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A Systematic Approach of Rock Slope Stability Assessment: A Case Study at Gunung Kandu, Gopeng, Perak, Malaysia

(Pendekatan Sistematik untuk Penilaian Kestabilan Cerun Batuan:
Kajian Kes di Gunung Kandu, Gopeng, Perak, Malaysia)

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ABSTRACT

The stability of the limestone cliff at Gunung Kandu, Gopeng, Perak, Malaysia was assessed based on the Slope Mass Rating (SMR) system on 53 cross sections of the Gunung Kandu hill slopes. The slopes of Gunung Kandu were identified as class I (very good) to IV (poor). The kinematic analysis showed that 12 out of 53 hill slopes of Gunung Kandu were identified as having potential wedge, planar and toppling failures. The assessment showed that the stability of the western flanks can be classified as stable to unstable with the probability of failure from 0.2 to 0.6. The stability of the eastern and southern flanks range from very stable to partially stable with the probability of failure from 0.0 to 0.4. While the stability of northern flanks are from very stable to stable with the probability of failure of 0.0 - 0.2. This systematic approach offers a practical method especially for large area of rock slope stability assessment and the results from probability of failure values will help engineers to design adequate mitigation measures.

Keywords: *Gunung Kandu; Kinta; limestone; slope mass rating; slope stability assessment*

ABSTRAK

Kestabilan cerun batu kapur di Gunung Kandu, Gopeng, Perak, Malaysia dinilai berdasarkan sistem Perkadaran Jasad Cerun (SMR) terhadap 53 keratan rentas cerun bukit Gunung Kandu dinilai dengan menggunakan Perkadaran Jasad Cerun (SMR). Cerun Gunung Kandu dikenal pasti sebagai kelas I (sangat baik) kepada IV (tidak baik). Analisis kinematik mendedahkan bahawa 12 daripada 53 cerun bukit Gunung Kandu yang telah dikenal pasti mempunyai ragam kegagalan baji, satah dan keterbalikan. Penilaian ini mendedahkan bahawa kestabilan bahagian tebing barat dikelaskan sebagai stabil kepada yang tidak stabil dengan kebarangkalian kegagalan daripada 0.2 ke 0.6. Kestabilan bahagian tebing timur dan selatan adalah daripada sangat stabil kepada separa stabil dengan kebarangkalian kegagalan daripada 0.0 ke 0.4. Manakala kestabilan bahagian tebing utara adalah sangat stabil sehingga stabil dengan kebarangkalian kegagalan sebanyak 0.0 - 0.2. Pendekatan sistematik ini menawarkan satu kaedah yang praktik terutamanya untuk penilaian kestabilan tebing bukit yang luas dan keputusan kebarangkalian nilai kegagalan akan membantu jurutera untuk mereka bentuk langkah mitigasi yang lebih baik.

Kata kunci: Batu kapur; Gunung Kandu; Kinta; penilaian kestabilan cerun; perkadaran jasad batuan

Introduction

The natural beauty of limestone is due to the uniqueness of karst processes which produce the spectacular shape of steep-sided limestone towers. However, the instability of a limestone hill can affect the surrounding areas. The significance of studying on Gunung Kandu Hills because of its location that is close to roads, residential areas and as also because its currently a tourist attraction. The Kinta Valley is embellished by the spectacular shape of steep-sided limestone towers and decorated with many limestone karst morphological features which protrude from the alluvial plain. Due to its unique features, the limestone hill at Gunung Kandu becomes one of the main attraction among tourists to the Kinta Valley. Many activities such as cave exploration, rock climbing and abseiling are actively conducted in the area.

The hill may pose a danger to the public and highway due to the adverse geological structural conditions such as jointing, fractures and day lighting rock blocks. Several reports on rock fall occurrences in the surrounding area can be obtained in Chung (1981) and Tuan Rusli and Ahmad Khairut (2012a & 2012b). In general, structural failure has been reported as the main causal factor of rockfalls at limestone hills in the Kinta Valley. Geological factors such as weathering and geological structures were investigated as the main causes for the failure at Gua Tempurung in April 2012, where a 750 m^3 rock block toppled down (Tuan Rusli & Ahmad Khairut 2012a).

