3D Slope Stability Analyses of a Complex Formation with a Block-in-Matrix Fabric

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3D slope stability analyses of a complex formation with a block-in-matrix fabric

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Abstract
Heterogeneous rock bodies composed of strong rock blocks surrounded by a weaker finer-grained matrix are often referred to as "BIMrocks" (Block-In-Matrix rocks). These complex formations present a high spatial, dimensional and lithological variability, which makes their characterization an extremely challenging task. As a consequence, geopracticioners have often planned engineering works in bimrocks ignoring the presence of the stronger rock inclusions. However, it is essential that blocks be considered in the analyses in order to obtain reliable results. In fact, rock inclusions strongly affects the strength, deformability and failure surfaces of these geomaterials.
In this paper 3D stability analyses are performed with the FLAC 3D code on slope models with variable Volumetric Block Proportions (VBP) to investigate the influence of the rock inclusions on their stability. In order to take the inherent variability of bimrocks into account, a Matlab code was implemented to generate spherical blocks of variable dimensions and locate them randomly within the slope models. Moreover, the stability of a matrix-only slope model is also analyzed by way of comparison. Finally, the paper compares and comments on the results of 2D numerical simulations previously carried out by the author for the same complex block-in-matrix formation.

Keywords: complex formations, block-in-matrix rocks, slope stability, volumetric block proportion

1 Introduction

Bimrocks are heterogeneous rock bodies composed of strong blocks embedded in a weaker finer-grained matrix. These complex formations present a chaotic arrangement and a high spatial, dimensional and lithological variability, which makes the collection of representative samples for laboratory testing extremely challenging. Hence, the determination of the geomechanical properties of bimrocks is extraordinary problematic (Goodman and Ahlgren, 2000; Medley, 2007). As a consequence, geopracticioners have often planned engineering works in bimrocks assuming the rock mass to be an

ideal isotropic and homogeneous continuum (i.e. completely neglecting the presence of the stronger rock inclusions), to the detriment of accurate results. In fact, as proved by several case histories reported in the literature and by many works published so far, it is essential that blocks be taken into account in the analyses in order to obtain reliable outcomes (Button et al., 2004; Medley, 2001; Wakabayashi and Medley, 2004). Laboratory and in-situ tests as well as numerical analyses performed on these geomaterials have shown that rock inclusions (their volumetric proportion, shape, position and orientation) strongly affects the strength, deformability and failure surfaces of these geomaterials. In particular, the presence of the blocks adds strength to bimrocks by forcing failure surfaces to negotiate tortuously around the blocks (Afifipour and Moarefvand, 2014; Coli et al., 2009; Lindquist, 1994; Medley, 1994; Medley and Sanz Rehermann, 2004; Napoli et al., 2018a, 2018b).
Furthermore, ignoring the presence of the hard blocks of rock during the characterization and design phases may lead to unpleasant technical problems and expensive surprises during construction works (Button et al., 2004; Kim et al., 2004; Medley, 2002).
In this paper 3D slope stability analyses in bimrocks are performed on simple slope models with variable Volumetric Block Proportions (VBP), to numerically investigate the influence of the rock inclusions on their stability. The analyses are performed using the FLAC3D code. In order to take the inherent variability of these geomaterials into account, a Matlab code is used to generate spherical blocks of different dimensions, according to specific statistical rules. The code also allows to locate randomly the rock blocks within the slope models. Moreover, the stability of a homogeneous equivalent material (i.e., 0% VBP configuration) is also analyzed by way of comparison. Finally, the paper compares and comments on the results of 2D stability analyses performed by the author (Napoli et al., 2018a) for the same complex block-in-matrix formation.

