Adjusted RQD Refines the Rock Mass Classifications

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GeoCalgary 2022 October 2-5
Reflection on Resources

ABSTRACT

The use of the RQD, even if its imperfection is recognized, is embedded in rock mechanic and it is difficult to generate a new concept to replace it. Introducing a complement seems to be the best method to contribute to the rock mass classifications systems. Joints are the most important features as it controls the behaviour of the rock mass; knowing its distribution and variability is essential. The QCF, or Quality Correction Factor, is the result of a simple and detailed analysis of the joint characteristics, such as the spacing and the number of joint sets that influence the use of the RQD in the rock mass classifications. The data obtained from boreholes was analysed by rock mass slices and resulted in the QCF, which is a parameter of direct use. With the QCF, it is possible to adjust the RQD and to improve the Q and RMR rock mass classifications. As a complement for enhancing the rock mass knowledge, some graphs showing the joint distribution into the rock mass, other than the stereographic analysis, were developed.

RÉSUMÉ

L'utilisation du RQD, même si son imperfection est reconnue, est très implantée en mécanique de roches et de ce fait il est très difficile de le remplacer. Introduire un complément semble être la manière de contribuer aux systèmes de classifications du massif rocheux. Les joints sont les traits les plus importants du massif rocheux qui contrôlent le comportement du massif, donc connaissant leur distribution et variabilité est essentiel. Le QCF (Quality Correction Factor) est le résultat d'analyses simples et détaillé des aspects des joints, tels que l'espacement et le nombre de familles de joints qui influencent l'usage du RQD dans la classification de massif rocheux. En analysant les données des forages par tranches de massif rocheux le QCF est obtenu comme un paramètre d'utilisation directe. Avec le QCF il est possible d'ajuster le RQD et améliorer ainsi les classifications Q et RMR des massifs rocheux. Comme un complément pour une meilleure compréhension du massif rocheux, quelques graphiques qui montrent la distribution des joints dans le massif rocheux, autres que l'analyse stéréographique, ont été développés.

1 SPACING ANALYSIS

The analysed data was obtained from boreholes surveys carried out with a televiewer equipment. The collected data is complete; every joint into the rock mass is considered for the present analysis. The basic data are the spacing, the dip angle and the dip direction of the joints. The treatment of the joint spacing, that can be done to any required length, was carried out by selected slices of the rock mass with a length of about 20m. The result is presented, on Figures 1 and 2, as the percentage of the sum of cores length, which are delimited by the joints, and for a determined spacing range (indicated interval on the Figures).

Figure 1 presents the variation of joints spacing, as a percentage, in function of the selected slices. In the figure, at first glance, the upper part of the rock mass (slide of 0-20m) has higher percentage of smaller blocks given the closed spacing of the joints, which translate into a lower RQD.

Two important parameters can be obtained from this type of graphs: One parameter is the RQD which is the value taken at the interception of any slice curve with the percentage corresponding to the spacing of 0.2m, indicated by the vertical arrow. This spacing represents the percentage of all the rock cores bigger than 0.10m. The other parameter resulting from the figure is the D50, which is the intersection of the slice curves at the 50%, indicated by the horizontal arrow.

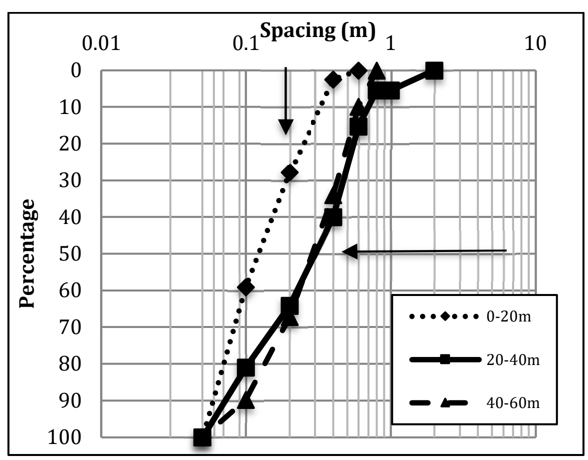

Figure 1: Size analysis of 3 slices from one borehole.

