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Stability of Rock Slope Using Kinematic Analysis: A Case Study at Bukit Gemilang, Sungai Besi, Kuala Lumpur

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ABSTRACT

Discontinuities are crucial for assessing the stability of rock slopes, with their geometric properties such as direction and orientation serving as key indicators. Conventionally, compasses have been used to measure the direction and orientation of these discontinuities, but this method requires considerable time for data collection. Recent advancements in remote sensing technology, particularly Terrestrial Laser Scanners (TLS), provide a more efficient alternative for measuring rock slope discontinuities. This study focuses on the stability of the rock slope at Bukit Gemilang, located in the Universiti Pertahanan Nasional Malaysia (UPNM) campus in Sungai Besi, Kuala Lumpur. Investigating this area is crucial because of the risks it poses to students and staff who pass by, particularly given the lack of prior studies reported in the literature. The paper aims to determine the orientation of the discontinuity features of the Bukit Gemilang rock slope using both conventional and TLS methods. Statistical tests indicate no significant difference between the data collected from the two methods, suggesting that TLS is a reliable tool for obtaining preliminary information on rock slope stability. This data is then utilized for kinematic analysis using Rocscience Dips software, which indicates low probabilities of planar, wedge, and toppling failures at 16.16%, 7.84%, and 4.04%, respectively. This suggests that the rock slope is considered stable. However, to enhance safety for road users on Bukit Gemilang, it is recommended to consider the installation of dowel bars and wire mesh in certain areas within the fractured rock zone.

1. Introduction

Rock slope stability assessment has gained major concern among researchers and engineers in recent decades to evaluate the potential hazard of rock slope failure [1]. The stability of a rock slope is primarily controlled by discontinuities such as joints, faults, folds, bedding, and foliation, which can

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act as the sliding plane for rock mass movement [2-5]. To assess the occurrence of potential failure, detailed information on the discontinuity properties within the rock mass is essential and should be characterized precisely [6]. There are various methods carried out to assess rock slope stability analysis that are classified into three broad approaches, namely kinematic, numerical, and empirical methods [7,8].

The conventional method involves using a compass and tape to provide visual inspection and direct measurement of discontinuities. However, this method exposes the researchers to rockfall impact during surveying and requires longer time to process the survey data [9,10]. The latter method, on the other hand, has been widely used due to its capability in providing high precision data at minimal cost compared to numerical methods such as the finite element method (FEM) and the conventional method [11-13].

The objective of this research is to determine the discontinuity features of Bukit Gemilang, Sg Besi, Kuala Lumpur, by using conventional and TLS methods. The data obtained from TLS was compared with the conventional method, and subsequently, rock slope stability analysis will be performed using kinematic analysis through Rocscience Dips software. It is expected that the integration of both methods could assist the researchers in achieving high accuracy and correct assessment results.

2. Study Area

This investigation was carried out at the UPNM campus located in the Kem Perdana Sungai Besi, Kuala Lumpur, approximately 12 kilometres south of Kuala Lumpur. It is situated between the latitude of E 101° 43’ 15’’ and the longitude of N 3° 3’ 38’’, covering an area of approximately 1.5 km². Most parts of the study area are covered by hilly terrain, and the highest point is Bukit Gemilang [14,15]. The scope of the study area is illustrated in Figure 1, where it covers an approximately 20 m² slope section. The selection of the slope was made based on the prevailing outcrop observed during the site visit. Discontinuity data, such as Dip Angle (DA) and Dip Direction (DD), were collected using a Breithaupt Compass and Leica Geosystems TLS.

