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Rock Mass Classification Techniques and Parameters: a Review

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Abstract

The rock mass classification system is utilized to categorize rocks, and has been used in engineering projects and stability investigations. It focuses on the parameters of rock mass and engineering applications, which include tunnels, slopes, foundations, etc. Rock mass classification is valuable in the areas where the collection of samples and yielding of observation is difficult. With the advancement in technology, various machine-based model algorithms have been used, i.e., ANN and MLR in rock mass classification from prior few years. In the present work, the rock mass classification has been discussed, i.e., rock load, stand up time, RQD, RMR, Q, GSI, SMR, and RMi along with their applications. Considering all the parameters, it is concluded that for slope stability in a poor rock condition, the applicability of GSI is sufficient when compared with RMR. GSI also provides a highly accurate valuation of geo-mechanical properties, making it a valuable tool for the engineers and geologists. Also, the RMR values obtained from the ANN model provide better results for tunnels when compared with MLR and the conventional method. The ARMR classification of Slate, Shale, Quartz Schist, Gneiss, and Calcschist at 5 different locations of the world were 51-54, 66-70, 57-60, 35, 65-70, respectively. The range for slate and shale was found to be moderately anisotropic, while quartz schist, gneiss, and calcschist were found to be slightly anisotropic and highly anisotropic.

1. Introduction

Rock mass classification is the technique of classifying or identifying a rock mass emanating from pre-determined relations and assigning it a unique characterization (or numeral) according to similar features so that the rock mass behavior may be predicted [1]. RMC systems permit the individual to classify an entity in the exact class by following a set of guiding principle. The categorization and classification of rock masses is a tool for effectively communicating predictable rock mass features but it should not be used in place of the rigorous technical design procedures [2]. The RMC systems have been introduced as a design assistance for the engineers, and are not meant to replace field surveys, quantitative aspects, measurements or engineering judgment [3]. In execution, the rock mass classification procedures have proven to be a beneficial design aid on a variety of engineering projects, particularly those involving underground construction, tunneling, and mining [4].

An aggregation of rock fragments divided by geological interstices such as fissures, bed levels, dyke intrusions, and faults is stated to as a rock mass [3]. The rock properties play a vital role in many areas of engineering and geology, as they are essential inputs for designs and analyses in rock engineering [76-78]. The International Society of Rock Mechanics (ISRM) has established rules and approaches for determining rock properties both in the laboratory and at site [79]. *In situ* stresses can greatly impact rock mass properties in numerous aspects such as stronger rock able to withstand higher stress, reducing stress concentration with displacement, and altering the permeability of the rock mass. Additionally, tectonic pressure, erosion, landscape, and other features can also affect the stress field, and *in situ* stress can vary with depth,

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and can be affected by discontinuities in the rock mass. A highly variable *in situ* stress field can exist in cracked rock masses [80]. Bedding surfaces, dyke invasions, and faults are less frequent than joints, and are separately dispersed [3]. The progress of geological classifications began primarily as a tool for the tunnel and mine construction. Further developments contributed to their applicability in slope stability analysis and foundational load carrying capacity. The primary objective of the preliminary classifications of rock masses was to take into consideration both the rock mass and the requirements and features of the interstices that split the rock into pieces, segments or masses, forming the rock bed. As a consequence, depending on the scale considered, an effort has been carried out to classify the key features of an isotropous and homogenous substance from the matrix scale to the asymmetry and fractures that comprise up the rock mass. As an outcome, it is indeed proven that the rock mass is an irregular, anisotropic, and assorted material. The majority of geological arrangements were established to aid the engineers in the construction of tunneling and mining support structures. The arenas of pertinence of RMCs such as gradient and sub-structure durability and the assessment of rock form attributes have been expanded as a result of the formation of these indices. RMR, Q index, GSI, and RMi have been the most extensively used classifications in the past, mostly for tunnel design [5]. Numerous studies have delved into the complexities of rock mass rating classification, with recent review focusing on assessing the blastability of rock mass classifications [67]. This ongoing examination of rock mass classification provides valuable insights into the blasting process, ultimately leading to more efficient and effective methods [68].

1.1. Benefits of RMC

Categorization of rock mass expands site characterization by necessitating the careful evaluation of participation data. A reasonable, quantitative evaluation is very significant than a subjective (non-agreed) evaluation. Categorization gives a specification of critical elements for every type of rock mass (domain), directing the process of characterizing rock. Classification yields quantifiable information for strategy purposes, allowing for a better engineering decision, and more operative project communication [3]. A quantifiable classification serves as the basis for thorough engineering judgment on a particular project, and it facilitates appropriate and efficient communication [4]. The mechanical qualities of a rock mass such as its compressibility or pliability can be determined and estimated by using the established relationships between rock mass structure and mechanical characteristics [2].

1.2. Drawbacks of RMC

As per Bieniawski (1993), the fundamental drawbacks of RMC systems emerge when:

- RMC is used as the definitive experiential "cookbook;" conceptual and scientific design approaches are disregarded.
- Utilizing a single rock mass categorization system, i.e., deprived of confirming the outcomes with minimum one additional system.
- Applying rock mass classifications with inadequate input data and without complete validation.
- Rock mass categorization results are misused (e.g., manipulated circumstances) [1].

Types of Rock mass classification and their modifications are shown below in Figure 1.

1.3. Types of classification systems

Ritter created an experimental approach for analysing the required specifications for tunnel construction in 1879, which led to the progress of rock mass classification schemes, and the advancement in the system begins. The majority of numerous characteristic classification techniques were based on civil engineering case studies [1, 4, 6-9]. The RMR, Q, and GSI systems are rock mass categorization techniques commonly used in rock engineering to aid in the development of subsurface structures [4]. Figure 2 contains a collection of well-known systems.

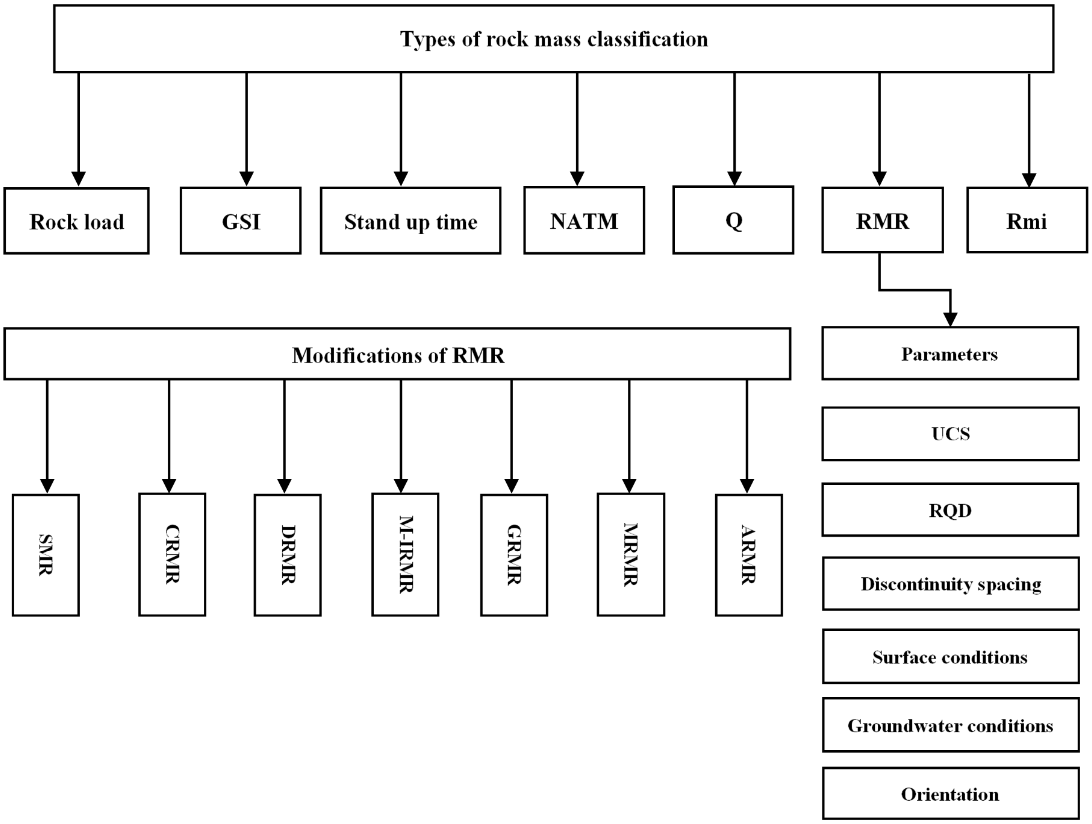


Figure 1. Types of Rock mass classification and their modifications

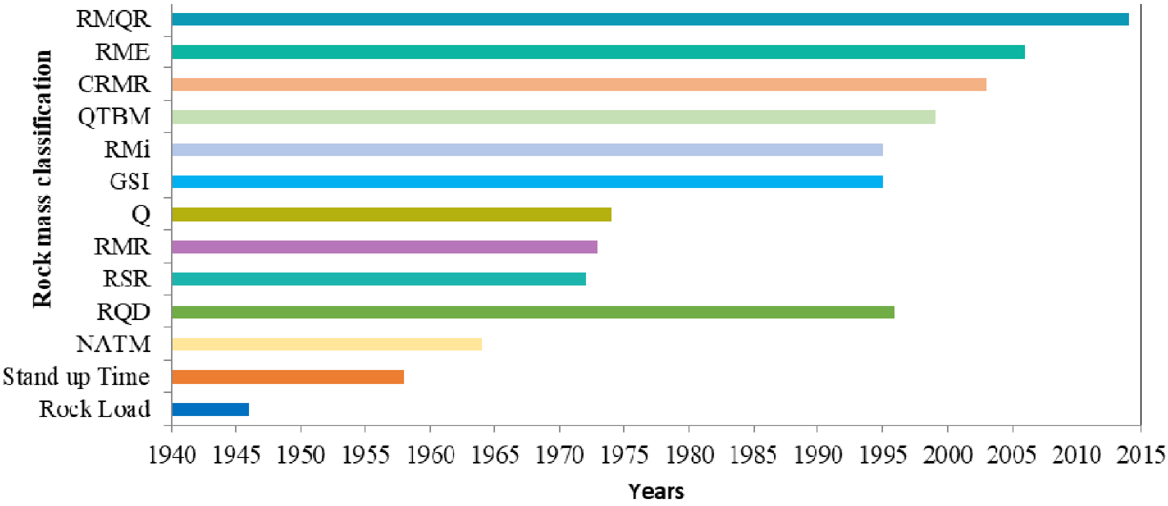


Figure 2. Different RMC systems

1.4. Rock load classification

Terzaghi, 1946, collaborated with the company named Procter and White Steel to develop the semi-quantitative but comprehensive classification system. The influence of bedrock on the design of tunnel with steel framing was discovered in this classification, and rock loads passed by steel sets were assessed using a quantitative characterization of rock types [4]. The goal of the approach is to calculate the rock load that will be passed through arches made up of steel erected to hold a tunnel. The load on fixed support in underground excavations is commonly referred to as rock load. It represents the rock pressure caused by the rock-load height above the subsurface excavation [10].

