Geological-Geotechnical Characterization of the village of Monsanto and evaluation of the stability conditions

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ABSTRACT

The stability of slopes and hillsides involving rock or soil masses depends crucially on the occurring geological and geotechnical conditions.

The village of Monsanto, municipality of Idanha a Nova, is located on a granite head. The tourist interest of the village lies largely in the fusion of the granitic rock mass with the man-made constructions and in the aesthetics of several granitic blocks scattered throughout the village.

In the present work the geological and geotechnical characterization of the rock mass has been carried out, namely by the field survey of the entire intervention area and by a set of laboratory tests on samples collected in the field (ultrasonic propagation velocity and the uniaxial compression strength). Based on this information the rock mass is classified using the *Rock Mass Rating* (RMR) and the Geological Strength Index (GSI). In addition, a kinematic analysis was performed using the *Dips 7.0* commercial software, with the objective of identifying the most probable failure mechanisms in each slope zone and the associated families of discontinuities.

Based on this comprehensive set of information, the sites with the highest vulnerability to instability and potential to lead to greater material and/or human losses in the event of a failure are identified.

For these sites, stabilization solutions are proposed, considering the mechanism of rupture, the geotechnical conditions and other significant restraints (poor accessibility, reduced visual impact).

Keywords: Slope stability, Geology, Kinematic analysis, Rock mass, Geotechnics

1 INTRODUCTION

1.1 Definition of rock mass

A rock mass is a set of juxtaposed and articulated rock blocks. Each block consists of an intact rock core bounded by discontinuity surfaces. According to Martinho (2014), the same rock mass can react in a different way according to the demands placed on it.

The characteristics of the rock mass may differ from place to place. Based on the geological history of the region, it is necessary to highlight the attributes of the rock mass that, alone or together, influence its behavior, before any intervention. This procedure is called geological-geotechnical characterization of the mass (Martinho, 2014).

When a mass is composed of intact rock, its properties may be assumed homogeneous. In this way, the failure mechanisms the rock mass are analyzed as a whole. In casa there are 1 to 3 joints, it is necessary to pay more attention to the discontinuities because these will be the zones where the rupture will preferentially occur. In this case, the mass behaves as heterogenous and anisotropic. When the rock mass is intensely fractured, it can be assumed as homogeneous and potential failure mechanism intercept the rock mass (intact rock + discontinuities). It is necessary to characterize the discontinuities because they influence the behavior of the rock mass.

1.2 Failure Modes

1.2.1 Planar Sliding

The planar sliding usually occurs in rock masses that are constituted by rocks with medium or high resistance affected by faults and joints. This type of failure consists of a displacement of the blocks of rock along one or more subparallel surfaces. According to Hoek and Bray (1981), this failure occurs when the direction of the plane of slip is approximately parallel to the face of the slope, admitting a maximum difference of 20º. In turn, the angle of inclination of the discontinuity where the breakage occurs should be less than that of the face of the slope, so that there is slippage.

This type of rupture occurs in the presence of lateral fractures perpendicular or subperpendicular to the plane, such that the sliding mass losses any lateral containment.

Hoek and Bray (1981) also add that for the occurrence of a planar failure in drained conditions, the inclination angle of the sliding plane must be greater than the angle of friction considered for it.

1.2.2 Wedge Sliding

The wedge sliding consists of a block slip that is made along the intersection of two or more discontinuities, usually occurs in more resistant rock mass. This type of failure is typical in rock mass that present several families of discontinuities. The orientation and spacing of the discontinuities will determine the shape and volume of the wedge. The directions of these discontinuities are divergent and, as a result, when intersecting, form a wedge-shaped block.

For this type of failure to occur, the line of intersection of the two planes should appear on the surface of the slope with a slope angle greater than the angle of friction of the discontinuities (Hoek and Bray, 1981).

1.2.3 Toppling

Toppling often occurs on steep slopes of rock mass where the discontinuities have a very pronounced inclination. Plans of discontinuity, which often consist of stratification or foliation, exhibit an inclination contrary to slope and parallel or subparallel direction to the slope. This type of instability requires a rotation of the blocks, and the stability of the slope is only conditioned by the slip resistance and the friction angle.

