Determination of RQD using GSI applied to Isotropic Igneous Rocks for Bieniawski's RMR

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ABSTRACT: Jointing degree is a fundamental parameter for geomechanical characterization of the rock mass. RQD parameter is a measure of drill core quality of the rock mass widely used on the main geomechanical classification systems, such as Q system (Barton et al. 1974) and RMR system (Bieniawski 1989). In this context, some correlations to calculate were proposed when core logging descriptions are absent. However, most of these correlations show limitation mainly when applied to isotropic rocks randomly jointed. This study presents an alternative correlation to RQD calculation, using the GSI quantification equation proposed by Hoek et al. (2013) and applied to an open-pit mine composed of igneous isotropic rocks. The proposed correlation based on GSI resulted in acceptable values of RQD and RMR for the conditions of the slope faces observed during the geomechanical mapping. These results are compared to RQD intervals calculated from limited drill holes distributed along the pit.

1 INTRODUCTION

1.1 *General Overview*

The Rock Quality Designation (RQD), as proposed by Deere et al. (1967), is a popular jointing degree measurement used on rock mass quality systems such as Q system (Barton et al. 1974) and Bieniawski`s RMR system (1976, 1989), although many authors (Palmstrom 2005, Choi and Park 2004, Edelbro 2003) and people involved in engineering geology characterization agree that RQD parameter has many limitations. Due to the lack of geomechanical core logging for RQD calculation, some correlations between rock mass parameters obtained from slope face mapping and RQD were proposed, such as the ones proposed by Priest & Hudson (1976) and by Palmstrom (1974, 2005).

Priest & Hudson (1976) suggest obtaining RQD through an equation based on joint frequency of the rock mass. Palmstrom (1974, 2005) suggests the estimation of RQD based on an equation using joint volumetric count (Jv), which is defined from joint set spacing parameter (S). However, both methodologies have some limitations as well.

The Jv parameter, for instance, has limitation when applied to isotropic rocks which lacks of a clear joint spacing pattern. In this context, this paper presents an alternative methodology for RQD estimation from slope face mapping using the GSI chart proposed by Marinos & Hoek (2000) and latter quantified by Hoek et al. (2013).

Hoek et al. (2013) proposed GSI quantification to help engineers with low field experience and low familiarity with GSI parameter. In order to solve this issue, these authors attributed values for blockiness based on RQD and values for joint condition, which is defined from Jcond (RMR, from Bieniawski 1989). Hoek et al. (2013), based on GSI chart, suggest summing values of blockiness (vertical axis) with joint condition values (horizontal axis) to calculate GSI (Fig. 1), as exposed in Equation 1.

