



Stability of Rock Slope Using Kinematic Analysis: A Case Study at Bukit Gemilang, Sungai Besi, Kuala Lumpur (Paper 1)

Nurul Afiffah Khairulazman¹, Jestin Jelani^{1*}, Zuliziana Suif¹, Nordila Ahmad¹, Nur Anati Azmi², Zainuddin Md Yusoff², Wan Mohamed Syafuan Wan Mohamed Sabri¹ Qalam A'zad Rosle³

¹ Department of Civil Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Kuala Lumpur, Malaysia

² Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, Kuala Lumpur, Malaysia

³ Department of Mineral and Geoscience Malaysia Selangor / Wilayah Persekutuan, Malaysia

ARTICLE INFO

Article history:

Received 29 October XXXX

Received in revised form 1 December XXXX

Accepted 9 December XXXX

Available online 10 December XXXX

Keywords:

Stereonet; Terrestrial Laser Scanner;
Discontinuities; Rock slope stability;
Conventional and Rocscience Dips

ABSTRACT

Discontinuities play a crucial role in assessing the stability of rock slopes, with their geometric properties like direction and orientation serving as key indicators. Traditionally, compasses have been widely employed to gauge the direction and orientation of these discontinuities. However, the conventional method necessitates more time for data collection. Recent advancement of remote sensing technology, Terrestrial Laser Scanners (TLS) offer a more convenient means of measuring rock slope discontinuities. This paper aims to determine the orientation of discontinuities features of Bukit Gemilang rock slope, located on the Universiti Pertahanan Nasional Malaysia (UPNM) campus, Sungai Besi, Kuala Lumpur, through the conventional and TLS methods. The statistical test reveals no significant disparity of data collected from both methods which implies the TLS is a reliable tool in providing valuable preliminary information pertaining to rock slope stability assessment. The output then used to assess the stability of the rock slope through kinematic analysis. Kinematic analysis from Rocscience Dips software shows the possibility of planar, wedge and toppling failure occurring is low with failure possibilities of 16.16%, 7.84% and 4.04% respectively. To mitigate potential risks to road users on Bukit Gemilang, it is advisable to consider the installation of dowel bars and wire mesh in specific areas within the fractured rock zone.

1. Introduction

Rock slope stability analysis has gained major concern among geologists and geotechnical engineers in recent decades. It becomes paramount important to evaluate potential hazard and anticipate the pattern of rock slope failure to avoid loss of human life, property, and negative impact on economy [1]. The stability of rock slope is primarily controlled by the discontinuities such as joints, faults, folds, bedding, and foliation which can act as the sliding plane for rock mass movement [2-5]. To assess the occurrence of potential failure, detailed information of 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 classified into three broad approaches, namely conventional approach, numerical method, and remote sensing technology [7-8]. The conventional method is using compass and tape to provide visual inspection

and direct measurement of discontinuities. However, this method exposed the researchers to rockfall impact during surveying and requires longer time to process the survey data [9-10]. The later 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 finite element method (FEM) and conventional method [11-12].

The objective of this research is to determine the discontinuities features of Bukit Gemilang, Sg Besi, Kuala Lumpur by using conventional and TLS method. The data obtained from TLS was compared with conventional method and subsequently rock slope stability analysis will be performed using kinematic analysis through Rocscience Dips software. It is expected integration of both methods could assist the researcher to gain 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 kilometers south of Kuala Lumpur. It is situated between latitude of E 101° 43' 15" and longitude N 3° 3' 38" covering an area approximately 1.5 km². Most parts of the study area are covered by hilly terrain and the highest point is Bukit Gemilang [13-14]. The scope of the study area is illustrated in Fig 1 where it covers approximately 20m² slope section. The selection of the slope is made based on prevailing outcrop observed during site visit. Discontinuities data, such as Dip Angle (DA) and Dip Direction (DD) were collected by using 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 geological compass that measured directly on the rock surface. This study used Breithaupt Compass with specification of ± 0.1 -degree accuracy for angle measurements in the horizontal and vertical planes as shown in Fig 2(a). The distance of each

discontinuity is collected using distance meter tape for manual mapping (see Fig 2(b)). A total of 110 measurements of discontinuities directions and orientations were measured and analyzed.

