ABSTRACT
The rockfall hazard assessment for roads is very important in geotechnical engineering business. As the process is very fast and complex, a hazard analysis is of fundamental importance for the adoption of preventive action plans and mitigation of potential impacts. Therefore, this article presents a hazard analysis for rockfall and the geological-geotechnical characterization of a rock slope on the BR-356, Ouro Preto, Minas Gerais, Brazil. In the methodology, parameters related to the geotechnical characterization, geometry and slope characteristics were inserted, as signs of block fall activity, impact of external influences and characteristics of the catchment area. According to Rock Mass Rating (RMR), the rock slope was classified as Very Good (Class I). The hazard classification for the slope analyzed varies from low to high. When the rainfall of the rainy season is considered, the slope is classified as a high hazard, while in the dry season, it is classified as low hazard. The study revealed that even if the hazard class is low, the slope deserves attention, since there is not enough space for rock blocks to be deposited before reaching the road, which can generate damages and temporarily paralyze the activities of the road.

KEYWORDS: rockfall, geological-geotechnical hazard, geological-geotechnical characterization, highway, Bação Complex.

AVALIAÇÃO DE PERIGO DE QUEDA DE BLOCOS E CARACTERIZAÇÃO GEOLÓGICO-GEOTÉCNICA DE UM TALUDE ROCHOSO NA BR-356

RESUMO
A avaliação de perigo de queda de blocos para rodovias é um tema muito importante no ramo da engenharia geotécnica. Como o fenômeno é muito rápido e complexo, uma análise de perigo é de fundamental importância para adoção de planos de ação preventiva e mitigação de impactos potenciais. Posto isto, este artigo apresenta uma análise de perigo de queda de blocos e a caracterização geológico-geotécnica de um talude rochoso, localizado às margens da BR-356, na cidade de Ouro Preto, Minas Gerais, Brasil. Na metodologia, parâmetros relacionados à caracterização geotécnica, geometria e características do talude, assim como indícios de atividade de quedas de blocos, impacto das influências externas e características da área de captação de blocos. Segundo o Rock Mass Rating (RMR), o maciço rochoso foi classificado como muito bom (Classe I). A classificação de perigo para o talude analisado varia de baixa até alta. Quando a precipitação da estação chuvosa é considerada, o talude é classificado como de perigo alto, enquanto em épocas de estiagem, o talude é classificado como perigo baixo. O estudo revelou que mesmo a classe de perigo sendo baixa, o talude merece atenção, visto que não há espaço suficiente para blocos de rocha se depositarem sem atingir a plataforma rodoviária, podendo gerar danos e/ou paralisar temporariamente as atividades da rodovia.

PALAVRAS-CHAVE: queda de blocos, avaliação de perigo, caracterização geológico-geotécnico, rodovia, Complexo do Bação.
1 INTRODUCTION

Geotechnical problems such as landslides on slopes occur frequently in various parts of the world with different causes. Among the various types of landslides, there is rockfall. According to Hoek and Bray (1981), rockfall corresponds to the detachment of a rock block from a slope, with little or no shear rupture of the rock bed. These blocks can have variable sizes and shapes, according to the orientation, spacing and persistence of the discontinuities present in the rock mass.

In urban areas, the natural characteristics are very important factors for the triggers of landslides, however, these agents are boost, often by anthropic action, which has intensified in recent decades (Effgen & Marchioro, 2017). Rockfall upon reaching the road surface can cause traffic stoppage and road bans, compromising the flow of cargo and/or passengers. The rockfall process is fast and difficult to predict, so a hazard analysis is of fundamental importance for the adoption of preventive action plans and mitigation of potential impacts.

Fell (2008) defined hazard as the description of the magnitude and probability of occurrence of the landslides. In case of rockfall the hazard analysis includes the estimation of the probability of occurrence and the intensity of the event.

