Italian Journal of Engineering Geology and Environment
www.ijege.uniroma1.it

HAZARD ASSESSMENT OF A ROCKY SLOPE OF MOUNT PELLEGRINO (NORTHERN SICILY): A COMPARATIVE STUDY OF DIRECT AND INDIRECT APPROACHES

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EXTENDED ABSTRACT

La valutazione della pericolosità da frana a valle delle pendici degli ammassi rocciosi fratturati è generalmente messa in correlazione con la probabilità di accadimento di fenomeni potenziali di crollo. I crolli sono fenomeni gravitativi estremamente rapidi e possono interessare volumi di roccia variabili da pochi metri cubi (crolli per blocchi singoli o multipli) a migliaia di metri cubi (crolli in massa). La pericolosità associata è legata alla propensione al distacco di blocchi potenzialmente instabili e all'energia del fenomeno. La velocità e la magnitudo di tali fenomeni implicano, in presenza di elementi esposti, anche elevate condizioni di rischio. La valutazione della pericolosità relativa ai fenomeni di crollo diventa, quindi, fondamentale per la gestione del territorio e per la definizione delle opere di prevenzione e di mitigazione del rischio a diversa scala. In tal senso, l'Autorità di Bacino del Distretto Idrografico della Sicilia ha previsto nell'aggiornamento del 2021 delle Norme di Attuazione del Piano Stralcio per l'Assetto Idrogeologico delle apposite direttive per la redazione degli studi di valutazione della pericolosità derivante da fenomeni di crollo, che prevedono diverse fasi di studio attraverso l'applicazione di modelli analitici ed empirici fino alla definizione degli interventi.

I dati in ingresso per la valutazione della pericolosità devono essere definiti attraverso metodi diretti e indiretti. Questi possono essere quindi ricavati dall'applicazione di metodi tradizionali e supportati dalle più recenti tecnologie di rilevamento in remoto che permettono di superare i problemi legati alla raccolta dei dati sul campo in termini di accessibilità, sicurezza, costi e tempi delle applicazioni.

La caratterizzazione dei fronti potenzialmente suscettibili passa, innanzitutto, dai rilievi geomeccanici degli ammassi rocciosi fratturati secondo le raccomandazioni dell'International Society for Rock Mechanics e prevede il rilevamento geomorfologico e l'individuazione di aree omogenee sulle quali vengono definiti i parametri delle discontinuità che attraversano una linea designata dall'operatore, secondo la metodologia della scanline. Conta molto la capacità dell'operatore nell'integrare i dati ottenuti dalla scanline con dati acquisiti in maniera random sul fronte roccioso per non escludere dall'analisi alcune delle peculiarità dell'oggetto di studio. I limiti di questo metodo sono: *i)* la necessità di raggiungere fisicamente il fronte roccioso; *ii)* i tempi lunghi e i costi a volte elevati; *iii)* gli errori e vizi di forma legati alla soggettività dell'operatore.

Le metodologie indirette includono una serie di approcci che superano i problemi menzionati e si basano sulla definizione di modelli tridimensionali dei fronti mediante l'acquisizione di immagini con fotocamere digitali, laser scanner o radar. Gli output di tali rilievi sono modelli digitali del terreno e modelli costituiti da nuvole di punti, che attraverso software dedicati, permettono di ricavare le caratteristiche geometriche utili all'analisi dei fenomeni in termini di magnitudo, cinematismi e aree di propagazione.

La bontà dei risultati ottenuti dipende dagli strumenti ma non sono sempre disponibili le tecnologie più recenti e costose (e.g. laser scanner o radar). In tal senso, viene qui presentato uno studio che, attraverso l'applicazione e il confronto di tecniche differenti, si propone di testare le potenzialità dell'applicazione di rilevamenti in remoto attraverso l'utilizzo di una macchina fotografica digitale economica e l'implementazione di un sistema di riferimento locale. L'area di studio è un fronte roccioso situato sul lato ovest del Monte Pellegrino (Sicilia nord-occidentale) che in passato è stato interessato da numerosi fenomeni di crollo. Il Monte è caratterizzato da rocce omogenee per litologia, principalmente carbonati pelagici altamente fratturati e carsificati. Tale assetto definisce elevate condizioni di rischio in un'area molto importante per la città di Palermo dal punto di vista naturalistico, religioso, turistico e culturale. L'uso di tecniche sia dirette che indirette ha permesso di individuare instabilità potenziali, definendo scenari possibili di rottura in termini di volume e cinematismi. L'orientamento dei piani di discontinuità è stato ottenuto da un'analisi geo-strutturale tradizionale e dalla costruzione della nuvola di punti attraverso il rilievo fotografico. I modelli tridimensionali così ottenuti hanno permesso di definire, attraverso procedure semi-automatiche implementate in codici di calcolo "open source", le caratteristiche geometriche dell'ammasso. Il raggruppamento in famiglie di discontinuità e la conseguente analisi cinematica applicata ai dati ottenuti ha permesso di definire i principali meccanismi di rottura potenziali. L'analisi dei risultati ottenuti ha evidenziato un buon accordo tra le misure derivate direttamente sul campo e i dati ottenuti tramite rilevamento da remoto attraverso le tecnologie economiche e di facile approccio.

