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ORIGINAL PAPER

Development of a directional continuous joint adjustment rating for the rock mass rating system

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Abstract

Rock mass rating (RMR) is a widely used empirical classification system for measuring the quality of rock masses. Joint orientation and trace length are joint parameters utilized as adjustment factors in RMR-based rock mass characterization. Since its inception, there has been a lack of modifications made to the adjustment factors, particularly regarding the directional continuous rating of joint orientation and trace length. The study endeavours to address the constraints by proposing a directional continuous rating function for joint orientation and trace length rating, serving as an adjustment factor in the RMR rating. The function is developed from 3528 graphical joint simulation patterns of a tunnel drive, with ratings assigned based on favourable and unfavourable joint orientations. Finally, the RMR is enhanced with directional continuous joint adjustment rating functions, which have been proven to be advantageous and more accurate compared to the conventional RMR_{89} joint adjustment rating chart.

Keywords Joint orientation · Trace length · Directional continuous rating · RMR adjustment rating

Introduction

The Rock Mass Rating (RMR) system is a widely used empirical classification tool for evaluating the quality of rock masses across diverse engineering applications such as mining, tunnelling, slope stability, and foundation design. The RMR system was first established by Bieniawski (1973), primarily relying on coal mining data. Subsequent revisions, particularly in 1989 and 2014, honed its parameters, ratings, and overall structure.

In 2014, the RMR system underwent significant modifications, introducing parameters Fs and Fe. Fs, linked to the method of excavation and RMR_{89}, and Fe, the function of uniaxial compressive strength, virgin stress ratio, tunnel depth, and shape coefficient, represented crucial advancements (Celada et al. 2014). Because of its trustworthiness, the RMR system and its parameters have been modified, revised, developed, and updated for its widespread application in both underground and surface scenarios (Rehman et al. 2018).

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RMR rating serves a multifaceted purpose, aiding stability evaluations, support system design, prediction of mechanical properties of rock masses, and assessment of the risk of rock structural failures. This comprehensive approach, in conjunction with other engineering parameters, facilitates the estimate of rock masses strength, deformability, and Poisson's ratio, ensuring to assessments of their inherent stability (Hashemi et al. 2010). Moreover, it enables the calculation of critical design parameters, including average stand-up time, rock load estimation, unsupported span of excavations in fractured rock mass, Hoek and Brown parameters (m_b), cohesion, and friction angle of rock mass.

The RMR_{89} system categorizes input parameters into distinct classes, each with its specific rating. These parameters encompass rock quality designation (RQD), uniaxial compressive strength (UCS), spacing of discontinuities, conditions of discontinuities, ground water, and adjustment rating for joint orientations (Bieniawski 1989). Joint properties such as RQD, aperture, roughness, persistence, spacing, weathering, infilling, joint orientation, and trace length are integral components. Notably joint orientation and trace length serve as the essential joint adjustment factors in the RMR_{89} classification system (Bieniawski 1989).

The RMR joint adjustment chart, as shown in Table 1, suggested by Wickham et al. (1972), adjusts the RMR value

Table 1 Tunnel orientation versus that of discontinuities (Bieniawski 1989)

Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		Irrespective of strike dip 0°–20°
Drive with dip		Drive against dip				
Dip 45–90	Dip 20–45	Dip 45–90	Dip 20–45	Dip 45–90	Dip 20–45	
Very favourable	Favourable	Medium	Unfavourable	Very unfavourable	Medium	Medium
0	−2	−5	−10	−12	−5	−5

considering favourable and unfavourable joint orientation and trace length. The joint orientation refers to the direction and dip of the joint in relation to the tunnel axis, whereas the joint trace length is defined as the distance between the scanline intersection point and the end of the joint trace. While simple, this chart lacks directional continuous rated values and has seen no updates since Bieniawski (1989) original work. Consequently, joint orientation exacerbates anisotropic behaviour from the microscale (intact rock) to the macroscale (rock masses) (Saroglou et al. 2019). Incorporating a directional continuous joint adjustment rating into the RMR system becomes imperative because the stability of underground excavation is principally controlled by discontinuities in the rock mass, including bedding, joints, faults, and fractures (Ghorbani et al. 2015).

The directional aspect of joint orientation significantly affects rock mass strength, deformation, and failure mode. In this regard, Jia and Tang (2008) studied the effect of different dip angles of joints on tunnel stability and concluded that the layered joints influence the failure mode. Moreover, Park and Min (2015) analysed the force distribution on the layer orientation and discovered that the stress regime differs depending on the plane orientation (0° to 90°). Furthermore, Vitali et al. (2021) conducted a numerical and analytical study on jointed rock masses and observed that the relative orientation of the tunnel with regard to the joint would affect tunnel stability performance. In addition, Schubert and Mendez (2017) modelled a foliated rock mass and observed that the relative orientation of the tunnel axis and joint strike influences the tunnel deformation when the strike is parallel and perpendicular to the tunnel axis.

Similarly, trace length serves as a pivotal geometrical property governing rock mass failure and stability in jointed rock masses. Ghorbani et al. (2015) observed the significant impact of various statistical density functions of joint trace length on stability parameters such as stress and displacements of tunnels in a jointed rock mass. Despite its significance, accurately measuring joint trace length is proven to be challenging due to limited rock exposures in the underground excavation (Zadhesh et al. 2014). As a result, it cannot be utilized to predict structural behaviour beyond the exposed surface, and biases exist in the sampling of trace lengths and in inferring joint size pragmatically (Zadhesh and Majdi 2022).

On the other hand, the shift from traditional stepwise ratings to continuous ratings has gained popularity in recent years. In view of that, Şen and Bahaaeldin (2003) replaced the traditional stepwise rating with a continuous rating that eliminates uncertainty for a novice engineer when giving a rating based on quantitative field data and laboratory measurements. Furthermore, Lowson and Bieniawski (2013) calculated the RMR parameters, such as UCS and fracture frequency, using a continuous rating rather than a stepwise method.

However, the lack of directionally dependent behaviour in the RMR adjustment factor, i.e., joint orientation, was not included in the anisotropic rock mass characterization, despite its importance. Existing methods such as *Q*-rating and GSI have overlooked the joint orientation adjustment factor, despite its profound impact on rock mass stability through favourable and unfavourable orientations (Barton 2002; Sonmez and Ulusay 1999). Even the anisotropic rock mass rating (ARMR) by Saroglou et al. (2019) has not incorporated these crucial factors. In addition to that, Maazallahi and Majdi (2021) developed a directional rock mass rating but failed to incorporate the RMR adjustment factors in the directional rock mass rating system. Exploring directional continuous adjustment factors holds the potential to enhance anisotropic rock mass characterization.

