RQD CLASSIFICATION OF ROCK MASSES

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Abstract: *The RQD index is used today as one of the basic elements of the two major contemporary classifications of rock masses: the RMR classification and the Q classification. RQD was defined by Deere in 1964 (Deere, 1964) and was intended to be used as a simple classification system for the stability of rock masses. Although the RQD classification is a simple and relatively inexpensive method of determining the quality of rock masses, however, it is not sufficient for an adequate description of the rock mass. The main disadvantages of this classification system are susceptibility to direction of measurement (orientation of cracks), thickness of the crack, crack infill, as well as to variation of spacing of cracks. This work presents the basics of the RQD classification, upon which the main rock mass classifications used in the construction of tunnels are established.*

Keywords: *RQD, rock mass, classification, discontinuity, rock quality*

1. INTRODUCTION

RQD stands for the rock quality designation and represents a rock mass classification system, based on the RQD index as a classification parameter for a quantitative estimation of the quality of rock mass. It was firstly introduced by Deere in 1964 and has been in the focus of a number of the further studies (Deere et al., 1967; Cording and Deere, 1972; Merritt, 1972; Deere, 1989) [1].

RQD is an index expressed in percentage and evaluated on the basis of measuring rock core pieces with a length greater than 100 mm along the core drill hole. The size of rock core is proposed to be minimum 54.7 mm (2.15 inches) in diameter and should be drilled with a double-tube core barrel.

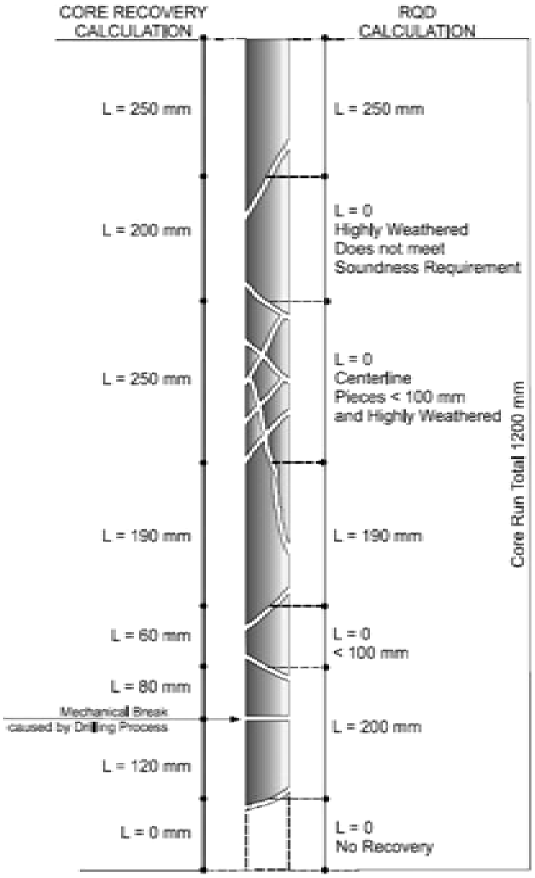
Although the RQD index is not sufficient for a thorough presentation of the quality of a rock mass, however, it is proved to be of vast fruitfulness in the construction of tunnels when it comes to appropriate selection of the type of a tunnel support. The RQD classification is nowadays a simple and relatively inexpensive method of determining the quality of rock masses and is used extensively worldwide, in particular in Europe and in US. Moreover, the RQD index is used today as one of the basic elements of the two predominant contemporary classification systems of rock masses – the RMR (rock mass rating) classification and the Q classification.

2. ROCK QUALITY DESIGNATION

In determining the RQD index only sound core pieces longer than 100 mm are to be considered (Figs. 1 and 2). Accordingly, RQD enables core logging as well as evaluation of the degree of jointing along the core drill hole, the so-called "core run", whereby RQD gives an average measurement of the degree of jointing along the total core run length (actual section). Consequently, it is meaningless RQD to vary between two differential values for that section. Measured along several sections, however, the RQD has a variation.

