Italian Journal of Engineering Geology and Environment
www.ijege.uniroma1.it

PRELIMINARY EVALUATION OF GEOELECTRICAL METHODS FOR THE QUANTIFICATION OF VOLUMETRIC BLOCK PROPORTION (VBP) OF MÉLANGES

Chiara CASELLE(*), Sabrina Maria Rita BONETTO(*) & Cesare COMINA(*)

(*)*University of Torino - Department of Earth Science - via Valperga Caluso 35, Torino (Italy)*
Corresponding author: chiara.caselle@unito.it

EXTENDED ABSTRACT

La presenza di unità caotiche con organizzazione interna di tipo block-in-matrix (e.g. *mélanges* e *broken formations)* comporta spesso varie problematiche connesse alla caratterizzazione geomeccanica. L'elevata eterogeneità, la distribuzione casuale dei blocchi all'interno della matrice e l'elevato contrasto in termini di competenza e di comportamento meccanico tra i blocchi e la matrice ne rendono difficile la parametrizzazione per la progettazione di scavi o di altre opere o per l'analisi di suscettibilità da frane. Per descriverne il comportamento, è necessario prendere in considerazione caratteristiche quali la resistenza meccanica dei blocchi e della matrice, l'eventuale allungamento e isorientazione dei blocchi, la complessità della matrice (intesa come presenza di isorientazione del fabric) e la percentuale dei blocchi all'interno della matrice (Nikolaidis & Saroglou, 2016; Napoli *et alii*, 2022).

In relazione alla scala dell'opera in progetto (quali ad esempio il diametro della galleria o la lunghezza del pendio in frana) è possibile stabilire una dimensione massima dei blocchi, al di sopra della quale la risposta meccanica può essere assimilata al comportamento della roccia intatta. Al di sotto di tale soglia, invece, l'unità caotica presenterà una risposta meccanica dovuta all'effetto combinato di blocchi e matrice (Medley & Lindquist, 1995). Secondo vari studi (Kalender *et alii*, 2014; Napoli *et alii*, 2018), il comportamento delle unità caotiche così definite (o bimrocks, secondo la definizione di Medley & Lindquist, 1995) risulta essere principalmente controllato dal parametro Volumetric Block Proportion (VBP), ovvero la percentuale di blocchi rispetto al volume totale dell'ammasso roccioso. Tale parametro, a seconda dell'approccio utilizzato, entra all'interno di formule empiriche per l'attribuzione di parametri meccanici (resistenza a compressione monoassiale, angolo di attrito) oppure viene utilizzato per creare il modello geologico su cui effettuare simulazioni ad elementi finiti.

La stima del parametro VBP viene tradizionalmente effettuata su affioramento, tramite stendimento lineare o tecniche di analisi d'immagine, o su carote di sondaggio, valutando la percentuale di blocchi presente sul totale dell'estensione lineare del sondaggio. Tuttavia, per consentire di rapportare le misure lineari o areali così ottenute all'ammasso roccioso nel suo insieme è necessario un elevato numero di punti di misura, che consenta di tenere conto della distribuzione tridimensionale dell'organizzazione blocco-in-matrice. I dati così ottenuti hanno inoltre un evidente problema di scala, legato alla difficoltà di quantificare blocchi di dimensioni superiori all'area in affioramento. Una stima attendibile del parametro VBP risulta molto dispendiosa in termini di tempo e richiede la disponibilità di un elevato numero di affioramenti ben rappresentativi dell'ammasso roccioso nel suo insieme o, in alternativa, di sondaggi, facendo aumentare il costo delle indagini in maniera spesso non sostenibile, in particolare per opere di modesta entità.

In questo studio proponiamo una metodologia alternativa per la stima del VBP, basata su indagini geofisiche indirette ed in particolare su tecniche geo-elettriche. Prendendo in considerazione il caso di formazioni caotiche con matrice argilloso-marnosa, tale matrice risulterà molto conduttiva rispetto al flusso di corrente elettrica, contrariamente ai blocchi di roccia al suo interno, che sono invece solitamente molto resistivi. Ciò rende le misure elettriche estremamente efficaci nel discriminarne la percentuale di blocchi all'interno del volume di roccia, dato che il valore di resistività misurato sull'unità caotica nel suo complesso deriverà da una media pesata in funzione delle frazioni dei due principali costituenti.