The values of the RQD for each slice, are 28, 64 and 67%, respectively, for the upper to the deeper slice of the borehole. The D50 values are 0.16, 0.3, and 0.3m respectively.

Figure 2 presents the analysis of three slices and a global slice (0-76.9m) from another borehole. The size analysis shows different curve shapes. The values of the RQD ranges from 91 to 97% (vertical arrow) and the D50 ranges between 0.5 and 0.8m (horizontal arrow).

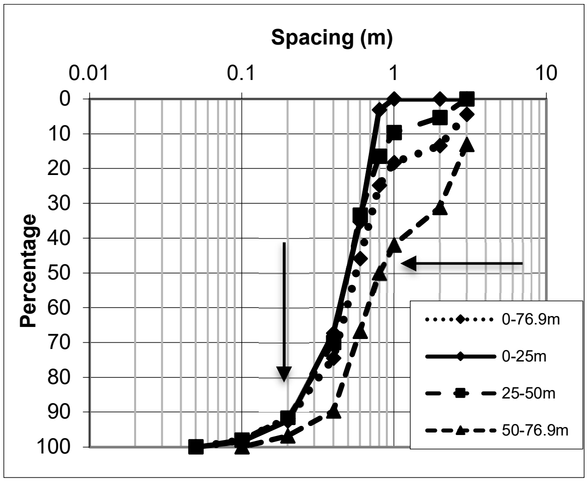

Figure 2: Size analysis of 3 slices and the global slice from one borehole.

2 THE QCF METHOD AND THE ROCK MASS CLASSIFICATIONS

Adjusting the RQD by de D50 value, produce a change in the rock quality ranking suggested by the RQD. Table 1 presents data from 6 different boreholes, each one treated with the same criteria of depth slices. The RQD and D50 values were obtained from figures similar to those shown previously.

The QCF (Quality Correction Factor) is equal to RQD*D50. The Figure 3 shows the QCF and RQD relationship constructed with the data presented in Table 1. The table as well as the figure show that for QCF<50, the RQD have a very long range of values, in those cases the D50 ≤ 0.5m (highlighted values in Table 1). RQD ranging from 75 to 90%, which are classified as Good Rock, having a D50 ≤ 0.5m does not have the same quality than other RQD with a D50 > 0.5m. Then, for equal values of RQD, the rock is of better quality if QCF is higher than 50. For any given RQD, the highest the QCF value, the highest the rock quality.

The values of D50 in Table 1 are taken as the joint spacing interval to obtain the joint ratings on the RMR and the Q systems. All of the Jn ratings are equivalent to 3 joint sets + random, which is the rock mass characteristic where the chosen boreholes were drilled.

To illustrate the differences that D50 put in evidence, certain data from Table 1 are explained, and referring to Table 2 for RMR ratings. Two RQD values of 91$^{(1)}$ and 86$^{(2)}$ %, which the respective D50 are equals to 0.50 and 0.60m, have QCF values of 46 and 52 respectively. As deducted, the QCF values indicates that the slice with RQD=86% is of better rock quality. The described joint spacing range in RMR is "Moderated" in both cases, but one has higher joints spacing.

Table 1: Data comparison between QCF, RMR and Q.

QCF			RMR System		Q System	
QCF	RQD	D50	RQD+ Sp Rtg	Total	Jn rating	RQD/Jn
3	28	0.12	8+8	16	12	2.33
19	64	0.30	13+10	23	12	5.33
20	67	0.30	13+10	23	12	5.58
46	91	0.50	20+10	30	12	7.58
46 $^{(1)}$	91 $^{(1)}$	0.50 $^{(1)}$	20+10	30	12	7.58
55	92	0.60	20+10	30	12	7.66
78	97	0.80	20+15	35	12	8.08
41	82	0.50	17+10	27	12	6.83
64	91	0.70	20+15	35	12	7.58
96 $^{(3)}$	96 $^{(3)}$	1.00 $^{(3)}$	20+15	35	12	8.00
34	80	0.42	17+10	27	12	6.66
63	90	0.70	17+15	32	12	7.50
96	96	1.00	20+15	35	12	8.00
23	75	0.30	13+10	23	12	6.25
52 $^{(2)}$	86 $^{(2)}$	0.60 $^{(2)}$	17+10	27	12	7.17
56 $^{(4)}$	93 $^{(4)}$	0.60 $^{(4)}$	20+10	30	12	7.75
0	0	0.07	3+10	13	20	0
100	100	1.00	20+15	35	12	8.33
200	100	2.00	20+20	40	12	8.33