Material of substance strength higher than 0.6 MPa does not comply with Deere's definition of 'hard and sound' and its inclusion leads to logged RQD values that are much higher than those computed on the basis of the original methodology (Fig. 1). The consequences are potentially dangerous, such as when designing support measures in weak rock masses on the basis of RMR and Q charts, which assume RQD data determined using the corresponding Deere's definition [2].

Another substantial issue is the practical necessity where, in many situations, cored borehole data are not available and RQD has to be estimated from exposures, radar, or photographs. Such estimation invokes consideration of 'sound rock', the difficulty of establishing that a discontinuity has zero tensile strength and would cause a break in core, and directional bias [3].



$$Core\ Recovery, CR = \frac{Total\ length\ of\ rock\ recovered}{Total\ core\ run\ length}$$

$$CR = \frac{(250+200+250+190+60+80+120)\,mm}{1{,}200\,mm}$$

$$CR = 96\%$$

$$RQD = \frac{\sum Length\ of\ sound\ pieces > 100\,mm}{Total\ core\ run\ length}$$

$$RQD = \frac{(250+190+200)\,mm}{1{,}200\,mm} * 100\%$$

$$RQD = 53\%$$

Figure 1: RQD determination after Deere (1989) [1]

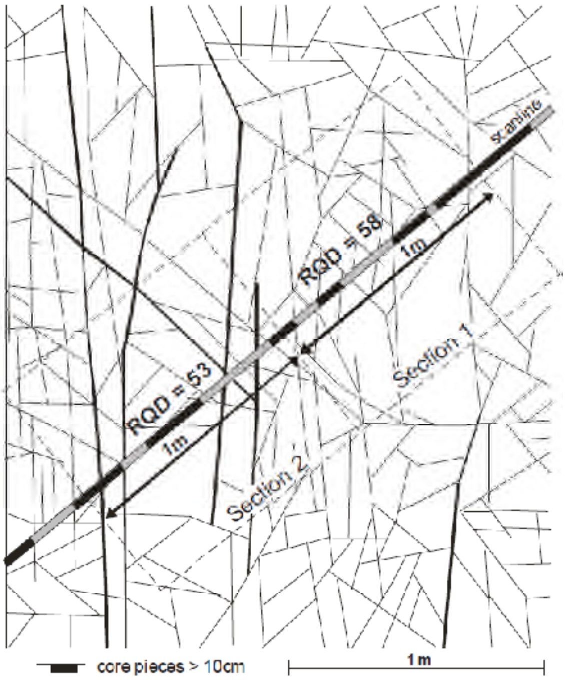


Figure 2: RQD values (core pieces longer than 100 mm are designated with black) [1]

Table 1: Rock quality designation (RQD) classification index [1]

RQD	Rock Mass Quality
< 25 %	Very poor
25 – 50 %	Poor
50 – 75 %	Fair
75 – 90 %	Good
90 – 100 %	Excellent

2.1. Limitations of the RQD

The RQD has several limits. For the case of the distance between discontinuities in the drill cores equal to or less than 10cm, RQD has a value of 0, whereas for the discontinuity spacing of 11cm or more, RQD is 100, as depicted in Figure 3. Therefore, the main disadvantage of the RQD lies in the fact that it does not take into consideration the core pieces shorter than 10cm, thus disregarding whether the excluded core pieces are of earth or rocky material.

