

## Avaliação geotécnica de áreas *non aedificandi* suscetíveis a movimentos de massa por ensaios pressiométrico

### Geotechnical evaluation of *non aedificandi* areas susceptible to mass movements by pressuremetric tests

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**RESUMO:** O presente estudo investigou as suscetibilidades a movimentos de massa de taludes em áreas classificadas como de alto potencial para acidentes naturais em Viçosa-MG-Brasil. Foram analisados diversos cenários de estabilidade com base nas características geológico-geotécnicas do terreno, considerando parâmetros de resistência e a geometria para uma análise bidimensional no software Geostudio Slope/W. A pesquisa baseou-se em uma carta urbana de suscetibilidade, que permitiram selecionar as áreas com alto potencial de movimento de massa para a realização dos ensaios PMT. Estes, por sua vez, subsidiaram as seguidas de simulações numéricas de estabilidade para identificar o grau de instabilidade e o fator de segurança da área em questão. Optou-se pelo ensaio PMT por sua rapidez e precisão na obtenção dos parâmetros do solo em profundidade, os quais, associados a simulações de estabilidade, possibilitaram uma avaliação dos taludes. Além disso, avaliou-se cenários com parâmetros geotécnicos obtidos e variou-se o intervalo de confiança para aumentar o grau de segurança da avaliação. Por fim, são fornecidas informações detalhadas, as quais podem subsidiar políticas públicas adequadas a cada localidade considerando suas peculiaridades geológico-geotécnicas.

**Palavras-chave:** Desastres Naturais, Riscos e Suscetibilidade, Estabilidade de Taludes, Ensaio de Campo, PMT

**ABSTRACT:** The present study investigated the susceptibilities to mass movements of slopes in areas classified as having high potential for natural accidents in Viçosa-MG-Brazil. Several stability scenarios were analyzed based on the geological-geotechnical characteristics of the terrain, considering resistance parameters and geometry for a two-dimensional analysis in the Geostudio Slope/W software. The research was based on an urban susceptibility map, which allowed the selection of areas with high potential for mass movement to carry out the PMT tests. These, in turn, subsidized the followed by numerical stability simulations to identify the degree of instability and the safety factor of the area in question. The PMT test was chosen for its speed and precision in obtaining the soil parameters in depth, which, associated with stability simulations, allowed an assessment of the slopes. In addition, scenarios were evaluated with geotechnical parameters obtained and the confidence interval was varied to increase the degree of safety of the evaluation. Finally, detailed information is provided, which can support public policies appropriate to each location, considering its geological-geotechnical peculiarities.

**Keywords:** Natural Disasters, Risks and Susceptibility, Slope Stability, Field Trial, PMT

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## 1. INTRUCTION

The cities design, as well as urban landscape formation, is an interaction result between social activities and the environment, among other factors. The urban form can then be considered the human actions product on the natural environment, making it necessary to establish a harmonious relationship between this environment and constructed objects. Some conditioners, such as soil, climate, vegetation and geological formation, can affect the location choice for human settling, assuming that pertinent characteristics to the space provide guidelines for environment use and occupation.

However, physical-environmental modified spaces quality has been continuously falling, affecting population life quality and the urban landscape as a whole. As such, the specialists' interest has been ignited due to the diverse effects caused by urbanization. Many nature events have occurred around the world, causing accidents in various cities where accelerated disorderly occupation advances more and more on terrain that is geologically unfavorable to occupation. the biggest cities problem is not only their disorderly growth, but population concentration. In this scenario, cities with up to 500 thousand inhabitants tend to present the biggest problems, since they have a limited land relative availability to the population, thus demanding adequate urban planning. Therefore, planning without knowing the location limitations can result in populations socio-economic damage. Attempts on the municipalities part to use regulate and soil occupation through laws that define land occupation parameters, retreats, utilization coefficients and permitted use, directly interfere in the city form. However, such laws are little often use due to their complexity in interpretation terms, inspection and application. The rapid urbanization process, without due governmental infrastructure provision and planning input, has contributed significantly to the existing socio-spatial inequality increase, as well as to the natural degradation and constructed urban spaces (RAMALHO, 1994; VIEIRA. 2000; MELLO, 2012).

One of the motivators for studies to be intensified in cities with up to 500 thousand inhabitants is portrayed by the UNFPA report (2017), which informs that by 2040, 52% of the world's population will inhabit these cities, highlighting concerns about immediate and mitigating full-fledged actions. necessary for the urban expansion areas that will absorb this population contingent. This is corroborated by the large number of cities that have these characteristics associated with the lack of human, technical and financial resources found, in general, in these municipalities.

Another worrying issue that corroborates the need for more advanced studies on land use is that part of the occupied urban areas are located in critical areas, which is a paradox, as estimates made by several researchers based on satellite images , revealed that all urban areas together cover less than 3% of the planet's territory, allowing us to infer, therefore, the existence of adequate spaces not yet explored near these occupations (WU et al., 2005; LIU & PU, 2008; WARREN, 2013; UNFPA, 2017).

Vicosa city, Minas Gerais, Brazil, as it has been growing without planning or urban guidelines, creating susceptible mass movements situations and environmental impact. The register lack for occupied areas, according to civil defense, which during rainy periods present imminent susceptibilities, only serves to complicate the municipal civil defense work, especially given the qualitative lack and quantitative data. As such, the city has expanded rapidly in the valley floor direction and slope areas, these occupations being mainly by low-income families (RIBEIRO FILHO, 1997; CRUZ et al., 2008; PARIZZI et al., 2011, ROQUE, 2013). Thus, with unsuitable occupation, especially in mass movements susceptible areas, there is an increase in disasters occurrences, making it necessary to conduct geotechnical studies in these locations.

Within this context, the present study objective was to diagnose and quantify geotechnical factors through PMT (Menard Pressuremeter Test) field trials on slopes areas previously classified as high-susceptible, followed by slope stability evaluation, based on parameters of resistance and geometry, considering a bidimensional analysis.

### *2.1 Study Area Profile*

According to Cruz (2008), Viçosa, MG, Brazil, is located at Minas Gerais State, with 299 km<sup>2</sup> territorial area and is situated on a plateau with rugged terrain composed of grouped

mountain chains, which are close to one another, with high declivities forming narrow valleys.

