Corrected Rock Fracture Parameters Applied to Qatari Rock Masses

Hrvoje Vučemilović

January 30, 2023

Corrected rock fracture parameters applied to Qatari rock masses
Paper ID: XX-XX

Hrvoje Vučemilović
hvucemilovic@gfos.hr
University of Osijek, Faculty of Civil Engineering and Architecture
Osijek, Croatia

ABSTRACT

This paper is the continuation of the author's previous publications and an attempt to shed light on some of therein presented propositions. In his previous work, author introduced a novel parameter for borehole rock mass evaluation, the FI_C, (Fracture Index Corrected) and applied it to Qatari rock masses along with RQD_C (Rock Quality Designation Corrected). This was the first case of such wide scale application of these borehole evaluation parameters. A short history is given on alternative proposals by several authors for improvements and amendments of *RQD* (Rock Quality Designation) since its proposal in 1963, with their authors' commentaries. Scale considerations are presented for both parameters which are essential consideration factor for any borehole parameter. The paper is concluded with remarks on assumed advantages and limitations of the two parameters and their future research and usage prospects. Paper is concluded with statements that Qatari rock masses are unique type of rock mass which has not been sufficiently researched or classified by the leading world scientists in this field.

Keywords: Qatar, Rock masses, Rock mechanics, Corrected Rock Quality Designation, Corrected Fracture Index

1 INTRODUCTION

In this paper, the author has utilized the same data set which was used by Vučemilović et al. (2021) [1], which consisted of exploration data from 201 boreholes spread over the southern regions and suburbs of the city of Doha. An analysis of relationship between *RQD* and λ (fracture frequency equivalent to *FI* – Fracture Index, or *FF* – fracture frequency) parameters shows how Qatari rock masses cannot be compared with a database of world-wide rock masses e.g. from Russo and Hormazabal 2019 [2].

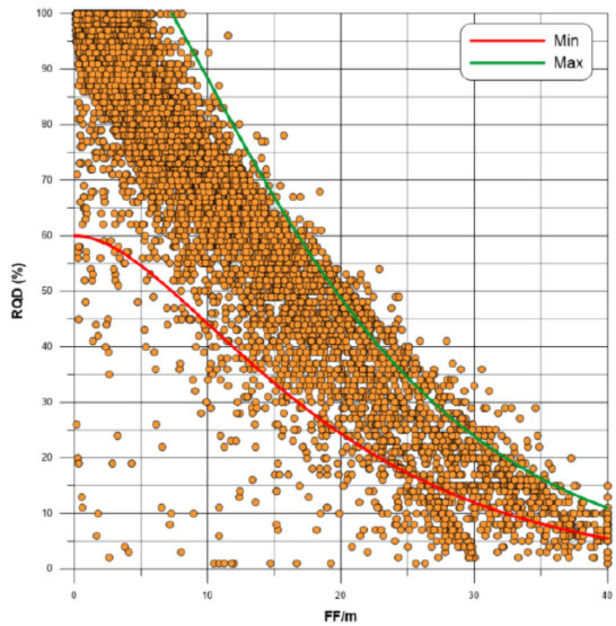

Figure 1: Relation between *RQD* and mean fracture frequency λ (*FF* – Fracture Frequency) according to Russo and Hormazabal 2019 [2]

