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Modified Value of Rock Quality Designation Index RQD in Rock Formation

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MODIFIED VALUE OF ROCK QUALITY DESIGNATION INDEX RQD IN ROCK FORMATION

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ABSTRACT

The rock quality designation, RQD, is a commonly index used in the description of rock mass quality. This RQD, index value is used to predict the engineering properties of the rock strata under study. The RQD index value was introduced for the engineering applications, such as mining and geotechnical engineering. Calculating of RQD index for rock formation is a great part due to its simplicity. However, this also leads to a number of limitations, including among other, a dependency of RQDm value on the borehole orientation and on the selected threshold value for the minimum intact core length. In this paper, a new modified RQDm index is introduced to overcome the limitations when assessing the ordinary RQD index value. This modified and corrected value of RQDm index will be more conservative to use for predicting the rock properties than the ordinary RQD.

INTRODUCTION

The rock quality designation, RQD, was initially proposed by Deere 1963, and since then it has been the topic of various assessments (e.g., Deere et al. 1988 and Deere 1989), mainly for civil engineering projects. Its application has also been quickly extended to other areas of rock mechanics, and it has become a fundamental parameter in geotechnical engineering. The success of the RQD is due, in large part, to its simple definition, which is the ratio of intact core pieces longer than 10 cm over the total drilling length.

However, this index is affected by a number of well known limitations. For instance, its value can be different for a given location when obtained from cores with different drilling orientations. In addition, the RQD may be affected by the rock strength and core size. Other neglected influence factors include water conditions, and joints aperture, alteration and roughness.

Although, these limitations have been addressed in rock mass classifications, such as the Rock Mass Rating (RMR), the Norwegian Geotechnical Institute's Q system, and the cumulative core index, The RQD is still used on its own, without correction, in many geotechnical engineering applications.

Another significant limitation of the RQD definition is its dependency on the selected threshold length of unbroken rocks (e.g., Terzaghi 1965; Harrison 1999; Hack 2002; Chen et al. 2005). This signifies that the RQD value would typically vary with different threshold length for the same core. In practice, a familiar observation associated with this drawback is that the RQD values tend to be either high or low in most rock engineering projects. Some values are less frequently encountered, due to the customarily and universally adopted, but very arbitrarily selected threshold value of 10 cm (for NX cores) in the assessment of RQD (Harrison 1999).

In this paper, the definition of rock quality designation, RQD, is reviewed and a simple modification is proposed. This leads to a new modified corrected definition of rock quality designation, RQDm.

ROCK QUALITY DESIGNATION INDEX, RQD)

The Rock Quality Designation index, RQD was developed by Deere et al 1967, to provide a quantitative estimate of rock mass quality from drill core logs. RQD is defined as the percentage of intact core pieces longer than 100 mm (4 inches) in the total length of core. The core should be at least NW size (54.7 mm or 2.15 inches in diameter) and should be drilled with a double-tube core barrel. The correct procedures for measurement of the length of core pieces and the calculation of RQD are summarized as follow:

$$RQD = \sum Pc / L \qquad (1)$$

Where, Pc= Length of core pieces › 10 cm and L is the total core length.

Palmström 1982 suggested that, when no core is available but discontinuity traces are visible in surface exposures or exploration adits, the RQD may be estimated from the number of discontinuities per unit volume. The suggested relationship for clay-free rock masses is:

$$RQD = 115 - 3.3\,Jv \qquad (2)$$

Where, Jv is the sum of the number of joints per unit length for all joint (discontinuity) sets known as the volumetric joint count.

RQD is a directionally dependent parameter and its value may change significantly, depending upon the borehole orientation. The use of the volumetric joint count can be quite useful in reducing this directional dependence. RQD is intended to represent the rock mass quality in situ. When using diamond drill core, care must be taken to ensure that fractures, which have been caused by handling or the drilling process, are identified and ignored when determining the value of RQD.