The city occupation initially occurred along the streams valleys, subsequently advancing onto the slopes. Much of this occupation has been carried out on cut slopes with subsequent material deployment in landfills without due preparation or compaction (CRUZ *et al.*, 2008). According to the Köppen-Geiger climate classification, the municipality is in a CWA climate type, high-altitude tropical with intense rains during the summer. Mean rainfall is around 1,300 mm/year, with a rainy period between November and March. Roque (2013) carried out soils profiling in Vicoso-MG, describing a total of five horizons:

- (1) Saprolite: Material from the soil-rock transition, consisting predominantly friable, structured, earthy matter, which, at depth, makes the transition to rocky cores in decomposition. This indicates heterogeneous, geotechnical properties and material behavior. The horizon thickness can vary according to slope depth, which can be from 5 m to as much as 20 m.
- (2) Young residual soil: This occurs over saprolite and under mature residual soil, possibly emerging on cut slopes, gullies or steep slopes. Its constitution is predominantly silty-sand, with little cohesion, low plasticity and is susceptible to surface erosion.
- (3) Mature residual soil: Sandy-clay, fine granulation with medium to high plasticity and brown or reddish-brown color. The thicknesses have 5 m mean and it is generally not very erosion susceptible and is used in earthwork.
- (4) Colluvial soil: Sandy-clay, fine granulation with medium to high plasticity. It is homogeneous, porous and brown, reddish brown and yellowish brown in color. This horizon is not very thick and it is also used as raw-material in earthwork.
- (5) Alluvial deposits: Poorly developed and occur together with fluvial beds and terraces. They present variable granulometry, with sandy-clay constitutions predominating.

For the determination and field tests location, mapping carried out by Silva (1993) was used as reference, which followed the methodology proposed by Bishop (1945). This study sought to register, identify and characterize the susceptibilities mass movements areas subject in urban zone, using visual classification techniques recommended by Brasil (2007) and the table (tables 5 to 7 in the appendix) completion with a susceptibility degree. Highlights three mapping forms that result in a susceptibility map, which may be applied according to availability and technical team experience to execute it:

- Simplified or heuristic method, which is more subjective and supplies an uncertainty degree as it basically depends on the professional experience in direct mapping and field surveys.
- Deterministic method, which is available and requires quantification, with quantity and quality.
- Statistical mapping method, which tends to reduce subjectivity, based on correlations between events and factors, measured in a standardized manner.

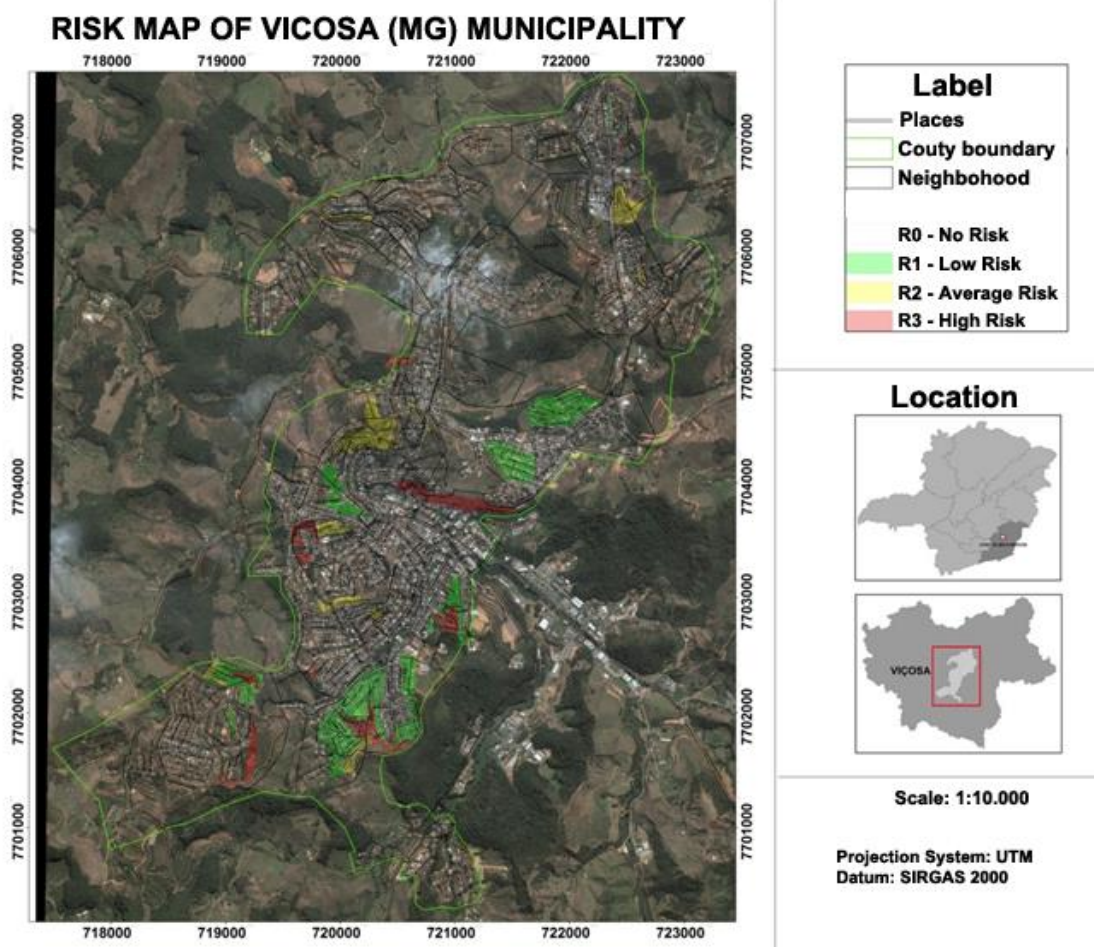
The heuristic and deterministic methods were adopted in this study, due to simplified execution and for being recommended in the case with little infrastructure municipalities. Initially, an inventory map should be elaborated, which is the basis for susceptibility chart

elaboration; previous historical events were then spatially distributed on this map, with the addition of information such as type, form, size and field information, indicating the areas with greater potential for mass movements. This information will produce a map with divided areas into various susceptibilities degrees and potential for damage to the occupation.

The following environmental perception and classification criteria for urban land division were adopted: areas with an inclination above 17° (30%), indicated by Federal Law 6766/1979, Art 3°, should have their occupation conditioned by the non-existence susceptibilities according to geological-geotechnical reports; and, areas with a slippage history should undergo a new assessment prior to occupation. These criteria should be followed by field completion checklist for final sectorization. These checklists have fields on the location typology, such as the presence movement evidence, water and vegetation. Plants, maps, street guides, aerial photos and satellite images, among others, are used for correct study area demarcation.

Mapping finishes with areas whose destructive processes and occurrence are homogenous, in relation to the probability degree. In this phase, pre-sectorization is carried out, using perception and basic parameters, linked to the professional experience responsible for the survey. The basic parameters that should be observed are: declivity/inclination, process typology, occupation position in relation to slope and occupation quality (vulnerability), which may vary according to soil type, rock, relief or anthropic intervention. This provides a susceptibility chart containing high, medium and low risk zones, which is presented in Figure 1.

Figure 1 – Risk map of the municipality.



Source: Roque (2013)

With this information, a probability degrees reclassification was carried out based on new information collected in the field, as presented in Table 1. It is then public agent possible to make appropriate decisions. From demarcated areas possession, plans were made for geotechnical validation of empirical classification through field trials application. Areas classified with a medium to high risk degree were selected from this map for the geotechnical investigations conducting to improve knowledge on the area profile.

Table 1 - Risk degree criteria determination.

