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Assessment of rock mass quality by the use of the Rock Mass Index (RMi)

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SUMMARY: RMi system is a geomechanical classification obtained through the multiplication of the uniaxial compressive strength of intact rock by a reduction factor of strength, named JP, which represents the effects of discontinuities on the strength of rock masses. JP factor is a combination of the block size, measured in terms of volume (Vb), and the joint condition factor of the joint (jC). Therefore, the RMi index is a dimensional number and it has the same unit of the uniaxial compressive strength. The individual components of the input in RMi, the strength of the intact rock and the characteristics of the joints are measured and combined to deduce the rock mass strength. In this paper the RMi index was applied in five rock masses with different characteristics. Geological and geotechnical surveys were carried out in these rock masses. The application of the method was discussed pointing out its advantages and disadvantages in relation to the traditional methods of geomechanical classification, i.e. the RMR and Q. The studied rock masses were classified according to the RMi as follows: a gneiss that was divided into ten sectors had an average value of 19.2 MPa and was classified as very strong; a quartzite that was divided into five sectors had an average value of 19.8 MPa and was also classified as very strong; a schist with only one sector had an average value of 3.8 MPa and was classified as strong; another schist that presented two very distinct sectors, with values of 0.008 MPa and 0.9 MPa and was classified as very weak and moderately strong and a phyllite with only one sector had an average value of 0.13 MPa and was classified as moderately strong. The geomechanical classification system proposed by Palmström (1995) offers best practice field guidelines to obtain the parameters. This is a great advantage because it reduces the uncertainties arising from the geotechnical survey. Furthermore, the method does not use the Rock Quality Designation (RQD), which it is an index that is highly dependent on the direction of the discontinuity surveys. In addition, the method has the advantage of providing a dimensional number, which represents the uniaxial compressive strength of the rock mass. The method has not been used by the geotechnical community, which can be considered a disadvantage.

KEYWORDS: Geomechanical Classifications, Rock Mass Index, geological and geotechnical survey, rock mass.

1 INTRODUCTION

Several authors, such as Bieniawski (1989), Barton et al. (1974) and Hoek (1994), proposed geomechanical classification systems for rock masses. These systems have been widely accepted by the geotechnical community. Although much less known and used by experts the classification proposed by Palmström (1995) has some advantages in relation to other traditional classification systems. The system proposed by Palmström is the Rock Mass Index (RMi). Figure 1 shows the intrinsic parameters of rock masses which are taken into consideration in RMi.

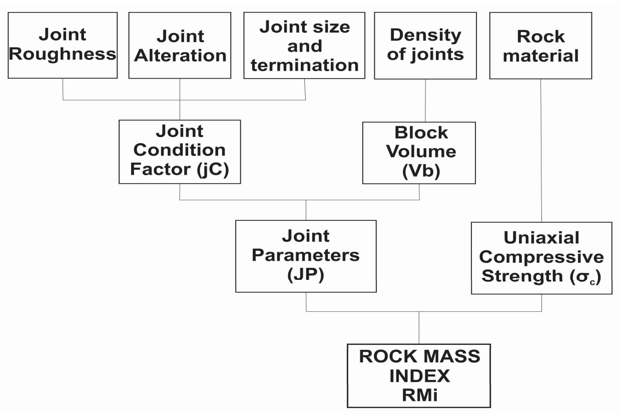

Figure 1. Main parameters of rock masses in RMi (Palmström 1995).