Furthermore, the RMR-based slope rock mass classification is crucial tool in assessing rock slope stability in highway slopes and mine benches (Basahel and Mitri 2017). Dhiman and Thakur (2022) proposed the new continuous slope mass rating (SMR) charts for easy calculation of the SMR class of rock slopes in the field. This has been proposed in view of reducing the calculation time, achieving continuous rating functions, and making it easier and more efficient to use the uncertainty joint conditions. This underscores the demand for directional and continuous RMR adjustment ratings for the assessment of surface and subsurface rock structural features.

The adjustment factors, such as joint orientation and trace length, are sought to change and construct the directional and continuous trend of calculating the RMR adjustment parameter. The study aims to develop a directional continuous rating function for joint orientation and trace length. The directional continuous adjustment rating functions can be derived by generating graphically simulated joint pattern for a driving tunnel and assign rating based on the favourable and unfavourable conditions.

Background of rock mass rating adjustment factors

The conventional RMR_{89} adjustment factor is computed based on the tunnel joint orientation and the trace length of the discontinuities, as outlined in Table 1. Joint orientation significantly influences the tunnel stability under various conditions, encompassing both favourable and unfavourable scenarios. A favourable joint orientation is one that has the least effect from gravity-induced ground instability and that possess the highest frictional resistance. Conversely, an unfavourable joint orientation amplifies has gravitational instability and diminishes frictional resistance.

Aside from joint orientation, the RMR adjustment chart indirectly represents the joint trace length through the strike, which can be parallel or perpendicular to the tunnel axis. The trace length plays a crucial role in tunnel stability; when joints are exposed parallel to the tunnel drivage, the likelihood of ground failure increases, whereas exposure perpendicular to the tunnel drivage decreases ground instability. The disparity in ratings between the joints parallel and perpendicular to the tunnel axis is referred to as the joint trace length rating, while the difference in ratings between direction and dip is referred to as the joint orientation rating.

In summary, the conventional RMR_{89} adjustment factor takes into account both joint orientation and trace length, with the former influencing stability under different gravitational conditions and the latter impacting ground failure probabilities based on joint exposure relative to the tunnel drivage. The joint trace length rating and orientation rating provide a quantitative assessment of these influences, contributing to a comprehensive understanding of tunnel stability.

Development of joint orientation and trace length rating chart

The strength of rock mass is notably influenced by joint orientation and trace length. The rock mass gains strength in favourable orientations and loses strength in unfavourable orientations of a joint, attributes to gravitational instability, and frictional losses at different orientations. Moreover, the exposure of trace length in an underground excavation is a key factor influencing potential failures. Considering all these aspects into account, a comprehensive rating chart for joint orientation and trace length has been formulated and presented in Fig. 1.

The joint orientation ratings of front and side views of tunnel tracing are illustrated in Fig. 1; values range from 0.4 to 1 for orientations spanning from 0 to 90°. The joint orientation top view for trace length ranges from 0.7 to 1. Notably, vertical joint orientation is assigned a higher rating than horizontal joint orientation, while the horizontal joint orientation is received a lower rating due to consideration of sagging, bending, separation, and slipping of the roof and sides. The joint trace length directed along (parallel) the tunnel is assigned a rating of 0.7, while it receives a rating of 1 when positioned across (perpendicular) the tunnel axis. This distinction recognizes the varying impact of trace length orientation on tunnel stability. The subsequent subsection outlines the simulation and function derivation.

Evaluation of graphical joint simulation pattern

The derivation of the RMR joint adjustment rating function is achieved through the creation of a graphically simulated joint orientation pattern. This pattern is generated by orienting the tunnel drive in every conceivable direction and dipping against a fixed joint plane set within a stereographic hemispherical projection (refer to Fig 2). In simpler terms, the simulation involves intersecting a joint plane with a tunnel undergoing changing orientations, producing the graphical simulation joint pattern depicted in Fig. 2. It is crucial to note that the joint properties, including dip direction and dip, remain constant throughout the graphical simulation for producing joint patterns. The stereographic hemispherical projection, with its three-dimensional network, enables the production of simulation patterns spanning from 0 to 360° in direction and 0 to 90° in dipping. This graphical output simulation was executed using AutoCAD, as illustrated in Fig. 3.

The driving tunnel systematically intersects the joint set at 15° intervals within a stereographic projection. A total of 3528 output results were generated, and the sample simulation graphical pattern at a 90° dip is displayed in Fig. 3. Ratings from Fig. 2 were then assigned to these 3528 graphical joint patterns. It is important to highlight that the 3528 simulated results encompass front view (FV), side view (SV), and top view (TV), as shown in Fig. 3. Amongst these, 2352 results represent joint orientation, while 1173 results correspond to joint trace length. In Fig. 3, FV and SV signify rating for joint orientation, while TV denotes rating for joint trace length.

The ratings from Fig. 2 are systematically assigned to the 3528-simulation output, thereby establishing directional continuous functions for both joint orientation and trace length. Detailed information about these proposed functions is expounded upon in the subsequent subsections.