IJEGE, Special Issue 1 (2024): 205-214, DOI: 10.4408/IJEGE.2024-01.S-23
E-ISSN 2035-5688 | ISSN 1825-6635 / ©Author(s)

ABSTRACT

The assessment of landslide hazard related to slopes in fractured rock masses is generally correlated with the probability of occurrence of potential rockfall phenomena. The propensity to detachment of rock blocks can be defined through direct or indirect approaches. The first, widely used for decades, is regulated by the International Society for Rock Mechanics recommendations, and provides for the definition of a series of parameters for discontinuities that cross a line designated by the operator, according to the so-called "scanline" methodology. The most applied indirect approaches are based on the construction of a 3D model of the studied front through input data acquired by a digital camera, laser scanner or radar. These two different approaches were used to analyze the discontinuities orientation of a rocky slope on the west side of Mt. Pellegrino (northern Sicily). In this context, it is essential to anticipate rockfall, given the presence of densely urbanized areas at the foot of the rocky slope. The main discontinuity sets were obtained from traditional geo-structural analysis and 3D Point Cloud model of the slope; the latter were derived by applying the Structure from Motion technique on frames captured during the surveys. The kinematic analysis applied to the obtained data allowed us to define from a geomechanical perspective, the main modes of failure. Moreover, back analyses were carried out on the already collapsed blocks to reveal the most likely rockfall volume and reached distance.

Keywords: *: fractured rock mass, rock mass characterization, Structure from Motion technique, 3D point cloud, semi-automatic extraction.*

INTRODUCTION

Rockfalls are gravitative phenomena ranging from rapid to extremely rapid, capable of reaching considerable distances from the source area (Hungr *et alii*, 2014). The phenomenon starts with free falling through the air, and evolves through rolling or bouncing along the slope surface depending on the characteristics of the ground on which the movement occurs, as well as the dimensions and shape of the fallen block (Varnes 1978; Evans & Hungr, 1993). These features identify a type of potentially high-hazard phenomenon that could create an equally significant risk scenario in case of intercepting vulnerable elements.

The hazard analysis, from a geomechanical perspective, is based on defining the propensity to detachment for blocks from a rock slope and determining the most likely detached volume. The first parameter is defined by kinematic analysis: the orientations of the main discontinuity sets are examined in relation to the orientation of the rock slope to assess if the movement is kinematically possible and what type of movement is more probable. The second parameter is defined by the analysis of spacing, number, and persistence of the identified discontinuity sets. Direct and indirect approaches can be applied to gather such information. The formers are based on the recommendations of the International Society of Rock Mechanics (ISRM) in accordance with parameters defined by Priest (1993). Characterization is carried out directly on the rock slope using a geological compass or Clar-type compass, metric tape, Smith's hammer, and Barton's comb (Hoek &Bray, 1981). The indirect approaches are based on 3D point cloud acquisition technologies that model the rock slope by analyzing the return times of an impulsive light signal (Laser Scanner) or radio waves (Synthetic-Aperture Radar). By processing these point clouds (PC), a three-dimensional model of the study area can be created. Furthermore, a 3D PC can be obtained using the Structure from Motion (SfM) technique (Ullman, 1979). From a correctly filtered dense point cloud, information about the presence of discontinuities and their orientations can be semi-automatically extracted.

Indirect approaches overtake the direct ones in the case of rocky slopes that are difficult to access and highly hazardous. In any case, there are other features in favor of indirect approaches to consider, including shorter survey time, better statistical representativeness of the data sample, and a lower weight of the measurement errors (Cappadonia *et alii*, 2023; Riquelme *et alii*, 2015). Although digital photogrammetry is considered a cost-effective technique, it requires the availability of suitable equipment such as a high-resolution digital camera for frame acquisition and a GNSS receiver for georeferencing the point cloud. While it is true that higher resolution frames result in a higher-quality final model, it is also true that more time is required to process the data, necessitating access to an appropriate workstation. In this respect, there are many applications demonstrating the achievement of well-defined models for rock mechanics applications using frames acquired with conventional cameras (Jordá Bordehore *et alii*, 2017; López-Vinielles *et alii*, 2020; Ozturk *et alii*, 2019; Riquelme *et alii*, 2019). The accurate georeferencing of the model, along with its resolution, is a crucial factor enabling the proper extraction of discontinuities. In this type of approach, georeferencing is implemented to achieve correct rotation, translation, and scaling of the model with respect to cardinal directions, rather than placing the model in real-world space. With this purpose, it is possible to establish a local reference system based on points detected on the object itself (Jordá Bordehore *et alii*, 2017, Francioni *et alii*, 2019, Riquelme *et alii*, 2020), replacing the function of a GNSS receiver. Nevertheless, this option is not only to be considered for budgetary reasons. In fact, the use of a GNSS receiver is not recommended for certain surveys, especially in areas with poor satellite coverage, such as at the base of a very height rock front.

