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A New Approach of Adjustment Factor 2023 ($NAAF_{23}$) for Modified Slope Mass Rating (M-SMR)

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Abstract: The Modified Slope Mass Rating (M-SMR) system is a SMR-based geomechanical classification system utilized for rock slope characterization in the Crocker Formation. The M-SMR rating is derived from the sum of the basic Rock Mass Rating (RMRb) and an adjustment factor. However, it has been observed that the parallelism correction parameter, F1, within both the M-SMR and SMR systems, can sometimes be overestimated, especially for toppling failures when the discontinuity dip direction (αj) is less than the slope dip direction (αs). This study was conducted on six rock-cut slopes to not only evaluate the production of a convincing F1 value but also to introduce a simplified New Approach of Adjustment Factor 2023 ($NAAF_{23}$) diagram for the M-SMR. This adjustment factor (F) includes four correction parameters (F1, F2, F3, and F4), similar to those used in SMR, but modifies the calculation approach for F1. The calculation now involves subtracting the higher value from the lower value among the discontinuity dip, slope dip, or intersection line orientations. The symbols A, B, C, and D represent the subtracted values, with A and B used when the discontinuity dip direction is higher than the slope dip direction and vice versa, and C and D used when the intersection line is higher than the slope dip direction and vice versa. For plane failures, A or B becomes the value, while for wedge failures, C and D are used. For toppling failures, the formula is 180 − A or B if A or B is less than 180, and A or B − 180 if A or B is greater than 180, eliminating the need for absolute symbols. A comparison F1 calculation using SMR is also conducted. The results show that F1 values become more convincing when using $NAAF_{23}$.

Keywords: $NAAF_{23}$, M-SMR, SMR, correction parameter, Crocker Formation

INTRODUCTION

Rock mass classification systems are widely used in evaluating slope stability and providing empirical support for feasibility studies. These systems aid in characterizing, classifying, and understanding rock mass properties. Notable rock mass classifications include the Rock Mass Rating (RMR, Bieniawski, 1973), Slope Mass Rating (SMR, Romana, 1985), Rock Mass Strength (RMS, Selby, 1980), Slope Rock Mass Rating (SRMR, Robertson, 1988), Mining Rock Mass Rating (MRMR, Laubscher, 1990), Modified Mining Rock Mass Rating (MRMR modified, Haines & Terbrugge, 1991), Chinese Slope Mass Rating (CSMR, Chen, 1995), Modified Rock Mass Rating (M-RMR, Ünal, 1996), Slope Stability Probability Classification (SSPC, Hack, 1998), and Modified Slope Mass Rating (M-SMR, Rahim, 2011, 2015).

From the list mentioned earlier, the Slope Mass Rating (SMR) is widely utilized in slope stability evaluations, particularly to refine the orientation parameter (R6) within the Rock Mass Rating (RMR) system. SMR transforms the discontinuity orientation parameter into adjustment factors, labeled as “F.” These adjustment factors are further defined by four correction factors (F1 to F4). The determination of these factors is influenced by the relationships among the slope orientation, the characteristics of discontinuities, the orientation of the intersection lines between discontinuities (which is a critical factor affecting rock slope stability), and the excavation method employed to construct the slope.

Since the SMR system’s introduction over thirty years ago (Romana *et al*., 2015), numerous methodologies have been proposed to refine the SMR and SMR-based systems, particularly concerning the adjustment factor (F). These

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refinements address various aspects, including the mode of failure, calculation methodologies, and the generation of more positive and convincing values. Specifically, for the SMR and Modified Slope Mass Rating (M-SMR), the parallelism value, represented by the F1 correction parameter, is overestimated when the slope's dip direction exceeds that of the discontinuity ($\alpha s > \alpha j$). This discrepancy suggests a need for revision in the calculation of F1.

This study aimed to calculate the F1 adjustment factor for both the Slope Mass Rating (SMR) and Modified Slope Mass Rating (M-SMR) systems on six rock-cut slopes within the Crocker Formation in Kota Kinabalu, Sabah, Malaysia, as shown in Figure 1. Additionally, the study incorporated the use of fictitious data to complement the analysis.