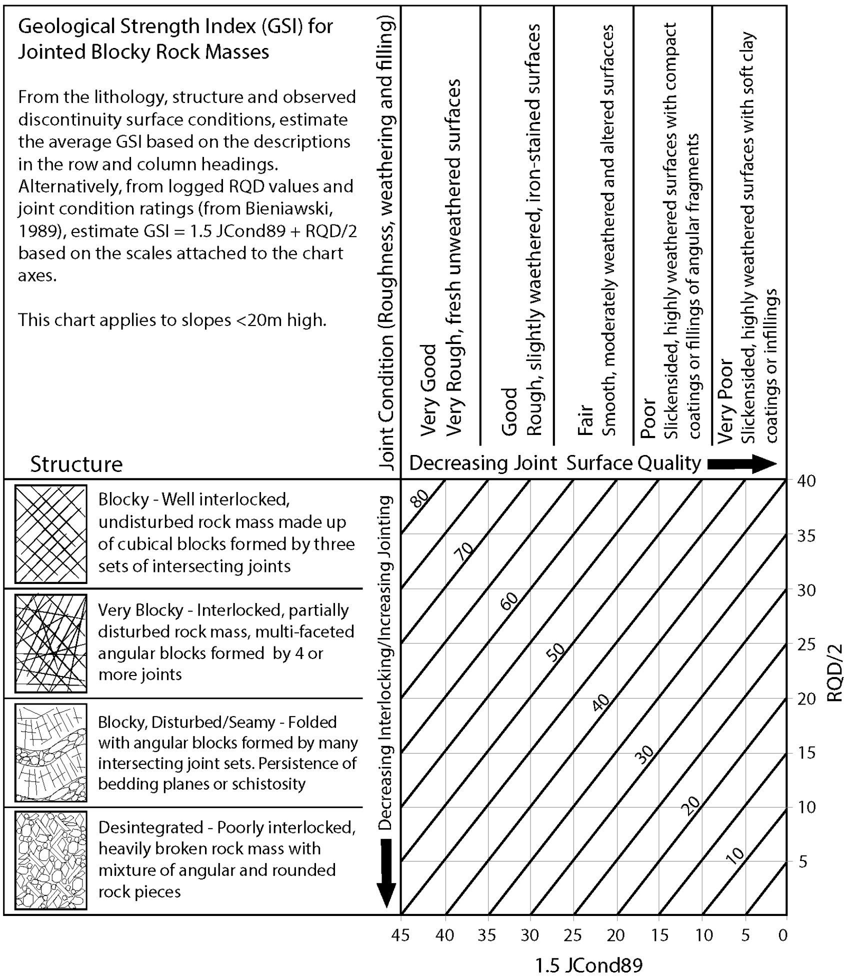

Figure 1. GSI chart showing the quantification of horizontal and vertical axes given by correlation with JCond89 and RQD respectively (modified from Hoek et al. 2013).

$$GSI = 1.5\ JCond_{89} + (RQD/2) \tag{1}$$

This paper presents two methodologies for RQD calculation based on GSI quantification applied to an open pit mine composed of isotropic ultramafic-alkaline rocks situated in Brazil. The results obtained were compared to Jv correlation (as proposed by Palmstrom, 2005) and to RQD values obtained from limited core logging.

1.2 *Geological and Geomechanical General Characteristics*

The open-pit mine studied is characterized by a central pluton of carbonatite surrounded by an older clinopyroxenite. In general, the clinopyroxenite is characterized by high uniaxial strength, with variable fracturing degree along the pit and joints occasionally filled with thin layers of hydrothermal alteration clay. The carbonatite is characterized by a medium uniaxial strength, with variable fracturing degree along the pit and joints lightly stained and oxided.

The fracturing degree and alteration of the lithotypes tends to increase towards to the brittle shear zone trending NNW-SSE, localized in the south of the open-pit. The main discontinuities are formed by a Riedel shear system, so they present a specific geometric relation with the major strike-slip fault and dip with a high angle to NNE and SSW. Minor discontinuities are randomly distributed, which is common in isotropic and homogeneous rock masses. Figure 2 illustrates geological and structural features of the open-pit mine.

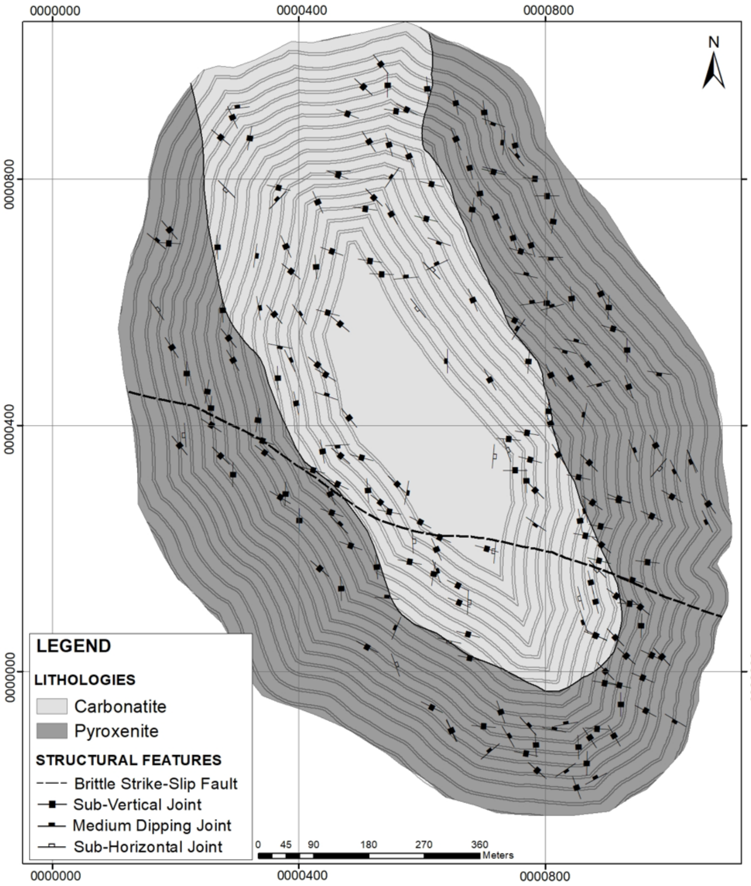

Figure 2. Geological and structural map of the open-pit mine showing the main joint systems.