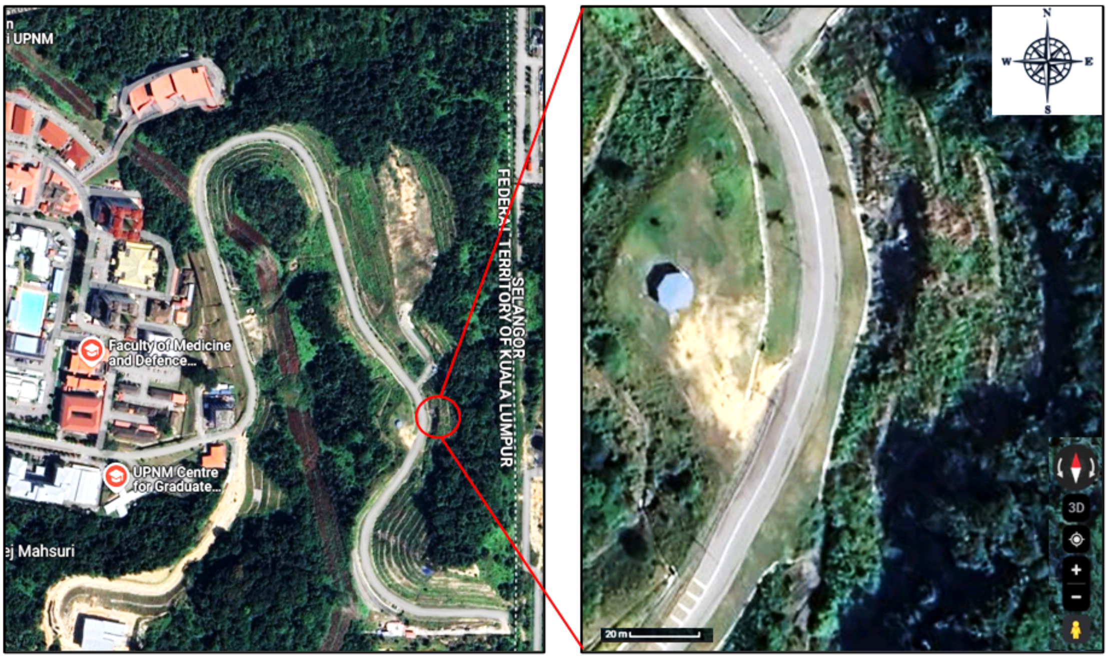


Fig. 1. Study area retrieved from Google Maps

3. Methodology
3.1 Collecting Data Using Conventional Method

The DD and DA data were obtained from a geological compass that measured directly on the rock surface. This study used a Breithaupt Compass with a specification of ± 0.1-degree accuracy for angle measurements in the horizontal and vertical planes, as shown in Figure 2(a). The distance of each discontinuity was collected using a distance meter tape for manual mapping (see Figure 2(b)). A total of 110 measurements of discontinuity directions and orientations were measured and analysed. Figure 2(c) shows the DA and DD readings obtained by using the compass.

The selection of a specific rock slope section for stability analysis is determined based on weathering conditions and the critical joint set existing in the rock mass [16,17]. Figure 3 shows the selected slope section with a width and height of 70 m and 5 m.

(a) (b) (c)

Fig. 2. Collecting discontinuities data by using compass (a) Breithaupt Geological Compass (b) Measuring distance using walking measure tape (c) DA and DD reading

Fig. 3. Width and height of the selected section of Bukit Gemilang outcrop

3.2 Collecting Data Using Terrestrial Laser Scanner

TLS able to collect and scan almost two million points per second of High-Dynamic Range (HDR) pictures in less than three minutes. This equipment is used to extract DA data from point clouds through Cyclone FIELD 360 software, which can be viewed using Leica TruView Cloud [18-20]. Figure 4 shows the study involving the setup of a TLS system in front of a rock slope section, as indicated by the red colour, scanning the 360-degree section, and collecting data at three points. The data is then imported into Cyclone FIELD 360 software and integrated with Global Navigation Satellite Systems (GNSS). The DA data were measured through Leica TruView software by selecting two points on the rock surface to generate angle measurements, as shown in Figure 5.