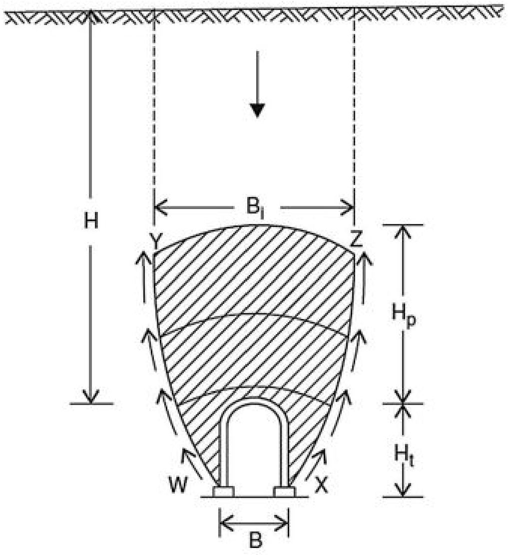


Figure 3. Tunnel support system

Figure 3 shows the rock load borne by steel arches constructed to support a tunnel, where B and H_t represent the breadth and height of the tunnel, respectively, H_p and B_i signify the height and breadth of the arched zone, correspondingly, and H represents the tunnel depth from the ground surface [11].

1.5. Stand-up time classification

The RMR system evaluates the integrity of rock masses and their ability to support unsupported spans in tunnelling. It was developed by Lauffer in 1958, and has been modified and updated by various authors [12]. The current system assigns a rock mass a rating from A to G, with A signifying very good rock and G signifying extremely poor rock, as indicated in Figure 4. The correlation of the active span with reinforcement and the unsupported span can be evaluated through this approach. The RMR system is often used in conjunction with the New Austrian Tunnelling Method (NATM), a general tunnelling strategy that takes into account the characteristics of the rock mass and the excavation method used [4].

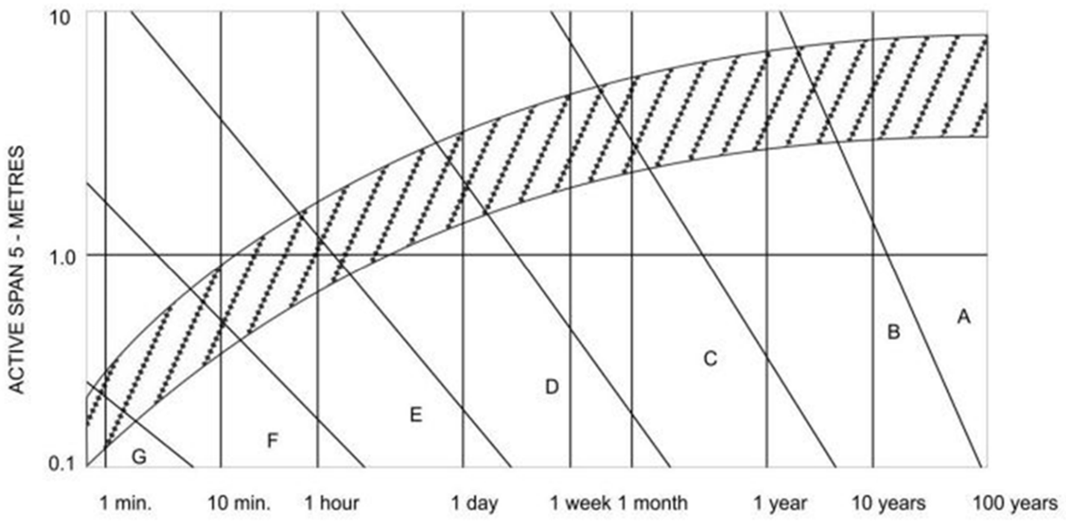


Figure 4. Active span and duration [13].

1.6. Rock quality designation (RQD)

The RQD rating gives a numerical evaluation of the extent of splitting or rupturing of the rock form, which is equal to 100 times the ratio of the total length of core pieces greater than 100 mm to the total length of the core run. As illustrated in Figure 5, the final range or percentage of different classes in this technique varies from zero to hundred [14]. There have been several approaches developed for determining the designation value that do not rely on the standard calculation method. These indirect methods utilize various input data, and have been integrated into rock categorization methods by the researchers such as Priest and Hudson, Palmstrom, and Zheng *et al*. [52-55]. Several investigators such as Bieniawski, Barton *et al*. and Hoek *et al*. have also contributed to the development of methods for categorizing rocks based on the RQD values [6, 8, 56].

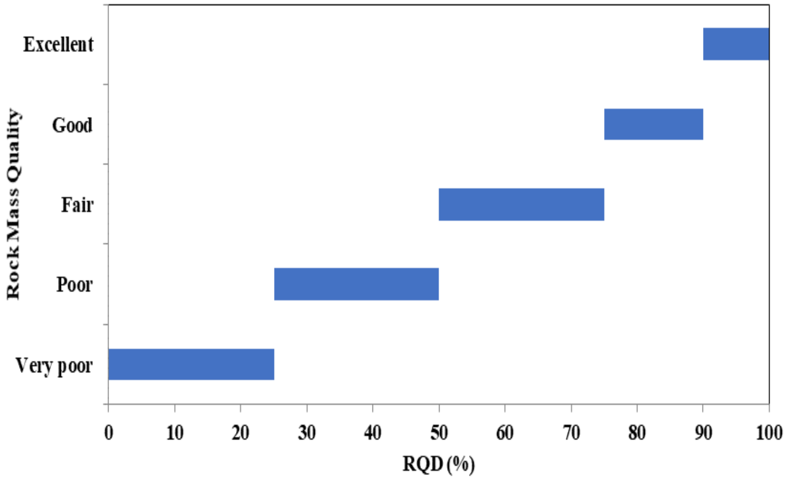


Figure 5. Classification of RMQ according to RQD

1.7. Rock mass rating system (RMR)

Between 1972 and 1973, Bieniawski established the RMR structure, also known as the geo-mechanics classification, for tunnels [8]. As the more case histories were examined, it was developed and improved. This technology has the benefit of demanding a few key requirements correlated to the mechanical and geometric state of rocky slopes. The RMR process utilizes the six basic conditions given below [1]:

1. UCS
2. RQD
3. Spacing between discontinuities
4. Surface condition of discontinuity
5. Groundwater levels
6. Orientation of the discontinuity in connection to the designed structure

The sites can be classified using the above method in the field. A structural region is defined by the presence of same rock types or discontinuities, and each section is uniquely identified and classified [4].

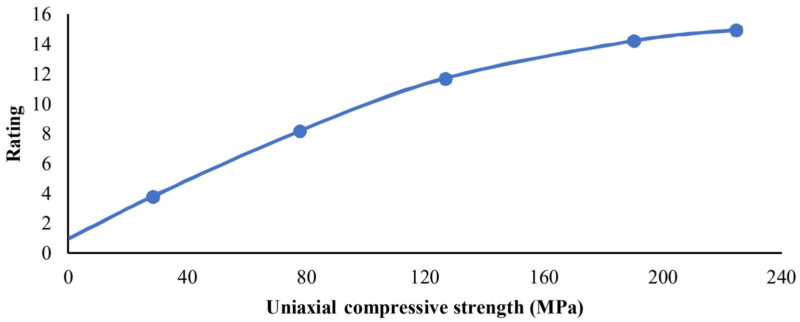


Figure 6. Rating for strength of intact material [3].

Bieniawski modified the RMR system resulting into DRMR. The DRMR system allows multiple users to obtain different RMR ratings based on their specific experiences and selection of discrete variables. However, this can lead to variability between the RMR values calculated by different operators. To address this issue, the RMR system was modified by converting discrete rating values into continuous rating values, resulting in the CRMR system. This amendment reduced the variability between the RMR values calculated by multiple operators up to 10% [15].

Figures 7 and 8 describe the RMR categorization parameters and their respective rock mass groups [1]. In addition, while investigating the impact of orientation of discontinuities, the SMR system has been proposed [16].

1.7.1. Applications of RMR system

- The RMR method provides suggestions for adopting tunnel rock reinforcement [1]. These recommendations are modified by variables such as subsurface depth, tunnel dimension and geometry, and excavating technique. Steel fibre reinforced shotcrete is commonly preferred to wire mesh in a variety of mineral extraction and civil engineering applications [4].
- Additionally, RMR is utilized to anticipate dredged material and stand-up time [17].
- RMR can be utilized to compute the physical characteristics of a rock bed [1].

The parameters involved in surface condition of discontinuity in RMR are mentioned in Figure 7. The final RMR-based classes also plotted with respect to the range are given in Figure 8.