1.2.4 Circular Failure

Circular failure is more frequent in soils, and may occur in very fractured rock masses, which present an isotropic behavior where the failure is not controlled by the discontinuity planes. Slightly spaced and massive fractures with intense weathering can cause this type of breakage.

The displaced mass is very variable in relation to its area, being able to be only a few square meters or to reach several hectares of extension. Another characteristic of this type of failure is that the displaced mass can go beyond the bottom of the rupture surface.

1.3 Site description

The village of Monsanto, located in the district of Castelo Branco, is considered a Historical village of Portugal, having been distinguished as the "most Portuguese village in Portugal" at 1939. In Monsanto vestiges of human presence can be found since the Paleolithic era and the village was donated by D. Afonso Henriques to the Order of the Templars after its conquest to the Muslims in 1165. Due to this title, any intervention has to be conducted very carefully to minimize the visual impact. This condition is of extreme importance because the main source of income for this village is tourism.

Figure 1: Monsanto side view taken from the access road to the village

1.3.1 Geological Background

At the geological level, the zone of study is in the Iberian Mass. In Monsanto, the most abundant lithology is the medium grain granodiorite. The latter has as main characteristics the occurrence of agglomerates of quartz grain randomly arranged by the rock and various micaceous concentrations. The agglomerates of biotites have a round shape with dimensions between 6x4mm and 26x20mm. The feldspar phenocrysts have a variable representation along the mass, and in the innermost parts their concentration is scarce. However, it tends to increase as the transition to the biotite-muscovytic granodiorite approaches (Antunes, 2006).

1.3.2 Topography

Naturtejo provided an Autocad file with the elevation contours of the urban area of Monsanto and this was used to obtain the distribution of gradients shown in Figure 2 and the map of of hypsometric lines shown in Figure 3, using the Arcgis program.

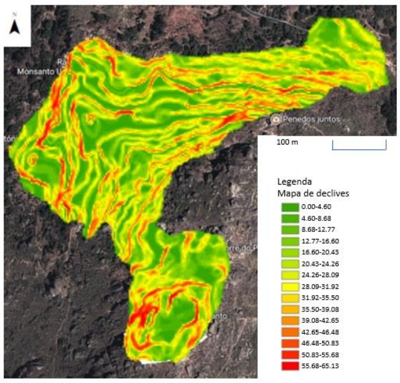

Figure 2: Map of Slopes

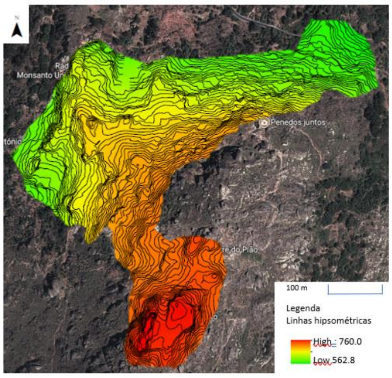

Figure 3: Map of hypsometric lines

The map of hypsometric lines shows that there is an altitude difference of approximately 200 meters, and, as expected, the highest point is at the castle location. The lower areas form the north and west outlines of the urban area, where agricultural land and some important infrastructure are located, namely the School building and the GNR Post.

The distribution of gradients in Figure 2 allows to identify where slopes have a steeper inclination. It is verified that there are vast flattened zones, that occur in the top of the mass and in the urbanized center of the town. The flattened areas, which are distributed approximately in levels, are limited by abrupt slopes that are more evident in the Northwest zone, where the delimitation of the settlement is located, in which the slope reaches values of the order of 65 degrees. In the zone that surrounds the castle also is a range of values of significant slopes, especially in the border West.

1.3.3 Climate Conditions

Precipitation is one of the main erosive agents and the factors that most influence erosion are total precipitation and rainfall intensity.

As expected, the autumn and winter seasons show more intense precipitation. The annual precipitation is of 758 mm, a value that is within the average of Continental Portugal. Through the IPMA it was also possible to obtain information that there are, on average, 26 days per year where the precipitation has an intensity higher than 10 mm / day. This factor is worrying because in these days a greater transport of particles disaggregated by the water occurs and, consequently, a greater erosion.

Temperature is also a factor that works as an erosive agent, and their variations cause contraction and expansion of the rock, leading to an increase in the opening of the discontinuities or the formation of new ones. Also, the formation of ice in the discontinuities causes an increase of volume and, consequently, the meteorization on the rock that forms walls of the discontinuity.

