PORE STRUCTURE EVOLUTION IN ANDESITE ROCKS INDUCED BY FREEZE-THAW CYCLES EXAMINED BY NON-DESTRUCTIVE METHODS

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Introduction

Mechanical or physical weathering (physical rock breakdown) is a key process that influences the appearance of geo-relief, especially at high altitudes or in polar periglacial regions. It is closely related to the regional and global climate (Grossi et al. 2007). Physical rock breakdown mainly stems from the propagation of cracks in the rock matrix (Eppes and Keanini, 2017). The sources of stresses induced by freezing and thawing (F-T cycling) and causing deterioration of rock material are still under discussion[3]. Frost damage may include a combination of several mechanisms, with crystallization pressure (Everett, 1961; Scherer, 1999; Steiger, 2005a, 2005b; Steiger et al., 2014; Walder and Hallet, 1985) currently being the main contributor. This is followed by subsequent hydraulic (Powers, 1945) or volumetric expansion (Hirschwald, 1908). The relative importance of these mechanisms varies depending on the material properties, moisture conditions, and thermal conditions (Hall, 1999).

In this study, we compare the values of petrophysical properties before and after 100 freeze-thaw (F-T) cycles, as well as the recorded length change behavior and temperature development on a vacuum-saturated fractured andesite rock sample taken from the Babina Quarry in Slovakia. This was done using a specially-constructed thermodilatometer, VLAP 04, equipped with two HIRT-LVDT sensors. Additionally, we employed non-destructive visualization of the rock pore network via µCT imaging to investigate the evolution of the pore structure and fracture network in pyroxene andesites throughout the freeze-thaw process.

Methods

Initial Properties of Rock Fabric

The basic hypothesis underlying our experimental approach is that the pressures induced by ice crystallization caused microcrack growing a this correlates with increase in pore volume, level of pore connectivity and changes in pore size distribution that are made possible through water supply to growing ice front. Rock deterioration induced by the effects of frost weathering results from the combined action of processes mainly linked to rocks' pore network system parameters (initial petrophysical parameters). In this study, we worked with fractured andesite core sample of a cylinder shape with a size of 5.0 cm in length and 3.2 cm in diameter. The solid phase, which controls mechanical strength of rocks and building materials by extent of cementation and mineral phase bonding was analyzed by scanning electron microscopy- SEM, of standard polished thin section.

Quantification of changes in pore system network before and after F-T cycling was performed repeatedly by set of nondestructive techniques, with emphasis on:

- pore interconnectivity by spontaneous imbibition method according to Hu et al.[13] and Maľa and Greif;
- pore size distribution by newly developed experimental method for identifying the pore structure of rocks according to Ondrášik et al. [15]. Results of representative pore radii distribution pattern was also verified by mercury intrusion porosimetry.

Non-destructive visualizations

Visualization and quantification of microcrack propagation before and after repeated freezing and thawing was performed on industrial µCT Phoenix | tome | x L 240 according to Maľa et al. (2022). Image processing was carried out in AVIZO 2019.1 software by several image visualization techniques.

Freeze-Thaw tests

To understand the internal structural changes of the sample induced by damage mechanisms during ice crystallization we simulated freeze thaw conditions by custom designed thermodilatometer VLAP 04 [14]. VLAP 04 is capable of controlling the temperature change in the range -17°C to +60°C and we simulated temperature change in the range from -10°C to +10°C with cooling rate of -0.18°C/min and subsequent heating rate of 0,21°C/min to avoid thermal shock. Porosity change induced by excessive pressure during F-T cycle results in a residual strain. A damage quantification can thus be derived from monitoring the length and temperature changes during the ice crystallization. This was measured by two linear variable differential transformer sensors (HIRT-LVDT-T101 F) of VLAP 04.

Results

Our results showed that the tested andesite from Babiná is a rock with extremely low porosity and a bimodal pore size distribution pattern which consists mainly of nanometric sized micropores, as well as a macropores. This corresponds to the results from the indicative rock pore structure method. Based on those results, the rock pore structure of Babina andesite predominantly contains hardly-accessible macropores, which are interconnected by micropores and mesopores. A part of this specimen's matrix contains a large amount of blind and isolated pores. Pore interconnection determined by the imbibition curve slope C(I) is also extremely low, but with a significant increase after F-T cycling. Non-destructive visualization by µCT showed only a slight increase in macroporosity of the sample after 100 F-T cycles. On the other hand, significant fracture opening corresponds to a 31 pp. increase of fracture volume. The largest dimensional changes of porous structures are also bound to the locations near the fracture. The physical breakdown of rock necessarily stems from the propagation of fractures. Freeze-thaw induced cracking of a brittle-elastic solid like pyroxene- andesite is caused by ice crystallization and hydraulic pressure build-up which led to rock fatigue failure. Subcritical cracking of the tested andesite results in total residual strain of 8x10-5 recorded after 100 F-T cycles.

Conclusion

Andesites from Babiná, which are rocks with very low total and effective porosity, as well as a high proportion of weakly interconnected micro- and mesopores, exhibit relatively good structural cohesion and high resistance to the effects of frost weathering. The main disintegration process of such volcanic rocks is subcritical fracture growth, which is induced by both crystallization and hydraulic pressures in the pore space. This process can lead to long-term deterioration of the rock material.

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ROCKFALL HAZARD EVALUATION IN A CULTURAL HERITAGE SITE: CASE STUDY OF AGIA PARASKEVI MONASTERY, MONODENDRI, GREECE.

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Introduction

The methodology that is usually followed for the evaluation of rockfall hazard within an area is discriminated in several stages, including a detailed engineering geology field survey and analysis of the data obtained during this survey, identification of the failure type mechanism, e.g., wedge, planar slide, toppling, and the assessment of the rockfall trajectory and the evaluation of critical parameters like the kinetic energy and the bounce height of the detached rock.

The study area concerns the rocky slope defined by Monastery of St. Paraskevi (northeast of Monodendri village) up to the natural entrance of the Vikos gorge in the Region of Epirus (northwest Greece). The structures of St. Paraskevi Monastery, including the Temple, were built more than 600 years ago, right under a nearly vertical limestone slope of more than 100m high. In the past, rockfall phenomena have occurred in the slope of the study region triggered by earthquake and rainfall resulting in the construction of protection measures.

The goal of this study is twofold: (i) to evaluate the rockfall potential, and (ii) to simulate the trajectories of likely to fail blocks in order to examine their run-out distance and to assess the rockfall hazard in terms of kinetic energy and bounce height.