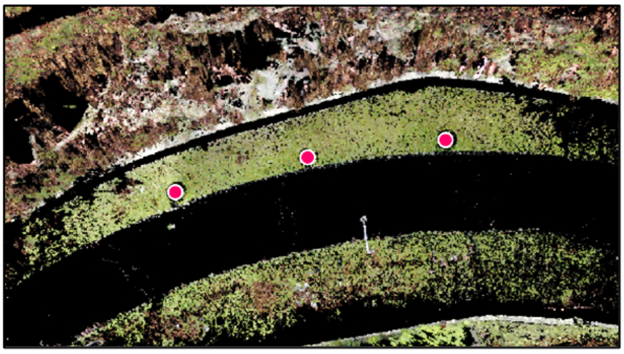


Fig. 4. Selected points for TLS setups from plan view

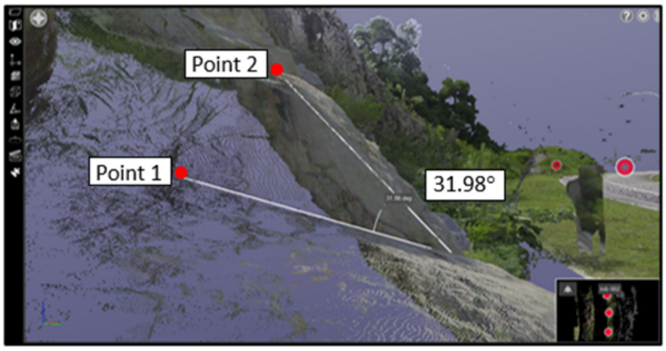


Fig. 5. Example of dip angle measurement through Truview application

4. Results

4.1 Comparative Analysis Between Conventional and TLS Measurement

In this approach, conventional observations were considered the true value to assess the accuracy of the TLS measurements. The differences between the discontinuity data measured through conventional methods and TLS were tabulated in Table 1. A statistical analysis using a t-test was conducted to determine the accuracy of data collection. The null hypothesis (Ho) of this study is "no significant difference in DA data between the conventional method and TLS." Meanwhile, the alternative hypothesis (H1) is "there is a significant difference in DA data between conventional and TLS." Equal variances were adopted for this study since the variance of the two groups, i.e., TLS and conventional, are not significantly different, with values of 607.29 and 669.93, respectively. Table 2 shows the t-test result for this study.

Table 1
Discontinuities data collection through conventional and TLS method

Site	TLS	Conventional	Site	TLS	Conventional	Site	TLS	Conventional
	DA (degrees)			DA (degrees)			DA (degrees)	
1	20	25	24	57	55	47	89	85
2	75	70	25	17	5	48	45	40
3	49	45	26	74	70	49	78	65
4	29	25	27	9	5	50	11	10
5	88	85	28	80	85	51	80	70
6	41	40	29	45	70	52	26	35
7	84	90	30	17	10	53	32	35
8	20	15	31	19	15	54	21	20
9	42	40	32	77	70	55	21	20
10	26	25	33	63	60	56	30	25
11	36	30	34	41	40	57	21	20
12	26	20	35	15	10	58	24	20
13	75	80	36	84	75	59	41	35
14	47	45	37	35	40	60	44	35
15	14	10	38	42	40	61	50	55
16	25	20	39	65	60	62	29	30
17	84	90	40	85	75	63	43	40
18	62	65	41	84	85	64	8	10
19	36	25	42	30	10	65	32	25
20	63	50	43	24	20	66	70	60
21	10	15	44	29	25	67	71	70
22	26	25	45	18	5	68	26	15
23	27	20	46	25	15	69	65	60

Table 1
Discontinuities data collection through conventional and TLS method

Site	TLS	Conventional	Site	TLS	Conventional	Site	TLS	Conventional
	DA (degrees)			DA (degrees)			DA (degrees)	
70	21	20	84	10	9	98	31	80
71	21	20	85	77	80	99	32	35
72	60	50	86	59	60	100	75	80
73	40	35	87	72	85	101	45	35
74	89	85	88	70	80	102	26	25
75	65	55	89	72	85	103	26	25
76	91	80	90	41	40	104	70	80
77	22	15	91	72	85	105	47	45
78	44	45	92	76	70	106	70	80
79	92	80	93	26	20	107	75	70
80	67	55	94	18	10	108	21	15
81	26	15	95	8	10	109	24	20
82	88	70	96	47	35	110	24	20
83	40	45	97	59	55			

Table 2
Statistical t-test result using two-samples assuming equal variances

	TLS	Conventional
Mean	45.78	43.04
Variance	607.29	669.93
Observations	110.00	
Pooled variance	638.61	
Hypothesized mean difference	0.00	
df	218.00	
t Stat	0.81	
P(T<=t) one-tail	0.21	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.42	
t Critical two-tail	1.97	

The p-value for two-tailed analysis is 0.42, which is larger than 0.05, thus implying that there is no significant difference between the data collected through conventional and TLS methods. Figure 6 shows that the test should fail to reject the Ho since the t-statistic value is not in the rejection region. The results proved that conventional and TLS yielded similar values and that the difference is not significant, which indicates that the accuracy of data collected from both methods is acceptable.