M-SMR AND ADJUSTMENT FACTOR

The Modified Slope Mass Rating (M-SMR) value is derived from the sum of the basic Rock Mass Rating (RMRb) and the adjustment factor (F) values. The concept of F originates from the discontinuity orientation parameter in the RMR, which is then adapted into the orientation factor in the Slope Mass Rating (SMR), and subsequently transformed into the adjustment factor in M-SMR (Rahim, 2011). Within the M-SMR framework, F is referred to as the New Adjustment Factor (NAF), which follows the principles of SMR but incorporates several modifications in parameter calculation. The NAF was later evolved into the New Approach of Adjustment Factor (NAAF) (Rahim *et al*., 2012), introducing a more comprehensive methodology for parameter calculations.

In the NAAF, the adjustment factor F is determined by four correction parameters. These parameters encompass the geometrical relationship between the slope face and the effect of discontinuities on the slope face (parameters F1, F2, and F3), as well as the excavation method used to create the slope (F4). The calculation of F involves the subtraction of the higher value from the lower value, emphasizing the difference in orientations or positions. Symbols K, L, M, and N are utilized to denote the subtracted values, which represent the differences between the discontinuity dip or the intersection line orientation and the slope direction, or vice versa. This approach underlies the calculation and conceptual framework of the Modified Slope Mass Rating (M-SMR).

F1 is a correction parameter that reflects the degree of parallelism between the intersection line or the dip direction of discontinuities and the dip direction of the slope. It is determined by subtracting the higher value of either the discontinuity dip direction (αj) or the intersection line direction (αi) from/ or, depending on the failure mode, adding it to the lower value of the slope dip direction (αs). This calculation is applicable for plane (P), toppling (T), and wedge (W) failure modes. Each of these failure modes (P, T, and W) is marked and calculated according to their specific characteristics and the relationship between the discontinuity orientations and the slope orientation.

For the calculation of the adjustment factor F1 in the context of plane and toppling failures, the symbols K or L are employed. K is used when the discontinuity dip direction (αj) is greater than the slope dip direction (αs), and L is used for the opposite scenario. For wedge failures, M or N symbols are used following the same principle, with M being used when the intersection line direction (αi) exceeds the slope dip direction, and N for the reverse.