<b>Risk Level</b>	<b>Description</b>
R0 – No risk	Geological-geotechnical factors (inclination, terrain type) and intervention level in a low movements potential sector; They have no signs or instability evidence. There are no slope instability processes evidences; If conditions are maintained, no events are expected in the rainy season period.
R2 – Low risk	Geological-geotechnical factors (inclination, terrain type) and intervention level, average movement potential in the sector; Some instability evidence signs, however incipient; Slopes and drainage margins; Initial development stage; If conditions are maintained, is reduced the event possibility during intense and prolonged rains during a rainy season.
R3 – Average risk	Geological-geotechnical factors (inclination, terrain type) and intervention level, high movement potentiality in the sector; Significant instability signs with process in development, with evolution monitoring; Ground cracks, slope subsidence etc.;If conditions are maintained, it is possible occur events during heavy and prolonged rains in a rainy season.
R4 – High risk	Geological-geotechnical factors (inclination, terrain type) and intervention level, very high movement potentiality of in the sector; Expressive instability signs are expressive, with an advanced development process stage, being impossible to evolution monitoring; Ground cracks, slope subsidence, inclined trees, landslides risks, erosive features etc; If conditions are maintained, events can occur during intense and prolonged rainfall in a rainy season.

Source: Brasil (2007)

## 2. MATERIAL AND METHODS

The PMT trial (Menard Pressuremeter Test) was chosen to obtain tension-deformation soils behavior in situ, in the geotechnical investigation, enabling a rapid and precise geotechnical evaluation. The tool functioning considers the soil to be tested as an elastic medium, using the Lamé (1952) theory to calculate the Young module. The test was based on measuring the amount of gas needed to expand the probe in order to measure soil deformation in situ. However, there were difficulties in calculating the volume variation that occurred with the increase in pressure, as they were not properly controlled, with its results can be interpreted interpreted through elasticity theories (BAGUELIN, 1978). Bishop (1945), Menard (1955, 1975), Briaud (1992) and Clarke (1996) complemented said statement, contributing to pressuremetric trial interpretation in relation to fundamental plasticity concepts.

The term pressuremeter (or pressure gauge probe) was first used by Ménard (1955) to describe the test equipment he invented. However, the pressure gauge can be defined as equipment that applies hydraulic pressure (liquid or gas) to the walls of a borehole through a flexible membrane. Thus, it can be said that Kögler created and worked with the first pressure gauge (ARAUJO, 2001). The French standards (P94-110/91 – AFNOR), EN ISO 22476-4 and the American (ASTM D-4.719/87) are used in Brazil for pre-hole pressure gauges, due to the lack of official specifications. These standards indicate how to obtain parameters of

resistance, limiting pressure (pl) and soil deformability, also known as pressure gauge modulus (EPMT).

Ten susceptible mass movements points were selected, in areas R2 and R3 (Figure 1), whose coordinates are shown in Table 2, were selected from the susceptibility chart developed by Roque (2013), based on the slope of the slope and the presence of residential occupation, where the field tests were carried out, allowing a numerical validation of the method proposed by Brasil (2007).

Table 2 - Locations where field trials were conducted.

PMT	Lat	Long	Elevation (m)
1	20° 46' 18.99" S	42° 53' 7.60" W	750
2	20° 46' 10.575" S	42° 53' 7.05" W	739
3	20° 45' 56.894" S	42° 53' 39.32" W	783
4	20° 45' 56.987" S	42° 53' 39.732 W	747
5	20° 46' 9.877" S	42° 53' 39.348" W	766
6	20° 46' 26.714" S	42° 53' 39.321" W	818
7	20° 46' 27.588" S	42° 53' 45.115" W	795
8	20° 45' 39.686" S	42° 53' 17.393" W	735
9	20° 45' 15.756" S	42° 53' 27.588" W	760
10	20° 45' 25.828" S	42° 53' 25.424" W	750

The following items were used in the field for execution of the present study:

- Dutch hand auger, to carry out pre-drilling;
- APAGEO GC type Ménard pressuremeter, to carry out investigations according to the procedures for the trial; and,
- Garmin, Etrex Legend H model GPS, was used in the geographical references point collection.

For soil classification, references Lamé (1952), Hoek (1981) and Guidicini & Nieble (1983), and were used, with  $\gamma$  (specific mass),  $c$  (cohesion) and  $\phi$  (friction angle) as standard references. Stability simulations were conducted in total tension terms and based on undrained resistance hypothesis, as they are areas that receive water input in the rainy season from the local drainage system, which can generate a critical mass of saturated soil. GeoStudio Slope/W software, by Geo-Slope International, was used as a computational tool. The stability analysis methods adopted for obtaining the safety factor were Bishop, Generalized Janbu and Morgenstern-Price. The simulations were expanded by carrying out

the study in strips, whereby soil parameters were each altered  $\pm 10\%$ , while maintaining the others fixed. The way in which this was varied is shown in Table 3, whose hypotheses adopted to compose a behavioral analysis interval were: O, soil parameters obtained by the PMT test preserved; SM, variation in  $\pm 10\%$  of original specific mass parameter; C, variation in  $\pm 10\%$  of original cohesion parameter; and, A, variation in  $\pm 10\%$  of the original friction angle parameter. The safety parameters adopted for the slopes project, based on semi-probabilistic methods, are shown in Table 4.

Table 3 – Soil parameters variation for each analysis.

Analyze	Hypothesis	$\gamma$	C	$\phi$
1	O	original	original	original
2	SM1	+ 10%	original	original
3	SM2	- 10%	original	original
4	C1	original	+ 10%	original
5	C2	original	- 10%	original
6	A1	original	original	+ 10%
7	A2	original	original	- 10%

Table 4 - Safety factor adopted for the field research development.

Level of security required	Limit State method based	Stress-Strain
	Standard: minimum safety factor	Standard: maximum displacement
High	1,5	Maximum displacements compatible with the safety factor required, neighboring constructions sensitivity and slope geometry
Average	1,3	
Low	1,15	

Source: NBR11682 (ABNT, 2009)

It was decided by the field team to carry out the pre-holes and carry out the PMT tests limited to depths of up to 13 meters. This decision was made based on the pattern of mass movements recorded in the civil defense database, which indicated ruptures in superficial layers, that is, the depth studied would meet this criterion. However, it should be noted that in some points the limit depth occurred at lower depths due to the high resistance of the ground during the pre-hole execution or due to high resistance readings in the pressure gauge equipment.

