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JRC estimation with 3D laser scanner images – SBMR 2016

Vitor Patricio Cantarella
University of Sao Paulo, Brazil, vcantarella@gmail.com
Joao Paulo Monticeli
University of Sao Paulo, Brazil, joao.monticeli@usp.br
Pedro Pazzotto Cacciari
University of Sao Paulo, Brazil, ppazzoto@gmail.com
Marcos Massao Futai
University of Sao Paulo, Brazil, futai@usp.br

SUMMARY: Roughness characterization and JRC estimation have been made on rock joints of the Monte Seco tunnel. The authors have adapted field profiling of discontinuity surfaces to be able to estimate JRC using 3D laser scanner images. Results indicate similarity between traditional and laser scanning methods. The data also confirms the JRC size effect and the importance of evaluating field scale roughness.

KEYWORDS: JRC, laser scanner, roughness profiling, shear strength of joints.

1 INTRODUCTION

The 905 km long Vitória–Minas Railway contains 44 tunnels. The majority of these tunnels are constructed in rock mass without any lining. In recent years, some tunnels have been presenting sporadic block falls, which have not represented generalized risk. The TUNELCON Project, partnership between Vale Company and Escola Politécnica da Universidade de São Paulo – EPUSP, seeks to study the geomechanical behaviour of these tunnels by the laboratory test, geological geotechnical mapping and numerical analyses.

The Monte Seco tunnel is located near to the cities of João Neiva and Ibiraçu in the state of Espírito Santo, where in the recent years, the block fall mechanism has been studied in detail (Cacciari et al., 2016; Cacciari, 2014).

One of the methodologies applied was the use of terrestrial laser scanner to map and characterize discontinuity properties of the rock mass. Since, the tunnel is in a heavily trafficked railway and detailed conventional mapping is impractical, 3D terrestrial laser scanner (3DTLS) appeared to be a practical alternative.

This paper review the mapping procedure with laser scanner and introduce the application of roughness characterization in 3D images to derive JRC values.

2 GEOLOGICAL BACKGROUND

The rock mass where the tunnel is situated lies inside the Aracuai orogen, formed during the Neoproterozoic collage of the Gondwana. The rock is described as a paragneiss, rich in biotite and cordierite, banded and foliated with pegmatictic portions rich in potassic feldspar. Structurally four discontinuity sets were identified (Figure 01).

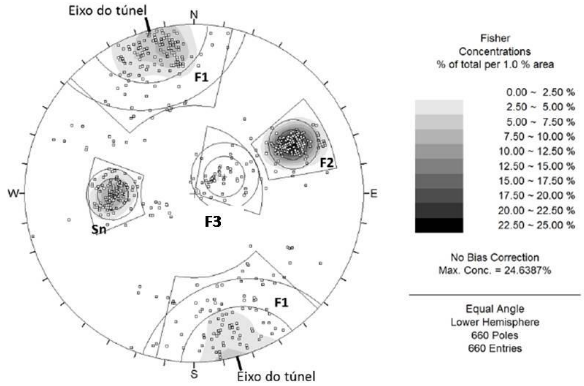

Figure 1. Structural distribution of fracture sets (Cacciari et al. 2014).

Collection and interpretation of structural data along with correlation with the regional lineaments allowed to interpret the tectonic nature of F1 and F2 fracture sets. F2 is a clear shear fracture with strike parallel to main lineaments and faults formed during the Cenozoic taphrogeneis. F1 seems to be a hybrid mode fracture formed with F2. F3 is interpreted as a sheet joint while Sn is the rock's foliation.

3 JOINT ROUHNESS COEFFICIENT

Joint roughness has been a major topic in the Rock Mechanics over the past four decades due to the fact that it influences the shear strength of rock joints and provokes dilation during shearing. Along these studies, Barton (1976) has derived an empirical criterion to describe shear strength considering the joint roughness effect. The formulation made by these authors remains one of the most used methods to model shear strengths of rock joints

The criteria can be generalized by the following expression (Barton,1976):

$$\tau = \sigma_n \tan\left[\mathrm{JRC}\log\left(\frac{\mathrm{JCS}}{\sigma_n}\right) + \phi r\right] \quad (1)$$

In which τ is the shear strength, σ_n is the effective normal stress, JRC is the joint roughness coefficient, JCS is the joint strength coefficient and ϕr is the residual friction angle

JRC can be determined from several different methods. Originally, Barton and Choubey (1977) have proposed 10 standard 10 cm profiles in which JRC can be evaluated by visual comparison.