2 Slope stability analyses

The aim of this research was to evaluate how the presence of rock blocks may influence the stability of slopes in bimrocks, by means of numerical simulations performed on simple geometries. The differences, advantages and disadvantages of performing 2D rather than 3D numerical simulations are also highlighted. The 3D analyses were carried out with the Finite Difference Method, implemented in FLAC3D, on the same complex formation analyzed by the author in a recent work (Napoli et al., 2018a). Here, 2D Finite Element (FEM) stability analyses were performed on heterogeneous slopes composed of circular rock blocks enclosed in a softer matrix, by means of a stochastic approach. In particular, to take the inherent spatial and dimensional variability of the bimrock into account, a Matlab code, performing Monte Carlo simulations, was implemented. The code generated circular blocks with random dimensions and positions within the slope geometry, according to specific statistical rules and given rock contents. To achieve a statistical validity of the results, ten extractions (i.e. ten stability analyses) were performed for VBPs equal to 25%, 40%, 55% and 70%.

In order to compare the results, the 3D slopes were created and assigned the same geometric characteristics (i.e., height and slope ratio), mechanical properties and constitutive model used by Napoli et al. (2018a). The rock inclusions were generated by means of the same Matlab code, adequately modified to produce spherical 3D blocks. However, according to the study of Song *et al.* (2008), the highest VBP considered in the 2D analyses (i.e., 70 VBP) could not be obtained in a 3D model. Hence, 3D slope models with 15%, 25%, 40% and 53% (i.e. the maximum VPB achievable) VBPs were examined. An example is given in Fig. 1.

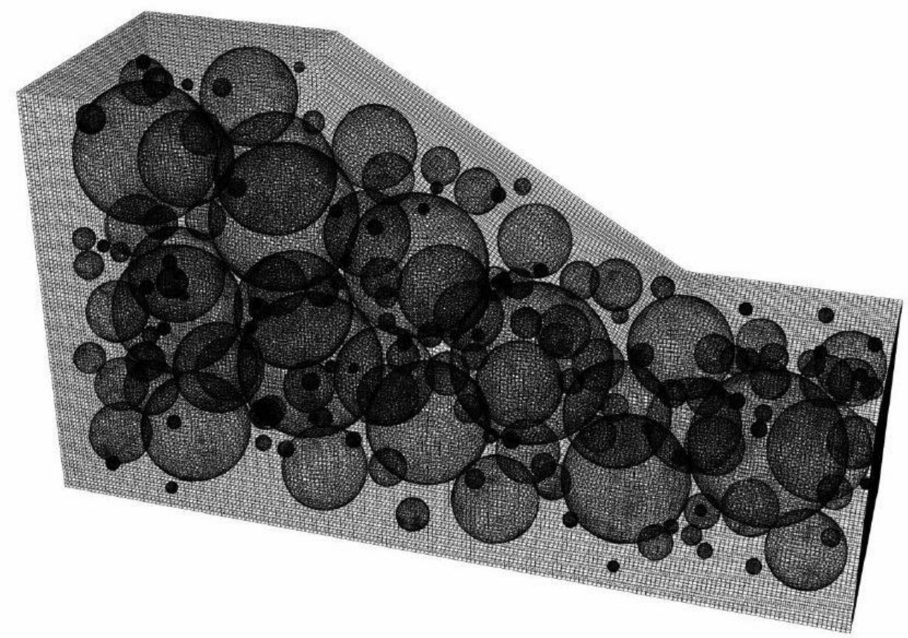

Fig. 1 The 40% VBP slope model analyzed with FLAC3D

A 0% VBP configuration (i.e. a matrix-only slope model) was also analyzed in order to evaluate potential inaccuracies arising from a simplified design approach, based on the strength and deformation properties of the matrix only.

3 Results

The safety factors (SF) corresponding to the global minimum stability state, obtained by applying the Strength Reduction Factor technique, are reported in Table 1 for the different VBPs considered. The results show a clear trend toward increasing SFs with increasing VBPs, even for low rock contents.