### 3. RESULTS AND DISCUSSION

Field trials supplied the original parameters (O), obtained through the PMT field trial, which are shown in Table 5 **Erro! Fonte de referência não encontrada.** The confidence interval was obtained through the variation of these parameters by  $\pm 10\%$  and simulating saturated conditions for each case: specific Mass (SM1 + 10%, SM2 - 10%), cohesion (C1 + 10%, C2 - 10%), friction angle (A1 + 10%, A2 - 10%), and the simulated safety factors were also compiled in Table A1, A2 and A3. These tables were placed in the Appendix for better visualization of the results obtained. The analyses results are presented as follows:

i. PMT 01

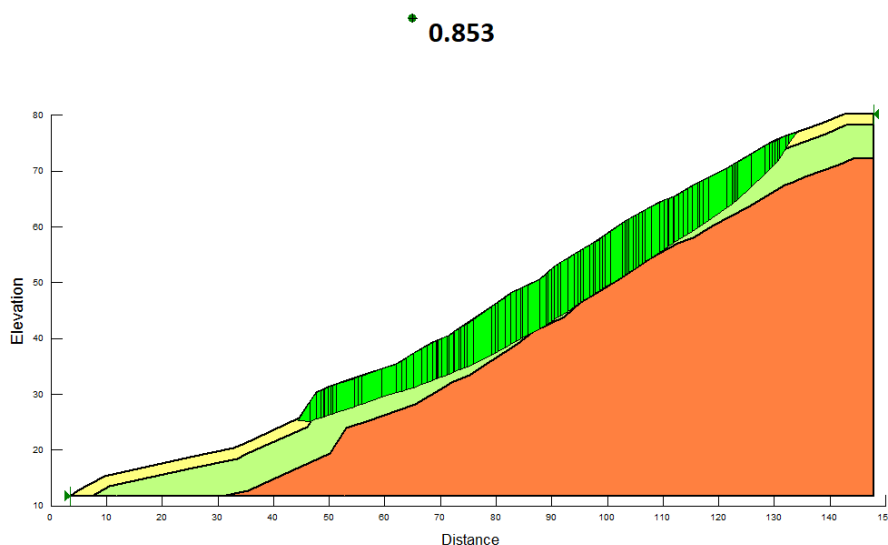
Trial PMT-01 was conducted on a critical slope situation (Figure 2).

Figure 2 - Slope where the PMT-01 test was performed.



The planned depth for the trial was 13 m, which was easily reached by manual investigation using the auger. During drilling, a geotechnical fault was found at 7 m, probably due to the slope rupture beginning. The obtained data and their variants were processed in GeoStudio Slope/W and results obtained for the calculated safety factors (SF), for the O hypothesis the FS = 0.853 (Figure 3). With the obtained parameters up to 6 m, it was possible to perceive that the slope is on the rupture brink through original data (O) analysis. In all simulated hypotheses the slope does not present minimum safety, indicating that in the condition of high rainfall, mass movements can occur.

Figure 3 - Simulation of the PMT-01 slope in the O hypothesis.

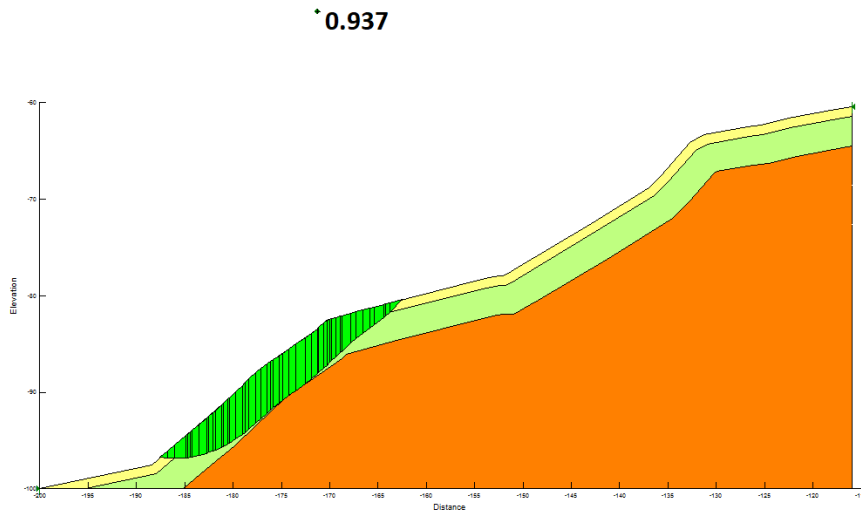




ii. PMT 02

Trial PMT-02 was halfway up an apparently stable slope. The planned depth for the trial was 13 m, of which a depth of 11 m was reached due to the soil rigidity and the manual equipment limitations. Analyzing the original parameters (O), it can be noted that slope stability according to the Janbu and Morgenstern-Price methods had an SF of 1.43 and 1.35, respectively. However, the Bishop method indicates that the slope is found in a alert state with SF =0.937 (Figure 4), that is, the slope is at the lower limit of stability, and it is necessary to carefully monitor its behavior during periods of high rainfall.

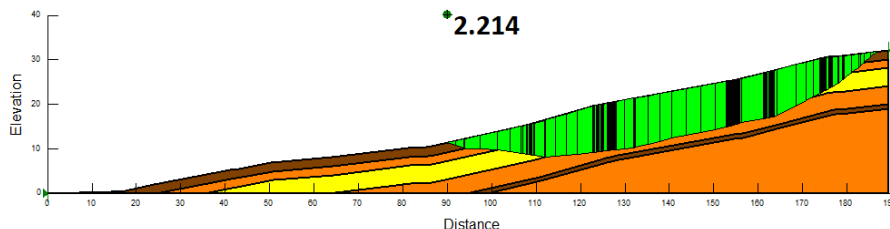
Figure 4 - Simulation of the PMT-02 slope in the O hypothesis.



iii. PMT 03

Trial PMT-03 was conducted on the apparently crest a stable slope with medium to large vegetation, on a street with little traffic and occupied houses on the top. Looking up from the base it is an extremely steep slope and contains rainfall runoff directly on the slope arising from the street, without a collecting system. The trial reached a 6 m depth of 13 m planned. Analyzing the original data (O) it can be perceived that it is stable and safe, with a minimum SF of 2.35 using the Morgesntern-Price method. In the variants, the stability situation was the same, as expected. The SF variation was small,  $2.14 \leq SF \leq 2.39$  (Figure 5). However, the drainage lack may provoke severe long-term damage and should be taken care of during the dry season.

Figure 5 - Simulation of the PMT-03 slope.

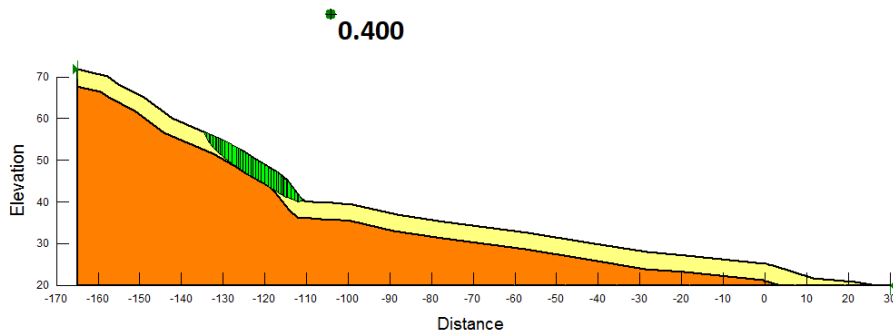


iv. PMT 04

Trial PMT-04 was conducted at the apparently stable slope base, reaching a 9 m depth of 13 m planned. Analyzing the original data (O) it can be noted that the slope substrate is in an imminent rupture situation, with a minimum SF of 0.858 according to the Janbu method. Regarding its variants, the minimum SF oscillated between  $0.400 < SF < 0.932$  (Figure 6), the first being when there was a reduction in cohesion and the second when there was a reduction

in specific mass. However, surface treatment of the soil with collection of rainwater on the slope is recommended, which is diverted from the street and in homes that do not have a drainage collection network.

