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Communication

Introducing Coefficients of Curvature (C_c) and Uniformity (C_u) Based on RQD for Rock Mass Characterization

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Abstract: This paper proposes a novel approach to rock mass characterization by adapting the coefficient of uniformity (C_u) and coefficient of curvature (C_c) from soil mechanics, redefining their mathematical formulations to align with RQD-based block size measurements. Specifically, C_u and C_c are calculated using D_{10}, D_{30}, and D_{60}, derived from cumulative RQD data, while accounting for the increasing scale of block size distributions in rock masses. An illustrative case study demonstrates the application of this method, yielding insights into block size variability and heterogeneity in rock masses. The proposed coefficients enrich rock mass classification, offering enhanced quantitative tools for engineering and geological analyses.

Keywords: RQD; coefficient of uniformity (C_u); coefficient of curvature (C_c); Rock mass

1. Introduction

Soil classification often relies on particle size distribution, described by coefficient of uniformity (C_u) and coefficient of curvature (C_c). These parameters provide insights into gradation, sorting, and mechanical behavior of soils. Rock masses, however, are traditionally classified using parameters like Rock Quality Designation (RQD), joint spacing, and fracture patterns. The RQD value was introduced to provide a quantitative estimate of rock mass quality from drill core logs for engineering geological and rock engineering analysis of the drill core 60 years ago by Deere [1,2]. According to the original definition, RQD is defined as the percentage of intact drill core pieces longer than 10 cm recovered during a single core run. The value of RQD is calculated using the following equation:

$$\mathrm{RQD} = \frac{\Sigma h_{10}}{h_b - h_a} 100\ [\%] \tag{1}$$

where Σh_{10} is the total length of the pieces longer than 10 cm, and h_b and h_a are the upper and the lower depths of depth intervals.

One of the basic problems of the RQD value is that it does not distinguish different rock cores longer than 10 cm [3]. The current methods for describing rock masses lack metrics analogous to C_u and C_c, which could potentially provide additional insights into block size variability and distribution. There is a question of whether soil classification principles can be adapted for rock mass descriptions using RQD and block size distributions. The goal of this paper is to explore the feasibility of introducing C_u and C_c for rock masses, redefined based on RQD-derived block size measurements, while considering modifications to their mathematical formulation.

2. "n" Rock Quality Designation (RQDn)

Somodi and Vásárhelyi [4] suggested introducing the RQD_n values, which can be calculated similar to RQD, but *n* depend on the investigated core-length:

$$\mathrm{RQD}_n = \frac{\Sigma h_n}{h_b - h_a} 100[\%] \tag{2}$$

where Σh_n is the total length of the pieces longer than n cm, and hb and ha are the upper and lower depths of the depth intervals.

The value of *n* in this equation can be arbitrary, but for engineering reasons, they suggested examining the total length of 10, 20, 30 … 100 cm pieces of core after 5 cm. Figure 1 shows an example where the RQD_n values are plotting in the function of *n* (cm). According to their analysis, the shape of the curves depends on the rock quality. They also suggested introducing the $\mathrm{RQD}_{10\%}$ value, which gives the core length corresponding to the 10% value (see Figure 1).

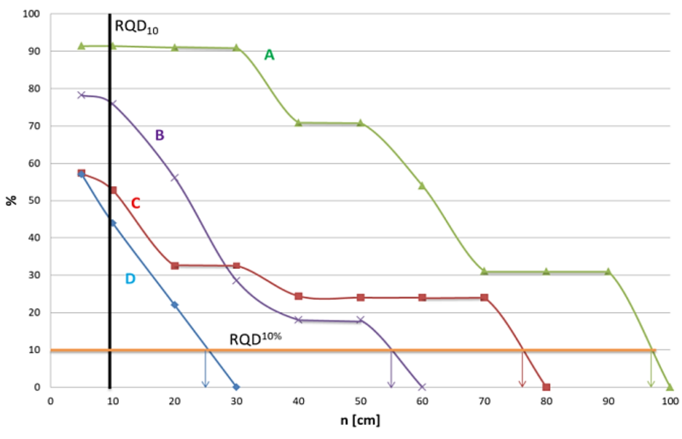

Fig. 1. Plots of different *n* values for the tested 3 m long core sections [4].

3. Methodology

A particle-size distribution curve can be used to determine C_u and C_c for a given soil (see Figure 2). C_u and C_c is defined as equations (3) and (4), respectively:

$$C_u = \frac{D_{60}}{D_{100}} \tag{3}$$

$$C_c = \frac{D_{30}^2}{D_{60} * D_{10}} \tag{4}$$

where, D_{60}, D_{30}, and D_{10} represent particle sizes corresponding to 60%, 30%, and 10% passing, respectively, in a cumulative size distribution curve [5].

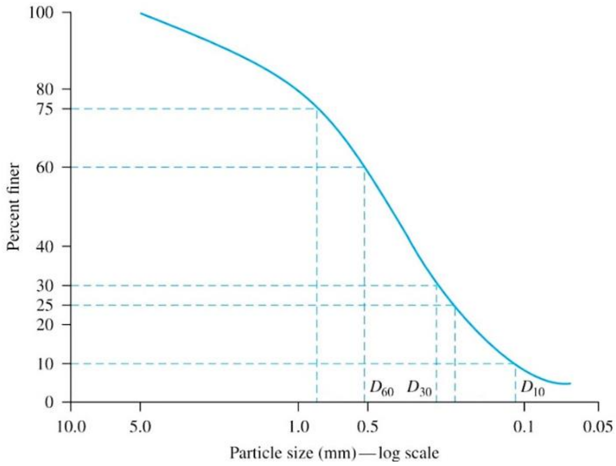

Fig. 2. Definition of D_{60}, D_{30}, and D_{10} [5].