This article presents a rockfall hazard assessment and a geological-geotechnical characterization of a slope located in BR-356, between the km 72 and 74 of the road, in the town of Ouro Preto, state of Minas Gerais, Brazil. The BR-356 highway is located in the states of Minas Gerais and Rio de Janeiro, and can be considered a strategic highway for the flow of materials and passengers, promoting the economy and mobility in Brazil. As it is an alternative link between the metropolitan area of Belo Horizonte and the northwestern region of Rio de Janeiro, a slope on a stretch of BR-356 highway was chosen for geological-geotechnical characterization and hazard analysis for the rockfall.

The slope is in the southeast portion of the Bação Complex, coordinates UTM 0637909/7750176 (Figure 1). The Bação Complex is comprised of approximately 385 km2 and is located in the southeast of the Quadrilátero Ferrífero, in the state of Minas Gerais, Brazil. According to Figueiredo et al. (2004) this Complex constitutes the crystalline basement granite-gneissic-migmatitic of the geological units of the Quadrilátero Ferrífero.
2 MATERIALS AND METHODS

The development of this study was based on the use of a geological-geotechnical survey and geometric parameters of a rock slope found on highway BR-356 in the section comprised in the district of Cachoeira do Campo, Minas Gerais, to determine the geomechanical classification of this slope and the rockfall hazard assessment.

The geological-geotechnical characterization model adopted for analysis was according to Santos et al. (2017). For the geological-geotechnical characterization of the slope, the RQD of the rock masses was determined by means of the relationship proposed by Palmström (1982), Equation (1). For determination of the volumetric joint count (Jv), the mean spacings of discontinuity families (Sj) by means of Equation (2), as proposed by Palmström (1982) were used.

\[
RQD = 115 - 3,3 J_v \tag{1}
\]

\[
J_v = \sum \frac{1}{S_i} \tag{2}
\]

The RMR determination was performed according to Bieniawski (1973), using the parameters of intact rock compressive strength, RQD, as spacing, discontinuity conditions and water condition.

For rockfall hazard assessment, the methodology proposed by Silveira (2017) was used. Silveira (2017) adjusted the methodology of Bauer and Neumann (2011) to Brazilian environmental conditions. In this methodology, the level of hazard is provided by means of a probability matrix (Figure 2A) versus intensity. The probability of rock falls is from the
susceptibility analysis. One of the characteristics that is being presented in the geotechnical characteristics of the slope is the catchment area of the blocks; analysis of indicators of recent activity and external influences such as precipitation and seismic effects. The intensity of the rockfall is given based on the total volume of fallen blocks in the catchment area. The rockfall hazard matrix can be viewed in the Figure 2B. The Tables 1, 2 and 3 show in detail, the classification of each of the characteristics observed in the field, an assigned score and also the weight, according to that proposed by Silveira (2017).

![Figure 2: A) Rockfall probability matrix e B) Rock-fall hazard matrix (adapted by Bauer and Neumann, 2011).](image)

**Table 1: Table for calculation of the susceptibility to the rockfall (Bauer and Neumann, 2011; adapted by Silveira, 2017).**

| 1) Orientation of discontinuities | Unfavorable | Fair | Favorable |
|----------------------------------|-------------|------|-----------|
| Characteristic                   |             |      |           |
| Probability estimation           |             |      |           |
| Rating (Valuation = 17%)         |             |      |           |
| Adverse or slope-parallel        | High        | Medium | Inward or vertical |
| High                             | 500         | 200   | 0         |
| 2) Weathering degree             | Strong weathering (W4 to W5) | Slight weathering (W1 to W3) |
| Probability estimation           |             |      |           |
| Rating (Valuation = 7%)          |             |      |           |
| High                             | 200         |       | 0         |
| 3) Structural configuration of discontinuities |

| Persistence                       | > 10m extent (high) | 1-10m extent (medium) | < 1m extent (low) |
|-----------------------------------|---------------------|-----------------------|------------------|
| Rating (Valuation = 7%)           | 200                 | 100                   | 0                |
| Degree of transection              | No or subordinate mineral bonds | Mineral bonds existent |
| Rating (Valuation = 7%)           | 200                 | 0                     |
| Open width/ Aperture              | Slightly open (0.5mm - 1 cm) | Closed (<0,5 mm) |
| Rating (Valuation = 7%)           | 200                 | 0                     |
| Condition of surfaces             | Slickensides       | Rough                 |
| Rating (Valuation = 7%)           | 200                 | 0                     |

| 4) Degree of loosening (alternative for category) |
| Clear indications available: wide open |
| Only subordinate indications |
| No indications give (low) |
### 3) Rating (Valuation = 28%)
|          | gaps and fractures, neck valleys etc. (high) | (medium) |          |
|----------|-----------------------------------------------|----------|----------|
| Rating   | 800                                           | 400      | 0        |