RMi is a geomechanical classification obtained through the multiplication of the uniaxial compressive strength of intact rock (σ_c) by a reduction factor of strength (JP), which indicates the effects of discontinuities on the strength of rock masses, see equation (1).

$$\mathrm{RMi} = \sigma_c \times \mathrm{JP} \quad (1)$$

JP factor is a combination of the block size, measured in terms of volume (V_b), and the joint condition factor (jC). JP factor is equal to 1 when the rock is intact and equal to 0 when the rock is completely fractured. It is calculated by the equation (2).

$$\mathrm{JP} = 0.2\sqrt{\mathrm{jC} \times \mathrm{V_b}^{0.37jC^{-0.2}}} \quad (2)$$

The jC factor and the volume V_b are calculated by equations (3) and (4), respectively.

$$\mathrm{jC} = \mathrm{jL} \times (\mathrm{jR} \times \mathrm{jA}) \quad (3)$$

Where:
jL is the joint length factor;
jR is the joint roughness factor;
jA is the joint surface weathering factor.

$$\mathrm{V_b} = \frac{S_1 \times S_2 \times S_3}{\sin\gamma_1 \times \sin\gamma_2 \times \sin\gamma_3} \quad (4)$$

Where:
S_1, S_2 and S_3 are the spacing of the three discontinuity families that formed a block
$\gamma1$, $\gamma2$, $\gamma3$ are the angles between the discontinuity families.

By observing equation (1), it can be seen that the RMI index is a dimensional number and it has the same unit of the uniaxial compressive strength. The individual components of the input in RMi, the strength of the intact rock and the characteristics of the joints are measured and combined to deduce the rock mass strength. Large-scale test results and strength measurements at the field were used to develop an expression for the RMi as close as possible to reality (Palmström, 1995).

This paper proposes the application of RMi index in five rock masses with different characteristics. Then, the use of this classification system is discussed and analyzed.

2 MATERIAL AND METHODS

2.1 Selection of the studied slopes

Five different lithologies were selected for this study: two hard rocks (gneiss and quartzite) and three soft rocks (two schists with different degrees of weathering and a phyllite).

2.2 Geological and geotechnical survey

Geological and geotechnical surveys of the five rock masses were carried out. They were performed basically in two stages.

In the first stage, study of the geological context and observation of petrographic features on hand samples have been done. Geological maps of the area, on a scale of 1:25000, were used in this study.

In the second stage the geotechnical survey of the discontinuities has been carried out. In this stage, the spacing, persistence, opening, roughness and weathering were measured or estimated in outcrops with easy access. Spacing and opening were measured with tapes. Persistence was estimated through observations in the outcrops. Roughness was estimated based on the roughness profiles proposed by Barton (1978). Weathering was described according to the International society of Rock mechanics, ISRM (1981), which correlates the degree of weathering with the characteristics of the rock mass.

Uniaxial compressive strength of intact rock was obtained by Geological hammer tests and Schmidt rebound tests (type N). The tests were performed based on the recommendations of ISRM (1981) and the American Society for Testing and Materials (ASTM, 2001), respectively.

In case of the Schmidt hammer test, correlation equations between the rebound value (R) and the uniaxial compressive strength (σ_c) were used. The correlation equations (5) and(6) have been proposed for seven different types of rocks (Katz et al., 2000) and schist (Shalabi et al., 2007), respectively.

$$\ln(\sigma_c) = 0.067 \times R_L + 0.792 \quad (5)$$

$$\sigma_c = 3.201 R_L - 46.59 \quad (6)$$

Where, R_L is the rebound value obtained by Schmidt hammer type L.

Equation (8), proposed by Aydin and Basu (2005), was needed to find R_L values through R_N.

$$R_L = \frac{R_N - 3.3673}{1.064} \quad (8)$$

Equations for estimating the uniaxial compressive strength for quartzite have not been found in the literature. Equations for other lithology types have not yielded coherent results.

2.1 Rock Mass Index (RMi) calculation

RMi system was applied in the five studied slopes. After geotechnical survey, the parameters associated with the characteristics of discontinuities were established. Then, the equations (1), (2), (3) and (4) were used to calculate the RMi.