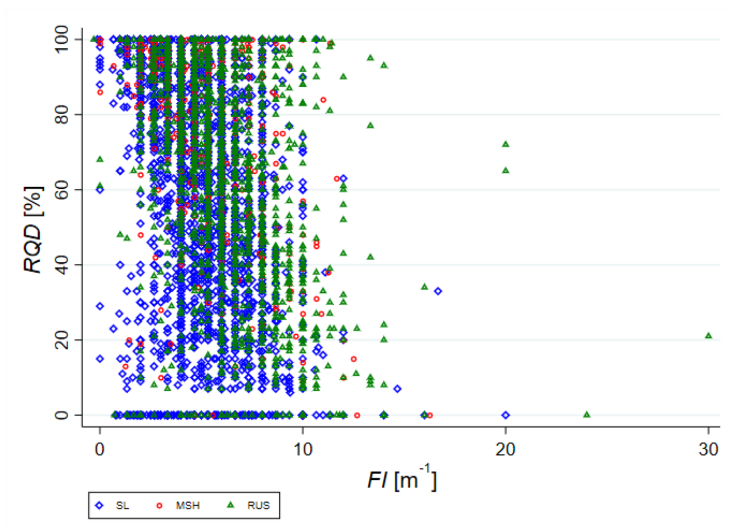

Figure 2: Relation between *RQD* and frequency λ (*FI*) for Qatari rock masses

The theoretical relationship between *RQD* and λ is loosely linear and has been established by Priest and Hudson (1976) [3] as one where *RQD* tends to decrease with the increase of λ in a more or less a narrow band diagonally. This was confirmed by Russo and Hormazabal (2019) [2] who have collected over 30,000 data points from varied rock mases (figure 1). This is not the case, however, for elaborated Qatari rock masses, which display a different trend in figure 2, where the dependence is also in a (wider) band but vertically down across entire span of *RQD* values. The graph is differentiated for SL (Simsima limestone), MSH (Midra shale) and RUS (Rus formation) geological members. It can be observed that RUS member assumes minimal *RQD* values to a lesser extent than

SL member, which is likely owed to the fact that SL layer Weathered Simsima is the most fractured of all layers from all three geological members. Data points for MSH member do not allow any similar conclusions.

Section 2 provides definitions in connection with *RQD*, λ (*FF*, *FI*), RQD_C and FI_C parameters relevant to this paper. Section 3 gives a review from the existing literature of some proposals on alternative parameters, improvements, and amendments of *RQD*, as it was originally proposed by Deere (1963) [4] and Deere and Deere (1988) [5], and includes their authors' commentaries on the prospects of their usage. At the end of this section, the most suitable parameter for Qatari rock masses is discussed and chosen. In section 4, scale considerations for both parameters are discussed in detail with conclusions on the applicability of scanning length adjustments of subject parameters for Qatari rock masses, given the maximum core box length utilized in Qatar. The Conclusions section, similarly, discusses the Author's stance on the advantages and limitations of the new parameters and presumed prospects for their further research and usage, and ends with a general commentary on uniqueness of Qatari rock masses in wider terms.

2 DEFINITIONS

RQD is a rock evaluation parameter introduced by Deere (1963) [4] as a parameter of estimation using exploratory boreholes. It is defined as sum of all solid core pieces, which are at least 10 cm long in a core run, divided by the total length of the core run. The equation by Hudson and Harrison (2000) [6] addresses the theoretical relationship between the theoretical *RQD* (*RQD**), fracture frequency λ, and length of the threshold t, which is assumed to have an arbitrary value.

$$RQD^* = 100(t\lambda + 1)e^{-t\lambda} \tag{1}$$

Fracture frequency λ is number of discontinuities in a core run divided by its total length, that is, number of discontinuities per meter of core run.

Li et al. (2009) [7] have proposed a corrected *RQD* parameter, or RQD_C which is expressed by a formula:

$$RQD_C = \frac{p_r}{N^a} \tag{2}$$

where p_r is percentage of core recovery, or *SCR* (Solid Core Recovery), and N is the number of unbroken core pieces in a core run and a is the exponent of a power law function.

Author's proposed corrected *FI* parameter (FI_C) can be defined as (Vučemilović et al. (2021) [1]):

$$FI_C = \frac{100(N-1)}{p_r L} \tag{3}$$

where p_r is the percentage of recovery, or *SCR* (0–100), N is the number of cores in a core run, and L is the length of a core run.

3 SOME ALTERNATIVE BOREHOLE FRACTURING PARAMETER PROPOSALS

Azimian (2015) [8] has proposed an improved *RQD* parameter (*RQDI*), which takes into account joint angles and orientations from the *WJD* (Weighted Joint Density) method developed by Haftani et al. (2015) [9] but also considers fractured zones, crushed zones, and void zones (referred to as vuggy or karstic zones). The proposal is presented with the formula

$$RQD_I = 100 - \left[100 \frac{f_i + CW + Fr + Cr + K}{L_t} \right] \tag{4}$$

where, f_i is the value from Haftani et al. (2015) [9], *CW* is the length of the void, or *K* washed core segment, *Fr* is the length of the fragmented core segment (with spacing of 15 – 50 mm), *Cr* is the length of the crushed core segment (with spacing < 15 mm). L_t is total core run length.

Araghi et al. (2006) [10] proposed the modified *RQD* parameter, *MRQD*. This parameter is obtained by subtracting the weak zone parameter *WZ* from the value 100.

$$MRQD = 100 - WZ \tag{5}$$

$$WZ = \frac{1.5nd + CW + Fr + Cr + VZ + C}{L_t} \tag{6}$$

Where *nd* is the number of discontinuities, *CW* is washed core portion length, *Fr* is fragmented core portion length, *Cr* is crushed core portion length, *VZ* is vuggy core portion length, *C* is void core portion length, and L_t is total core run length. The method is very similar to the one introduced by Azimian (2015) [8] but it does not include the joint orientation parameter f_i.