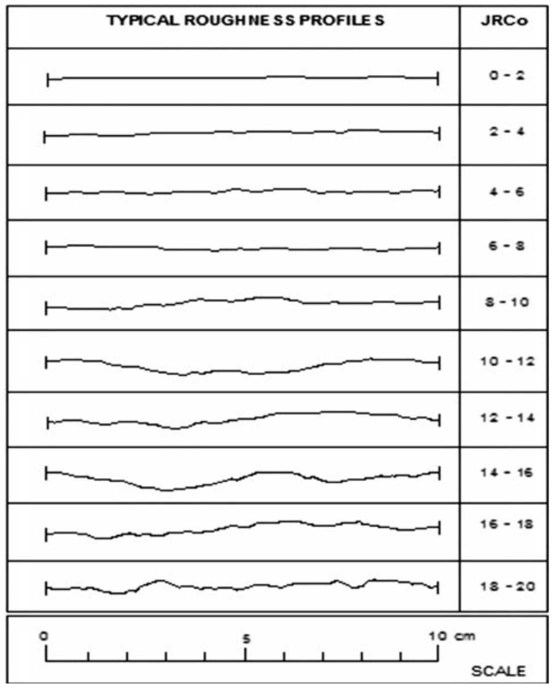

Fig 02. Ten standard profiles. After Barton and Choubey (1977).

However, Barton (1981) does states JRC is more reliable when it is back-calculated from tilt-tests on joint samples:

$$\mathrm{JRC} = \frac{\alpha - \phi r}{\log\left(\frac{JCS}{\sigma_n}\right)} \quad (2)$$

Where α is the angle where sliding occurs.

Bandis et al. (1981) have investigated JRC and revealed the scale dependency involved with this parameter. To treat the scale-effect from laboratory 10 cm profiles to field scale length, Bandis et al. (1981) proposed the following correction:

$$JRCn = JRC_0 \left(\frac{Ln}{Lo} \right)^{-0.02*JRC_0} \quad (3)$$

Where:

- JRC_0: Joint roughness coefficient – lab. scale
- JRC_n: Joint roughness coefficient – in situ scale
- Ln: Field scale length (in situ)
- Lo: Length laboratory.

Barton (1981 and 2013) has also investigated the scale dependency associated with JRC and has stated that the formula from Bandis does not always produce good results to derive in situ JRC_n due to the fact that often rough joints are planar when visualized in large scale, while smooth joints might also be highly undulated. Therefore, he proposed a methodology to improve reliability in JRC determination:

-Evaluate JRC using the standard profiles and tilt-tests in small samples and drill-cores and correcting the size-effect using Bandis formulation.

-Perfoming Tilt-tests and pull-tests in in situ block sizes and back calculating JRC directly.

-Surface profiling real sized joints using a straight edge and offset method (Figure 3). Maximum amplitudes and profile length from 1 m and above can be computed and JRC estimated through a chart (Figure 4)

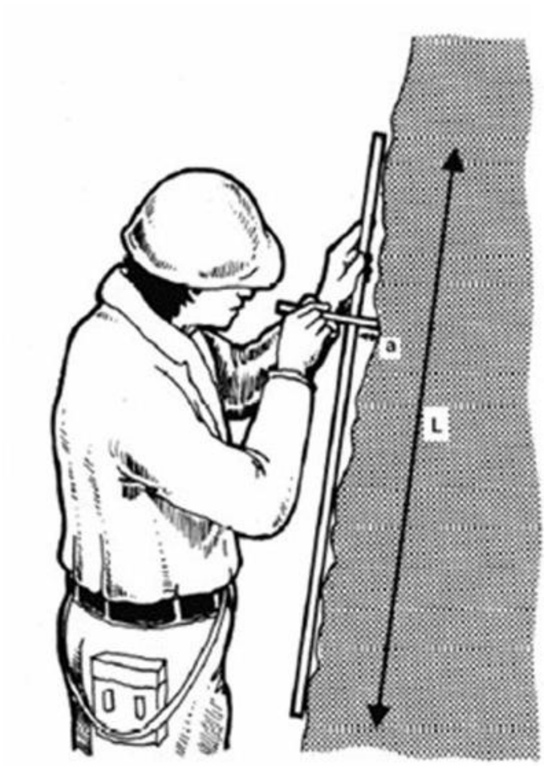

Figure 03. Surface profiling methodology. From Milne et a. (1991)

