Rock Cut-Slope Quarry Assessment (NW Portugal): A Preliminary Hazard Assessment

Luís Ramos, Ana Mendes, José Filinto Trigo, Fernando Pedro Figueiredo, Liliana Freitas, Maria José Afonso, and Helder I. Chaminé

Abstract

To safeguard the operations in rock quarrying, it is required to evaluate slope stability hazards systematically. This work investigates the slope stability in a rock quarry in NW Portugal and demonstrates the significance of geological, geotechnical, and geomechanical in situ investigations. The rock mass is a monzogranite, medium-grained, two-mica, essentially biotitic, predominantly fresh to slightly weathered (W_{1-2}) to moderately weathered (W_3), and highly fractured. The geomechanical classifications and geotechnical indexes RMR, GSI, SMR, SQR, and Q-Slope allowed five geomechanical zones. Globally, the Southern part of the quarry has a fair to very good quality and the Northern part has a poor to fair quality. Three cut-slopes were studied in the Northern part of the quarry, which was considered unstable to partially stable. Several potential failures may occur, namely wedge slides and toppling failures. The application of the RHRSm2 system and the SQI permitted the classification of the cut-slopes with a high to very high-risk level and an urgent to very urgent intervention. RocFall and Swedge Rocscience software were used to model block fall in different areas and potential rock failures.

Keywords

Cut-slope • Quarry • Slope stability • Hazard assessment

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1 Introduction

The hazard assessment of rock slopes is a vital issue for risk analysis in quarries. The geomechanical characteristics of rock masses, the geometrical parameters of slopes, and external factors, like precipitation and blasting, are among the most critical parameters that can lead to rock slope failures (e.g., Wyllie & Mah, 2004).

In Northern Portugal, rockfalls are a common rock slope instability (Trigo et al., 2020). This work assesses the stability of several cut-slopes in a granitic quarry, where there is a history of frequent falling blocks with different shapes and dimensions.

2 The Curviã Rock Quarry

The rock cut-slopes are in the Curviã quarry (Joane, V. N. Famalicão, NW Portugal; see Fig. 1). The geological unit that outcrops in the study area is a monzogranite, medium-grained, with a porphyric tendency, two-mica, essentially biotitic (Montenegro de Andrade et al., 1986). The rock mass is predominantly fresh to slightly weathered (W_{1-2}) to moderately weathered (W_3) and highly fractured.

In the first stage, this work involved a geological, geomorphological, and hydrological description of the area and, later, geotechnical and geomechanical in situ surveys and investigations. Next, the scanline surveys were used to study the free rock mass surfaces (ISRM, 2007). Then, the geostructural data were analysed with Dips (Rocscience software). Also, the weathering grade and rock strength were evaluated considering the ISRM (2007) recommendations. Finally, all the information was collected in a geodatabase,

A. Malheiro et al. (eds.), *Advances in Natural Hazards and Volcanic Risks: Shaping a Sustainable Future*, Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-031-25042-2_29