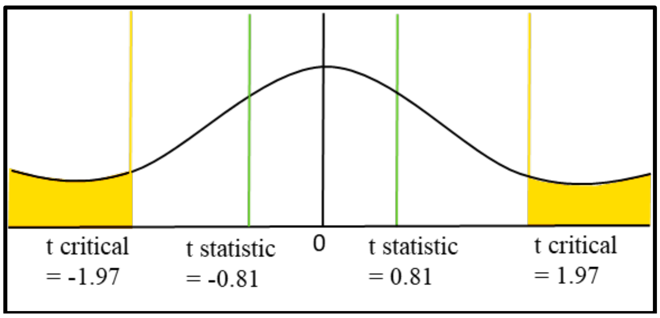


Fig. 6. Schematic drawing of t-test result distribution

4.2 Stability Analysis of Bukit Gemilang Slope Using Stereonet: Rocscience Dip Software
4.2.1 Planar failure analysis

Figure 7 shows the discontinuities contour plot of Bukit Gemilang for planar failure analysis. There are four density concentration regions identified, which indicate that there are four dominant joint sets existing on the Bukit Gemilang rock slope, namely F1, F2, F3, and F4. The pink area indicates the potential failure zone in the normal slope. Based on this research, the slope face direction 80°/145° (indicated by the green line) is parallel with the discontinuities F2 plane 12°/92° (in red line) and slightly falls into the potential failure region. The analysis shows that planar failure is the most prominent failure that can occur at the Bukit Gemilang slope, with a percentage of 16.16%. Figure 8 (a) shows two locations of potential planar failure identified at the site within chainage numbers 30m to 40m. Figure 8(b) explains the discontinuities joint, F2, parallel with the slope face [21,22].

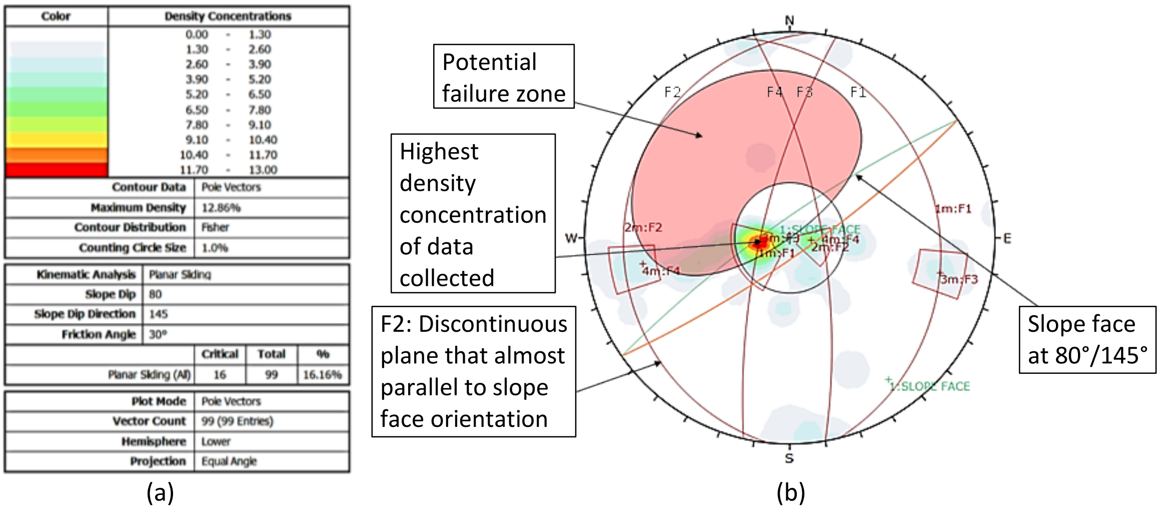


Fig. 7. Contour plot of poles to discontinuities (a) Density concentration (b) Planar sliding analysis