Figure 6 - Simulation of the PMT-04 slope.



#### v. PMT 05

Trial PMT-05 was conducted on the central slope section, approximately, achieving a 6 m perforation, it has low vegetation on a street with a high all vehicle types traffic volume, as it is the main access to the neighborhood (Figure 7). The slope was divided into two segments by an avenue, and there is no residential occupation in the part above this avenue, while there is residential agglomeration in the segment below this avenue, indicating that the susceptibility analysis must be carefully observed in this stretch.

Analyzing the original data (O), in all methods a mass movement potential with  $SF = 0.612$  was verified (Figure 8). Such a measure is plausible due to the high slope and direction of surface water to the body of the slope, representing a real condition of slope instability. Added to this is the fact that at the base of the slope there are several geometric alterations of the slope due to anthropic actions of cuts that amplify the danger. It can be observed in the simulation that the mobilized mass is in the stretch with high slope, which when moving, may cause material and human losses.

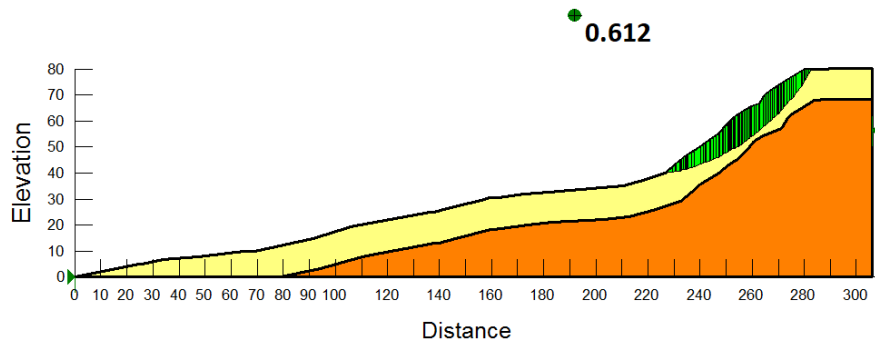
In other scenarios, in general,  $SF$  varied around 0.650 in all methods, considered to be of high susceptibility. This area presents risk behavior in its highest section and it was found in all the simulated situations. Under the conditions evaluated, the slope is on the verge of failure when saturated. This approach was chosen because it is an extreme scenario, possible to occur, although the rupture can happen with saturation below 100%.

This situation shows the public manager the need for actions on the spot, due to the real risk of human and material losses, in addition to being one of the access routes to several neighborhoods with intense traffic. It is suggested the implementation of a surface drainage system on the avenue, containing a set of measures that lead this water to safer places for disposal. Another measure that must be evaluated is the implementation of a containment as soil nailed in order to increase the local  $SF$ .

Figure 7 - Slope where the PMT-05 test was performed.



Figure 8 - Simulation of the PMT-05 slope.



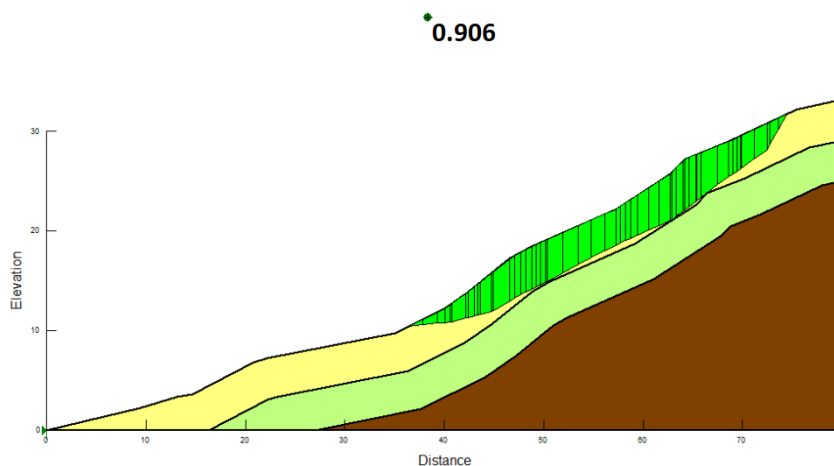
vi. PMT 06

Trial PMT-06 was conducted on slope top and the planned 10 m depth for this trial was reached. The slope presents a change of slope from its central part towards the top, accentuating it. The situation on this slope is complicated by the large residential density in the highest part of the slope, with the release of waste and wastewater.

After the simulations and evaluating the original data (O), by the Janbu method, the worst safety factor  $SF=0.906$  was obtained (Figure 9), indicating that the slope is susceptible to landslides. The other methods showed slightly better results for the FS and are described in Tables 6 and 7. When the soil parameters are changed in search of other high susceptibility scenarios, it is verified that the stability conditions are drastically altered. It was observed that the increase in the specific mass promotes the reduction of the SF, probably due to the increase in the weight of the potentially mobilized mass, leading to the breaking limit state condition; meanwhile, for the condition where the friction angle was high, the inverse effect of increasing the SF occurs, allowing us to infer that with more accentuated angles it is possible to have slopes with more critical relief conditions for those soil conditions.

In the condition given for the original parameters, the slope is in a situation of imminent susceptibility to mass displacement, requiring further investigation at other points. An important detail is the high resistance to rupture identified in the deeper layers, which do not prevent a possible movement of the more superficial layers.

Figure 9 - Simulation of the PMT-06 slope.



vii. PMT 07

Trial PMT-07 was conducted on a high inclination slope, in the direction from the center to the top, with the houses presence above and below slope (Figure 10). Pre-drilling reached a 6 m depth of 10 m planned. Analyzing the original data (O), a situation with a good

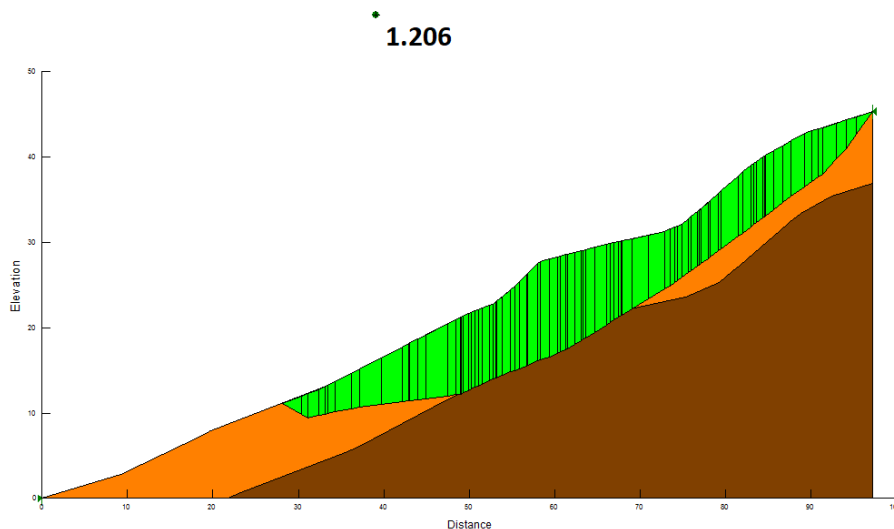
level of slope stability was found, with  $SF \approx 1.5$ , with emphasis on the result obtained by the Morgenstern-Price method.