Chemical weathering from dissolution of water was also reported to be the main causal factor of the rockfall incident at Gunung Tunggal as the cohesive strength along joints and fractures decreased due to chemical weathering (Chow & Majid Sahat 1988).

The literature study showed insufficient studies conducted on quantitative limestone rock slope assessment in Malaysia. Local researchers focused their study on rock mass classification using Geological Strength Index (Norbert et al. 2016), landslide of soil slope (Lee & Pradhan 2006; Norbert et al. 2013; Zulfahmi 1999), assessment of rock fall potential at limestone hills (Muhammad Fahmi et al. 2016; Norbert et al. 2015) and prediction of uniaxial compressive strength using ultrasonic laboratory results (Goh et al. 2016). Meanwhile, Ailie et al. (2017, 2016) and Abdul Ghani and Goh (2012) had characterized the roughness of discontinuity surfaces by establishing an empirical relationship between JRC with peak friction angles of schist and granite.

As a response to these issues, the main scope of this paper was to evaluate the stability of Gunung Kandu (Figure 1), using the Slope Mass Rating (SMR) method as previously proposed by Romana (1985). The significance of this study is the quantification of rock slope stability which enables the relevant agencies to appreciate the urgency of the slope stability issue.

MATERIALS AND METHODS

GEOLOGY OF STUDY AREA

The study area is located in the southern part of Kinta Valley, Ipoh, Perak. The main lithology at Gunung Kandu is a massive limestone hill that is intensely fractured and jointed. Foo (1983) named the limestone in Kinta Valley as the Kinta Limestone Formation. The limestone in Kinta Valley was deposited in a shallow marine environment with an age from Devonian to Permian (Sutharalingam 1968). Schist and granite also make up the geology of the Kinta Valley at the eastern and western flanks of the valley (Hutchison & Tan 2009). Norbert et al. (2015), stated that a straight 26 km long scarp was found on the eastern flank of the Kledang Range which is suggestive of a major fault with the several smaller faults that have been observed at the eastern side of the Kinta Valley. The location of research stations for discontinuities survey are shown in Figure 1.

SLOPE MASS RATING (SMR) METHOD

The slope mass rating method by Romana (1985) was used to assess the stability of the limestone hill slopes. Seven components that are used by the SMR are:

Uniaxial compressive strength (UCS), rock quality designation (RQD), discontinuities spacing, conditions of discontinuities, ground water conditions, adjusting factors

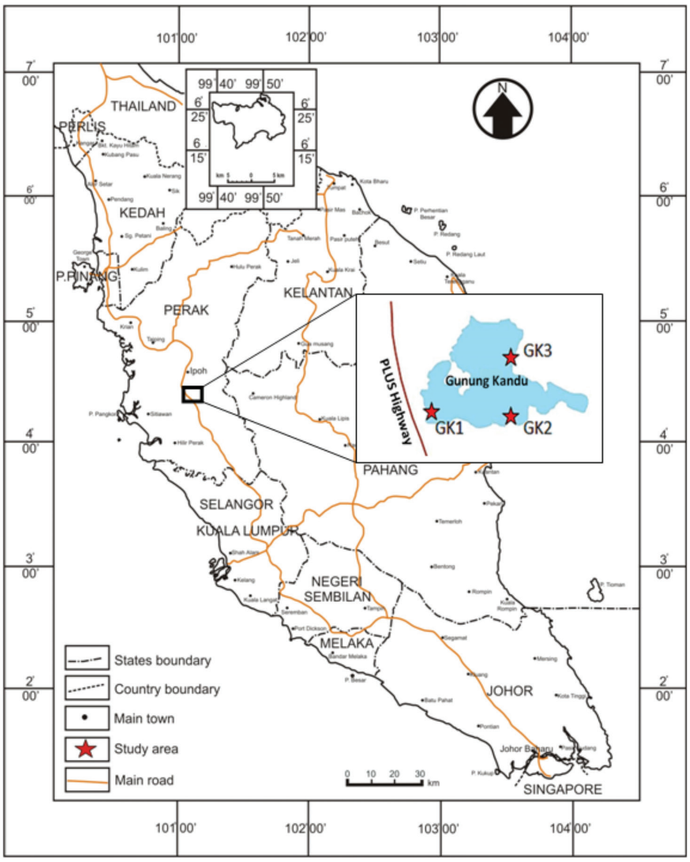

FIGURE 1. Location of GK1, GK2 and GK3 at Gunung Kandu, Gopeng, Perak, Malaysia

for joints (F1, F2, F3) and adjusting factor for excavation (F4).