2 METHODOLOGY

The methodology was basically based on: data collection from slope face mapping and calculation of RQD and RMR through the correlations that follow.

2.1 *Slope Face Mapping Data Collection*

During geomechanical mapping of slope faces, data from 248 points were collected. In each point, it was collected parameters of the rock matrix and discontinuities, resulting on 505 data of the rock mass. The rock mass geomechanical parameters were collected and estimated as suggested by ISRM (Brown 1981) and includes:

- Uniaxial Compressive Strength (UCS), based on hammer blow (R);
- Weathering (W), based on weathering degree of rock matrix mineralogy;
- Discontinuities' orientation (dip/direction);
- Spacing of joints/discontinuities (S);
- Condition of discontinuities, given as:
  - Joint Roughness (Jr), as proposed by Barton (1987);
  - Joint Alteration/Weathering (Ja);
  - Joint Persistence;
  - Joint Infilling;
  - Joint Separation.
- Number of joint sets (Jn);
- Groundwater condition.

In each point, it was defined a value of GSI and blockiness based on rock mass fracturing, as shown in Figure 1.

2.2 *RQD and RMR Calculation*

Considering the works developed by Hoek et al. (2013) and Bieniawski (1989), two distinct possibilities are presented for the determination of RQD values from GSI data:

1. Modifying the equation proposed by Hoek et al. (2013) in which RQD is isolated, as shown in equation 2. Thus, GSI and $Jcond_{89}$ are used as input data for RQD calculation;

$$RQD = (GSI - 1.5\ JCond_{89})2 \qquad (2)$$

2. Estimating RQD directly from blockiness (Scale B/Y axes of chart shown in Figure 1) which was defined by visual inspection of rock mass and directly correlated with GSI quantification chart. It was considered the following RQD values for each blockiness pattern based on slope face mapping:

- For intact rock mass, i.e. less fractured than blocky pattern, it was assigned a RQD value of 90%;
- For blocky pattern, it was assigned a RQD value of 70%;
- For very blocky pattern, it was assigned a RQD value of 50%;
- For blocky/disturbed pattern, it was assigned a RQD value of 30%
- For desintegrated pattern, it was assigned a RQD value of 10%.

The disturbed and desintegrated patterns were assigned only for sheared material under brittle condition which is located on fault plane in southern part of the mine.

RQD values calculated from two methodologies were used as input data on basic RMR calculation and then compared to basic RMR values calculated through RQD-Jv correlation, as suggested by Palmstrom (2005). RQD values greater than 100% were considered as 100%, while negative RQD values were considered equal to 0%.

3 RESULTS

3.1 *RQD and RMR through GSI Equation*

The histograms presented in figures 3 and 4 show RQD and RMR values obtained from GSI-RQD correlation, as exhibited in Equation 2. RQD histogram indicates a wide variation with a mean around 73.30%. The histogram calculated from RMR frequency also presents a considerable variation with a mean around 72.05. Theses variations may occur because rock masses of different geomechanical quality were not individualized.

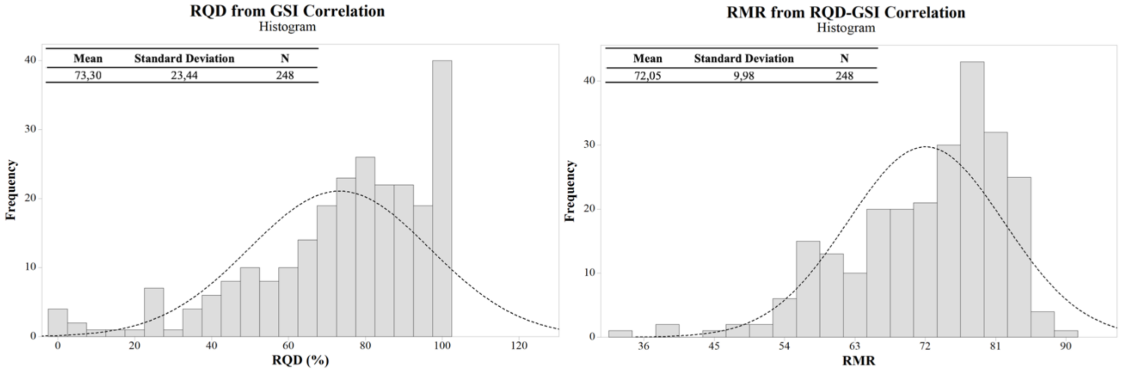

Figure 3 (left) and 4 (right). Histograms of the frequency ratio and distribution fit of RQD and RMR calculated from GSI-RQD correlation, as shown in equation 1.