La potenzialità delle tecniche geoelettriche per questo scopo è stata valutata tramite simulazioni Monte Carlo. Attraverso un algoritmo Matlab sviluppato ad-hoc, sono stati generati in maniera casuale 31 modelli bidimensionali costituiti da blocchi di roccia e matrice in proporzioni note (VBP 25%, 40%, 60%). Tali modelli sono stati parametrizzati associando opportuni valori di resistività alla matrice e ai blocchi. Tramite il software Res2d_mod, è stato simulato il segnale corrispondente al passaggio di corrente tramite sequenza Wenner – Schlumberger attraverso 72 elettrodi posti lungo il bordo superiore dei modelli (che simula la superficie del piano campagna). Il segnale così ottenuto è stato sottoposto a procedimento di inversione tramite il software Res2d_inv e, per ciascun modello, è stato preso in considerazione il range di resistività ottenuto.

I risultati mostrano una ben riconoscibile proporzionalità tra il valore di VBP e il range di resistività, confermando le buone potenzialità dell'approccio geo-elettrico per la stima del parametro VBP. Tale approccio, per quanto non possa da solo sostituire l'osservazione diretta su affioramento o in sondaggio, consente di incrementare, con limitati costi di indagine, l'area indagata, migliorando l'affidabilità della stima del parametro, nonché la sua rappresentatività in contesti non direttamente accessibili.

IJEGE, Special Issue 1 (2023): 21-25, DOI: 10.4408/IJEGE.2023-01.S-03
E-ISSN 2035-5688 | ISSN 1825-6635 / ©Author(s)

ABSTRACT

Chaotic rock units (including mélanges, broken formations and complex formations) represent some of the most challenging rock masses for technical characterization. The most commonly accepted methods for the parametrization of mechanical properties in these rocks require the quantification of the percentage of rock blocks on the total volume of the rock mass (i.e. the Volumetric Block Proportion – VBP). Traditional methods for the quantification of VBP are often time consuming and expansive, requiring a large number of accessible outcrops and/or drilling boreholes. In this study, we propose an alternative methodology for the estimation of VBP based on indirect (geo-electrical) measures. We considered chaotic units with soft clay-rich (low resistivity) matrix and hard (high resistivity) blocks. In these conditions, geoelectrical surveys are suited for the quantification of matrix percentage. In order to evaluate the applicability of geoelectrical techniques in this context, we realized 31 simulations, following a Monte Carlo stochastic approach. The good direct relationship between VBP and modeled electrical conductivity confirms the suitability of the ERT methodology for the estimation of VBP in chaotic units.

***Keywords**: chaotic rock units, bimrocks, mechanical characterization, Electrical Resistivity Tomography (ERT), Monte Carlo simulation*

INTRODUCTION

Chaotic rock units, including mélanges and broken formations, represent a wide range of internally disrupted and mixed rocks, which differ from coherent successions or rock assemblages as characterized by blocks embedded in a pervasively deformed matrix (i.e., block-in-matrix fabric), without restriction to any particular lithological unit (e.g., Festa *et alii*, 2019). For geo-engineers, chaotic units represent one of the most tricky challenges due to their high heterogeneity, their chaotic organization and the strength contrast between the different elements (blocks and matrix). In many contexts, due to the difficulty of classification and characterization, engineering projects on chaotic formations are cautelatively designed only considering the mechanical features of the matrix, neglecting the contribution of blocks to the overall strength. However, this assumption leads to inaccurate modeling of the behaviour of the rock mass (e.g. homogeneous yielded zones and stress distributions instead of tortuous yielded zones controlled by the blocks distribution, overestimation of strains, unexpected and unpredicted oversized blocks). This inaccuracy may in turn lead to inappropriate and over-conservative models (i.e. uneconomical predictions) and to unexpected technical problems during engineering works, with possible significant economic repercussions.