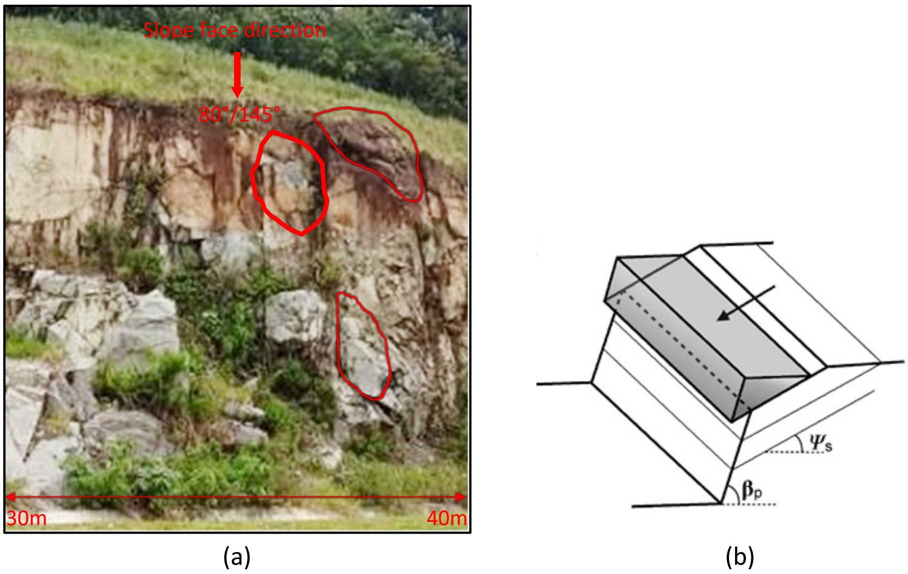


Fig. 8. (a) Location of potential planar failure on Bukit Gemilang (b) Schematic illustration of planar failure

4.2.2 Wedge failure analysis

Figure 9 shows the discontinuities contour plot of Bukit Gemilang for wedge failure analysis. The pink area indicates the potential wedge failure region in a normal slope. The results show that there are no two joint sets that have intersected each other, except for F3 and F4. The discontinuity joint F3 plane 74°/103° intersects with the discontinuity joint F4 plane 72°/260°, however, it does not lean on the potential failure zone. Therefore, the possibility of wedge failure occurring at the Bukit Gemilang slope is considered low, with a percentage value of 7.84%. Figure 10(a) shows the potential location of wedge planar failure identified at the site within chainage 35m to 45m. Figure 10(b) shows the schematic drawing of how the wedge failure can occur if the F3 and F4 joint sets intersect with each other and the direction is parallel to the slope direction [23].