Methods

For the purposes of this study, we used a geological compass to measure the orientation of the discontinuities, in terms of dip and dip direction, while a Schmidt hammer was used for estimating the uniaxial compressive strength (UCS) of the intact rock and the joint compressive strength (JCS). Furthermore, the roughness of the joints was assessed based on a profilometer. Finally, the filling material and the weathering conditions at the area were also assessed.

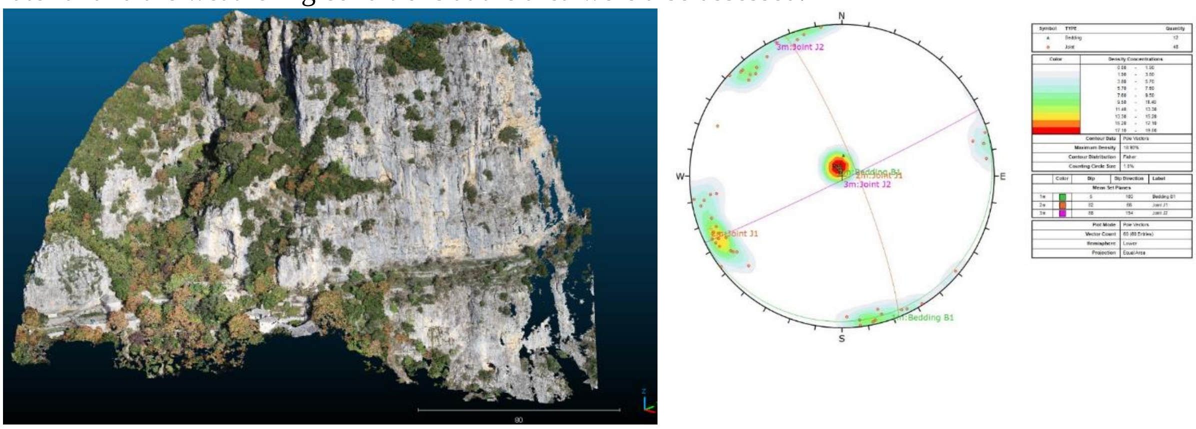

Figure 1. Left. 3D model of the slope face. Right. Stereographic projection of concentration lines of discontinuity poles from field survey based on geological compass.

Furthermore, considering the steep morphology of the rock slope, it was decided to conduct a RPAS survey in October 2021 as well as in May 2023 to reconstruct an accurate and detailed 3D model of the studied area. The RPAS imagery was collected using a DJI Phantom 4 Pro V2.0 In order to detect the discontinuity sets and measured their orientation at the studied area, the generated on CloudCompare™ point cloud was analyzed by applying recently developed SfM-based methodologies (proposed by Riquelme et al. 2014 and described by Valkaniotis et al. 2018, Papathanassiou et al. 2021 among others). Supervised analysis using the open source software Discontinuity Set Extractor (DSE) (developed by Riquelme et al. 2014), and manually oriented (CloudCompare™) approaches were applied in the developed 3D model.

Results

The outcome arisen from the comparison of the information regarding the discontinuity sets obtained by the DSE, as well as from the field survey based on geological compass is shown in Table 1.

Table 1. Comparison of major discontinuity levels (dip/dip direction) of tectonic diagram by the DSE as well as the traditional tectonic diagram at different locations on the slope face

Set	Field Survey Measurements	DSE		
	Site D	Site A	Site B	Site C
	Dip/Dip Direction	Dip/Dip Direction	Dip/Dip Direction	Dip/Dip Direction
B1	5°/160°	23°/144°	08°/162°	08°/135°
J1	82°/068°	77°/081°	76°/088°	85°/093°
J2	88°/154°	86°/150°	83°/141°	88°/148°

Following this step, we assessed the mean volume of the likely to be detached rock boulders from slope face as 1.18m, while the maximum volume was estimated as 3.3m³. After that step, we estimated the parameters of the trajectory, kinetic energy, impact, distance and bounce height for three critical profiles. The trajectories were extracted from the developed point cloud with the open-source software CloudCompare™ and imported on the software Rocfall of Rocscience for estimating their parameters. Considering the results of the simulation, it is concluded that rockfall phenomena can threat the zone between Monastery of St. Paraskevi and natural entrance of Vikos gorge.

Conclusion

By comparing the results of traditional field survey with those provided based on the developed 3D point-cloud, using open-source software, i.e., Discontinuity Set Extractor (DSE), we found out that are in agreement. Regarding the rockfall hazard, it is pointed out that construction of rockfall barriers is necessary. In additional, scaling is suggested as the primary mitigation measure that should be realized in advance in order to minimize the risk.

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ARE OUR MONUMENTS MELTING AWAY? EXPLORING THE IMPACT OF CLIMATE CHANGE ON STONE SURFACE FINISHES OF BELGIAN HERITAGE BUILDINGS

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Introduction

With the climate change and its ensuing challenges, we fear adverse repercussions for the materials and structures of our heritage buildings. These concerns include increased rainfall in European countries combined with acidification due to pollution, primarily caused by the rise in CO_2 and the presence of SO_X and NO_X compounds from human activities (IPCC 2023; Saiz-Jimenez et al. 2004). This acidic environment particularly impacts limestone, which is sensitive to the interaction of calcium carbonate ($CaCO_3$) with acid solutions (Basu et al. 2020).

Investigating material alteration involves understanding of phenomena affecting the intrinsic properties of rocks and plays an essential role in the diagnosis and preservation of stone masonry heritage buildings (Trudgill and Viles 1998). This analysis helps us to better understand the behaviour of these limestones and serves as a reference for further investigation in other acidic environment expositions.

Weathering of ashlar, especially in historic buildings, has been observed for several decades (Brimblecombe 2000; Cartwright et al. 2008; MEDISTONE and Bromblet 2010). By controlling independent parameters, it is possible to understand how the material behaves under controlled weathering conditions (pH solution, period cycling). In particular, exposure to acidic atmospheres is a concern that has been studied by many scientists (De Kock et al. 2017; Gibeaux et al. 2018; Menéndez 2018; Rodríguez et al. 2023; Salvini et al. 2022; Vagnon et al. 2021; Vázquez et al. 2015; Yan et al. 2022), with repetitive cycles enabling the correlation of various parameters such as porosity, water absorption rate, roughness, mass loss, pH values...