When using Palmström's relationship for exposure mapping, blast induced fractures should not be included when estimating Jv. Deere's RQD was widely used, particularly in North America, after its introduction. Cording and Deere (1972), Merritt (1972) and Deere (1989) attempted to relate RQD to Terzaghi's rock load factors and to rock-bolt requirements in tunnels. Figure (1) shows the procedure for measurement and calculating of RQD of two meter core length after Deere, 1989 In the context of this discussion, the most important use of RQD is as a component of the RMR (Rock Mass Rating) and Q(rock tunneling quality index) rock mass classifications.

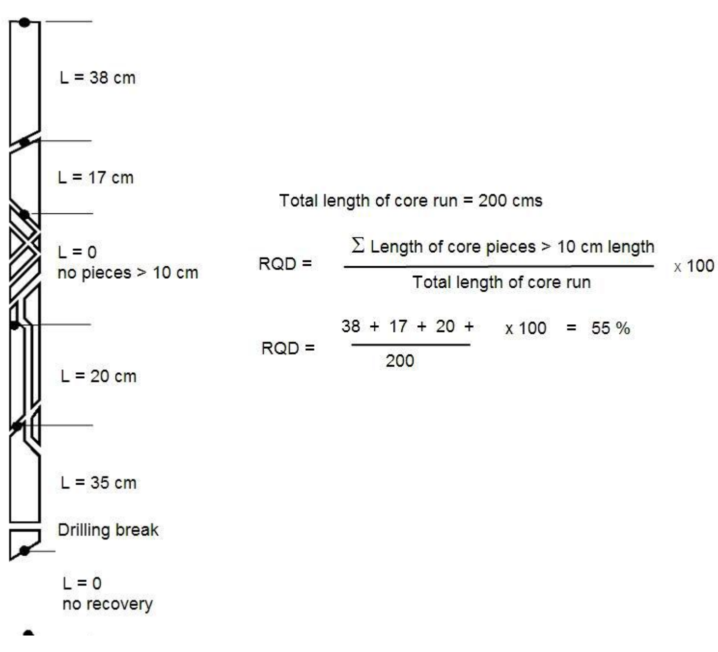

Fig. 1: Procedure for measurement and calculation of RQD (After Deere, 1989).

CORRECTED DEFINITION OF THE RQD

By examining the core shown in Figure 1, one sees that the quality of the rock mass not only depends on the accumulative length of unbroken pieces, but also the number of unbroken pieces, N. Thus, the designation could be expressed using the following function:

$$RQDm = \sum Pu / f\,(N) \qquad (3)$$

Where, RQDm is the modified corrected rock quality designation, Pu is the ratio of recovered cores in Length and f (N) is a function of the total number of unbroken pieces.

The value of the summation of the different ratio of core lengths will give the value of Pu as follow:

$$\sum Pu = Pu1 + Pu2 + Pu3 \qquad (4)$$

Where,
Pu1= percentage of unbroken pieces less than 5 cm,
Pu2= percentage of unbroken pieces ranged between 5-10 cm,
Pu3= percentage of unbroken pieces more than 10 cm,
The function f (N) is a function of the total number of unbroken pieces. It can take various forms, and in our work we suggest a good prediction for its relation as follow:

$$f\,(N) = N^{f} \qquad (5)$$

Where, f is a material parameter that serves as the exponent in the power law function.

SCHEMATIC PRESENTATION

The variation of RQDm with parameter f varying from 0 to 1.0 in normal (a) and log-log (b) planes, respectively.

In the latter case, the variation of RQDm with the number of N pieces become straight lines (with the slope equal to f).

It can be seen also that RQDm would nearly remains constant if the parameter f = 0 (or f (N) = 1), as with the RQD, which is independent of the number of unbroken pieces.

Another difference between RQDm and RQD is that the former considers the total length of all unbroken pieces (Pu, equivalent to the recovered rate commonly used by geological engineers) while the latter includes only those segments longer than 10 cm.