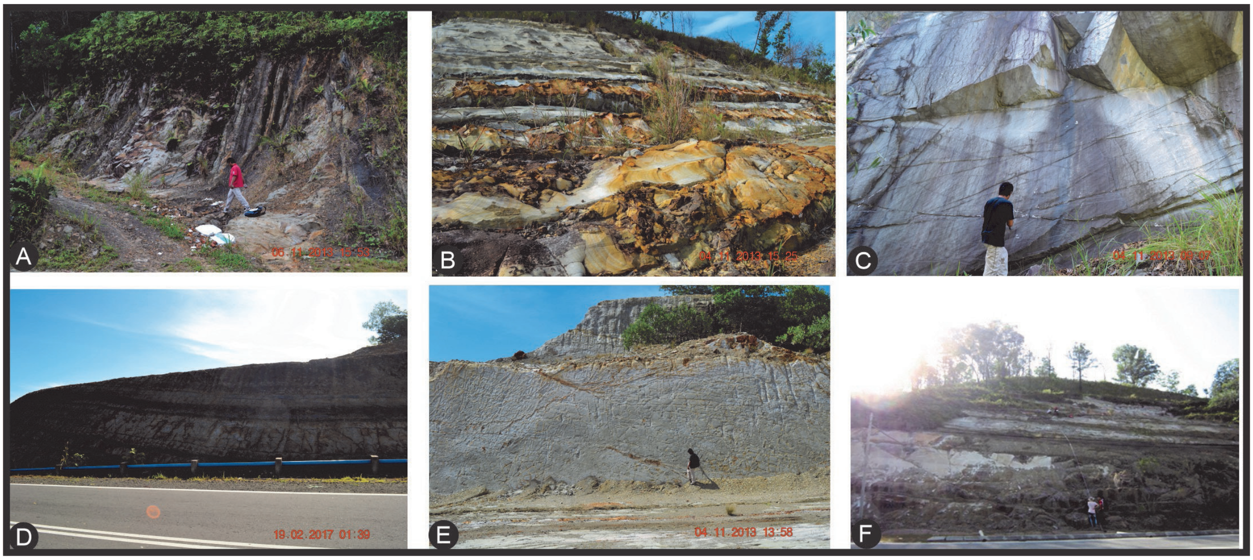

Figure 1: Selected rock cut slopes (outcrops). View to the east. A – Slope BU (Bundung); B – Slope MD (Mardi); C – Slope BS (Bandar Sierra); D – Slope KB (Kibagu); E – Slope BG (Bukit Gayang); F – Slope SU (Sulaman).

For both plane and wedge failures, if K, L, M, and N fall within the ranges of 270° to 360°, 180° to 270°, and 90° to 180°, then 360°, 270°, and 180° are subtracted from these values, respectively. If K or L fall within the range of 0° to 90°, then K or L remains unchanged. In the case of toppling failures, if K or L are within 90° to 180°, 180° is subtracted from K or L, and if within 180° to 270°, K or L is subtracted from 180°.

F2 addresses the dip angles of discontinuities or the plunge of the intersection line for plane or wedge failures, respectively. It represents the probability of discontinuity shear strength. For toppling failures, this value remains constant at 1.00. The dip or plunge angles of discontinuities and intersection lines are always considered positive.

F3 captures the relationship between the angle of discontinuity dips and the slope angle, focusing on the probability of discontinuities emerging or "daylighting" on the slope face in the context of plane, toppling, and wedge failures. This relationship is quantified by subtracting the higher angle from the lower among the discontinuity dip angle, the intersection line, and the slope dip angle, ensuring the result is a positive value.

F4 serves as a correction parameter that relates to the methods of blasting and excavation utilized. It accounts for the impact these methods have on the stability and classification of the slope, adjusting the overall assessment to reflect the effects of the chosen excavation techniques.

METHODOLOGY

This study compiled a comprehensive review of published works on the Slope Mass Rating (SMR) and SMR-based classification systems, with a particular focus on the adjustment factor, serving as a foundational study. The field component of the research entailed geological mapping, a slope survey, and a scanline discontinuity survey, adhering to the guidelines set forth by the International Society for Rock Mechanics (ISRM, 2015). The slope survey was divided into two main activities: a survey of slope failures and measurements of slope geometry. Laboratory experiments included tilt tests, which were conducted in accordance with the procedures described by Alejano *et al*. (2018).

The potential modes of failure were assessed using the Markland test (Markland, 1972), an integral part of the data analysis phase focused on calculating the F value. According to this analysis, for plane and wedge failures, if the parallelism between the discontinuity or intersection line and the slope dip directions is less than 20°, the failure is considered potential; if the parallelism exceeds 20°, the failure is deemed possible. Conversely, for toppling failures, parallelism of less than 10 degrees indicates potential failure. Additionally, the analysis utilized an average basic friction angle (ϕb) value of 28° for the Crocker Formation's fine sandstone, as reported by Rahim *et al*. (2017) in their study (Table 1).

The F value was determined using the proposed $NAAF_{23}$, as detailed in Table 2. $NAAF_{23}$ closely mirrors the calculations of the original NAAF but simplifies the correction parameter F1 for plane, wedge, and toppling failures. Moreover, the symbols used for calculation, previously K, L, M, and N, were changed to A, B, C, and D.

The calculation involves subtracting the higher value from the lower one among the discontinuity dip or intersection line directions and the slope dip directions, or the reverse. The resulting subtracted values are labelled as A and B for plane and toppling failures, and C and D for wedge failures. Specifically, in the case of toppling failures, the value of A or B is determined to be either more or less than 180°. If it exceeds 180°, then 180° is subtracted from it, and vice versa. The calculation does not employ the absolute value symbol, which is a departure from previous methodologies.

Table 1: The value of basic friction angle, ϕ_b, of fine sandstone of the Crocker Formation by tilt testing (taken from Rahim *et al*., 2017).