The values of respective components of Rock Quality Designation (RQD), discontinuities spacing, conditions of discontinuities and ground water conditions were determined from scan line discontinuity surveys, based on the recommendations by ISRM (1981). F1 was the rating adjustment for the difference of dip direction between joints and slope face. F2 was the rating adjustment of dip angle of the respective joint. F3 was the rating adjustment for the difference of dip angle between joints and slope face. The total rating, RMR_b was determined as:

$$RMR_b = \text{Rating (a)} + \text{Rating (b)} + \text{Rating (c)} + \text{Rating (d)} + \text{Rating (e)} \quad (1)$$

The rating for SMR was determined based on following equation suggested by Romana (1985):

$$SMR = RMR_b + (F1 \times F2 \times F3) + F4 \quad (2)$$

Results and Discussion

A total of 3 discontinuity surveys were conducted at Gunung Kandu and 53 cross sections of hill slopes were assessed. The 53 cross sections were labeled as GKS1 to GKS53. The discontinuity surveys conducted at Gunung Kandu were labeled as GK1, GK2 and GK3. The orientation (dip direction/dip angle) of slope faces of GK1, GK2 and GK3 were 218°/82°, 172°/78° and 284°/70, respectively. These 3 slopes represented the western, southern, northern and eastern flanks of Gunung Kandu, respectively (Figure 2) from which the values of RMR_b are extrapolated to the entire 53 cross sections of Gunung Kandu. The locations of respective cross section are shown in Figure 2. The stereographs of respective slopes are shown in Figure 3. Slopes of GK1, GK2 and GK3 have 3 to 5 major joint sets. The orientation of the major joint sets and slope faces of respective slopes are presented in Table 1. The respective dip direction and dip angle of J1, J2, J3, J4 and J5 for GK1 were 331°/38°, 217°/49°, 135°/35°, 99°/59° and 279°/60°. The respective orientations (dip direction/dip angle) of J1, J2 and J3 for GK2 were identified as 322°/59°, 211°/60° and 91°/65°. The dip direction and dip angle of J1, J2, J3 and J4 for GK3 were 360°/51°, 194°/70°, 135°/75° and 80°/64°.

The peak friction angles of the geological discontinuities for respective slopes for kinematic analysis were determined based on the tilt testing method, suggested by Abdul Ghani and Goh (2012). The peak friction angle of 49°, 37° and 55° were used in the kinematic analysis for the respective slopes GK1, GK2 and GK3. Figure 4 shows the results of kinematic analysis for the respective slopes. The modes of failure for slope GK1 were wedge and planar failure with the dip direction and dip angle of 231°/49° and 217°/49°, respectively. A wedge failure was identified on slope GK2 with the dip direction and dip angle of 154°/44°. No failure was identified for slope GK3. The results of kinematic analysis were utilized in rock mass classification assessment based on SMR method.

Tables 2, 3 and 4 show the results of the assessment of RMR_b for the respective slopes of GK1, GK2 and GK3. The respective rating of RMR_b for discontinuity surveys at GK1, GK2 and GK3 were 71, 81 and 70. The interpreted results of RMR_b (71) for GK1 was utilized in classification of slope mass rating (SMR) for slopes GKS24 to GKS39. Meanwhile, the interpreted results of RMR_b (81) for GK2 was utilized for slopes GKS20 to GKS23 and GKS40 to GKS51. Finally, the interpreted results of RMR_b (70) for GK3 were utilized slopes GKS1 to GKS19 and GKS52 to GKS53.