According to the IPMA, there are, on average, 5 days a year with the temperature below 0ºC.

2 GEOLOGICAL-GEOTECHNICAL CHARACTERIZATION

Several visits to the village of Monsanto were carried out and a visual inspection was made throughout the locality in order to select the locations where the discontinuities were surveyed, inspection of the locals that needed intervention and samples were taken from the granitic blocks. In the survey of discontinuities, locals were chosen on the different slopes of the mass and near the places to intervene. The selection of the locals was carried out in such a way as to obtain a greater number of information from the entire mass. The characterization of the walls of the discontinuities includes the Schmidt hardness analysis (ISRM, 1978a) for resistance evaluation.

Samples of the granite blocks where taking from an excavation work that was taking place inside a house in order to enlarge the living space. These samples correspond to the interior of a large rock block, being more suitable for laboratory tests than the altered, and sometimes friable, rock that is closer to the outcropping surfaces.

2.1 Laboratory Tests

With the blocks collected at Monsanto, four cylindrical samples were prepared to perform the ultrasonic velocity test and the uniaxial compression test. The ultrasonic velocity test, being a non-destructive test, was performed first. The samples followed the dimensions recommended in the procedures of the International Society for Rock Mechanics (ISRM, 1978b). The recommendations of the ISRM recommend that the samples be in the form of a cylinder with a diameter of 54 mm and that its height be between 2.5 and 3 times the diameter. They also advise that at least 5 samples be tested. In this article only 4 samples were tested, since the rock tends to disaggregate during the preparation of the test pieces. The samples tested were 54 mm in diameter and 142 mm in height.

2.1.1 Ultrasounds

The ultrasounds speed determination test consists of transmitting high frequency (55KHz) longitudinal waves, and measuring the time of the wave travel between the two ends of the test sample. The results of this test are in the table 1.

Table 1: Time and Velocity of the longitudinal waves

	Sample 1	Sample 2	Sample 3	Sample 4
Time (µs)	55,60	49,40	42,30	52,10
Velocity (m/s)	2553,96	2874,49	3356,97	2725,53

The values obtained from the test are substantially inferior to the values reported in the literature for intact coarse grained granite, about half, confirming the visual characterization performed in situ indicating that the granite analyzed is altered (W3, locally W4)

2.1.2 Uniaxial Compression

The uniaxial compression test consists of applying compressive axial force to the sample until it is fractured. This test is used to study the strength and deformability of the rocks, in this case only the uniaxial compression strength was measured. In this test a loading rate of 1.8 KN / s was used.

The results obtained are shown in Table 2.

Table 2: Results of the uniaxial compression tests

	Sample 1	Sample 2	Sample 3	Sample 4
Fractured Force (KN)	119,05	110,78	127,13	100,85
Strength (MPa)	51,90	48,29	55,42	43,97

2.2 Field work

In Monsanto, 9 stations were selected in specific locations to map the discontinuities. These were chosen in such a way as to be near the places to intervene and to be representative of the various slopes of the village. This information allows to obtain the predominant families in each place and thus to predict the most probable failure mechanism in those places. By making a collection of information on the various elevation slopes, there is more information about the whole rock mass. At each station, data were obtained regarding the attitude of joints, spacing, continuity, opening, roughness and strength, Figure 4 shows the locations where the stations were performed. The outcrops show blocks of yellowish rock (W3) and, near the joints, sometimes crumbling rock (W4). In the zones of higher and flattened heights, where the chaos of blocks characteristic of the granite landscape predominate, granite is strongly sandblasted, totally friable (W5) or forming soil (ISRM, 1981).

Figure 4: Satellite image (Google maps) with location of joints stations

Joint analysis was performed with the aid of the Dips 7.0 program from the network projection of the same area of the attitude of the planes in each station and representation of its poles. The program generates isodense diagrams that allow the identification of the main families of joints.

The joints obtained from station 1 and station 2 presented similar orientations and directions and, being close, were analyzed as being a single station. The data were obtained on a slope with the direction N65º and slope 65ºNW. The resistance of the walls of the discontinuities was determined based on the hardness of Schmidt, assuming a density of 25 KN / m3 for altered granite.

