A 2023 perspective on Rock Mass Classification Systems

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ABSTRACT: Dozens of rock mass classification systems (RMCS) have been developed since the 1950s for applications like tunnelling, mining or rock slopes. The abundance of systems and ongoing discussions amongst scholars and practitioners are symptomatic of the complexity of the problem and show that the community has not converged to commonly accepted procedures. Based on an online survey, this study aims to give an overview of the international spread of RMCS in use. The survey shows that GSI, RMR and the Q-system are the dominating systems in the world for underground engineering- and slope-related applications and thus have managed to prove their practical applicability throughout up to five decades. Conversely, the survey highlights that almost no system developed in the past 25 years has become internationally accepted, thus raising the question of whether today's RMCS can still live up to technological and scientific standards in 2023?

Keywords: Rock Mass Classification, Tunnelling, Slopes, Mining, World Map.

1 INTRODUCTION

Rock mass is a complicated geomaterial that incorporates a variety of discontinuities in nature, and it is thus challenging to derive mechanical properties directly. In practical applications, it is even more difficult to predict the specific location, orientation and mechanical properties of discontinuities. Rock mass classification is imperative to carry out engineering design of underground and surface excavations. This classification was the aim of all the sophisticated schemes and procedures developed throughout decades of rock engineering worldwide. The Rock Mass Rating (Bieniawski, 1973), Q-system (Barton et al., 1974), Basic Quality (BQ) (China Planning Press, 2014), Geological Strength Index (GSI) (Hoek, 1994) or rock mass type classification as part of the NATM (ÖGG, 2021) are just a few approaches towards quantifying and classifying rock mass at present. The wide range of available systems is symptomatic of the complexity of the underlying challenge of rock mass classification. Ongoing technical debates among scholars and practitioners (e.g., Anagnostou and Pimentel (2012)) show that the community has not yet converged to an optimum solution to that problem.

This contribution aims to provide a global overview of the current state of rock mass classification in 2023. To this end, a survey was conducted to find out the international distribution of the usage of RMCS. Besides the popular classifications mentioned above, some new developments are incorporated in the survery, e.g. ARMR and A-BQ for anisotropic rock mass based on original RMR and BQ (Saroglou et al., 2019; Guo et al., 2020). The initial results of this survey are presented in the form of two world maps. The first map represents RMCS used for underground applications (i.e., tunnels, caverns and underground mining) and the second for RMCS of rock slopes, including slopes in the context of civil engineering, mining and natural slopes.

After elaborating on the international distribution, in the last part of the study, rock mass classification methods are discussed with respect to today's scientific standards, methodological developments and available data. Evaluation criteria are, for example, open accessibility of the scientific basis of the classification system, difficulty of application of a system, or reproducibility of individual characterization results. Based on this 2023 perspective on rock mass characterization, possible future developments will be finally addressed.

2 SURVEY AND RESULTS

The survey on the international spread of RMCS was conducted with the online tool "Microsoft Forms" and participants were asked to respond to the following question "Which rock mass classification system have you used in this country/region the most?" with these three sub-questions:

- Select a rock mass classification system (alphabetically sorted) or enter a new one
- Country/region
- Application of system

Participants in the survey could enter as many combinations of RMCS, countries/regions and applications as they want. One combination would be for example: "Q-System" – "Norway" – "Tunnels and Caverns". The survey was open for over two months in autumn 2022 and was advertised on different social media platforms. In total, 798 suggestions were collected for 7 different possible applications: "Tunnels and Caverns", "Slopes – Civil Engineering", "Slopes – Mining", "Slopes – Natural", "Underground Mines", "Foundations" and "Oil and Gas Reservoirs". To simplify the collected results for this contribution, these categories were merged into two main categories: "Underground" which is comprised of: "Tunnels and Caverns" and "Underground Mines"; "Slopes" which is comprised of: "Slopes – Civil Engineering", "Slopes – Mining", "Slopes – Natural". The collected suggestions were processed in a way that the dominating RMCS for a country/region is determined by majority votes in case of multiple different suggestions. In case that more than one system received the same number of votes for one country/region, the whole country/region is set to "tie". A deeper analysis – also including "tie countries/regions"– will be done in a follow up study.