The stability assessment and probability of failure distribution of the entire Gunung Kandu is given in Tables 5, 6 and Figure 5. The hill slopes of Gunung Kandu were

TABLE 1. Orientation of major joint sets and slope face for discontinuity survey at GK1, GK2 and GK3, Gunung Kandu, Gopeng, Malaysia

Slope	Major joint set/Slope face	Dip direction (°)	Dip angle (°)
GK1	Slope face	218	82
	J1	331	38
	J2	217	49
	J3	135	35
	J4	099	59
	J5	279	60
GK2	Slope face	172	78
	J1	322	59
	J2	211	60
	J4	091	65
GK3	Slope face	284	70
	J1	360	51
	J2	194	70
	J3	135	75
	J4	080	64

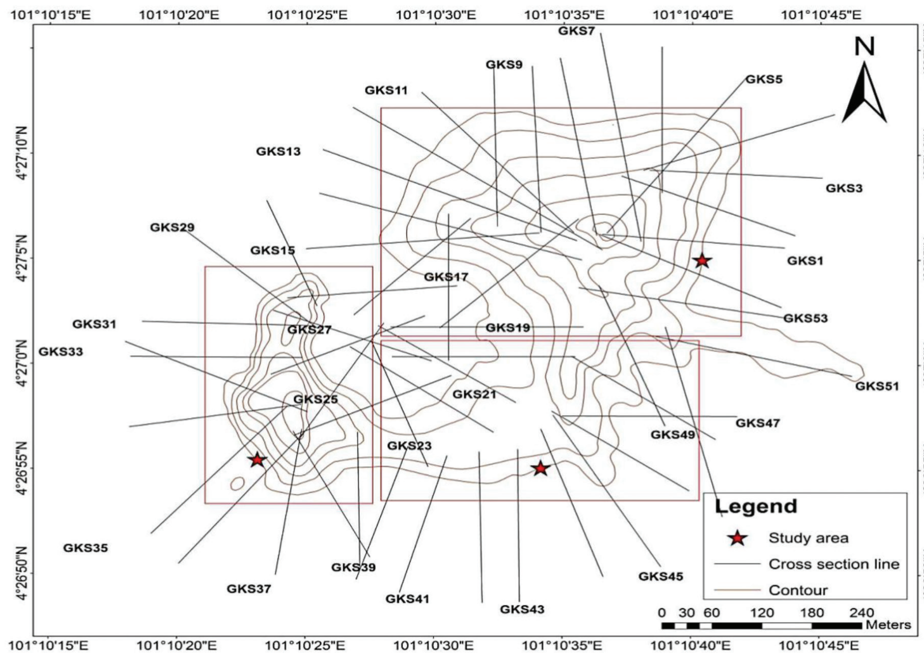

FIGURE 2. Location of cross sections of 53 hill slopes at Gunung Kandu, Gopeng, Perak