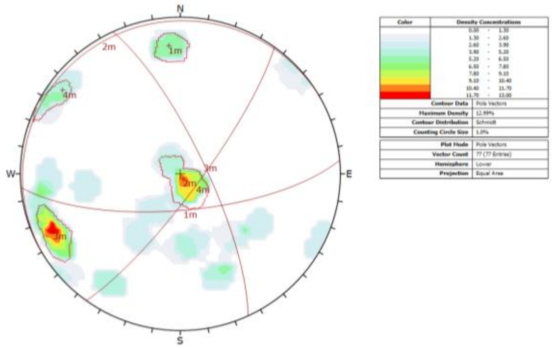

Figure 5: Isodensity diagram of stations 1+2

Table 3: Summary of the sets of discontinuities and their characteristics (stations 1+2)

	Spacing (mm)	Continuity (m)	Opening (mm)	Roughness JRC	Strength(MPa)
Set 1 N85º; 71ºSE	200 - 6000 (600-2000)	<1 - 10 (1-3)	<0.1 - 100 (0.1-0.25)	2 - 16 (6/8)	48 - 120 (120)
Set 2 N60º; 3ºNW	60 - 2000 (60-200)	<1-3 (<1)	<0.1 - 2.5 (<0.1)	2 - 14 (6/8)	40 - 155 (155)
Set 3 N155º; 77ºNE	200 - 6000 (600-2000)	<1 - 10 (3-10)	<0.1 - 100 (0.5-2.5)	4 - 12 (10/12)	27 - 57 (30)
Set 4 N36º; 80ºSE	60 - 2000 (600-2000)	<1 -10 (3-10)	<0.1 - 2.5 (0.25-0.5)	2 - 8 (6/8)	60 - 74 (60)

Stations 3 and 4, given the proximity and complementarity of the data obtained, were treated as a single station. These data were obtained in two slopes practically orthogonal to each other.

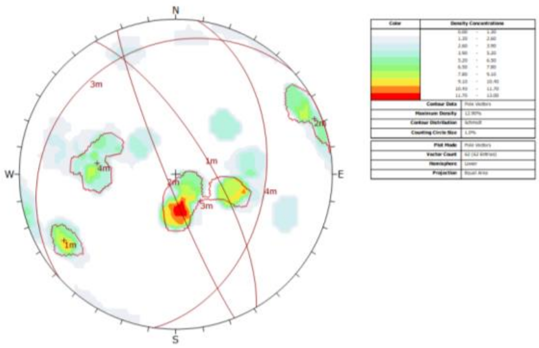

Figure 6: Isodensity diagram of stations 3+4

Table 4: Summary of the sets of discontinuities and their characteristics (stations 3+4)

Spacing (mm)	Continuity (m)	Opening (mm)	Roughness JRC	Strength (MPa)

Set 1 N149º; 72ºNE	200 - 6000 (200-600)	1 - 10 (1-3)	<0.1 - 100 (<0.1)	4 - 10 (4/6)	34 - 112 (36)
Set 2 N158º; 85ºSW	200 - 2000 (200-600)	<1-10 (1-3)	0.25 - 100 (2.5-10)	2 - 12 (2/4)	40 - 56 (54)
Set 3 N48º; 19ºNW	60 - 2000 (200-600)	<1 - 20 (1-3)	0.1 - 100 (10-100)	4 - 14 (4/6)	36 - 74 (52)
Set 4 N8º; 42ºESE	200 - 2000 (600-2000)	<1 -10 (1-3)	<0.1 - 100 (10-100)	4 - 14 (10/12)	32 - 103 (55)

Stations 5 and 6 are in the center of Monsanto. This case is like the previous ones where the data of both stations were grouped. This station was where there were fewer records of discontinuities because the slopes are in the center of the village, where the outcrops are scarce and of reduced extension. It is concluded that there are two subvertical families of joints and some subhorizontal random joints. The data were obtained on a slope with the direction of N70º and the slope of 75ºNW.