Methods

Two ornamental limestones were subjected to short artificial exposure: Belgian Blue Stone (BBS - Carboniferous in age) and Gobertange Stone (GS - Lutetian in age). Both rocks are found on historical monuments and newly built constructions in Belgium. BBS is composed of approximately 96% calcite, 1-10% magnesium carbonate, less than 2% quartz, others iron minerals and numerous fossils, mainly crinoids (De Barquin 2001). GS is principally composed of 73-87% calcite, 11-25% quartz and others iron minerals (Pierre et Marbres de Wallonie asbl 2024)

30 x 30 x 31mm cubes have been used for the tests. Density and porosity of samples are first determined. Two test conditions were chosen: exposure to urban synthetic rainwater composed of a mixed solution of 600 ml of HNO_3 (10-5 mol/l) and 400ml of H_2SO_4 (5.10-6 mol/l) carried at pH 5 (Eyssautier et al. 2016; Gibeaux et al. 2016); and to an exaggerated exposure of a stone kitchen worktop with an acid source like vinegar (acetic acid CH_3COOH 7% - pH 2.44). The experiments were carried out during 5 cycles of immersion and drying, without continuous agitation. (Bureau de Normalisation 2003; Xie et al. 2004). Between each cycle, the solution is renewed, starting from a known pH, and measured at the end of each phase. To ensure that the pH remains almost constant during the test, the stone specimens are alternatively immersed in approximately 130mL solutions for 24 hours (passive immersion) and then dried in a ventilated oven for 24h at 100°C.

These tests focus on the characterizing the evolution of exposed surfaces in terms of surface roughness and specific area, by using 3D optical profilometry in laboratory (Nikiema 2024). Other indicators, such as mass loss and porosity variation, are also explored.

Results

Both rocks have different initial properties: porosity less than 1% for BBS and 6-10% for GS. There is a general increase in porosity for all tested samples. Concerning the mass, each phase is characterised by a mass loss, especially with the acetic acid test. Nonetheless, GS seems to lose mass more significantly (rate of cumulative mass lost compared to initial mass after 5 cycles: BBS – 38% / GS – 43 %). After 5 cycles in immersion with acetic acid, each face of the cubes reduced by approximately 2.5mm for BBS and 4mm for GS (Figure 1-a).

A change in texture is observed for the test with acetic acid test during which partial dissolution of the rock matrix occurs. For BBS, the predominantly calcite matrix around the fossils in the rock dissolves first, revealing the fossils and increasing roughness (Phase 1 Surface roughness, all the irregularities characterising the surface, Sa = 3.843µm (std. DV 0.343) - Phase 5 Sa = 105.611 µm (std. DV 14.721)). For GS, the alteration process appears different, with more selective dissolution, revealing quartz grains (Phase 1 Sa = 11.225µm (std. DV 3.801) - Phase 5 Sa = 57.777 µm (std. DV 7.245)).

The tests in the synthetic acid rain do not show a significant trend in mass loss or change in roughness over just 5 cycles, for both rocks (Figures 1,2).

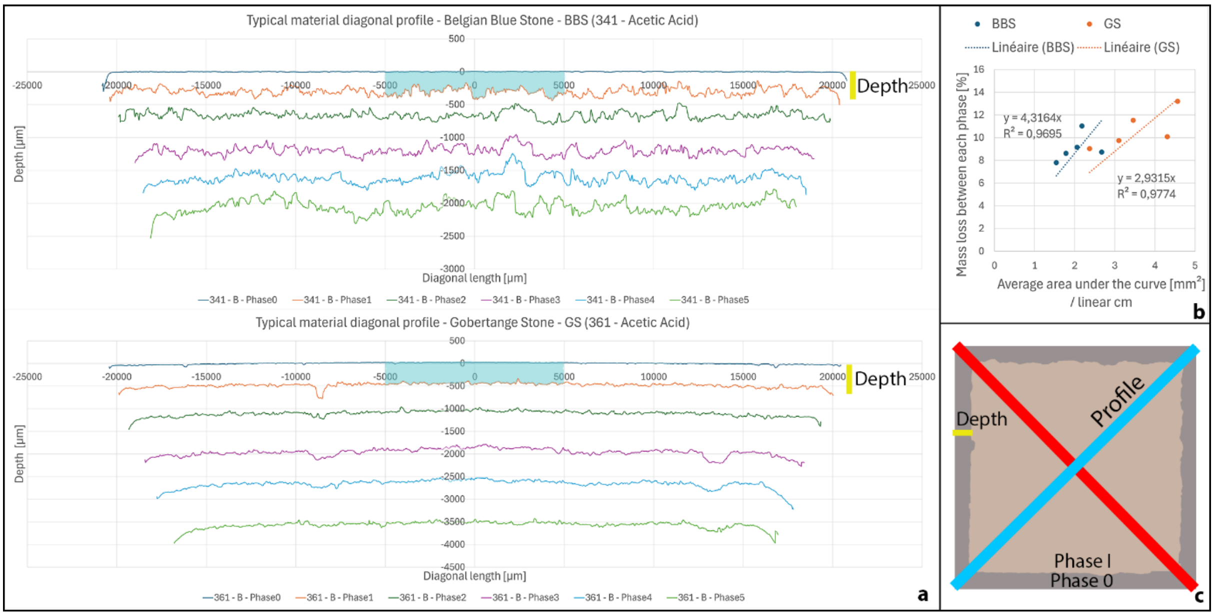

Figure 1. (a, c) Set of typical profiles for immersion of the two stones studied in acetic acid - (b) Correlation between mass loss and area under the curve per phase

Conclusion

These preliminary tests highlight key parameters, such as porosity and main matrix composition to analyse and help to understand the weathering mechanisms of building stones under cyclic acid rains attack.

Results highlight the five immersion/drying cycles had a greater impact with 7% dilute acetic acid (pH 2.44) than with synthetic acid rain (pH 5). This underscores the importance to pursue the efforts of industrialized countries to reduce polluting gases and to protect stone surfaces from household acid attacks, which are irreversible for our stone thresholds and worktops. However, the study, which involved a limited test campaign, does not allow to emphasize the aggressive nature of pH=5 rain. Further tests are necessary on these materials to determine the long-term impact of these pollutants.