The advantages of the corrected definition, RQDm, over the original definition of RQD are fairly clear. For instance, for two different cores broken in pieces longer than 10 cm, the RQD will be 100% for both cores whatever the number of unbroken pieces, while the corrected definition will give two different RQDm values based on their unbroken pieces number; a smaller index is expected to be associated with the more fractured core. Also, for two different cores broken in

pieces smaller than 10 cm, the original definition simply gives a RQD of 0%, while the former RQDm index can make a distinction based on the number and broken length of the cores.
In the following, parameter f will be taken as factors ranged between 0 to 1 values according to the length of the unbroken pieces. Thus, the corrected definition of RQDm can describe the quality of rock mass from very bad to very good quality, with the index varying in a continuous rather than in an abrupt manner.
Another advantage is that the definition of RQDm simplifies and accelerates the surveying work due to the fact that one does need to verify if the length of unbroken pieces is larger than the (arbitrarily selected) threshold value. Thus from different investigations and different works the value of the factor f could be define as a product value of the multiplication of three factors f1, f2, and f3 as follow:

$$f = (f1) \times (f2) \times (f3) \qquad (6)$$

Where,
f1= factor represent the percentage of unbroken pieces less than 5 cm.
f2= factor represent the percentage of unbroken pieces ranged between 5-10 cm.
f3= factor represent the percentage of unbroken pieces more than 10 cm.

So, to find these factors we should find in field work the percentage values of the unbroken lengths of the core run for the three different percentages, Pu1, Pu2, and Pu3 as illustrated in equation 4. and after knowing this three percentages, the corresponding three values f1, f2, and f3 will be define according to the following linear equations:

$$f1 = 1 + 0.003 \quad Pu1 \qquad (6a)$$
$$f2 = 1 + 0.\ 001 \quad Pu2 \qquad (6b)$$
$$f3 = 1 - 0.00995 \quad Pu3 \qquad (6c)$$

Figures 1a, 1b, and 1c illustrated the relation between each unbroken pieces percentages Pu1, Pu2, and Pu3 with the three different factors f1, f2, and f3, respectively.

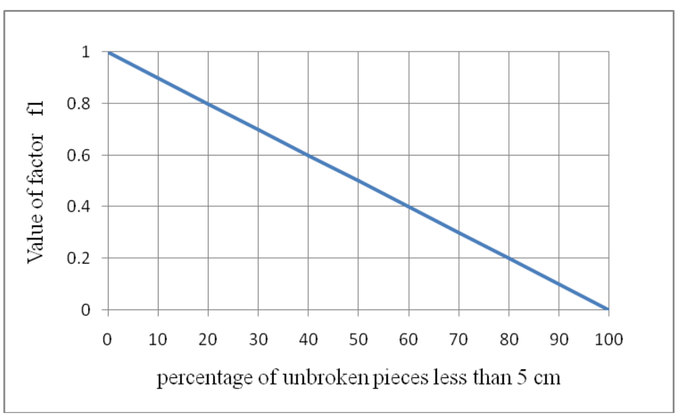

Fig. 2a: value of factor f1 for the percentage of unbroken pieces Pu1.

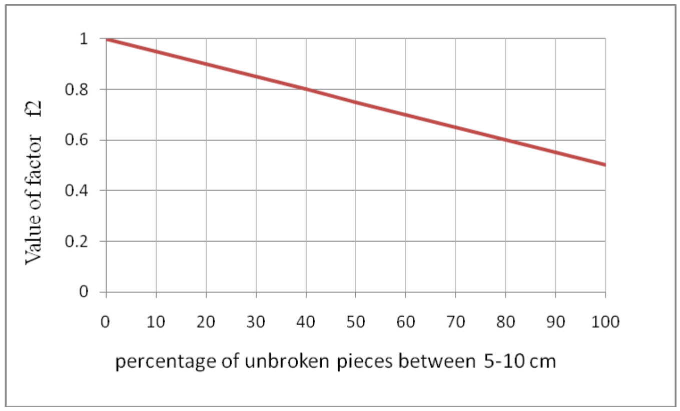

Fig. 2b: value of factor f2 for the percentage of unbroken pieces Pu2.