Lithology	Basic friction angle, ϕ_b (degree)
Fine sandstone	Minimum = 26
	Average = 28
	Maximim = 29

RESULTS

Table 3 presents the F1 values for toppling failures using the NAAF, $NAAF_{23}$, and SMR methods, based on hypothetical data. It compares cases where the discontinuity dip direction (α_j = 30°) is less than the slope dip direction (α_s = 220°), and vice versa. The F1 value appears reasonable (indicating parallelism) across all methods, except when $\alpha_s > \alpha_j$ in the SMR calculation, where F1 is notably overestimated at 370°.

The results from the Markland test for six selected slopes are detailed in Figure 2 and Table 4. The data identify potential and possible wedge, plane, and toppling failures. Specifically, wedge failure is identified as possible in slopes BU (Bundung), KB (Kibagu), and BG (Bukit Gayang) with intersection line directions of 68°, 329°, and 299°, respectively. Slope SU (Sulaman) shows potential for wedge failure at intersection line directions of 326° and 299°, and it is deemed possible at 339° and 292°. Plane failure is only potentially identified in slope KB, with a dip direction of 343°.

For toppling failures, slope BU's risk is linked to joint 3 (J3) with a 244° dip direction, slope MD (Mardi) to bedding (B) at 312°, slope BS (Bandar Sierra) to joint 2 at 134°, and slopes KB, BG, and SU to bedding (B) at dip directions of 60°, 134°, and 135°, respectively. The opposite slope dip directions for these slopes are 56°, 130°, 354°, 235°, 326°, and 317°.

Table 2: $NAAF_{23}$ for Modified Slope Mass Rating (M-SMR) system.

Case		VF	F	Fr	UF	VUF
P	A or B	> 30°	30-20°	20-10°	10-5°	5°
W	C or D					
T	180° - A or B (A or B < 180°) A or B - 180° (A or B > 180°)					
F_1		*0.15*	*0.40*	*0.70*	*0.85*	*1.00*
Relationship		$F_1 = (1 - \mathrm{Sin}\,[\alpha_j - \alpha_s])^2$ or $(1 - \mathrm{Sin}\,[\alpha_i - \alpha_s])^2$				
P	$\lvert\beta_j\rvert$	< 20°	20°-30°	30°-35°	35°-45°	45°
W	$\lvert\beta_i\rvert$					
F_2	**P/W**	*0.15*	*0.40*	*0.70*	*0.85*	*1.00*
	T	*1*	*1*	*1*	*1*	*1*
Relationship		$F_2 = \mathrm{Tan}^2\,\beta_j$ or $\mathrm{Tan}^2\,\beta_i$				
P	$\beta_j - \beta_s$	> 10°	10°-0°	0°	0-(-10°)	< -10°
W	$\beta_i - \beta_s$					
T	$\beta_j + \beta_s$	< 110°	110°-120°	120°-140°	140°-170°	170°-180°
F_3		*0*	*-6*	*-25*	*-50*	*-60*
F_4		Natural slope	Presplitting	Smooth blasting	Blasting & mechanical	Deficient blasting
		+15	*+10*	*+8*	*0*	*−8*

Note: P- planar; T- toppling; W-wedge; α_j - discontinuity dip direction; α_s- slope dip direction; α_i – plunge direction of intersection line; β_j - discontinuity dip angle; β_s - slope dip angle; β_i – plunge of intersection line; VF - Very Favourable; F - Favourable; Fr - Fair; UF - Unfavourable; VUF - Very Unfavourable; $A = (\alpha_j - \alpha_s)$ if $(\alpha_j > \alpha_s)$; $B = \alpha_s - \alpha_j$ if $(\alpha_s > \alpha_j)$; $C = \beta_j - \beta_s$ if $(\beta_j - \beta_s)$; $D = \beta_s - \beta_j$ if $(\beta_s > \beta_j)$; joint (j) will be change into intersection (i) for wedge failure; Z = parallelism in degree and depends on mode of failure.

Table 3: Example of the issues of toppling failure in SMR and M-SMR using fictitious data where $\alpha_s > \alpha_j$ and $\alpha_j > \alpha_s$.