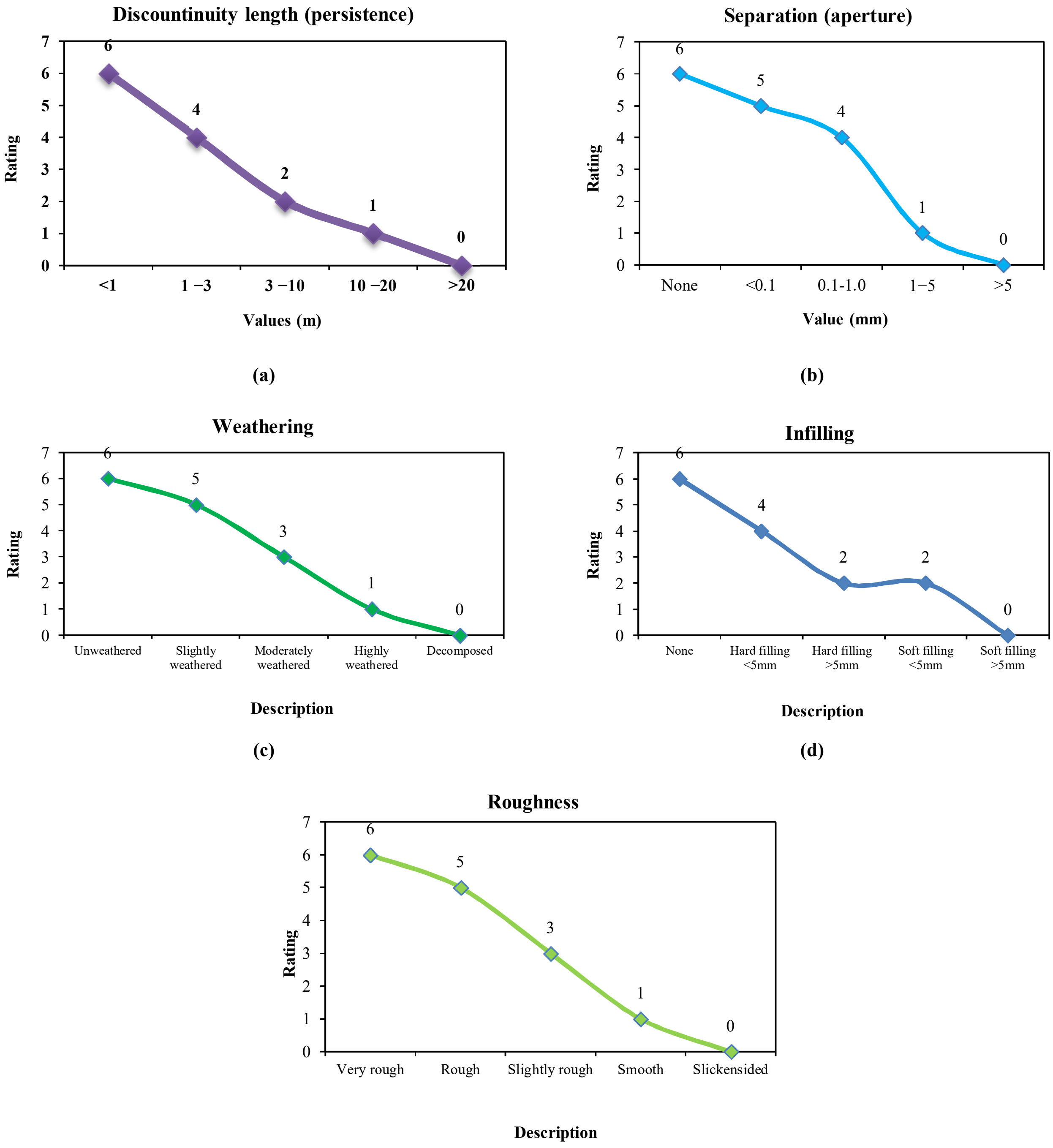
1.8. Modifications of RMR

a). Mine rock mass rating (MRMR)

The MRMR classification system was foremost familiarized in 1974 as a way to better understand how rock masses would behave in different mining environments. Unlike the previous CSIRO geo-mechanics classification system, MRMR takes into account the need to alter *in situ* rock mass ratings (RMR) based on the specific mining environment [8, 59]. Since its introduction, the system has been refined and enhanced, and has been effectively executed in mining projects all over the world [60-62]. To determine how rock masses will behave in a mining situation, the engineers use MRMR to adjust RMR for factors such as “weathering, mining-induced stresses, joint orientation, and blasting effects”. These adjusted ratings are then known as MRMR. The adjustment percentages used are based on the observations made in the field and are specific to the scale and impact of the proposed mining activity. In addition to providing more accurate predictions, the MRMR system also encourages engineers to think more critically about the mining operation. For example, poor blasting may have a significant impact on the stability of a drift or pit slope but have no bearing on the cavability of the rock mass. Similarly, assessing the joint orientation of a pit slope will help the engineers determine if it poses a threat to regional stability. The MRMR system has been so successful that it has been adopted by Engineers International, Inc. for use in their caving mine rock mass classification and support valuation system. It is clear that the MRMR system is an invaluable tool for mining engineers, helping them navigate the complex and ever-changing terrain of mining operations [63].

b). Anisotropic rock mass rating (ARMR)

Anisotropy, the presence of distinct directional properties, affects the performance of rock masses at different scales. The Anisotropic Rock Mass Rating (ARMR) system is a classification system developed specifically for anisotropic rock masses. It considers factors such as anisotropy strength, rock strength, and groundwater conditions. ARMR system is also associated with the modified Hoek-Brown failure criterion, which takes into account the orientation of anisotropy planes and the anisotropy level in the rock mass [64]. The ARMR values for rock masses in China (Slate), the USA (Quartz schist), Australia (Shale), Italy (Calcschist), and Greece (Gneiss) were found to be 51-54, 66-70, 57-60, 35, and 65-70, respectively. The range of slate and shale falls under moderately anisotropic while quartz schist, gneiss, and calcschist falls under slightly anisotropic and highly anisotropic [65]. Figure 9 depicts rock mass quality as per ARMR values.



(a)

(b)

(c)

(d)

(e)

Figure 7. a) Discontinuity length. b) Separation. c) Weathering. d) Infilling. e) Roughness.

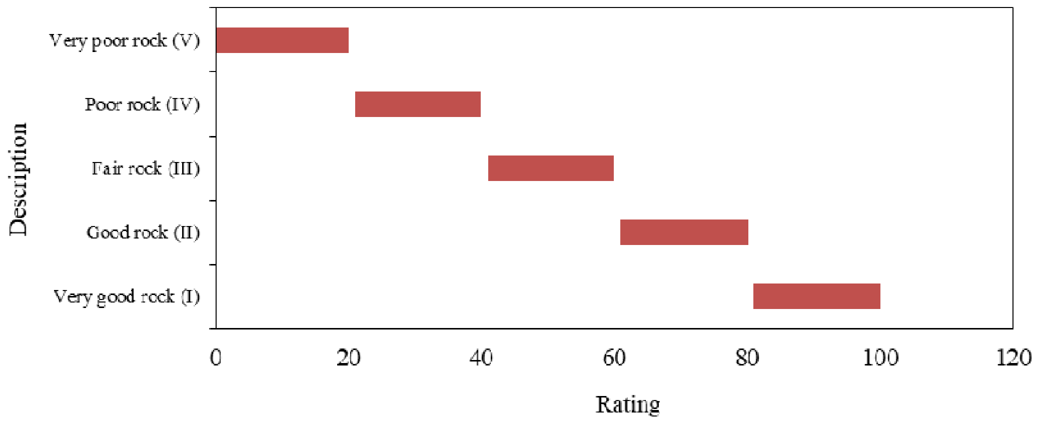


Figure 8. Criteria for classification of fracture condition in RMR

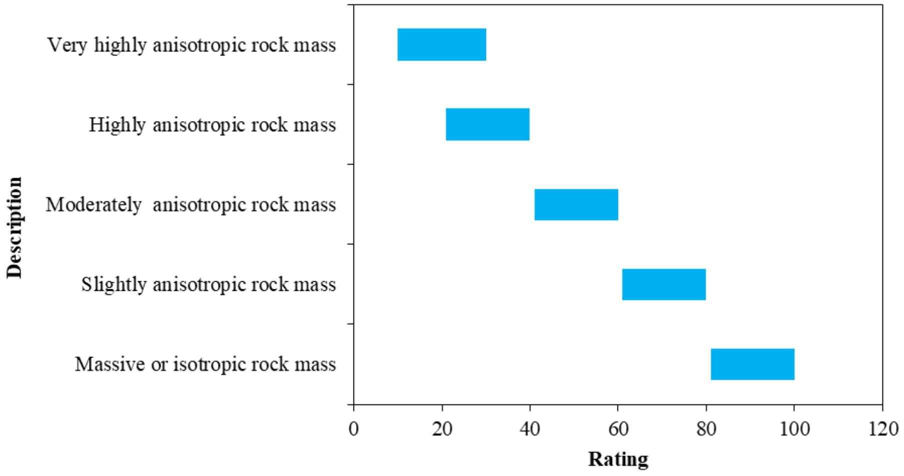


Figure 9. Rock mass quality as per ARMR values.

1.9. Rock tunnelling quality index (Q-system)

The tunnelling quality index system, generally called as the Q-system, was established in 1974 as a quantitative rock mass classification technique established on tunnelling information [6]. Numerous system improvements were proposed [18-19]. Total nine classes are there in this method. The quality index deviates from 0.001 to 1000 on a logarithmic scale, and is computed as follows, using Equation (1):

$$Q = \left(\frac{RQD}{Jn}\right) \times \left(\frac{Jr}{Ja}\right) \times \left(\frac{Jw}{SRF}\right) \quad (1)$$

where RQD represents rock quality designation; J_n signifies the number of rated joint sets; Jr denotes the rated joint surface roughness. J_w represents the valuation for infiltration and pressure impacts, whereas J_a represents the rating for the extent of modification or clay-filling joint set. Water has the ability to dissolve gap infillings. SRF is a valuation for weak regions that interrupt the digging, stress–strength ratios in fragile rocks, and material that is being compressed or expanded [6,18].

The uniaxial compressive strength (UCS) (c) of an unbroken rock plays a chief role in rock mass characteristics; therefore, a data scaling factor is derived using Equation (1), and changed to Q_c as follows [18]:

$$Q_c = \left(\frac{RQD}{Jn}\right) \times \left(\frac{Jr}{Ja}\right) \times \left(\frac{Jw}{SRF}\right) \times \left(\frac{\sigma c}{100}\right) \quad (2)$$

A New Austrian Tunnelling Method (NATM) has been employed for tunnel construction, depending upon rock mass behaviour. If drilling and blasting to be adopted in this approach, it is must to have detailed geological data [20].

The tunnel stability challenge during construction is induced by geomorphological structural components or the low strength-to-stress ratio and rock explosion condition that arises when the adjacent rock mass is enormous [21]. Tunnel dredging in a very loaded, combined rock mass becomes less likely to result in rock erupting than tunnel excavation in a huge rock mass [22-23]. By splitting the complete rock mass, de-stress blowing is an effective method for minimizing rock bursts [24-25].