2.1 World map of rock classification systems for underground applications

The world map of rock mass classification systems for underground applications is given in Figure 1. Results for a total of 62 countries/regions were gathered. While there are 21 "tie" countries/regions (indicating a possible disagreement in the community), the most applied system was the Q-system with 20 countries/regions in total and it is followed by RMR in third place with 9 countries/regions.

2.2 World map of rock classification systems for slopes

The world map of rock mass classification systems for slopes in general is given in Figure 2. Results for 70 different countries/regions could have been acquired and the most dominating system is GSI with 24 countries/regions in total. The second place is held by countries/regions in a tie situation (18 countries/regions), followed by RMR and Q-slope (Barton and Bar, 2015) with 11 and 8 countries/regions, respectively.

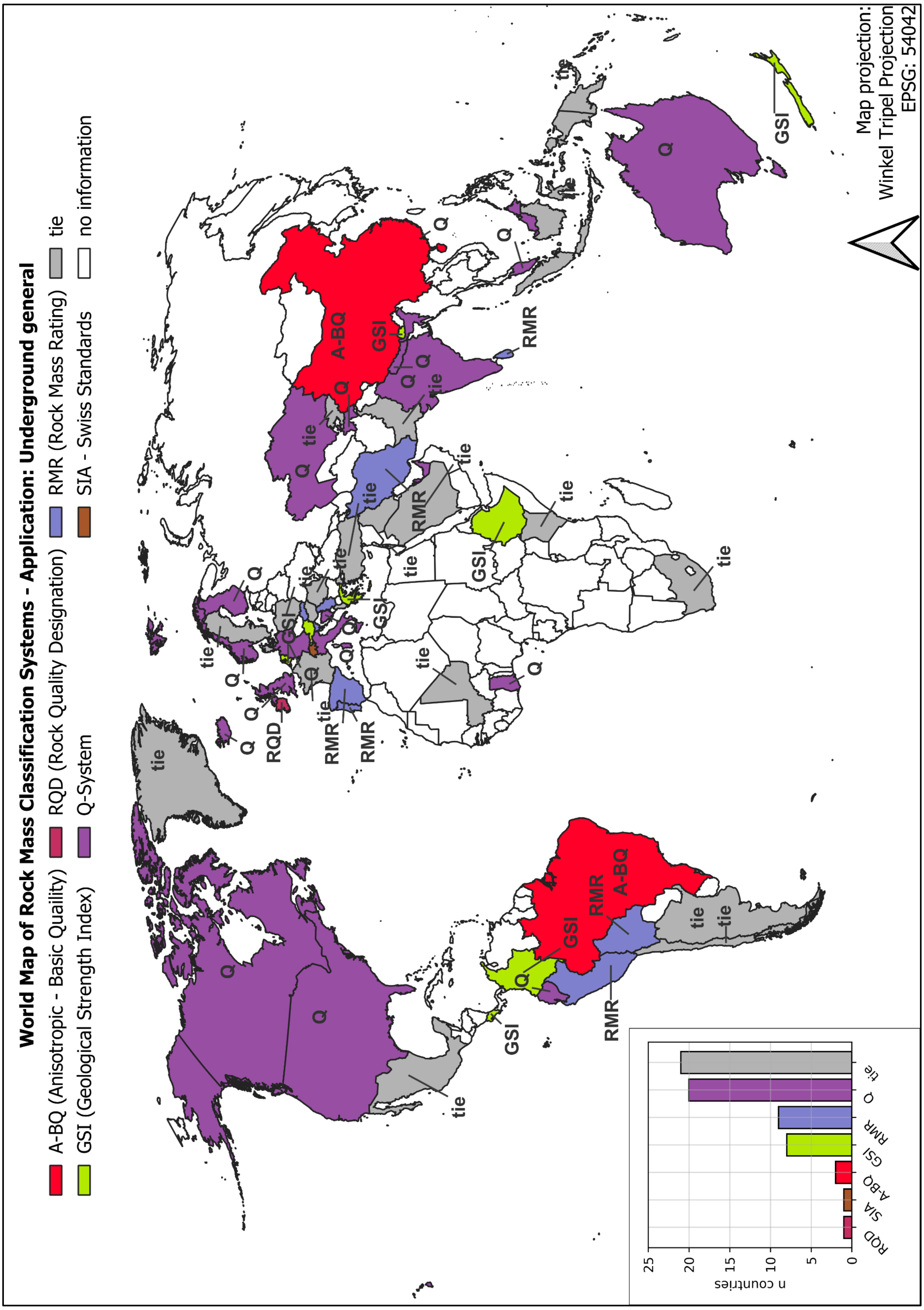

Figure 1. World map of rock mass classification systems for underground applications (i.e., tunnels, caverns, underground mining).

