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Systematic Approach to Sustainable Rock Slope Stability Evaluation

Abdul Ghani Rafek[a*], Nur Huda Mohd Jamin[a], Goh Thian Lai [b], Norbert Simon[b] and Azimah Hussin[b]

[a]*Department of Geosciences, Faculty of Geosciences and Petroleum Engineering, Universiti Teknologi Petronas, Bandar Seri Iskandar, Perak D.R., Malaysia*

[b]*Geology Program, Faculty of Science & Technology,Universiti Kebangsaan Malaysia, Bangi, Selangor D.E., Malaysia. *ghani.rafek@petronas.com.my*

Abstract

Geological discontinuities play an important role in the evaluation of rock slope stability. Romana's Slope Mass Rating (SMR) system provides a methodology to quantify rock slope stability. Employing Bieniawski's Rock Mass Rating (RMR) to classify the rock mass of an investigated slope, SMR enables an objective determination of the rating adjustment values based on discontinuity orientation-slope orientation, respective dips angles and slope excavation methods. However the surface roughness of the discontinuities and their peak friction angles (α_p) that are fundamental in determining rock slope stability are not directly considered in this evaluation. A more sustainable approach to rock slope stability assessment proposed here combines the SMR determination with the determination of the peak friction angle, α_p of the discontinuity surfaces. Based on this proposal, the potential for slope failure can be quantified as follows: if SMR predicts failure and dip angle of the discontinuity (β_i) > the peak friction angle (α_p) the slope has a very high failure potential; if SMR predicts failure and $\beta_i < \alpha_p$, the slope has intermediate failure potential; if the slope is stable according to SMR & $\beta_i > \alpha_p$, the slope has low failure potential and if stable according to SMR and $\beta_i < \alpha_p$, the slope can be considered as stable.

Keywords: Rock Mass Rating; Slope Mass Rating; Discontinuity roughness;

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1. Introduction

Geological discontinuities play an important role in the determination of rock slope stability. In particular, the orientation of geological discontinuities i.e. dip direction and dip angle with respect to the slope orientation represents an important input parameter in the evaluation of rock slope stability. The Slope Mass Rating (SMR) system introduced by Romana[1] enables an objective determination of the rating adjustment values for the classification of the rock mass of an investigated slope based on Bieniawski's[2] Rock Mass Rating (RMR) system. With the application of these rating adjustments, the determined Slope Mass Rating (SMR) value can be used to classify the investigated slope into one of five possible slope stability classes. However for this determination the surface roughness of the discontinuities and the peak friction angle, α_p are generally not taken into consideration, in spite of the fact that α_p controls the shear behavior of the discontinuities. Therefore, a systematic approach to sustainable rock slope stability determination proposed here combines the application of RMR, SMR and the determination of the peak friction angle, α_p of discontinuity surfaces for the classification of failure potential. The results of this approach are compared with the standard procedures of the SMR classification to gauge its effectiveness.

2. Methodology

The proposed rock slope stability determination involves the following fundamental steps:

2.1 Determination of the Rock Mass Rating, RMR for an investigated slope,

2.2 Application of Romana's[1] rating adjustments to the RMR values to determine the respective Slope Mass Rating, SMR values,

2.3 Input of the discontinuity surface peak friction angle, α_p that is determined from tilt testing, for the quantification of the influence of discontinuity roughness on slope stability, and

2.4 Classification of the rock slope stability into the respective stability classes.

The consideration of the discontinuity surface roughness and the input of the peak friction angle, α_p is the main difference of this approach compared with the standard procedures recommended by Romana[1]. For the determination of the basic Rock Mass Rating, RMR_{basic} systematic discontinuity surveys and rock material sampling for strength determination is carried out. The investigated slope's RMR is determined based on the five parameters shown in Table 1.