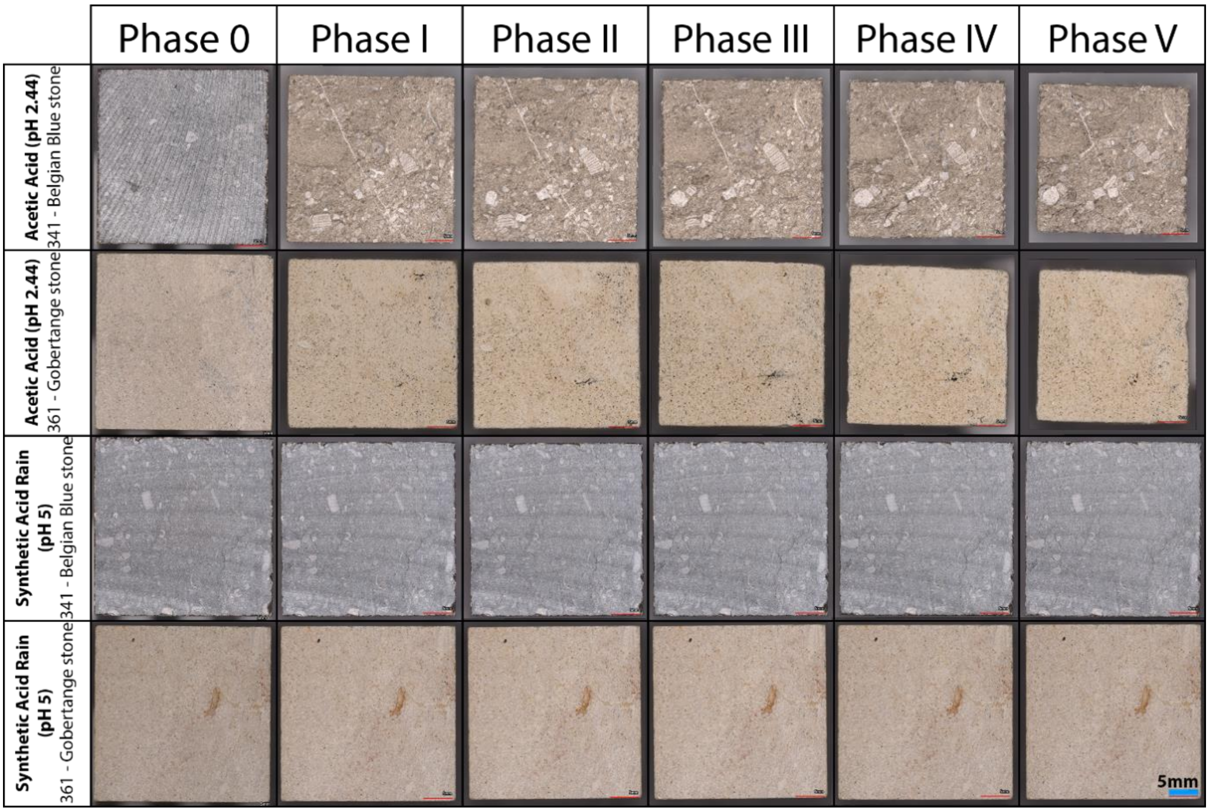

Figure 2 - Appendix. Mapping and evolution of surface finishes following the test phases. There is a noticeable reduction in the size of the samples and a change in texture for both stones following immersion in an acetic acid solution. The surface almost does not change when immersed in a synthetic acid rain solution.

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CLIMATE CHANGE ADAPTATION AND CULTURAL HERITAGE: THE CASE STUDY OF THE ARCHAEOLOGICAL SITE OF ANCIENT MESSENE, GREECE

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Introduction

''The majority of heritage sites in the Mediterranean are vulnerable to an increasing rate of threats from man-made global warming and extreme events'' (Kapsomenakis et al., 2022). This study contributes to relatively few studies that examine the effects of climate change on individual sites, specifically tangible heritage (Orr et al., 2021). To bridge the gap between climate change science and the planning of climate change adaptation for cultural assets, it is necessary to analyse climate data and cultural heritage information. Several research efforts are devoted in analyzing a single scenario and a single climate model without considering the potential uncertainties (Sesana et al., 2021). In this study we use climate projections (of e.g. temperature, precipitation) from a selected (after evaluation) regional climate model for two future periods (2031-2060, 2071-2100) under three different emission scenarios (Representative Concentration Pathways RCPs) to estimate and analyse relative climate indices identifying the most significant risks to the study site: the archaeological site of Ancient Messene in South Greece. The IPCC 2001 vulnerability assessment analysis follows, in our methodological approach, for assessing the impacts of climate indices changes or extreme climate events, on the case study site. Through this process, it was presumed that it is possible to identify the sites needs as efficiently as possible and propose adaptation measures or policies.

Methods

The archaeological site of Ancient Messene was chosen, as the case study site, because of its monumental nature, historical significance, documented vulnerability to extreme climate events and susceptibility to the anticipated effects of climate change. To identify the most significant risks to the study site, an analysis of related climate indices, was conducted using climate projections (of e.g. temperature, precipitation, relative humidity, wind speed) from a selected regional climate model for two future periods (2031-2060, 2071-2100) under three different emission scenarios (RCPs). The GCM/RCM pair used in this study (MPI-ESM-LR_RCA4) was selected out of 5 GCM/RCM pairs (regional climate models hereafter) after evaluation with temperature/precipitation station observations. The 1971-2000 period served as a reference /control period for estimating changes of the climate indices (e,g hot days, dry days, fire weather index). The RCPs (https://climate.copernicus.eu/sites/default/files/2021-01/infosheet3.pdf) examined here were namely the: RCP2.6 (very low future emissions, severe mitigation), RCP4.5 (intermediate scenario with mitigations measures and moderate future emissions), and RCP8.5 (very high future emissions, no mitigation policies). Statistical analysis using the z-test and t-test assessed the significance of differences in climate values. For the vulnerability assessment of the study site to the impacts of climate change, the risk assessment methodology from IPCC, 2001 was used based on the analysis of the climate projections and indices. This approach is based on exposure, sensitivity, and adaptive capacity McCarthy et al. (2001). High vulnerability arises from high exposure and sensitivity combined with limited adaptability, whereas increased adaptive capacity and reduced exposure and sensitivity decrease vulnerability. In this study, vulnerability assessment was viewed as an essential step in assessing the impacts of extreme climate events on the study site and proposing measures or policies to address them on all human activity sectors.

Results

The analysis indicated a warmer, drier future with an increased frequency of hot and dry days and decreased annual precipitation across all scenarios. Under RCP8.5, hot days and consecutive dry days could rise by up to 60 and 20 days by 2100 respectively, significantly elevating the fire risk and droughts

