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

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

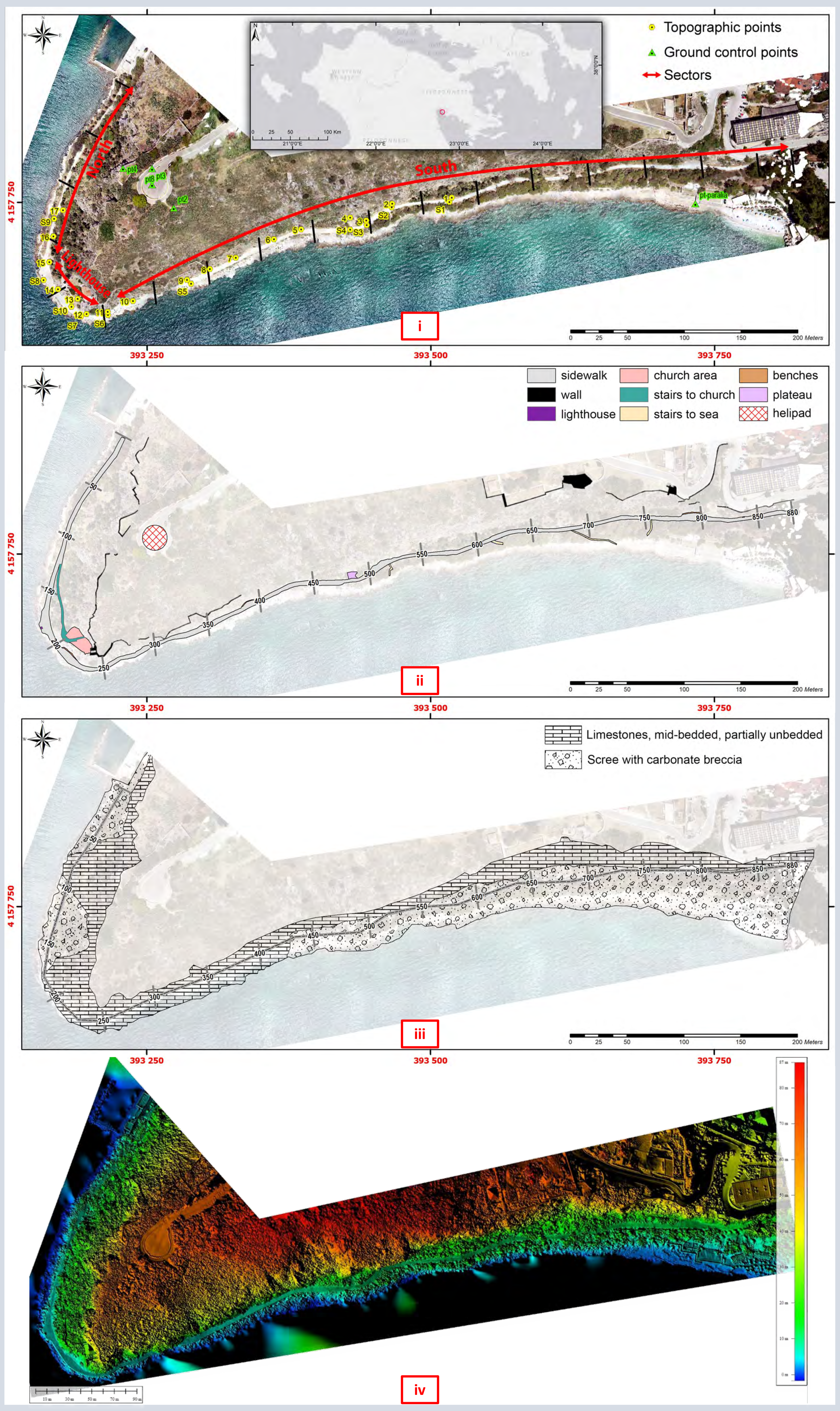
[1] Department of Geology & Geoenvironment, National and Kapodistrian University of Athens, Zografou, Greece

[2] Institute of Oceanography, Hellenic Centre for Marine Research, 46.7 km Athens-Sounion, 19013 Anavyssos, Greece.