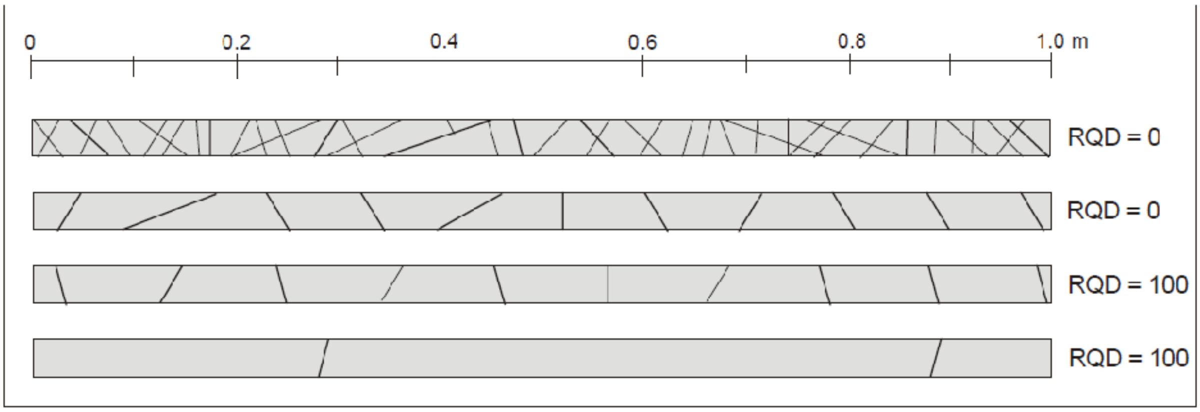


Figure 3: The extreme values of RQD for various joint densities along drill cores (after Palmstrom, 2001) [4]

On the other hand, the RQD is directional, attributed to one-dimensional measurements, and is appeared to be susceptible to the direction of a borehole. In Figure 4 three extreme examples are presented, in which the RQD has values 0 and 100 for the same type and degree of jointing of a rock mass solely due to the direction of the borehole (Choi and Park, 2004) [4].

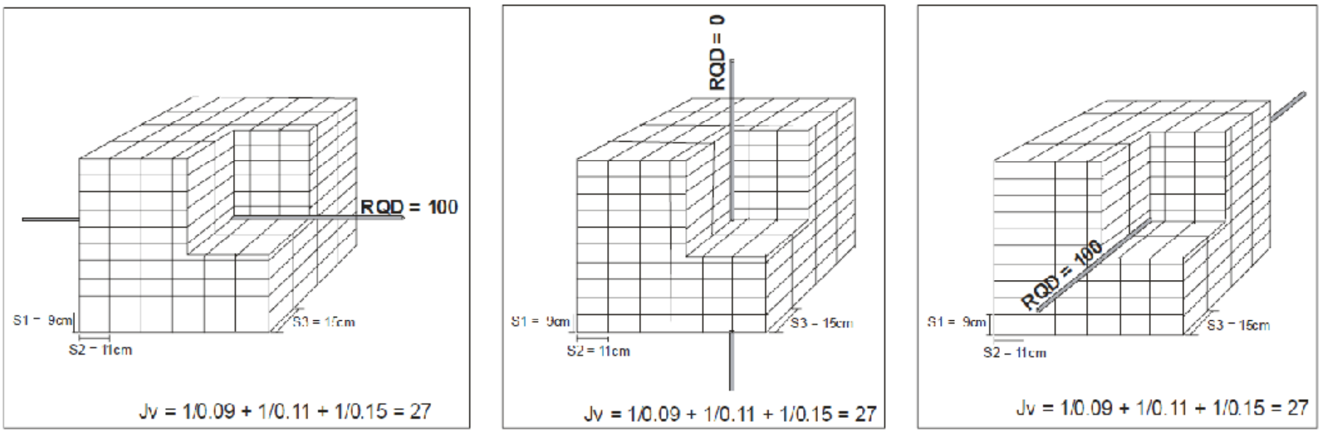


Figure 4: Variation of the direction of a borehole in a rock block resulting in different values of RQD [4]

2.2. Correlation between RQD and Jv

Considering that RQD is a one-dimensional, averaged measurement that takes into account only core pieces larger than 10cm, it is found to be rather difficult to relate RQD to other discontinuity spacing measurements. With a view toward determining such relations, simulations using blocks of the same size and shape penetrated by a borehole at different angles have been employed as the most convenient method.

Introducing the volumetric joint spacing (Jv), Palmstrom (1974) suggested a simple relation between RQD and Jv, as follows [4]:

$$RQD = 115 - 3.3\ Jv \quad (1)$$

where RQD = 0 for Jv > 35 and RQD = 100 for Jv < 4.5.