*Total: Rock mechanics (1+2+(3 or 4))*

### 5) Slope height

| Probability estimation | Rating (Valuation = 20%) | 80m     | 66m     | 57m     | 10m     |
|------------------------|---------------------------|---------|---------|---------|---------|
| Very high              | High                      | Medium  | Low     |
| 600                    | 200                       | 100     | 0       |

### 6) Slope angle

| Probability estimation | Rating (Valuation = 7%) | Inclined plane (favorable to rockfall) | Subvertical or vertical slope with features of launch | Below 30° or almost 90°; (unfavorable rockfall) |
|------------------------|-------------------------|--------------------------------------|-----------------------------------------------------|------------------------------------------------------------------|
| High                   | Medium                  | Low                                 | Low                                                 | 0                                                                |
| 200                    | 100                     | 0                                    | |||                                                                 |

### 7) Catchment area

| Probability estimation | Rating (Valuation = 7%) | Small distance, high slope, with little or no vegetation | Distance and/or moderate slope. Little or none vegetation | Long distance, low slope, with or without vegetation |
|------------------------|-------------------------|----------------------------------------------------------|----------------------------------------------------------|-------------------------------------------------------|
| High                   | Medium                  | Low                                                      | Low                                                      | 0                                                     |
| 200                    | 100                     | 0                                                        | ||                                                                 |

*Total: Slope Geometry and catchment area (5+6+7)*

### 8) Initial activity

| Probability estimation | Rating (Valuation = 14%) | Active | Not active |
|------------------------|---------------------------|--------|------------|
| High                   | 500                       |        | 0          |

*Total: Activity [1+2+(3 or 4)+5+6+7+8]*

| Classification | Probability estimation | 1900 a 3000 | 800 a 1900 | 0 a 800 |
|----------------|-------------------------|--------------|------------|---------|
| High (> 60)   | High                    |              |            |         |
| Strong        | 50                      |              |            |         |
| Medium        |                         |              |            |         |
| Low (< 30)    |                         |              |            |         |
| Weak          |                         |              |            |         |

*Table 2: Table for determining the impact of external influences and calculating the probability of rockfall (Bauer and Neumann, 2011; adapted by Silveira, 2017).*

### 1) seismic effects

| Probability estimation | Rating | Tectonic seismic effects | Mine, karsts regions and heavy traffic | without seismic effects |
|------------------------|--------|--------------------------|---------------------------------------|-------------------------|
| High                   | 50     | High                     | Medium                                | Low                     |
|                         |        |                           | 20                                    |                         |

### 2) precipitation

| Probability estimation | Rating | > 129 mm/6 dias | 48.2–129 mm/6 dias | < 48.2 mm/6 days |
|------------------------|--------|-----------------|-------------------|-----------------|
| High                   | 50     | Low             | Medium            | Low             |
|                         |        |                 | 20                |                 |

*Table 3: Table for determining the intensity of rockfall (Bauer and Neumann, 2011; adapted by Silveira, 2017).*

| Intensity | High-magnitude Rockfalls | Low-magnitude Rockfalls |
|-----------|--------------------------|-------------------------|
| Total volume | Rock avalanche | Large rockfall | Medium rockfall | Small rockfall | Single blocks |
3 RESULTS AND DISCUSSIONS

The studied rock mass is inserted in the Bação Complex, which consists predominantly of gneisses of tonalitic and granodioritic composition (Gomes, 1986; Gomes, 1987). In addition, the Bação Complex composes the basement of the supracrustal rocks of the greenstone belt Rio das Velhas, which surround it; subordinately, pelitic derivation shales and amphibolites (Fonseca and Evangelista, 2013). The gneisses belonging to the Bação Complex frequently show a well developed compositional banding, with dark micaceous bands alternating with clear quartz–feldspatic ones (Bacellar et al., 2005).