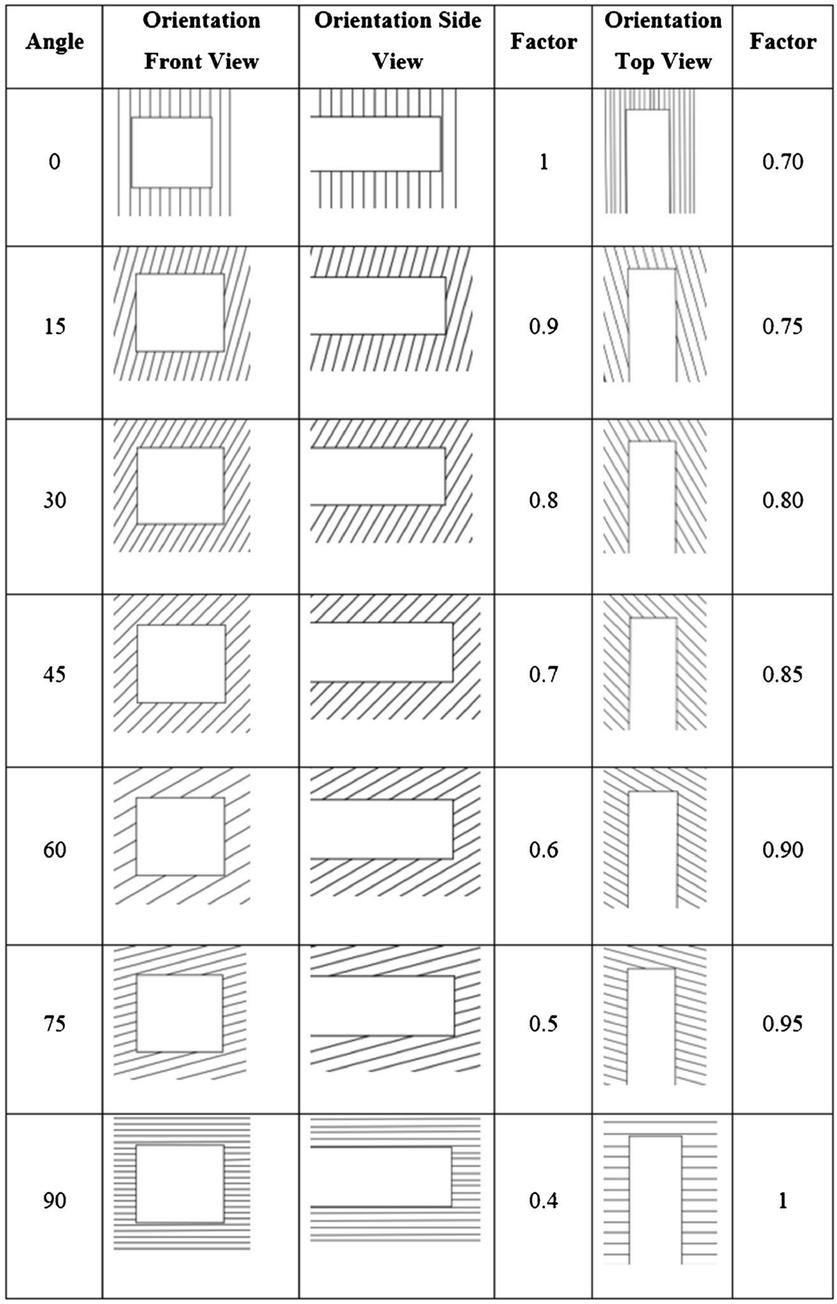

Fig. 1 Ratings of joint orientation and trace length

Development of joint orientation function

Figs. 4 and 5 visually represent the orientation ratings corresponding to the 2352 joint simulation pattern. Through a meticulous process of curve fitting applied to these orientation ratings, two distinct functions for rating directional joint orientation were derived (refer to Eqs. 1 and 2). The conditions outlined in Eqs. (1) and (2) $[(\theta_{DipDir}-90) to\ (\theta_{DipDir}+90)]$ are instrumental in selecting the orientation angle within the range of 0° and 360°, defining the application scope of each equation. These equations serve as comprehensive analytical functions formulated to evaluate directional continuous ratings for joint orientation. It is noteworthy that the curve fitting process applied to Figs. 4 and 5 resulted in the establishment of Eqs. (1) and (2). In Eqs. (1) and (2), the terms "dip direction" and "dip" pertain to the characteristics of the discontinuity plane, while "plunge" refers to the orientation of the tunnel axis.

$$Or_1 = 0.7 + \left(0.255 * \sin\left(1.984 * \left(136.5 + \left(\theta_{plunge} - \theta_{dip}\right)\right)\right)\right) \text{ for } = \left(\theta_{DipDir} - 90\right) to \left(\theta_{DipDir} + 90\right) \tag{1}$$

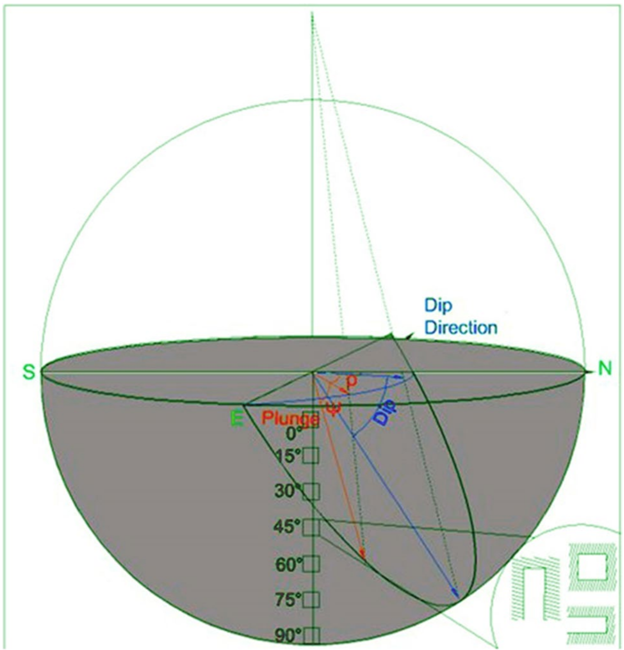

Fig. 2 Intersection of joint plane with a tunnel undergoing changing orientation in a lower hemispherical stereographic projection

$$Or_2 = 0.7 + \left(0.255 * \sin\left(1.984 * \left(316.5 - \left(\theta_{dip} + \theta_{plunge}\right)\right)\right)\right) \text{ for } \neq \left(\theta_{DipDir} - 90\right) to \left(\theta_{DipDir} + 90\right) \quad (2)$$

θ_{DipDir} = direction of the joint (0° − 360°)

θ_{dip} = dipping of the joint (0°to 90°)

θ_{plunge} = dipping of the tunnel (0°to 90°)

Development of joint trace length function

The joint trace length is defined as the exposed trace length of a joint measured in relation to the tunnel axis. In the RMR_{89} rating chart (refer to Table 1), the joint trace length is categorized as either strike parallel or strike perpendicular to the tunnel axis. Notably, in the RMR adjustment factor, tunnel drives along the joint plane are assigned a higher trace length rating than drives across the joint plane (see Table 1). Consistent with this approach, the proposed rating chart assigns a higher rating to joint strikes along the tunnel axis compared to strikes across the tunnel. Additionally, a continuous rating has been introduced to bridge the gap between parallel and perpendicular directions.