In 2005, an improvement of the relation was proposed [4]:

$$RQD = 110 - 2.5\ Jv \quad (\text{for } Jv = 4 \text{ to } 44) \quad (2)$$

According to Priest and Hudson (1976), a correlation between discontinuity frequency and RQD is given in the following form [5]:

$$RQD = 110.4 - 3.8 / \dot{x} \quad (3)$$

where $\dot{x}$ denotes an average value of spacing of discontinuities assuming an exponential distribution.

The same authors also presented the following expression relating RQD and fracture frequency [6]:

$$RQD = 100e^{-0.1\lambda}(1+0.1\lambda) \quad (4)$$

in which λ means the total frequency of joints.

The above presented correlations, however, may be inappropriate and misleading, not only due to the fact that RQD considers solely sound core pieces, but also for the necessity to assess discontinuities associated with zero tensile strength.

The correlation between RQD and Jv is also introduced in the Q classification system proposed by Barton et al. in 1974 [10]. With regard to Figure 5 related to the results from core logging of a 223 m long core drill hole in gneiss mainly with few joints and large block sizes, the correlation Jv – RQD is fairly poor. This finding is particularly true considering the core pieces with lengths around 100 mm.

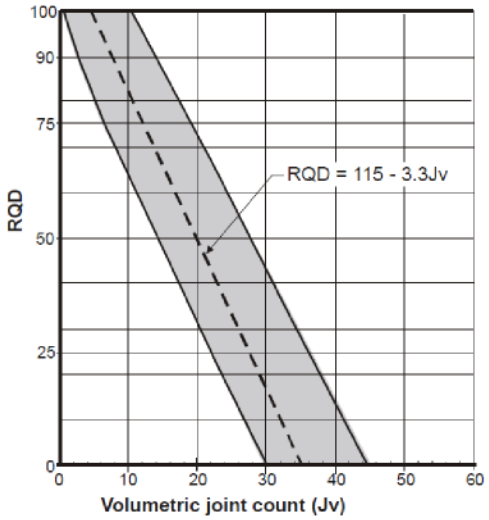


Figure 5: Correlation of RQD and Jv with the variation range (modified into linear scale for Jv, after Palmstrom, 1974) [4]

This correlation was further investigated by Sen and Eisa (1991) [4] considering various sizes and shapes of rock blocks. The RQD values exhibit a significant variation for the different types of blocks, as well as a reduction with increasing difference between the lengths of the block sides, i.e. distance between joints (Fig. 6).