A similar situation was found for the other cases where the physical indices were varied. Only in the case in which the friction angle was reduced was a reduction in SF noted, reaching 1.206 (Figure 11), a situation which classifies the slope as stable with good resistance in the substrate, despite the high inclination and being associated with low vegetation.

Figure 10 - Slope where the PMT-07 test was performed.



Figure 11 - Simulation of the PMT-07 slope.



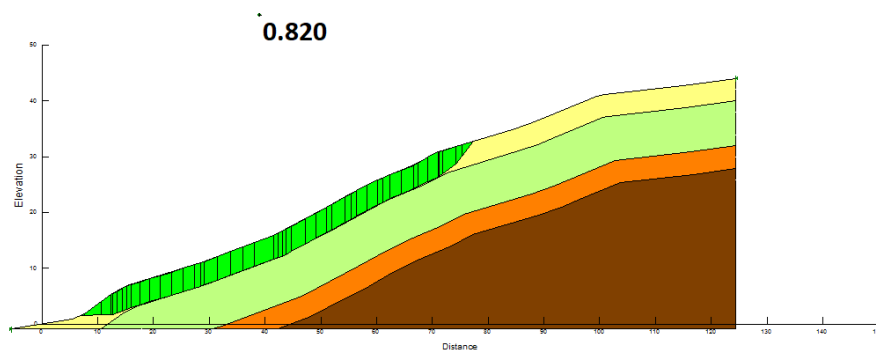
viii. PMT 08

Trial PMT-08 was conducted on a slope with high inclination, in the direction from the center to the base, with the houses presence in the vicinity (Figure 12). A 9 m perforation was reached of the 13 m depth planned for this trial. Analyzing the original data (O) in all the methods, a high-risk situation was found, with  $SF < 1.0$  (Figure 13). Visually, slope fragility can be noted due to the surrounding occupation, cuts and hydric erosion, which was confirmed after various analyses. In all the simulated scenarios, the slope is at high-risk. Only for the case in which the specific mass was reduced is a small increase in SF noted, reaching 0.957, a situation which classifies the slope as on the brink of rupture and in an alert state.

Figure 12 - Slope where the PMT-08 test was performed.



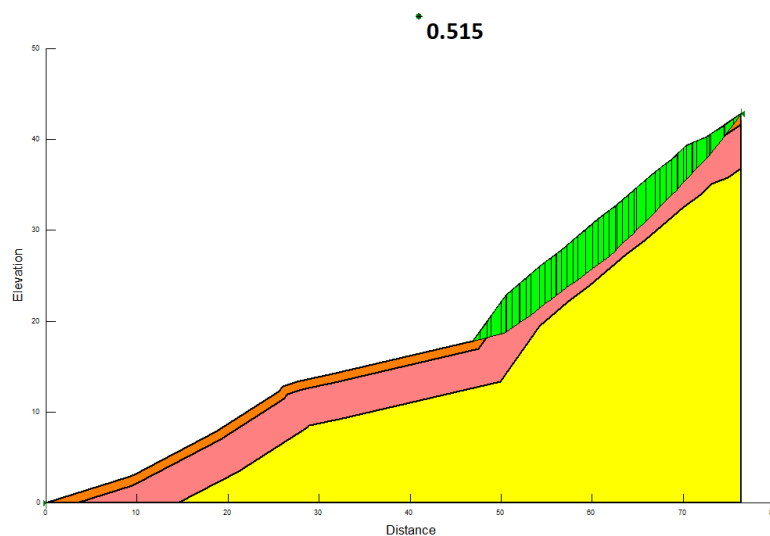
Figure 13 - Simulation of the PMT-08 slope.



ix. PMT 09

Trial PMT-09 was conducted on a slope with high inclination, in the direction from the center to the base, with the houses presence on the top. An 8 m perforation was reached and 10 m depth planned for this trial. A result based on the original data (O) collected in the field can be observed, with an  $SF < 1.0$  (Figure 14), demonstrating that the slope is found on the rupture brink, with the slope having a mass movement high-risk in all methods. An intervention is recommended for this slope so as to establish a better technical solution for slope stabilization.

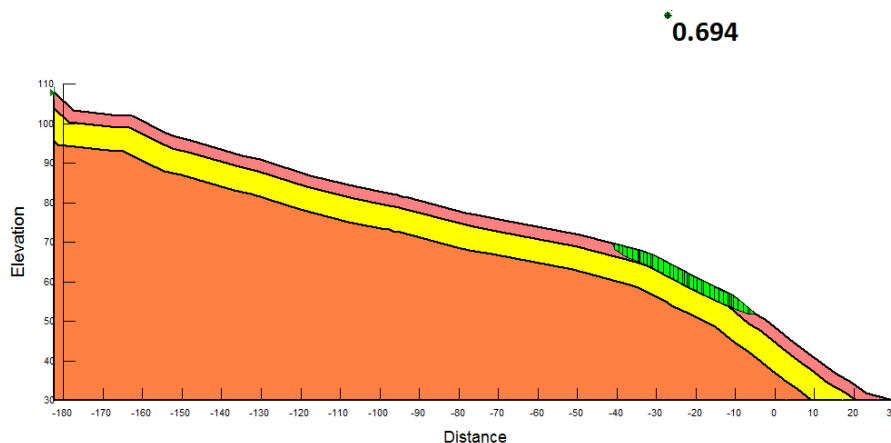
Figure 14 - Simulation of the PMT-09 slope.



x. PMT 10

The PMT-10 test was planned to be carried out at a depth of 10 m, reaching an elevation of 8 m. The results of the analysis of the soil parameters obtained by the PMT test (O), indicated that the slope presented  $SF < 1.0$  (Figure 15), that is, in the imminence of rupture. This situation confirms the observations made by Roque (2013) when classifying the site as highly susceptible. When the soil parameters were changed in order to know the simulated behavior, it was possible to verify an increase in the SF guaranteeing a minimum stability ( $SF > 1.0$ ). This situation presents a situation that demands more investigations to obtain the soil parameters at other points in order to better understand the slope behavior, since a cohesion and specific mass variation showed an increase in SF.