3 RESULTS

3.1 Characterization of the studied rock masses

The first slope (TLD-01) is located at Cabanas neighborhood, Mariana city. The region is an irregular settlement. Rock falls are a common occurrence in this site. The entire slope is 275 meters in length and it has variable height. An outcrop which is 30 meters in length and with an average height of 47 meters was selected. This outcrop has been selected because of its accessibility and the ease to perform field survey. The TLD-01 slope can be seen in Figure 2, which shows the high vulnerability situation of the buildings below it. The outcrop of TLD-01 was split in five sectors, for taking into account the different geomechanical behavior observed when data from geotechnical survey were analyzed. The rock mass was classified as quartzite.

Figure 2. First studied slope (TLD-01).

The second slope (TLD-02) is located in the railway which connects the cities of Ouro Preto and Mariana. It is 9 meters high, with a dip of 89^0. This rock mass has apparently regular quality and high degree of fracturing. Rock blocks forming a stepped base can be seen, although block toppling failure was not identified in this site. Maybe it has occurred during the slope excavation due to blasting. The rock mass was classified as a schist. The TLD-02 slope is shown in Figure 3.

Figure 3. Second studied slope (TLD-02).

The third slope (TLD-03) is located in the Inconfidentes's highway near the km 88. The slope was split in two sectors, given that they have different geomechanical characteristics. Sector 1 has high degree of fracturing and weathering, 100 meters in length, two benches of approximately 15 and 20 meters in length and a berm of 2 meters wide. Sector 2 has low degree of weathering and fracturing. The rock mass was also classified as a schist. TLD-03 slope is shown in Figure 4.

Figure 4. Third studied slope (TLD-03).

The fourth slope (TLD-04) is located in the BR-381 highway in Betim. Betim is a city located in the metropolitan region of Belo Horizonte, capital of Minas Gerais. The outcrop has 138 meters in length and an average height of 10 meters. This slope was split in 10 sectors, for taking into account the different geomechanical behavior observed. The rock mass was classified as a gneiss. Figure 5 shows part of the studied slope.

Figure 5. Fourth studied slope (TLD-04).

The fifth slope (TLD-05) is located in São Bento neighborhood, Belo Horizonte city. The outcrop has 30 meter in length and a height of 15 meters. The rock mass was moderately weathered. Flexural toppling was identified along the slope. The rock mass was classified as a phyllite. Figure 6 shows the studied slope.

Figure 6. Fifth studied slope (TLD-04).

3.2 Geological and geotechnical data

The geological and geotechnical data were obtained as described in the methodology. Tables 1 shows the lithology and the five slope orientations. Table 2 shows the orientation of the discontinuities for the five studied slopes.

Table 1. Lithology and slope orientation for the five studied slopes.

Slope	Rock mass type	Slope orientation (Dip/Dip direction)
TLD-01	Quartzite	82/137
TLD-02	Schist	88/259
TLD-03	Schist	55/215
TLD-04	Gneiss	88/357
TLD-05	Phyllite	80/285

Table 2. Orientation of the discontinuities for the five studied slopes.

Slope	Discontinuities (Dip/Dip direction)		
	Family 1	Family 2	Family 3
TLD-01	22/324	62/221	59/159
TLD-02	37/195	46/139	49/042
TLD-03	68/267	82/204	47/198
TLD-04	83/100	21/077	75/177
TLD-05	76/318	29/285	88/222

Table 3 shows the characteristics of discontinuities for the five studied slopes. Average values for each evaluated parameter at the field were showed.

TLD-01 was split in sectors according to the difference found in the values of uniaxial compressive strength of the rock.

TLD-03 was split in sectors according to the weathering difference found between the two sectors.

TLD-04 was split in ten sectors according to the differences found in discontinuity spacings. The characteristics associated with the condition of discontinuities were the same in all sectors.

Table 3. Characteristics of the discontinuities for the five studied slopes.