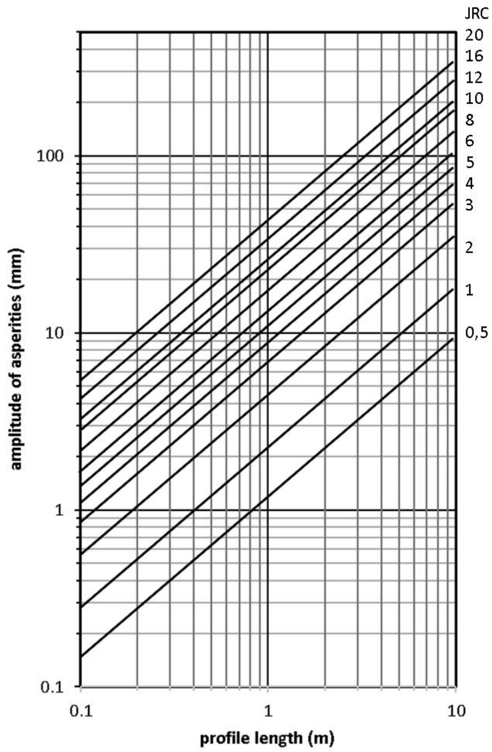

Figure 04. Chart for determining JRC from surface profiling Barton (1981).

4 DISCONTINUITY MAPPING THORUGH 3DTLS IMAGE

The tunnel was surveyed with a terrestrial laser scanner. The scanner used was the Faro Focus 3D (Faro technologies Inc.) which operates with the LIDAR technology, consisting basically in the emission and subsequent capture of response of electromagnetic waves. The result is a highly detailed point cloud of the tunnel wall surface, with points represented by a position (x,y,z) value and an intensity measure (Figure 05).

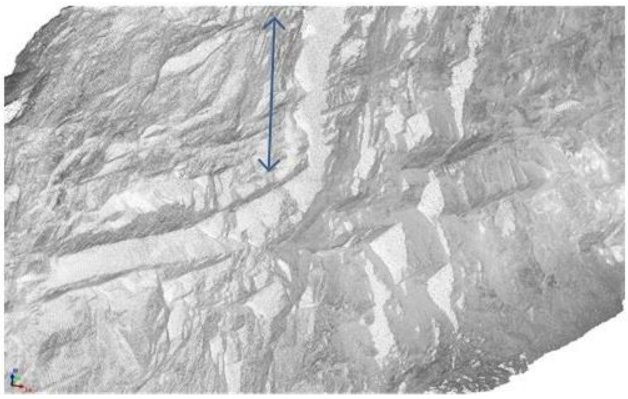

Figure 05. Tunnel point cloud. The blue bar represents 1.5 m.

From the 3DTLS point cloud, structures can be identified through visual interpretation of the discontinuities. The different discontinuities can then be mapped, assigning a trace length and a representative plane to every visible discontinuity (Figure 06).

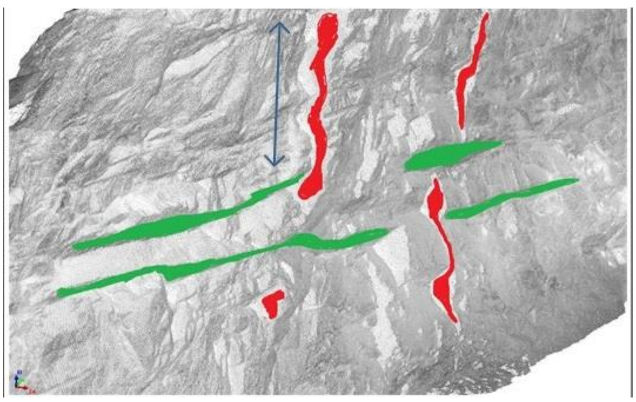

Figure 06. Discontinuity mapping. F1 fractures assigned in red and F2 fractures assigned in green. The blue bar represents 1.5 m.