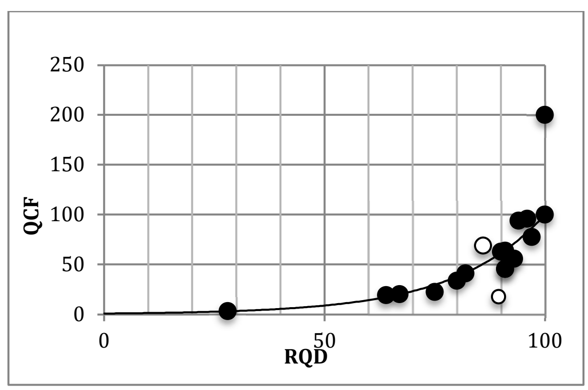

Figure 3: QCF and RQD relationship.

Actually, RQDs of the same range or rating are not equivalent. From Table 1 the RQD of 96$^{(3)}$ and 93$^{(3)}$ %, have very different D50, equals to 1.00 and 0.60m and its QCF are 96 and 56 respectively. Although both have the same joint spacing denomination of Wide, the first one represents a better rock mass quality.

The difference on quality could be even more significant when comparing the data of the two white dots in Figure 3: One of the dots has a RQD=86%, a D50=0.60m and a QCF=52. The RMR ratings are, 17 for the RQD, and 15 or 10 for the joint spacing, the total rating is 32 or 27. The other dot has a RQD=90%, a D50=0.36m and a QCF=32, The RMR ratings are, 20 for the RQD, and 10 for the joint spacing, de total rating is 30**.**

One of the reasons for the difference is that the RMR classification grants a single note to a range of RQD and joint spacing values. The Figure 3 indicates that in the first dot case the QCF method rates higher the rock mass than the RMR. In the second case the QCF rates the quality almost identical as the RMR. More important, comparing both cases, the QCF rates better the rock mass with a RQD=86% than with a RQD=90% (52 against 32) because of the difference on the D50 that enhance the quality of a rock mass that has a joint spacing of 0.60m.

Table 2: Excerpt from Bieniawski's 1989 RMR rock mass classification system.

RQD	90-100	75-90	50-75	25-50	<25
Des.	Exc.	Good	Fair	Poor	V Poor
Rating	20	17	13	8	3

Joint Spacing	>2.0m	2.0m-0.60m	0.60-0.20m	0.20-0.06m	<0.06m
Des.	V Wide	Wide	Mod	Close	V Close
Rating	20	15	10	8	5

Table 3: Excerpt from Barton's 1974 Q rock mass classification system.

Joint Set Number Jn	Massive or few joints	0,5-1,0
	One joint set	2
	One joint set + random	3
	Two joint sets	4
	Two joint sets + random	6
	Three joint sets	9
	Three joint sets + random	12
	Four or + joint sets, heavily jointed	15
	Crushed rock, earthlike	20

In the Q system the RQD is taken as is, and affected by the Jn (Table 3). With the data from Table 1, the Figure 4 shows the relationship between QCF, the RMR (RQD+spacing rating) and the Q (RQD/Jn). The unique Q rating of the drilled rock mass (3 joint sets + random) applied to the RQD produce a very narrow result. On the contrary, for the same rock mass, the RMR system shows more variability because both the RQD as well as of the joint spacing have range ratings.