The top view in the joint tracing from Fig. 3 indicates the trace length. Ratings from Fig. 2 were systematically assigned to 1176 simulated images, and the corresponding results are presented in Fig. 6. The directional continuous trace length ratings, as depicted in Fig. 6, were derived through a curve fitting process yielded Eqs. (3) and (4). Equation (3) represents the calculated trend angle ($\theta_{caltrend}$), serving as the conversion function for trend spanning 0 to 360° to be input in the trace length function outlined in Eq. (4). Finally, the overall normalized adjustment rating can be obtained through Eq. (5), achieved by multiplying the orientation and trace length of the corresponding joint orientations.

$$\theta_{caltrend} = 44.488 + 37.986 * \sin\left(1.987 * \left(45.871 + \theta_{trend} + \theta_{dir}\right)\right) \quad (3)$$

$$P = \left(-0.000037 * \theta_{plunge} * \theta_{caltrend}\right) + \left(0.00333 * \left(\theta_{plunge} + \theta_{caltrend}\right)\right) + 0.7 \quad (4)$$

$\theta_{caltrend}$ = calculated trend angle $\left(0^{o} - 90^{o}\right)$

θ_{trend} = trend of a tunnel axis $\left(0^{o} - 360^{o}\right)$

P= trace length of a joint

$$OTL = Or * P \quad (5)$$

OTL = orientation and trace length

Or = orientation

Practical application of the proposed RMR joint adjustment factor

Site description

The field study was conducted at a metal mine (see Fig. 7), situated in Jharkhand state, India. The major rock formations of the area belong to the argillaceous and arenaceous metasediments of the Archean age, comprising phyllites, mica schist, and quartzite. The mines consist of three adit sections that are spaced by 400–500 metres apart and located within a 1-km radius. Geotechnical mapping was carried out within the mines (see Fig. 7), and the principal joint sets along with the corresponding RMR parametric values are detailed in Table 2.

Example calculation of the joint adjustment factor

Before performing the calculations, the trend and plunge planes must be defined. The trend-plunge network plane is a lower hemispherical stereonet projection (Fig. 8), represented

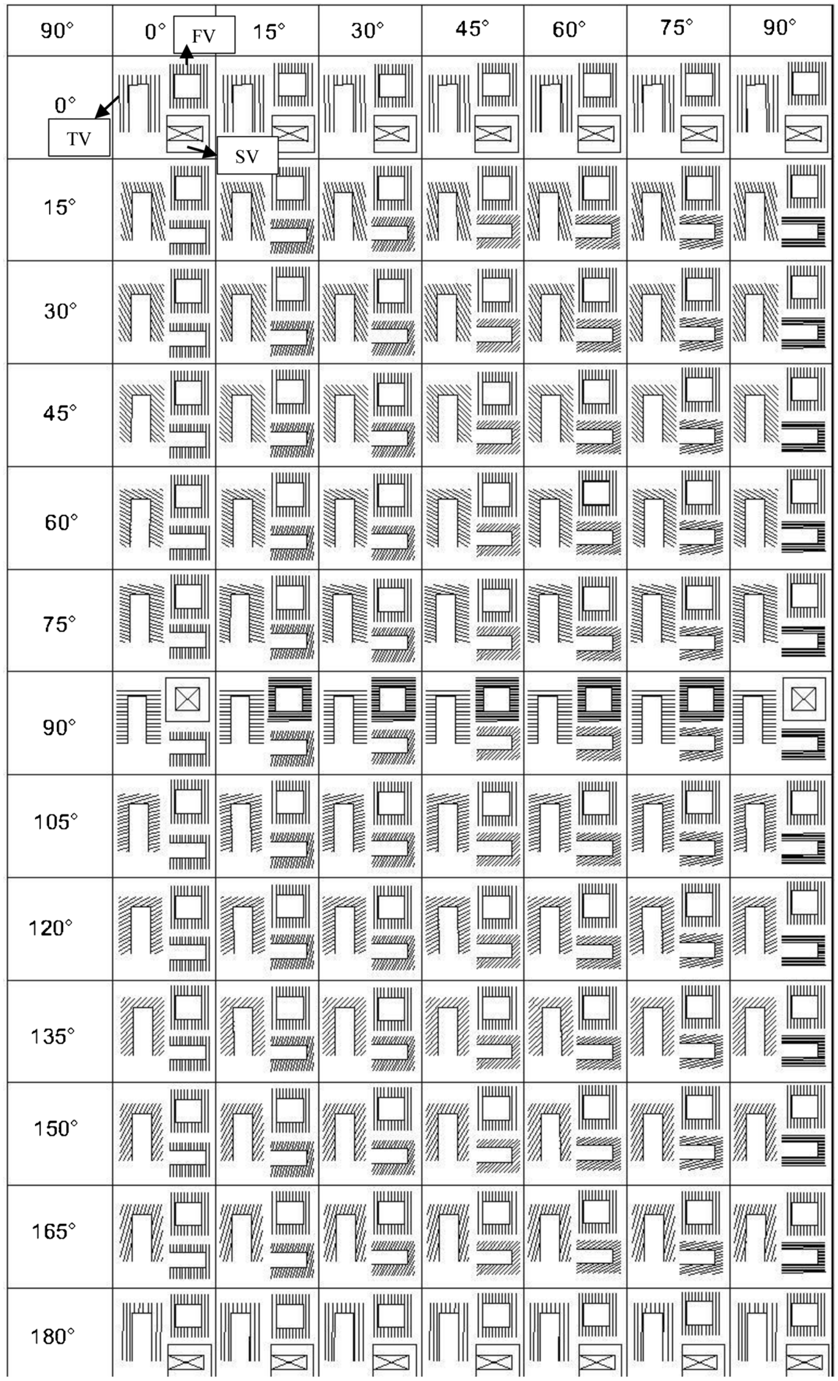

Fig. 3 Graphical simulation chart showing joint orientation and trace length (90 ° direction and 90 ° dip) of an orienting tunnel; the top column 0 ° to 90° represents the plunge, and the row (0 ° to 180 °) represents the trend. Note: The "X" in the figure denotes the joint set invisible in a particular orientation

as a planar network. In application, the trend-plunge nodes symbolize the tunnel axis, pointing in a specific direction and dipping. For accurate calculations, a trend-plunge network plane with trend values ranging from 0 to 360° and plunge values ranging from 0 to 90° is recommended, with a 5° interval. The calculations were conducted using a lower hemispherical stereonet projection, as illustrated in Fig. 8. In stereonet projection, the trend line and plunge line intersect at any point to form a node, as shown in Fig. 8 (right). The nodes in the trend-plunge network are empty spaces that can cover all spatial orientations (direction and dip), forming an empty space that covers all spatial orientations (direction and dip). Each node is assigned a unique adjustment rating, resulting in a total of 1387 nodes for the given condition (5° interval). This implies the potential to generate 1387 adjustment ratings for joint orientation and trace length (OTL) ratings. The following lines outline the detailed procedure for calculating the directional continuous adjustment ratings for orientation and trace length.