Introduction

Recent advances in the use of **Unmanned Aerial Systems** (**UAS**) and **photogrammetry processing** have opened new opportunities for collecting data of discontinuity properties. 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, and is rather 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.



Study area

The described methodology is applied at the steep slopes of the "Path of Arvanitia" [*image above*], at the outer walls of Akronafplia castle, in the S border of the old city of Nafplio, aiming to map and analyze the rock discontinuities of the alpine basement of the castle. A promenade was constructed along the rocky coastline that surrounds the peninsula, 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 S and W parts[*i-iii*].

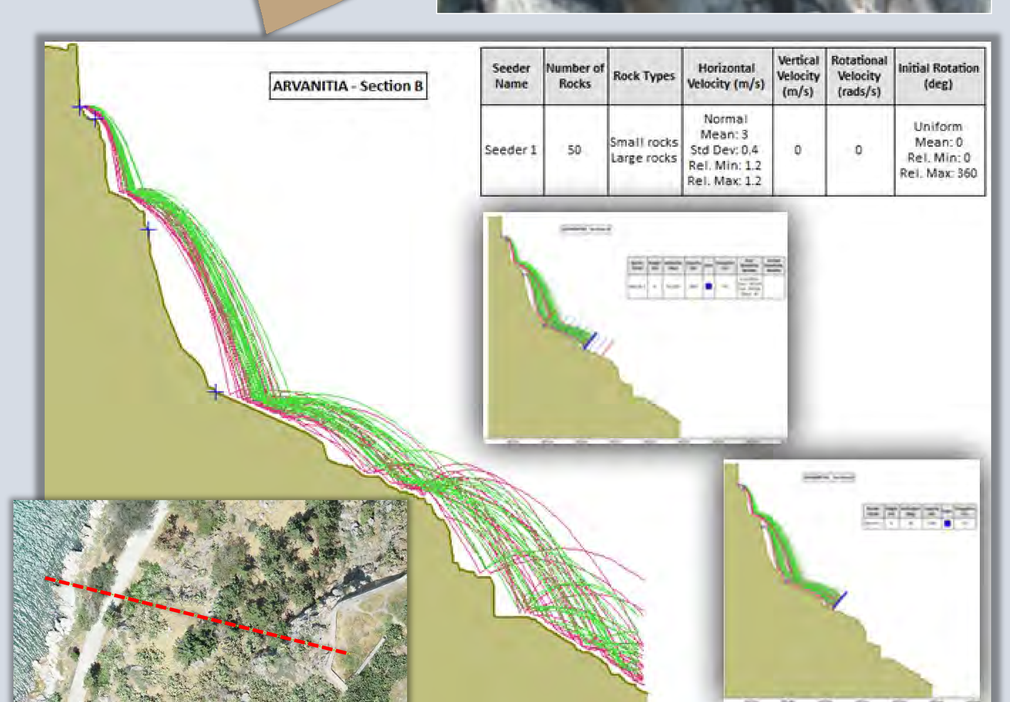
Materials

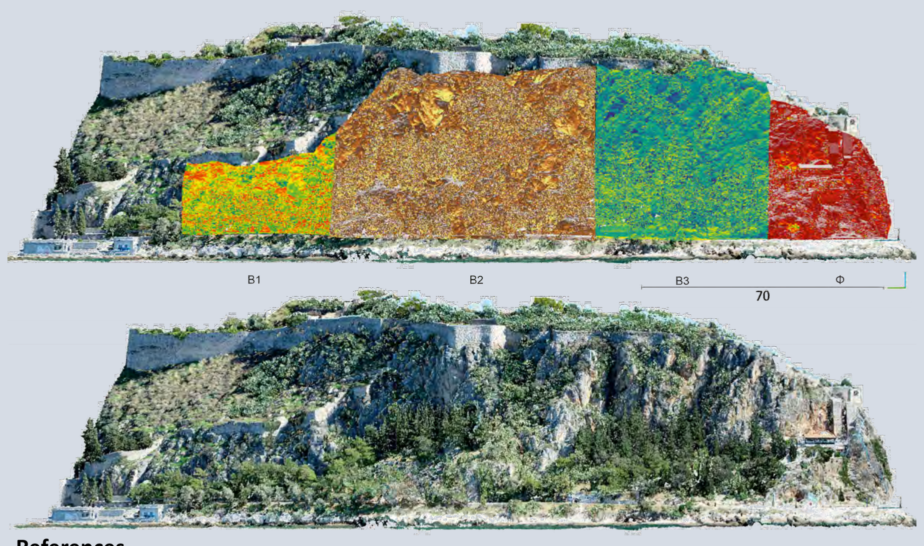
DJI Phantom 4 pro RTK drone (FC6310R camera – focal length 8.8mm) and **total station** [*1-4*], for the 3D representation of the Akronafplia peninsula. The field work was accomplished in 3 different phases, vertical to the slope, by mapping the N, E and S parts of the obverse face and in a single horizontal plane [*a*].

11 targets were placed on the slopes, and measured with the same high-precision equipment [*5-6*]. The dataset was completed with the acquisition of **1678 images**, processed based on Structure-from-Motion photogrammetry techniques, to produce DSMs [*iv*] (3 cm resolution) and ortho-mosaics [*b*] (1.5 cm resolution), of different aspects of the cliff, based on a dense point cloud consisted of **~248 million points**.

Methods

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 [*c*]. The rock joints were traced across the entire 3D model and digitized for the construction of a **failure density map** for each of the three obverse faces [*d*]. This resulted in the identification of the largest joint intersections and failure concentrations, yielding the **high-risk locations** of the peninsula steep slopes. The slopes were divided into 18 different segments [***image below***] 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** [***adjacent image***].