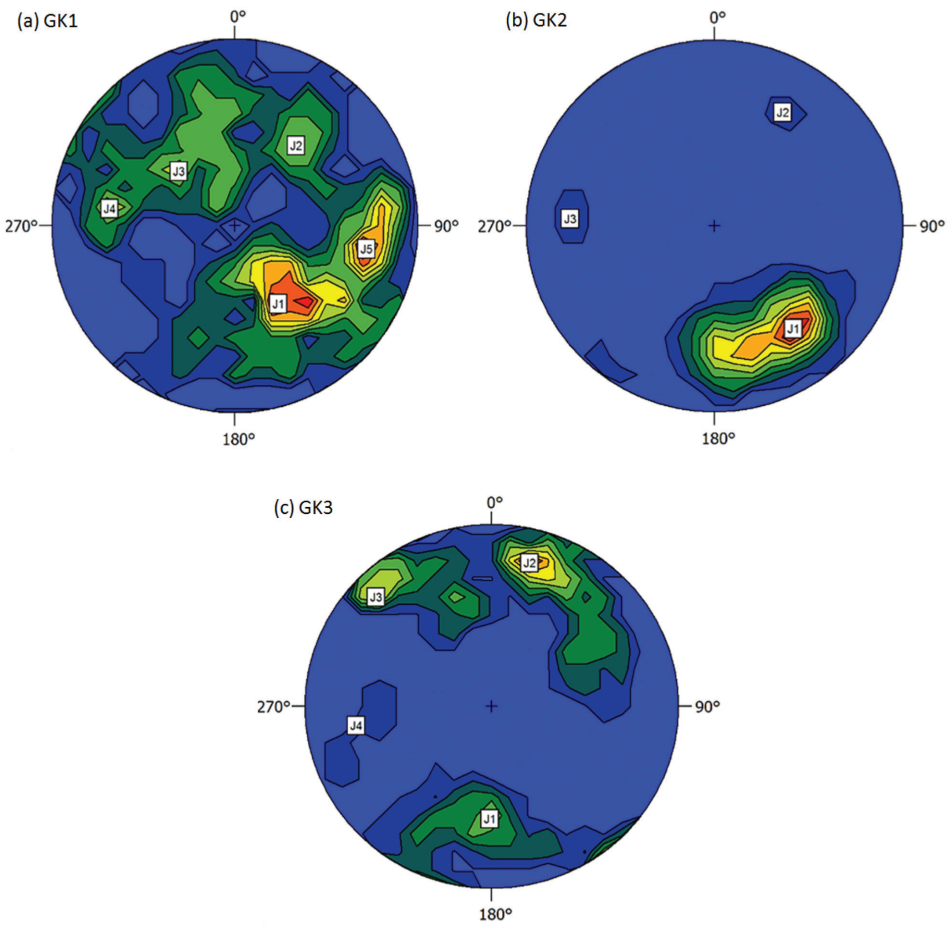

FIGURE 3. Stereographic plot of slope of (a) GK1,(b) GK2 and
(c) GK3, Gunung Kandu, Gopeng, Perak

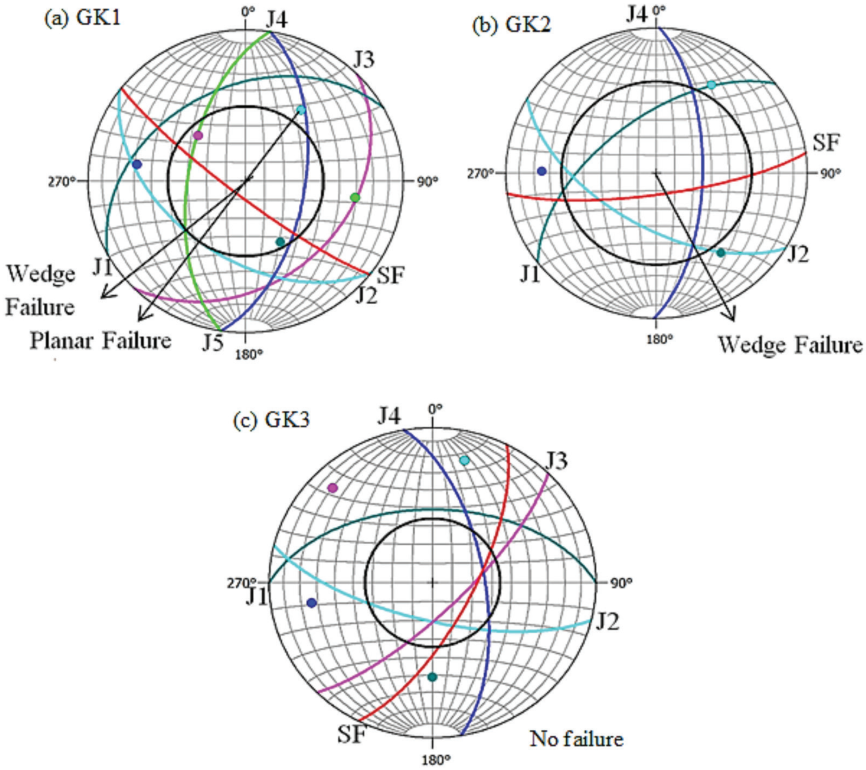

FIGURE 4. (a) For slope GK1, a planar and a wedge failure were identified with the dip direction and dip angle of 231º/49º and 217º/49º, respectively, (b) For slope GK2, a wedge failure was identified on slope GK2 with the dip direction and dip angle of 154º/44º and (c) For slope GK3, no failure was identified

TABLE 2. Results of assessment of RMR_b for discontinuity survey at GK1, Gunung Kandu, Gopeng, Perak, Malaysia

