Rock slope stability of the quarries of Estremoz marble zone (Portugal) – A case study

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1. INTRODUCTION

The **Estremoz Marble Zone** is one of the most important **dimension stone** production centre in the World. In these quarries located in the Alentejo Region (Southern Portugal), rock slopes, some of them with more than one hundred meters high, has been mined. This work emphasizes **structural control** in the **marble quarrying** and presents a case study, in which the **analysis of the stability of a slope** was based on a geological and structural data. The analysis was carried out in order to evaluate a possible failure of the slope due to the quarrying progress which could affect a surrounding quarry and a road close to the slope quarry.

These **marbles** have been quarried since antiquity as a valuable geological resource. In the 20th century, with the introduction of modern quarrying and manufacturing technologies, mainly in the 1970s, the marble industry expanded, and is now exported worldwide. However, due to the lack of geological knowledge by the owners of the quarries many mistakes have been made, with bad economic consequences. One of the most common situations is related to **slope stability problems**, because the quarrying orientation is not always made in agreement with **geological structure**. Moreover, the great depths of the quarries give rise to an increase of the *in situ* stresses in the rock mass mainly in the bottom levels and consequently to an increase in the intensity of fracturing.

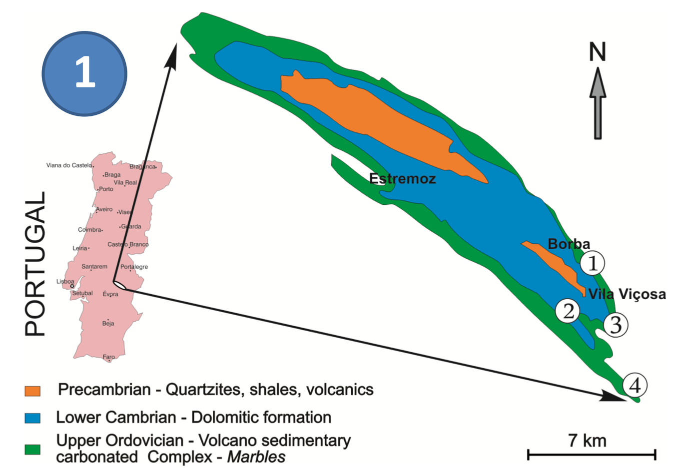


Figure 1. Geological sketch of the Estremoz anticline and point locations with references in the text. 1 - Location of the case study. 2 – Sliding in a quarry located in the southwestern flank of the anticline. 3 – A 120m deep quarry, located in the southeast periclinal end of the geological structure. 4 - Karst cavity discovered as a result of earthquake, Alandroal.

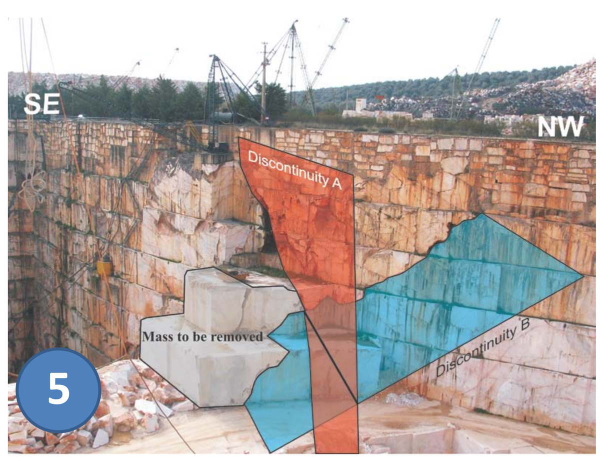
Figure 2. Rock fall of the southwest slope of the quarry induced, mainly by the effect of the water pressure within the discontinuities. This accident also has even cut a road whose profile is visible on the top of the slope. This quarry is located at point 2 in Figure 1.

Figure 3. Vertical view of 120m deep quarry, located in the southeast periclinal end of the geological structure. In the upper right at the bottom of the quarry can be seen the entrance of a gallery for the underground extraction of marble. This quarry is located at point 3 in Figure 1.