Slope	Family	Persistence (m)	Aperture (mm)	Roughness	Filling (mm)	Weathering
TLD-01	1	20	1 to 5	Rough (planar)	soft gouge <5mm	Slightly weathered (all sector) Unweathered (sector 4)
	2	5	20 to 100	Rough (undulating)	None	Unweathered
	3	5	10 to 50	Rough (undulating)	soft gouge <5mm	Unweathered
TLD-02	1	15	< 0.1	Smooth undulating	soft gouge <5mm	Slightly weathered
	2	10	0.1 to 1	Slightly rough	soft gouge <5mm	Slightly weathered
	3	10	0.1 to 1	Slightly roughness	None	Slightly weathered
TLD-03	1	10	0.1 to 1	Slightly rough (undulating)	soft gouge <5mm	Highly weathered (sector 1) Slightly weathered (sector 2)
	2	10	0.1 to 1	Rough (undulating)	soft gouge <5mm	Highly weathered (sector 1) Slightly weathered (sector 2)
	3	20	< 0.1	Smooth (planar)	soft gouge <5mm	Highly weathered (sector 1) Slightly weathered (sector 2)
TLD-04	1	10	< 0.1	Smooth planar	None	Slightly weathered
	2	>20	0.1 to 1	Polished undulating	None	Slightly weathered
	3	10	< 0.1	Smooth	None	Slightly weathered
TLD-05	1	15	0.1 to 1	Smooth planar	None	Moderately weathered
	2	<1	< 0.1	Polished undulating	None	Moderately weathered
	3	<1	< 0.1	Rough	None	Moderately weathered

3.3 Strength tests in intact rock

Two types of strength tests were made to obtain the uniaxial compressive strength. In case of the Schmidt rebound tests, correlation equations were used to obtain the uniaxial compressive strength, according to the lithology. The results obtained for the uniaxial compressive strength in each sector of the five studied slopes were showed in Table 4.

Table 4. Uniaxial compressive strength of intact rocks.

Slope	Sector	σ_c (MPa) Geological hammer test	σ_c (MPa) Schmidt rebound test
TLD-01	1	50 to 100	-
	2	100 to 250	
	3	50 to 100	
	4	100 to 250	
	5	100 to 250	
TLD-02	-	25 to 50	27
TLD-03	1	1 to 5	24.88
	2	5 to 25	33.92
TLD-04	All sectors	100 a 250	170
TLD-05	-	5 a 25	14

3.4 Application of the Rock Mass Index

Rock masses were classified according to Rock Mass Index. The discontinuity in the worst condition was used to obtain the RMi and to describe the quality of the studied rock masses. This decision was taken in order to made a conservative analysis. The values of the parameter used to calculate the joint condition factor, jC, are shown in Table 5. The equation (3) was used to calculate jC.

Table 6 shows the values of JP, Vb and σc used for calculation of the Rock Mass Index. Values of JP and Vb were calculated based on the equations (2) and (4).

The results obtained for RMi through the equation (1) are shown in Table 7. An advantage of RMi is the fact that it has a clear physical meaning, as it represents the compressive strength of the rock mass.

Table 5. Values of the parameter used to calculate the joint condition factor (jC).

Slope	Sector	jL	jR	jA	jC
TLD-01	1	0,75	2	2	0,75
	2	0,75	2	2	0,75
	3	0,75	2	2	0,75
	4	0,75	2	1	1,5
	5	0,75	2	2	0,75
TLD-02	-	0,75	2	3	0,5
TLD-03	1	0,75	2	0,75	0,38
	2	0,75	2	0,75	0,38
TLD-04	1	0,75	1,25	1	0,94
	2	0,75	1,25	1	0,94
	3	0,75	1,25	1	0,94
	4	0,75	1,25	1	0,94
	5	0,75	1,25	1	0,94
	6	0,75	1,25	1	0,94
	7	0,75	1,25	1	0,94
	8	0,75	1,25	1	0,94
	9	0,75	1,25	1	0,94
	10	0,75	1,25	1	0,94
TLD-05	-	0,75	1	3	0,25

Table 6. Determination of the parameters JP, Vb and σ_c of the studied slopes.