This study aims to evaluate the propensity to detachment of a rock slope located on the western side of Mt. Pellegrino (Sicily). For this purpose, kinematic analysis was carried out on data obtained from field survey through traditional approach, and on data obtained from semi-automatic extraction from 3D PC built with the Structure from Motion (SfM) methodology.

The results obtained allow a comparison to be made between the direct and indirect approaches to define the propensity to detachment of blocks from a rocky slope.

STUDY SITE

The study area (Fig.1) is located in the western side of Mount Pellegrino (594 m a.s.l.) in the urban zone of Palermo (Sicily, Southern Italy), in a strategic area of the city from a naturalistic, cultural and religious point of view (Cafiso & Cappadonia, 2019; Cappadonia *et alii*, 2021). The rock face under study was selected because several exploration pedestrian paths develop at its base.

Mount Pellegrino is part of the Sicilian Chain and is the result of the deformation and overthrust of carbonate platform terrain, which were subsequently broken up by high-angle normal faults during the Plio-Quaternary extensional and transtensional tectonic, determining its present shape (Agate *et alii*, 2017; Cappadonia *et alii*, 2020). The Mount is part of a block-faulted structural setting where the morpho-structural depression is filled with Quaternary marine and continental deposits; the tectonic edifice consists of a Structural Stratigraphic Unit deriving from the deformation of the Panormide Domain, homogenous carbonates rocks mainly (Fig.1, Catalano *et alii*, 2013). Cappadonia *et alii* (2021) highlights how each sector is characterized by different stratigraphic and structural conditions and several rockfall phenomena. In the study area, rock masses are characterised by sub-vertical bedding planes and several discontinuities isolating unstable rock blocks giving rise to rockfall phenomena.

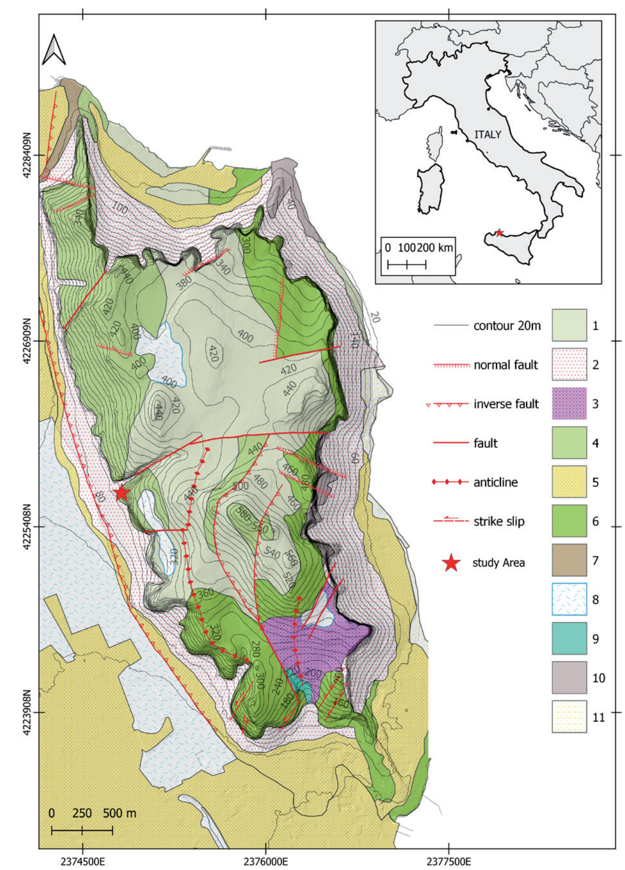

Fig. 1 - Mt. Pellegrino geological map: 1. Bioclastic wackestone-packstone (Barremian – Aptian); 2. Detritus and poor sorted materials (Upper Pleistocene-Holocene); 3. Massive grey limestones and dolomitic limestones (upper Triassic); 4. Bioclastic packstone (Cenomanian – Senonian); 5. Terraced calcarenites (Calabrian); 6. Coralgal biolitites (Tithonian – Neocomian); 7. Bioclastic packstone to rudstone (middle Lutezian-late Cuisian); 8. Eluvial and Colluvial deposits (Upper Pleistocene-Holocene); 9. Reddish marly carbonates and nodular pseudobreccias (middle – Upper Liassic); 10. Dolomitic limestones and dolomites (upper Triassic – lower Liassic); 11. Sands (Upper Pleistocene-Holocene). Modified from Catalano *et alii, 2013*

METHODS

The geometrical, geological and structural factors that directly influence the rockfall hazard of the study area were defined by using both traditional and modern approaches through on-field surveys and data processing.