The rock that constitutes the rock mass marginal to highway BR-356, is gneiss of fine to average granulometry, with milimetric to centimetric bundles with felsic and mafic layers that sometimes are folded. The mineralogy is predominantly quartz, feldspar and biotite.

Figure 3: Apertures in the discontinuities present in the rock mass.

The basic parameters for the geotechnical characterization of the rock mass were collected in the field. The basic Rock Mass Rating was determined in order to allow a classification for the rock mass that composes the slope studied. Figure 4 presents the slope studied and allows to observe the distribution of discontinuity families giving rise to the blocks of rock present in the rock mass. Another important point to observe in Figure 4 is the proximity between the highway and the slope.
Figure 4: Slope study in the Rodovia dos Inconfidentes (BR-356) with highlight for the formation of blocks.

The geological hammer test was used in the rock mass with the objective of intact rock compressive strength on the classification proposed by ISRM in 1981. The hammer test was applied to several points of the rock mass presenting similar results with flakes after successive hammer blows, resounding when struck by the hammer. The rock mass was classified as R6 implying an extremely high resistance, bigger than 250 MPa.

Regarding the discontinuity families, the values of persistence and spacing were determined. Due to the homogeneous behavior of the measurements for spacing and persistence, their means were selected for the analysis. Table 4 summarizes the data collected.

Table 4: Mean values of persistence and spacing.

| Family | Medium persistence (m) | Medium spacing (m) |
|--------|------------------------|--------------------|
| 1      | 3.90                   | 2.29               |
| 2      | 1.19                   | 0.95               |
| 3      | 3.90                   | 2.29               |

Observing the average values of spacing, it is possible to conclude that the rock mass presents a low degree of fracturing, reflecting in a high RQD value. Due to the spacing values being in bands greater than 1 meter it is not possible to calculate the spacing using the equations proposed by Hudson and Harrison (1997) and Palmström (1982). Besides that, the visualization of the rock mass in the field lets confirm to conclude that the rock mass presents a low degree of fracturing. Thus the selected range of RQD for the mass in study is between 90% and 100%.

Figure 3 presents the image of part of the slope where it is possible to evaluate the parameters related to the discontinuities, such as aperture, filling and roughness of the rock mass. Apertures of the discontinuities between the values of 1 and 5 millimeters were identified,
with no filling. Regarding the roughness, it was concluded that the discontinuities in rock mass presents slight roughness.

Regarding the weathering of the rock mass, irrelevant bands were identified slightly weathered in points along the slope, but the absence of weathering is predominant in the rock mass. Therefore the rock mass was classified as not weathered.

The survey of the parameters allowed classification according to the Rock Mass Rating - RMR. The rock mass was classified as very good, presenting value of 88 for the basic RMR. Table 5 presents the results.

Table 5: Basic RMR results for the rock mass.

| Parameter                | Condition          | Range of values |
|--------------------------|--------------------|-----------------|
| Intact rock strength     | > 250 MPa          | P1 15           |
| RQD                      | 90 – 100%          | P2 20           |
| Discontinuity spacing    | 0.6 – 2 meters     | P3 15           |
| Persistence              |                    |                 |
| Aperture                 |                    |                 |
| Discontinuity condition  | Roughness          | P4 23           |
|                          | Filling            | 6               |
|                          | Weathering         | 6               |
| Presence of water        | Dry condition      | P5 15           |

Classification

Basic RMR 88 Class I

From the parameters collected in the field, it was possible to perform the susceptibility analysis to rockfall according to the methodology proposed by Silveira (2017) for the studied slope. Table 6 presents the parameters analyzed and the score given for susceptibility analysis.