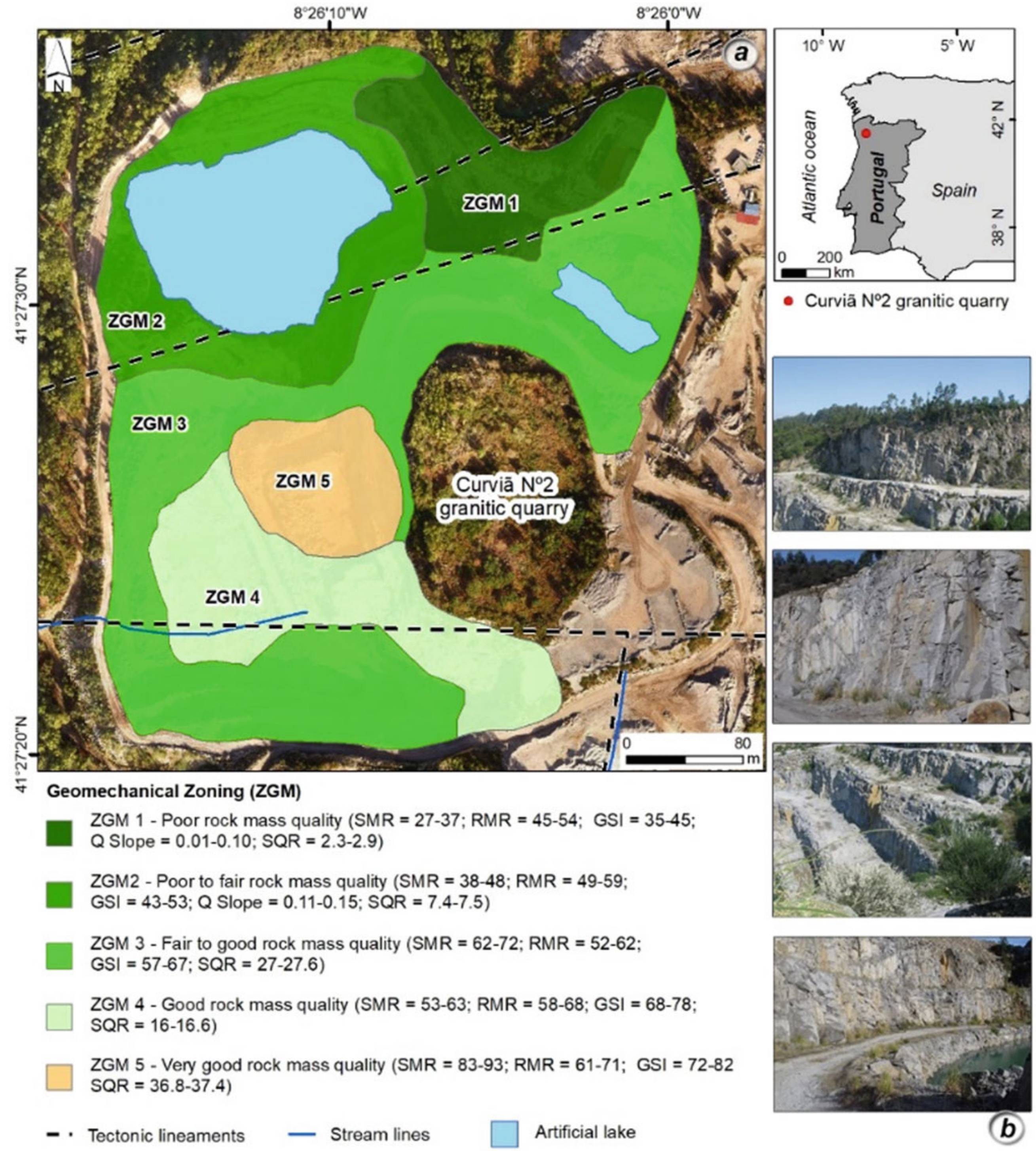
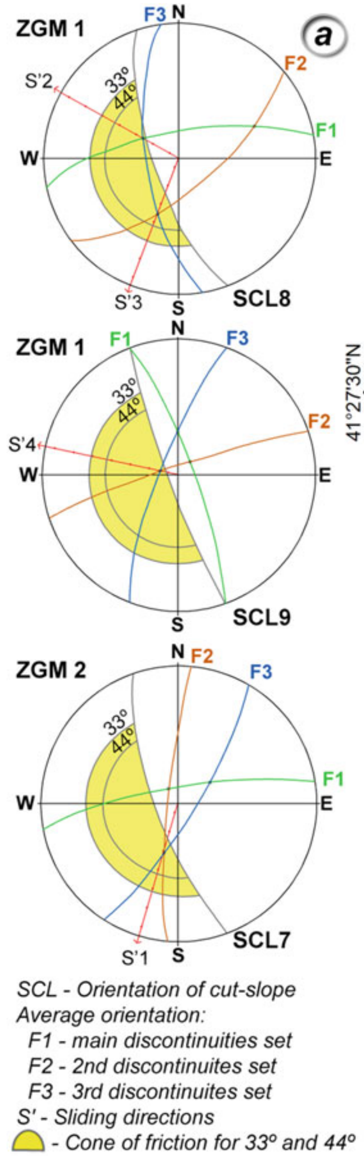
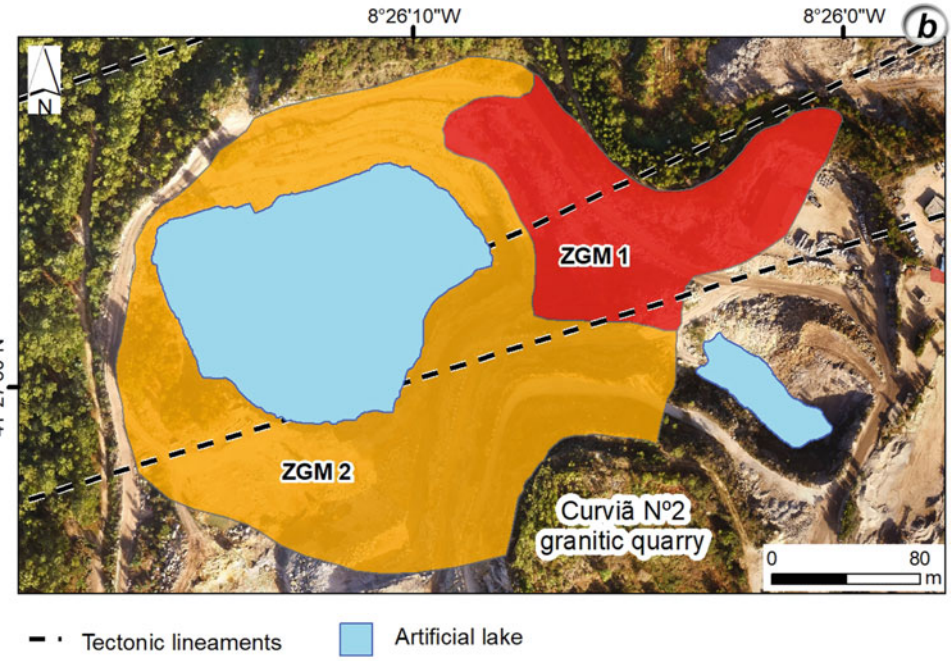