On-field surveys

The traditional approach to detect the orientation of any plane is based on collecting data on field through a geological compass or Clar-type compass, which requires direct access to the location. The values of dip direction and dip angle of the discontinuities intersecting a line placed parallel to the direction of the front were acquired using the "scanline" method; 84 Dip direction/Dip measurements were taken over a horizontal scanline 40 m length.

The second phase involved the acquisition of a set of data necessary for the construction of a 3D PC (three-dimensional point cloud) through a photogrammetry process. There is no standardized procedure for this indirect approach, but there are several recommendations need to be considered for the successful creation of a 3D model for geomechanical purposes. Firstly, it is essential that the model is correctly referred to the magnetic north and that it is full-scale. To properly rotate, translate and scale the 3D PC, at least three ground control points (GCPs) must be positioned on the rock slope, measuring the inter-distance between them. Finally, the direction of the plane on which the known points lie must be measured (Jordá Bordehore *et alii*, 2017). This procedure allows for alignment with magnetic north, using a local reference system in which one of the known points serves as the origin, and the others are referred to the first based on their inter-distances.

To simplify the positioning and measurement of inter-distances between GCPs, markers have been printed on paper in a single table, which has been vertically positioned in the N-S direction using a geologist's compass (Fig. 2a). The correct roto-translation of the 3D PC must be assessed through check planes (CkPs). Acquisitions of discontinuity orientations are

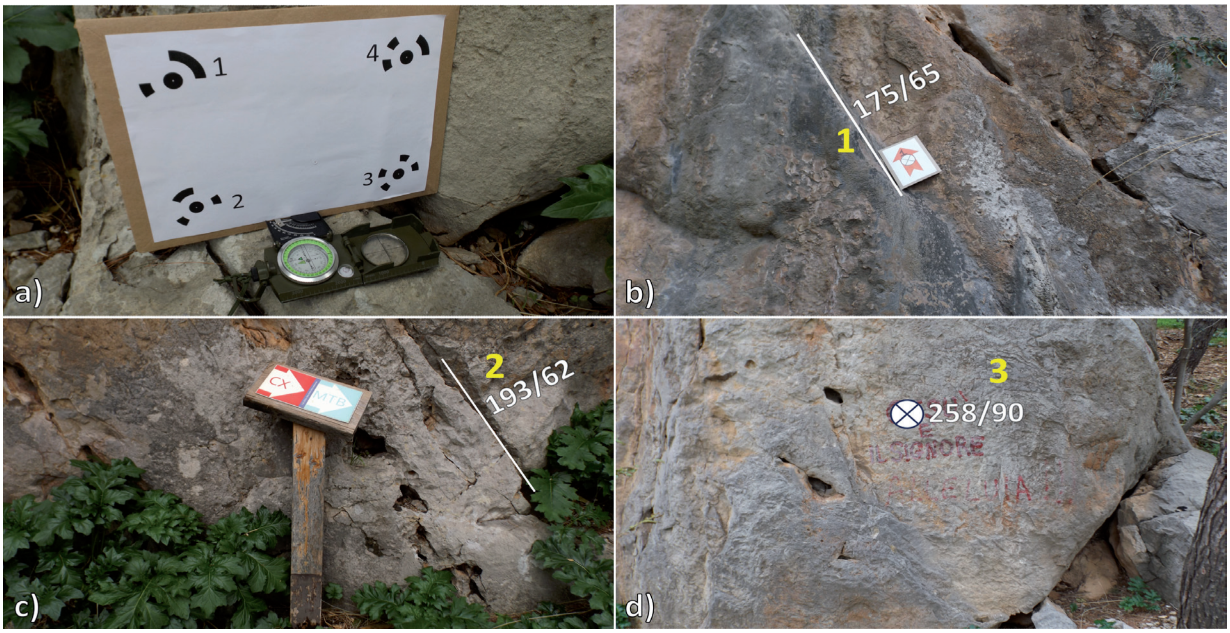

Fig. 2 - a) Detail of the table containing the GCPs and the compass indicating the N-S direction; b) CkP 1 on discontinuity, measured orientation 175/65. b) CkP 2 on discontinuity, orientation 193/62. c) CkP 3 on rock front, orientation 258/90

then made on designated points to compare the field-acquired measures with the orientation values measured on the same points using the Compass plugin (Thiele *et alii*, 2017) available in the open-source software CloudCompare. Three CkPs have been selected, two on discontinuities, and the third directly on the rock front (Fig. 2b, c, d). The measured orientations in terms of dip direction/dip are reported in the pictures.

The 3D PC's quality is contingent upon both the quality of the captured photos and the extent of overlap among them. The acquisition of frames was carried out using an entry level digital camera (Fujifilm FinePix S4600), capable of capturing photos with a resolution of up to 4608×3456 px (16 MP). Due to the nearly constant orientation of the rock slope, pics were taken along a straight path parallel to the front, with an initial distance of 2-3 meters from it. Horizontal and vertical acquisitions were made to ensure an overlap of at least 75% between consecutive frames. This procedure was performed over an angle of approximately 120° both horizontally and vertically for each station along the path. Additional shots were taken from 5-6 meters from the rock slope to capture comprehensive views.