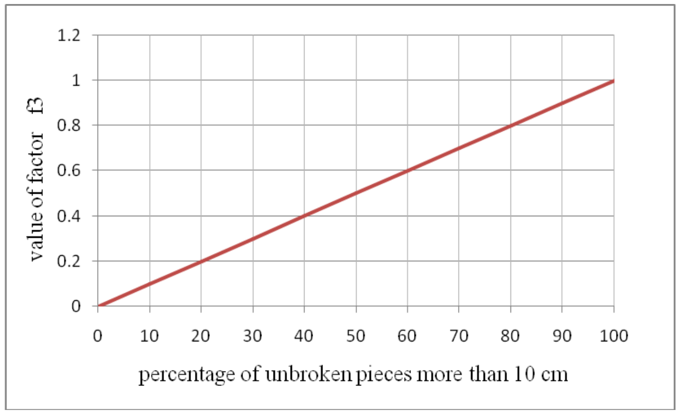

Fig. 2c: value of factor f2 for the percentage of unbroken pieces Pu3.

EXAMPLES OF CALCULATION

By applying the proposed new method for calculating and measurement of RQD index for the critical cases of rock mass designation with the two extreme values (100% vs. 0%) , as shown in table 1.
From this table, it is obvious that the extreme values are high significant values due to its effect on the rock mass quality. Tests from (a) to (f) illustrated the effect of the different number of the unbroken pieces more than 10 cm, where by increasing the number of unbroken pieces from N=1 to N=12, the modified value of RQDm reduces from 100% to 25%. This new value RQDm will be important to describe the different rock core quality according to the total unbroken parts. In case of the RQD is nearly equal to zero, the modified value RQDm will not be zero at all if there is an unbroken samples less than 10 cm. From the table it is illustrated that the effect of the fracture numbers of the unbroken pieces which could be ranged from 10 to 40 pieces gives a value for the modified RQDm more than zero and ranged between 0.40% and 7.20%.
In our study, many boreholes were taken from different sites to apply the new method of calculation and measurement of modified rock quality designation for rock. Three boreholes were chosen and presented for calculation of the modified

rock mass quality index RQDm. These boreholes were done by a core length (scan interval) equal to 1.50 meter. One borehole (BH1) was 15.0 meter depth and the other two boreholes (BH2 and BH3) were 20.0 meter in depth. Photos 1, represents the core box samples used in the study. RQDm could be evaluated for the samples under investigation as shown in tables 2, 3, and 4 as shown below.

Table 1. Comparison between RQD and the modified RQDm

Test	RQD	N	f	F (N)	RQDm %
a	100	1	0.05	1	100
b	100	3	0.05	1.056467	95
c	100	5	0.05	1.083798	92
d	100	7	0.05	1.102186	91
e	100	10	0.05	1.122018	89
f	100	12	0.55125	3.934583	25
g	0	11	1.1	13.9808	7.2
h	0	13	1.1445	18.83251	4.3
l	0	15	1.2463	29.22554	3.4
m	0	18	1.3	42.84047	2.3
n	0	18	1.18	30.28458	2
o	0	20	1.18	34.29378	1.7
p	0	30	1.09	40.74386	0.7
q	0	40	1.06	49.90954	0.4

Photo 1. Represent the Core samples from one borehole

Table 2. RQD and RQDm for BH1 (15.00m)

Depth	RQD	N	Pu1	Pu2	Pu3	F(N)	RQDm
0.0-1.5	24	6	5	13	24	4.14	10
1.5-3	33	13	15	12	33	6.44	9
3-4.5	70	10	0	21	71	2.15	43
4.5-6	55	14	7	14	55	3.69	21
6-7.5	45	15	15	11	45	5.16	14
7.5-9	49	15	11	16	49	4.57	17
9-10.5	47	14	12	9	47	4.60	15
10.5-12	91	6	0	0	91	1.27	71
12-13.5	100	5	0	0	100	1.08	92
13.5-15	100	5	1	4	95	1.17	85

Table 2. RQD and RQDm for BH2 (20.00m)

Depth	RQD	N	Pu1	Pu2	Pu3	F(N)	RQDm
0.0-1.5	60	5	4	10	60	2.03	36
1.5-3	33	12	2	27	33	5.83	11
3-4.5	46	10	1	14	46	3.74	16
4.5-6	75	10	1	15	75	1.96	46
6-7.5	65	8	1	1	65	2.22	30
7.5-9	75	8	2	12	82	1.60	60
9-10.5	56	13	3	30	56	3.49	26
10.5-12	97	7	2	0	97	1.17	85
12-13.5	37	14	15	16	37	6.15	11
13.5-15	63	10	7	11	63	2.60	31
15-16.5	95	5	1	4	95	1.17	85
16.5-18	70	9	2	9	70	2.11	38
18-19.5	96	8	0	0	96	1.20	80
19.5-20	100	1	0	0	100	1.00	100