The example calculation utilized data from Table 2. Firstly, the orientation functions are conditionally dependent, which

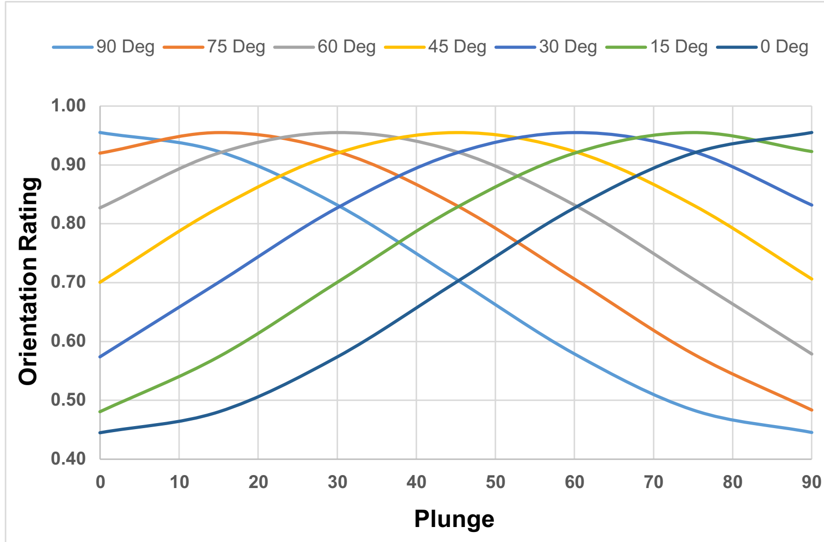

Fig. 4 Orientation rating for =($\theta_{DipDir}-90$)*to* ($\theta_{DipDir}+90$)

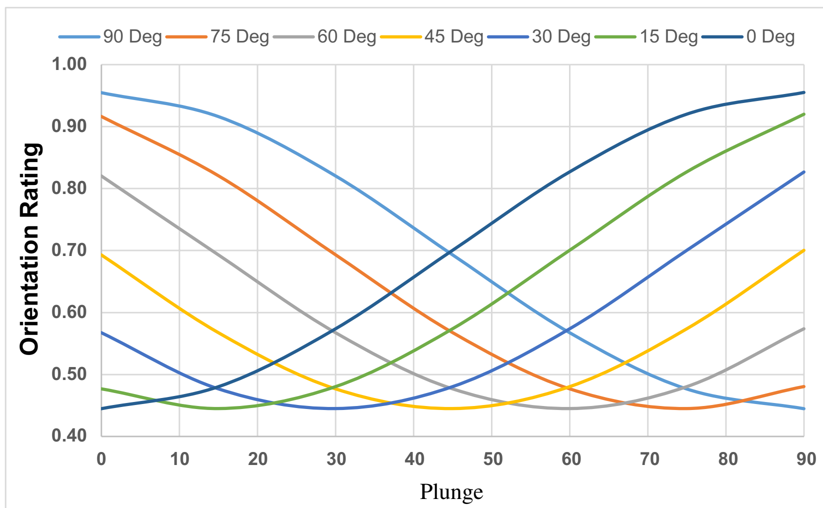

Fig. 5 Orientation rating for ≠($\theta_{DipDir}-90$)*to* ($\theta_{DipDir}+90$)

can be obtained by entering the joint direction (θ_{DipDir}). The resulting output determine the trend range (0 to 360°) in which the Eqs. (1) and (2) apply. The output values of Eqs. (1) and (2) are applicable only within the trend; refer to Table 3 (Or_1, Or_2). Secondly, for joint trace length calculation, a calculated trend was derived, converting the linear trend (0 to 360°) into a sine waveform using Eq. (3), as presented in Table 3. This calculated value was then input into Eq. (4) to obtain the trace length ratings, as documented in Table 3.

The proposed adjustment rating system was calculated using Microsoft Excel, and the resultant output of the geotechnical mapping is shown in Table 3 only for the three mutual perpendicular directions *X*, *Y*, and *Z*. In total, 1387 simulation results were generated using the proposed function at 5° intervals of trend and plunge of the tunnel axis, amongst which *X*, *Y*, and *Z* are the three-simulation results showcased in Table 3. The *X*-direction represents (trend 0, plunge 0); similarly, the *Y*-direction represents (90, 0), and the *Z*-direction represents (90, 90). Finally, the multiplication of orientation and trace length resulted in the joint adjustment factor using Eq. (5), and results are shown in Table 4.

Comparison of conventional RMR_{89} adjustment with proposed RMR adjustment

In the conventional calculation results (refer to Table 4), the minimum (critical) RMR_{89} rating and the maximum RMR_{89} rating are 50 and 54, respectively, representing a difference of 4. The minimal difference is attributed to the rating from the conventional joint adjustment chart, which is −5, despite considering multiple joint orientations (direction and dip). Moreover, the conventional RMR_{89} adjustment rating resulted a unidirectional noncontinuous rating.

