3. Histograms (relative frequencies) for A, B, R_C and R_I.

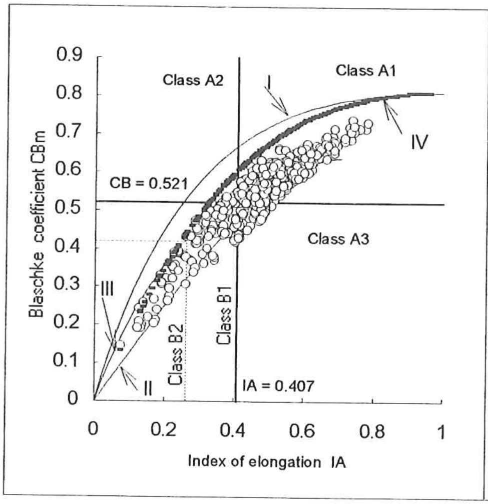

Fig. 4. {IA, CBm} diagram for the 401 blocks (circles); I limit curve for any polygons, II curve for rhombus, III curve for rectangles, IV curve for ellipses (rectangles), straight lines: limits of classes.

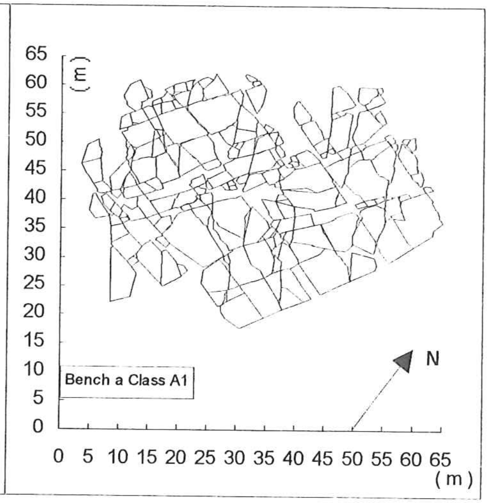

Fig. 5. The 175 (64%) blocks of bench a having IA > 0.407 and CBm > 0.521, part of the class A.

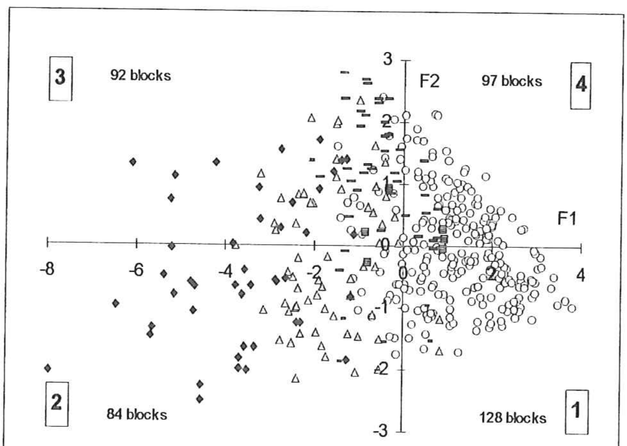

Fig. 6. Plot of the blocks on F1, F2 axis of the principal component analysis. Circles: class A1, segments: class A2 and A3 triangles: class B1 diamonds : class B2, quadrats : factors.

Table 5. Correlation between shape parameters and principal factors. F1 and F2

	F1	F2
IA	0.938	0.112
CBm	0.903	-0.049
CBd	0.908	0.276
DCI	-0.852	0.233
DCG	-0.345	0.933
DIG	-0.794	-0.263

CONCLUSION

The shape parameters inferred from field data {IA, CB_m, CB_d, DCI, DCG and DIG } are efficient classifying blocks with respect to the chronology of the rock mass geological fracturation. Associated with size criteria {A, B, R_I, R_C, DF}, it seems that we have an efficient tool to contribute to the modelling and/or simulating of natural fracture network in a rock mass.

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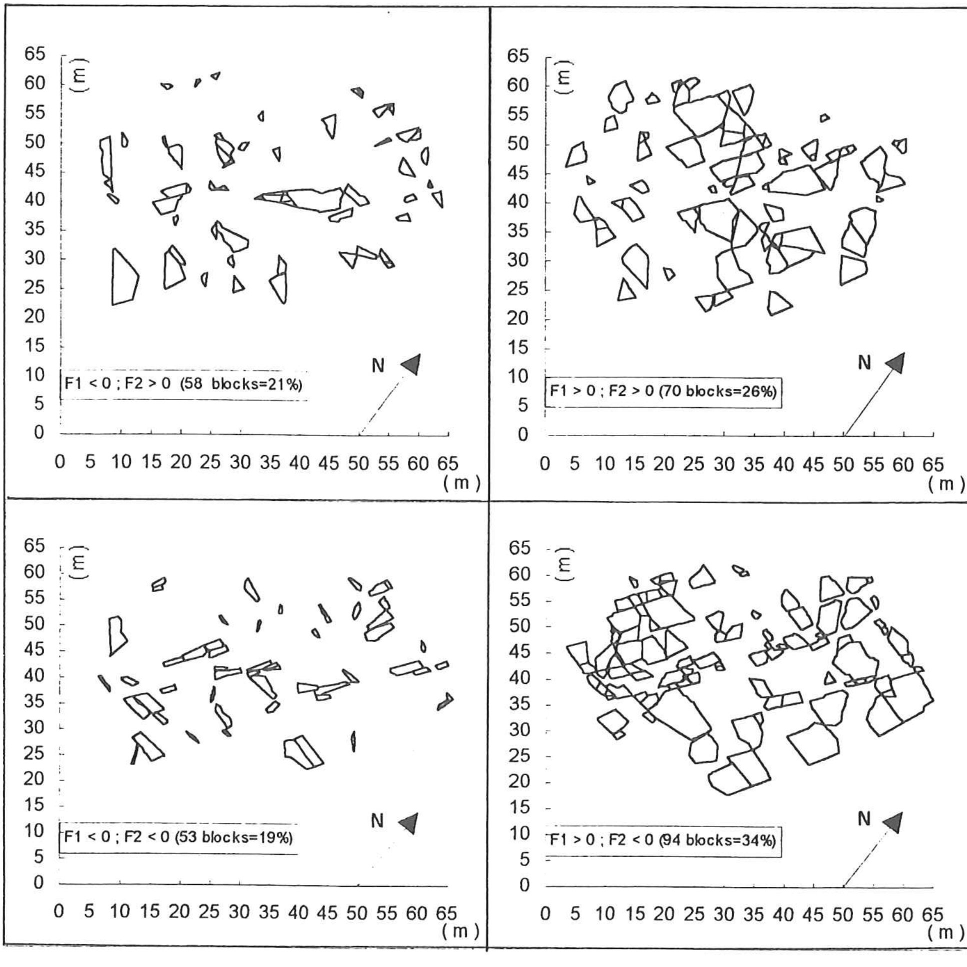

Fig. 7. Blocks separated using F1 and F2 criteria.

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