1.9.1. Significance of Q–system

The Q value is employed to assess the stability value for a given-size tunnel, in addition to the use of construction by determining the Equivalent Dimension (De) of the excavation [6].

$$D_e = \frac{Excavation\ span\ (s), diameter\ (d)\ or\ height\ (m)}{Excavation\ Support\ Ratio\ (ESR)}$$

In the context of roof support, span/diameter is applied, whereas wall height is used for wall support. The value of ESR is decided by the anticipated use of the construction and the necessary level of safety [26].

1.10. Geological strength index (GSI)

With an emphasis on rock structural factors including discontinuity rate and surface phenomenon, GSI was created by Hoek in 1994 and 1995, and further amended by Hoek and Brown for entire hard and weak intact rock [58]. Basic graphics for measuring GSI were formulated in accordance to pictorial examination of geological structures. The graphs were straightforward and simple to use but personal experiences had a significant impact according to different persons rated the same rock mass using the GSI scale. Marinos and Hoek developed a graph with specific provision of rock categories based on the Terzaghi's classifications. The GSI assessed rating was a range, not an explicit value [27].

In order to meet the need for a relatively accurate GSI evaluation that can represent the comparatively authentic condition of the affected rock mass, Sonmez and Ulusay presented surface condition rating (SCR) of fractures and structural rating (SR) to compute the results in accordance with the quantitative chart of GSI. SCR is assessed using three metrics that are comparable to that used in RMR_{14}: roughness rating (Rr), weathering rating (Rw), and infilling rating (Rf). Block volume (Vb) and joint condition factor were established to construct another quantifiable GSI chart (Jc) [28-29]. The discontinuities modification factors, small-scale smoothness, and large-scale discontinuity waviness indices—all of which have the the Q and RMi rating method—all contribute to the determination of Jc [28-29].

1.10.1. Applications of GSI system

The main intent of the GSI is to utilize as a device for evaluating the variables in the Hoek-Brown strength criteria for rock masses, as well as the compressibility and strength of rock masses utilising relationships developed from other classification systems [30]. The Hoek-Brown strength criterion employs the uniaxial strength of rock material as a fundamental characteristic; hence, it is not taken into consideration in the GSI.

1.11. Slope mass rating (SMR)

Romana established SMR, a conventional solid mass classification method for slopes of rock. The basic RMR system, incorporating the impact of the excavation approach, is transformed into the SMR system by adding modification parameters that include discontinuity orientations in relation to slope inclination. The SMR value is computed by deducting a factor based on the joint-slope connection from the RMR rating and then accumulating a component based on the excavation method, as illustrated in the resulting equation [16, 31].

$$SMR = RMR + F_1 F_2 F_3 + F_4$$

where "F_1 is defined by the symmetry of the joint strike (α_j) (or the plunging direction of the intersecting line of two planes (α_i) and the slope face strike (α_s)". It diverges between 1 and 0.15 when the joint and slope face strike are approximately parallel when the angle between strikes is 30° [16, 31].

In the situation of a planar failure, "F_2 represents the joint dip angle (β_j) or the plunge of the lines of collision between 2 planes (β_i) in the case of a wedge-type failure". It varies from 1 to 0.15 for joints that dip more than 45° and less than 20° [16, 31].

"F_3 replicates the impact of the relationship among the slope face dip (β_s) and the joint dip (β_j) or the plunge of two plane intersection lines (β_i)". It varies from 0 (very favourable) when $\beta_j - \beta_s$ or $\beta_i - \beta_s$ is larger than 10, to -60 (extremely favourable) when $\beta_j - \beta_s$ or $\beta_i - \beta_s$ is less than –10 [16, 31].

F_4 is a dynamic adjustment factor that is influenced by the manner of excavation [16]. The values have been decided experimentally as shown in Figure 10.

Figure 11 depicts the various types of SMR data that indicate the slope stability requirement.

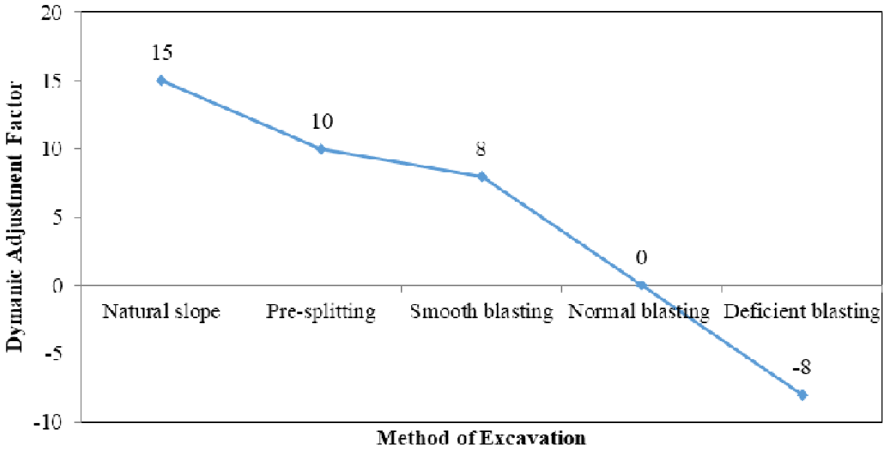


Figure 10. Modification factor F_4 for the method of excavation.

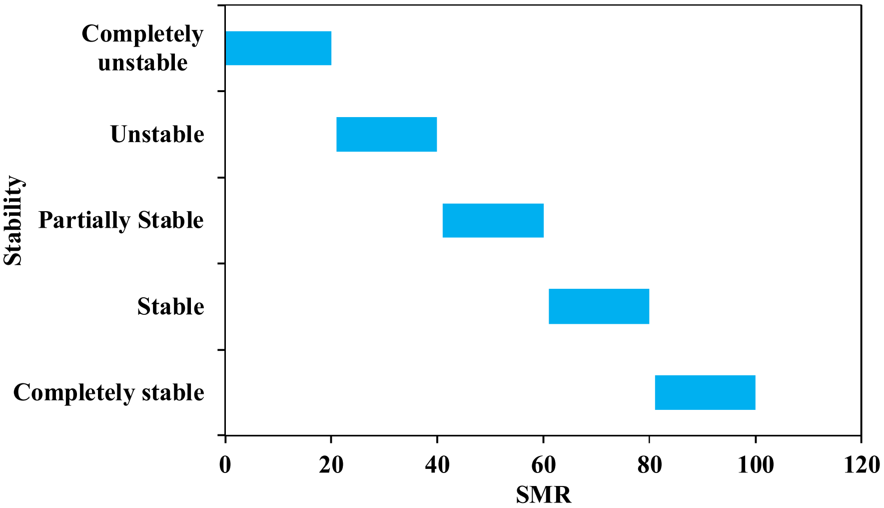


Figure 11. Classes of SMR [16].

Hussain et al. delved into the depths of the geotechnical landscape along NH-1D from Kargil to Leh, J&K, utilizing the SMR method for a comprehensive stability analysis of the slopes. By combining this with kinematic analysis, they were able to uncover the potential types of failure and the direction in which they may occur. The RMR values, calculated from selected surfaces, revealed a range from 11 to 89, with the lower values indicating areas of potential instability. The outcome of the study discovered that out of the 20 surfaces analysed, a staggering 65.28% were at risk of wedge failure, 22.26% were at risk of toppling failure, and 12.45% were at risk of plane failure [70]. Numerous researchers have delved into the complex field of slope stability and have explored various techniques for safeguarding against the catastrophic effects of landslides in various geographical locations [71-72].

1.12. Rock mass index (RMi)

Rock mass strength as a material for construction can be categorised using the rock mass index [23]. It demonstrates the numerous adverse consequences of joints lead to a depletion in the natural strength of rock mass [26]. Further, it reflects the UCS of the rock mass in MPa, and is represented as:

$$Rmi = \sigma_c . JP$$

where σ_c represents the complete rock material's UCS in MPa. The four joint features are blocking volume, also known as joint density, joint roughness, joint size, and joint alteration, collectively known as JP, the jointing parameter. JP is a decrease factor that depicts that jointing affects the strength of the rock mass. For intact rock, JP has a value of 1, while for fragmented rock masses, it has a value of 0. The four jointing factors can be used to calculate the following jointing values [26]:

$$JP = 0.2\ (jC)^{0.5}.\ (Vb)^{D}$$

where Vb is in m^3, and $D = 0.37 \times jC^{0.2}$

Joint condition factor jC is associated with jR, jA, and jL as follows [26]:

$$jC = jL\left(\frac{jR}{jA}\right)$$

1.12.1. Significance of RMi

As per Palmstrom, RMi can be employed for preliminary evaluations throughout the initial phases of a project's viability design. This technique provides a progressive approach appropriate for engineering discretion. Using RMi, the relation $s = JP_2$ can be utilized to discover the Hoek-Brown Criterion parameter (s) values. Consequently, the application of factors in RMi can enhance the process of other classification structures. The RMi method has a greater variety of applications than other categorization systems since it incorporates a wide variety of rock mass discrepancies [57].

2. Implementation of Various Methods by Researchers

2.1. RMR, Q, GSI, and Rmi

Tzamos and Sofianos evaluated four classification systems, namely "RMR, Q, GSI, and RMi," as well as the prevalent characteristics of these systems, which are employed to assess the rock structure and the joint surface conditions. The joint conditions ratings (JC) identify the joint surface conditions, while the rock dimension or joint spacing ratings assess the rock structure (BS). The rock mass fabric index (F) is, therefore, represented as a linear function of the rock formation and fracture conditions of the component rocks, i.e., F = F (BS, JC). All rock mass classification systems' ratings are compiled into a single rock mass fabric index graphic. The chart validity is tested using the data from multiple projects. The utilization of the chart improves input, associates rock mass categorization systems, and promotes the usefulness of these systems [32].

Aksoy et al. carried out a study to ascertain the rock mass deformation modulus by utilizing different experimental approaches and for the explanation of rock mass in tunnels RMR, Q, GSI, and RMi were used [33]. The rock mass classification of tunnels at 5 different locations have been analysed, and their values are represented in Figure 12.