Data processing

To construct the 3D Point Cloud (3D PC), the acquired photos were imported into a commercial software (Agisoft Metashape), which allows the processing of digital images through the Structure from Motion (SfM) technique. The local reference system was defined using Ground Control Points (GCPs) on the rock slope (Jordá Bordehore *et alii*, 2017). Four markers, printed on a single sheet placed on the slope's face (Fig. 2a), were used for this operation. The chosen markers are easily recognizable by the software, simplifying this processing phase. By knowing the inter-distance between the points and referencing the plane on which they lie to the north, the 3D PC can be correctly rotated and translated according to the cardinal directions. Once the known points were marked, the alignment of the photos was performed to create a sparse point cloud. At this stage, a preliminary data filtering could be applied if clusters of points projected outside the rock slope were observed. The goal is to obtain a cleaner dense point cloud representing the rock slope in three dimensions. The selection of certain parameters is crucial in this processing phase, considering the specific case study. A significant choice during alignment is the amount of information to extract from each photo which can be processed at their maximum quality or using a lower resolution. The latter option should be considered if high-performance hardware is not available or if the photos are noisy in terms of focus and exposure. For the alignment of the frames acquired for this work, a high-quality setting was chosen, which was also maintained for the construction of the dense point cloud.

In this context, it is also necessary to define the depth filtering parameter of the software. This can be set to aggressive, moderate, mild, or disabled. The aggressive setting is useful for eliminating outliers but may result in the loss of details crucial for orientation information extraction. Conversely, disabling filtering completely would lead to the production of a very noisy point cloud, prolonging post-processing operations. Due to the presence of vegetation, including bushes at the base of the rock slope, the 'mild' setting was chosen. This allowed filtering as much as possible the portions covered by vegetation without losing information on the rockfall front. The 3D PC was imported into CloudCompare software, in which a manual filtering of the point cloud was applied to clean it from the remaining vegetated areas and very noisy zones. In the same software, using the Compass plugin (Thiele *et alii*, 2017), it was possible to evaluate the accuracy of georeferencing. The plugin allows selecting a plane from the 3D PC to obtain information about dip direction and dip. In this way, those planes for which orientation measurements had been previously collected during the on-field survey (CkPs, Fig. 2), were investigated. The extraction of discontinuities from the 3D PC was performed through the Facet plugin (Dewez *et alii*, 2016) in CloudCompare. The same operation was repeated using the software Discontinuity Set Extractor (Riquelme *et alii*, 2014), widely used in literature (Riquelme *et alii*, 2016; Sarro *et alii,* 2018; Gallo *et alii*, 2021). The identification of the main discontinuity sets aims to evaluate the potential activation of unstable blocks according to specific modes of failure. This step was carried out through kinematic analysis, relating the orientations of the front and main discontinuity sets (Markland, 1972). For this purpose, the software Dips (Rocscience, 2020) was used, allowing the analysis of the most probable kinematics by plotting the envelope.

RESULTS

To assess the expected volume of potentially unstable blocks, a back analysis was carried out. The measurements with metric tape of the already collapsed block sizes underlying the rock mass indicate a representative volume of 0.5 m^3. The analysis was carried out on a sample of 100 data collected on field. The distance reached by these boulders ranges from 0 to 10 meters with a high incidence in the first 5 meters, intersecting the pedestrian path at the base of the rockfall front.

During the field operations, 215 photos of the rock front were collected. After processing, it resulted in a dense cloud with approximately 52,000,000 points. Finally, a 3D point cloud of about 1,300,000 points with a minimum inter-distance of 5 mm was obtained through manual filtering and resampling (Fig. 3).

To assess the accuracy of the proposed approach to georeferencing the model, a comparison was carried out between three field measurements located at distinct points (Fig. 3) and the measurements extracted at the same points using the Compass plugin. The results of the comparison are reported in Fig. 4. The field measurement at point 1 was taken on an outcropping discontinuity plane with dip direction/dip equal to 175/65, while the digital measurement at point 1 extracted from the 3D point cloud is 170/66. The field and digital measurements at point 2, relating to a discontinuity plane, are 193/62 and 189/60, respectively. The measurements at point 3 were taken on the slope free face and are 260/90 and 256/88 (Fig. 4). The comparison does not reveal a significant discrepancy, with an error falling within the range of ±5° for dip direction and ±2° for dip angle. These errors are certainly comparable to measurement errors during field operations carried out with a compass. Once the accuracy of georeferencing was assessed, semi-automatic extraction of discontinuities was performed using the DSE software and the Facet plugin. It is well known that the dip and dip direction of a set of discontinuities can be represented on a stereonet as point features representing the perpendicular to the plane (pole). Once the poles are plotted in the equal area lower hemisphere stereographic projection (Hoek & Bray, 1981), data cluster sets can be well visualized, and the representative values of the discontinuity sets can be evaluated by the highest density contour value or the mean dip direction/dip value. As shown, in Fig. 5a, the field data grouped into three main clusters, highlighting three discontinuity sets having the following dip direction/dip: 256/84 (J1), 297/82 (J2), 155/84 (J3). DSE (Fig. 5b) identifies two main clusters for the poles of the following