Figure 5 shows the relationship between the RQD, adjusted with the joint spacing (RMR), and the Jn (Q) ratings. These examples seem to indicate that spacing cannot be ignored. For the rock mass classification both, spacing and joint set number, should be considered together.

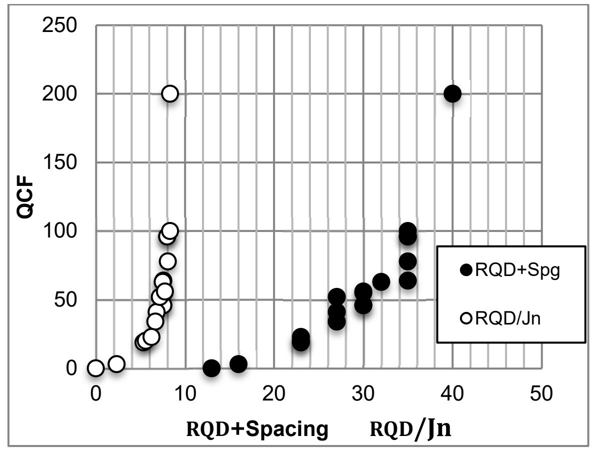

Figure 4: QCF, RMR and Q systems relationships.

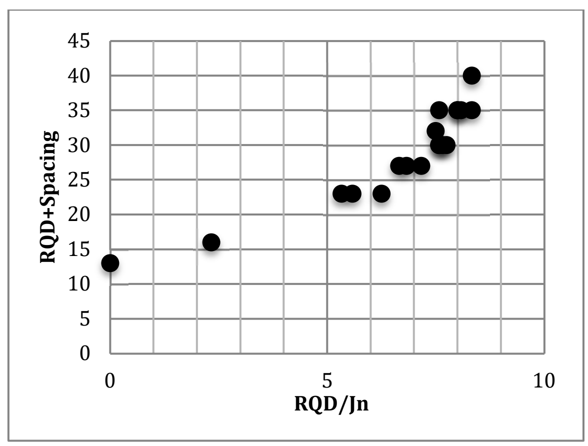

Figure 5: Relationship of RQD treated as per RMR and Q systems.

In order to test the last argument, Tables 4 to 7 present the comparison between the RMR and Q systems and their adjustments by QCF. Most of the data are not shown because they are kept constants through the cases. The modifications included in each table are: in the QCF-RMR case, the RQD rating and the rating for the Joint Spacing were replaced for the unique and equivalent value of QCF/ #sets, obtaining the QCFs3-RMR and QCFs1-RMR. The sub-numbers "1s" and "3s" stand for 1 joint set and 3 joint sets. The D50 is equal to the joint spacing.

Table 4a: for the RMR system the total rating means a Good rock. The adjusted QCFs3-RMR obtains a Fair rock as well as the QCF1s-RMR. The reason for the difference between the original class (RMR) and the modified is the impact of the unique value of the joint spacing of the QCF, divided by the number joint sets, instead of a spacing rating. In the cases of Q system, for QCF-Q3s and QCF-Q1s, the factor RQD/Jn was replaced by the QCF/#sets. There are four cases, two representing the Q calculations, Q1s, Q3s, which represents the cases of 1 and 3+random joint sets cases respectively. And two others representing the Q adjusted by the QCF: QCF-Q3s and QCF-Q1s.

Table 4a: Comparison of RMR & QCF (=RQD*D50).

	RMR	QCF3s RMR	QCF1s RMR
UCS (MPa)	100-150		
Rating	12	12	12
RQD	100	-	
Rating	20	-	
J Spacing (m)	0.11	-	
Rating	8	(100*0,11)/3	(11/1)
Persistence	>20		
Rating	0	0	0
Aperture (cm)	0.01-0.1		
Rating	4	4	4
Roughness	Smooth		
Rating	1	1	1
Infilling	None		
Rating	6	6	6
Weathering	Unweather		
Rating	6	6	6
Groundwater	Dry		
Rating	15	15	15
Joint Orientation	Fair		
Rating (Tunnel)	-5	-5	-5
Total Rating	67	43	50
Class Number	II	III	III
Description	Good	Fair	Fair

Table 4b: Comparison of Q & QCF.