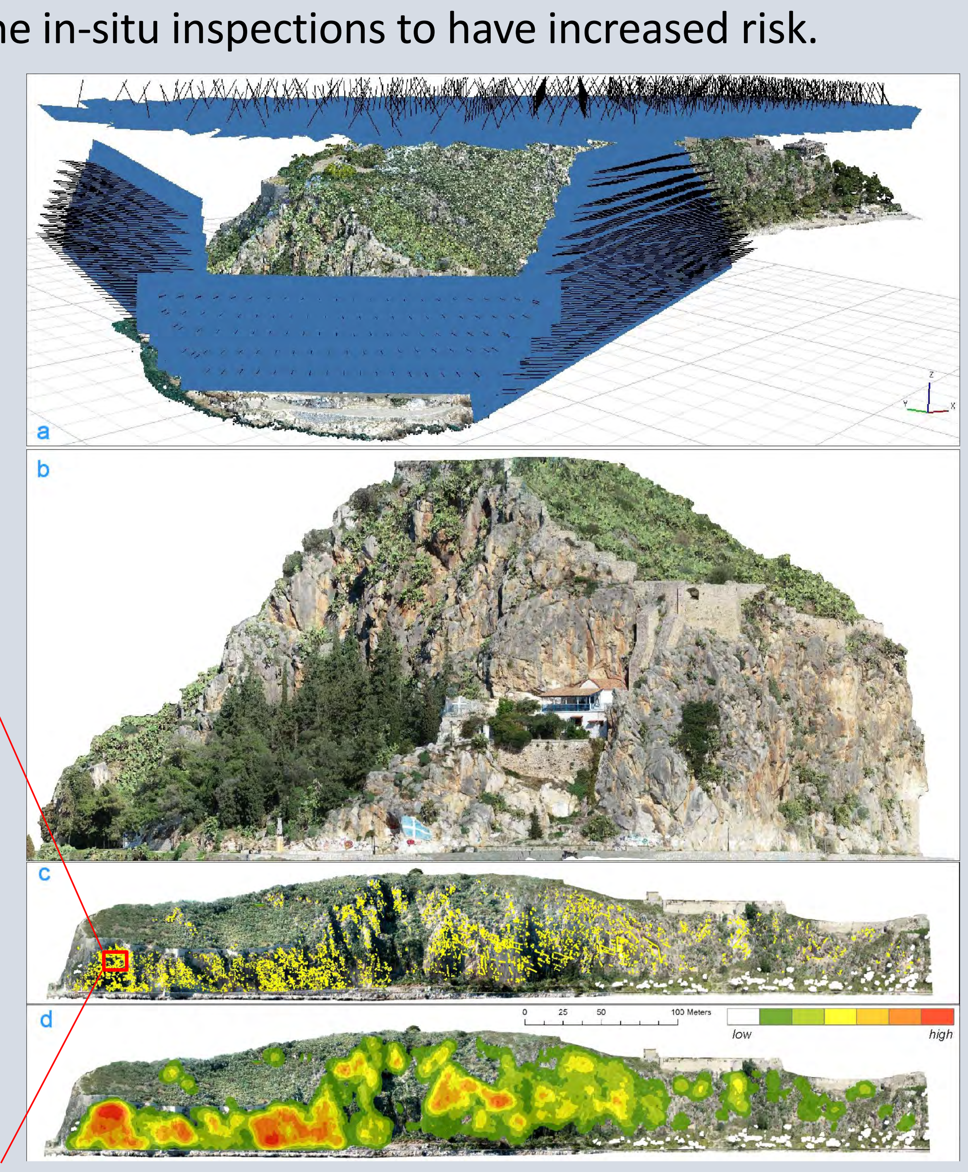




Results

The derived datasets were 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. The **geotechnical analysis** for the determination of potentially unsafe rock masses included the statistical processing of discontinuities and the **creation of structural analysis stereo-diagrams** [***adjacent image***].

Specialized software was used for the examination of possible wedge and plane sliding and eventually the possibility of **rock falls**. 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. 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.



Discussion

From the analysis it was found that the highest risk of the 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.

References

Ismail, A., Ahmad Safuan, A.R., Sa'ari, R., Wahid Rasib, A., Mustaffar, M., Asnida Abdullah, R., Kassim, A., Mohd Yusof, N., Abd Rahaman, N., Kalatehjari, R., 2022. Application of combined terrestrial laser scanning and unmanned aerial vehicle digital photogrammetry method in high rock slope stability analysis: A case study. Measurement, 195, 111161.

