Application of the point counting technique for estimating the VBP of geotechnically complex formations (bimrocks/bimsoils)

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ABSTRACT: The estimation of the Volumetric Block Proportion (VBP) of geotechnically complex block-in-matrix formations (such as melanges) is crucially important for reliable predictions of their mechanical behavior, and for reducing safety risks and extra costs caused by unexpected technical problems that can occur during excavation/construction works. However, estimating site-scale VBPs is extremely difficult.

This paper describes a statistical investigation of virtual block-in-matrix models to determine the amount of bias introduced when the point counting technique is used to infer VBPs from in-situ 0D (point) measurements (PBP). A graph is provided to obtain an uncertainty factor (UF) to adjust the measured PBPs to real VBPs, on the basis of the block content measured and the size of the area analyzed. To validate the approach, the results are compared to those provided recently by Napoli et al. (2020), where the uncertainty in estimates of VBPs from 2D measurements was investigated.

Keywords: Bimrocks, bimsoils, point counting technique, volumetric block proportion (VBP), uncertainty factor, statistical analysis.

1 INTRODUCTION

It is well known that the mechanical behavior of geotechnically complex block-in-matrix formations, such as bimrocks and bimsoils (like melanges and colluvia/SRMs) is strongly influenced by the presence of blocks. Previous findings in the literature show the importance of taking blocks into account in the planning, designing and construction phases of any engineering work, since the strength, deformability and failure mode of these geomaterials mainly depend on their volumetric block proportion (VBP) (Hunt & Del Nero 2010, Khorasani et al. 2019, Lindquist 1994, Medley 1994, Napoli 2021, Napoli et al. 2021, Sonmez et al. 2004 and Zhang et al. 2015). However, assessing VBP is recognized as a major problem and a key challenge by all geopractitioners and researchers working in the broad field of geotechnically complex formations. VBPs can be, and often are, estimated by assuming the stereological equivalence of 0D (point), 1D (linear) or 2D (areal) field measurements and actual 3D (volumetric) values. Nonetheless, it has been demonstrated that the uncritical application of this simple assumption can lead to much error (Haneberg 2004, Lu et al. 2020, Medley 1997 and 2001, Medley & Goodman 1994, Napoli et al. 2022, Ramos-Cañón et al. 2020 and Vallero et al. 2020) with attendant financial, construction and safety consequences.

This paper describes a statistical approach implemented using a custom-created Matlab code to obtain computer-generated 3D bimrock models, which were investigated to determine the amount of bias introduced when VBPs are inferred from in-situ 0D (point block proportions, PBP) measurements of bare slopes, outcrops and tunnel faces. To this aim, the point counting technique was applied.

2 METHODS

The point counting technique is a method used in several research fields to easily obtain quantitative estimates of the abundance of objects of interest, p_i. Specifically, the proportion of p_i can be determined by superimposing a grid over an image or a sample, counting the intersection points, n_i, and dividing them by the total number of points of the grid, N_p (Medley & Goodman 1994).

Since it is an easy and quick method to be employed in the field, this technique is proposed in this research paper for estimating bimrock/bimsoil VBPs. The uncertainty in such estimates was statistically investigated to produce an easy-to-use chart which, for different dimensions of the outcrop investigated, allows VBPs to be estimated by adjusting PBPs with an uncertainty factor (UF).

Finally, a comparison was performed with the 2D approach results recently developed by Napoli et al. (2020), which estimates VBPs by areal block proportions (ABPs).

2.1 The statistical analysis

In order to statistically quantify the uncertainty in estimates of real VBPs from PBP measurements, the same 3D bimrock domains analyzed by Napoli et al. (2020), with 10%, 20%, 30%, 40% and 50% VBPs, were used. The same 150 equidistant and parallel square cross section planes of Napoli et al. (2020) were considered, each one containing a number of solid circles (the intersection between the planes and spherical blocks). A regular square point grid was superimposed on each section plane, as shown in Figure 1.