	Q3s	QCF-Q3s	Q1s	QCF-Q1s
RQD	100	-	100	-
Jn	3+random		1 set	
	12	(11/3)	2	(11/1)
Jr	Smooth planar		Smooth planar	
	1	1	1	1
Ja	Unaltered		Unaltered	
	0.75	0.75	0.75	0.75
Jw	Dry		Dry	
	1	1	1	1
SRF	1	1	1	1
Rating	11	5	65	14
Class	B	C	A	B
Desc.	Good	Fair	V Good	Good

Table 4b: In Q3s the rock quality is Good and Q1s is Very Good. The improvement of the rock quality is only due to 1 joint sets. For the same rock mass characteristics but adjusted by the QCF, the QCF-Q1s gives a Good rock, while the QCF-Q3s gives a Fair rock. In both cases the introduction of the D50 by means of the QCF decreased the rock quality compared to the Q3s and Q1s. So, the QCF is effective in balancing the rock qualities.

From Tables 5 to Tables 7, the same exercise is reproduced with changes on RQD, joint spacing, Jn and introducing the QCF. The results are also shown in Figures 6 and 7. The bold dots and the strait lines belong to the data adjusted by QCF divided by # sets.

Table 5a: Comparison of RMR & QCF.

	RMR	QCF3s RMR	QCF1s RMR
UCS (MPa)	100-150		
Rating	12	12	12
RQD	64	-	
Rating	13	-	
J Spacing (m)	0.30	-	
Rating	10	19/3	19/1
Total Rating	62	45	58
Class Number	II	III	III
Description	Good	Fair	Fair

Table 5b: Comparison of Q & QCF.

	Q3s	QCF-Q3s	Q1s	QCF-Q1s
RQD	64	-	64	-
Jn	3+random		1 set	
	12	19/3	2	19/1
Rating	7	8	42	25
Class	C	C	A	B
Desc.	Fair	Fair	V Good	Good

Table 6a: Comparison of RMR & QCF.

	RMR	QCF3s RMR	QCF1s RMR
UCS (MPa)	100-150		
Rating	12	12	
RQD	90	-	
Rating	17	-	
J Spacing (m)	0.36	-	
Rating	10	(32/3)	(32/1)
Total Rating	66	50	71
Class Number	II	III	II
Description	Good	Fair	Good

Table 6b: Comparison of Q & QCF.

	Q3s	QCF-Q3s	Q1s	QCF-Q1s
RQD	90	-	90	-
Jn	3+random		1set	
	12	(32/3)	2	(32/1)
Rating	10	14	56	42
Class	C	B	A	A
Desc.	Fair	Good	V Good	V Good

Table 7a: Comparison of RMR & QCF

	RMR	QCF3s RMR	QCF1s RMR
UCS (MPa)	100-150		
Rating	12	12	
RQD	86	-	
Rating	17	-	
J Spacing (m)	0.60	-	
Rating	10	(52/3)	(52/1)
Total Rating	66	56	91
Class Number	II	III	I
Description	Good	Fair	V Good

Table 7b: Comparison of Q & QCF.

	Q3s	QCF-Q3s	Q1s	QCF-Q1s
RQD	86	-	86	-
Jn	3+random		1 set	
	12	(52/3)	2	(52/1)
Rating	9	22	56	68
Class	C	B	A	A
Desc.	Fair	Good	V Good	V Good

In Figure 6, the data not corrected by QCF have values not aligned with the others dots tendency. The adjustment by QCF/#sets corrects and improves the rock mass classification. Also the adjusted dots differentiate between them by the #sets. As it was mentioned on the comments for Figure 3, the QCF recomposes the RQD quality and therefor the rock mass classifications.