In the last decades, several studies focused on the definition of an appropriate methodology for the characterization of these geological complex rock units. For geo-engineering purposes, Medley (1994) introduced the definition of "bimrock" (acronymous of the term block-in-matrix rock of geologists, see Raymond, 1984), that refers to rock masses "composed of geotechnical significant blocks within a bonded matrix of finer texture". In this context "geotechnical significant blocks" means that there is sufficient mechanical contrast between blocks and weaker matrix (Medley, 1994). In these geo-mechanical conditions, several authors suggested that the mechanical response of a bimrock is mainly controlled by a parameter defined VBP (Volumetric Block Proportion), i.e. the percentage of rock blocks on the total volume of the rock mass (Kalender *et alii*, 2014; Nikolaidis & Saroglou, 2016; Napoli *et alii*, 2018, 2022a, 2022b).

For an appropriate design of engineering projects in presence of bimrocks it is therefore necessary to obtain an accurate estimation of the VBP. However, in the common practice, the definition of this parameter is not straightforward. The traditional methodological approaches include 1D measurements (linear block proportions, LBPs) on drilling boreholes or linear scanlines on outcrops or 2D measurements (areal block proportions, ABPs), often performed with automatic or semi-automatic elaboration of photographic images. It is assumed that linear or areal data may be confidently equalized to VBP (i.e. LBP = ABP = VBP). Nevertheless, several bias may be found using these approaches, especially in case of insufficient number of measures or strongly anisotropic bimrocks. The block-in-matrix fabric may show different degrees of anisotropy. Moreover, depending on the outcrop orientation with respect to the shape and distribution of blocks, the evaluation of the VBP may differ. For example, in case of high planar anisotropic texture with elongated blocks (e.g. sheared chaotic rock units), the VPB estimation differs from the section view parallel to the block long axis to that one parallel to the block short axis. Therefore, 1D or 2D methodological approaches could result over- or underestimated. Moreover, a proper application of these methodological approaches requires direct access to several outcrops of the rock mass (for ABP) or the execution of expansive drilling holes (for LBP), causing, in some cases, the impossibility to acquire the large amount of data necessary to reduce the measure biases.

For all these reasons, in this study, we propose and discuss the applicability of an alternative methodological approach for the measure of VBP in bimrocks based on indirect non-destructive (geo-electrical) measures. Through the implementation of a Monte Carlo simulation, we evaluate the capability of Electrical Resistivity Tomographies (ERTs) to correctly estimate the percentage of blocks in 2D geological sections.

METHODS

For definition, bimrocks consists of two main elements (matrix and blocks) with significant geotechnical difference. Considering the case of soft BIM rocks (*sensu* Napoli *et* *alii*, 2022b), we consider a softer matrix manly consisting of argillaceous sediments and/or strongly sheared, fissured or fractured. The presence of clays implies a very high electrical conductivity (i.e. low electrical resistivity). In case of water saturation, also the presence of fissures and fractures corresponds to high conductivity values. Conversely the herder blocks, consisting of compact rock, have usually high resistivity values.

In these conditions, electrical surveys are able to discriminate among rock blocks and matrix. However, due to resolution limitations, the ERTs will only be able to clearly identify the biggest blocks. In the remaining portions of the bimrock, the ERT section will show a homogeneous resistivity value that is the result of the electrical effect of both "good quality-high resistivity" blocks and low resistivity matrix.

The aim of this study is therefore to evaluate the possibility to use this "averaged" resistivity value to retrieve the two-dimensional ABP of the bimrock. At this purpose, we performed 31 electrical simulations with the modeling software of the Res2dInv suit on simulated geological sections with pre-defined values of ABP.

Following the procedure proposed by Napoli *et alii*, 2018, the geological sections were randomly generated by a specifically developed Matlab algorithm, in order to simulate the random spatial and dimensional distribution of the rock blocks in a real chaotic unit. For each considered level of ABP, ten 2D sections were generated and, hence, ten resistivity models were created in order to consider the statistical variability.