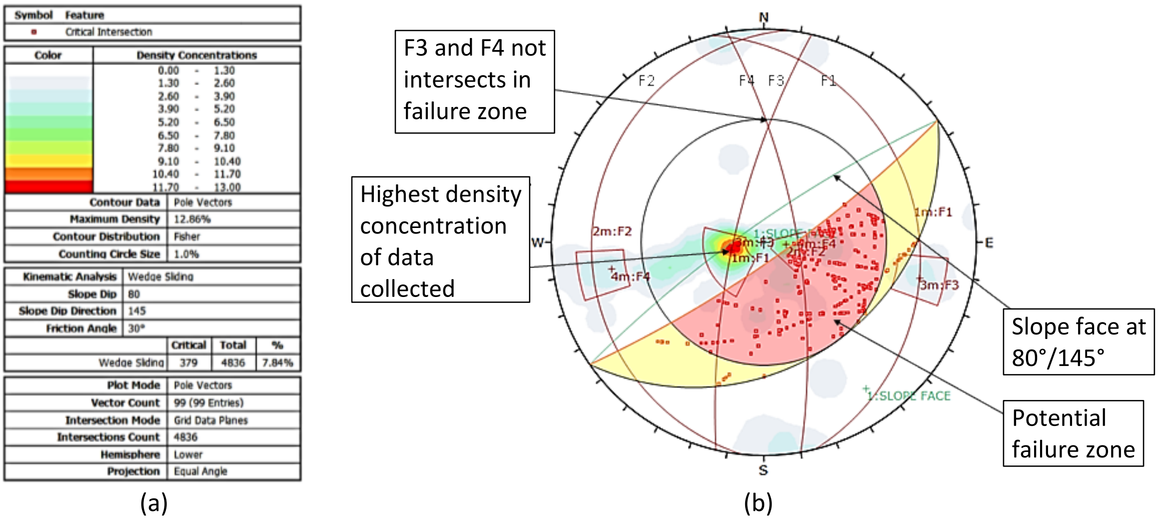


Fig. 9. Contour plot of poles to discontinuities (a) Density concentration (b) Wedge sliding analysis

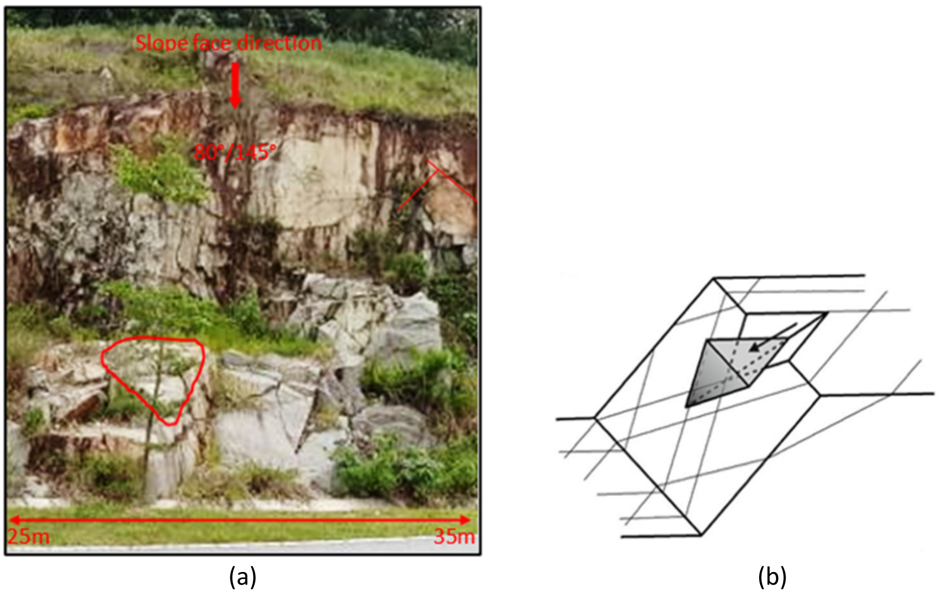
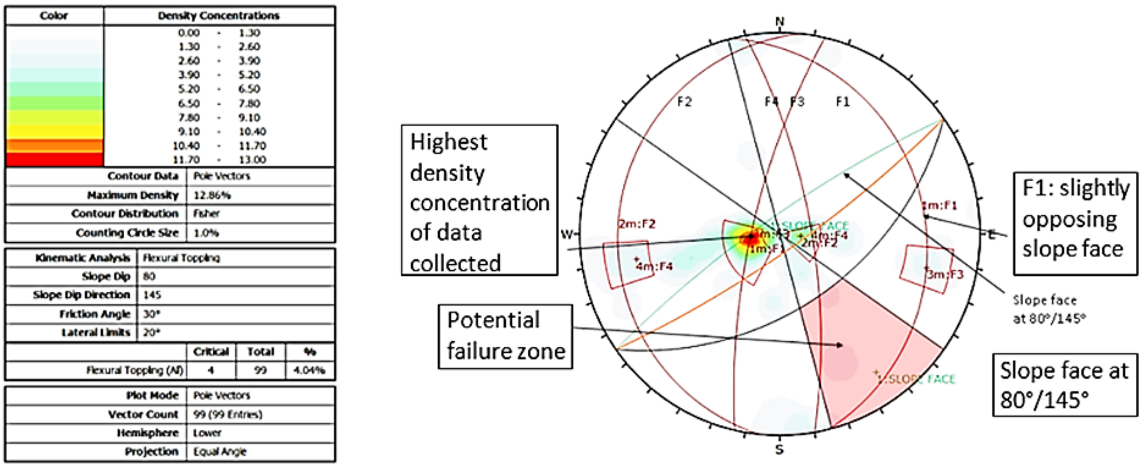