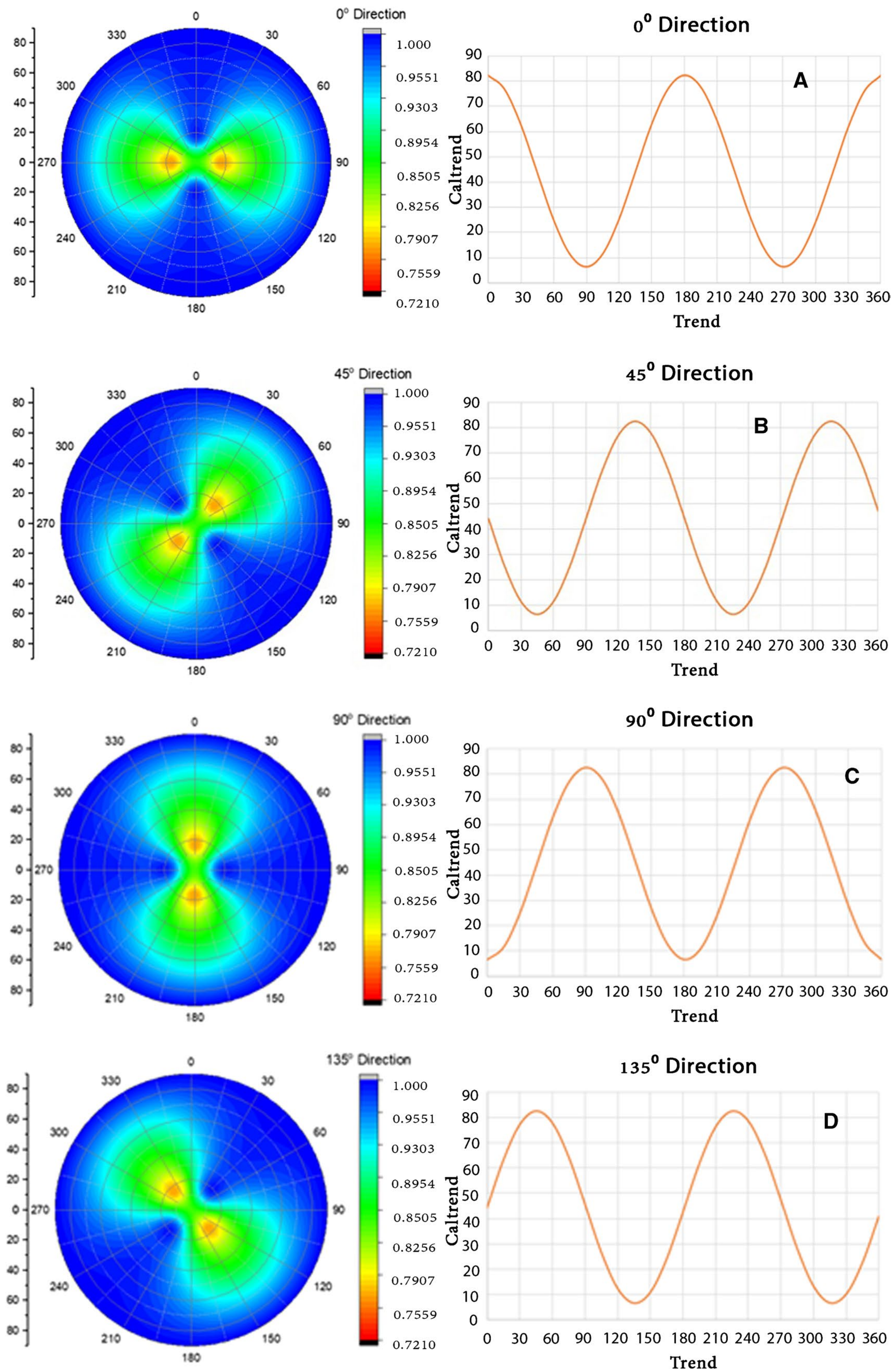

Fig. 6 Polar plot showing the trace length rating of various directions having a 45° interval (left): **A** 0° direction, **B** 45° direction, **C** 90° direction, **D** 135° direction, **E** 180° direction, **F** 225° direction, **G** 270° direction, and **H** 315° direction. Corresponding sinusoidal trend $\theta_{caltrend}$ (right)

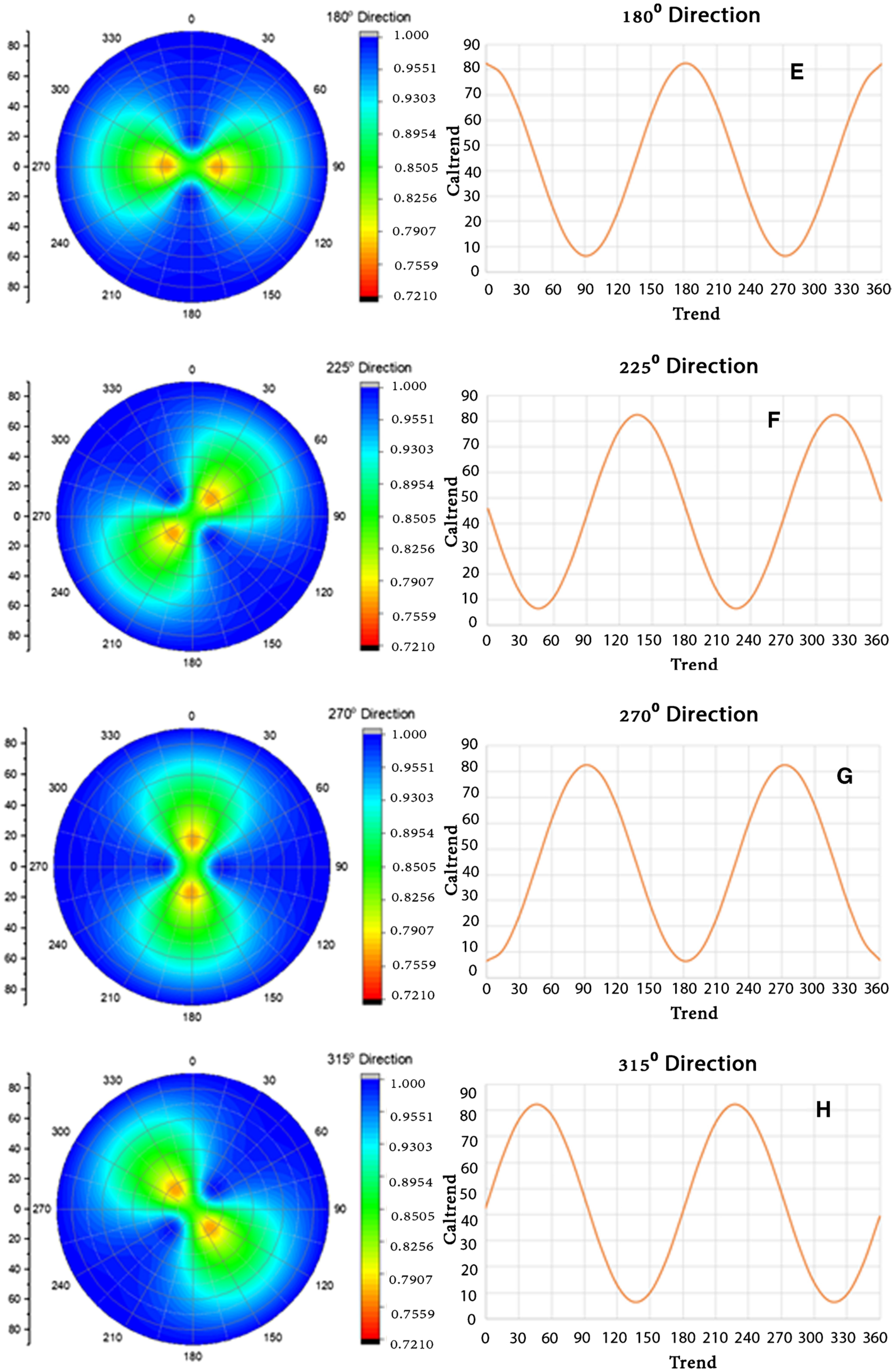

Fig. 6 (continued)

