A critical look to the practical use of Rock Mass Rating (RMR) and Slope Mass Rating (SMR)

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ABSTRACT: RMR and SMR are two of the most applied classifications for tunnels and slopes, respectively, excavated in rock masses. Five parameters are used to compute the basic RMR classification for each discontinuity set. However, it is not clarified the whole Rock Mass RMR value. Here, the rock engineering community interprets the possibilities of calculating RMR in different ways. In addition, given that SMR is calculated from RMR by adding four correction factors, different interpretations arise. In this work, different cases of rock masses were analysed and both indexes, RMR and SMR, were assessed using different interpretations of RMR calculations. From this analysis, it can be concluded that, occasionally, there is a significant difference in the RMR and SMR values obtained depending on the followed procedure.

Keywords: RMR, SMR, rock engineering, interpretation criteria, critical look.

1 INTRODUCTION

Assessing the stress-strain behaviour of a rock mass is a complex task which has not been conveniently solved to date. It is well known that the strength of the rock mass is a function of the strength of the intact rock, the shear strength of the discontinuities, the structure of the rock mass and the geo-environmental conditions to which the rock mass is subjected, mainly, in situ stress and hydrogeological conditions.

The establishment of the whole behaviour of discontinuities and intact rock is a complicated task. However, there is a vast experience acquired on successful and failed construction practices depending on the state of the rock masses. The needed information comprises the properties of the intact rock along with the discontinuities, and the structure. The application of this experience makes it possible to determine which properties are more important and which others are less important to predict whether a rock mass will behave properly during and after a geotechnical work. This led to the birth of rock mass classifications.

Rock mass classifications enable assigning a quality index to the rock mass, estimating its behaviour, and proposing support measures for proper functioning. Specifically, the Rock Mass Rating (RMR) system was introduced 50 years ago by Professor Bieniawski (Bieniawski 1973) and was later updated in 1989 (Bieniawski 1989). From then until today, its intensive use has allowed a relative homogenisation of criteria of a complex problem as the characterisation of rock masses, facilitating communication between geologists and engineers.

With underground works, the RMR (Bieniawski 1989) and Q (Barton et al., 1974) indexes are the most used rock mass classifications. However, the direct application of the RMR index is difficult for slopes, since the correction factors are not precisely defined. In contrast, the SMR geomechanical classification (Romana, 1985) defines these correction factors, being one of the most widely used index worldwide (Romana et al. 2015). This classification is derived from the basic (RMRb) or RMR (Bieniawski 1989) and is calculated using four adjustment factors which depend on the geometric relationship between the discontinuities and the studied slope, as well as the excavation method.

More recently (Celada et al., 2014), various authors, including Bieniawski, introduced some modifications to the classic RMR (Bieniawski 1989), highlighting a modification in the criteria for calculating the RMRb by substituting the assessment of the RQD and the spacing of the discontinuities by evaluating the number of joints per meter in the excavation's face and expanding the evaluation criteria of the characteristics of the discontinuities.

In this work, the RMRb has been assessed for two examples previously published in two well-known rock mechanic textbooks using different approaches to the problem. The RMRb assessed has been then used for calculating, the RMR for a tunnel and the SMR for a slope. In addition, four expert users have solved the same case studies without knowing the original solution included in the textbook. The aim of this work is to humbly contribute to highlight the different currents that exist when applying these geomechanical quality indexes, analyse the differences through the rating obtained and raise reasonable doubts to rock mass classifications. Likewise, some reflections are made on the importance of homogenization or even the proposal of guidelines, for a better understanding among the specialists involved in geotechnical projects in rock masses.

2 METHODOLOGY

As aforementioned, this paper analyzes two practical problems published in two rock mechanics textbooks: “Engineering Rock Mechanics. Part 2: Illustrative Worked Examples” (Harrison and Hudson 2000) and “*Problemas de Mecánica de Rocas. Fundamentos e Ingeniería de Taludes*” (Arzúa *et al*. 2015).

The work begins by analyzing the methodology used by the authors of each of the proposed case studies. Subsequently, each case study is solved by using the other authors’ method. Likewise, both case studies have been solved by four of the authors of this work, independently and without knowing the solution published in the textbooks.

Case study 1 (Harrison and Hudson, 2000), develops in a mudstone rock mass with three sets of joints. It is projected to excavate a westward tunnel at a depth of 200 m.