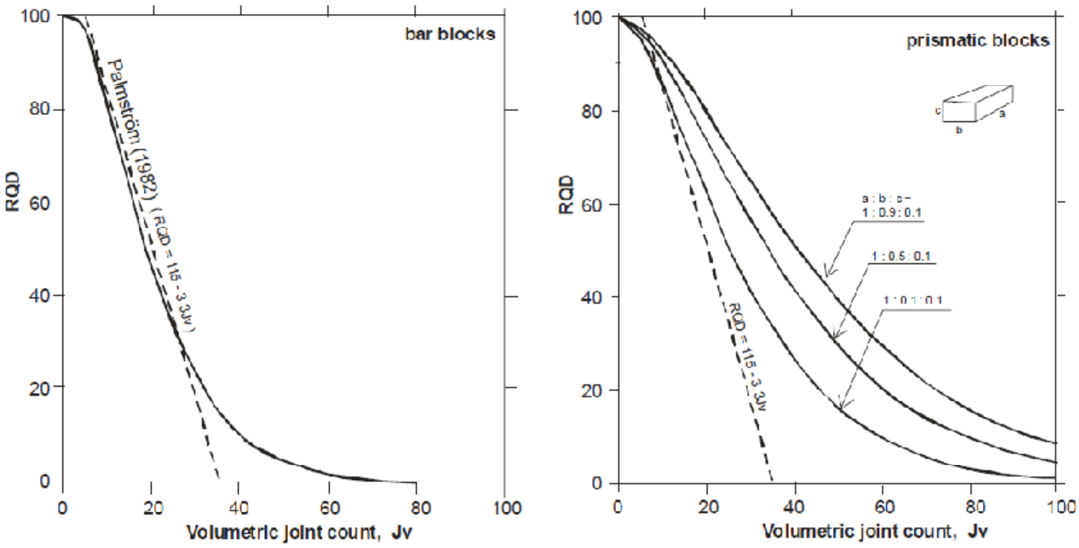


Figure 6: Correlation of RQD and Jv after Sen and Eissa (1991) for bar blocks (left) and for prismatic blocks (right) [4]

2.3. Directionality

RQD is also related to the angle between the directions of a borehole (sample) and a crack (fracture) [7]. On one hand, a core with a discontinuity extending along it is considered solid (Fig. 1). On the other hand, the spacing between the fractures is subjected to directional bias. Assuming that all the fractures are parallel planes aligned along a single direction (Fig. 7a) and considering two consecutive fractures (Fig. 7b), the spacing measured along the sample direction (direction N^o 1) is l_1, whereas the joint intercept measured along the direction N^o 2, perpendicularly to the fracture direction and independently of the sample direction, actually attains $l_1\sin\theta$. By invoking this correction to each segment (Fig. 7c), it should be noticed that it cannot be applied directly to their sum with the common factor $\sin\theta$, having in mind that after correction some segments appear to be shorter than 10 cm (for instance, the case of segment l_2 in Figure 7c) and according to the principle upon which determination of the RQD index is established, they should be excluded from the summation. In three dimensions, this problem is of immensely complex nature, considering that a direction is defined by two angles (azimuth and dip). In practice, only the angle between the fracture and the sample is roughly evaluated on the samples.

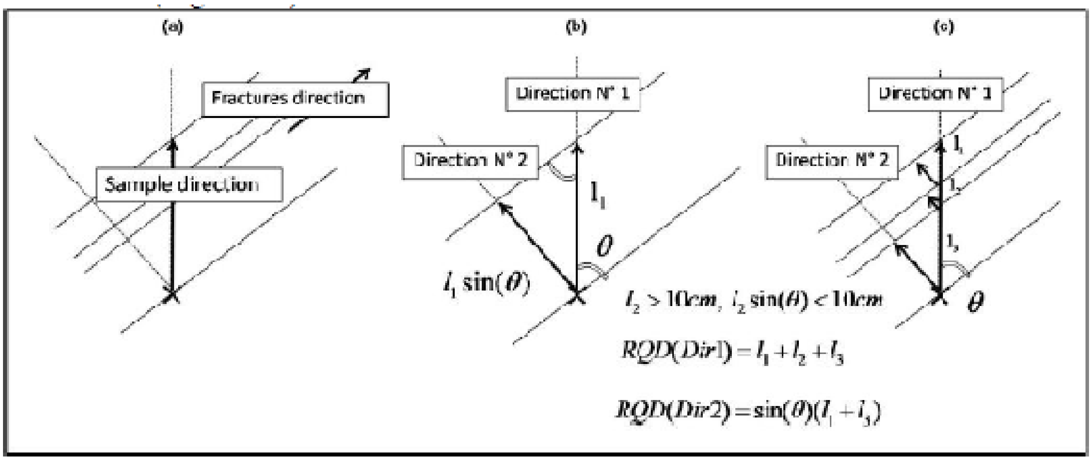


Figure 7: RQD directionality [7]

3. FIELD STUDIES

Recently, Pells and Pells (2014) have studied mapping and rock mass classification of seventeen structural regions, based on field work considering a number of various rocks in unlined spillways of major dams in South Africa. The research results have revealed the substantial problems in relation to assessing RQD from exposures. These same rock exposures had been previously investigated independently by van Schalkwyk et al. (1994). A comparison of the RQD values determined from these two studies is shown in Figure 8, indicating a huge discrepancy in the interpreted results [8].