3.2 *RQD and RMR through Blockiness Pattern*

The histograms shown in figures 5 and 6 present RQD and RMR values calculated from blockiness patterns, as explained before. The RQD histogram presents a sharp predominance of RQD values of 70% (blocky rock mass), resulting in a mean of 70.16%. The RMR frequency ratio gives a mean of 69.91.

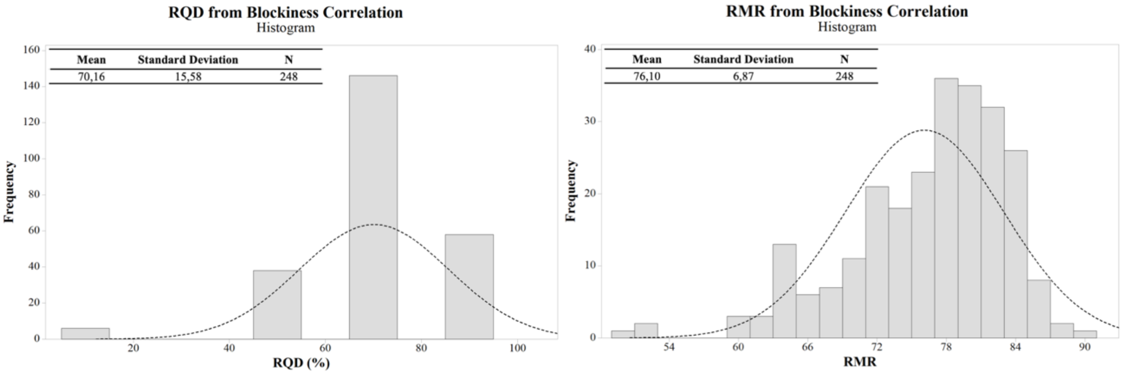

Figure 5 (left) and 6 (right). Histograms showing the frequency ratio and distribution fit of RQD and RMR calculated from Blockiness-RQD correlation.

3.3 *RQD and RMR through Jv Correlation*

The histograms shown on figures 7 and 8 present RQD and RMR values obtained from RQD-Jv correlation. On RQD histogram, the overestimation of RQD calculated from this correlation is clear (mean of 97.35%) when compared with results of RQD calculated from RQD-GSI correlation. As a result, there is a general elevation on RMR values, leading to a mean of 76.10.

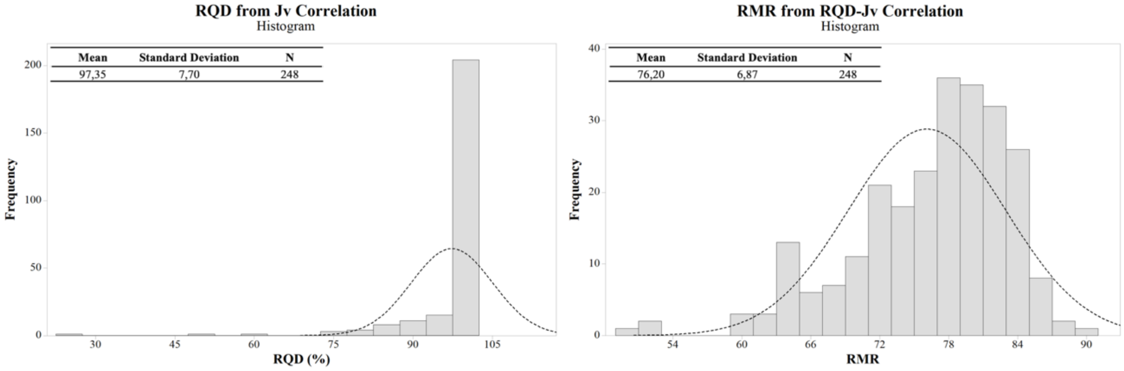

Figure 7 (left) and 8 (right). Histograms showing the frequency ratio and distribution fit of RQD and RMR calculated from Jv-RQD correlation as proposed by Palmstrom (2005).

Despite of the overestimated values of RQD calculated through RQD-Jv correlation, the values of RMR are less sensible to this situation once the other parameters used on its calculation seem to attenuate the difference.