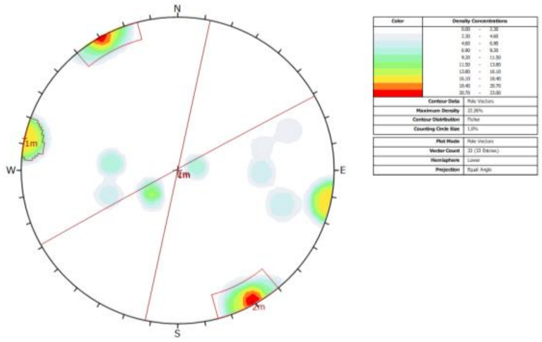

Figure 7: Isodensity diagram of stations 5+6

Table 5: Summary of the sets of discontinuities and their characteristics (stations 5+6)

	Spacing (mm)	Continuity (m)	Opening (mm)	Roughness JRC	Strength (MPa)
Set 1 N12º; 90º	60 - 200 (60-200)	1 - 3 (1-3)	0.25 - 0.5 (0.25-0.5)	4 - 6 (4/6)	60 (60)
Set 2 N59º; 89º	60 - 2000 (60-200)	1-10 (3-10)	0.25 - 0.5 (0.25-0.5)	4 - 8 (6/8)	30 - 68 (30)

Station 7 is on the northwestern slope of Monsanto and is limited by the fact that it has few readings as block chaos predominates in the area. The data were obtained in a vertical slope with the direction of N65º and the slope of 65ºNW.

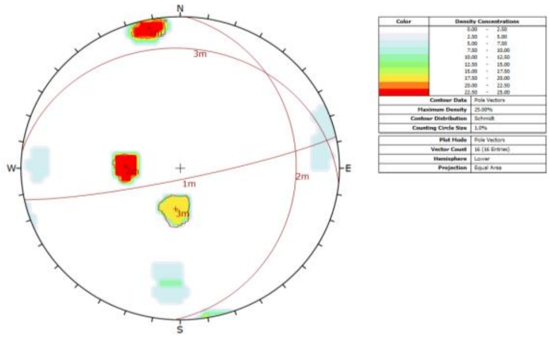

Figure 8: Isodensity diagram of station 7

Table 6: Summary of the sets of discontinuities and their characteristics (station 7)

	Spacing (mm)	Continuity (m)	Opening (mm)	Roughnes s JRC	Strength (MPa)
Set 1 N78º; 84ºSSE	200 - 2000 (600-2000)	1 - 10 (3-10)	10 - 100 (10-100)	6 - 12 (6/8)	29 - 58 (30)
Set 2 N2º; 28ºE	200 - 600 (200-600)	3-10 (3-10)	10 - 100 (10-100)	6 - 8 (6/8)	29 (29)
Set 3 N96º; 22ºNN E	200 - 2000 (600-2000)	1 - 10 (3-10)	0.25 - 100 (0.25-0.5)	8 - 10 (8/10)	27 (27)

Station 8 is on the east slope of Monsanto. The data were obtained in a flattened area at the top of the elevation and have a direction of N10º and a slope of 40ºESE.

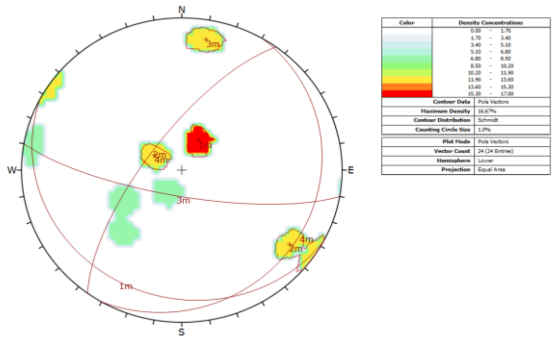

Figure 9: Isodensity diagram of station 8

Table 7: Summary of the sets of discontinuities and their characteristics (station 8)

	Spacing (mm)	Continuity (m)	Opening (mm)	Roughness JRC	Strength (MPa)
Set 1 N118º; 18ºSW	600 - 2000 (600-2000)	3 - 10 (3-10)	2.5 - 10 (2.5-10)	10 - 12 (10/12)	30 (30)
Set 2 N36º; 72ºNW	600 - 2000 (600-2000)	3 - 10 (3-10)	0.1 - 0.25 (0.1-0.25)	8 - 10 (8/10)	47 (47)
Set 3 N100º; 76ºSS W	200 - 600 (200-600)	3 - 10 (3-10)	0.1 - 0.25 (0.1-0.25)	6 - 8 (6/8)	60 (60)
Set 4 N1º; 12ºE	60 - 600 (60-200)	1 -10 (1-3)	0.1 - >1000 (0.1-0.25)	8 - 14 (8/10)	44 - 71 (71)

The 9+10 station is also on the east slope of Monsanto, a little south of station 8, in a flat area of the granite mass. In this, the values of the 2 sites analyzed were included. The data were obtained on a slope with the direction of N10º and slope of 50ºESE.