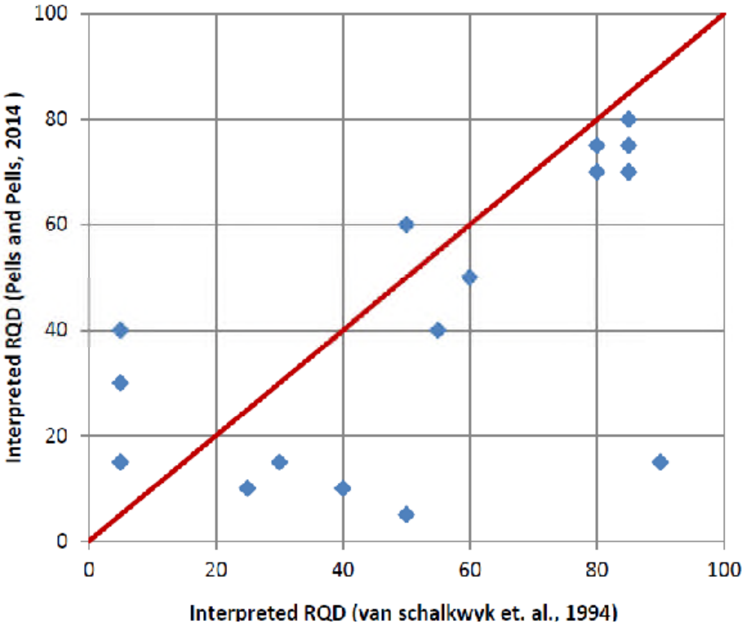


Figure 8: Comparison of interpreted RQD values at various unlined spillway sites, Pells and Pells (2014) and van Schalkwyk et al. (1994) [8]

Another field study with data collection was performed in Australia [8], in which 13 practicing professionals were asked to independently classify three different sites in the Sydney area – a diatreme, an exposure typical of Hawkesbury Sandstone, and Hawkesbury Sandstone altered to columnar jointing adjacent to a dolerite dyke (Fig. 9). The range of interpreted RQD values at these exposures is presented in Figure 10.

Figure 9: Hawkesbury Sandstone with non-typical orthogonal discontinuities influenced by adjacent dyke (West Pymble Quarry) [8]

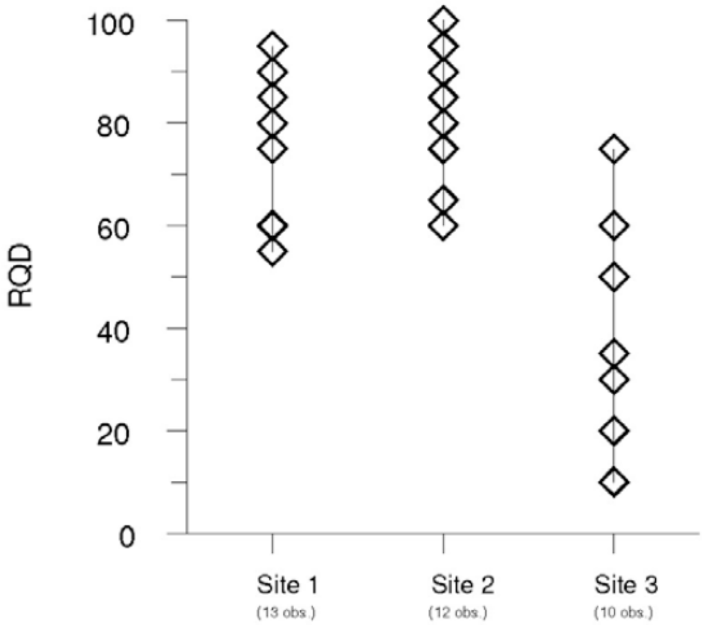


Figure 10: The range of RQD values interpreted by independent professionals at three rock exposures in Sydney [8]

The above presented field researches showed that the variation in the interpreted RQD values, assessed by multiple professionals, was quite great, which can be considered as errors. Accordingly, in situations when cored borehole data are not available and RQD has to be estimated from exposures, radar, or photographs, it should not be overlooked that this process is associated with error and personal bias.