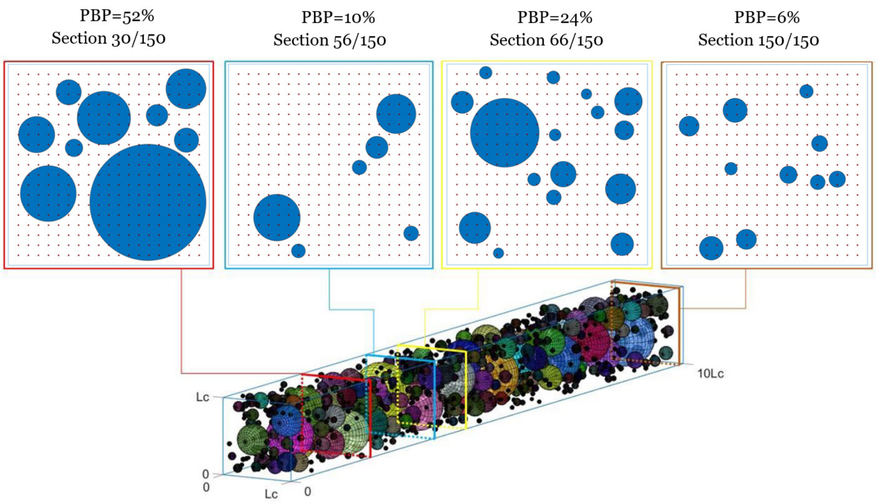

Figure 1. Intersected blocks and PBPs obtained from four section planes of the 30%VBP model from Napoli et al. (2020).

The grid spacing, g_s, had to be narrow enough that all the geotechnically significant rock blocks (i.e. blocks large enough to influence the mechanical properties of the bimrock/bimsoil) could be detected (Figure 1). According to the literature, the diameter of the smallest significant block is equal to

d_{min}=5%L_c, being L_c the characteristic engineering dimension (Medley, 1994). In practice, however, it is a matter of spatial perspective that the further away an observer is from an outcrop, the smaller the blocks will appear to be. Hence, the g_s value to use as if a grid with spacing $g_s=0.05L_c$ were directly superimposed on the outcrop will depend on the distance, L, from the tunnel/slope/outcrop face at which the survey is carried out, and can be determined from Figure 2 as a function of L_c.

For each section, the grid points falling inside and on the external boundary of the disks (blocks)

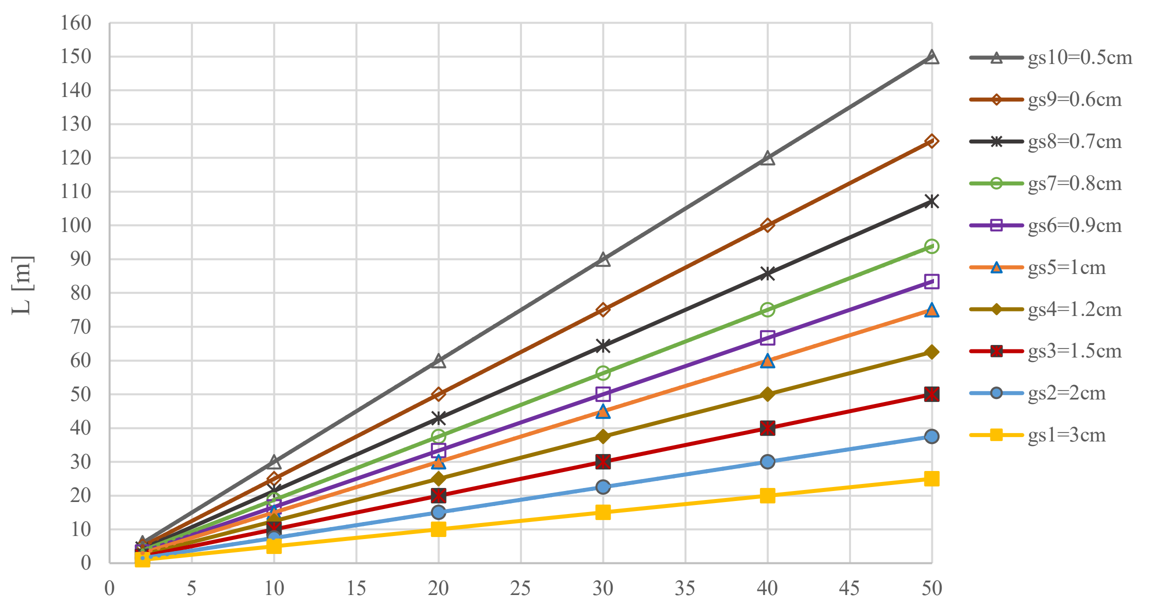

Figure 2. Correlation between L_c, L, and grid spacing, g_s.

were identified. Then, the PBP of each section of the 3D domain was computed as the ratio between the number of grid points falling inside the blocks, n, and the total number of grid points on that section, N_p.

Due to the statistical variability of the dimensions and positions of the discs obtained by slicing the 3D domains, the PBPs evaluated on different cross-sections also were variable. Moreover, the PBP values only rarely were numerically equivalent to the true VBP. This result, as expected, indicates that inferring 3D block proportions as equivalent to the PBP measured by means of the point counting technique on an outcrop area will generally yield erroneous estimates. As a consequence, it is of particular interest to determine how big the area surveyed with this technique should be, in order to obtain acceptably accurate estimates of the VBP (i.e. with sufficiently small errors). To this aim, a statistical processing of the results obtained was performed, in a manner similar to the procedures followed for statistical analyses of VBPs using 1D and 2D measurements (Napoli et al. 2020, 2022). Multiple subsets of combined section planes from the 150 cross-section slices were analyzed to simulate the increase in the area investigated. The latter's size was varied by increasing the number of sections, β, considered simultaneously. Hence, grids containing $\beta \cdot N_p$ points were analyzed. The value of β was set equal to 1, 2, 4, 6, 8, 10, 15, 20, 30 and 50.