Fig. 1 Curviã quarry. **a** Geomechanical zoning; **b** several aspects of the benches and cut-slopes

and geotechnical and geomechanical zoning mapping was performed.

To assess the rock mass quality was used rock mass classifications and geotechnical indexes, such as: Rock Mass Rating (Bieniawski, 1989); Geological Strength Index (Hoek et al., 2013); Q-system (Barton et al., 1974; NGI, 2015); Slope Mass Rating (Romana, 1985); Slope Quality Rating (Fereidooni et al., 2015) and Q-Slope (Barton & Bar, 2015). Moreover, SMR, SQR, and Q-Slope, the Markland Test (Wyllie & Mah, 2004), and the Eurocode 7 (NP EN 1997-1, 2010) were applied for the stability analysis. The susceptibility and level of geotechnical risk were evaluated using the





Geomechanical zoning (ZGM)	ROCKFALL HAZARD RATING SYSTEM (RHRSM2)	SLOPE QUALITY INDEX (SQI)
ZGM 1	570 Hazard degree - Very high Intervention - Very urgent	3.51 Slope state - Bad Risk level - High
ZGM 2	462 Hazard degree - High Intervention - Urgent	3.36 Slope state - Medium Risk level - Medium

Fig. 2 Stability analysis of the cut-slopes of zones ZGM1 and ZGM2. **a** Markland diagrams; **b** rockfall hazard and slope quality mapping

RHRSm2 system and an updated version of the Slope Quality Index (Pinheiro et al., 2015). Rockfall modelling and potential rock failures were developed with RocFall and Swedge software (Rocscience).

The integrated analysis of the various rock mass classifications shows a rock mass of fair to very good quality in the Southern part of the quarry (ZGM3, ZGM4, and ZGM5), while in the Northern part, the rock mass is of poor to fair quality (ZGM1 and ZGM2), (Fig. 1).

The three studied cut-slopes are in the geomechanical zones ZGM1 (2) and ZGM2 (1). Their orientation is NNW-SSE, with steep angles (75º–85º).

Considering the SMR values and the classes established by Romana (1985), zone ZGM1 is considered unstable, while zone ZGM2 is partially stable. To emphasise the proposals of stability and failure types of Romana (1985), the cut-slopes were characterised based on the Markland Test (Fig. 2a). In zone ZGM1, several potential failures may occur, namely wedge slides, with effective sliding directions towards SW and NW, and toppling failures. Moreover, in zone ZGM2 wedge failures may occur, with active sliding directions towards SW.

The analysis of the rockfall hazard (RHRSm2) and the cut-slopes quality (SQI) allowed us to distinguish the zones ZGM1 and ZGM2 (Fig. 2b). The slope state is less good in zone ZGM1, with a higher risk level and rockfall hazard. Therefore, in this zone, immediate intervention of the slopes is required.