4. RQD IN ROCK MASS CLASSIFICATION SYSTEMS

The RQD index is used as one of the basic elements of the two major contemporary classification systems of rock masses: the RMR (rock mass rating) classification suggested by Bieniawski in 1973 [9] and the Q classification proposed by Barton et al. in 1974 [10]. Both systems are widely applied nowadays in engineering practice for design of tunnels, mines, rock slopes, and foundations, as well as for assessment of rock excavation and erosion.

Considering the both aforementioned classification systems, the RQD index has been modified to some extent by incorporating other factors that have influence upon rock mass strength and stiffness. As to the RMR classification system, Bieniawski modified the RQD index by assigning a rating to this index, and then combined this with ratings for strength, discontinuity orientations and conditions, and groundwater pressures. In defining the Q-rate, Barton et al. modified the RQD index by reducing it for the number of joint sets (RQD/Jn), and then incorporated joint roughness, joint alteration (Jr/Ja), and rock load and water pressures (Jw/SRF).

Yet, after 40 years of application, Lowson and Bieniawski (2013) [7] recommended that RQD index should not be used in the RMR classification system, explaining that "this parameter was included originally among the six RMR parameters because the case histories collected in 1972 all involved RQD. Over the years it became apparent that RQD was difficult to determine at tunnel face, being directed to borehole characterisation. For the best practical use, this led to the preferred use of "fracture frequency" as an inverse of "fracture density". Neither of these approaches changed the basic allocation of rating values to these parameters."

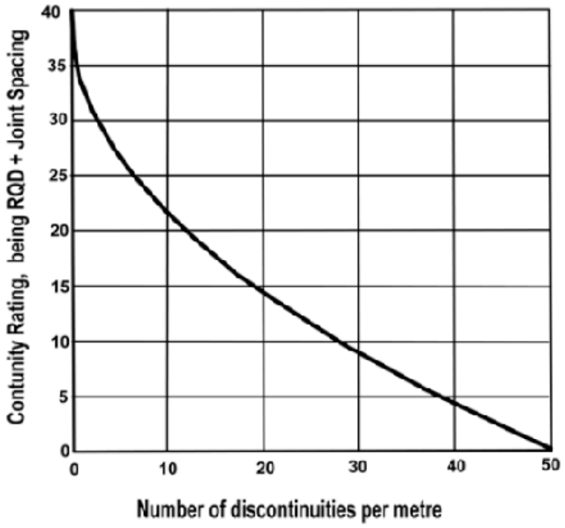


Figure 11: Combined rating of the discontinuity density parameters RQD plus discontinuity spacing (after Lowson and Bieniawski, 2013) [7]

Some of Bieniawski's RMR parameters were used by Hoek (Hoek, 1994; Hoek, Kaiser, and Bawden, 1995) in order to create the Geological Strength Index (GSI) that enables estimation of rock mass shear strength in accordance with the Hoek-Brown failure criterion (Hoek and Brown, 1988). The GSI index also took into consideration the RQD index, because it required to be computed from the numerical values in the 1976 version of Bieniawski's RMR, however, considering groundwater a value of 10 was always assigned. In 1995 Hoek, Kaiser, and Bawden proposed the same equation, introducing Q' that comprises the first two parts of Barton's Q index and relating Q' to GSI [10]:

$$Q' = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \tag{5}$$

where: J_n – the joint set number;
J_r – the joint roughness number;
J_a – the joint alteration number.

5. INFLUENCE OF RQD VARIABILITY UPON ROCK MASS INDEX INTERPRETATION

Taking into consideration that great majority of rock mass classification indices is determined on the basis of the RQD index, the question that arises is what error in a rock mass index will result from a certain error in RQD.

With regard to the RMR classification system, in which RQD is not used directly, but rather as a rating, by running hundreds of practical scenarios, it has been found that ±30% variation in RQD will result mostly in less than 6% error in RMR. Exceptions are extreme cases such as high water pressures or unfavourable discontinuity orientations, where an underestimation of an already low RQD of 30% causes an error of about 25%.