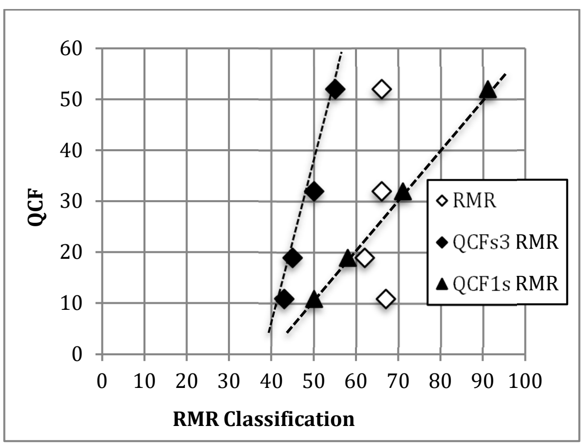

Figure 6: Comparison between RMR and its adjustments by QCF and joint set number.

Figure 7 shows the same pattern between the two group of data, and it shows also the same tendency due to the #sets. The slope of QCF-Q3s is steeper than the slope of QCF-Q1s. The latest slope indicates a rapid increase on rock mass quality with QCF, while with the increment of Jn the increase on rock mass quality is obviously reduced. The number of joint sets acts imposing the magnitude of the increase of the rock mass quality interacting with QCF. This remark seems applicable to the RMR cases in Figure 6 too.

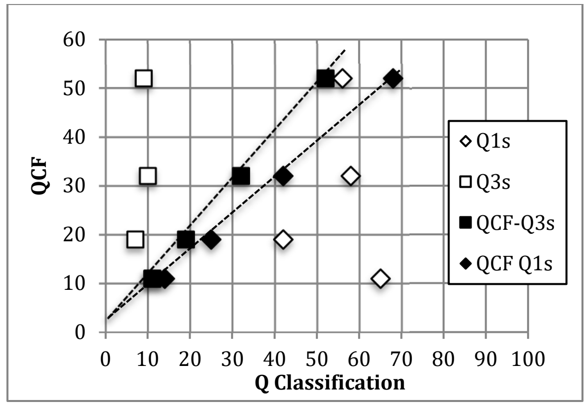

Figure 7: Comparison between Q and its adjustments by QCF and joint set number.

After all the discussed cases, it seems natural for the rock mass quality to depends on both, the joints spacing and on the joint set number. No doubt about the importance of the joint spacing. To a certain extent any number of joint sets could produce the same RQD value. Joints could be distributed randomly in the rock mass or being concentrated in a short space with portions of the rock mass without joints. The typical case of a fault zone where a highly concentration of joints of one or two sets yield a very low RQD. The number of joint sets have also a geometrically impact on rock mass excavations. These are the reason for RMR and Q systems to care about the characteristics of joints.

If spacing is as important as joint set number for assessing the rock mass quality, then a real and unique number adjusting the RQD value is more adequate and precise than ranges of RQD and spaces (RMR), or different ratings based on joint sets number (Q). To this point the QCF, together with the joint set number, seem suited for being considered into the rock mass classifications as shown in the examples. More over, the QCF and the #sets are the product of the data obtained directly from the rock mass being investigated without interpolations of foreign data.

3 DIP AND DIP DIRECTION

The Figures hereafter are an illustration of some additional joint analysis that complements the regular stereographic analysis. The analyses assist in the awareness of the variation of jointing with depth, to be considered for slopes, underground excavations and the grouting holes orientation among others applications. Such analysis improves the visibility of the joint set that has to be followed as the excavation progresses. And it demonstrates that either the Dip angle or the Dip Direction are not always constant throughout the rock mass. Important variations can take place without being noticed if relying only on the global standard stereographic joint analysis, unless rock mass depth slices are put into contribution.

Figure 8 presents, as an example, the regular joint analysis carried out with the data obtained testing several boreholes with televiewer equipment. In order of importance, the most developed joint sets are the subhorizontal and the subvertical. The same borehole data presented in Figure 8 is presented now on Figures 9 and 10. Figure 9 shows the great variation of the dipping angles in function of the rock mass depth slices, that the stereographic analysis cannot put in evidence. Each rock slice has a very different joint composition.