Parameter	Value	Rating
Uniaxial compressive strength, UCS	84.0 MPa	7
Rock Quality designation, RQD	99.36 %	20
Spacing of discontinuities	0.93 m	15
Condition of discontinuities	Discontinuities length 1-3 m, separation 1-5 mm, slightly rough, no infilling, unweathered	14
Ground water condition	Completely dry	15
Total rating for RMR_b		71

TABLE 3. Results of assessment of RMR_b for discontinuity survey at GK2, Gunung Kandu, Gopeng, Perak, Malaysia

Parameter	Value	Rating
Uniaxial compressive strength, UCS	84.0 MPa	7
Rock Quality designation, RQD	96.73%	20
Spacing of discontinuities	2.33 m	20
Condition of discontinuities	Discontinuities length 1-3 m, separation 0 mm, slightly rough, no infilling, unweathered	19
Ground water condition	Completely dry	15
Total rating for RMR_b		81

TABLE 4. Results of assessment of RMR_b for discontinuity survey at GK3, Gunung Kandu, Gopeng, Perak, Malaysia

Parameter	Value	Rating
Uniaxial compressive strength, UCS	84.0 MPa	7
Rock Quality designation, RQD	98.61%	20
Spacing of discontinuities	0.82 m	15
Condition of discontinuities	Discontinuities length 1-3 m, separation >5 mm, slightly rough, no infilling, unweathered	13
Ground water condition	Completely dry	15
Total rating for RMR_b		70

TABLE 5. Results of slope stability assessment for GKS1 to GKS28, Gunung Kandu, Gopeng, Perak, Malaysia

Slope	Orientation	Failure Mode	F1	F2	F3	F4	RMR_b	SMR	Class and Stability	Probability of failure
GKS1	(092/48)	-	-	-	-	-	70	70	II, Good	0.2
GKS2	(113/39)	-	-	-	-	-	70	70	II, Good	0.2
GKS3	(094/35)	-	-	-	-	-	70	70	II, Good	0.2
GKS4	(070/29)	-	-	-	-	-	70	70	II, Good	0.2
GKS5	(038/31)	-	-	-	-	-	70	70	II, Good	0.2
GKS6	(360/35)	-	-	-	-	-	70	70	II, Good	0.2
GKS7	(351/34)	-	-	-	-	-	70	70	II, Good	0.2
GKS8	(351/36)	-	-	-	-	-	70	70	II, Good	0.2
GKS9	(360/30)	-	-	-	-	-	70	70	II, Good	0.2
GKS10	(360/22)	-	-	-	-	-	70	70	II, Good	0.2
GKS11	(305/26)	-	-	-	-	-	70	70	II, Good	0.2
GKS12	(305/64)	-	-	-	-	-	70	70	II, Good	0.2
GKS13	(305/26)	-	-	-	-	-	70	70	II, Good	0.2
GKS14	(305/29)	-	-	-	-	-	70	70	II, Good	0.2
GKS15	(267/25)	-	-	-	-	-	70	70	II, Good	0.2
GKS16	(225/31)	-	-	-	-	-	70	70	II, Good	0.2
GKS17	(180/38)	-	-	-	-	-	70	70	II, Good	0.2
GKS18	(227/38)	-	-	-	-	-	70	70	II, Good	0.2
GKS19	(270/27)	-	-	-	-	-	70	70	II, Good	0.2
GKS20	(270/36)	-	-	-	-	-	81	81	I, Very Good	0.0
GKS21	(308/29)	-	-	-	-	-	81	81	I, Very Good	0.0
GKS22	(308/26)	-	-	-	-	-	81	81	I, Very Good	0.0
GKS23	(340/36)	-	-	-	-	-	81	81	I, Very Good	0.0
GKS24	(066/45)	-	-	-	-	-	71	71	II, Good	0.2
GKS25	(031/50)	-	-	-	-	-	71	71	II, Good	0.2
GKS26	(065/66)	-	-	-	-	-	71	71	II, Good	0.2
GKS27	(113/64)	Toppling (279/60)	0.7	1	-25	15	71	69	II, Good	0.2
		Planar (099/59)	0.7	1	-50	15	71	51	III, Fair	0.4
GKS28	(087/63)	Toppling (279/60)	0.7	1	-25	15	71	69	II, Good	0.2
		Planar (099/59)	0.7	1	-50	15	71	51	III, Fair	0.4