Considering the Barton's equation for the Q-rate, it is evident that any % error in the RQD-value produces an equal % error in the Q-value.

When it comes to the GSI index, having in mind that originally this rock mass identifier was RMR without considering the groundwater and discontinuity orientation factors, the conclusion that can be drawn is that within a GSI range of 10 to 100, a 30% error in RQD affects the error in GSI up to 5%.

This is exactly the point where the significance of accuracy of the RQD index evaluation becomes pronounced. Namely, there is an observable discrepancy amongst the resulting quantitative rock mass parameters attributed to a great variability in the RQD values interpreted by a number of professionals in the aforementioned field studies in South Africa and Australia (Section 3). This inconsistency in the interpreted RQD values yields an error that cannot be tolerated and disturbs the confidence in application of the quantitative rock mass classifications.

6. CONCLUDING REMARKS

Considering the methodology for determining the RQD index originally proposed by Deere in 1964, it is notable that in different countries of the world there is a great variety in the definitions of RQD that are no longer consistent with the original definition.

Majority of the contemporary classification systems such as RMR, Q, GSI, and MRMR are based on assessment of the RQD index from exposures. However, it’s turned out that this process is associated with personal bias and error that cannot be tolerated and put into disorder the reliance in application of the quantitative rock mass classification systems.

Recently, the limitations of the RQD index have met with criticism by the inventors of the RMR and MRMR systems, who have recommended its replacement by a more convenient parameter in the form of fracture frequency.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support of the Ministry of Education, Science, and Technological Development of the Republic of Serbia in the framework of the scientific–research projects TR 36028 and TR 36043 (2011-2017).

REFERENCES

[1] Deere, D. U.: *Rock quality designation (RQD) after 20 years*, U.S. Army Corps Engrs. Contract Report GL-89-1. Vicksburg, MS: Waterways Experimental Station, 1989.
[2] Hencher, S.R.*: Practical Rock Mechanics*, Taylor & Francis group, London, 2015.
[3] Hencher, S. R.: *Characterising discontinuities in naturally fractured outcrop analogues and rock core: the need to consider fracture development over geological time*, Geological Society of London Special Publication 374, Advances in the Study of Fractured Reservoirs, pp. 113-123, 2014.
[4] Palmstrom, A.: *Measurements of and correlations between block size and rock quality designation (RQD)*, Tunnelling and Underground Space Technology, Vol. 20, pp. 362-377, 2005.
[5] Priest, S. D., Hudson, J. A.: *Discontinuity spacings in rock*, J. Rock Mech. Min. Sci. & Geomech., Vol. 13, Pergamon Press, Great Britain, pp. 135-148, 1976.
[6] Hudson, J.A., Priest, S.D.,: *Discontinuities and rock mass geometry,* Int. J. Rock Mech. Min. Sci & Geomech. Abstr., Vol 16, 1979, pp 339 – 362, 1979.
[7] Seguret, S. A., Guajardo, C.: *Geostatistical evaluation of rock-quality designation and its link with linear fracture frequency*, 17th Annual Conference of the International Association for Mathematical Geosciences, Freiberg, Germany, September 5–13, 2015.
[8] Pells, P. J., Bieniawski, Z. T., Hencher, S. R., Pells, S. E.: *RQD: time to rest in peace,* Canadian Geotechnical Journal, 54, pp. 825–834, 2016.
[9] Bieniawski, Z. T.: *Engineering classification of jointed rock masses*, Trans. S. Afr. Inst. Civil Eng., Vol. 15, pp. 335-344, 1973.
[10] Barton, N. R., Lien, R., Lunde, J.: *Engineering classification of rock masses for the design of tunnel support*, Rock Mechanics, Vol. 6, No. 4, pp. 189-236, 1974.
[11] Hencher, S. R. : *The new British and European standard guidance on rock descrip*tion, Ground Engineering, 41, No.7, pp. 17-21, 2008.