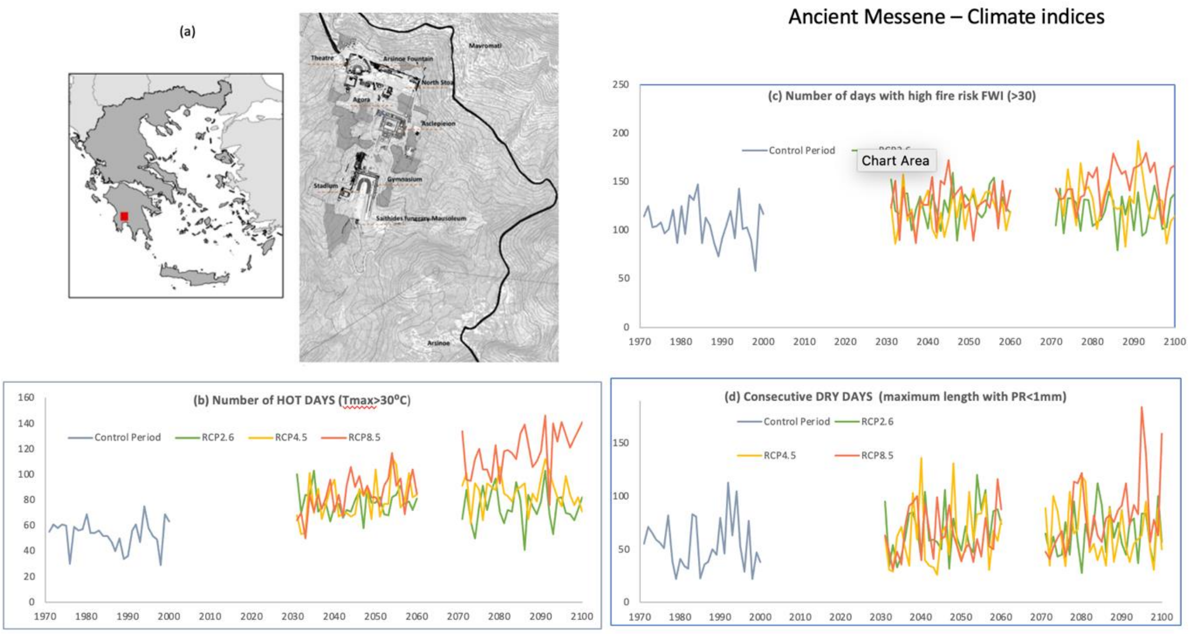

Figure 1. (a) The geographical location of the archaeological site and the topographical plan of the archaeological site of Ancient Messene (ELLET, 2021); (b),(c),(d) Climate indices for 2 future periods (2031-2060, 2071-2100) under 3 RCPs-1971-2000 is the reference period.

(Figure 1b,d). A notable increase in days (60) with high fire risk (FWI fire weather index >30), with extreme values under RCP8.5 was shown (Figure 1c). These findings highlight fire risk, drought conditions as primary threats to Ancient Messene, underscoring the urgent need for adaptation measures and policies addressing their impacts on the archaeological site. The vulnerability analysis approach outlined by IPCC in 2001 was employed to assess the impact of these threats on the study site. This approach also facilitated the identification of priorities for adaptation measures.

Conclusion

The analysis revealed the site's moderate-to-high risk exposure due to its location, prone to warm, drought conditions, wildfire. The site's adaptability is hindered by inadequate infrastructure, including a poor drainage network, lack of comprehensive fire protection, and insufficient emergency vehicle access. The incomplete legal framework for protection zones further exacerbates the site's vulnerability, highlighting the need for significant improvements in infrastructure, management, and legal protection to enhance resilience to climate change. Priorities for adaptation measures include developing a fire protection study and implementing necessary measures, as well as improving road infrastructure and internal routes for safe access and evacuation. These steps, along with enhanced management and legal protection, are vital to bolster the site's resilience against climate change impacts (ELLET, 2021).

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QUALITATIVE ASSESSMENT OF THE ROCKFALL RISK; CASE STUDY ARCHAEOLOGICAL SITE OF DELPHI, IN GREECE

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Natural hazards, such as rockfalls are often caused by extreme and intense weather and climate phenomena, endangering human life and impacting society, economy and tourism, worldwide. Monumental areas near steep rocky slopes are frequently threatened by this type of geological phenomena. Rockfall hazard varies in terms of their intensity, severity, extent, as well as in terms of their effects to the elements exposed at risk, including visitors safety and Monumental Sites sustainability. In the present work, the Archaeological Site of Delphi, in Greece was studied. This Site is facing rockfall phenomena from ancient times till nowadays. Modelling rockfalls, in 3D environment contribute to avoid loss of human life and property damage, so, many factors should be taken into account, such as the distribution and calculation of rock block volumes, their geometric and mechanical characteristics, the mechanisms of failure etc. Alongside, UAV systems constitute an innovative technology for obtaining three-dimensional (3D) data and aerial photographs, they reduce time and cost of work, compared to classic conventional field working and they provide the possibility of creating high-resolution data. This study aims at an initial qualitative risk assessment. This was achieved by creating tables (Risk matrix) and spatial distribution maps, in ArcGIS environment, both for Direct Material and Direct Intangible loss, through three-dimensional trajectometric analyses, by calculating the intensity (kJ), the probability of reaching the Monumental area (Ppropag) and the simultaneous determination of rock blocks trajectory termination (stop points).

Introduction

In mountainous areas rockfalls are a major threat causing serious damage to infrastructure and buildings, Cultural Heritage Sites and loss of human life (Scavia et al. 2020). Understanding the severity of the rockfall phenomena and the social and economic impacts, many researchers have developed risk assessment techniques, for rocky slopes, based on visual monitoring, simple calculations and estimating rock mass properties, through systems classification and evaluation (Pantelidis 2009). Risk assessment can be achieved, either qualitatively or quantitatively. For the qualitative characterization of Risk, the descriptive and qualitative elements of the area being studied are taken into account, as well as the expected social effects of the natural phenomena under consideration. The qualitative assessment of the risk includes the subjective criterion of each researcher, with the designation "High", "Medium" and "Low", through a table of qualitative assessment of the risk (Risk matrix).

Methods-Results

In the present work, an initial approach for qualitative risk assessment (Risk) was carried out, by creating tables (Risk matrix) and maps, in ArcGIS environment, both for Intangible (Fig. 1) and Material loss that might be caused, based on the colour gradation of the 3D spatial visualization of the probability of propagation (Ppropag) of rock blocks at the elements of Risk in the Site, also considering rock blocks trajectories termination (stop points). So, according to the 3D spatial distribution map of Fig. 1 the degree of Risk seems to be high in the entirety of the Monuments of the Site, as well as in the Kastalia Spring (red colour), while medium appears at the Entrance of the Archaeological Area, the visitors corridor, the road network and the Archaeological Museum (yellow colour). Finally, it appears small at the Parking area (green colour). In order to export the above results, a four-step methodology was followed including the following steps: 1) assessment of the rockfall susceptibility, 2) evaluation of the rockfall hazard through 3D trajectrometric analysis, in 2D and 3D environment, 3) examination of the degree of Risk according to the spatial allocation of the selected critical zones on the rocky cliff, which were used for Hazard determination.