Table 6: Susceptibility to rockfall according proposed by Silveira (2017).

| Parameter            | Score | Classification |
|----------------------|-------|----------------|
| Orientation          | 500   |                |
| Weathering           | 0     |                |
| Persistence          | 100   |                |
| Degree of transection| 200   |                |
| Aperture             | 0     |                |
| Roughness            | 0     |                |
| Slope Height         | 2     |                |
| Slope angle          | 100   |                |
| Catchment area       | 100   |                |
| Activity             | 500   |                |
| Susceptibility (total)| 1502 | High           |

The analysis showed that the studied slope obtained a score of 1502 for the susceptibility, which encompasses the parameters related to rock mechanics, slope geometry and activity indications. The susceptibility to rockfall of the studied slope is between the range of score of 800 to 1900, being classified as Medium Susceptibility. The lowest scores occurred in the parameters of weathering and in the structural configuration of the rock mass (apertures and roughness of
the discontinuities) due to the good conditions of the rock mass, which is competent and little weathered. However in this slope, the presence of minerals bonds was not identified, which culminated in the maximum score for the transection degree of the slope analyzed.

The parameters that most influenced the susceptibility to rockfall in this slope was a favorable orientation to the formation of blocks and signs of activity. The signs of activity were identified directly in the field, from fallen blocks, fractures in the rock mass, open and displaced joints and presence of vegetation between the discontinuities. Figure 5 shows the studied slope, as well as its discontinuities.

![Figure 5: Marginal slope to BR-356 highway with its discontinuities.](image)

The probability of rockfall was analyzed considering the susceptibility to rockfall and the impact of external influences, such as seismic effects and precipitation. In the case of the BR356 highway, an important highway linking the capital of Minas Gerais to the historic cities of Ouro Preto and Mariana, it is exposed to the vibrations generated by the intense traffic of cars and heavy vehicles. Thus, the region studied is generally in a zone of medium seismicity, so the score in this parameter was 20 points.

The values for rainfall were obtained through studies that related the pluviometric index with mass movements in the region of Ouro Preto. Castro (2006) points out that five-day accumulated rainfall is considered to be the most effective in the landslide process, when the accumulated five-day rainfall is above 22 mm. For precipitation above 128 mm/5 days, the probability of occurrence of more severe landslides becomes greater. According to Silva (2014), the minimum cumulative precipitation required to cause geotechnical accidents is 48.2 mm/6 days. From 129 mm/6 days, the region is in a state of attention.

Although Castro (2006) and Silva (2014) relate rainfall to landslides, these data were used in this analysis of rockfall hazards because there are situations in which these events are associated. In addition, as Silveira (2017) emphasizes, there is not enough data to associate
rockfalls to rainfall, since it is a phenomenon that has not been studied so much in the region of Ouro Preto.

In order to analyze the behavior of the slope in both dry and wet periods, the probability of rockfall occurrence was calculated taking into account the maximum and the minimum precipitation of the region. For the maximum precipitation, the score was 50 points and for the minimum precipitation, the score was 0. Table 7 presents the scores for the impact of external influences according to the Silveira (2017) proposal.

Table 7: Impact of external influences according to Silveira (2017).

|                                | Maximum | Minimum |
|--------------------------------|---------|---------|
| Precipitation                  | 50      | 0       |
| Seismic effects                | 20      | 20      |
| Total external impact          | 70      | 20      |

Table 8 presents the probability of occurrence of rockfall in the analyzed slope. The maximum probability is represented by the rainy periods and the minimum probability is represented by the dry periods. The probability of rockfall occurrence was given by the probability matrix presented in Figure 2a.

Table 8: Rockfall probability occurrence according to Silveira's proposal.

|                                | Maximum | Minimum |
|--------------------------------|---------|---------|
| Susceptibility                 | Medium  | Medium  |
| Impact degree                  | Strong  | Weak    |
| Probability                    | High    | Medium  |

From the previous tables, it was possible to perceive that precipitation exerted a major influence on the result of the impact degree of the external influences and, consequently, on the final probability of occurrence of rockfall. High rockfall probability occurrence in the rainy season. The analyzed slope obtained a high rockfall occurrence probability for the rainy season. With this, it is possible to affirm that the impact degree of external influences was the parameter that most influenced the result of this analysis.