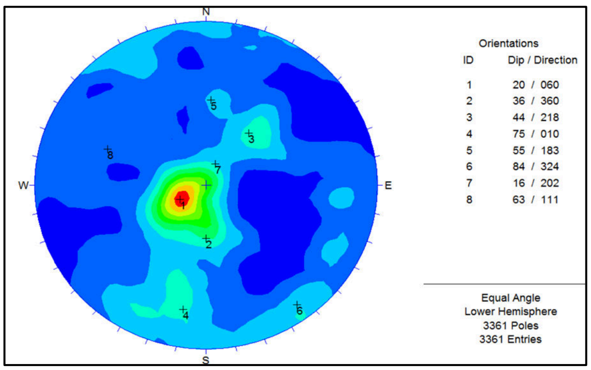

Figure 8: Stereographic joints analysis.

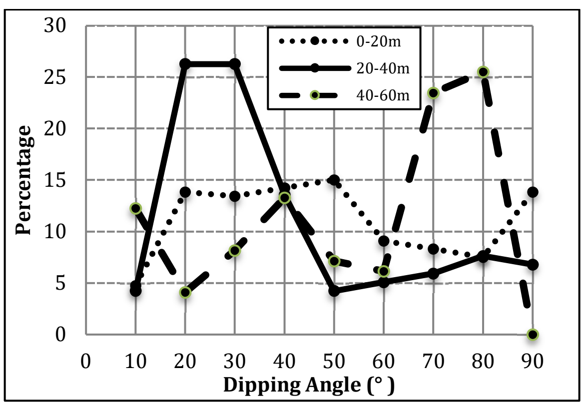

Figure 9: Joint Dip angles variations with Depth.

Figure 10, shows that, although the differences, all the slices have smaller variations but not less important. All Dip Directions are present in the three slices. The depth slice between 0-20m has the smallest variations, similar to the case of the dipping angle on Figure 9.

4 CONCLUSIONS

For any chosen slice of rock mass, the spacing analysis (Figs 1 and 2) shows the joint spacing composition and yields the RQD and the D50 values, and the unique QCF. Particular concentration of joints in short intervals can be analysed by performing small slices.

The QCF approach allows differentiating between RQD of the same numerical value but of different qualities. Values of QCF higher than 50 constitutes better rock masses, with joints spacing bigger than 0.5m, from those RQD with spacing smaller than 0.5m.

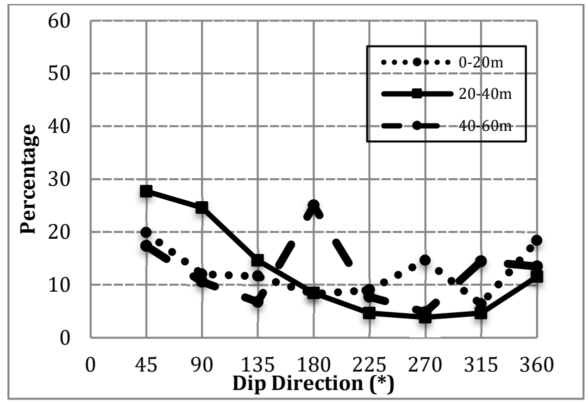

Figure 10: Joint Dip Direction variations with Depth

The QCF seems to be a reasonable approach to be incorporated into the rock mass classification RMR and Q systems.

When doing a site characterisation, there are a few possibilities. All the boreholes presents the same pattern or the boreholes show a difference for each working area. Or even in a long structure as a tunnel the boreholes present differences along the axis. Obviously, in the first case the mean value of QCF, spacing and #sets, will fit the entire site for the rock mass classification. In the other two cases it will be recommended to determine the sectors with similar patterns and its means values, thus dividing the working sites with its own patterns.

The analyses by rock mass slices allow appreciating the variations of the Dip and Dip Direction with depth. The analysis presented here is based on in-hole televiewer tools that allow having all the details of the rock mass encountered during drilling, such as joint Spacing, Dip and Dip Direction among other information. In the case of no having such a tool the spacing analysis can be done from the borehole logs, taking into account the core losses and the way the RQD is done at the field.

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