3.4 *RQD from Core Logging vs. RQD from GSI Equation*

The values of RQD calculated from GSI correlation were compared with RQD values from drill core description. This was possible only on areas with drillholes information. So, only some field points could be verified. The RQD of core logging data available were quantified and individualized in intervals instead of unique values, as indicated:

- 0 to 25%;
- 25 to 50%;

- 50 to 75%
- 75 to 90%;
- 90 to 100%.

Considering this information, it was made a qualitative comparison between RQD intervals from core logging and the values calculated from GSI correlation. Among the 22 values (from RQD-GSI correlation) observed, 10 values match with core logging description intervals. However, if it is considered a margin of 5% on interval of core logging, 17 values match, resulting on 77% of RQD values from GSI correlation that match with core logging RQD, as shown in the chart on Figure 9. The divergent values (Fig. 9) may be a result of poor individualization of geomechanical intervals along some core samples.

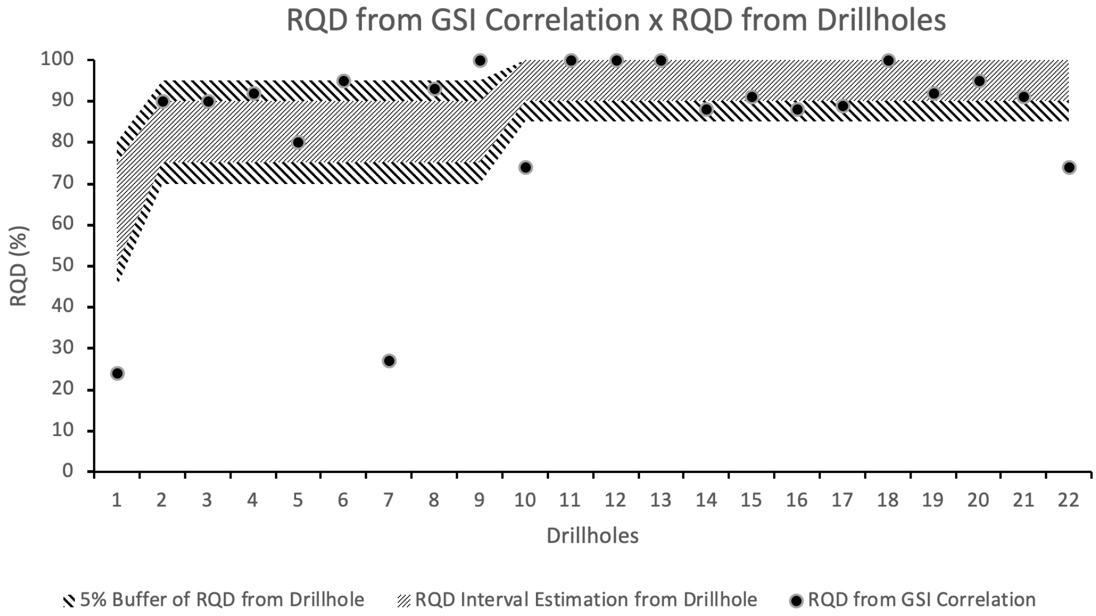

Figure 9. Comparison between RQD obtained from core logging and GSI correlation.

3.5 *Geomechanical Map*

As a result of RMR calculation from RQD obtained from GSI correlation, it was made a 2D geomechanical model of the open pit mine in which the RMR values were divided into classes, given as:
- Class I and II includes RMR values greater than 60;
- Class III includes RMR values ranging from 60 to 41;
- Class IV includes RMR values ranging from 40 to 20;
- Class V includes RMR values lower than 20.

Considering the mentioned information, the mine is made up of rocks essentially defined as classes I and II, with the presence of Class III rock masses confined to small areas and bordering the transcurrent zone. Class IV rock masses occur along the shear zones and associated with saprolite units, while the soil units are defined as Class V, as shown in Figure 10.