DEFINITION OF THE 2D RESISTIVITY SECTIONS

The size distribution of blocks in chaotic units was observed to follow a given frequency function that can be written as (Napoli *et alii*, 2018):

$$f(d) = -\frac{1+q}{a^{1+q} - b^{1+q}} d^q$$

with an associated probability distribution:

$$F(d) = -\frac{a^{1+q} - d^{1+q}}{a^{1+q} - b^{1+q}}$$

where q is the fractal dimension, here assumed equal to –2.3, and a and b are the minimum and maximum diameter of the blocks, respectively. Following the bimrock's definitions (Wakabayashi & Medley, 2004), these minimum and maximum values may be fixed as the 5% and 75% of the "engineering characteristic length", i.e. the size of the considered engineering project. For our simulations, we considered a hypothetical tunnel with diameter of 7m, and hence fixed minimum and maximum block diameters to 0.35 m and 5.25 m respectively.

Based on this frequency distribution, the ad-hoc written Matlab code randomly generates a number of circles' diameters and center coordinates. The circles are fitted in the 2D sections (with sizes of 57m x 10m), that is sampled in a grid of 285 x 50 cells (in agreement with the requirements of Res2D_mod software). The number of circles is increased up to reach the pre-fixed value of ABP (25% - 40% - 60%). An example of 2D section with ABP value of 40% is shown in Fig. 1a. In each section, a 2m thick layer of clay-rich (i.e. conductive) cover was also included. Eventually, one model only consisting of matrix (i.e. 0% end-member) was created.

MODELING OF RESISTIVITY RESPONSE

The 31 so-created 2D sections were imported in Res2d_mod software to simulate the distribution of electrical signal. At this purpose, resistivity values of 10 Ohm m and 10 000 Ohm m were attributed to matrix and rock blocks respectively.

We simulated the presence of 72 electrodes with spacing of 0.8 m and a Wenner-Schlumberger signal acquisition array. The so-generated apparent resistivity sections (Fig. 1b) were then imported in the Res2d software for the inversion (Fig. 1c). The resulting resistivity section were used to evaluate the resistivity range. In particular, we decide to consider the entire range of resistivity identified by the inversion. In the example section (Fig. 1c), this corresponds to resistivity values ranging from 18 Ohm m (yellow) and 57 Ohm m (purple).

RESULTS

The results of the simulations show a clear positive relationship between the modeled resistivity and the correspondent value of ABP (Fig. 2). In the Figure, the resistivity ranges from 10 Ohm m (end-member with only matrix) to few hundreds Ohm m (ABP = 60%). The results allow for a distinction among the selected ABP values of 25%, 40% and 60%, corresponding to resistivity ranging from 12 to 50 Ohm m, from 20 to 100 Ohm m and from 50 to 400 Ohm m respectively. Empirical relationships may be therefore created to retrieve the ABP value from geo-electrical measure, after opportune calibration for the resistivity characteristics and maximum and minimum sizes of the rock blocks.

CONCLUSIONS

Bimrocks represent one of the most challenging geological contexts for the rock mass characterization. The most generally accepted classification methods for the characterization of mechanical response require the estimation of the VBP parameter that describes the percentage of blocks on the total volume of the rock mass. However, the correct estimation of this parameter is non-trivial and requires a big number of outcrops and/or drilling cores. For this reason, we propose here an alternative methodology based on non-destructive geo-electrical surveys. We report in this study the resistivity modeling of 31 geological sections randomly generated based on pre-fixed values of ABP (the 2-dimensional correspondent of VBP). The results of resistivity models show that the resistivity ranges obtained in the simulated ERTs have