Figure 15 - Simulation of the PMT-10 slope.



Complementary geotechnical assessment allows the validation of the mapping carried out by Roque (2013), who used the empirical method indicated by Brasil (2007). This allows the indication of which areas of higher priority to receive an intervention, since it is possible to analyze the behavior of the slopes in different scenarios, extrapolating the initial knowledge of the field agent, contributing with more geotechnical information in the urban area, serving as support for decision making.

#### 4. CONCLUSION

Based on the ten evaluated areas, five areas (PMT-01, PMT-05 and PMT-09) are in a critical situation, with safety coefficients well below the minimum recommended. These areas are occupied, which compounds the human losses risk. Another six areas (PMT-02, PMT-04, PMT-06 PMT-08 and PMT10) are in an alert situation, given that the safety coefficients are close to 1.0. The other two areas (PMT-03 and PMT-07) were considered stable, given that the safety coefficient was well above 1.0 (Table 6 and 7).

These evaluations were carried out with the original soil parameters found during the dry period, which may therefore vary upon entering the rainy period. As such, scenarios were simulated in which the parameters varied by  $\pm 10\%$  in specific mass, cohesion and friction angle, producing a confidence interval foreseeing possible changes generated by the rainy period. All the areas classified as high-risk were verified and appraised through PMT trial and stability evaluation methods (Bishop, Janbu and Morgenstern-Price) considering existing norms for trial methods and slope stability evaluation.

Thus, with the results obtained, it was possible to conclude that the evaluation carried out by Roque (2013), through the empirical method proposed by Brasil (2007) for cities with little civil defense structure, can be implemented with some degree of assertiveness and

indicate with good precision in areas susceptible to mass movements. Even so, this method is a good way to indicate susceptible areas, serving well municipalities without technical staff, which present generalized settlements in *non aedificandi* areas, but having subjective analyses, dependent on observations and premises, with high dependence on technical experience, which can provide inaccurate data.

For the study in question, the areas classified as high susceptibility in the chart showed results consistent with the results obtained by field trials. And the extrapolations presented possible scenarios, which in some cases require an expanded investigation on the slopes studied, either due to the heterogeneity of soil parameters and situations to which the slope is subjected, such as poorly executed engineering solutions, insufficient drainage and anthropic actions.

## ACKNOWLEDGMENTS

The authors wish to thank CAPES, Personnel Higher Level Improvement Coordination, Federal University of Viçosa, Santa Cruz State University and the Federal Rural University of Rio de Janeiro.

## 5. REFERENCES

ABNT - ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 11682: **Estabilidade de Encostas**. Rio de Janeiro, 2009.

ARAÚJO, S.P.M. **O ensaio pressiométrico de Mènard e sua utilização na estimativa da capacidade de carga e recalque de fundações assentes em solo residual de gnaiss**. 2001. 177F. Dissertação (Mestrado em Engenharia Civil) – Universidade Federal de Viçosa, Viçosa.

BAGUELIN, F.; JÉZÉQUIEL, J.F.; SHIELDS, D.H. **The Pressuremeter and Foundation Engineering**. *Trans Tech Publications S.A.*, 1978. 617p.

BISHOP, R.F.; Hill R.; Mott, N.F. **The theory of indentation and hardness tests**. *Proc. Physical Soc.*, v.57, n.321, 1945.

BRASIL. Presidência da República. Lei Federal 6766, de 19 de Dezembro de 1979. **Dispõe sobre o Parcelamento do Solo Urbano e dá outras providências**. <[http://www.planalto.gov.br/ccivil\\_03/leis/l6766.htm](http://www.planalto.gov.br/ccivil_03/leis/l6766.htm)>

BRASIL. Ministério das Cidades / Instituto de Pesquisas Tecnológicas – IPT. **Mapeamento de Risco em Encostas e Margens de Rios**. Brasília, 2007. Disponível em: <<https://www.capacidades.gov.br/biblioteca/detalhar/id/170/titulo/mapeamento-de-riscos-em-encostas-e-margens-de-rios-->>.

BRIAUD, H. L. **The Pressuremeter**. *Trans Tech Publications*: Rotterdã, A.A.Balkema, 1992.

CLARKE, B. G. **Pressuremeter in Geotechnical Design**. 2ed. *Chapman & Hall*, Cambridge: Grã-Bretanha, 1996. 357p

CRUZ, T.A.; ALVARENGA, S.C.A.; CARMO, M.I. SILVA, A.R. (CoordS.). **Retrato social de Viçosa 2007**. Viçosa, MG: CENSUS, 2008.

GUIDICINI, G.; NIEBLE, C.M. **Estabilidade de taludes naturais e de escavação**. 1ed. *Edgard Blücher*: São Paulo, 1983. 194p.

HOEK, E.; BRAY, J.W. **Rock Slope Engineering**. 3ed. *Institute of Mining and Metallurgy*: London, 1981. 358 p.

LAMÉ, G. **Leçons sur la theorie mathématique de l'élasticité dès corps solides**, *Bachelier*, Paris, 1952.

LIMA, R.S. **Expansão urbana e acessibilidade - O caso das cidades médias brasileiras**. 1998. 91f. Dissertação (Mestrado) - Escola de Engenharia de São Carlos. Universidade de São Paulo, São Carlos.

LIU, D.; PU, R. **Downscaling thermal infrared radiance for subpixel land surface temperature retrieval**. *Sensors*, v. 8, n. 4, p. 2695–2706, 2008.

MELLO, F.A.O. **Análise do Processo de Formação da Paisagem Urbana de Viçosa, MG**. 2012. 103f. Dissertação (Mestrado em Engenharia Civil) - Universidade Federal de Viçosa, Viçosa.

MÉNARD, L. **Travail personnel sur le pressiômetro**. Ecole Nationale des Ponts et Chaussées, Paris, 1955.

MÉNARD, L. **The Ménard Pressuremeter, Interpretation and application of pressuremeter test results to Foundation Design**. *Sols Soils*. 1975.

PARIZZI, M.G. **Retroanálise de escorregamento de talude na área de risco do Taquaril, Belo Horizonte, MG**. *Geonomos*, v.2, n.19, p.32-41, 2011.

RAMALHO, G.G.C. **Mapeamento geotécnico de Viçosa com uso de sistema de informações geográficas**. 1994. 110f. Dissertação (Mestrado em Engenharia Civil) – Universidade Federal de Viçosa, Viçosa.

RIBEIRO FILHO, G.B. **A formação do espaço construído: cidade e legislação urbanística em Viçosa, MG**. 1997. Dissertação (Mestrado em Urbanismo). PROURB/UFRJ, Rio de Janeiro.

ROQUE, L.A. **Mapeamento das áreas de risco geológicogeotécnicos associados a movimentos de massa na área urbana de Viçosa – MG**. 2013. Dissertação (Mestrado em Engenharia Civil) – Universidade Federal de Viçosa, Viçosa.