Martino, S., Mazzanti, P., 2014. Integrating geomechanical surveys and remote sensing for sea cliff slope stability analysis: the Mt. Pucci case study (Italy). Nat. Hazards Earth Syst. Sci., 14(4), 831-848.

Migliazza, M., Carriero, M.T., Lingua, A., Pontoglio, E., Scavia, C., 2021. Rock Mass Characterization by UAV and Close-Range Photogrammetry: A Multiscale Approach Applied along the Vallone dell'Elva Road (Italy). Geosciences, 11(11), 436.

Wang, S., Zhang, Z., Wang, C., Zhu, C., Ren, Y., 2019. Multistep rocky slope stability analysis based on unmanned aerial vehicle photogrammetry. Environmental Earth Sciences, 78(8), 260.

Yoon, W.S., Jeong, U.J., Kim, J.H., 2002. Kinematic analysis for sliding failure of multi-faced rock slopes. Engineering Geology, 67(1), 51-61.

Acknowledgments

The authors appreciate the contribution of rope-access technician P. Sarelas during the fieldwork.

This research was funded by the municipality of Nafplio, the Port Funds of Nafplio and the Ministry of Culture through the research grant "*Research of the rockfall risk at the Arvanitia route trail of the Municipality of Nafplio, with innovative techniques*".

*Contact: evasilak@geol.uoa.gr