Ahmed (2013) [11] proposed a modified *RQD*, which is similar to that of RQD_C, designated as *RQDm.* He suggested that the logging session includes the core pieces lesser than 10 cm and lesser than 5 cm, along with those larger than 10 cm.

$$RQDm = \frac{\sum pu}{N^f} \tag{7}$$

$$\sum pu = pu1 + pu2 + pu3 \tag{8}$$

$$f = f1 \times f2 \times f3 \tag{9}$$

where $f1 = 1.003pu1$, $f2 = 1.001pu2$ and $f3 = 0.99005pu3$
and where
$pu1$ - percentage of core pieces less than 5 cm
$pu2$ - percentage of core pieces 5 – 10 cm
$pu3$ - percentage of core pieces > 10 cm
N – number of cores
f – exponent of the power function

The next question raised is; which *RQD* modification is best suited for the rock masses at hand? The author has concluded that the most suitable parameter for estimation of the subject rock masses is the *RQD* corrected, RQD_C, which was proposed by Li et al. (2009) [7].

1. The parameter is simple and does not have a very detailed decomposition of types, length wise, of core run segments;

2. Its starting point is p_r, percentage of recovery, or *SCR*, as opposed the maximum value of 100 (as proposed for *RQDI* and *MRQD*), which is considered a bias;
3. Unlike *RQDm*, the RQD_C does not have a fixated exponent value, which proves to be very useful since it lends adjustability.

4 SCALE CONSIDERATIONS FOR RQD_C AND FI_C

If we consider the data at hand from the Qatari rock masses, we must note the following:

1. RQD_C and FI_C values were calculated, for great majority of data, with 1.5 m scanning interval.
2. It would be of interest to develop theoretical dependencies of RQD_C vs FI_C, such as for 1.0 metre scanning intervals.
3. Similarly, it would be of interest to present theoretical dependence of RQD_C vs FI_C for different lengths of scanning interval and how this dependence changes for different values of *SCR* parameter.

Figure 3 shows theoretical FI_C versus RQD_C for different values of solid core recovery (*SCR*, or p_r). All curves display a logarithmic relationship. The larger the *SCR*, the lower is the maximum reached FI_C value. The lesser *SCR*, the steeper is the increase of FI_C over smaller RQD_C spans, and this span gradually shifts toward ever lower RQD_C values.

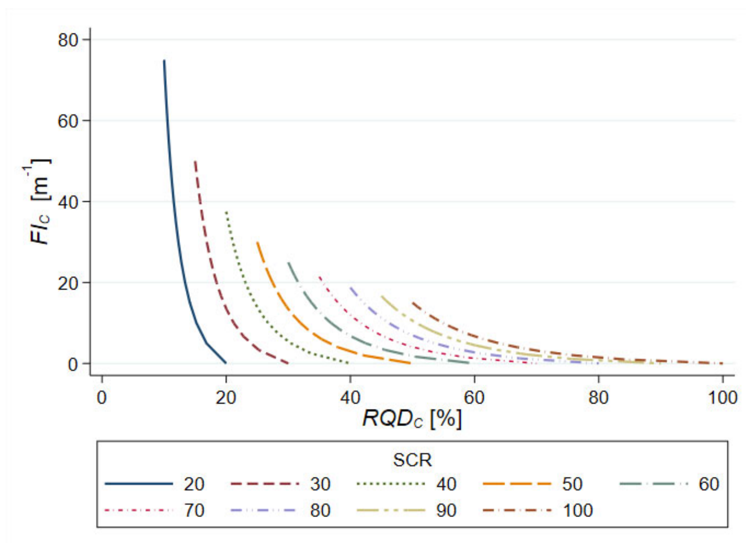

Figure 3: Theoretical variation of FI_C versus RQD_C, for different values of *SCR* and exponent *a* value (of RQD_C) of 0.25, and scanning interval of 1.0 m.

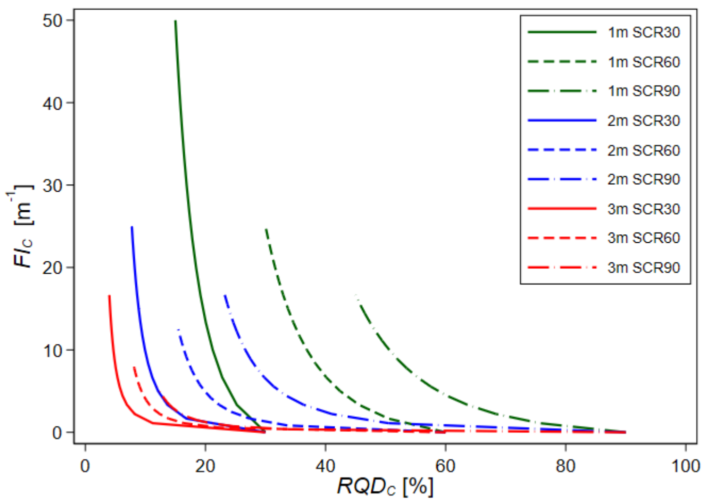

Figure 4: Theoretical variation of FI_C versus RQD_C, for different scanning intervals and values of SCR~~,~~ for exponent a value (of RQD_C) of 0.25.