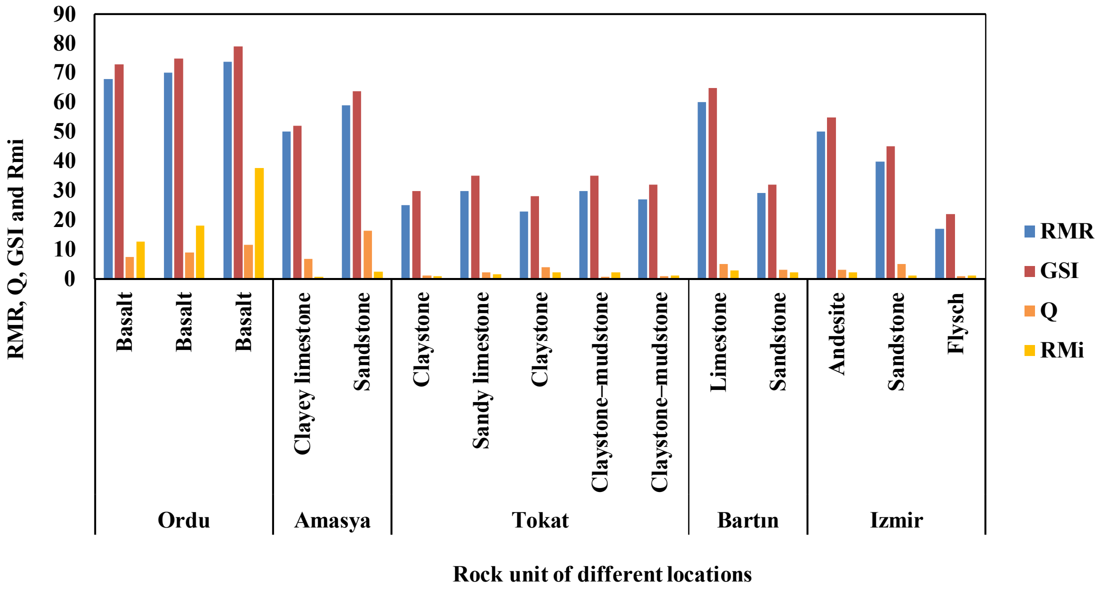


Figure 12. RMR, Q, GSI, and RMi values of different locations.

Figure 11 depicts that in the area of Ordu the RMR values of basalt rock ranges from 68 to 74, which falls in the category of good rock (II). The RMi is 12.41, 17.97, and 37.7 that lies in very high strength zone as the range varies from 1 to 100. In the region of Amasya, the rock type is clayey limestone, sandstone, and RMR values are 50, 59, respectively, which falls in the category of fair rock (III) and poor rock (IV). The RMi is 0.41, 2.34, which lies in moderate and high strength zone, respectively. In Tokat area, 5 types of rocks are found namely clay stone, sandy limestone, clay stone, clay stone-mudstone having the RMR values 25, 30, 23, 30, and 27, respectively, which falls under the category of poor rock (IV). The rock mass index of the particular area is 0.004, 0.01, 0.003, 0.01, and 0.006, which lies in very low and low strength zone. In the Bartin area, 2 types of rocks are present, namely limestone and sandstone having RMR values 60 and 29, which falls under the category of good rock (II) and poor rock (IV). The rock mass index is 2.82 and 0.00906, which lies in high and very low strength zone, respectively. In the Izmir area, 3 types of rock are present, namely andesite, sandstone and flysch having RMR values 50, 40, 17 respectively which descends in the category of fair rock (III) and very poor rock (V). The rock mass index is 0.44, 0.069, and 0.001, which lies in weak and very weak strength zone. The result revealed that by means of the experimental equation proposed by Palmstrom and Singh (2001) to compute rock mass deformation modules yields more accurate outcomes in tunnels with rigid (nearly fragile level) and bulky block sized rock mass. However, for moderate and weak rock masses (particularly for extreme blocky rock mass), the findings deviate from the measured distortion values. As a result, it is suggested that using RMi-based rock mass distortion components is further feasible [81].

Zhang conducted a study to determine the RQD, deformation modulus, and UCS of rock masses. The deformation modulus and UCS of rock have been calculated using quantitative approaches at 5 distinct locations, and the findings are contrasted with the results of other experimental approaches that rely on RMC indices such as RMR, Q, and GSI. The UCS values from the experiential techniques based on RQD tend to be in the middle of the comparable values from various experiential approaches that rely on RMR, Q, and GSI. Deformation modulus values from such methods are often conventional and close to the lower bound. When evaluating the mechanical characteristics of rock masses, experimental methods are mainly based on RQD, which is a helpful tool but it must always be used in conjunction with other quantitative procedures in accordance with RMR, Q, and GSI [34]. The value of RMR, Q, and GSI of 5 sites are shown in Figure 13.

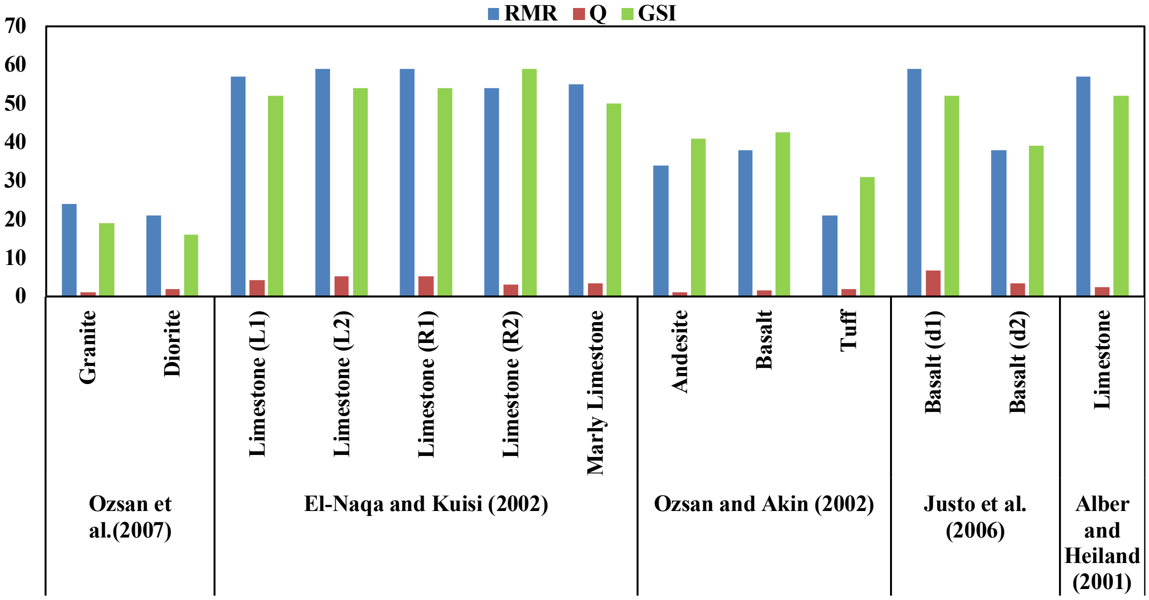


Figure 13. RMR, Q, and GSI values of different locations by different authors.

2.2. RMR and GSI

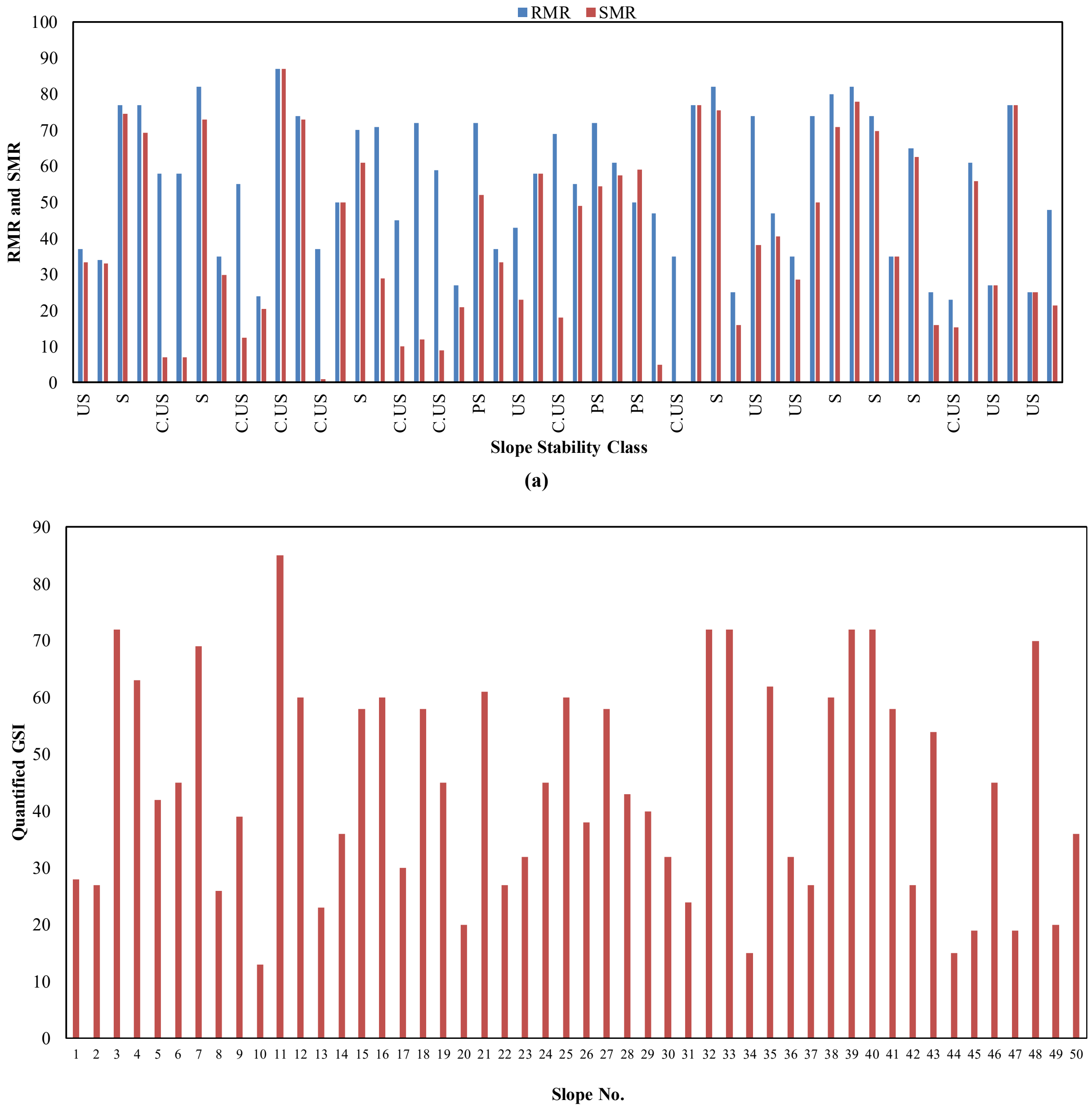
Sarkar et al. investigated the geo-technical factors to identify rock mass and evaluate steadiness of the slope of road in Garhwal Himalaya India. RMR and GSI were explored for rock mass characterization. GSI, based on the fragmentation and the sub-surface condition of disruptions, is beneficial for identifying rock mass in the field. To interpret rock mass quality, employ GSI and RMR independently. The suggested experiment uses SMR to estimate stability of the slope using RMR and discontinuity direction data. In weak rock mass circumstances, GSI can define slope failures. The RMR, SMR, and GSI values of 50 slopes are shown in Figure 14 [35].