Figure 4. Karst cavity opened near a marble factory. This opening is probably related to a seismic event. This factory is located at point 4 in Figure 1.

Panoramic view of the southwestern limb of the Estremoz anticline

Figure 5. Southwest face of the quarry with the main discontinuities sets: A – open vertical discontinuity associated with karst cavity oriented N-S; B – planar discontinuity with orientation 50/072. The masses highlighted in gray are to be removed. This quarry is located at point 1 in Figure 1.



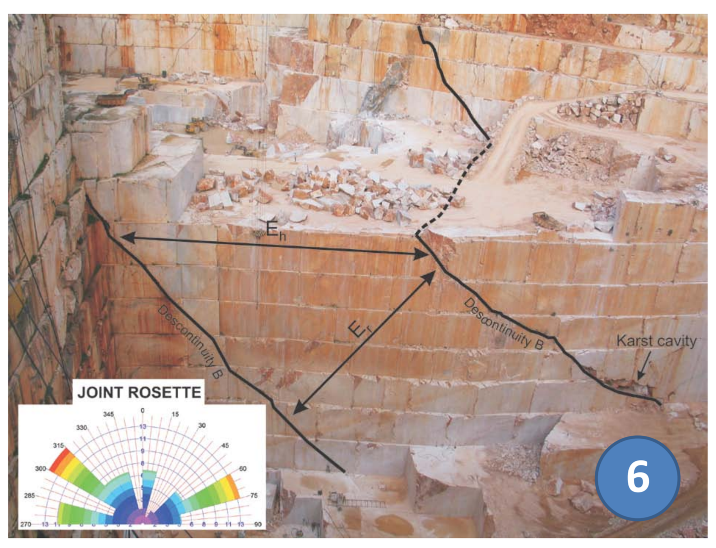


Figure 6. View to NW, which identifies the intersection of two discontinuities in set B. Horizontal (Eh) and normal (Er) spacing are indicated, and despite being apparent, they are very close to the actual spacings. On the right is possible to see the development of a karst depth, which demonstrates the unpredictable nature of these structures. A joint rosette inserted shows the joint sets identified in the quarry. This quarry is located at point 1 in Figure 1.

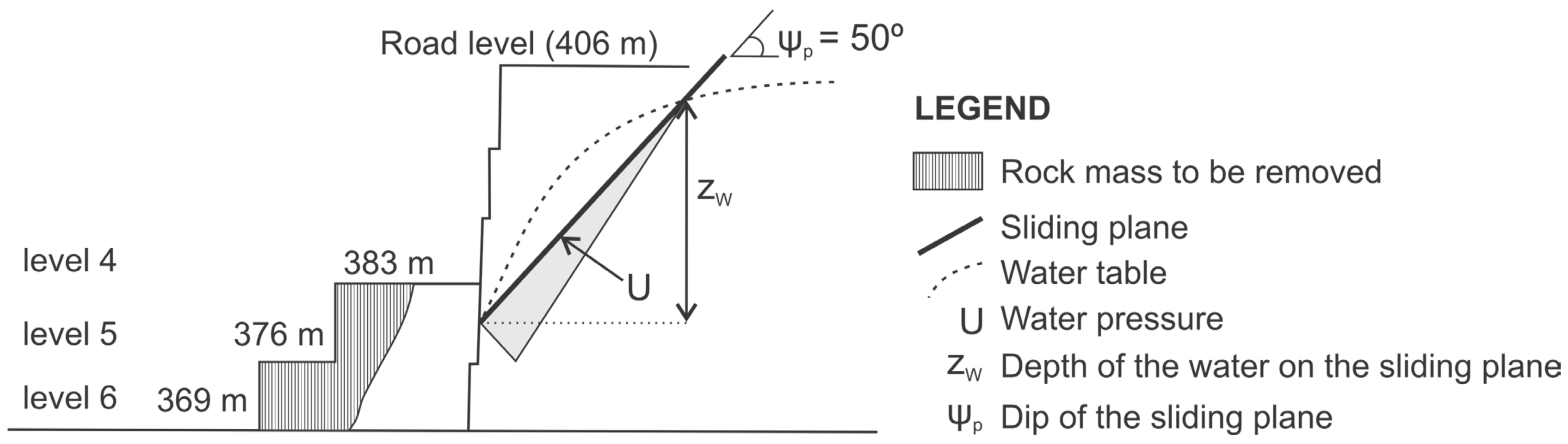


Figure 7. Geometry of the slope south of the quarry and types of actuating forces.