Case study 2 (Arzúa et al. 2015), applies to a granodiorite quarry in which two sets of discontinuities, whose characteristics are presented by the authors, are recorded. Here, the basic RMR (RMRb) is calculated and the RMR for an underground mine at a depth of 120 m and a direction N10W is evaluated. In addition, it is also proposed to calculate the SMR for a quarry front whose orientation is (90/070).

3 RESULTS AND DISCUSSION

First, case study 1 is analysed. As is well known, five parameters are used to compute the basic RMR: uniaxial compression strength, rock quality designation (RQD), spacing, condition of discontinuities and groundwater conditions. All these parameters are rated to obtain the basic RMR (Bieniawski 1989). This value is then corrected by considering the orientation of the joints with respect to the tunnel direction to determine the final value of the RMR.

In this example, there are three sets of joints, so the RMR system must be assessed for each of them and identify the most critical set for this specific tunnel. Some parameters, such as the uniaxial compression strength of intact rock or the RQD, are general for the whole rock mass. However, the parameters that refer to the spacing or the state of the joints are independent for each set, although they are sometimes unified.

Since the uniaxial compression strength is 55 MPa, the authors establish a conservative value of X1= 6, although using the tables, a value of X1= 7 would strictly correspond to it. On the other hand, since at 200 m depth the vertical stress will be approximately 5 MPa, it is assumed that all the joints will be closed, so the groundwater flow through the joints will probably be between damp to wet, with rating values ranging from 7 to 10, instead of a single value (X5= 7 to 10).

For an RQD= 60%, it is assigned a value of X2= 12, although, if the original table is used, it should be assigned a value of X2= 13. In addition, an average value of the spacing of 0.4 m is set for all the discontinuity sets, so it is taken as X3= 10. Next, the authors calculate the value of RMRb and RMR for each set of discontinuities as described below:

Classification using set 1: The bedding planes are highly weathered, slightly rough and continuous. An aperture of less than 0.1 mm is assumed and, therefore, no fill is presumed. This implies adopting a value of the discontinuity conditions X4= 1+3+0+5+6= 15. Therefore, the value of the basic RMR of the rock mass is RMRb= 6+12+10+15+(7 to 10) = 50 to 53. After correcting for the orientation of the set with respect to the tunnel (-5), an RMR = 45 to 48 is obtained.

Classification using set 2: These joints are slightly weathered (rating value= 5), they are slightly rough (rating value= 3) and their persistence will probably be in the range of 1 to 2 m (an appropriate rating value for this is 2, although, according to the original table, the rating value would be 4). Regarding the aperture and infilling, they have the same characteristics as the previous set, so values of 5 and 6 are adopted, respectively. So X4= 5+3+2+5+6= 21 and, therefore, the following RMRb value were obtained: RMRb= 6+12+10+21+(7 to10) = 56 to 59. After discontinuity/tunnel orientation adjustment (-12), RMR values between 44 and 47 are obtained.

Classification using set 3: The joints representing set 3 have the same mechanical characteristics as set 2, and then RMR_b= 56 to 59. After orientation rating adjustment (-5) an RMR between 51 and 54 is obtained.

The results indicate that set 2 leads to the most critical score, with an RMR_{tunnel}= 44 to 47.

In the second case study, the uniaxial compression strength is 73.74 MPa, so, X1= 7 and, for RDQ of 95%, X2= 20. Regarding the spacing, it should be noted that here the authors take a balanced average value of X3 for each joint and then, an average value for both joints is adopted, X3= 12. The condition of discontinuities, evaluated based on persistence, aperture, roughness, infilling and weathering surface, is initially obtained for each joint, where X4(J1)= 1+4+3+4+5= 17 and X4(J2)= 4.6+6+5+6+6=27.6, although, later, it is averaged, considering a single value, X4= 22. Likewise, the groundwater condition is averaged, where X5= (10+15)/2= 12.5. The basic RMR is obtained as the sum of the five previous factors, RMR_b= 73.5. The orientation rating adjustment factor, X6, will be different for each joint, thus X6(J1)= 0 and X6(J2)= -5. The authors propose to perform an average adjustment, thus RMR= 73.5-2.5=71, although it is also noted that the most unfavourable value could be taken.

As seen, both approaches are different. These two problems have been proposed to four practitioners of rock mass classifications, and each one of them addressed the problem differently, but none of them followed the above-described approaches. Finally, both reference case studies have been solved using the approaches described in the textbooks.

When case 1 is solved with the approach proposed by Arzúa et al. (2015), RMRb and RMR provide total scores of 58.8 and 51.5, respectively.