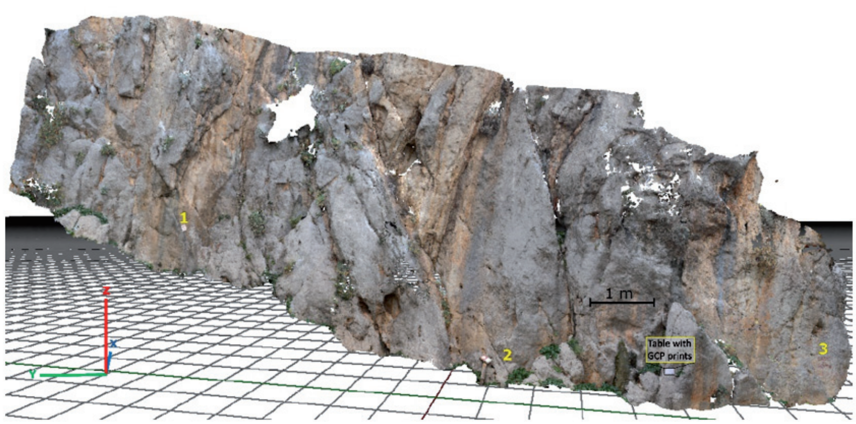

Fig. 3 - The 3D point cloud representing a rock face on the westward exposed slope of Mt. Pellegrino. The numbers (1, 2, 3) indicate the position of the Check Planes (CkPs). The table with GCP prints is indicated

discontinuities: 247/85 (J1) and 275/75 (J2). Similarly, Facet (Fig. 5c) identifies: 243/87 (J1) and 287/80 (J2). The comparison of the results obtained shows agreement in defining the J1 and J2 sets for all three techniques, with an error within a range of 4÷22° for dip direction and 3÷7° for dip angle of the mean discontinuities. For the identification of J1, larger discrepancy between field data and extraction using Facet is observed. For J2, the greatest discrepancy is observed between field data and extraction using

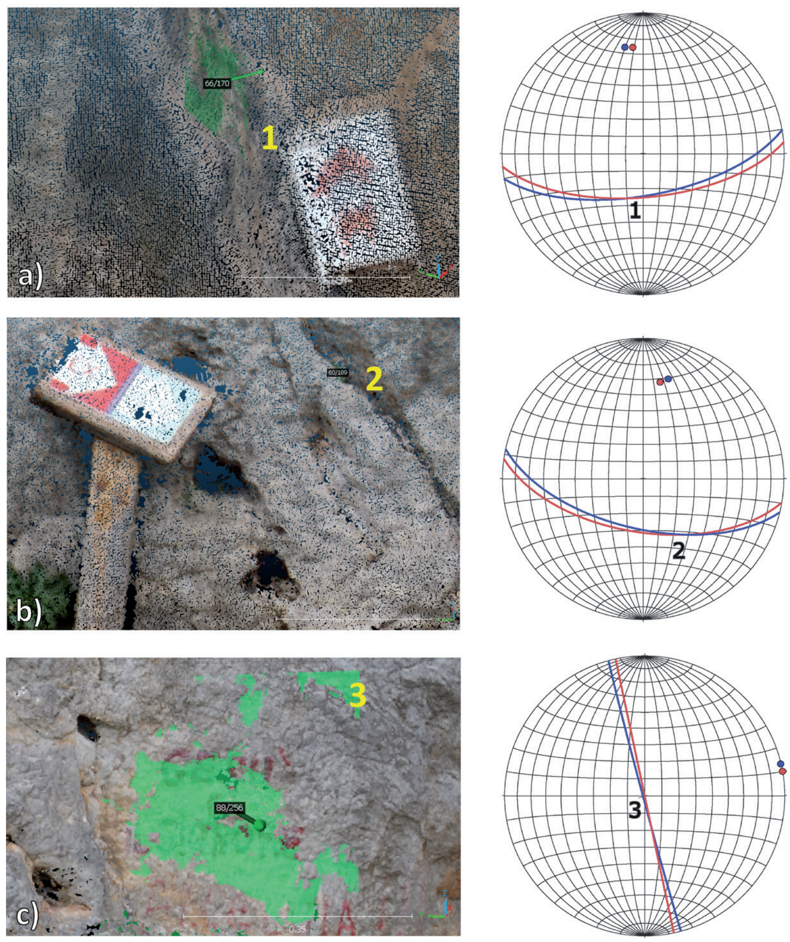

Fig. 4 - Comparison between on-field measurement (in red) and semi-automatic extraction (in blue) for CkPs and poles. a) on-field 175/65, extracted 170/66; b) on-field 193/62, extracted 189/60; c) on-field 260/90, extracted 256/88. The point (1, 2, 3) position is shown in Figure 3. Equal-area lower hemisphere stereographic projection is used for representing the results