US: Unstable

S: Stable

C.US: Completely Unstable

PS: Partially Stable



(a)

(b)

Figure 14. a) RMR and SMR b) Quantified GSI.

Singh et al. executed a study regarding rock mass characterization of four locations along the right bank of river Sutlej, Luhri Himachal Pradesh, and evaluated on the basis of subsurface and stability properties. For every portion kinematic analysis, the RMR_{basic}, SMR, and GSI values were established. Four areas (L-1 to L-4) were picked for the current study and evaluated based on several geotechnical and stability properties. For each of these sections, kinematic analysis, the RMR_{basic}, SMR, and GSI values were established. A conclusion that can be drawn from the kinematic analysis is that the local joint set "J2" is among the most important and primarily liable for slope motions. In all portions besides the L-4, wedge failure because of double plane movement is anticipated to be the most typical kind of failure. Additionally, RMR_{basic} has been estimated as a crucial factor required for SMR calculation. The first two locations (L-1 and L-2) might not require any significant brace, according to SMR values but the L-3 and L-4 will probably need necessary support measures to reduce the possibility of downfall. The categorization of the rock masses in this area is significantly more precise and effective through the application of improved GSI. The GSI values can also aid in the assessment of the Hoek and Brown rock mass indices (mb and s), which can be incorporated in arithmetical solution for the stability examination of heavily jointed rock mass [36].

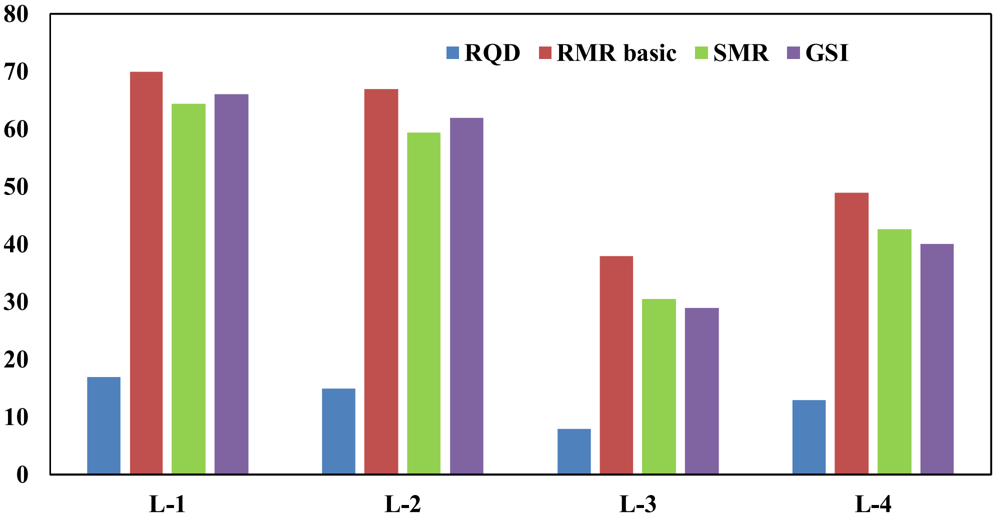


Figure 15. RQD, RMR_{basic}, SMR, and GSI values of four different locations.

Kumar and Pandey have attempted to evaluate "RMR, GSI and Kinematic Analysis" utilising the site data correlating to Vindhyan sandstone. The information was gathered from rocks within and round Markundi Hill along SH-5, Chopan, and Sonbhadra at seven distinct places. Using a modified equation presented by Hoek [56], the link between RMR and GSI has been investigated, and the RocScience Dips software has been employed to apply kinematic analysis to identify the weak zone of failure. For site S-4, the assessed RMR value is 35, while for location S-1, the assessed RMR value is 58. The RMR values at other sites, "S-2, S-3, S-5, S-6, and S-7", range from 42 to 49, indicating that the "Vindhyan sandstone at Markundi" is differentiated by both poor and fair rock mass. The projected maximum and minimal GSI values for location S-1 are 34 and 46, respectively, for position S-4. It is further confirmed by the GSI value of the same geological stratum that the rock mass is both poor and fair [37].

Zhang et al. conducted a study to determine the correlation between the two systems, i.e. RMR and GSI, using the improved RMR (RMR_{14}). Field data from six construction tunnels was collected and analysed using the "Monte Carlo simulation method". A basic quantifiable link between RMR and GSI was anticipated, as well as a comprehensive correlation that takes into account the uniaxial compressive strength of the intact rock. These proposed correlations were then applied to assess 36 sites at the Suocaopo Tunnel in China. The outcomes showed that the simplified correlation had good competency, and the comprehensive correlation was more accurate due to the consideration of intact rock properties [69].

2.3. RMR and SMR

RMS, RMR, and SMR are three methodologies for classifying rock masses that have been explored by Brook and Hutchinson for their utility to weak rock masses. The methodology included factors like groundwater ratings, interruption characteristics and direction, and uniaxial compressive rock strength. On the Saddle Road in the Ruahine Range of New Zealand's North Island, 14 profiles that were newly excavated road cuttings were used to compute the rock mass classification values. Mean slope and minimum slope angle was calculated at each profile in accordance with the guidelines for classifying rock masses. All three categorization algorithms appeared to be of limited use considering the subaerial conditions at the research site. It is difficult to identify the specific modifications that the RMR, RMS, and SMR classification systems provide to the relative weightings of the different factors for weak rock masses. Over the recent eras, RMC methods have been proposed to identify cuts at high risk of failure and investigate mitigation strategies [38].

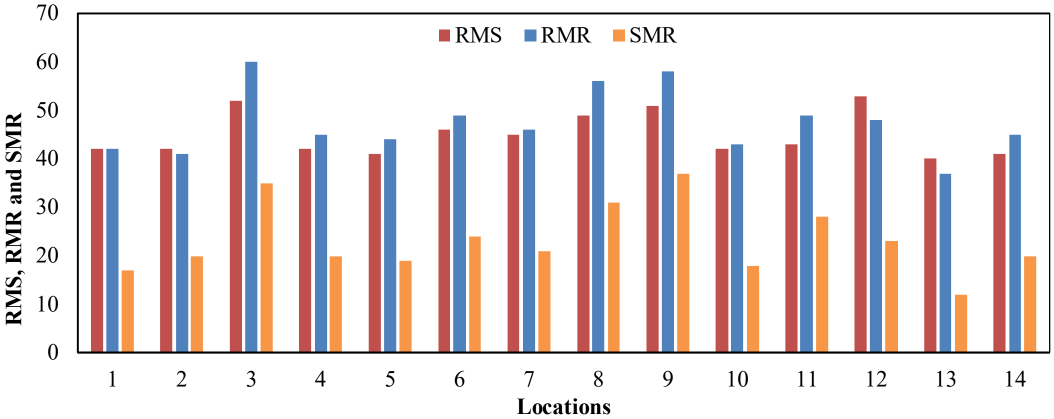


Figure 16. RMS, RMR, and SMR values of 14 locations.

Yousif et al. investigated about the application of RMR and SMR on rock slope stability of seven sites along the edges of Al- Salman Depression, in South Iraq, and the values of RMR fall under the category of good rocks (II) and fair rocks (III). The SMR values falls under the category of good and stable class, of all the location except 4th, which lies in normal, partially stable class. Figure 17 depicts the RMR and SMR values of seven locations [39].

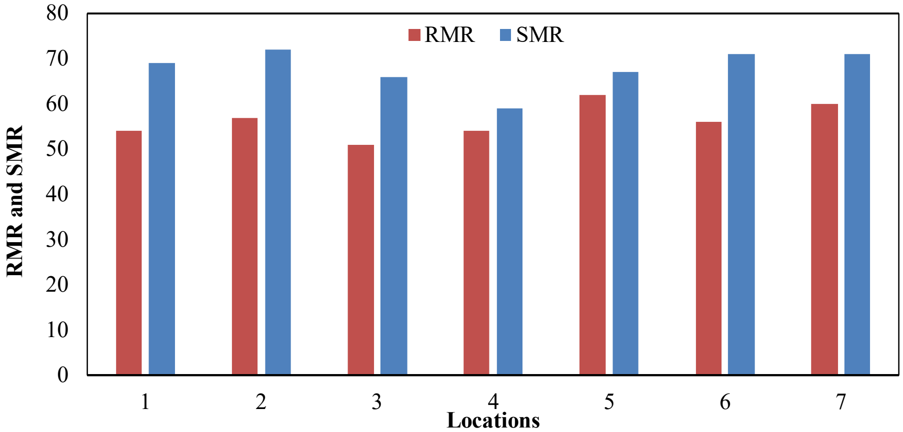


Figure 17. RMR and SMR values of four locations of South Iraq.

Singh and Kumar carried out a study for the valuation of slope stability along the road cut of NH-154A Himachal India as the rocks are highly fragile in nature in the particular area [40]. According to RMR, five sites “L16R8, L25R10, L26R11, L27R14, and L29R13” have fair rock slope (class III) and the rest are good (class II). Kinematic analysis found seven sites “L5R2, L6R3, L9R4, L12R5, L13R6, L14R7, and L18R9” to be stable, while the other seven have slope failure modes (planar and wedge). The modified SMR approach was used on the seven sites where faults were discovered. The slopes were divided into unstable and entirely unstable classes based on SMR values 6-38. Planar failures at three sites “L3R1, L19R14, and L27R12” are unstable and in

SMR class IV. Another planar failure at L27R12 is entirely unstable and in SMR class V. Planar failures at L16R8 and L29R13 are both entirely unstable and in SMR class V. The wedge failure at L16R8 is entirely unstable and in SMR class V, while the wedge failures at four sites "L25R10, L26R11, L27R12, and L29R13" are unstable and in SMR class IV [40]. Figure 18 depicts the types of rocks and their failures at different locations with SMR, RMR, and RQD values.

