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Introducing an innovative methodology for mapping rock-discontinuities, based on the interpretation of 3D photogrammetry products. The case of Akronafplia castle

Emm. Vassilakis[1], M. Stavropoulou[1], A. Konsolaki[1], I.K. Giannopoulos[1], S. Petrakis[1,2], E. Kotsi[1], E. Lekkas[1], A. Kokkoromytis[1]

(1) Dpt of Geology & Geoenvironment, National and Kapodistrian University of Athens, Zographou, Greece, evasilak@geol.uoa.gr (2) Institute of Oceanography, Hellenic Centre for Marine Research (HCMR), Anavissos, Greece.

Recent advances in the use of Unmanned Aerial Systems (UAS) and photogrammetry processing have opened new opportunities for collecting data of discontinuity properties and have made it possible to overcome safety issues using conventional methods (Ismail et al., 2022). The orientation of discontinuities (dip/strike), number of joint sets, and other relevant geological data are collected during geological survey field mapping. However, this method has several drawbacks, including site accessibility difficulties, limitations for the use of traditional tools to evaluate the rock characteristics, restrictions on the identification and localisation of site structural features, not to mention that is time-consuming. Additionally, the data acquisition ends up being impossible to the unreachable sections of the area of interest and this makes the data to be deficient. So, the accessibility to state-of-the-art close-range remote sensing technologies grants comprehensive and up-to-date data over the study area (Migliazza et al., 2021).

The described methodology is applied at the steep slopes of the "Path of Arvanitia", at the outer walls of Akronafplia castle, located in the southern border of the old city of Nafplio and aims to map and analyze the rock-discontinuities of the alpine basement of the castle. A historical promenade has been formed along the rocky coastline that surrounds the peninsula of Akronafplia, and it is frequently used by the city inhabitants during the last few centuries. It is a rather risky trail characterized by strong relief with steep, almost vertical, rocky slopes, mainly at its southern and western parts.

We used a DJI Phantom 4 pro RTK drone, equipped with an FC6310R camera and a focal length of 8.8mm for the 3D representation of the Akronafplia peninsula. The field work was accomplished in three different phases, either vertical to the slope, by mapping the north, east and south parts of the obverse face and in a single horizontal plane (Fig. 1a). In addition, the establishment of several topographic bases was carried out, along the entire route trail, with surveying equipment (total station). Also, eleven (11) targets were placed on the slopes, and measured with the same high-precision equipment, to maximize the accuracy of the photogrammetry processing that followed. The dataset was completed with the acquisition of 1678 images that were processed based on Structure-from-Motion photogrammetry techniques, to produce (a) DSMs (0.03m resolution) and (b) ortho-mosaics (0.015m resolution), of different aspects of the cliff face (Fig. 1b), based on a dense point cloud that consisted of ~248 million points.

The data acquisition and the photogrammetric process were followed by structural analysis, focused on the examination of all possible modes of slope failure in a jointed rock mass (Yoon et al., 2002). First, the rock joints were traced across the entire 3D model and digitized (Fig. 1c) for the construction of a failure density map for each of the three obverse faces. This resulted in the identification of the largest joint intersections and failure concentrations, yielding the high-risk locations of the peninsula steep slopes (Fig. 1d). Following, the slopes were divided into 18 different segments and the analysis was performed in each segment separately, due to the continuous change of their orientation and slope angle. The point clouds of each segment were used for extracting the facets of the planes that form the rock failures, followed by rock failure analysis. The latter provides way more accurate and larger number of structural measurements than the classic field work with the use of a geological compass.

The derived datasets were in turn used for the inspection of rock block stability at each one of the segments, including the statistical analysis of discontinuities for assigning them into clusters (Wang et al., 2019). In particular, the geotechnical analysis for the determination of potentially unsafe rock masses included, initially, the statistical processing of discontinuities and the creation of structural analysis stereo-diagrams. Furthermore, specialized software was used for the examination of possible wedge and plane sliding and eventually the possibility of rock falls (Martino and Mazzanti, 2014). The statistical analysis and the examination of all possible rock mass failures was carried out using a safety factor for static (SF=1.4) and for seismic (SF=1.0) conditions. For the estimation of the safety factor of all possible wedge and plane failures, the height and orientation of the slope along with discontinuity orientations and their strength parameters were imported, taking into consideration the Mohr-Coulomb shear strength criterion. Rock falls analyses were also carried out at selected cross-sections that were identified on the photogrammetric products and verified during the in-situ inspections to have increased risk.