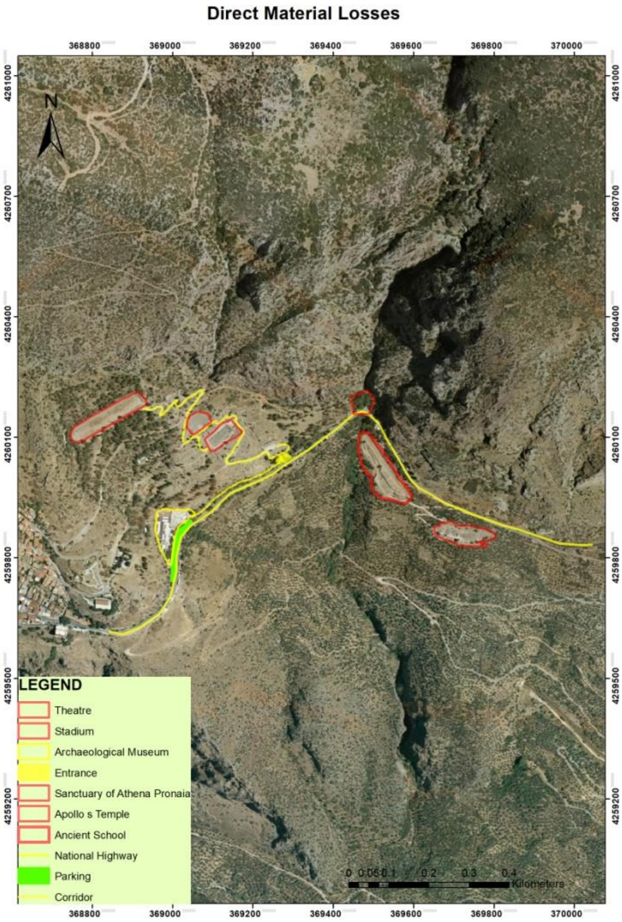

Figure 1. Distribution map of qualitative Risk assessment (Risk matrix), based on the rockfall probability in the Archaeological Site of Delphi, as well as its Direct Material Losses-effects.

Conclusion

The aim of this study was the development of a detailed rockfall hazard assessment and a preliminary rockfall qualitative Risk assessment methodology in the Archaeological Site of Delphi, the results of which can be used in proposing the appropriate rockfall interventions in the examined Area. This UNESCO World Heritage Site, is a symbol and the center of Greek culture, the sustainability of which, as well as staff and thousands of visitors safety constitute the main objective of the present work.

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THE VERSAILLES GRAND CANAL: A GEOTECHNICAL ENQUIRY, III

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Introduction

The Versailles castle park planning needed important geotechnical works. The park's masterpiece, the Grand Canal (Figure 1), was built over a period of almost fifteen years in the last third of the XVIIth century. The principal results of an archive investigation focused on this basin were communicated at the 17th ECSMGE (Vernhes and Heitzmann, 2019) and completed at the 3rd ISSMGE TC301 International Symposium (Vernhes *et al.*, 2022), with field and coarse GIS data. The archives proved to be sufficient to determine phases in the construction of the basin but with almost no spatial details. The current and original terrain topography then became the main target to assess the earthworks overall volume and thus decipher the planners' strategy.

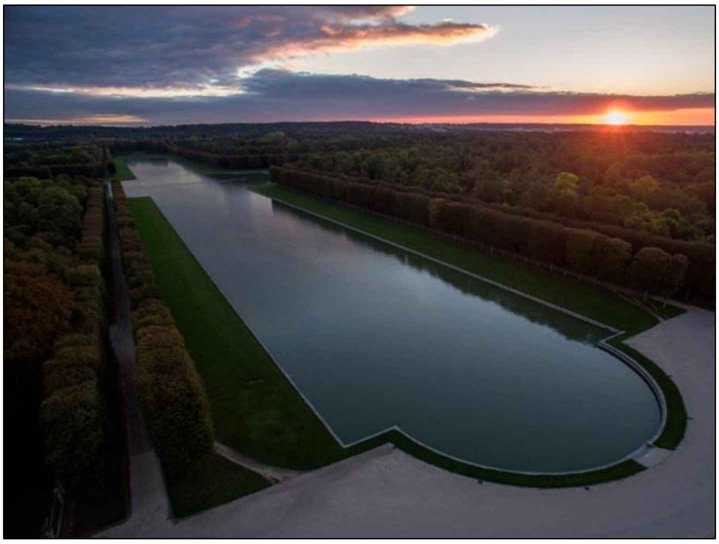

Figure 1. Aerial view of the *Grand Canal*'s Northern branch (© Th. Garnier)

Methods

The geological data constraint for such an objective, based on field surveys, proved to be tricky. According to the most recent geological map, issued by Jean Goguel in 1967, the grounds in which the two meters deep and 230,000 m² canal had been dug are tabular late Eocene to Oligocene layers, what could have helped to offer clues on earth movements through geophysical and light geotechnical field investigations. However, boreholes (Lablaude, 1997) revealed that the topographical depression in that area is filled with recent mixed Eocene and Oligocene origin colluvia.

Relying on the former coarse GIS data entailed a high level of uncertainty in the 2022's conclusions. The present extended abstract aims at showing the scientific potential of the French National Geographical Institute (IGN) Lidar covering of France's surface, coincidently available since 2022. Its processing by the authors now offers a finer Digital Elevation Model of the Grand Canal area. As an example, the previous 1-meter topographical model had made it impossible to get rid of the artifacts due to the many trees all around the canal. The 2022 LiDAR dataset being classified, a 75 cm DEM was created excluding the vegetation from the pointcloud, revealing unseen ground details.

Results

As an example, Figure 2 shows a map with a range of heights and a shading mode meant to visualise the Gally creek hydraulic trenches (see e.g. landmark ‘c’), necessary to prevent higher flooding risk in the park provoked by the canal’s barrier effect on the local hydrographic and hydrogeological natural regimes. This map also makes obvious the extent of the fine fill layers near the canal, originally particularly hard to see towards the West of the Southern arm.