Slope	Sector	V_b (m^3)	JP	σ_c (MPa)
TLD-01	1	0,26	0,13	90
	2	0,26	0,15	120
	3	0,29	0,14	90
	4	1,33	0,26	150
	5	0,54	0,15	120
TLD-02	-	0,16	0,14	27
TLD-03	1	0,0024	0,032	2,5
	2	0,26	0,091	10
TLD-04	1	1,35	0,22	170
	2	1,67	0,24	170
	3	0,13	0,089	170
	4	0,45	0,14	170
	5	0,045	0,06	170
	6	0,17	0,098	170
	7	0,16	0,096	170
	8	0,0024	0,02	170
	9	0,081	0,076	170
	10	0,13	0,09	170
TLD-05	-	0,0073	0,009	14

Table 7. Determination of the RMi of the studied slopes

Slope	RMi (MPa)	Description of rock mass
TLD-01	11,7	Extremely strong
	18	Extremely strong
	12,6	Extremely strong
	39	Extremely strong
	18	Extremely strong
TLD-02	3,8	Strong
TLD-03	0,08	Weak
	0,91	Moderate
TLD-04	36,9	Extremely strong
	40	Extremely strong
	15,1	Extremely strong
	24,5	Extremely strong
	10,2	Extremely strong
	16,8	Extremely strong
	16,4	Extremely strong
	3,4	Strong
	12,9	Extremely strong
	15,3	Extremely strong
TLD-05	0,13	Moderate

4 DISCUSSION

The degree of weathering is a huge obstacle in the geotechnical survey. Visibility of discontinuities is hampered by weathering; it happened during field survey in the sector 1 of the TLD-03 and TLD-05 slopes. In the TLD-01 and TLD-04 geological structures are more clearly defined, facilitating the data acquisition. Therefore, it can be observed the use of Schmidt hammer should be avoided in soft rocks.

Geologist hammer test proved to be a simple and effective method for estimating the uniaxial compressive strength of the rocks.

Although the RMi is not a geomechanical classification system widely used, it is reliable, once description of discontinuity parameters permits an objective evaluation of them. Another advantage of RMi is the fact that it has a clear physical meaning, as it represents the compressive strength of the rock mass. It could be seen that the compressive strength of the rock mass of sector 1, TLD-03, is many times smaller compared to the other studied rock masses, except the TLD-05. In case of sector 2, TLD-03, the difference in strength compared to TLD-02 and TLD-03 is clear. Moreover, the compressive strength of the quartzite and the gneiss in TLD-01 and TLD-04, respectively, is higher than the schists in other slopes.

The RMi index proved to be a classification system that offers best practice field guidelines to obtain the parameters compared to RMR and Q-system. Therefore, the system is less subjective and more quantitative than others classification systems. The jL, jA, jR, Vb and σc were taken easily, without doubts. Another advantage of the RMi is that exists correlation equations with Hoek and Brown parameters and Young's modulus.

CONCLUSION

The geomechanical classification system proposed by Palmström (1995) offers best practice field guidelines for obtaining the parameters needed in most of the classifications. This is a great advantage because it reduces the uncertainties arising from the geotechnical survey. Furthermore, the method does not use the Rock Quality Designation (RQD), which it is an index that is highly dependent of the direction of the discontinuity surveys.

The studied rock masses were classified according to the RMi as follows: the gneiss was divided into ten sectors, it had an average value of 19.2 MPa and was classified as very strong; the quartzite was divided into five sectors, it had average of 19.8 MPa and was also classified as very strong; the first surveyed schist was not sectored, it had a value of 3.8 MPa and was classified as strong; the second schist showed two very distinct sectors, with values of 0.008 MPa and 0.9 MPa and was classified as very weak and moderately strong; the phyllite was not sectored, it had a value of 0.13 MPa and was classified as moderately strong.

Rock Mass Index proved to be a geomechanical classification more quantitative and reliable, once description of discontinuity parameters permits an objective evaluation of them.

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