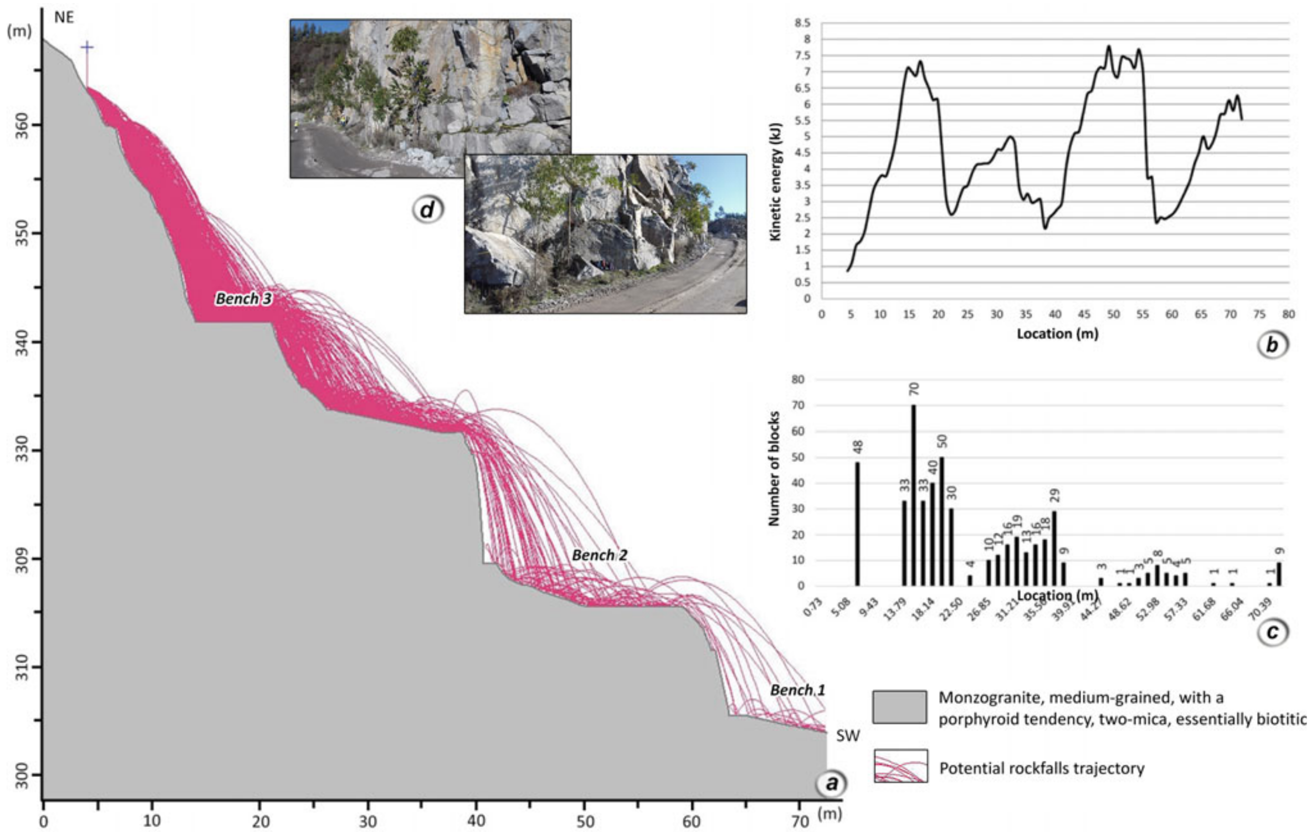


Fig. 3 Geotechnical modelling of rockfalls from profile 6; **a** Topographic profile and potential rockfalls trajectory; **b** relation between maximum total kinetic energy (kJ) and location (m); **c** relation between the number of blocks and location (m); **d** general aspects of bench 3

The geotechnical modelling of rockfall was analysed in zone ZGM1, applying the RocFall software. To illustrate this, profile 6 was selected (Fig. 3). Profile 6 has an extension of 73 m and a difference in elevation of 63 m (Fig. 3a). If the rockfall takes place in bench 3, the maximum kinetic energy generated is 7.79 kJ at 51 m (Fig. 3b), and the blocks are quite distant from each other, whereas 70 blocks are deposited at 15 m (Fig. 3c), and the mass of each block is approximately 40 kg.

3 Concluding Remarks

The hazard assessment of cut-slopes is a crucial element of quarry risk management. Since quarries get deeper over time and the cut-slopes angle becomes steeper, the regular check of benches and haul roads will permit the identification of small-scale rock failures that might reveal larger-scale ground instabilities. This assessment can be done with engineering geology surveys, hazard assessment maps and geotechnical modelling.

Acknowledgements Labcarga|ISEP re-equipment program (IPP-ISEP|PAD'2007/08), Centre GeoBioTec|UA (UID/GEO/04035/2020) and CGEO (UIDB/00073/2020) supported this study.

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