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A new risk assessment methodology for volcanic rock slopes applied to the characterization of road embankments on the island of S. Nicolau, Cape Verde

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Abstract. The Cape Verdean archipelago is a part of the Macaronesia. It is constituted by ten volcanic islands located in the mid-Atlantic Ocean, at approximately 600 kilometers from the west coast of Africa, near Senegal. Since the entire archipelago is of volcanic origin, the traditional rock mass classification systems don't allow for the proper management of the risks derived from slopes and slope movements. Therefore, it has been developed a rock classification and risk assessment methodology specifically for volcanic rock slopes. This new methodology was tested in the island of São Nicolau.

São Nicolau has an area of 332 km^2 and is mainly constituted by lithologies of very old rocks, sedimentary formations, colluvial deposits and pyroclasts. This lithology is prone to slope instability, mostly landslides and rock falls. A total of 28 slopes, distributed all over the island, some with prior registered accidents, were evaluated. The new methodology was then applied to the various sites, giving special attention to the level of risk, and to adjacent terrain and existent structures.

Keywords: volcanic rocks, slope stability, risk assessment, geomechanical classifications

1 Introduction

Volcanic rocks exhibit highly heterogeneous geomechanical behavior unlike most of the other lithological groups. Applying classic geomechanical classifications, like RMR and the Q-system, and the geological index GSI, to characterize and estimate volcanic slopes stability, has not resulted in reliable results. It becomes evident that it is necessary to develop specific criteria for volcanic rocks. That's where the project MACASTAB comes in.

MACASTAB (project co-financed by the INTERREG Mac 2014-20 program) was a pioneering project in the study of the specific conditions from the natural environment of the 4 archipelagos which comprise the Macaronesia, all of them with volcanic origin. It focused on preparing a methodological guide that allowed a straightforward analysis of the risks of slope instability, specifically adapted to the volcanic rock masses in the islands of the Macaronesia. The technical team involved consisted of experts from Canary Islands, Azores, Madeira and Cape Verde Islands [4]. Although the final document is yet to be published, the methodology has already been shared with the scientific community in international conferences and technical papers ([1], [2], [3]).

2 Method developed in MACASTAB

The method developed in the project MACASTAB, specifically for volcanic slopes, rests in two rating systems and one index. The VSR (Volcanic Slope Rating), the VRHRS (Volcanic Rockfall Hazard Rating System) and the ISVS (index of susceptibility for volcanic slopes).

The VSR is a geomechanical classification for volcanic slopes. It depends on 7 different parameters, rock mass strength, block size, smoothness, persistence and separation of the discontinuities, rock mass heterogeneity index (IH) and surface regularity. Each of these parameters is measurable in the field and the sum of the ratings gives the value of VSR.

For the case of road slopes, VSR gives way to VRHRS. The VRHRS consists of applying to the VSR two adjustment factors that incorporate the risk analysis of the slope (based on the geometry of the slope, the geometry of the road and prior instabilities) and the degree of exposure of the element to be protected (road, vehicle, pedestrian) when it crosses the study area.

Table 1. Recommendations according to VRHRS

VRHRS score	Group	Recommendations
> 500	A (maximum risk)	Road slopes that require immediate action
300 - 500	B	Road slopes with short to medium term priority of action
< 300	C (minimum risk)	Road slopes with low priority of action

The ISVS depends on several parameters, namely the “Type of Rock Mass”, which includes three different lithological groups, the “Slope Angle”, classified into three intervals (<45°, 45–75° and >75°), the “Sea or Gully Erosion”, consisting of slope proximity to the coast or gullies and “Instability Indicators” related to previous instability processes. The ISVS is calculated by scoring the four described parameters and establishing four degrees of susceptibility to instability. The maximum value for susceptibility is 100, even if a higher value results from the calculation.

Table 2. Degree of susceptibility according to ISVS

ISVS score	Susceptibility
< 35	Low
35 -59	Moderate
60 - 79	High
> 80	Very High

3 Results

Both indexes, VRHRS and ISVS, were applied in São Nicolau (Cape Verde Islands). The studies conducted were funded by the LEC – EPE (Laboratory of Civil Engineering of Cape Verde) in collaboration with the DNA (National Directorate for the Environment of Cape Verde).