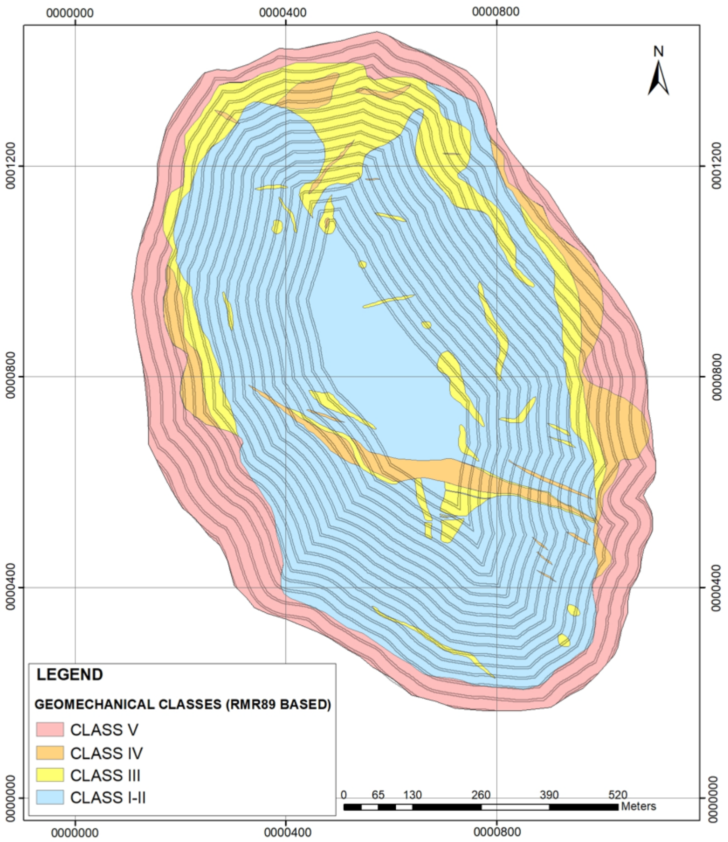

Figure 10. Geomechanical map of the open-pit mine, based on RMR89 obtained from RQD-GSI correlation.

4 DISCUSSIONS

The Jv parameter, proposed by Palmstrom (1974, 2005), is widely used on geomechanical surveys when there is no drillholes which should allow the RQD estimation through core logging. However, as mentioned by the author, the correlation between Jv and RQD presents low reliability since RQD may show different values in function of joint orientation and disposition over the rock mass. In addition, it is difficult to find a reliable correlation of RQD once its calculation considers only samples greater than 10 centimeters.

Choi and Park (2004) demonstrated that, for Korean conditions, a single rock mass may present different values of RQD depending on the orientation of the drillhole and the shape of rock blocks on a rock mass. As a result, Jv and other jointing degree parameters may lead to unreliable values of RQD. Besides that, Jv parameter presents a limitation when applied to isotropic and homogeneous rock mass with random fracturing. It happens because Jv, as shown in equation 3, is given by the sum of the inverse of joint sets spacing (S) which is given by the mean distance between two joints of the same set. On isotropic rock mass without clear structural features, it is difficult to estimate joint spacing (S). Trying to solve this matter, Palmstrom (2005) suggests applying 5m of joint spacing for random joints which may result in overestimated geomechanical condition of rock mass. Palmstrom (2005) mentions this limitation of the Jv correlation.

$$\mathrm{Jv} = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \cdots + \frac{1}{S_n} + \frac{\mathrm{Nr}}{5\sqrt{A}} \tag{3}$$

where S1, S2, S3, Sn are mean joint spacing of a joint set; and Nr is the number of random joints of a defined area in m^2.

As an alternative to Jv parameter, it was proposed the correlation between RQD and GSI applied to isotropic rocks. RQD-GSI correlation seems to be more suitable to randomly fractured rock masses when compared to other methods. However, as a result of being GSI based, this correlation may present the same limitations of GSI system when applied to some materials such as: extremely weathered rock masses (with soil behavior), rock masses controlled by structural fabrics and intact rock masses in which joints do not repeat along an outcrop.

5 CONCLUSIONS

Both methodologies presented in this study – RQD calculation from blockiness; and RQD from GSI quantification equation (Eq. 2) – seemed to be applicable to the conditions of the open pit mine studied, being experimentally applied to mines with similar geological background. The Jv-RQD correlation leads to overestimated values, resulting in elevated values of RMR in regions of the pit where rock masses of lower geomechanical quality should be expected. On the other hand, RQD-GSI correlation results in more sensible values of RMR, allowing a more precise geomechanical delimitation of rock mass along the pit. Thus, it is considered that the method presented turned out to be more suitable for isotropic rocks.

It is important to highlight that the lithotypes and rock masses of different geomechanical qualities were not individualized. The poor blasting control could influence on final results once the perturbation of explosion may superficially overbreak the rock mass, inducing to underestimated values of RQD. This fact must be considered during slope face mapping. Moreover, it must be considered when the field results are compared with core logging results. This may be a reason why the comparison between field and core logging show some divergent results.

Despite of the limitation of core logging data, the results of RQD obtained from slope face mapping showed acceptable correlation between them. However, the reliability of proposed methodology may be confirmed with new surveys and studies.

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