From the analysis it was found that the highest risk of the above three modes of slope instabilities and especially of wedge failure is in the Northern part of the study area. Therefore, immediate actions are required, which should focus on measures to reduce the risk of these structural instabilities. These measures pertain to the nailing of individual rock blocks, the removal of unsafe rock blocks and the installation of either restraining nets or dynamic rockfall barriers at several places.

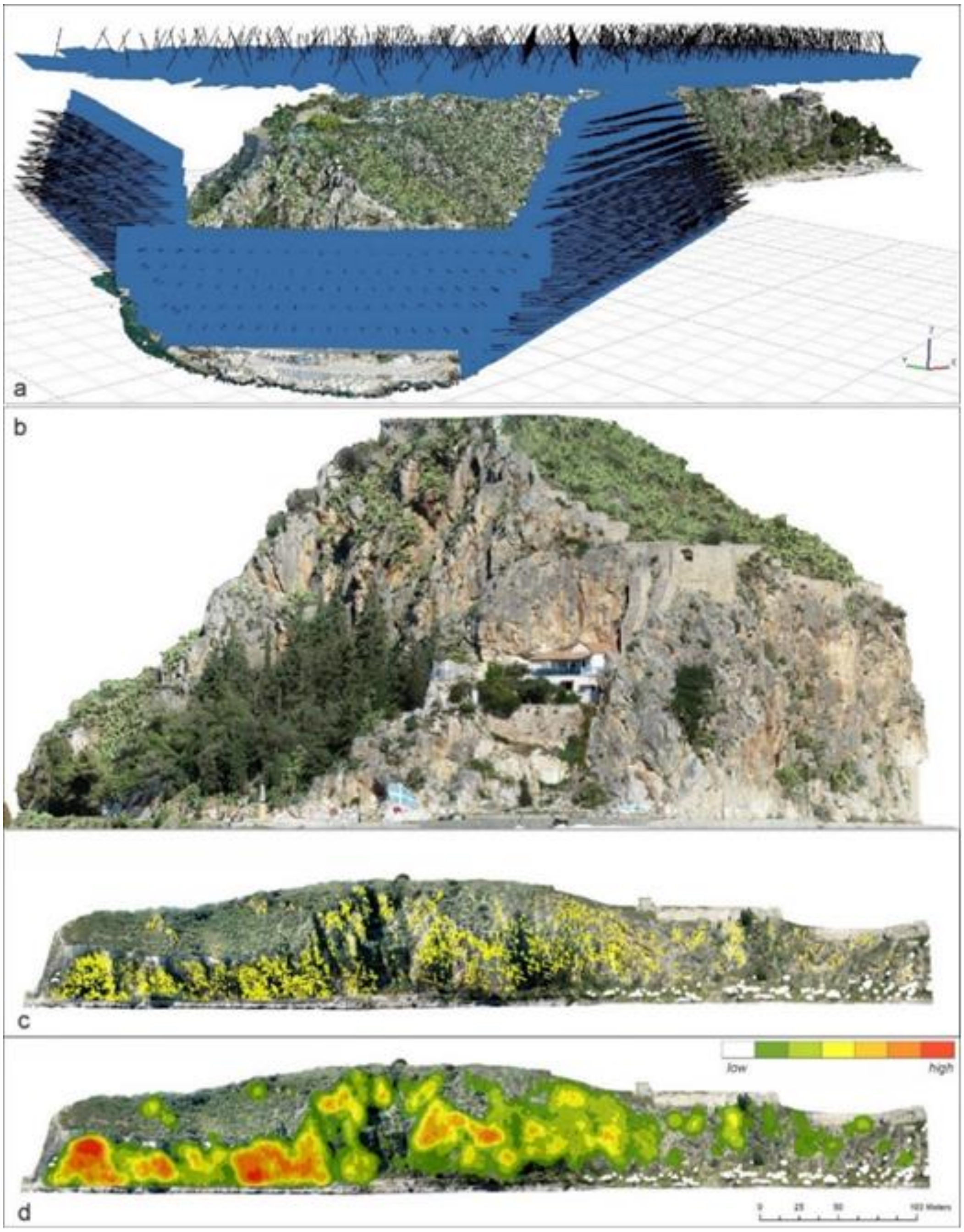

Figure 1. Distribution of the drone flights (a) for the 3D representation of the area of Akronafplia with very high resolution (b). After the data acquisition, the main discontinuities where mapped (c) and the density was measured (d).

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