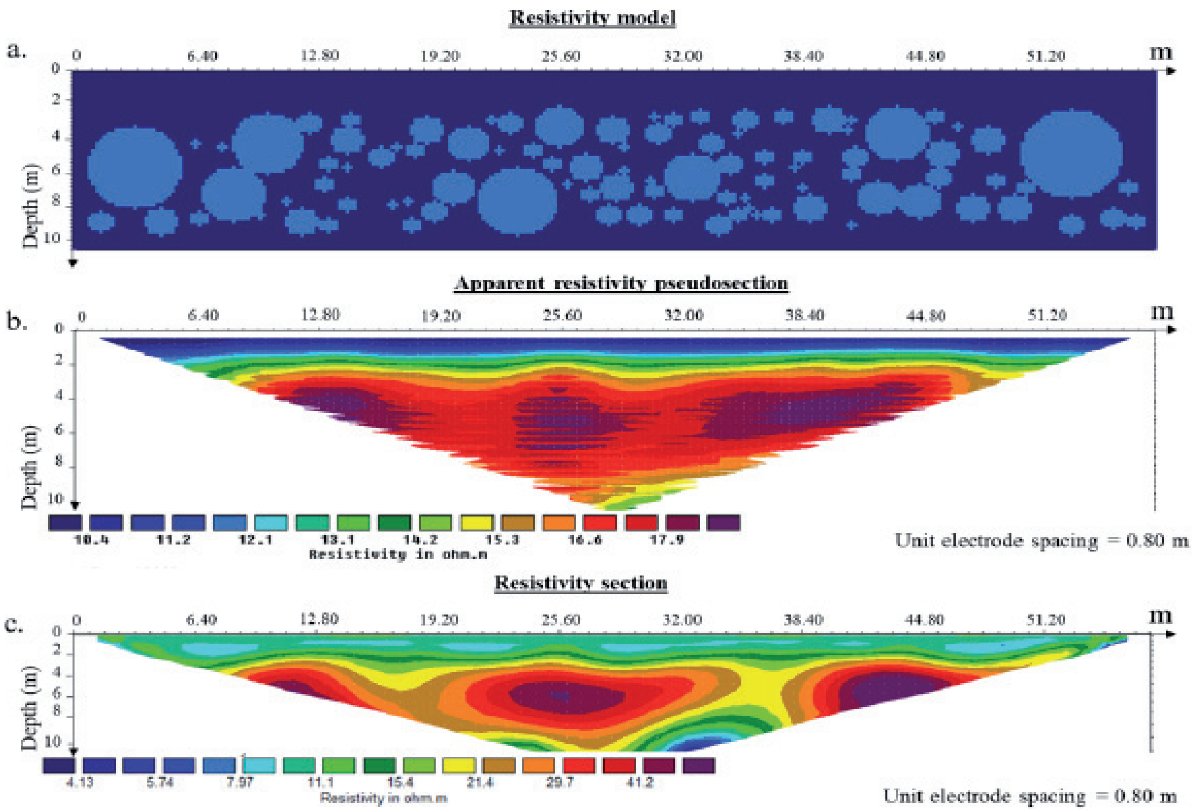

Fig. 1 - a. Example of resistivity model for a value of ABP = 40%. The center coordinates and the relative diameters were randomly generated by the Matlab algorithm; b. Apparent resistivity pseudosection generated by Res2d_mod software; c. Resistivity section after inversion with Res2d software. The section identifies the 2m thick cover layer and returns the bimrock volume as a homogeneous unit, with resistivity values ranging from 18 Ohm m (yellow) and 57 Ohm m (purple)