Table 1. Bieniawski's Rock Mass Rating Classification

(a) Classification Parameters and their Ratings

	Parameter		*Ranges of values*				
1	Strength of intact rock material	Point load strength index (MPa)	> 10	4–10	2–4	1–2	For this low range, uniaxial compressive test is preferred
		Uniaxial compressive strength (MPa)	> 250	100–250	50–100	25–50	5–25 1–5 < 1
		Rating	15	12	7	4	2 1 0
2	Drill core quality RQD (%)		90–100	75–90	50–75	25–50	< 25
		Rating	20	17	13	8	3
3	Spacing of discontinuities		> 2 m	0.6–2 m	200–600 mm	60–200 mm	< 60 mm
		Rating	20	15	10	8	5
4	Condition of discontinuities		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered wall	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge > 5 mm thick or Separation > 5 mm Continuous
		Rating	30	25	20	10	0
5	Groundwater	Inflow per 10 m tunnel length (L min^{-1})	None	< 10	10–25	25–125	> 125
			or	or	or	or	or
		Ratio $\frac{\text{Joint water pressure}}{\text{Major principal stress}}$	0	< 0.1	0.1–0.2	0.2–0.5	> 0.5
			or	or	or	or	or
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing
		Rating	15	10	7	4	0

Stereographic plotting of discontinuity data enables the determination of the orientation and dip of the major discontinuities. This information together with the RMR_{basic} value is used to determine the Slope Mass Rating, SMR. The relevant parameters are shown in Table 2, Fig.1. & Fig.2.

Table 2: Romana's Slope Mass Rating System

$SMR = RMR_{basic} + (F_1 x F_2 x F_3) + F_4$

Correction parameters for SMR

Type of failure		Very favorable	Favorable	Fair	Unfavorable	Very unfavorable
P	$\lvert \alpha j - \alpha s \rvert$					
T	A $\lvert \alpha j - \alpha s - 180 \rvert$	> 30°	30–20°	20–10°	10–5°	< 5°
W	$\lvert \alpha i - \alpha s \rvert$					
P/T/W	F1	0.15	0.40	0.70	0.85	1.00
P/W	B $\lvert \beta j \rvert$ ó $\lvert \beta i \rvert$	< 20°	20–30°	30–35°	35–45°	> 45°
P/W	F2	0.15	0.40	0.70	0.85	1.00
T		1.00				
P	$\beta j - \beta s$	> 10°	10–0°	0°	0–(−10°)	<(−10°)
W	C $\beta i - \beta s$					
T	$\beta j + \beta s$	< 110°	110–120°	> 120°	–	–
P/T/W	F3	0	−6	−25	−50	−60
Excavation method (F4)						
Natural slope		+ 15	Blasting or mechanical			0
Presplitting		+ 10	Deficient blasting			−8
Smooth blasting		+ 8				

P: planar failure; T: toppling failure; W: wedge failure. α_j: dip direction of the discontinuity; α_s: dip direction of the slope; α_i: dip direction of the intersection line of two sets of discontinuities; β_j: discontinuity dip; β_i: angle of plunge of the intersection line of two sets of discontinuities; β_s: slope dip.