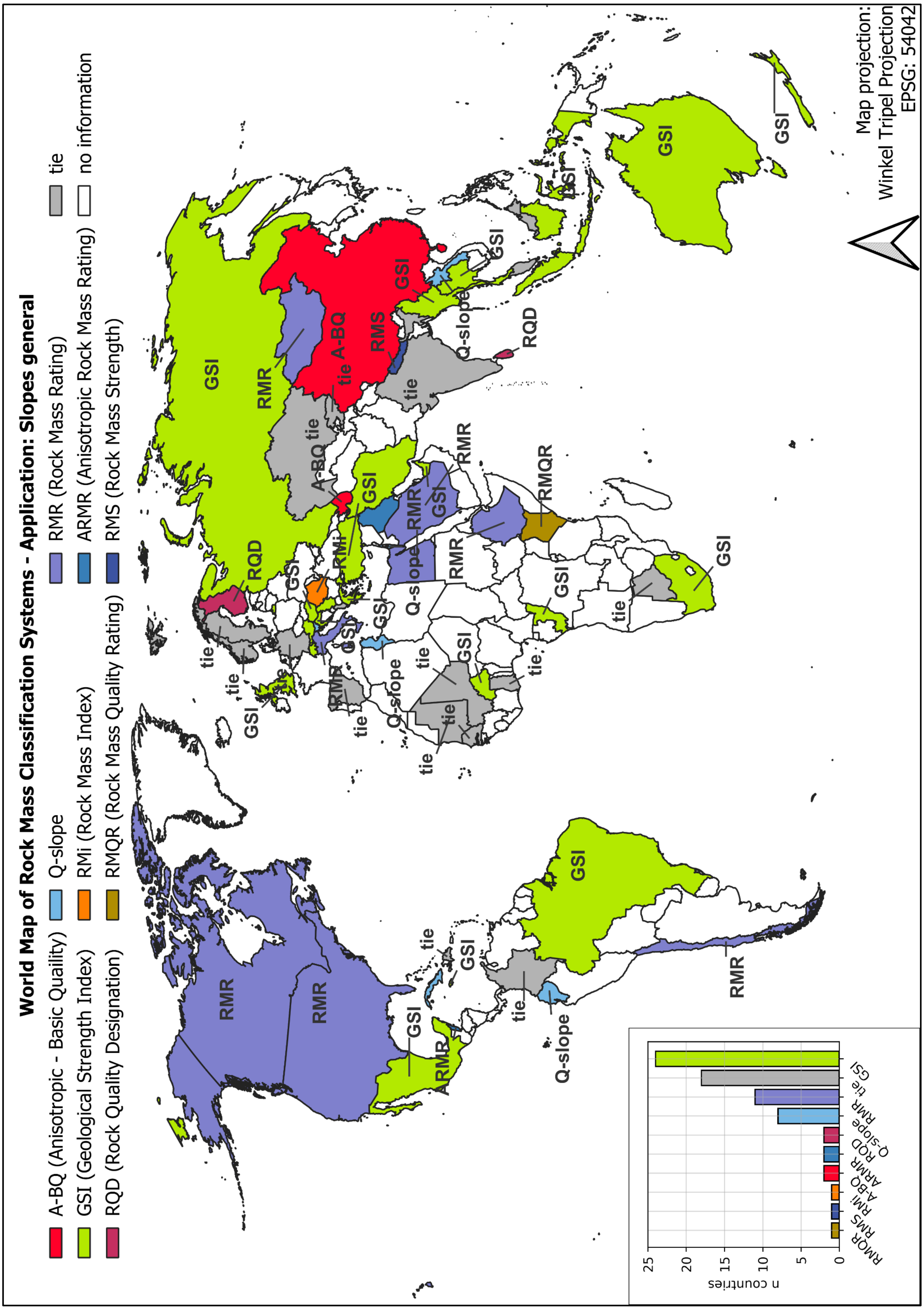

Figure 2. World map of rock mass classification systems for rock slopes, comprising: slopes for civil engineering, mining and natural slopes.