3. Some other methods used

Hoseinie et al. analysed and classified 6 rock mass prerequisites, which include "characteristics and grain size, Mohs hardness, UCS, joint density, joint filling (aperture), and joint dipping", to determine a new classification system for calculating the RDi. Specifically, physical modelling has been utilized to investigate the influence of joint features on drilling rate. In the projected RDi system, each rock mass is allocated a rating between 7 and 100, with a good rating indicating greater ease of drilling. Derived from the RDi rating, the drilling rate can be designated into five classes: "slow, slow-medium, medium, medium-fast, and fast" [41]. Hamidi et al. investigated the execution forecasting of hard rock TBMs using the Rock Mass Rating (RMR) method. Researchers found that the applicability of RMR in giving a statistical model of TBM field penetration index (FPI) is very limited due to the ratings (weights) allocated to the input variables and their influence on FPI. Multivariate linear, non-linear, and polynomial regression analyses can counteract the constraint. This approach was tested in the "Zagros long tunnel in western Iran", which comprises sedimentary rocks. Due to its low association with FPI, groundwater was left out from RMR assessment and analysis. The inclination between the tunnel axis and discontinuity surfaces modified RMR's discontinuity orientation correction factor. Correlation coefficients for observed and anticipated FPIs were 0.87, 0.87, and 0.86. However, the correlations depicted in this assessment are only applicable for soils and sediments analogous to the Zagros tunnel, and hence more research is required to establish a standardized system [42].

Hajiazizi and Khatami used numerical analysis to evaluate the Q-system. The incorporation of seismic factors in rock mass classification does not affect the stress–strain behaviour of rocks in subsurface areas. In other words, seismic force has little influence on subsurface areas when rocks are elastic but it can considerably influence the instability when rocks are plastic. Orientation of joint sets has no impact on the results but number of sets increases. Whenever the tunnel width increases from 5 to 20 metres, the maximum support force rises by 28% [43]. Liu and Dang investigated the M-IRMR valuation method in China's Sanshandao Gold Mine undersea deposit. M-IRMR incorporates nine valuation indexes: resistance to compression, RQD, joint interval, joint state, subsurface state, joint direction, subsurface stress, blasting vibration, and impacted area. The rock mass rating (RMR) approach was employed during the assessment procedure, and 4 geological factors (rock compressive strength, rock quality index, joint density, and subsurface stress) were adjusted based on the undersea deposit remarkable properties. The M-IRMR rock quality classification and integrity analysis technique was utilised in the Sanshandao Gold Mine undersea deposit from 420 to 690 m. The conclusions were accurate with specific situations, providing a systematic base for selecting the appropriate mining way and prevent support network of the undersea deposit [44].

Chen et al. proposed the Q_{HLW} approach to classify rock masses for HLW disposal. The system evaluates rock suitability on repository and tunnel regions. The process utilizes the Q-system and examines the substrate rock long-term safety, design, and construction. Other factors including the fault zone, subsurface composition, and temperature effect are considered since all affect long-term HLW disposal safety. The suggested system focuses avoidance by limiting undesirable rock volume, especially near significant fissure zones. The anticipated system constructability index is Q′ (the product of the first 4 parameters in the Q-method). The Q_{HLW} approach uses various factors to classify host rock relevance into 3 classes at the repository and tunnel scales. The technology is employed for preliminary verification at Beishan, China, a prospective HLW disposal area. Using a repository-scale categorization algorithm, the best disposal location in Xinchang is selected. Two deep boreholes are used for tunnel-scale rock classification. The predicted technique helps in determine optimum rock proportions for HLW disposal [45].

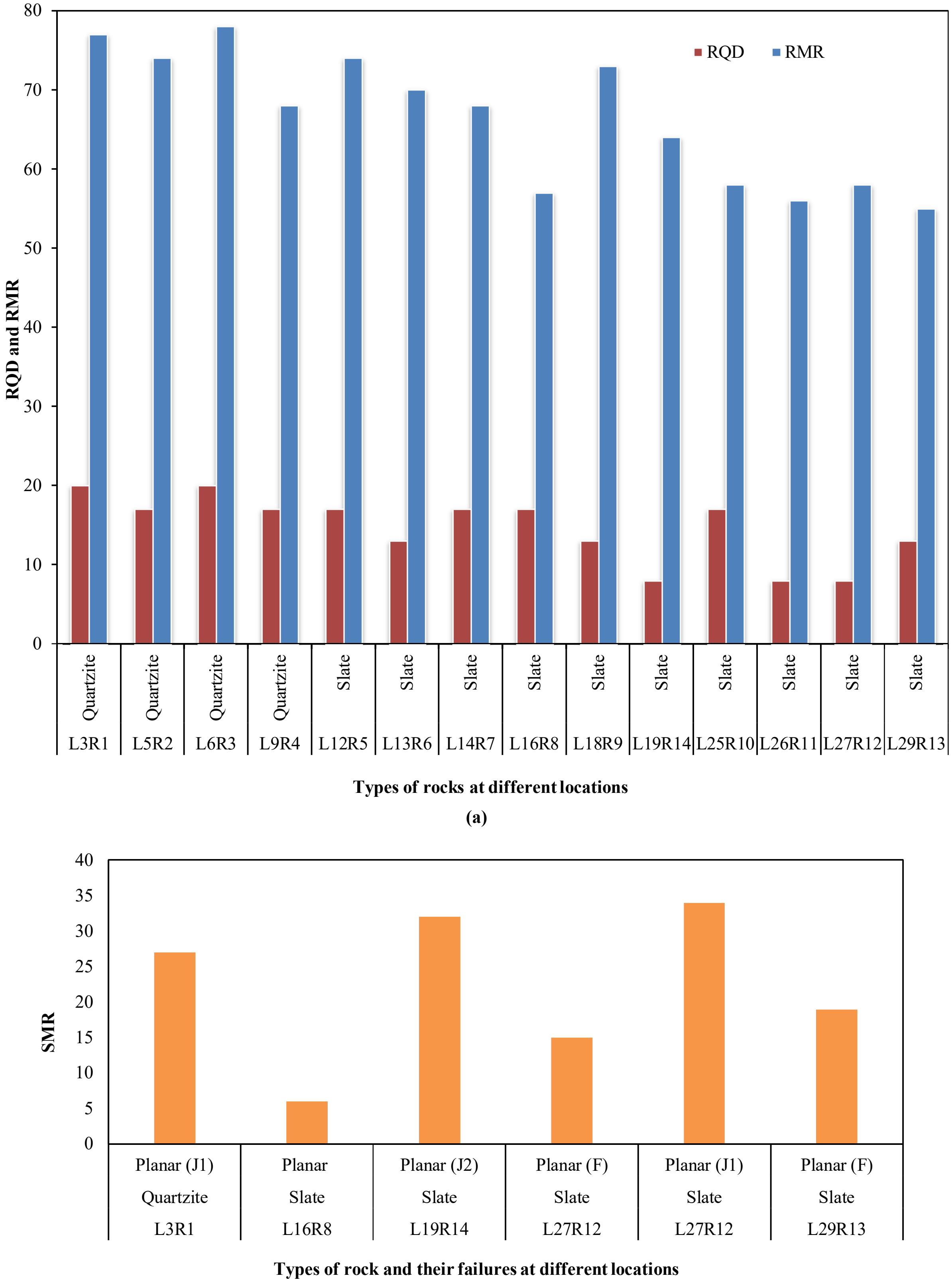
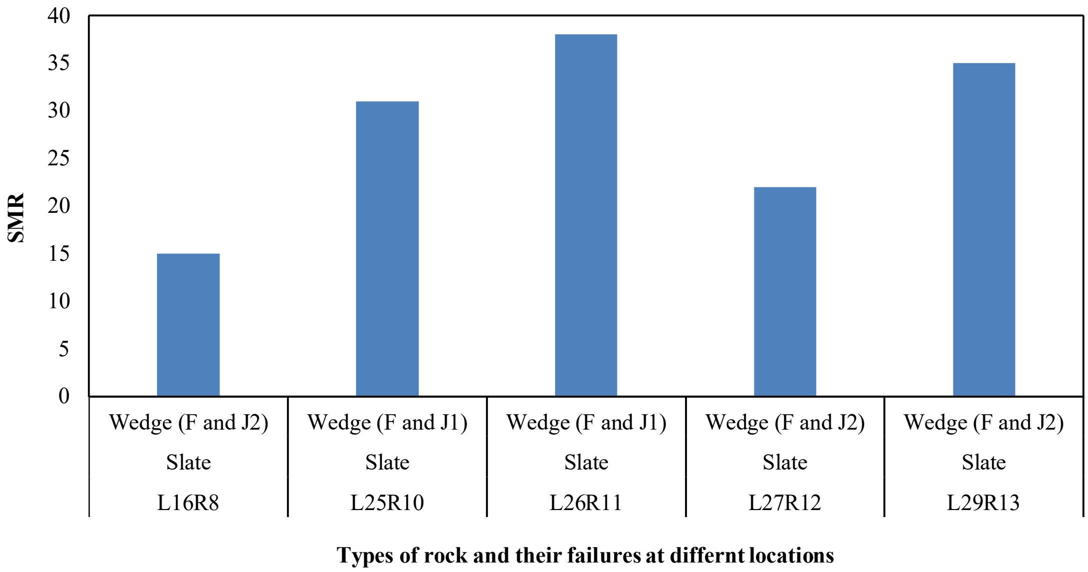


Figure 18. a) RMR and RQD b) SMR



(b)

Continuous of Figure 18. a) RMR and RQD b) SMR.