identified as class I (very good) to IV (poor). No failure were identified at GKS1 to GKS26, GKS29, GKS30, GKS38, GKS39, GKS41 to GKS43, GKS45 to GKS48 and GKS50 to GKS53. Twelve (12) out of the 53 hill slopes of Gunung Kandu were identified as having potential wedge, planar and toppling failures. These slopes were GKS27 to GKS28, GKS31 to GKS37, GKS40, GKS44 and GKS49. The assessment showed that the stability of Gunung Kandu ranges from completely stable to unstable with the probability of failure from 0.0 to 0.6. The rating for the western flank range from stable to unstable with the probability of failure from 0.2 to 0.6. The stability of the eastern and southern flank range from very stable to partially stable with the probability of failure of 0.0 to 0.4 and the stability of the northern flank is classified as very stable to stable with the probability of failure from 0.0 to 0.2. The results also showed that the western flank of hill was less stable that eastern, southern and northern flanks of hill.

The assessment results showed most of the slopes are classified as very stable to partially stable from class I to III except for slope GKS35 and GKS36. Slopes GKS35 and GKS 36 of western flank are classified as unstable and class IV slopes because the dip direction (217°) of potential planar failure are almost parallel with the dip directions of slope face of GKS35(221°) and GKS36 (217°) with the differences of 2° to 4°. Therefore, both slopes were rated as very unfavourable in F1, SMR. In addition, both slopes anticipated very unfavourable 'daylighting' condition which contributed to high score of F3 in SMR. It is suggested that discontinuum approach using numerical or limit equilibrium method is conducted to determine the factor of safety for both slopes and proposed appropriate mitigation measures.

TABLE 6. Results of slope stability assessment for GKS29 to GKS53, Gunung Kandu, Gopeng, Perak, Malaysia

Slope	Orientation	Failure Mode	F1	F2	F3	F4	RMR_b	SMR	Class and Stability	Probability of failure
GKS29	(340/59)	-	-	-	-	-	71	71	II, Good	0.2
GKS30	(313/57)	-	-	-	-	-	71	71	II, Good	0.2
GKS31	(270/67)	Planar (279/60)	0.85	1	-50	15	71	44	III, Fair	0.4
		Wedge (230/48)	0.15	1	-60	15	71	77	II, Good	0.2
GKS32	(270/65)	Planar (279/60)	0.85	1	-50	15	71	44	III, Fair	0.4
GKS33	(296/65)	Planar (279/60)	0.7	1	-50	15	71	51	III, Fair	0.4
GKS34	(265/69)	Planar (279/60)	0.7	1	-50	15	71	51	III, Fair	0.4
GKS35	(221/59)	Planar (217/49)	1	1	-60	15	71	26	IV, Poor	0.6
GKS36	(219/61)	Wedge (231/49)	0.7	1	-60	15	71	44	III, Fair	0.4
		Planar (217/49)	1	1	-60	15	71	26	IV, Poor	0.6
GKS37	(190/54)	Wedge (229/48)	0.15	1	-50	15	71	78	II, Good	0.2
GKS38	(153/53)	-	-	-	-	-	71	71	II, Good	0.2
GKS39	(180/49)	-	-	-	-	-	71	71	II, Good	0.2
GKS40	(195/51)	Wedge (155/44)	0.15	0.85	-50	15	81	90	I, Very Good	0.0
GKS41	(195/42)	-	-	-	-	-	81	81	I, Very Good	0.0
GKS42	(180/40)	-	-	-	-	-	81	81	I, Very Good	0.0
GKS43	(180/34)	-	-	-	-	-	81	81	I, Very Good	0.0
GKS44	(163/45)	Wedge (155/44)	0.85	0.85	-50	15	81	60	III, Fair	0.4
GKS45	(145/34)	-	-	-	-	-	81	81	I, Very Good	0.0
GKS46	(124/31)	-	-	-	-	-	81	81	I, Very Good	0.0
GKS47	(090/47)	-	-	-	-	-	81	81	I, Very Good	0.0
GKS48	(124/36)	-	-	-	-	-	81	81	I, Very Good	0.0
GKS49	(160/46)	Wedge (155/44)	0.85	0.85	-50	15	81	60	III, Fair	0.4
GKS50	(167/34)	-	-	-	-	-	81	81	I, Very Good	0.0
GKS51	(103/31)	-	-	-	-	-	81	81	I, Very Good	0.0
GKS52	(098/40)	-	-	-	-	-	70	70	III, Fair	0.4
GKS53	(114/45)	-	-	-	-	-	70	70	III, Fair	0.4