System	DC	Operation			F1	Issue
M-SMR (NAAF)	$\alpha_s = 220°$ $\alpha_j = 30°$	$\alpha_s > \alpha_j$ (90°<K<180°)	$(\alpha_s - \alpha_j) = 190°$ (180°<K<270°)	K − 180°	190° − 180° = 10°	Parallel
	$\alpha_j = 220°$ $\alpha_s = 30°$	$\alpha_j > \alpha_s$ (90°<K<180°)	$(\alpha_s - \alpha_j) = 190°$ (180°<L<270°)	L − 180°	190° − 180° = 10°	Parallel
M-SMR ($NAAF_{23}$)	$\alpha_s = 220°$ $\alpha_j = 30°$	$\alpha_s > \alpha_j$	$(\alpha_s - \alpha_j) = 190°$ (A>180°)	A − 180°	190^0 − 180° = 10°	Parallel
	$\alpha_j = 220°$ $\alpha_s = 30°$	$\alpha_s > \alpha_j$ (90°<K<180°)	$(\alpha_s - \alpha_j) = 190°$ (B>180°)	B − 180°	190^0 − 180° = 10°	Parallel
SMR	$\alpha_s = 220°$ $\alpha_j = 30°$	$\alpha_s > \alpha_j$	$(\alpha_j - \alpha_s) =$ 30° − 220° = −190°	$\lvert(\alpha_j - \alpha_s) - 180°\rvert$	[−190° − 180°] = [−370°] = 370°	Overestimated
	$\alpha_j = 220°$ $\alpha_s = 30°$	$\alpha_j > \alpha_s$	$(\alpha_j - \alpha_s) =$ 220° − 30° = 190°		[190° − 180°] = [10°] = 10°	Parallel

Note: DC - discontinuity

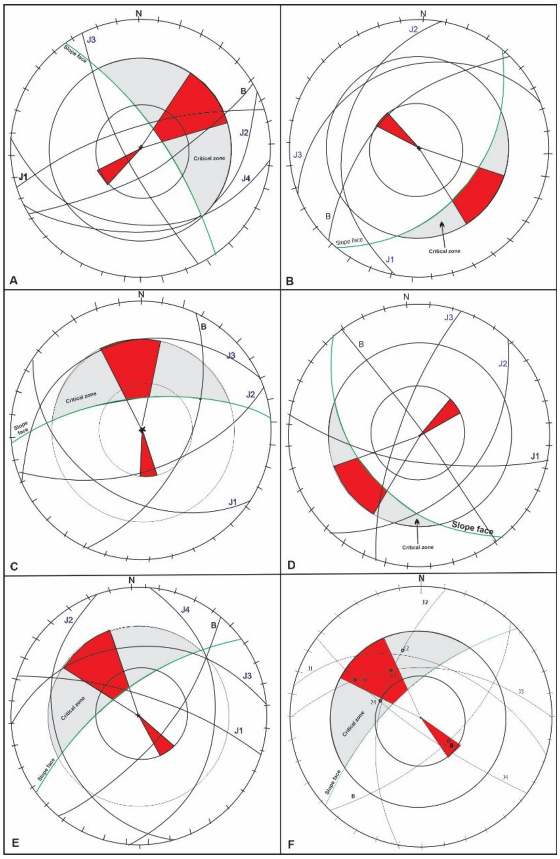

Figure 2: Markland test. A – Slope BU; B – Slope MD; C – Slope BS; D – Slope KB; E – Slope – BG; F – Slope SU.

Using the $NAAF_{23}$ method, the F1 values for potential toppling failures exceed 180° for slopes BU, MD, BS, and BG but are less than 180° for KB and SU. Slopes BU, MD, and SU are categorized under group A, while BS, KB, and BG under group B. The A and B values were then subtracted from or added to 180° to determine the F1 values. The calculated F1 values for slopes BS, BG, KB, and BG are 9, 5, 12, and 1, respectively, indicating convincing levels of parallelism.

However, the F1 values for toppling failure according to the SMR method for slopes BS, KB, BG, and SU are 369, 355, 372, and 359, respectively, which suggests an overestimation of parallelism (Figure 3). In contrast, the F1 values for slopes BU and MD are considered reasonable at 8 and 2, respectively.