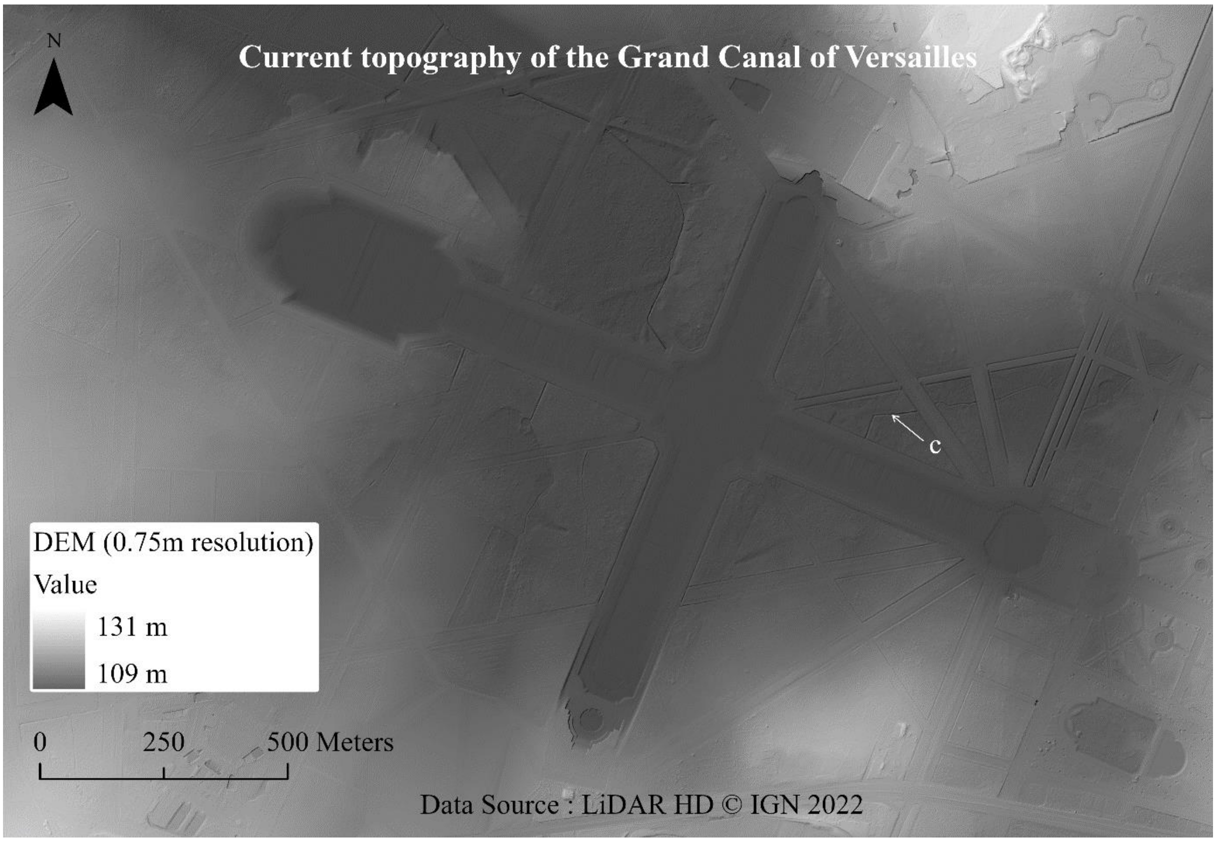

Figure 2. Digital Elevation Model of the Grand Canal in Versailles, computed from LiDAR aerial data acquired by the French Geographical Institute (IGN) in 2022. The heights reference is the average sea level at Marseille.

Conclusion

After full exploitation of today’s new DEM, the next step will be to enhance the original topography DEM hypothesis, now easier to assume. An idea to give better foundations and realism to the solution will be to use computer-assisted (AI) characterization of natural vs. man-modified topography, using as an input IGN data in areas recognised to be with similar geomorphological conditions.

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STABILITY OF THE HISTORICAL MONUMENTS: THE PHANTOM MENACE?

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Introduction

The Prague and Vyšehrad castle are two main dominants of historical UNESCO site of Prague, one of the most beautiful and well-preserved medieval cities. However, as the originally medieval fortifications are naturally built on the prominent hilltops, they did not avoid problems with the long-term stability of numerous buildings. As both castle complexes are more than 1000 years old, the stability issues go deep into history and literally deep into many meters of the aggravated anthropogenic deposits. Therefore, it was decided to monitor the displacement to observe the stability of the site for their protection. Various monitoring systems were considered (Klimeš et al. 2011, Greif et al 2017, Fantini et al. 2016).

Figure 1. Three monitored sites in the underground of the Prague Castle

Methods

In August 2020, the monitoring was established at the Prague castle, and in February 2022 at the Vyšehrad castle. The monitoring was initiated by the archeologists and heritage sites´ authorities, who observed indications of movements at several places of the monuments. Several pairs of automatic extensometers Gefran supplemented with dataloggers Tertium Beacon (Racek et al. 2021, Crosta et al 2017, Tertium 2017) were installed across the most prominent open cracks in the walls. The devices were set to measure once every hour, with the dilatation accuracy of 0,05 mm and temperature accuracy of 0,1 °C.

Results

The results of the 3 years monitoring (2 years at Vyšehrad) were analysed. The largest movements at Prague castle exceeded 1 mm at the most significant opening. Generally, data from Prague castle show combination of thermal expansion with a significant trend for opening of the cracks. The largest clear trends reached 1 mm (1A) and 0,52 mm (1B) for the observed period. At the Vyšehrad castle, the largest movements were observed on the brick wall at the viewpoint, with the clean trend exceeding 3 mm in 2 years. This magnitude of movements is considered a significant potential threat for the stability.