Table 1 Average SFs and standard deviations yielded by the 3D analyses

VBP [%]	SF [-]	Standard deviation [-]
0	1.12	-
15	1.18	-
25	1.25	0.047
40	1.41	-
53	1.52	0.079

Shear strain contour plots illustrated in Fig. 2 show that the presence of blocks of different sizes and positions within each bimrock configuration considerably influence shear strain concentrations and, hence, the position and shape of failure surfaces. In fact, the failure surfaces of the heterogeneous models are far different from that of the homogeneous matrix-only model. In particular, the presence of the blocks makes the failure surfaces more tortuous and superficial with increasing VBP. As a consequence, higher SFs and smaller volumes involved are obtained for greater rock contents.

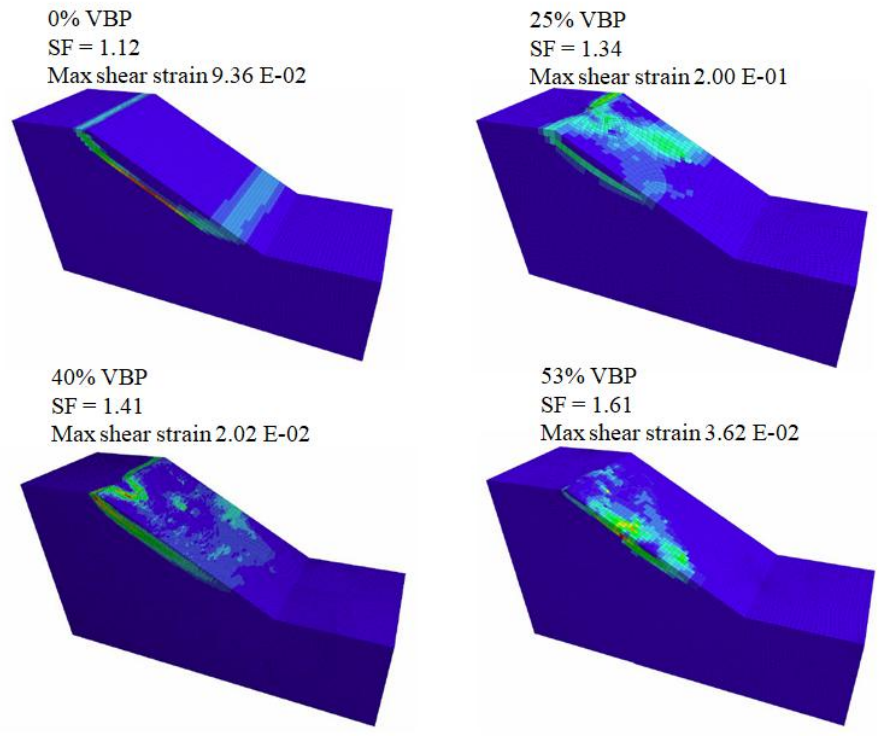

Fig. 2 Maximum shear strains for one of the ten configurations analyzed for VBPs equal to 0%, 25%, 40% and 53%.

This outcome is in accordance with previous results from the literature (Irfan and Tang, 1993; Napoli et al., 2018a, 2018b). In particular, this study confirms that an important underestimation of the safety factor and a wrong position of the failure surface (with a significant overestimation of the volume involved) is provided by a simplified design approach, which ignores the presence of the blocks within the bimrock.
Fig. 3 compares the results obtained in this research with the SFs yielded by the 2D analyses from Napoli et al. (2018a). Although 3D SFs are greater than the average 2D SFs, it is possible to notice that the same clear trend toward increasing SFs with increasing VBPs is registered.