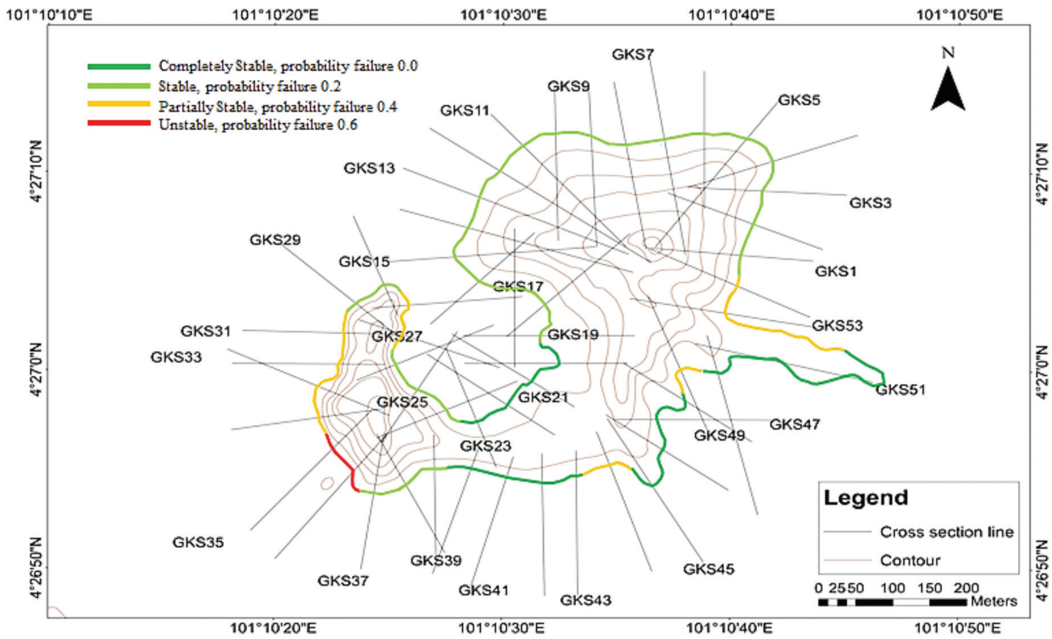

FIGURE 5. Map of slope stability assessment of Gunung Kandu, Gopeng, Perak, Malaysia

The relevant agencies such as Federal Department of Town and Country Planning and city council could use the results of this study in their development planning. The area under unstable slope should be restricted for future development unless the unstable slope is engineered with comprehensive mitigation measures.

CONCLUSION

A total of 53 cross section of hill slopes at Gunung Kandu were assessed. The stability assessment results based on SMR showed that 12 out of the 53 hill slope cross sections were identified as having potential wedge, planar and toppling failures. The assessment showed that the stability of Gunung Kandu range from completely stable to unstable with the probability of failure from 0.0 to 0.6. The stability of the western flank range from stable to unstable with the probability of failure from 0.2 to 0.6. The stability of the eastern and southern flanks ranges from very stable to partially stable with the probability of failure from 0.0 to 0.4, while the stability of northern flank range from very stable to stable with the probability of failure from 0.0 to 0.2.

The SMR results of slopes were differed from each other and mainly depend on the orientation between slope faces and respective potential mode of failures. This approach is useful to narrow down the critical area by identified unstable slopes. Intensive analysis of discontinuum approach is recommended to be conducted on unstable slopes. This systematic approach offers a practical method especially for large area of rock slope stability assessment and results of probability of failure values will help the engineers better to design adequate mitigation measures.

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