From position data, along with trace length and dip/dip direction, several useful parameters for fracture characterization can be quantified, including RQD, fracture spacing, intensity, and orientation distribution (Cacciari and Futai., 2016).

5 ROUGHNESS CHARACTERIZATION WITH 3DTLS

The method applied here was to extract the discontinuity surface from the 3DTLS image (Figure 07), generate a 3D surface model from the extracted points and then evaluate the deviation of the surface from a best-fit (mean) plane. This procedure allows estimating the roughness amplitude, as shown in Figure 08.

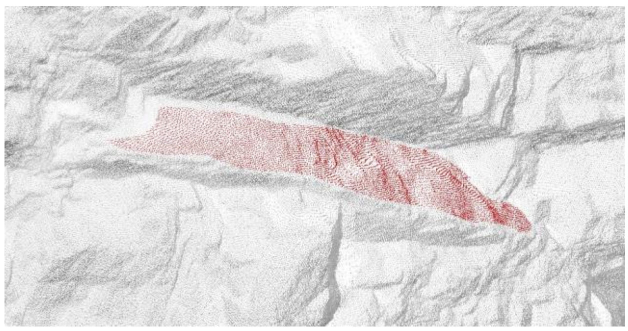

Figure 07. Selection and extraction of discontinuity plane. Fracture length in the horizontal direction is 1.5 m.

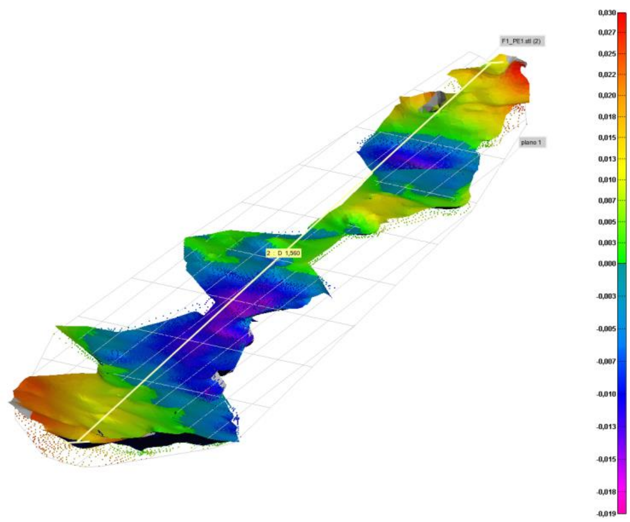

Figure 08. Roughness amplitude map of a discontinuity, units in meters. Yellow line is showing the profile length, 1.56m.

The amplitudes derived from this method have to be evaluated critically, since they are obtained from deviations of an average plane and not from a straight line on the edge of the surface. In Figure 08 for example, the borders should be excluded since its high amplitudes might not be from the joint surface, but from the intact rock (rock bridges) itself. The amplitude of asperities and the profile length can then be computed and plotted in the chart of Figure 04, to emulate a surface profiling campaign in the field.

Another simple but useful way to emulate the length profiling method is, extracting a section from the discontinuity 3D model (Figure 07), and drawing a line passing between the two extremities of the section, as to mimic the straight edge used on the field. Then the amplitude is measured as the distance between the projected line and the section (Figure 09). The advantage of the latter method is the possibility of sampling the joint for different profile lengths, which could be useful for considering different block sizes, the size-dependency related with JRC and a possible anisotropy.

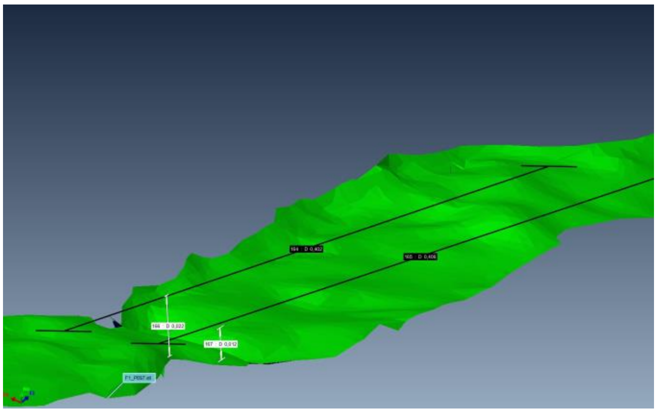

Figure 09. section extraction from joint surface model (black lines) and roughness amplitude measurement (white lines). Black lines have 0.4 m.