For each size of the area investigated (i.e., for each β value), a great number, θ, of combinations of β sections was examined, statistically combining the results. The sections were extracted randomly from the total 150, avoiding duplicates, and the average PBP and standard deviation provided by the grid subsets were determined.

The maximum number of subsets extracted for each β (i.e., θ) was limited to 5000 in order not to exceed the computational and storage capacity of the workstation used.

Finally, an uncertainty factor (UF) describing the deviation between the measured PBP and the actual VBP value was determined as shown in Eq. 1.

$$UF_{\beta=i} = \frac{\sigma(PBP_j)|_{\beta=i}}{\text{VBP}} \quad ; \quad j = 1, 2, \dots, j_{max} \tag{1}$$

where:

- $i = 1, 2, 4, 6, 8, 10, 15, 20, 30, 50$: values of β, representing the number of section planes analyzed simultaneously;
- j =number of subsets;
- j_{max}= number of subsets considered for each β = $min\left(\binom{150}{\beta}, \theta\right)$;
- $\sigma(PBP_j)|_{\beta=i}$= standard deviation of the PBP values provided by all the subsets considered for β =i;
- VBP= actual VBP of the complex formation simulated.

3 RESULTS AND DISCUSSION

The average PBPs and standard deviations were computed for each bimrock model as a function of the size of the outcrop area investigated, β. These results were then used to define the uncertainty factor, UF, defined as the ratio between standard deviation and mean (essentially the Coefficient of Variation) (Figure 3a). According to previous findings (Medley 1997 and Napoli et al. 2020, 2022), a decreasing trend of the UF as a function of β was obtained for each VBP value. Moreover, lower uncertainties in the measurements were found for higher VBPs.

The trend of the UF as a function of β was well approximated by a logarithmic law, as also evident in Medley (1997) and Napoli et al. (2020, 2022). The outcome of this approximation is shown in Figure 3b and Table 1. Figure 3b shows the lines to be used to adjust the PBP estimate in order to obtain a range of VBP, in which the actual 3D block quantity is contained.

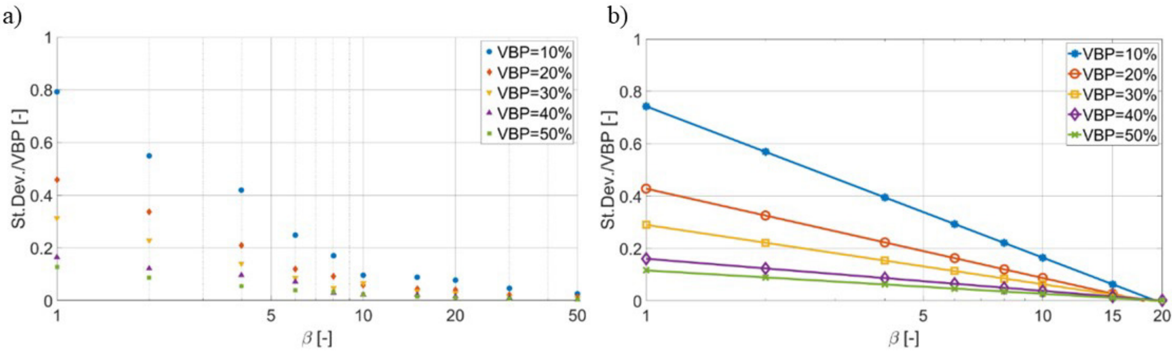

Figure 3. a) uncertainty in the VBP estimate via point counting, as a function of the grid dimension (expressed as multiples, β, of the number of points on one section, N_p) and real block contents (VBP); b) linear fitting of the uncertainty factors shown on a semi-logarithmic plot. (Note: symbols on trend lines are line markers and not data points).

Table 1. Specifications of the linear fittings of Figure 3b.

VBP [%]	Fitting equation	c1 [-]	c2 [-]	R^2 [-]
10		0.2509	0.7428	0.956
20		0.1481	0.4285	0.951
30	UF=-c1·ln(β)+c2	0.0984	0.2902	0.944
40		0.0533	0.1609	0.950
50		0.0388	0.1164	0.961

For example, in the case of a survey which yields an estimated PBP = 30% using a regular point grid with $3N_p$ points (i.e., $\beta = 3$) and spacing equal to $0.05L_c$, the UF would be equal to 0.18 and the real VBP can be computed as (30 ± 0.18x30) = 24.6÷35.4%. The lower value is appropriate for use in strength estimates from a chart of VBP vs strength; and the higher value for construction excavations (where blocks are defined as larger than $0.05L_c$).