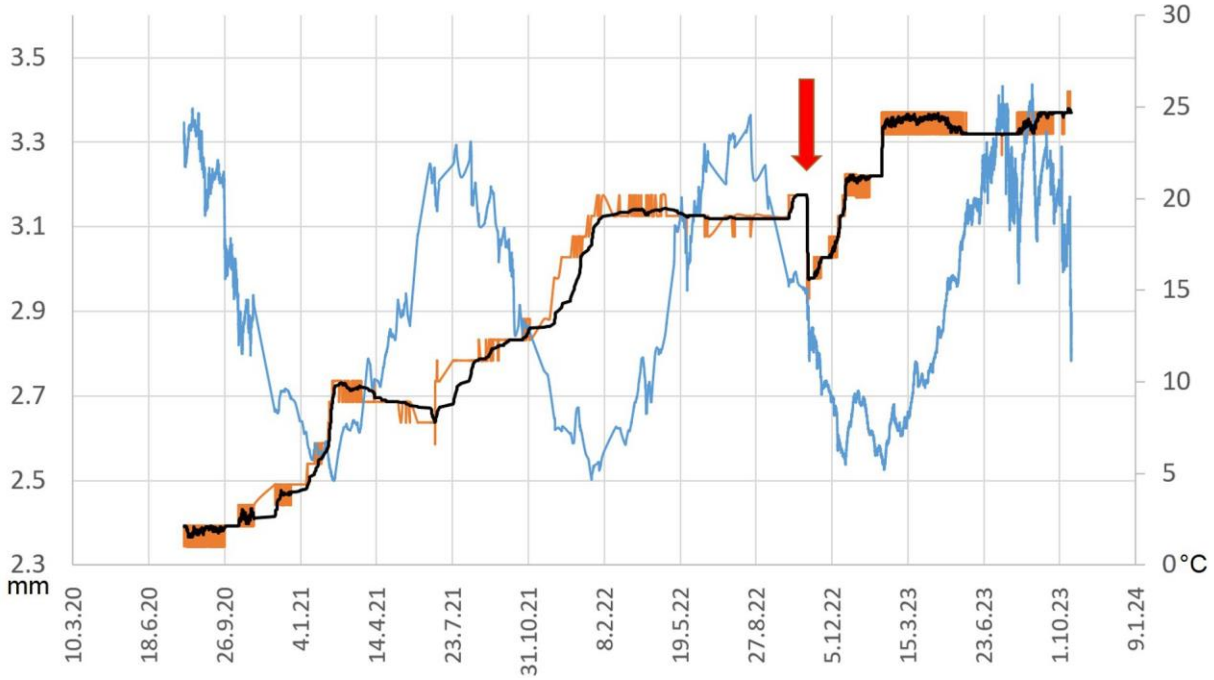

Figure 2. Displacement chart of the fastest moving 1A measurement (see Fig. 1). Orange line: measured displacement, black line - 1 day running average, blue line - temperature. The red arrow indicates prominent reverse impulse

Conclusion

The monitoring shows distinct and clear irreversible displacement trends, at some monitored cracks exceeding 1 mm per year. The influence of temperature can be distincly observed as cyclic phases with yearly period. The causes of the movements are currently being investigated, however, most likely they are connected to the underground seeping of water, causing erosion in the anthropogenic deposits, which leads to subsidence and consequent opening of the cracks.

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SAFEGUARDING "SHIPWRECK": ASSESSING ROCKFALL RISKS ON THE WORLD-FAMOUS BEACH IN ZAKYNTHOS ISLAND, GREECE

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Introduction

This research focuses on the engineering geological hazard and risk assessment of rockfalls and proposes protection measures for the cliffs surrounding the Shipwreck beach in Zakynthos and its safer accessibility. Located in the north-western part of Zakynthos Island in the Ionian Sea, Shipwreck Beach is a significant tourist destination in Greece. The area's characteristics include a high volume of visitors, exceptional natural beauty, steep and high slopes, and significant rockfalls, presenting technical challenges for protection measures (Figure 1 & Figure 2). The key requirements for risk management are preserving the aesthetic environment, maintaining tourist appeal with acceptable risk, and providing economically and technically feasible risk reduction solutions. In the study area, the rock mass is composed of thin-bedded blocky limestone, which generally exhibits high strength but is affected by various systems of discontinuities and fractures. Rockfalls have occurred due to factors such as steep slopes, strong earthquakes, marine erosion undercutting the steep slopes developing subvertical tensile cracks, and weather-induced discontinuities. These rockfalls involve fragments of various sizes, impacting the beach zone and the sea. Many overhanging rock blocks pose a high risk, threatening beach access, the surrounding marine zone, and viewing areas at the top of the slopes.

Figure 1. The world famous "Shipwreck" beach in Zakynthos island, Greece (left photo). Numerous overhanging rock blocks, from the vertical and high (up to 200m) slopes, present a significant danger, jeopardizing beach access, the nearby marine area, and the viewpoints at the top of the slopes (right photo)

Methods

Engineering geological surveys mapped rock mass qualities, main structural features, and evaluated the rock, discontinuity and rock mass properties along with on-site and laboratory tests. A 3-d point cloud, generated by thousands of images captured from two UAVs from a team of team of surveying engineers, was used in the geospatial analysis and 3D reconstruction programs. Automated (Riquelme ets al., 2014) and conventional measurements assessed joint systems and blocks. Dangerous overhanging blocks were mapped and analyzed using 3D risk analysis, with geotechnical software RocSlope3 by Rocscience Inc. determining critical volumes and detachment locations. Rockfall analyses, including static and seismic conditions, were performed using Rocfall 3 (Figure 2).

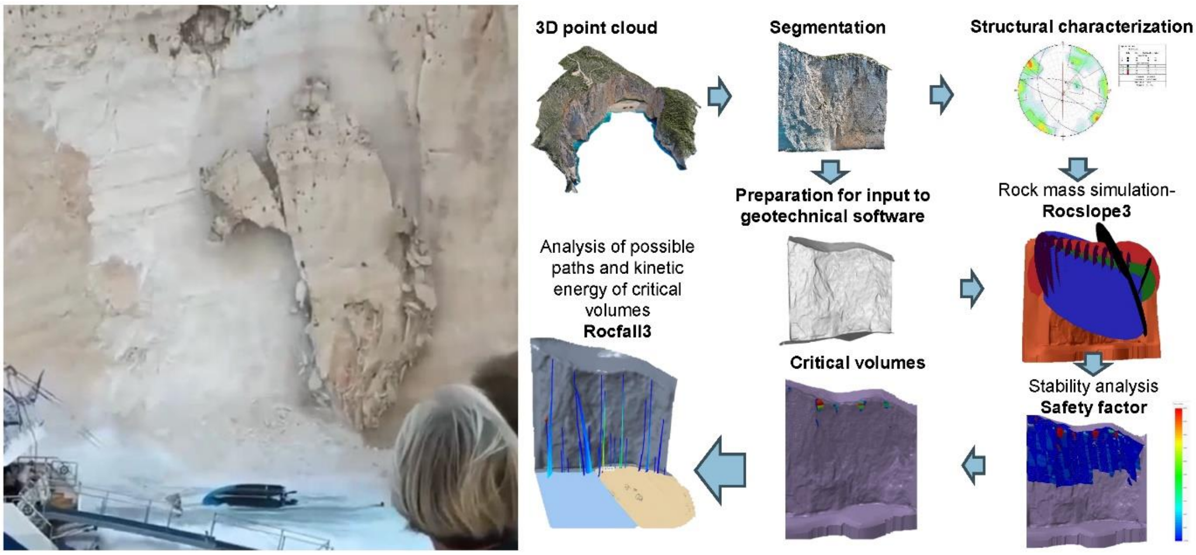

Figure 2. Rockfall risk analysis methodoly. A recent rockfall (~300 m^3), occured in summer 2018 under static conditions, is shown in the left photo.

Results

The study found a very high risk of falling blocks from various locations on the slopes. The main failure mechanism is block toppling due to undercutting and stress relief. Access zones were delineated based on a 3D analysis. Risk reduction can be achieved through protection measures, including unobtrusive interventions and observation points if unstable zones are avoided or stabilized. The study proposes installing a long-term geotechnical monitoring system for the slopes.

Acknowledgments

This study is an integral part of the interdisciplinary original research titled "Research-Documentation and Proposals by the National Technical University of Athens for the Preservation of the Shipwreck and Safe Visitor Access to the Area.". The detailed results of the research can be downloaded from the website: https://navagio-zakynthou.ntua.gr/

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