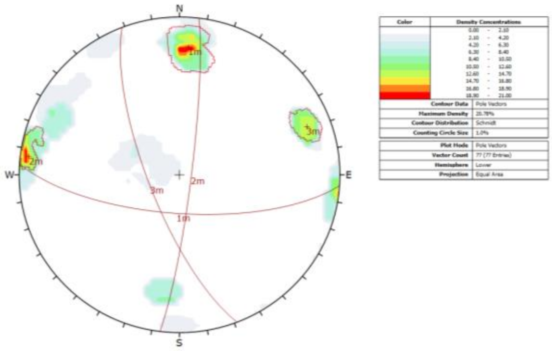

Figure 10: Isodensity diagram of stations 9+10

Table 8: Summary of the sets of discontinuities and their characteristics (stations 9+10)

	Spacing (mm)	Continuity (m)	Opening (mm)	Roughness JRC	Strength (MPa)
Set 1 N94º; 70ºS	200 - 2000 (200-600)	1 - >20 (>20)	0.1 - 100 (0.1-0.25)	4 - 12 (4/6)	49 - 184 (49)
Set 2 N7º; 84ºESE	200 - 2000 (200-600)	1-10 (1-3)	2.5 - 100 (2.5-10)	2 - 10 (8/10)	40 - 74 (74)
Set 3 N159º; 74ºSW	20 - 2000 (20-60)	1 - 10 (1-3)	<0.1 - 1000 (<0.1)	4 - 12 (10/12)	57 - 67 (57)

2.3 RMR CLASSIFICATION

For this mass, the RMR classification was used. The information for this classification was obtained previously in the work performed in situ and in the laboratory tests. The laboratory tests allowed us to measure the values of uniaxial compression strength obtained using the Schmidt hammer, which are conditioned by the state of weathering. One of the parameters necessary for RMR classification is the Rock Quality Designation (RQD). The RQD, introduced by Deere et al (1967), encompasses two important parameters, the state of alteration and fracturing. This classification system is indicative of the quality of the rock mass and is obtained through samples of drilling holes. For this dissertation, no boreholes were drilled to the mass, so the equation 1 which estimates the RQD value as a function of the mean spacing of the discontinuities was used (Priest and Hudson, 1976).

$$RQDt=100\, e^{-\lambda t}(\lambda t+1) \qquad \text{Equation 1}$$

The results obtained reflect the observations of all the field work in which it was verified that some areas of the mass are in better state and others in worse state. When classifying the discontinuities, it was possible to notice that the uniaxial compression strength differed from zone to zone, but also in the opening and spacing of each family of discontinuities. The results obtained were class II and class IV, having been done a general assessment of the mass was made. The classes presented correspond to the basic RMR.

3 KINEMATIC ANALYSIS

Having the isodensity diagrams that allow to identify the main families of joints, it is possible to perform a kinematic analysis, designing the plane corresponding to the slope and the angle of friction allowed for the joints and to determine the failure mechanism most likely to occur. For the kinematic analysis a conservative value of 30º was used.

For station 1+2 the results obtained are in the Table 9.

Table 9: Result of the kinematic analysis of stations 1+2

	Planar Sliding	Toppling	Wedge
All Set	12,99%	11,69%	27,01%
Set 1	-	100,00%	-
Set 4	-	37,50%	-

In analyzing Table 9, it is concluded that the toppling is the one that is most likely to happen considering family 1. However, it is necessary to consider family 4, regarding toppling, and some probability of wedge breakage by intersection of the various joints.

For station 3+4 the results obtained are in the Table 9.

Table 10: Result of kinematic analysis of stations 3+4

	Planar Sliding	Toppling	Wedge
All Sets	14,52%	4,84%	21,21%
Set 3	29,41%	-	-
Set 4	-	9,09%	-

Table 10 shows that the most likely failure mechanism is the wedge cracking, for the intersections of families 1 and 2. However, the planar sliding caused by family 3 and the flexural toppling caused by family 4, also should be considered.

For station 5+6 the results obtained are in the Table 11.