Table 3. RQD and RQDm for BH3 (20.00m)

Depth	RQD	N	Pu1	Pu2	Pu3	F(N)	RQDm
0.0-1.5	69	6	0	12	69	1.89	43
1.5-3	51	12	7	13	51	3.76	19
3-4.5	85	10	0	15	85	1.57	64
4.5-6	80	10	7	9	80	1.77	54
6-7.5	88	7	4	6	88	1.38	71
7.5-9	67	10	3	22	67	2.37	39
9-10.5	85	12	5	10	85	1.63	61
10.5-12	67	11	4	11	67	2.44	34
12-13.5	93	6	0	0	93	1.23	75
13.5-15	34	7	5	11	34	3.87	13
15-16.5	96	4	1	0	96	1.13	86
16.5-18	67	12	8	8	67	2.54	33
18-19.5	75	12	10	0	75	2.09	41
19.5-20	58	2	2	0	58	1.37	44

DISCUSSION

The ordinary rock mass quality RQD take into consideration only the percentage of the unbroken pieces bigger than 10 cm in the core run. On the other hand, the modified rock mass quality RQDm presented in the present study take into consideration the percentage of the total unbroken pieces of the run core sample beside the number of the fracture joints N. It was obvious from the new method that the number of fracture joints for the unbroken pieces of the core sample has a great effect on the value of the modified rock mass quality index RQDm.

According to that, modified RQDm index will have a value compared to ordinary RQD which is equal zero when the unbroken pieces less than 10 cm, as shown in Table 1.

Also, from Figures 3, 4, and 5 show a comparison between the ordinary RQD index and the calculated modified RQDm index predicted from the three boreholes (BH1, BH2, and BH3) chosen from the tested core samples.

As shown from the figures, the modified RQDm index was decreased than the ordinary RQD index with the increase of the fracture joints of the unbroken pieces. For the run core of only one fracture joint the value of the RQDm index equal the ordinary RQD index. While, for the increase of the unbroken pieces (increase in fracture joints), a significant decrease in the modified RQDm index was recorded to be nearly one third of the ordinary RQD index when N = 15.

From the data shown in figures 3 to 5, a relationship was predicted between the ordinary RQD index and the modified RQDm index. Figure 6 showed this relationship and from that a good prediction of the modified RQDm could be predicted by drawing the trend line for all presented data. The predicted value of the modified RQDm index was of high confidence as shown on the relationship curve (R = 96.9 %). According to that, the following equation was predicted from the relationship to get the modified RQDm index directly from RQD index:

$$RQDm = 0.01\,(RQD)^2 - 0.178\,RQD + 3.21 \qquad (7)$$

This equation should be more investigated by geotechnical engineers to get a best fit relationship with more data and more case studies and with different core run samples length.

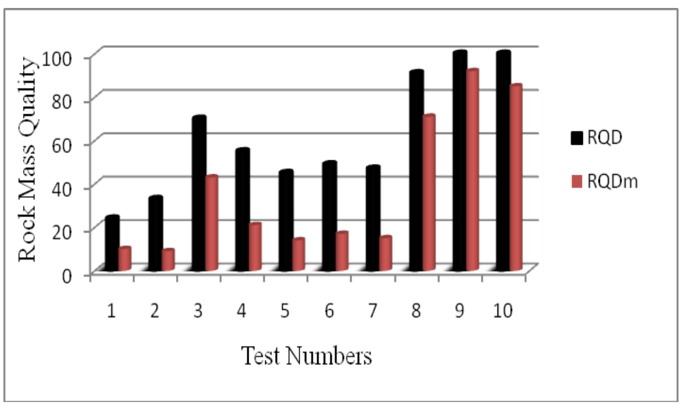

Fig. 3: The comparison between RQD and modified RQDm(BH1)