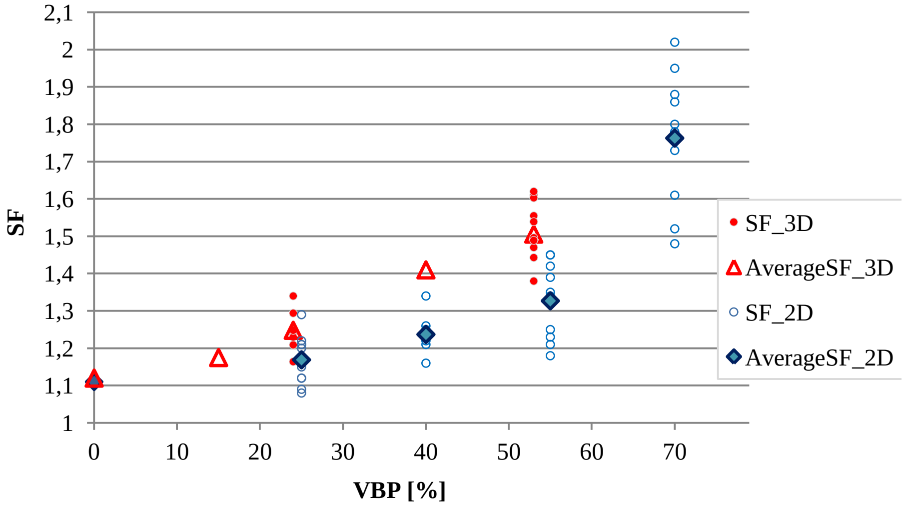

Fig. 3 Comparison of the SFs obtained from the 2D and 3D numerical analyses. The 3D SFs of the 25% VBP configurations were slightly shifted on the left to avoid graphical overlapping.

However, since a high data dispersion was provided by the 2D simulations, further 3D slope models with the same VBP should be analyzed to achieve a statistical validity and better compare the results obtained. Hence, the stochastic approach used by Napoli et al. (2018a) was applied to generate 9 more configurations with 25% (the smallest VBP analyzed with both the 2D and 3D methods) and 53% VBPs (the maximum VBP analyzed with the 3D method).
The SFs and the standard deviations obtained, reported in Table 2, indicate that a lower data scattering is obtained from 3D rather than from 2D simulations. Moreover, these results confirm that higher SFs are provided by the 3D simulations.

Table 2 Average SFs and standard deviations of the ten 25% and 53%-55% VBP configurations analyzed with the 2D and 3D methods.

	2D analyses		3D analyses	
	VBP = 25%	VBP = 55%	VBP = 25%	VBP = 53%
Average SF	1.17	1.33	1.25	1.52
Standard deviation	0.067	0.102	0.047	0.079

In order to validate the results of the ten 25% and 53% VBPs 3D analyses, a t-Student confidence interval was calculated for the SFs, using a significance value, α, equal to 0.05 (i.e. a confidence level of 95%). With a t value ($t_{1-\alpha/2} = t_{0,975}$) of 2.26, corresponding to n=9 degrees of freedom, it was found a SF confidence interval of 1.21-1.28 for 25% VBP and 1.46-1.58 for 53% VBP. These intervals, containing the true average SFs with 95% probability, can be considered acceptable and confirm that 10 extractions are sufficient to achieve a statistical validity of the results, as observed with the 2D FEM analyses.

6 Discussions and conclusions

In this work 3D numerical analyses were carried out with FLAC3D to evaluate how the presence of rock blocks affect the stability of slopes in bimrocks. VBPs from 0% to up to 53% are considered in the analyses, since this is the maximum rock content achievable with a 3D model. Furthermore, a comparison with the results of 2D numerical simulations performed in a recent study by Napoli et al. (2018a) is made. In order to do this, the 3D slopes were created and assigned the same geometrical and mechanical properties of the 2D models. The stochastic approach used by Napoli et al. (2018a) to take the high variability of bimrocks into account was applied to generate ten configurations with 25% and 53% VBPs. The aim was to achieve a statistical validity of the SFs obtained and better compare the two works.
The results obtained confirm previous findings from the literature. In fact, they (i) show that the presence of rock inclusions strongly influence the behavior of the rock mass, increasing its overall strength, and (ii) demonstrate that the simplified approach (i.e. the 0% VBP model), which neglects the presence of the blocks, is over conservative and leads to a failure surface with unrealistic shape and position. From the comparison with the results of the 2D FEM analyses, it is found that for a given VBP the 3D simulations provide higher SFs and a lower data dispersion. This outcome could be due to the different confinement of the 3D models with respect to the 2D models, which should lead to more reliable results. However, to reduce considerably the computational time (from up to 5 days to less than 8 hours per simulation) the authors argues for a stochastic 2D modelling. In fact, potential mistakes resulting from 2D rather than 3D analyses should be found to lie on the side of safety.