The practitioner one assigns scores via the tables, averages only the groundwater condition, calculates an RMRb for each joint, and chooses the most unfavourable value as the RMRb of the rock mass. The orientation rating adjustment of the three joints applies to this unique RMRb and the lowest of the three results is considered as the RMR: RMRb= 53 and RMR= 41. The fourth practitioner adopts a similar solution, but the only difference is that he works with ranges instead of with averaged values. The results obtained are RMRb= 52 to 55 and RMR= 40 to 43.

The practitioner two, considers the rates through the continuous charts for strength, RQD and spacing (Bieniawski, 1989). He analyzes the rating of each joint individually, calculates the basic RMR of each joint and applies the joint/tunnel orientation adjustment to this value. He does not average any value, working with ranges, even the RMRb and RMR values are presented in a range of values that cover all the joints. The final design will be more or less conservative based on his knowledge of the rock formation, risk, etc., being their results RMRb= 50 to 62 and RMR= 44 to 57.

The third practitioner considers rates the parameters using Bieniawski's tables, assesses the groundwater condition considering the most unfavourable option and takes a global value for the joints' condition. He calculates an RMRb for each joint and chooses the most unfavourable value as the basic RMR of the rock mass. But for the calculation of the RMR of the tunnel, he applies the orientation rating adjustment of the three joints to the respective RMRb and considers the lowest of the three results as the RMR of the tunnel. So, his results are RMRb = 57 and RMR= 50.

From all this, it can be deduced that there are notable differences between the different approaches, which can reach up to ten points.

The second case study, addressed with the approaches of Hudson and Harrison (2000) exhibits results of RMRb= RMR= 65.

The first and fourth practitioners obtain identical values, since they work on specific values, as there are no parameters with different values, and obtain the following results: RMRb=64, RMR=59. The only difference is that the fourth expert rejects the value of the RQD obtained through drilling cores, and recalculates it from Jv (Palmström 1982), although in this case both methods provide the same RQD score. Practitioner two uses the same approach as in the previous case, exhibiting results of RMRb=60 to 83 and RMR=60 to 78. The third practitioner, in this case, disaggregates the rating of the condition of discontinuities., giving a result of RMRb= and RMR= 64. The results of RMR and RMRb obtained by the different experts and the approaches described in the textbooks are summarized in Table 1.

Table 1. Summary of the RMR_b and RMR values for the two case studies, according to different methodologies. P1 to P4 indicates the number of practitioner.

	Authors 1	Authors 2	P1	P2	P3	P4
Case study 1						
RMR_b	56-59	60	53	50-62	57	52-55
RMR	44-47	52	41	44-57	50	40-43
Case study 2						
RMR_b	65	74	64	60-83	64	64
RMR	65	71	59	60-78	64	59

Based on the conditions of the second case study, the calculation of the SMR is proposed for a quarry slope with a 90/065 orientation and considering that a deficient blasting was used for the excavation of the slope. Therefore, the geometric corrections (Romana, 1985) for set 1 will be F1xF2xF3= 0.15x1x(-25)= -3.75 and for the second set F1xF2xF3= 0.7x0.85x(-60) = -35.7. Additionally, the adjustment for the excavation, corresponding to a deficient blasting will be -8.

Authors of the first case study and practitioner 3 propose the geometry adjustment and excavation for each set from individual RMRb (i.e., 36 and 48, respectively) and then take the minimum of the SMR values. The authors of the second case study and practitioners 1 and 4 start from a single RMRb value and apply the reductions to each joint, taking the lowest SMR values for each joint set, that are, 30, 21 and 21, respectively. The second practitioner considers the RMRb of set 2, which is the critical discontinuity set, and applies the adjustments, obtaining an SMR = 38-39.

From this analysis, it can be concluded that there are different ways of approaching the rating value of RMR, considering two main options:

a) Based on a single value of RMRb, representative of the rock mass. This value is subsequently adjusted founded on the orientation of each set of discontinuities.
In this case, for the computing of the RMRb as the single representative value of the rock mass, two main ways are also used:
a1) Individualized computing of the parameters X1 to X5 for each set and ulterior selection of the RMRb value representative of the rock mass, and then to select between three options: minimum value, range of values or critical value.
a2) Calculation of the average values of the parameters X1 to X5 to computing a single value of the RMRb.

b) Based on the individualized calculation of the RMRb for each set, also performing the subsequent adjustment by orientation, individually.