Fig. 7 Geotechnical investigation in the mine to determine the parameters mentioned in Table 3.

The proposed normalized rating, ranging between 0.32 and 0.95, was upscaled to RMR joint adjustment ratings on the scale of 0–12 using Eq. (6). This accomplishment involved scaling and transforming the normalized rating to fit within the RMR_{89} joint adjustment range of 0–12. According to the proposed RMR adjustment function (Eq. (6)), the minimum rating earned is 0 and the maximum is 12 (refer to Table 4). These values are to be subtracted from RMR_{89} rating to obtain an adjusted RMR_{89} (RMR_{adj}). The

Table 2 Geotechnical mapping dataset of the mine

Phyllite rock	UCS (MPa)	RQD	Dip Dir	Dip	Spacing (m)	Persistence (m)	Aperture (m)	Roughness	Infilling	Weathering	Water condition
Joint 1	45	56	90	6	0.07	1–3	0.1–1	Smooth	Soft < 5 mm	Slightly	Damp
Joint 2		87	230	45	0.16	1–3	0.1–1	Smooth	Soft < 5 mm	Slightly	Damp
Joint 3		83	175	35	0.14	1–3	0.1–1	Smooth	Soft < 5 mm	Slightly	Damp

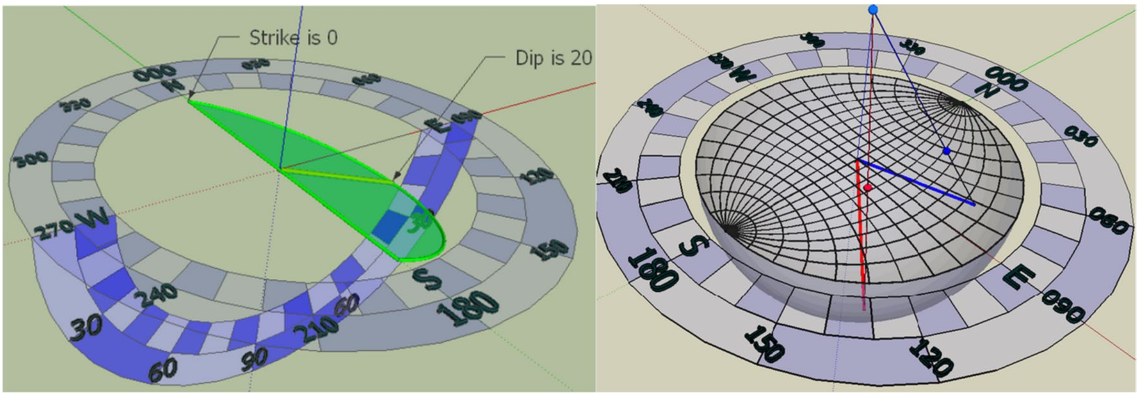

Fig. 8 Illustration of trend-plunge network plane (web.williams.edu); (left) image showing a trend ring (0–360°), plunge ring (0–90°), strike (0–180°), dip direction (90°), dip (20°), trend of TI plane (270°), and plunge of TI plane (70°); (right) illustrating the lower hemispherical network and node.

Table 3 Output of proposed adjustment rating function

Or_1^{J1}	0°–180°		
Or_2^{J1}	185°–360°		
Or_1^{J2}	140°–320°		
Or_2^{J2}	325°–135°		
Or_1^{J3}	85°–265°		
Or_2^{J3}	270°–80°		
Directions	X (0, 0)	Y (90, 0)	Z (90, 90)
Or_i^{J1}	0.45	0.45	0.95
Or_i^{J2}	0.71	0.71	0.70
Or_i^{J3}	0.61	0.62	0.79
$\theta_{caltrend}^{J1}$	82.47	6.5	82.47
$\theta_{caltrend}^{J2}$	49.11	39.10	49.11
$\theta_{caltrend}^{J3}$	7.37	81.76	7.37
P_i^{J1}	0.98	0.72	1
P_i^{J2}	0.86	0.83	1
P_i^{J3}	0.72	0.97	1
$J1_{adj}$	0.44	0.324	0.95
$J2_{adj}$	0.61	0.59	0.7
$J3_{adj}$	0.44	0.60	0.79

minimum (critical) RMR_{adj} rating is 43, while the maximum value is 55, resulting in a variance of 12 (see Table 4). Notably, even with the same input data, there is a significant variation in the computation between the conventional and proposed RMR adjustment ratings. Finally, it becomes evident that the directional continuous RMR adjustment function provides a differential rating concerning tunnel orientation.

$$RMR_{adj} = RMR_{89} - (0.95 - OTL) \quad (6)$$

Discussion

Discussion on the study methodology

The conventional RMR_{89} joint adjustment rating is considered non-continuous and unidirectional, reducing the lump-sum value of the RMR in terms of the adjustment factor. This reduction significantly impacts the assessment of rock mass characterization. This study addressed these limitations by proposing the RMR adjustment rating, a directional and continuous joint adjustment function for rating favourable and

Table 4 Comparison of conventional RMR adjustment factor with directional-continuous adjustment factor

Joints		RMR	Conventional Adjusted RMR	Directional continuous adjustment ratings		
				X	Y	Z
RMR adjustments	J1	–	−5	−9.69	−12	0
	J2	–	−5	−6.46	−6.84	−4.75
	J3	–	−5	−9.69	−6.65	−3.04
RMR J1		55	50	45.31	43	55
RMR J2		59	54	52.54	52.16	54.25
RMR J3		59	54	49.31	52.35	55.96
RMR critical		–	50	45.31	43	54.25