Fig. 10. (a) Location of wedge failure on Bukit Gemilang outcrop (b) Schematic illustration of wedge failure

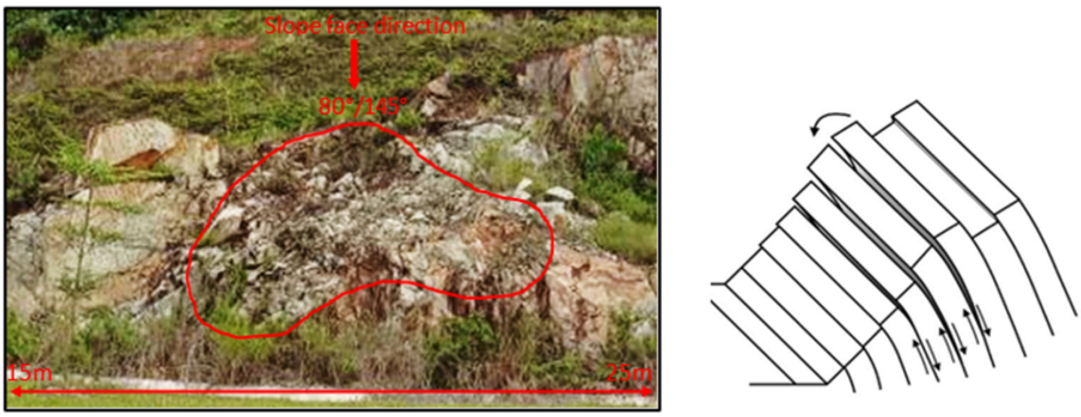
4.2.3 Toppling failure analysis

Figure 11 shows the contour plot of the discontinuity plane of Bukit Gemilang for toppling failure analysis. Based on this research, three out of four discontinuity planes, which are F2 12°/96°, F3 74°/103°, and F4 72°/260°, were not opposed to the slope face direction 80°/145°. However, F1 18°/256° very slightly opposes the slope face direction. The analysis shows that there is a very low possibility of toppling failure occurring at Bukit Gemilang, with a percentage value of 4.04%. Figure 12(a) shows the potential location of toppling failure identified at the site within chainage 15 m to 20m. Figure 12(b) shows a schematic drawing of the potential toppling failure that can occur [24,25].



(a) (b)

Fig. 11. Contour plot of poles to discontinuities (a) Density concentration (b) Toppling sliding



(a) (b)

Fig. 12. (a) Location of toppling failure on Bukit Gemilang outcrop (b) Schematic illustration of toppling failure

5. Conclusions

It was found that the predominant factor affecting rock slope instability at Bukit Gemilang is the joint set. A total of four predominant joint sets, F1, F2, F3, and F4, exist on the Bukit Gemilang slope, which derived from 110 joint planes data collected for stability analysis through conventional and TLS methods. The results of the statistical analysis t-test show that there is no significant difference in obtaining discontinuities' direction and orientation through both methods since the p-value is 0.42, which is larger than the 0.05 confidence interval. During the study, TLS complemented the conventional data collection by measuring inaccessible joint sets, especially on high and steep slopes at Bukit Gemilang. In addition, using TLS was time-effective and convenient compared to the conventional method, with a time difference of 15 minutes and 5 hours, respectively. However, TLS has limitations, which are unable to measure some of the joint discontinuities under small exposure planes and are being obscured by vegetation. Based on Rocscience Dip analysis, the stability of the Bukit Gemilang rock slope is considered stable, with the possibility of planar failure, wedge failure, and toppling failure occurring at low rates of 16.16%, 7.84%, and 4.04%, respectively.

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