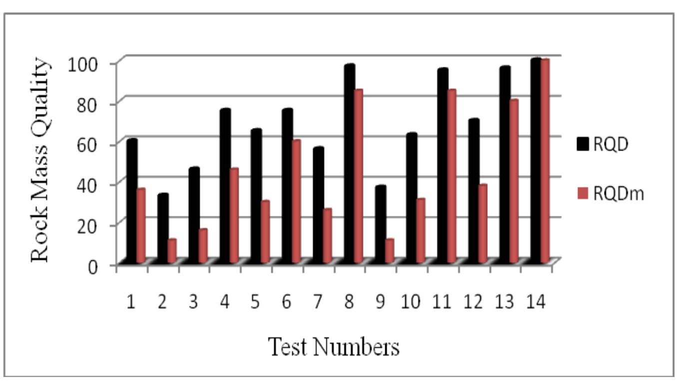

Fig. 4: The comparison between RQD and the modified RQDm(BH2)

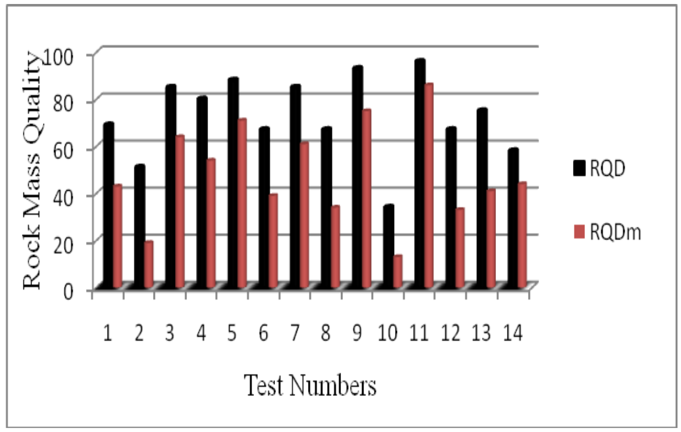

Fig. 5: The comparison between RQD and the modified RQDm(BH3)

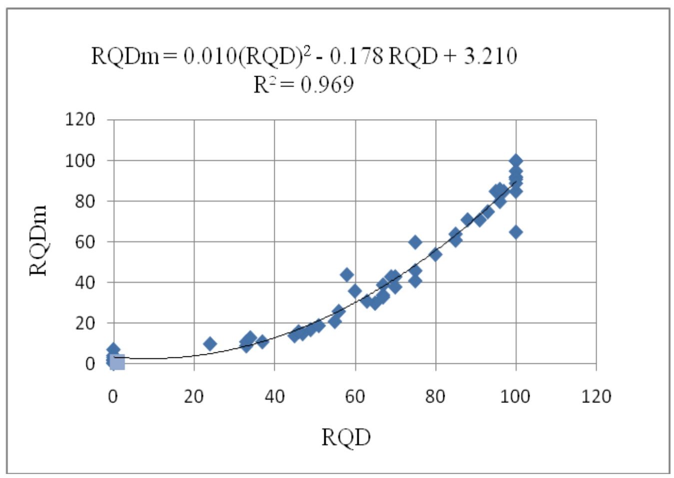

Fig. 6: The relation between RQD and the modified RQDm

CONCLUSION

In the study, the original rock quality designation RQD index was modified with a new index. The modified rock mass quality designation RQDm considers the total unbroken core sample pieces and the number of fracture joints in each core run. This new modified RQDm index keeps the original definition's simplicity, and does not require an arbitrary definition of threshold length, thus eliminates the limitation of the original RQD. It has been shown that this modified rock mass quality designation RQDm index can describe the quality of rock masses in a continuous and progressive manner, which gives a better representation of the actual quality of rock masses. It has been shown also, that this modified RQDm index behaves as other geotechnical and geomechanical rock properties. Geotechnical engineers should required to do some corrections to the predicted equations and modified method when the scan (run) interval differ from the used one in the present study which was 1.5 meter, while there is some scan interval such as 1.0, 2.0, or 3.0 meter or more.

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