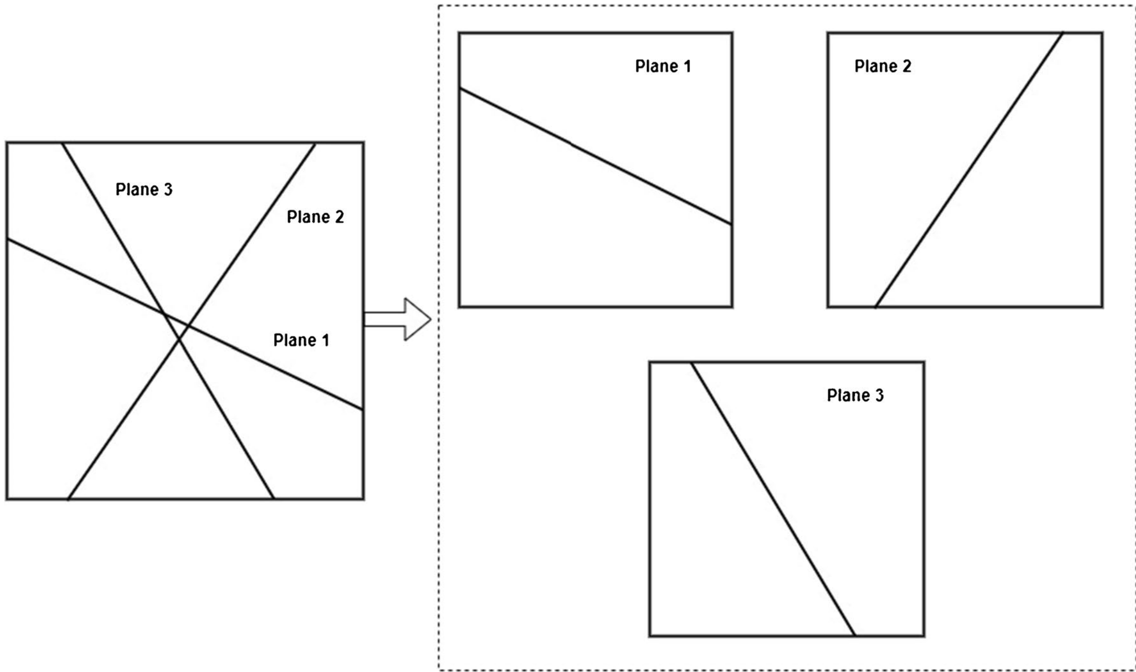

Fig. 9 Illustration of multiple joint sets discretized into the single weak plane.

unfavourable joint orientations. The methodology adopted to achieve a critical RMR joint adjustment rating involves discretizing the multiple joint set into a single weak plane for individual assessment, as illustrated in Fig. 9. In addition, the study used a graphically simulated joint pattern to provide evaluations on basis of favourable and unfavourable pattern.

Each joint orientation is assigned adjustment ratings to deduce values from the corresponding RMR, as shown in Table 4. Finally, the minimum adjusted RMR is considered the critical RMR for that orientation (refer to Table 4). The results indicate that the conventional adjusted RMR employs a unidirectional rating system, with RMR ranging from 50 to 54, showing a difference of 4. In contrast, the integration of RMR with directional continuous adjustment rating yields multifaceted results ranging from 43 to 55 concerning orientation, indicating a difference of 12. These considerable differences between the existing and proposed ratings underscore the significance of integrating the proposed adjustment rating function in the RMR.

Discussions on the proposed functions

The assessment of 3528 graphical simulation joint patterns yielded a function known as the normalized adjustment rating, with the rating ranging from 0.32 to 0.95. Initially, joint orientation and trace length were assessed separately as a directional continuous function in Eqs. (1) to (4). The joint orientation adjustment factor is determined by multiplying the orientation and trace length ratings (Eq. (5)). For performing the RMR rating, the normalized adjustment rating has been scaled up and transformed into an equivalent rating, ranging between 0 and 12 (Eq. (6)). Comparative results indicated that the proposed RMR adjustment rating function outperformed the conventional RMR joint adjustment chart.

Implication, limitations, and applicability

To calculate the directional continuous adjustment rating, it is recommended to implement Eqs. (1) to (6) in a spreadsheet program. By employing these functions, joint adjustment ratings can be computed more efficiently, with greater accuracy and precision in the field. This study marks a significant step towards enhancing the accuracy and efficiency of rock mass rating systems, with potential applications in the design and construction of tunnels and underground excavations.

However, these proposed functions are limited to assessing a drive along a dip and against a dip. This exclusion arises because the state of the rock mass deteriorates along and against a dip, contingent on the support installation. Here, it is assumed that support installation occurs immediately after excavation. Nevertheless, further research is essential to determine the condition and extent of ground instability that may have occurred during excavation drives along and against a dip. The proposed function has the potential to complement other rock mass characterization applications. Particularly, the normalized rating function (Eq. (5)) can be utilized in evaluating applications involving joint orientation or trace length. The resulting directional continuous adjustment rating promises to revolutionize the calculation of RMR adjustment parameters, offering a more precise and comprehensive approach to evaluating rock mass stability.

Conclusions

The study introduces a directional continuous RMR adjustment rating for joint orientation and trace length, designed to assess tunnels and drives in any orientation and serving as an efficient adjustment rating within the RMR characterization system. The directional continuous adjustment rating functions were developed based on 3528 simulated joint patterns. A new rating guideline chart is proposed to facilitate for assessment of favourable and unfavourable joint patterns.

Equations (1) and (2) are utilized to determine joint orientation, while Eqs. (3) and (4) are employed to assess joint trace length. Finally, Eq. (5) calculates the normalized joint adjustment rating, and Equation (6) is formulated to assess the RMR joint adjustment rating, spanning from 0 to 12. The comparative analysis of the RMR_{89} joint adjustment with the proposed adjustment rating function indicates that the proposed directional continuous adjustment rating function outperforms the conventional rating chart in terms of efficacy and accuracy. The implication of directional continuous RMR adjustment rating can refine the results of stability evaluation, support system design, and the prediction of the mechanical properties of rock mass.

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Author contributions GG: conceptualization, methodology, software, validation, writing—original draft, writing—review and editing, visualization, and formal analysis. AKM: writing—review and editing—and Supervision.

Declarations

Conflict of interest The authors declare no competing interests.

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