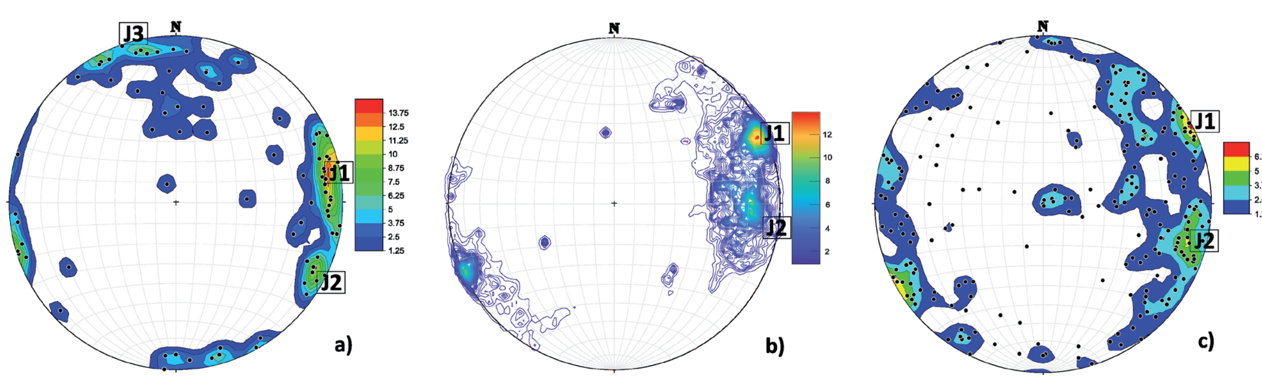

Fig. 5 - Comparison between data obtained from field survey (a), DSE (b) and Facet (c). Equal-area lower hemisphere stereographic projection is used for representing the results

DSE. Comparing the two methods for semi-automatic extraction from the 3D PC, an excellent overlap is observed. However, the recognition of J3, achieved only through field data, is the result that most differentiates the two approaches.

Given that the discontinuity sets exhibit orientations favoring the formation of prismatic blocks, a classical kinematic analysis (Markland, 1972; Goodman, 1989) was carried out to evaluate potential failure mechanisms evolving on the rock face. To this aim, only the field data have been used, since they are considered as well representative of the three main sets. The rock was characterized by the parameters 260/90. The friction angle was set at 30°. In the absence of laboratory testing, this parameter can be considered as a conservative estimate of the shear strength for discontinuities at residual conditions in unaltered carbonate rocks (Hoek & Bray, 1981). A lateral limits angle of 20° was considered to extend the critical zone of the poles. Three main failure modes have been investigated: toppling, planar sliding, and wedge sliding (Fig. 6). Toppling can be trigged due to the presence of J1 (72.7% of the discontinuity detected as J1, Fig. 6a), planar sliding can occur along discontinuities belonging to J1 (72.7% of J1, Fig. 6b), while wedge failure occurs along the intersection lines between the plans J1 and J2, J2 and J3, J1 and J3 (probability is about 67% for the intersection defined between the plans, Fig. 6c).