The intensity of the rockfall is measured by the volume of material that falls from the slope. In the analyzed rock mass, it was possible to verify falls on a small scale, with fragments having a diameter greater than 200mm and blocks with a volume of up to 100 m³. However, due to the fact that it is a highway with intense traffic, it is possible to consider the possibility of a rockfall occurrence, causing damage to the highway, paralyzing traffic and, possibly, causing accidents involving fatalities.

Knowing the probability of rockfall and the intensity of the event for the slope, it was possible to classify its hazardous degree. This result was obtained by means of the hazard matrix of Figure 2B given above and presented in Table 9.
Table 9 - Classification of the rockfall hazard to the marginal slope of the BR356 highway, according to the adaptation proposed by Silveira (2017).

| Seasons | Probability | Intensity | Hazard Class |
|---------|-------------|-----------|--------------|
| Drought | Medium      | Up to 100m³ | Low          |
| Rainy   | High        | Up to 100m³ | High         |

The hazard classification for the analyzed slope varies from low to high. When the precipitation is that of the rainy season, the probability of rockfall occurrence in the place is high, consequently the hazard is high, since the impact degree of external influences indicated by this methodology is strong. At the time of year, when drought occurs, when precipitation is minimal, the probability is medium, consequently the hazard is low.

With regard to the characteristics used for the susceptibility analysis, it is possible to cite as a differential, the orientation of the discontinuities, transection degree, activity of the rock mass and mainly the lack of a catchment area. This slope is susceptible to rockfall, which in this case the rocks are bulky. If there is a fall, these blocks would have little time to lose energy and speed, since the distance between the slope and the highway is small.

4 CONCLUSIONS

Studies of rockfall hazard analysis in highways are important, especially in highways with a high flow. The rock mass of the slope studied is a gneiss of small to average grains, very fractured, verified by the presence of discontinuities, with unfavorable orientation. The RMR was applied, and the rock mass was classified Class I. The hazard classification for the slope analyzed varies from low to high, according to the precipitation considered.

The study presented a considerable probability of detachment of blocks, especially in the rainy season. Thus, there are alternatives for hazard reduction, such as the installation of rockfall protection barriers, installation of bar anchors in critical blocks or the removal of the larger blocks by fragmentation. In addition, on highways where there are hazard of detachment of blocks, it is necessary to have “hazard signs”.

5 REFERENCES

Alkmim, F. F., & Marshak, S. (1998). Transamazonian Orogeny in the Southern São Francisco Craton Region, Minas Gerais, Brazil: Evidence for the Paleoproterozoic collision and collapse in the Quadrilátero Ferrífero. Precambrian Research, 90, 29-58.

Bacellar, L. A. P., Coelho Netto, A. L., & Lacerda, W. A. (2005). Controlling factors of gullying in the Maracujá Catchment, southeastern Brazil. Earth Surface Processes and Landforms, 30, 1369–1385.

Bauer, M. & Neumann, P. (2011). A guide to processing rock-fall hazard from field data. In Vogt, N., Schuppener, B., Straub, D. & Bräu, G., Geotechnical Safety and Risk, In Proceedings of the 3rd International Symposium on Geotechnical Safety and Risk. Munich, Germany, 149-156.
Bieniawski, Z.T. (1973). Engineering classification of jointed rock masses. Trans. S. African Instrn. Civil Engineers., 15(12), 35 – 344.

Castro, J.M. G. (2006). Pluviosidade e movimentos de massa nas encostas de Ouro Preto. (Dissertação de mestrado). Programa de Pós-graduação em Engenharia Civil, Escola de Minas, Universidade Federal de Ouro Preto, Ouro Preto, MG, Brasil.

Effgen, J. F., & Marchioro, E. (2017). Mapeamento de áreas suscetíveis a movimentos de massa no município de Vila Velha-ES, como uso de análise de processos hierarquizados (AHP). São Paulo, UNESP, Geociências, 36 (4), 731 – 742.

Fell, R., Corominas, J., Bonnard, C., Cascini, L., Leroi, E., & Savage, W. Z. (2008). Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. Engineering Geology, 102, 85–98.