3 DISCUSSION

The survey results from 62 countries/regions indicate that a ‘tie’ was the most common outcome which could be symptomatic of various factors including: (i) the simultaneous use of multiple RMCS for cross-validation on projects; (ii) a possible disagreement in the community; (iii) limited or no governmental regulation, (iv) different international experts bring their preferred system.

Notwithstanding the above, the most frequently used RMCS, except for the more recent Q-slope system, are all at least 25 years old – i.e. Q-system, GSI and RMR. In varying degrees the RMCS introduce some form of bias, subjectivity, and can be based on limited or specific case histories. Examples include:

- Rock Quality Designation (RQD) is subject to sampling bias since it is directionally dependent based on the drilling direction (Deere, 1989).
- Slope Rock Mass Rating (SRMR) was introduced based on case studies from only two locations (Robertson, 1988).
- Slope Stability Assessment Methodology (SSAM) was developed specifically for coal mine slopes (McQuillan et al., 2018).
- Water parameter estimations in both RMR and the Q-system require estimation based on visual inspections and are often very subjective.
- Subjectivity is also prevalent in GSI estimations using the nomographs (charts), particularly between experienced and inexperienced engineers. This often profoundly affects the reproducibility of results for GSI, and some elements in other RMCS.

The introduction of modern technology, such as geophysics, drilling data, scanning and remote sensing for site investigations, has greatly increased data availability and reduces subjectivity for many elements. Although some RMCS have general correlations with and can be supplemented by data from modern technology, they still require validation with physical access to drill core or rock faces for certain elements (Barton, 2002; Bar et al., 2021). No RMCS has yet been developed specifically to integrate with modern massive digital data. Besides, the development of engineering constructions require new classification systems to evaluate some special rock mass, e.g. bimrock.

RMCS include single parameter measurements such as RQD, graphically-derived outputs such as GSI and multi-parameter estimations such as RMR and Q. All RMCS convert engineering geological descriptions to ‘numbers’ that are put onto groups of similar rock mass for engineering purposes. RMCS are a fast and relatively simple means of assessing geomaterials and are supported by several decades of use and experience.

4 CONCLUSION AND OUTLOOK

A survey about the worldwide use of RMCS shows a considerable diversity of systems in use, with no single system covering more than 35% of the 62 assessed countries/regions for underground construction (Q-system used most) and 70 countries/regions for slope assessment (GSI system used most). A second observation is an abundance of "tie"-countries/regions with no single major system in use which will be investigated in more detail in a follow up study.

With an ever-increasing need for underground and slope engineering projects for raw materials and infrastructure and a global shortage of geotechnical engineers, it is foreseen that fast geomaterial assessment methods such as RMCS will continue to be a fundamental approach in the next decades. High requirements for documentation on reproducibility set higher demands on systems in use.

Almost all systems are over 25 years old, in varying degrees subjective, and incorporate none of the available digital big objective datasets that often have been around for decades. Even though more technologically complex datasets like scanning and sensor-based drilling data are not available worldwide, the whole world's surface is covered by satellite-based remote sensing data. In underground construction, the high-resolution image data from a standard smartphone provides objective rich data that can be utilized in a RMCS. Different geological regions, site-specific conditions, cultural differences and available technical equipment will most likely be barriers for merging existing systems into just a few. However, shortcomings in terms of subjectivity and the lack of rich datasets in the system might lead to the development of the systems. It is possible to see at least two ways forward.

One way is to develop existing systems by incorporating new datasets and using modern technology such as deep learning based on big data to assess input parameters less subjectively. If new systems are developed, they should be based on open databases. A database will be a base for a fully reproducible and comprehensible system that is easier to trust, easier to be informed about limitations, and probably tears down barriers between systems, thus making it possible to merge them. In the future it is crucial to continuously update and improve RMCS to stay up to date with technological advancements and to meet the demands of the community and industry.

Another way is to build new systems around the objective part of the existing knowledge and available modern data sources (e.g. 3D DEM modelling of fractured rock masses). Such systems should be agile and consider the minds and skills of the new engineers as well as the experience from older engineers.

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