SILVA, A.N.R. **O custo do solo urbano ocioso e uma nova sistemática de tributação de propriedade**. 1993. 137f. Tese (Doutorado) — Curso de Pós-Graduação em Engenharia Civil. Escola de Engenharia de São Carlos. Universidade de São Paulo, São Carlos.

UNFPA. **Situação da População Mundial 2017 - Desencadeando o Potencial do Crescimento Urbano**. Relatório anual. 2017. Disponível em: <<http://www.unfpa.org.br>>

VIEIRA, V. **Caracterização preliminar do risco geológico da área urbana de Viçosa-MG**. 2000. 92f. Dissertação (Mestrado em Engenharia Civil) – Universidade Federal de Viçosa, Viçosa.



**WARREN, M. S. Desagregação espacial de estimativas de evapotranspiração real obtidas a partir do sensor MODIS.** Revista Brasileira de Meteorologia, v. 28, n. 2, p. 153–162, 2013.

**WU, S.; QIU, X.; WANG, L. Population Estimation Methods in GIS and Remote Sensing: A Review.** GIScience & Remote Sensing, v. 42, n. 1, p. 80–96, 2005. Disponível em: <http://bellwether.metapress.com/openurl.asp?genre=article&id=doi:10.2747/1548-1603.42.1.80>

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APPENDIX

Table A1 – Original field parameters obtained through pressuremetric trial (O) for each point in the field. Variants were obtained by varying each parameter by ± 10 %: Specific Mass  $\gamma$  ( $\gamma \pm 10\%$ ), Cohesion ( $c \pm 10\%$ ), and Friction Angle ( $\phi \pm 10\%$ ).

PMT Field Test	Silt-Sandy			Silt			Silt clayey			Medium clay (yellow)			Medium clay (brown)			Medium clay-sandy			Medium Silt clayed			Saprolitic Soil			
	$\gamma$	c	$\phi$	$\gamma$	c	$\phi$	$\gamma$	c	$\phi$	$\gamma$	c	$\phi$	$\gamma$	c	$\phi$	$\gamma$	c	$\phi$	$\gamma$	c	$\phi$	$\gamma$	c	$\phi$	
1	18	20	25	17	25	25	-	-	-	17	10	20	-	-	-	-	-	-	-	-	-	-	-	-	-
2	18	20	25	17	25	25	-	-	-	17	10	20	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	17	25	25	17	25	25	17	10	20	-	-	-	-	-	-	-
4	-	-	-	17	25	25	-	-	-	-	-	-	-	-	-	-	-	-	16	10	18	-	-	-	-
5	-	-	-	17	25	25	-	-	-	-	-	-	-	-	-	-	-	-	16	10	18	-	-	-	-
6	-	-	-	-	-	-	16	10	18	-	-	-	-	-	-	-	-	-	16	10	10	19	10	35	-
7	-	-	-	17	25	25	18	25	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	16	10	10	19	10	5	-	-	-	-	-	-	-	-	-	17	10	20	-	-	-	16	10	10	-
9	16	10	10	-	-	-	-	-	-	17	25	25	-	-	-	-	-	-	16	10	18	-	-	-	-
10	16	10	10	-	-	-	18	25	25	17	25	25	-	-	-	-	-	-	-	-	-	-	-	-	-

Units of the variables

c = kPa

$\phi$  = degree

$\gamma$  = kN/m

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Table A2 – Safety Factor simulated through the Bishop (B), Generalized Janbu (JB) and Morgenstern-Price (MP) methods for original parameters of trials PMT 01 to PMT 05, conducted in the field, with their variants.

Test	Data	$\Delta$	PMT 01			PMT 02			PMT 03			PMT 04			PMT 05		
			Bsp	JB	MP	Bsp	JB	MP	Bsp	JB	MP	Bsp	JB	MP	Bsp	JB	MP
O	Original	-	0,907	0,688	0,880	0,971	1,438	1,354	2,421	2,430	2,356	0,913	0,858	0,905	0,679	0,676	0,668
SM 1	$\gamma$ 1	+10%	0,874	0,482	0,853	0,941	1,193	1,303	2,385	2,360	2,323	0,875	0,834	0,862	0,663	0,660	0,653
SM 2	$\gamma$ 2	-10%	0,933	0,667	0,903	1,016	1,488	1,402	2,465	2,435	2,398	0,954	0,932	0,938	0,698	0,695	0,686
C 1	c 1	+10%	1,103	1,047	1,060	1,160	1,483	1,398	2,460	2,430	2,393	0,945	0,894	0,934	0,696	<b>0,612</b>	0,685
C 2	c 2	-10%	0,883	<b>0,418</b>	0,860	0,937	1,265	1,257	2,381	2,214	2,320	0,870	<b>0,400</b>	0,857	0,661	0,658	0,652
A 1	$\phi$ 1	+10%	0,868	0,745	0,858	1,041	1,426	1,399	2,646	2,316	2,577	0,965	0,912	0,950	0,833	0,824	0,821
A 2	$\phi$ 2	-10%	0,723	0,689	0,711	<b>0,911</b>	1,332	1,251	<b>2,202</b>	2,214	2,142	0,854	0,760	0,842	0,625	0,631	0,615

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Table A3 – Safety Factor simulated through the Bishop (B), Generalized Janbu (JB) and Morgenstern-Price (MP) methods for original parameters of trials PMT 01 to PMT 10, conducted in the field, with their variants.

Test	Data	$\Delta$	PMT 06			PMT 07			PMT 08			PMT 09			PMT 10		
			Bsp	JB	MP	Bsp	JB	MP	Bsp	JB	MP	Bsp	JB	MP	Bsp	JB	MP
O	Original	-	1,067	1,024	1,035	1,515	1,493	1,479	0,906	0,941	0,866	0,717	0,794	0,706	0,950	1,100	0,932
SM 1	$\gamma$ 1	+10%	1,032	0,906	0,995	1,477	1,502	1,443	0,892	0,925	0,828	0,681	0,515	0,669	0,881	0,875	0,881
SM 2	$\gamma$ 2	-10%	1,114	1,159	1,079	1,560	1,698	1,521	0,957	0,904	0,916	0,748	0,837	0,736	1,247	1,078	1,220
C 1	c 1	+10%	1,110	1,019	1,075	1,556	1,692	1,517	0,952	0,910	0,911	0,745	0,833	0,733	1,243	1,085	1,216
C 2	c 2	-10%	1,028	0,996	0,991	1,474	1,498	1,439	0,855	<b>0,761</b>	0,824	0,690	0,754	0,679	0,874	0,870	0,870
A 1	$\phi$ 1	+10%	1,282	1,279	1,279	1,643	1,374	1,605	0,947	0,887	0,912	0,766	0,837	0,753	0,968	0,976	0,963
A 2	$\phi$ 2	-10%	0,999	0,973	<b>0,968</b>	1,391	<b>1,206</b>	1,356	0,861	0,820	0,824	0,670	0,752	<b>0,660</b>	0,700	<b>0,694</b>	0,703

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