3.1 Comparison between uncertainties in ABP and PBP measurements

The uncertainties in the VBP estimation via the point counting technique were compared to those related to 2D (ABP) measurements, as determined by Napoli et al. (2020). As shown in Figure 4, the results provided by the two methods are very similar, although for low β values slightly higher errors in VBP estimates are provided by PBPs compared to VBP estimates from ABP measurements.

For instance, if a survey which yields an estimated VBP = 30% is considered (i.e., the violet lines in Figure 4), using an investigation area three times larger than L_c^2 (i.e., $\beta = 3$), the UF are equal to 0.178 and 0.182 for the 2D and 0D measurements, respectively. Therefore, the real VBPs are:

VBP = ABP ± (UF x ABP) = 30 ± (0.178 x 30) = (24.7 ÷ 35.3)%

VBP = PBP ± (UF x PBP) = 30 ± (0.182 x 30) = (24.5 ÷ 35.5)%

which are almost equal.

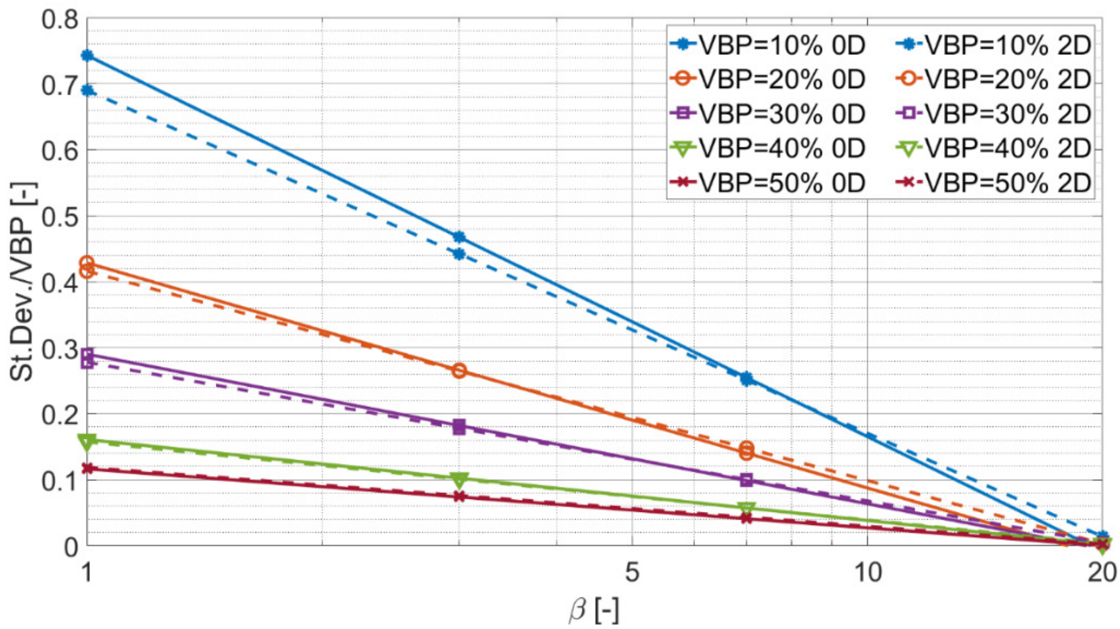

Figure 4. Comparison between UF values associated to PBP and ABP (Napoli et al., 2020) measurements. (Note: symbols on trend lines are line markers and not data points).

4 RESULTS AND DISCUSSION

This paper proposes the 0D point-counting approach as an alternative to both the 1D boring/scanline measurements (Lu et al. 2020, Medley 1997, Medley & Goodman 1994 and Napoli et al. 2022) as well as to the 2D method of Napoli et al. (2020) for estimating the VBP of bimrocks/bimsoils. The PBP approach is particularly well-suited when rapid observations are required in possibly difficult situations such as steep bare slopes, mine-pit walls or tunnel faces. A chart similar to that produced for the 1D and 2D approaches (Medley & Goodman 1994 and Napoli et al. 2020, 2022) was developed which, for a given size of the outcrop area investigated, β, allows VBPs to be estimated by adjusting PBPs with an uncertainty factor (UF).

A comparison with the chart obtained by Napoli et al. (2020) was performed, highlighting the strength of the procedure proposed in this research. In fact, the UFs found are fully comparable to those of the 2D approach.

Further research could be performed to develop an application for portable devices (smartphones, tablets, etc.) to allow 0D measurements to be easily carried out on site, by automatically generating and visualizing the grid on device screen.

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