Figueiredo, M. A., Varajão, A. F. D. C., Fabris, J. D., Loutfil, I. S., & Carvalho, A. P. (2004). Alteração superficial e pedogeomorfologia no sul do Complexo Bação - Quadrilátero Ferrífero (MG). Rev. Bras. Ciênc. Solo, 28(4), 713-729.

Fonseca, G. M. & Evangelista, H. J. (2013). Rochas ultramáficas plutônicas do greenstone belt Rio das Velhas na porção central do Quadrilátero Ferrífero, Minas Gerais, Brasil. REM - Revista Escola de Minas, 66(1), 67-75.

Gomes, N. S. (1986). Determinações geotermométricas e geobarométricas em paragêneses minerais de alto grau metamórfico no Complexo do Bação, Quadrilátero Ferrífero – Minas Gerais. In CONGRESSO BRASILEIRO DE GEOLOGIA 34, Anais do XXXIV Congresso Brasileiro de Geologia, Goiânia, Goiás. pp. 1424-1436.

Gomes, N. S. (1987). Caracterização química de paragêneses minerais de alto grau metamórfico no Complexo do Bação, Quadrilátero Ferrífero, Minas Gerais. REM - Revista Escola de Minas, 40(1), 25-36.

Hoek, E., & Bray, J.W. (1981). Rock Slope Engineering. (Revised 3rd Edition). The Institution of Mining and Metallurgy, London.

Hudson, J.A. & Harrison J.P. (1997). Engineering rock mechanics: an introduction to the principles. Elsevier SciencE Ltd Oxford, UK.

Palmström, A. (1982). The volumetric joint count - a useful and simple measure of the degree of jointing. Proc. IV Int. Congr. IAEG, New Delhi, pp.221-228.

Santos, T. B., Lana, M. S., Santos, A. E. M., & Silveira, L. R. C. (2017). Applicability of geomechanical classifications for estimation of strength properties in Brazilian rock masses. Anais da Academia Brasileira de Ciencias, 89, 859-872.

Silva, N. L. (2014). Correlação Entre Pluviosidade E Movimentos Gravitacionais De Massa No Alto Ribeirão Do Carma/MG (Dissertação de mestrado). NUGEO, Escola de Minas, Universidade Federal de Ouro Preto, Ouro Preto, MG, Brasil.
Silveira, L. R. C. (2017). Avaliação do perigo de queda de blocos em taludes urbanos e ferroviários e simulação de sua trajetória (Dissertação de mestrado). Programa de Pós-graduação em Engenharia Mineral, Escola de Minas, Universidade Federal de Ouro Preto, Ouro Preto, MG, Brasil.

COMO CITAR ESTE ARTIGO:
Silva, D. DE F. S. DA, Santos, A. E. M. (2020). Rockfall hazard assessment and geological-geotechnical characterization of a rock slope in BR-356. Holos. 36(8), 1-13.

SOBRE OS AUTORES

D. DE F. S. DA SILVA
Engenheira geóloga pela Universidade Federal de Ouro Preto. Mestre em Geotecnia pelo Núcleo de Geotecnia da Escola de Minas. Atualmente é técnica do Centro de Pesquisas Professor Manoel Teixeira da Costa e doutoranda no Instituto de Geociências na Universidade Federal de Minas Gerais.
E-mail: denisefss@yahoo.com.br
ORCID ID: http://orcid.org/0000-0002-9695-2449

A. E. M. SANTOS
Engenheiro de minas pela Universidade Federal de Ouro Preto. Mestre em engenharia mineral. Atualmente é professor no Departamento de Minas e Construção Civil no Centro Federal de Educação Tecnológica de Minas Gerais e Doutorando em Engenharia Mineral na Universidade Federal de Ouro Preto.
E-mail: allanerlikhman@cefetmg.br
ORCID ID: http://orcid.org/0000-0003-4302-3897

Editor(a) Responsável: Francinaide de Lima Silva Nascimento
Pareceristas Ad Hoc: Julio Pontes e Marisa Moura de Abreu