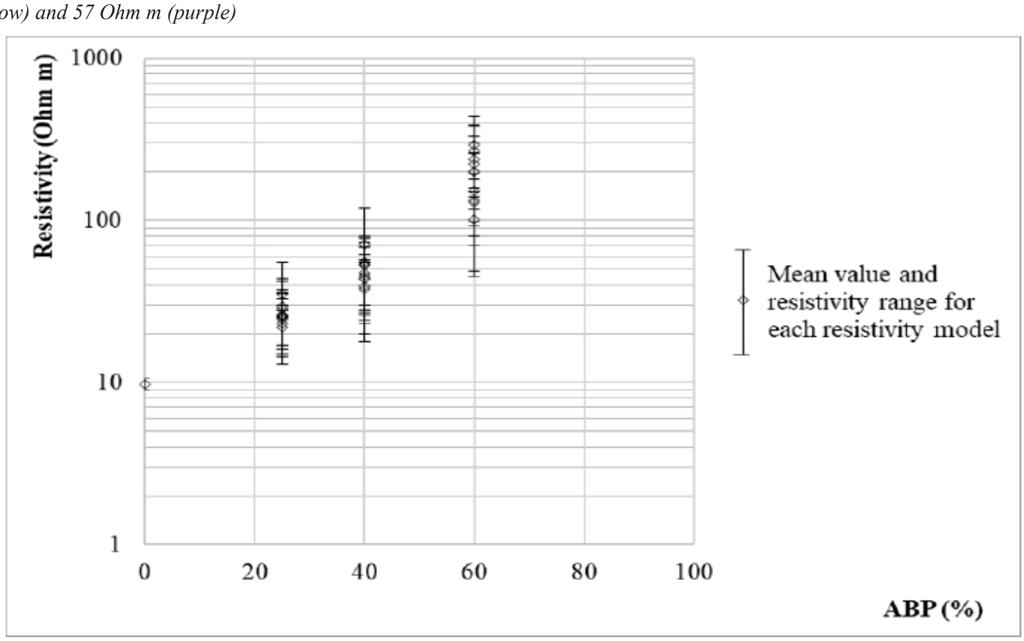

Fig. 2 - Range of resistivity obtained for the 10 resistivity model performed for each selected value of ABP. The ABP = 0%, with resistivity = 10 Ohm m, was also included

a positive proportionality with the correspondent ABPs and could be therefore used its estimation. These promising results suggest the good potentialities of geo-electrical methods for the investigation and characterization of bimrocks.

Despite they cannot replace traditional analysis approaches, they may indeed represent a fast and low-cost approach to increase the number of data, especially in not-accessible areas accessible areas.

REFERENCES

FESTA A., PINI G.A. OGATA K. & DILEK Y. (2019) - *Diagnostic features and field-criteria in recognition of tectonic, sedimentary and diapiric mélanges in orogenic belts and exhumed subduction-accretion complexes*. Gondwana Research, **74**: 7-30.

KALENDER A., SONMEZ H., MEDLEY E., TUNUSLUOGLU M. & KASAPOGLU K.E. (2014) - *An approach to predicting the overall strengths of unwelded bimrocks and bimsoils.* Engineering Geology, **183**. https://doi.org/10.1016/j.enggeo.2014.10.007

MEDLEY E. & LINDQUIST E. (1995) - *The engineering significance of the scale-independence of some Franciscan melanges in California*. In: Daemen, J.J.K. & Schultz, R.A. - Proceedings of the 35th U.S. Symposium on Rock Mechanics, CRC Press.

NAPOLI M.L., BARBERO M., RAVERA E. & SCAVIA C. (2018) - *A stochastic approach to slope stability analysis in bimrocks.* International Journal of Rock Mechanics and Mining Sciences, **101**: 41–49. https://doi.org/10.1016/j.ijrmms.2017.11.009

NAPOLI M.L., MILAN L., BARBERO M. & MEDLEY E. (2022) - *Investigation of Virtual Bimrocks to Estimate 3D Volumetric Block Proportions from 1D Boring Measurements.* Geosciences, **22**. https://doi.org/10.3390/geosciences12110405

NAPOLI M.L., FESTA A. & BARBERO M. (2022B) - *Practical classification of geotechnically complex formations with block-in-matrix fabrics*. Engineering Geology **301**: 106595. https://doi.org/10.1016/j.enggeo.2022.106595

NIKOLAIDIS G. & SAROGLOU C. (2016) - *Engineering geological characterisation of block-in-matrix rocks*. Bulletin of the Geological Society of Greece **50**: 874–884. https://doi.org/10.12681/bgsg.11793

RAYMOND L.A. (1984) - *Classification of melanges*. In: RAYMOND L.A. (Ed.), *Melanges: Their Nature, Origin and Significance.* Boulder, Colorado Geological Society Of America Special Papers, **198**: 7–20.

WAKABAYASHI J. & MEDLEY E. (2004) - *Geological characterization of Melanges for practitioners.* Felsbau 22.

Received February 2023 - Accepted March 2023