6. ROUGHNESS OF MONTE SECO TUNNEL JOINTS

Joint samples obtained from drilling cores have previously been treated with profilometer and JRC evaluated using the standard profiles (Figure 02). After that, values were corrected to in situ scale size using the formulation in Eq. 03. The results are presented in Table 01.

Table 01. Results for JRCo from profilometer and JRCn from Bandis correction (Barrios 2014).

			JRC_0 (profilometer)	Average Value	Variance	Standard Deviation
Shear fractures	**F1**	R16	10	9.83	6.17	2.48
		R34	8			
		R36	11			
	F2	R15	7			
		R17	9			
		R21	14			
Foliation	Sn	R5	4	10.13	22.13	4.70
		R10	15			
		R12	6			
		R13	6			
		R19	15			
		R20	16			
		R22	10			
		R37	9			
Sheet joints	F3	R23	12	14.00	8.00	2.83
		R25	16			
All values				11	14.80	3.85

		L_o (cm)	L_n (cm)	**JRC_n (Bandis et al - 1981)**	Average Value	Variance	Standard Deviation
Shear fractures	**F1**	**10**	94	6.39	5.77	0.34	0.58
		7	94	5.28			
		7	94	6.21			
	F2	**12**	155	4.89			
		13	155	5.76			
		8	155	6.11			
Foliation	Sn	**8**	173	3.13	4.94	1.28	1.13
		11	173	6.56			
		6	173	4.01			
		7	173	4.05			
		6	173	5.47			
		8	173	5.86			
		8	173	5.41			
		7	173	5.05			
Sheet joints	F3	**5**	161	5.22	5.16	0.02	0.15
		6	161	5.43			
All values					5.15	0.87	0.93

The values obtained for JRC_0 reveal a high roughness for all fracture types, when corrected the JRC_n values become much smaller and variance diminishes.

Good exposures of fracture planes allowed to carry more detailed analysis regarding roughness characterization. 39 well-exposed planes were selected from the 3DTLS image to analyze roughness using the method in Figure 08.

Average values obtained for JRC from virtual profiling were very similar (4 to 6) to the Bandis corrected JRC values from profilometer (Figure 08 and Table 01).

Although the averages are similar, the surface profiling revealed large scatter (Figure 10), registered in profilometer analysis, and masked by Bandis correction (Table 01).

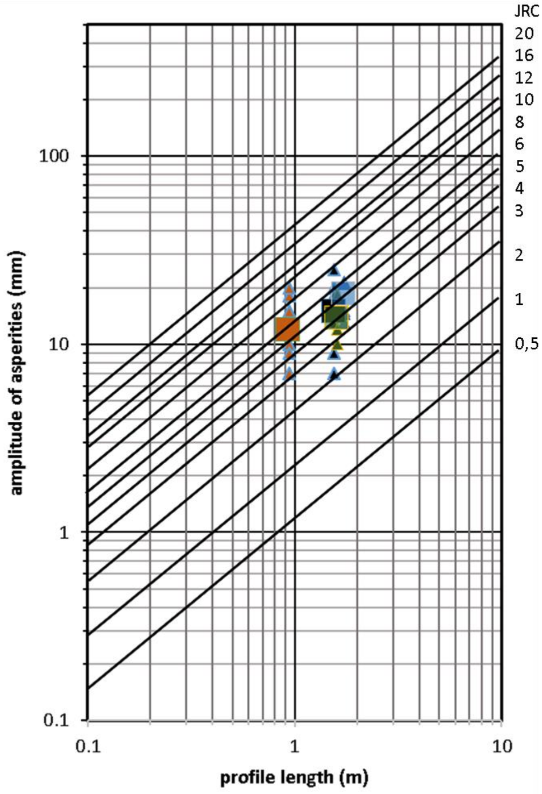

Figure 09. JRC values plotted on Barton's chart for virtual surface profiling. .F1:orange triangles, F2: black triangles, F3:green tringles, Sn: blue triangles. Average values displayed in squares, with the same colors.