In figure 4, the theoretical dependence of RQD_C vs FI_C is shown for three different scanning interval lengths including 1.0 m, 2.0 m, 3.0 m, and SCR values of 30, 60, and 90. We can see overall reduction of FI_C and RQD_C in magnitude and span with increased scanning interval, but within the same scanning interval, FI_C is decreasing and RQD_C is increasing with the increase of SCR. The latter is an identical tendency as in figure 3.

The graphs in figures 5 and 6 display the values of RQD_C and FI_C versus scanning intervals which were given to obtain the borehole core box data. The predominant interval is 1.5 m although it may not be readily visible from the graphs due to the point density. Table 1 shows the percentages of three most frequent scanning interval lengths, over the entire data sets for RQD_C and FI_C.

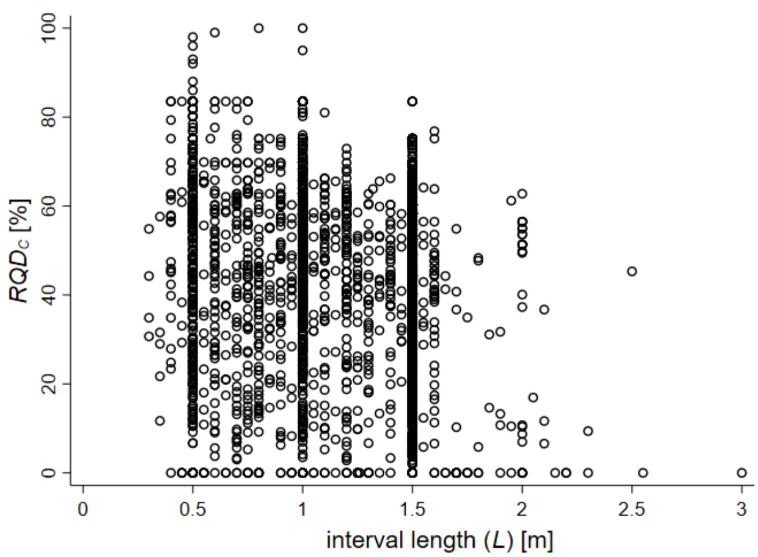

Figure 5: RQD_C values against scanning interval lengths

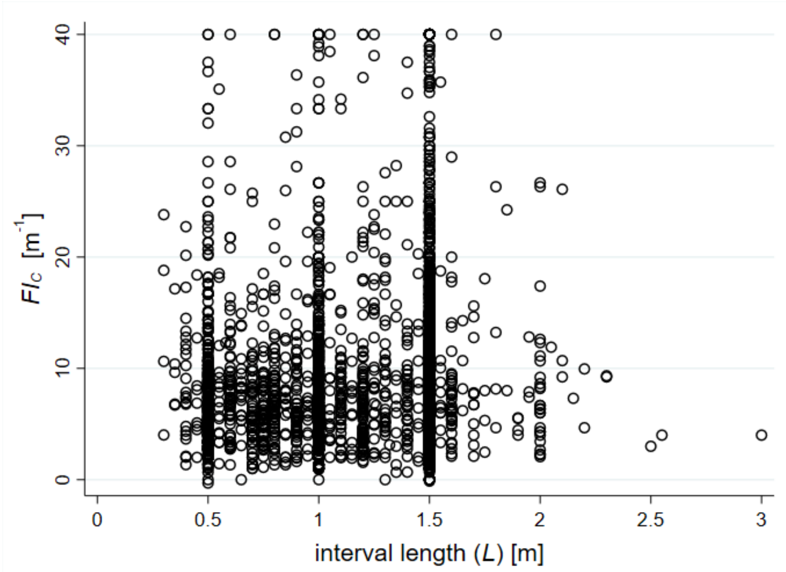

Figure 6: FI_C values against scanning interval lengths

Table 1: Proportions of different scanning intervals for RQD_C and FI_C

	***L* = 0.5 m**	***L* = 1.0 m**	***L* = 1.5 m**	***L* = other**
***RQD*$_C$ & *FI*$_C$**				
n	359	627	3314	1363
percentage	6.3 %	11.0 %	58.5 %	24.0 %