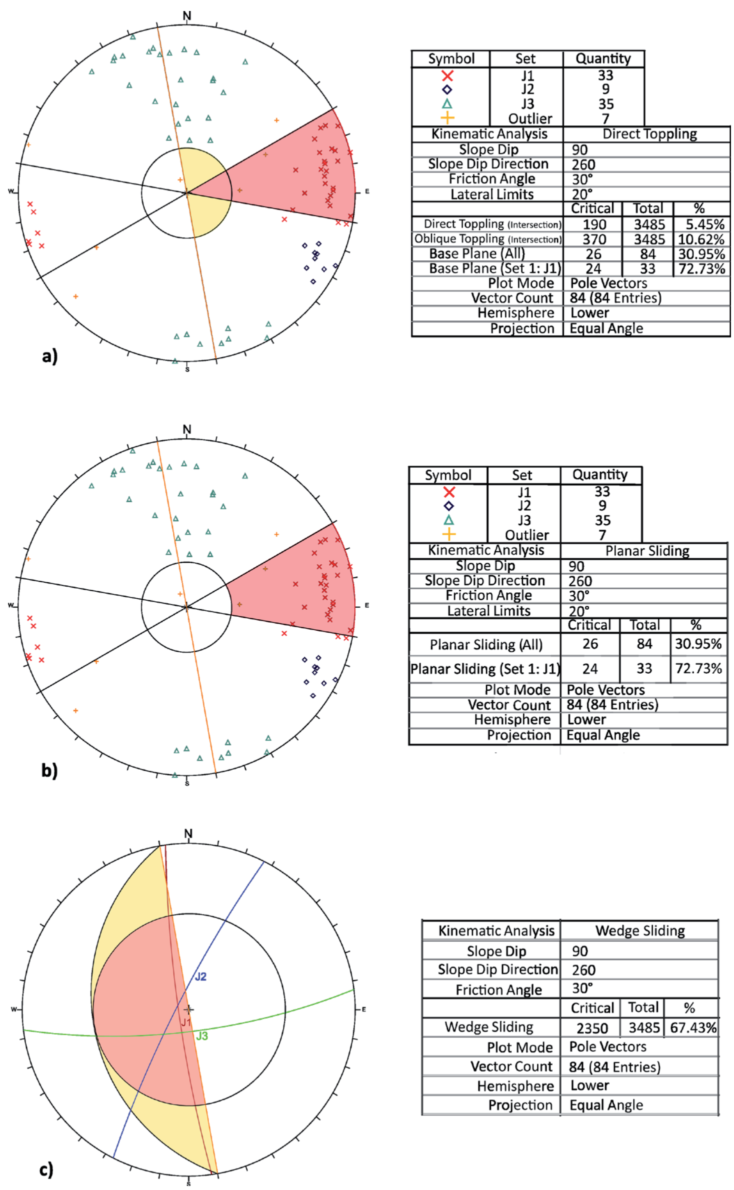

Fig. 6 - Results of the kinematic analysis for toppling (a), planar sliding (b) and wedge failure mechanism (c). The shaded areas are the critical for the different failure modes

DISCUSSION AND CONCLUSIONS

For the studied area, rockfalls represent a source of hazard and risk in the light of high environmental, cultural and touristic relevance. In this regard, a characterization of the rocky slope was carried out. In particular, this study was conducted through the direct and indirect approaches that enabled the collection of input data about the orientation of discontinuities along a fractured rock face. Based on the conducted back analysis, it was possible to define the most frequent volume of already collapsed blocks as 0.5 m^3. These data are consistent with some randomly spacing measurements acquired directly on the front. The number of blocks present at the base of the slope can be explained by the sub-vertical inclination of the front and the morphological conditions of the slope below, leading to the dissipation of most of the kinetic energy of the blocks upon initial impact. The direct approach, applied using a geological compass along a scanline, allowed for the collection of 84 measurements and the identification of three main discontinuity sets (J1, J2, J3 in Fig. 5). Using an indirect approach based on digital photogrammetry with low-cost equipment, a 3D point cloud (3D PC) was generated by using a local reference system for the model. The quality of georeferencing was assessed through a comparison between measurements taken on Check Planes (CkPs) in the field and measurements semi-automatically extracted from the 3DPC at the same points, with an acceptable error of ± 5° for dip direction and ± 2° for dip angle. The initial cloud was manual filtered and then resampled obtaining a dense point cloud composed of 1,300,000 points. The presence of vegetation led to the loss of information in some sectors of the model, resulting in gaps. The use of more sophisticated and costly instruments would have allowed more detailed coverage of the vegetated sectors present above 3 meters from the ground. Moreover, the higher density of Ground Control Points (GCPs) on the rock slope results in less distortion of the model when moving away from the sheet containing GCPs (Francioni *et alii*, 2019).

Nevertheless, the reliability of the model obtained for the purposes of this work can be assessed based on the strong overlap of measurements taken on the Check Planes both in the field and remotely on the model (Bordehore *et alii*, 2017).

The semi-automatic extraction of discontinuities was conducted using DSE software and the Facet plugin, implemented within the open-source software CloudCompare. Both software have identified two main discontinuity sets, comparable to the J1 and J2 sets obtained from field data. The J3 set, detected only in the field, is poorly represented in the Facet results and not represented at all in DSE. From field observations, it can be stated that J3 is mainly characterized by closed discontinuities, from the front observed only as lines. This condition results in poor detectability by semi-automatic extraction software, which typically extracts information from three-dimensional elements (Menegoni *et alii*, 2019). Since the two applied approaches are consistent in the presence of J1 and J2 sets, but only field survey allowed for the definition of the J3 set, the data obtained in the field were used for the kinematic analysis. From this analysis, it is evident that discontinuities belonging to the J1 set have a high probability of generating toppling and planar sliding. Wedge sliding, occurring along the intersection lines between two discontinuities, is more likely to occur along the intersection between J1 and J2, J2 and J3, J1 and J3. Analysis of both field-acquired data and semi-automatic extraction reveals the sporadic occurrence of discontinuities with low dip angles. These planes do not cluster to create sets, however, they can generate local kinematic patterns if they intersect with other discontinuity planes.

Further development of this study will involve comparing the results obtained with those derived from indirect approaches using more sophisticated tools, implementing the rock mass characterization with other discontinuity parameters such as persistence and spacing extracted from the 3D PC.

ACKNOWLEDGEMENTS

This study was carried out within the RETURN Extended Partnership and received funding from the European Union Next-GenerationEU (National Recovery and Resilience Plan – NRRP, Mission 4, Component 2, Investment 1.3 – D.D. 1243 2/8/2022, PE0000005).

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Received January 2024 - Accepted March 2024