Hussain et al. used geomorphological and scientific data along the tunnel axis of the Golen Gol Hydropower Project in Chitral, Pakistan to calculate the RMR value utilizing three distinct methodologies including the standard method, Multiple Linear Regression (MLR), and Artificial Neural Networks (ANN). ANN- and MLR-based RMR values were estimated and compared. ANN-based models yield more realistic average RMR values for all 3 drill holes, in accordance with an evaluation. The MLR model surpasses the RMR value, which is unsustainable. ANN-based models can increase RMR and establish a continuous tunnel support system [46]. Jun et al. distinguished rock mass intrinsic features (Group A), extrinsic variables (Group B), and structure aspects (Group C). Also, correlation calculations or charts in between 3 categories of elements are developed to compare all evaluation criteria included in the $[BQ]_{GSI}$ as well as other international common systems (i.e., RMR, Q, and RMi). The $[BQ]_{GSI}$ system and its international counterparts, RMR, Q, and RMi, expertly navigate through normal and high stress conditions to reveal that the Q system is the ultimate rock mass evaluator, even under the most minimal of stress levels. The RMi system is recommended under high or extremely high in situ stress [47].

Khatik and Nandi suggested a GRMR system that relates to the most prevalent techniques, and two rock load calculations based on whether all of the rock factors included by the system have an impact. Data from three Indian coal mines validated the GRMR approach. GRMR uses an ANN-based semi-analytical model. ANN model outcomes are predicted to be close to analytical GRMR estimations [48]. Kundu et al. suggest continuous functions for RMR_{89} and RMR_{14} lump ratings. Continuous functions allow less-skilled workers to compute RMR accurately. Rough surface and abrasion are two quantitative RMR sub-parameters. The Joint Roughness Coefficient and the *I5 index (indices of surface weakening) were employed to characterize roughness and environmental parameters, respectively. 71 case studies from the Indian Himalayas were used to evaluate RMR_{89} and RMR_{14} continuous functions. A Windows application called "Quick RMR" utilizes the continuous functions to compute RMR_{89} and RMR_{14}. Free GNU GPL 3.0 open-source software is readily available. Quick RMR identifies input restrictions and errors analyses and maintains RMR data for numerous locations, and transfers all outcomes into a single excel sheet for analysis generating and further computation. By employing geometric analysis in deep learning-based neural networks and sonar data [49].

Rehman et al. investigated the challenge of designing tunnel support for jointed rock masses under high stress. By analysing plotting data from four tunnelling projects in Pakistan, the study proposes an empirical approach to extend the application of Tunnelling Quality Index (Q) and Rock Mass Rating (RMR) systems. Parameters for stress conditions are recommended; rock mass quality is determined through back-calculations, and experiential equations and graphs are anticipated for stress reduction factor characterization. The study also adjusts the RMR system for stress conditions, and finds that heavy support is recommended for stability in a case study. The exploration reports suggest that the tunnel will pass through a jointed rock mass under high in-situ stress environments, and the modified Q and RMR systems provide a valuable solution to this issue [66]. The study conducted by Yang et al. used the generalized Hoek-Brown failure criterion and a varying disturbance factor, determined by measuring P-wave velocities, to estimate rock mass properties in the excavation damaged zone (EDZ). The data showing the disturbance factor decreases linearly with depth and a numerical calculation using FLAC was conducted to assess slope stability with varying rock mass parameters, resulting in different failure surfaces and factors of safety. This approach is useful for quickly estimating EDZ properties when in-situ tests are not available [73]. Teymen and Menguc executed a study to compare various techniques for “predicting the uniaxial compressive strength (UCS) of rocks including simple regression (SRA), multiple regression (MRA), artificial neural network (ANN), adaptive neuro-fuzzy inference system (ANFIS), and genetic expression programming (GEP)”. The researchers evaluated the predicted UCS values against actual values using various graphs. The performance indices (PI_{at}) were used to depict the best method for the usage, and it was found that PI_{at} = 2.4 for testing data recommends; MRA was the most successful, with only a small difference in performance values (2.44, 2.33, and 2.22) compared to the other techniques. The results also indicated that MRA could predict UCS of rocks with higher accuracy than the other methods. In accordance with the performance index assessment of models, i.e., P2, P9, and P8 were the most successful models, while P7 was the weakest [74]. Zhao et al. conducted a study on the failure process and mechanism of a rock mass during the transition from open-pit to underground mining using micro seismic monitoring and analysis methods. The study found that the main failure type of the rock mass was shear failure, with tensile failure concentrated in the roof of goafs. The study revealed that the rock in the bottom of the pit and the top of the goaf may be at risk for additional deterioration. The study found that micro seismic monitoring and hybrid moment tensor analysis can well examine the failure process and mechanism of rock mass [75].

Siddhartha et al. examined RDNN for classification and estimation of Rock/Mine in underwater acoustics. RDNN models were then employed for metal classification. In addition, a unique method for underwater acoustic rock/mine forecasting and classification known as the Rock or Mine Detection Neural Network was established. The performance of the model is enhanced by the proposed RDNN approach, which outperforms the results by obtaining good precision of 92.85% mean efficiency [50]. In the region of Alem Ketema, North Shoa, Ethiopia, Asmare and Hailemariam carried out a comprehensive investigation of rock slope failure analysis utilising the slope stability probability categorization (SSPC) approach. In accordance with standards, the SSPC system evaluated the amount of degradation, intact rock strength, digging technique, abrasive condition, and packing material. Three-step classification approaches are used by the slope stability probability classification (SSPC) system. The process is broken down into three steps: surface exposure of rock, reference rock mass, and slope rock mass. After completing all stages, 92 natural rock slope sections received their slope rock mass stability prospects classified. Two methods—orientation-dependent stability and orientation-independent stability—were used to determine the durability of the rock mass on the slope. According to the total assessment, 80.4% of rock slope portions had less than 5% stable probability, 10.9% had reliability probability of 5% to 49%, 6.5% had durability probability of 50% to 95%, and the additional 2.2% showed stability probability of greater than 95%. These results were all contrasted with the perceptual reliability assessment. Different stability probability maps were produced [51].

4. Conclusions

In general, rock mass classification is intended for assistance of engineer and the geologist in detecting and assessing the aspect of rock mass, especially in areas where it is difficult to collect samples and yield observations. With the help of this system, it becomes easier to evaluate the stiffness and elastic modulus of a rock mass by integrating the impact of variances and perfectly preserved rock into a simulated continuum. In this review paper, the following points were concluded:

1. For classification of rock mass and to evaluate the slope stability along a road cut two types of rock mass classifications were fully observed, i.e., RMR and GSI. For superior understanding

of rock mass condition, it is preferable to use RMR and GSI separately. It has been found that the applicability of GSI is solely sufficient in poor rock condition to define slope instability.

2. The GSI system is a distinct mode to conveniently capture the complex and varied nature of rock mass structure and composition, setting it apart from other rock mass classification methods. It also provides a highly accurate valuation of geo-mechanical properties, making it a valuable tool for the engineers and geologists. With the GSI system, the certainty level in understanding and predicting the behavior of rock mass is at its peak, surpassing other classification systems.
3. The RMR classification system is obligatory for design of underground structures specifically for tunnels. For valuation of RMR values 3 different approaches including conventional method, MLR, ANN were used. It has been found that ANN based model is better, and can be utilized for the approval of the support system of tunnel.
4. Five methods-SRA, MRA, ANN, ANFIS, and GEP-were employed to forecast the UCS of rocks. To decide the most effective method, performance indices (PI_{at}) were applied. The findings revealed that MRA had the highest mean PI_{at} of 2.6, which makes it an outstanding method as compared to ANN, ANFIS, and GEP having PI_{at} values 2.22, 2.44, and 2.33, respectively.
5. The ARMR classification system has been implemented to various types of rock masses in five locations around the world including China, the United States, Greece, Australia, and Italy. These rock masses include Slate, Quartz Schist, Gneiss, and Calcschist. The results of the classification revealed that the ARMR values for the rock masses in these locations were found to be as follows: China: 51-54, United States: 66-70, Australia: 57-60, Italy: 35, and Greece: 65-70. The range of slate and shale falls under moderately anisotropic while quartz schist, gneiss, and calcschist falls under slightly anisotropic and highly anisotropic.
6. For metal classification of rocks or mine in underwater acoustics RDNN model achieves high accuracy of about 92.85% resulting in the better-quality model performance.

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تکنیک‌ها و پارامترهای طبقه بندی توده سنگ: مقاله مروری

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چکیده:

سیستم طبقه‌بندی توده سنگ برای طبقه‌بندی سنگ‌ها استفاده می‌شود و در پروژه‌های مهندسی و تحقیقات پایداری استفاده شده است. این سیستم بر پارامترهای توده سنگ و کاربردهای مهندسی تمرکز دارد که شامل تونل‌ها، شیب‌ها، پی‌ها و غیره می‌شود. طبقه‌بندی توده سنگ در مناطقی که جمع‌آوری نمونه‌ها و بازده مشاهده دشوار است ارزشمند است. با پیشرفت تکنولوژی، الگوریتم‌های مدل مبتنی بر ماشین‌های مختلفی از جمله ANN و MLR در طبقه‌بندی توده سنگ از چند سال قبل استفاده شده‌اند. در کار حاضر، طبقه بندی توده سنگ، یعنی بار سنگ، زمان ایستادن، RQD، RMR، Q، GSI، SMR و RMi به همراه کاربردهای آنها مورد بحث قرار گرفته است. با در نظر گرفتن تمام پارامترها، نتیجه گیری می‌شود که برای پایداری شیب در شرایط سنگ ضعیف، کاربرد GSI در مقایسه با RMR کافی است. GSI همچنین یک ارزیابی بسیار دقیق از خواص ژئومکانیکی ارائه می‌دهد و آن را به ابزاری ارزشمند برای مهندسان و زمین شناسان تبدیل می کند. همچنین، مقادیر RMR به‌دست‌آمده از مدل ANN نتایج بهتری را برای تونل‌ها در مقایسه با MLR و روش مرسوم ارائه می‌دهد. طبقه بندی ARMR اسلیت، شیل، کوارتز شیست، گنیس و کلشیست در ۵ نقطه مختلف جهان به ترتیب ۵۴-۵۱، ۷۰-۶۶، ۶۰-۵۷، ۳۵، ۷۰-۶۵ بود. محدوده برای تخته سنگ و شیل به طور متوسط ناهمسانگرد است، در حالی که کوارتز شیست، گنیس و کالکشیست کمی ناهمسانگرد و بسیار ناهمسانگرد هستند.

کلمات کلیدی: طبقه بندی توده سنگ، پایداری شیب، ارزیابی، RMR، ANN.