2. CASE STUDY

A stability analysis was carried out of the southwest slope of quarry 5145 (point 1, see Figures 1 and 5). This study aimed to evaluate the problem of possible instability of the slope that corresponds to the southwest limit of the referred quarry, based on the geological and structural data of the rock mass that were collected on the site. The assessment of slope stability in study was considered fundamental due to the possibility that it may affect adjacent properties between Borba and Vila Viçosa, particularly the Plácido Simões quarry located to the east, and even the National Road EN255, due to their proximity to the slope.

A geological site reconnaissance of the rock mass was made consisting of a survey of physical and geometrical characteristics of the main discontinuities sets in the exposed surface of the slope in study. Thus six scan lines were made observing and recording discontinuities. The structural data obtained in the field were subjected to analysis and processing leading to its graphic representation contour pole density plots of the measured fractures, and as a joint rosette (see Fig. 6).The analysis of these diagrams reveals the existence of five major sets of discontinuities, but there is a marked dispersion around their geometric centres.

The calculation of the **factor of safety** was accomplished by the method of limit equilibrium, using two-dimensional analysis for plane failure (Hoek & Bray, 1981), for a vertical slope section of unit thickness taken at right angles to the slope face, considering the following assumptions:

i. In this two-dimensional analysis the role of the connecting surfaces to the slide are not considered.
ii. The action of vertical loads due to the movement of heavy vehicles loaded (W_2). are considered in addition to the weight of the rock mass(W_1). The value of 500kN/m was adopted.
iii. Vibrations were considered in the upper surface of the slope whether as a result of the movement of heavy vehicles on the National Road EN255, or as a result of the operation of the crane located in the top of the slope. It is considered that the combination of all those vibrations reach a value of one tenth of the acceleration of gravity.
iv. The presence of water on the sliding plane, considering the worst conditions for the stability of the slope, after the period of heavy rain.
v. The probable reduction in the factor of safety to the removal of adjacent frontal benches to the slope, should be compensated through the installation of rock bolts.

3. CONCLUSIONS

This paper highlights the importance of the knowledge of the **structural control in the marble quarrying** in the Alentejo Region (Southern Portugal) and presents a case study. Nevertheless, due to the lack of geological knowledge by the owners of the quarries, a lot of mistakes have been carried out (Figs. 8, 9 and 10), in this mining activity, with serious economic consequences. One of the major problems is related with the instability of the quarries slopes, because the orientation of the quarrying is not always made in agreement with geological structure (Figs. 9 and 10).

This work contains references to some recent examples on the **influence of discontinuities on the rock slope stability** of the quarries of marble located in the Alentejo region as well as on the geomechanical behaviour of the rock masses which if not adequately addressed can decrease the safety of people and cause material damage.

In the case study presented, the analysis of the stability of a slope was done, based on a geological and structural data, in order to evaluate a possible failure of the slope due to the mining evolution that could affect a quarry and a road next to the slope of the quarry in analysis.

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Figure 8. Example of procedure not appropriate of marble quarrying that can decrease the safety of people and cause material damage.

Figure 9. Sliding surface parallel to schistosity that may affect the adjacent building (a factory of equipments for marble Industry) with bad economic consequences and endangering the safety of people.

Figure 10. Aspect of an instability of a quarry slope, due to the fact that orientation of the quarrying is not in agreement with geological structure. This situation can be aggravated by the presence of water within the discontinuities (see picture inside), that contributes to increase the water pressure on the face of slope and, at the same time, decrease the shear strength of the discontinuities that occur in the rock mass.