DISCUSSIONS

The correction parameter for parallelism, F1, within the discontinuity adjustment factor F in the SMR system, involves subtracting the discontinuity dip direction or the intersection line directions from the slope dip direction for plane and wedge failures. For toppling failures, this value is further reduced by 180°. To ensure values remain positive, the 'absolute' symbol is applied. However, this methodology can result in negative values when the discontinuity dip or intersection line directions are less than the slope dip directions in both plane and wedge failures, as well as in toppling failures. In cases of toppling failure, subtracting an additional 180° from an

Table 4: Summary of the discontinuity plane and intersection line, mode of failures, probability to fail and F1 values for toppling failure by SMR and M-SMR systems. Red- potential zone; Grey- possible zone.

Slope	Slope dip direction	Mode of failure	Discontinuity dip direction or intersection line direction	Failure level	F1 (For toppling)	
BU (BUNDUNG)	56	Toppling	244	Potential	SMR M-SMR	8 8
		Wedge	68	Possible		
MD (MARDI)	130	Toppling	312	Potential	SMR M-SMR	2 2
BS (B. SIERRA)	354	Toppling	165	Potential	SMR M-SMR	369 9
KB (KIBAGU)	235	Toppling	60	Potential	SMR M-SMR	355 5
		Planar	343	Potential		
		Wedge	329	Possible		
BG (BT. GAYANG)	326	Toppling	134	Potential	SMR M-SMR	372 12
		Wedge	299	Possible		
SU (SULAMAN)	317	Toppling	138	Potential	SMR M-SMR	359 1
		Wedge	326	Potential		
		Wedge	299	Potential		
		Wedge	339	Possible		
		Wedge	292	Possible		