Table 11: Result of kinematic analysis of stations 5+6

	Planar Sliding	Toppling	Wedge
All Sets	0,00%	18,18%	3,24%
Set 2	-	75,00%	-

The failure mechanism most likely to happen is the flexural toppling, conditioned by family 2.

For station 7 the results obtained are in the Table 12.

Table 12: Result of kinematic analysis of station 7

	Planar Sliding	Toppling	Wedge
All Sets	6,25%	25,5%	3,67%
Set 1	-	100,00%	-

At this station the most probable failure mechanism is the flexural toppling, as shown in Table 12. In this case, family 1 is the most worrying because it is subvertical and subparallel to the slope.

For station 8 the results obtained are in the Table 13.

Table 13: Result of kinematic analysis of station 8

	Planar Sliding	Toppling	Wedge
All Sets	8,33%	0,00%	0,00%
Set 4	28,57%	-	-

In Table 13 it can be verified that the most probable failure mechanism is the planar sliding. This result was already expected because, in the fieldwork, it was possible to identify enough situations where this occurred. The family 4 is the one that contributes most to the planar failure in the place.

For station 9+10 the results obtained are in the Table 14

Table 14: Result of kinematic analysis of stations 9+10

	Planar Sliding	Toppling	Wedge
All Sets	2,60%	19,48%	3,43%
Set 3	-	100,00%	-
Set 2	-	21,74%	-

In Table 14 the failure mechanism most likely to happen is the flexural toppling. In this place there are two families that contribute to this break, the family 3, with greater probability, and the family 2.

4 LOCATIONS AND SOLUTIONS

During fieldwork campaigns in the village of Monsanto it was possible to identify places that need intervention.

Being fundamental the historical record for the evaluation of the probability of occurrence of land movements, it was sought to find out from the habitants and in the parish council the existence of blocks movement records. The response was negative in both cases and therefore this factor cannot be used in the present analysis of potential instability. The selected places are represented in Figure 11: and represent those that, due to the size of the blocks, the inclination of the slopes and/or the attitudes of the discontinuities, appear to be more dangerous in relation to mass movements.

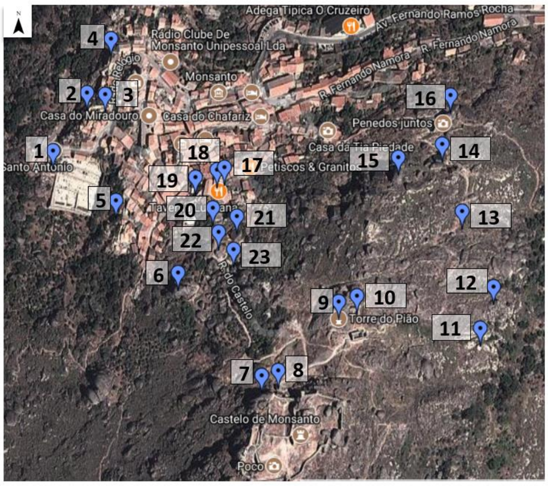

Figure 11: Image adapted from Google maps consulted in September 2017 with location of selected places

In this article, it only describes the three most important places. For each one is given the solution to the instability and the constraints of the place.

Accessibility to the sites is, in most cases, difficult because the center of the village is characterized by narrow streets and on the east slope the only access is by footpaths that are part of the access rails to Monsanto Castle, which it's located at the top of a hill. All these constraints mean that the transport of machinery to the sites can be limited. The village is densely urbanized, which means that the fall of a block can cause material and / or human damages.

Point 4 is a place where a stone wall is built with the base on a rock block. This block is bounded by two large subhorizontal joints (Figure 12: Local 4 watching by the street, showing the block and the subhorizontal joints.). The site is on private land, making it difficult to properly visual inspection. The existence of the construction on the block prevents the observation of possible subvertical joints parallel to the slope. The joints parallel to the slope would cause the block to fall.


Figure 12: Local 4 watching by the street, showing the block and the subhorizontal joints.

However, the existence of subvertical joints perpendicular to the face of the block and also to the slope has been verified (Figure 13)).

Figure 13: Subvertical joint perpendicular to the face of the block (arrow)

However, in nearby slopes and to the north of point 4 it was possible to visualize the family Nº20; 90º, parallel to the slope and which can, in turn, be parallel to a possible fracture in the block (Figure 14).