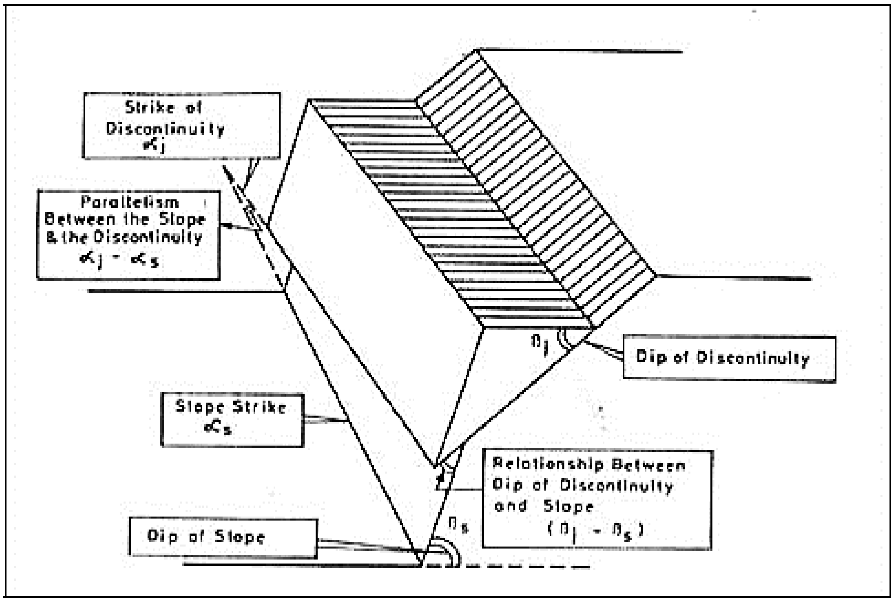

Fig.1. : SMR adjustment parameters for plane failure.

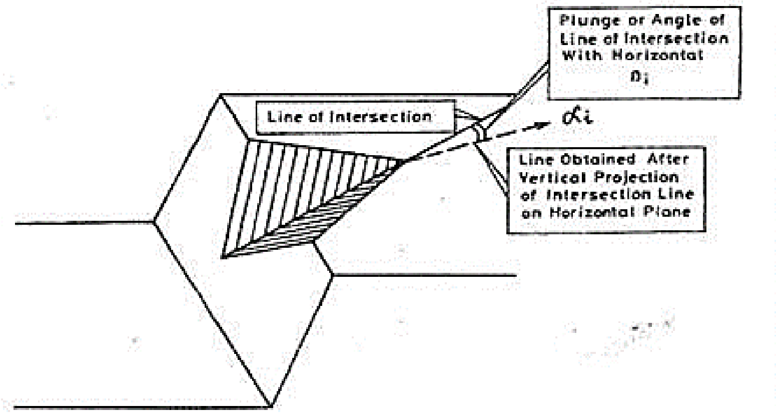

Fig.2. : SMR adjustment parameters for wedge failure.

For the determination of the peak friction angle, α_p of the discontinuity surfaces, tilt testing is conducted according to the procedures outlined by Ghani & Goh [3]. Rock blocks containing natural discontinuities are collected at the test sites and carefully separated along the natural discontinuity into two blocks. This pair is tested using a self-fabricated tilt testing apparatus as shown in Fig. 3.

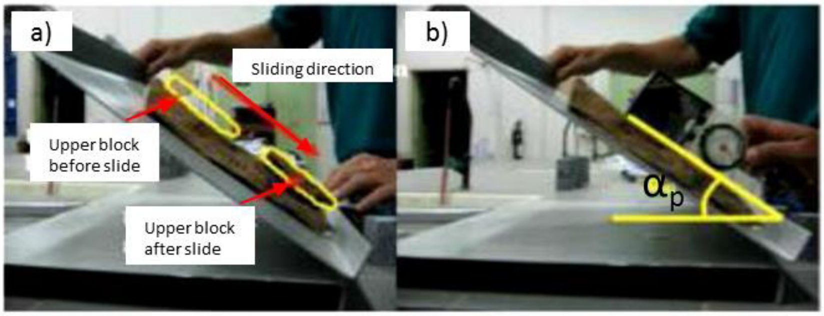

Fig.3. : Tilt testing for the determination of peak friction angle, α_p. (a): position of upper block before and after sliding. (b): measurement of α_p.

3. Results and discussion

The stability of eighteen (18) rock slopes with granite and schist as bedrock were investigated using the proposed slope stability analysis approach with the peak friction angle, α_p being obtained from tilting and compared with the SMR analysis method. The results are presented in Table 3.This comparison shows that only 46% of the results for the prediction of slope failure applying the two different methods are the same. The main reason for this difference is the consideration of the peak friction angle, α_p of the discontinuity planes that are the failure planes or the lines of intersection in the case of wedge failure. Therefore the systematic approach that is proposed here combines the determination of the peak friction angle, α_p of the geological discontinuities, together with the determination of SMR ratings. Based on this approach, four stability classes can be determined as follows:

(i) SMR rating predicts failure and the geological discontinuity dip angle, $\beta_i > \alpha_p$ the slope has a very high failure potential;
(ii) SMR predicts failure and the geological discontinuity dip angle, $\beta_i < \alpha_p$ the slope has intermediate failure potential;
(iii) SMR predicts stability and the geological discontinuity dip angle, $\beta_i > \alpha_p$ the slope has low failure potential;
(iv) SMR predicts stability and the geological discontinuity dip angle, $\beta_i < \alpha_p$ the slope is stable.