A total of 28 slopes, distributed all over the island, some with prior registered accidents, were evaluated. The new methodology was then applied to the various sites, which consisted mainly in determining the values of VRHRS and ISVS. It was finally possible to establish the slope susceptibility and the level of risk involved, which allowed for recommendations regarding the several slopes stability.

The location of the slopes is given in Fig. 1. The estimated values for the indexes are on Table 3.

Fig. 1. Location of the slopes analyzed in S. Nicolau.

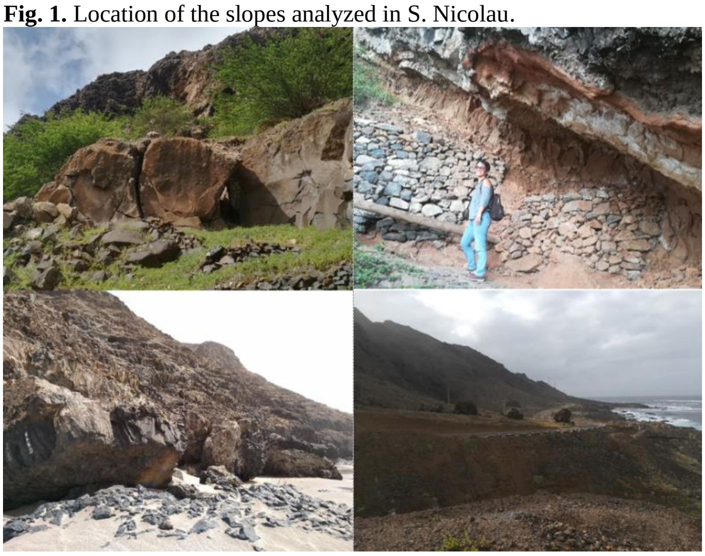

Fig. 2. Slopes 10, 17, 21 and 26 (from upper left, clock wise)

Table 3. Susceptibility and recommendations for the slopes analyzed

Slopes	VSR	VRHRS	Group	Recommendations	ISVS	Susceptibility
01	56	204	C	Road slopes with low priority of action	78	High
02	60	98	C	Road slopes with low priority of action	55	Moderate
03	53	225	C	Road slopes with low priority of action	24	Low
05	67	221	C	Road slopes with low priority of action	66	High
06	66	231	C	Road slopes with low priority of action	48	Moderate
07	62	234	C	Road slopes with low priority of action	66	High
08	45	331	B	Short to medium term priority of action	108	Very High
09	70	247	C	Road slopes with low priority of action	36	Moderate
10	86	425	B	Short to medium term priority of action	78	High
11	36	269	C	Road slopes with low priority of action	48	Moderate
12	71	174	C	Road slopes with low priority of action	66	High
14	66	231	C	Road slopes with low priority of action	66	High
16	70	229	C	Road slopes with low priority of action	72	High
17	59	333	B	Short to medium term priority of action	78	High
18	55	79	C	Road slopes with low priority of action	84	Very High
19	65	76	C	Road slopes with low priority of action	48	Moderate
21	44	354	B	Short to medium term priority of action	24	Low
22	40	339	B	Short to medium term priority of action	96	Very High
23	55	187	C	Road slopes with low priority of action	78	High
26	58	376	B	Short to medium term priority of action	48	Moderate

4 Discussion

From the 28 analyzed slopes, we were able to classify 22. For the remaining 6, due to difficulties to access them, we could not collect all necessary data. As for the "Recommendations", fourteen slopes with low priority of action and six with short to medium term priority of action were identified. As for slope susceptibility, we were able to distinguish 2 slopes with low susceptibility, 6 moderate, 9 high and 3 slopes with very high susceptibility.

5 Conclusions

A new method for assessing risk in volcanic rock slopes has been developed. With the indexes VRHRS and ISVS it is possible to easily determine the slope susceptibility to instability and to establish the priority of action. This new method was applied to road embankments in the island of S. Nicolau and the results were reported to the municipalities who will, in due time, perform all the preventive measures necessary.

We are confident that this new method will help ensure the safety of infrastructures and population by enabling an easy and fast identification of the slopes presenting a higher risk of rockfalls.

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