6.1. Roughness estimation for the highly fractured region.

An 8m-long region of the tunnel has brought special attention due to mapping revealing high fracture density and small blocks. The region thus behaves differently from the rest of the tunnel and must be treated separately.

Assuming an average plane orientation (dip/dip direction), average spacing and persistent discontinuity planes a block model was idealized (Figure 10). From this model, the block lengths in each fracture set were estimated (0.35 m in F2, 0.5 m in Sn and 0.4 m in F1). Although the fractures are considered persistent, the short spacing between them are responsible for the formation of small blocks. Thus, profiling the whole joint surface (as in the previous method), is not representative for the field scale.

Therefore, a second virtual surface profiling campaign was employed to characterize JRC with respect to block length.

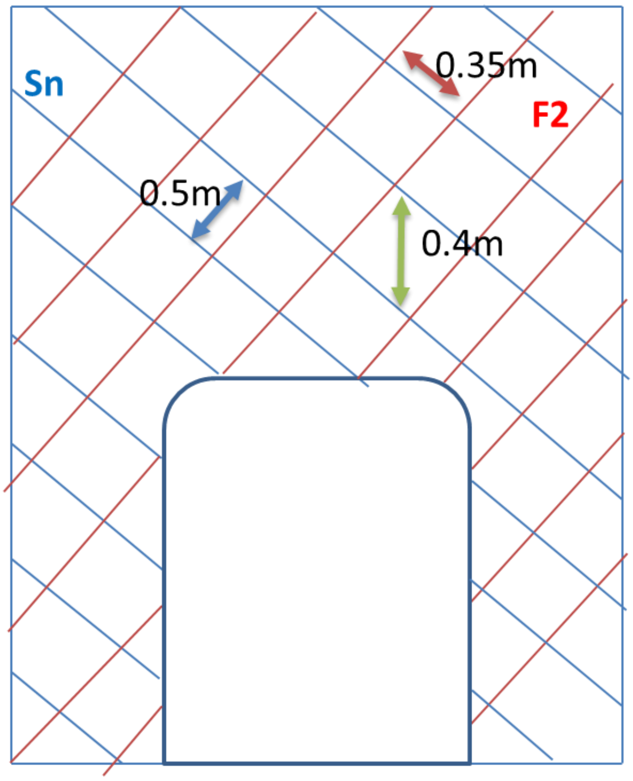

Figure 10. Block model for the highly fractured section of the tunnel. Sn in blue, F2 in red. F1 is perpendicular to tunnel axis and therefore is not visible, F3 is absent in this section.

In this analysis, sections of about the block size where extracted and analyzed individually for each fracture set (as in Figure 09). Values of block length and amplitude of asperities were plotted on Barton's chart and JRC values were computed (Figure 11).

In general, is possible to affirm that these smaller blocks have higher JRC, which is consistent with Bandis model. However, values derived from profiling have significant higher values than compared with JRCo and Bandis corrected values for F1 and F2 (Figure 12). This could be due to the fact that few samples were available (3 for each) for F1 and F2 profilometer analysis, or to the fact that the survey profiling focused a restricted region in

which the average roughness could differ from the average from the rock mass. For Sn fractures, values obtained seem to roughly correlate with Bandis correction (Figure 12).
Values obtained with scanner also revealed high variability as seen in profiling full fracture lengths (Figures 11 and 9).
A summary for the average JRC values can be seen in Figure 12. Virtual profiling correlated very well with Bandis corrected values for profile length. All values also seem to follow the size-dependency model predicted by Bandis and JRC reduces with larger length of profile.