Figure 14: Joints on the slopes north of point 4

In this case there is no proposal for a solution, as it was not possible to observe the site in a more detailed way. However, is proposed that an inspection be carried out at the place to confirm the existence of the family of subvertical joints parallel to the slope.

Point 6 consists of a tourist spot, the "Penedo do Pé Calvo", located at the top of the slope, above the graveyard, as shown in Figure 15, which is quite visited by tourists.

Figure 15:View from the graveyard

It consists of two large blocks, separated by a subvertical joint but with irregular layout, that rest on another granitic block limited by subhorizontal joint. In this block sub-vertical or vertical cracks are observed indicating that the rock's compressive strength has already been exceeded (Figure 16). Thus, the two blocks may fall along the slope due to the rupture of the block at the base.

The solution proposed for this local is the injection of cement or epoxy resin into the contact between the unstable blocks and the foundation block and in this to seal the fractures, in order to prevent the advance of the degradation. Steel cables may also be used to prevent movement of the block, provided a location for anchorage to a stable bulk is found. After the intervention it is necessary to have a monitoring of the fractures in order to verify the possible variation of the opening. Another relevant point about the proposed solution is that it fits the landscape, with a reduced visual impact.

Figure 16: Vertical fractures due to compression

Point 14 is a tourist spot known as Penedos Juntos (Figure 17). At the base of this slope is the School and the GNR building. The presence of these buildings makes this place a priority for an intervention.

Figure 17: Penedos Juntos, person for scale

At the local the erosion caused by the passage of water in the foundations of the block is very visible in Figure 18. At the base of the block there are only 2 points of support on the ground, constituted on the spot by a large granite block. Between the two blocks of granite there is a small thickness of granite very altered that presents/displays subvertical cracks, indicating that the resistance to the compression has already been exceeded. The meteorization at this location is facilitated by the existence of cracks and by being in an inclined zone, as seen in Figure 19. It will be seen that the lower block has a very clear and clean surface, with the quartz crystals in relief, because of the surface runoff of the rainwater which seems to have a preferential path here.

Figure 18: Erosion make by the water of the rain

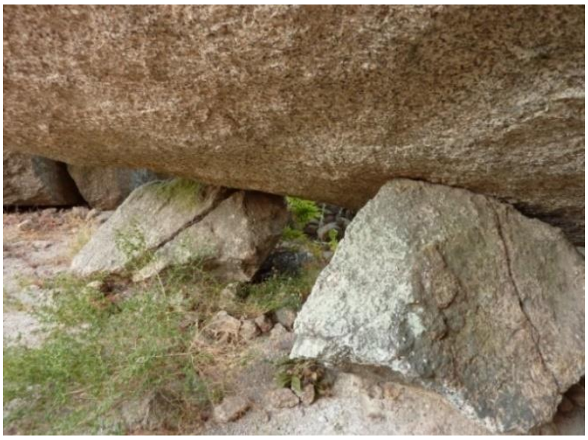

Figure 19: Granite fragments on which the block is supported, showing compression fractures

The solution proposed for this local is the cleaning of the foundations, so that the degradation in the foundation can be better verified. Subsequently, the construction of a support wall should be carried out to prevent the degradation from evolving. This construction should be done in a phased way to avoid the total destabilization of the block. The support wall will replace the supports that present cracking and a drainage system should be created to prevent the percolation of the rain from further erosion.

5 DISCUSSION AND CONCLUSION

To sum up, this article aimed at the geotechnical and geological characterization of Monsanto as well as the identification of the instability sites and the recommendation of a solution.

Through the survey of joints in several places of the rock mass, it was possible to ascertain the characteristics of the mass to classify the same. The classification was obtained for the family of discontinuities that presents better characteristics, more favorable scenario, and for the family of discontinuities that presents worse characteristics, less favorable scenario. The mass is then in the range of classes II to IV.

The laboratory tests allowed to confirm what had already been identified in the field, that is, that the rock presents degradation and that its resistance is reduced.

The kinematic analysis carried out in Dips 7.0 showed that the most frequent failure mechanisms in the analyzed locals are planar sliding and flexural toppling. The results obtained were those expected when visualizing slopes in field work.

With all the previous information it was possible to develop a solution to each place or what kind of information is needed to have a solution.

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