After orientation rating adjustment, by either of the two RMRb computing methods, n RMR values are obtained, one for each set of discontinuities. At this point, you must select the RMR value of the tunnel, which is chosen between these four options: minimum, medium, range or critical value.

Regarding the computing of the SMR, it should be noted that, since the computing of SRM value is also based on RMRb value, the different methodologies coincide with those previously mentioned for the calculation of RMR. Furthermore, it can be said that, by substituting the tunnel orientation adjustment for the Romana's geometric adjustments for each set, the same computing methods are proposed to obtain a SMR representative value for the slope. (Figure 1).

Another critical issue is the computing of the Rock Quality Designation (RQD), originally developed to obtain it from drilling cores. Although it can also be estimated in outcrops from the volumetric joint count (J_v) (Palmström 1982) or the discontinuity frequency per meter (λ) (Priest and Hudson 1976) determined in several scan lines. This is not a minor issue, since the original RQD and the one determined from λ are clearly directional and do not represent the real three-dimensional structure of the rock mass, providing different values to those calculated from J_v.

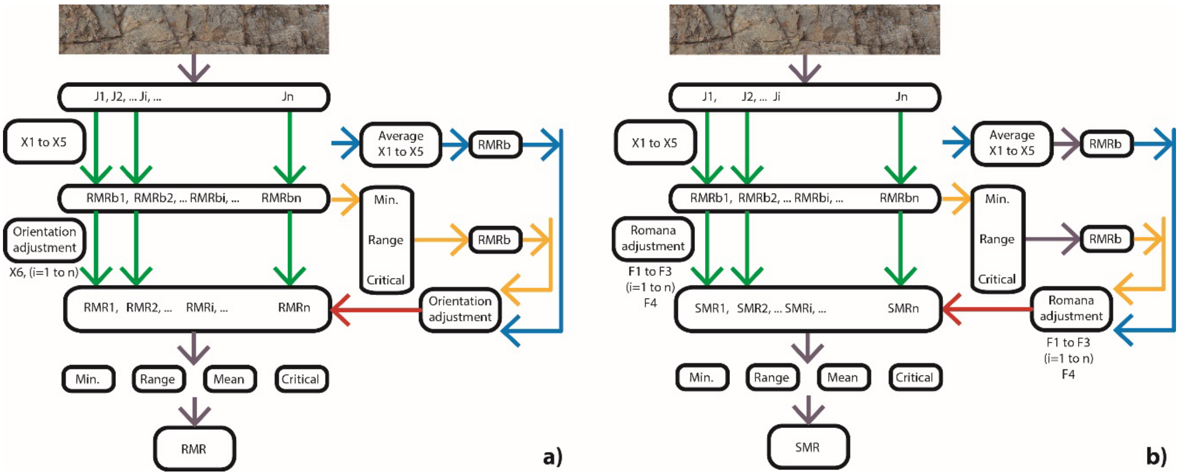

Figure 1. Flow chart of the different approaches used for the calculation of RMRb, RMR and SMR.

4 CONCLUSIONS

Practitioners use different approaches when considering the parameters of the discontinuities that control the stability, as well as when choosing the design value of a parameter in which different options are possible (average value of all of sets, individual parameter for each set or the critical discontinuity parameters).

The drilling core RQD is clearly directional and exhibits conceptual problems for understanding the rock mass structure. If rock mass structure is a key factor for characterising their behaviour, the calculation of the RQD must involve all the existing discontinuity sets. Therefore, the directional calculation methods will be less representative than those obtained from the volumetric joint count.

On the other hand, spacing is also a contradictory parameter, since an average value, individual values for each set of joints or even a unique parameter characteristic of the critical set can be selected.

It has also been observed that some authors use different methodologies for the calculation of the RMRb depending on whether it is used to calculate the RMR or the SMR.

The differences obtained in this study are remarkable, since RMRb exhibits maximum differences of 24% for case 1 and 38% for case 2. On the other hand. the RMR values show high differences too, being 42% for case 1 and 32% for case 2. However, the most noticeable is the difference in SMR calculus with values that oscillate in a range of 90%.

The use of RMR and SMR indexes are commonly applied in tunnels and slopes, respectively. Nevertheless, there are no established standard criteria for the calculation of RMR and SMR. This fact represents a serious difficulty in communication among practitioners.

For all these reasons, it would be necessary to develop a comprehensive study, in which different users of rock mass classifications participate. This would enable practitioners to reach a consensus and establish a systematization and standardization for the application of geomechanical classifications.

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