References

Afifipour, M., Moarefvand, P., 2014. Mechanical behavior of bimrocks having high rock block proportion. Int. J. Rock Mech. Min. Sci. 65, 40–48.

Button, E., Riedmueller, G., Schubert, W., Klima, K., Medley, E., 2004. Tunnelling in tectonic melanges-accommodating the impacts of geomechanical complexities and anisotropic rock mass fabrics. Bull. Eng. Geol. Environ. 63, 109–117. https://doi.org/10.1007/s10064-003-0220-7

Coli, N., Berry, P., Boldini, D., Bruno, R., 2009. In situ large size non conventional shear tests for the mechanical characterization of a bimrock in The Santa Barbara open pit mine (Italy), in: 43rd US Rock Mechanics Symposium and 4th U.S.-Canada Rock Mechanics Symposium. American Rock Mechanics Association This, Asheville, NC June 28th – July 1, 2009.

Goodman, R.E., Ahlgren, C.S., 2000. Evaluating Safety of Concrete Gravity Dam on Weak Rock: Scott Dam. J. Geotech. Geoenvironmental Eng. 126, 429–442. https://doi.org/10.1061/(ASCE)1090-0241(2000)126:5(429)

Irfan, T.Y., Tang, K.Y., 1993. Effect of the coarse fractions on the shear strength of colluvium. Geo Report 23.

Kim, C., Snell, C., Medley, E., 2004. Shear strength of Franciscan complex melange as calculated from back-analysis of a landslide. 5th Int. Conf. Case Hist. Geotech. Eng.1, 8.

Lindquist, E.S., 1994. Strength and Deformation Properties of Melange. Ph.D. Thesis. University of California, Berkeley.

Medley, E.W., 2007. Bimrocks - Part 1: Introduction. Newsl. Hell. Soc. Soil Mech. Geotech. Eng. Athens, Greece 17–21.

Medley, E.W., 2002. Estimating Block Size Distributions of Melanges and Similar Block-in-Matrix Rocks (Bimrocks). Proc. 5th North Am. Rock Mech. Symp. 509–606.

Medley, E.W., 2001. Orderly Characterization of Chaotic Franciscan Melanges. Felsbau 19.

Medley, E.W., 1994. The engineering characterization of melanges and similar Block-in-matrix rocks (Bimrocks). Ph.D. Thesis. University of California at Berkeley.

Medley, E.W., Sanz Rehermann, P.F., 2004. Characterization of Bimrocks (Rock/Soil Mixtures) With Application to Slope Stability Problems. Eurock 2004 53rd Geomech. colloquium.

Napoli, M.L., Barbero, M., Ravera, E., Scavia, C., 2018a. A stochastic approach to slope stability analysis in bimrocks. Int. J. Rock Mech. Min. Sci. 101, 41–49. https://doi.org/10.1016/j.ijrmms.2017.11.009

Napoli, M.L., Barbero, M., Scavia, C., 2018b. Analyzing slope stability in bimrocks by means of a stochastic approach, in: European Rock Mechanics Symposium, EUROCK 2018. 22-26 May 2018, Saint Petersburg.

Song, C., Wang, P., Makse, H.A., 2008. A phase diagram for jammed matter. Nature 453,629–632.

Wakabayashi, J., Medley, E.W., 2004. Geological Characterization of Melanges for Practitioners. Felsbau 22, 10–18.