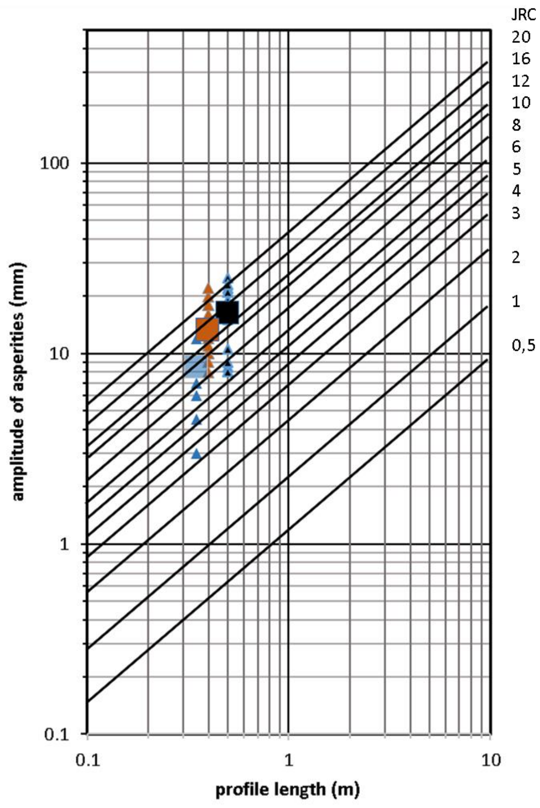

Figure 11. Figure 09. JRC values plotted on Barton's chart for profiling in the highly fractured region. .F1:orange triangles, F2: black triangles, Sn: blue triangles. Average values displayed in squares, with the same colors.

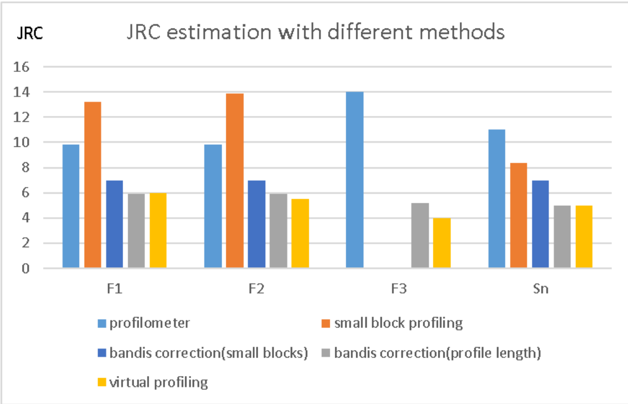

Figure 12. Average JRC for each fracture set and analysis.

7. CONCLUSION AND FUTURE ADVANCES

Virtual surface profiling using laser scanner images is a useful substitute to field profiling and should be considered as a valid alternative whenever field surveying is restricted.
The Monte Seco rock mass contains slightly undulating joints with average JRCn varying from 4 to 6.
Future developments should focus on the use of the whole point cloud of fracture surfaces and application of quantitative methods already described in the literature. Focus should also be turned towards automatization of processes.

REFERENCES

Bandis, S. C., Lumsden, A. C., & Barton, N. R. (1981). *Experimental studies of scale effects on the shear behavior of rock joints*. International Journal of Rock Mechanics and Mining Sciences &Geomechanics. Abstracts, vol. 18, pp. 1-21.

Barrios, B. N. Q., (2014). *Caracterização da. Rugosidade*. Relatório de Iniciação Científica – Escola Politécnica da Universidade de São Paulo (EPUSP). Departamento de Engenharia de Estruturas e Geotécnica. São Paulo, p. 33, 2014.

Barton, N. (1982). *Shear Strength Investigations for Surface Mining*, Ch. 7, 3rd Int. Conf. Surface Mining, Vancouver, SME 1982, pp. 171-196.

Barton, N. (2013). Shear strength criteria for rock, rock joints, rockfill and rock masses: Problems and some solutions. *Journal of Rock Mechanics and Geotechnical Engineering*, *5*(4), 249-261.

Barton, N. and Choubey, V. D. (1977). *The Shear Strength of Rock Joints in Theory and Practice*. Rock Mech., vol. 10, n°. 1, pp. 1-54.

Cacciari, P.P (2014). *Estudo de um túnel em maciço rochoso fraturado por investigação geológico-geotécnica e análises pelo método dos elementos distintos.* Dissertação de Mestrado – Escola Politécnica da Universidade de São Paulo. Departamento de Engenharia de Estruturas e Geotécnica. São Paulo. 180p.

Cacciari, P.P.; Futai, M.M. (2016) Mapping and characterization of rock discontinuities in a tunnel using 3D terrestrial laser scanning. *Bull Eng Geol Environ*, Vol. 75, p. 223–237.

Milne D, Germain P, Potvin Y (1992) Measurement of rock mass properties for mine design. In: Hudson JA (ed) Proceedings of the ISRM symposium on rock characterization: Eurock ‘92, Chester, England, 1992. Thomas Telford, London, pp 245–250.