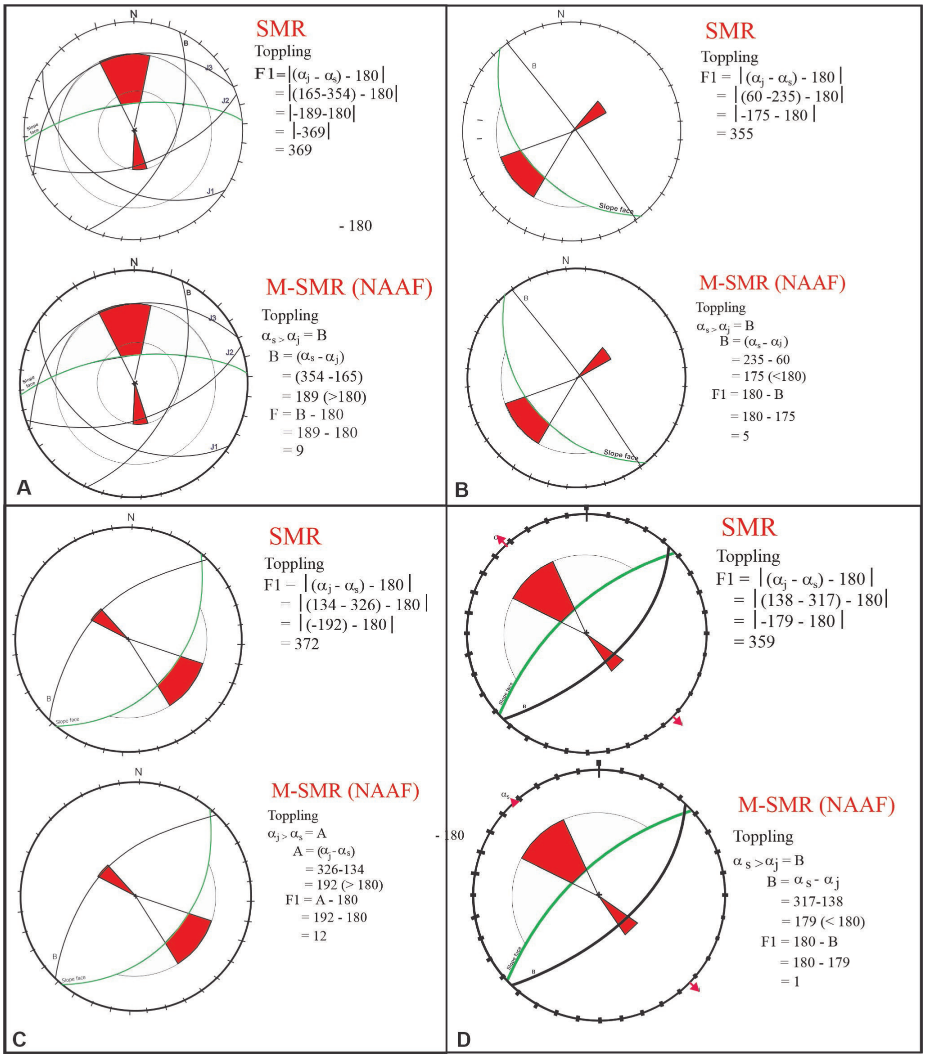

Figure 3: Result of F1 calculation for SMR and M-SMR ($NAAF_{23}$). Note: A – slope BS; B – slope KB; C – slope BG; D – slope SU.

already negative value results in an even more negative outcome, since subtracting a negative from a negative yield a larger negative number.

The first issue concerns the overestimation or representation of parallelism by larger numbers. For instance, it is debatable whether 355° or 5° better represents parallelism. Although both angles could theoretically imply similar levels of parallelism, smaller values (like 5°) are intuitively easier to understand as indicating closer alignment than larger ones (like 355°). This concept is illustrated in Table 4 and Figures 3A, 3B, 3C, and 3D. Secondly, for the F1 value to truly reflect parallelism, the discontinuity dip direction (αj) must always exceed the slope dip direction, as highlighted in Tables 3 and 4.

To address the issues mentioned earlier, the Modified Slope Mass Rating (M-SMR) updated the New Adjustment Factor (NAF) (Rahim, 2011) to the New Approach of Adjustment Factor (NAAF) (Rahim *et al.*, 2012). Essentially, NAAF follows the original framework established by Romana (1985) and Anbalagan *et al*. (1992) but modifies the approach by subtracting the higher value from the lower value among the discontinuity dip or intersection line direction and the slope dip direction, without applying the absolute value operation.

The operations are categorized based on whether the discontinuity or intersection line direction is greater or less than the slope dip direction. K is used for a higher discontinuity dip direction, while L is used when it is lower, applicable in plane and toppling failures. For a higher intersection line direction in wedge failures, M is used, and N for the lower. This ensures that results are always positive, eliminating the need for the absolute value symbol. For toppling failures, K or L is subtracted from or added to 180° depending on its value relative to 180°, followed by a subtraction from 180°, guaranteeing positive, smaller, or more convincing values.

While NAAF is effective under most conditions, it was considered complex. It has been re-evaluated and redesigned to be simpler and more user-friendly, leading to the development of $NAAF_{23}$ for M-SMR. $NAAF_{23}$ retains the core concept of NAAF but changes the symbols back to A, B, C, and D for clarity. $NAAF_{23}$ has been simplified, and its operation is detailed in the methodology section.

The overestimation of the F1 adjustment parameter in SMR, as compared to $NAAF_{23}$, is illustrated in Tables 3 and 4, and Figure 3. For example, in Figure 3D, the discontinuity dip direction of 138° and a slope dip direction of 317° result in an F1 value of 359° for SMR, which, before applying the absolute value, is negative and overestimated in terms of parallelism. Using the $NAAF_{23}$ approach for the same data results in an F1 value of 1°, accurately reflecting parallelism and providing a more convincing representation.

The findings from this study indicate that the updated $NAAF_{23}$ is highly effective in calculating the parallelism of the F1 correction parameter, offering a solution that is both more convincing and user-friendly.

CONCLUSIONS

The M-SMR system has been successfully applied to calculate the value of the adjustment factor, specifically the parallelism correction parameter (F1), for toppling failures using $NAAF_{23}$. $NAAF_{23}$ ensures that the F1 value is never overestimated. Additionally, it provides F1 values that are more convincing and user-friendly.

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AUTHORS CONTRIBUTION

IAR: Conceptualization, investigation, writing original draft, validation, formal analysis writing and editing. MFA: writing and editing.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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