The application of this classification is shown in the last column of Table 3.

Table 3: Comparison of slope failure potential between proposed slope stability analysis and SMR system very high failure potential; IF: intermediate failure potential; LF: low failure potential; NF: stable.

Slope name	SMR system		Tilt test and slope stability analysis			Systematic approach
	Value of SMR	Potential of failure	β_i (°)	α_p (°)	Potential of failure	Potential of failure
BP2	75, 72, 79, 79	NF, NF, NF, NF	41, 32, 59, 41	59, 59, 59, 59	NF, F, F, F	NF, LF, LF, LF
BP1	22, 37, 55, 58	F, F, F, F	51, 66, 62, 63	60, 55, 55, 54	NF, NF, F, NF	IF, IF, F, IF
SH0	71, 48, 23, 45, 54	NF, F, F, F, F	54, 52, 49, 45, 54	55, 55, 55, 55, 55	NF, NF, NF, NF, NF,	NF, IF, IF, IF, IF,
SH2	41, 39, 39	F, F, F	42, 41, 41	60, 60, 60	NF, NF, NF	IF, IF, IF
SH4	62	NF	48	41	F	LF
SH5	27, 68, 68, 68	F, NF, NF, NF	42, 38, 38, 38	46, 41, 41, 41	NF, NF, NF, NF	IF, NF, NF, NF
KR5	58, 53	F, F	45, 50	55, 59	NF, F	IF, F
KRF2	66	NF	64	59	NF	NF
KR2	55, 23, 34	F, F, F	35, 34, 63	59, 41, 46	NF, F, NF	IF, F, IF
PS1	69, 64	NF, NF	58, 78	55, 55	F, F	LF, LF
PS2-1	80, 40	NF, F	58, 65	60, 60	NF, F	NF, F
PS2-2	38, 76, 66, 53, 33, 31, 69	F, NF, NF, F, F, F, NF	47, 65, 74, 64, 46, 77, 38	60, 60, 60, 60, 60, 55, 60	NF, F, F, F, NF, F, NF	IF, LF, LF, F, IF, F, NF
PS2-4	47, 27, 66, 67	F, F, NF, NF	72, 70, 36, 38	41, 41, 41, 41	F, F, NF, NF	F, F, NF, NF
PS3-1	37, 61	F, NF	36, 73	41, 38	F, F	F, LF
PS3-2	62, 66	NF, NF	77, 55	38, 42	F, F	LF, LF
PS4	27, 42, 18, 44	F, F, F, F	66, 52, 47, 67	42, 38, 50, 38	F, NF, F, NF	F, IF, F, IF
PS7-2	73	NF	29	38	NF	NF
UP1	48, 31, 31, 31, 31	F, F, F, F, F	36, 35, 58, 41, 32	52, 44, 38, 59, 59	NF, F, F, F, F	IF, F, F, F, F

4. Conclusion

Applying Romana's [1] Slope Mass Rating system, (SMR) together with the determination of geological discontinuity plane's surface roughness, the following systematic approach to rock slope stability evaluation is proposed:

(i) SMR rating predicts failure and the geological discontinuity dip angle, $\beta_i > \alpha_p$ the slope has a very high failure potential;

(ii) SMR predicts failure and the geological discontinuity dip angle, $\beta_i < \alpha_p$ the slope has intermediate failure potential;

(iii) SMR predicts stability and the geological discontinuity dip angle, $\beta_i > \alpha_p$ the slope has low failure potential;

(iv) SMR predicts stability and the geological discontinuity dip angle, $\beta_i < \alpha_p$ the slope is stable.

Slopes in category (i) would need immediate mitigation followed by (ii). The category (iii) would need attention after the two earlier cases and (iv) can be considered as having long term stability.

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