5 CONCLUSIONS

RQD is the most frequently used ubiquitous rock evaluation parameter, but obviously it does not work on all rock masses, e.g. on jointed shales as testified by Barton (2021 – personal correspondence). In this paper, a short review is presented on some propositions from the available literature on alternatives to standard *RQD* by previous authors, along with commentaries from authors which argue against the wide spread usage of their parameters. Author has used these previous proposals to come up with the comparative conclusion on which parameter could be suited for Qatari rock masses. A new corrected parameter was selected and investigated, the RQD_C together with author's proposed corrected fracturing index (FI_C). The RQD_C parameter applied to Qatari rock masses displays, as opposed to *RQD*, statistical soundness and accordingly possesses the potential for practical usage and further research. The advantage of using the corrected parameters is their greater sensitivity for detection of fractures (RQD_C and FI_C) and loose core portions (FI_C). Possible limitations of the FI_C parameter are that it can only be used for slightly and moderately weathered rock masses, otherwise it might not be useful for detecting weathered spots within fresher rock masses. Scale considerations were also taken into account for both parameters towards the end of this paper and, as expected, both parameters reduce with scale increase. However, these considerations are warranted only in locations, countries or areas which use core box lengths above 1.5 m, which is maximum length used in Qatar. Minor adjustments at smaller scanning lengths are considered not impactful. Conclusively, Qatari rock masses are a separate "stock" of rock masses not falling under any group of rock masses researched so far by the world's-leading scientists in the field, and as such they possess features worthy of a wider systematic research effort.

REFERENCES

[1] Vučemilović H, Mulabdić M & Miščević P (2021) Corrected Rock Fracture Parameters and Other Empirical Considerations for the Rock Mechanics of Rock Masses of Doha, Qatar. Geotech Geol Eng 39, 2823–2847 (2021). https://doi.org/10.1007/s10706-020-01658-y

[2] Russo A, Hormazabal E (2019) Correlations between various rock mass classification systems including Laubscher (MRMR), Barton (Q) and Hoek and Marinos (GSI) systems. Geotechnical Engineering in the XXI century1: lessons and future challenges, NP Lopez-Acosta et al. (Eds), © the Authors and IOS Press, CC BY-NC 4.0, https://doi.org/10.3233/STALI90347

[3] Priest S and Hudson J (1976) Discontinuity Spacings in Rock. Int. J. Rock Mech. & Min. Sci & Geomechanics Abstracts, 13 (5),1976, pp. 135-148

[4] Deere DU (1963) Technical description of rock cores for engineering purposes. Rock mechanics and engineering geology 1(1): 18. Vienna: Springer.

[5] Deere DU and Deere DW (1988). The Rock Quality Designation (RQD) Index in Practice. In: Rock Classification Systems for Engineering Purposes, Kirkaldie, L. (Ed.). American Society for Testing and Materials, Philadelphia, ISBN: 0-8031-0988-1, pp: 91-101.

[6] Hudson JA, Harrison JP (2000) Engineering Rock Mechanics. Amsterdam: Pergamon.

[7] Li L, Ouellet S, Aubertin M (2009) An improved definition of rock quality designation, RQDc. ROCKENG09: Proceedings of the 3rd CANUS Rock Mechanics Symposium, Toronto, May 2009 (Ed: M.Diederichs and G.Grasselli).

[8] Azimian A (2015) A New Method for Improving the RQD Determination of Rock Core in Borehole. Rock Mechanics and Rock Engineering · June 2015. Springer-Verlag Wien 2015. 10.1007/s00603-015-0789-8.

[9] Haftani M, Chehreh HA, Mehinrad A, Binazadeh K (2015) Practical Investigations on Use of Weighted Joint Density to Decrease the Limitations of RQD Measurements. Rock Mechanics and Rock Engineering, June 2015. 10.1007/s00603-015-0788-9

[10] Araghi MS, Samani FB, Goudarzi MT (2006) A proposal for the modification of RQD (MRQD), ISRM International Symposium 2006, 4th Asian Rock Mechanics Symposium, Rock mechanics in underground construction, 8-10 November Singapore, Leung CF and Zhou YX (eds) © 2006 by World Scientific Publishing Co. Pte. Ltd, ISBN 981-270-437-X

[11] Ahmed TMF (2013) Modified Value of Rock Quality Designation Index RQD in Rock Formation. International Conference on Case Histories in Geotechnical Engineering. 1. https://scholarsmine.mst.edu/icchge/7icchge/session05/1