4. Applicability to Rock Masses

For rock masses, block size distribution is derived from RQD measurements or fracture spacing. These parameters can replace particle size measurements in soil mechanics. However, some modifications need to be applied and new definitions are proposed for rock mass as below.

Reverse the soil formula for C_u to reflect the increase in the x-axis scale for rock size distributions:

$$C_u = \frac{D_{10}}{D_{60}} \tag{5}$$

Adjust C_c to emphasize different variability trends in rock masses:

$$C_c = \frac{D_{60} * D_{10}}{D_{30}^2} \tag{6}$$

where D_{10}, D_{30}, and D_{60} using cumulative RQD data are defined as below and distribution curve can be prepared based on recovered core lengths. D_{10}: Block size below which 10 % of the data lies; D_{30}: Block size below which 30 % of the data lies; D_{60}: Block size below which 60 % of the data lies.

5. Example Calculations from Data

The analyzed data originated from exploration boreholes drilled in the Carboniferous Mórágy Granite Formation (MGF), selected as host rock of the repository of low- and intermediate-level radioactive wastes. The Bátaapáti radioactive waste repository is found in a slightly metamorphosed-granitoid rock type of Carboniferous age, the Mórágy Granite Formation in South Hungary [4,6]. The number of 23 boreholes with diameter of 63.5 mm diameter were drilled. Eight of them were of depths between 300–411 m. In underground research program, 100–150 m long research boreholes were drilled in the axis of tunnel driving or in other directions with the aim of geological, hydrogeological, geotechnical research concepts. Figure 3 shows rock core photographs demonstrating typical fractured conditions of the cores drilled in monzogranite type rock. Figure 4 shows how the RQD values interpreted for the original 10 cm length compare with the core lengths varies for different RQD_n values.

However, due to the geological and tectonic history of the Mórágyi Formation described above, the rock mechanics-geotechnical parameters are extremely inhomogeneous, thus their spatial extension on the site is rather limited. One of the primary factors in this limitation is the presence of the wide, clayey fracture zones. Table 1 shows the different coefficient values for the tested 3 m long core sections.

Table 1. The coefficient values for the sample in Figure 1.

	D_{60} (cm)	D_{30} (cm)	D_{10} (cm)	C_u	C_c
A	58	82	97	1.67	0.83
B	19	30	55	2.89	1.16
C	4	33	75	18.75	0.28
D	5	16	25	5	0.48

According to the obtained values for D_{60}, D_{30} and D_{10} from Figure 4, we can calculate the coefficients as below:

Coefficient of uniformity (C_u=75/4 = 18.75)

Coefficient of curvature (C_c=4*75/33^2 = 0.28)

Figure 3. Rock cores with different fracture density of the Mórágy Granite Formation.

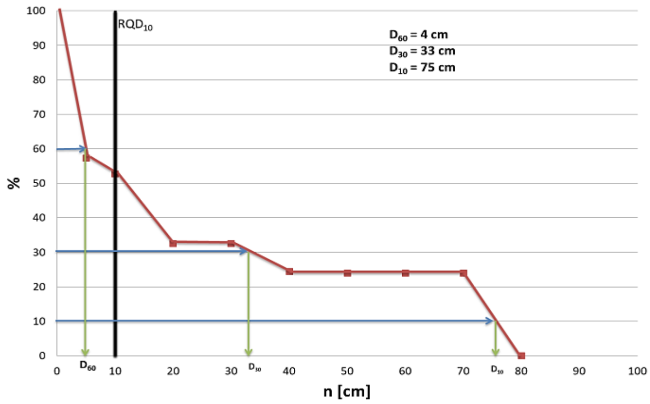

Fig. 4. Relationship between RQD_{10} and RQD_n and definition of D_{60}, D_{30}, and D_{10}.

6. Conclusions

This study has introduced an innovative adaptation of soil classification principles, specifically the coefficients of uniformity (C_u) and curvature (C_c), to rock mass characterization based on Rock Quality Designation (RQD). By redefining C_u and C_c to accommodate the unique characteristics of block size distributions in rock masses, this work provides a novel framework for evaluating the variability and gradation of rock fragments. The approach reverses the traditional formulas used in soil mechanics to reflect the increasing scale of block size distributions in rock masses, offering a meaningful correlation between RQD-derived metrics and the heterogeneity of rock masses. The case study applied to the Carboniferous Mórágy Granite Formation demonstrates the feasibility and utility of this methodology. The derived C_u values indicate the degree of variability in block size distributions, with higher values signifying poorly sorted, heterogeneous distributions. The C_c values further enhance the characterization by capturing the uniformity of the block size distribution, with lower values suggesting non-uniformity. Together, these coefficients provide a more nuanced and quantitative understanding of rock mass gradation, complementing traditional metrics like RQD and joint spacing. The proposed method fills a critical gap in rock mass classification, bridging the conceptual divide between soil and rock mechanics. This work lays the foundation for further exploration and refinement of these coefficients in diverse geological contexts.

Author contributions

Conceptualization, B.V.; methodology, B.V.; validation, S.N. and M.S.; formal analysis, S.M.D.; investigation, S.N.; writing-original draft, S.M.D. and M.S.; preparation, S.M.D.; writing – review and editing, B.V.; supervision, B.V. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

Data availability

All relevant data related to this manuscript are available and can be provided upon reasonable request.

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