The selection of specific rock slope section for stability analysis is determined based on weathering condition and critical joint set exist in the rock mass [15]. Fig 3 shows the selected slope section with width and height of 70m and 5m. Fig 4 shows the DA and DD readings obtained by using compass and the results tabulated in Table 1.



Fig. 2. (a) Breithaupt Geological Compass (b) Measuring distance using walking measure tape

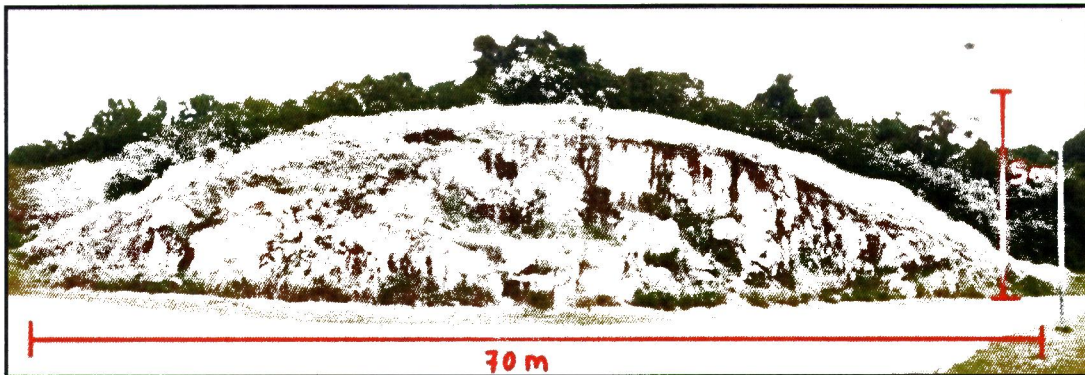


Fig. 3. Width and height of the selected section of Bukit Gemilang outcrop



Fig. 4. Discontinuities data collection by using compass

3.2 Collecting Data using Terrestrial Laser Scanner

TLS is able to collect and scan almost two million points per second High-Dynamic Range (HDR) picture, 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 [16-18]. Fig 5 shows the study involves setting up a TLS setup in front of a rock slope section as indicated by red color, scanning the 360-degree section, and collecting data at three points. The data is then imported into Cyclone FIELD 360 software and integrated with GNSS. The DA data were measured through Leica TruView software by selecting 2 points on rock surface to generate angle measurement as shown in Fig 6.



Fig. 5. Selected points for TLS setups from plan view

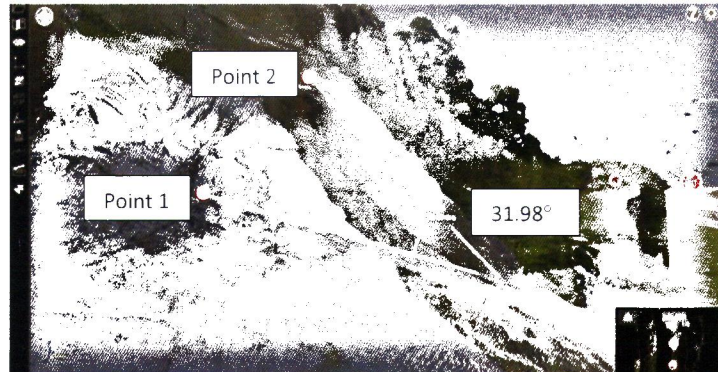


Fig. 6. Example of dip angle measurement through Truview Application.

4. Results

4.1 Comparative Analysis Between Conventional and TLS Measurement

In this approach, conventional observations were considered as the true value to assess the accuracy of the TLS measurements. The differences between discontinuities data measured through conventional and TLS were tabulated Table 1. A statistical analysis using t-test is conducted to determine the accuracy of data collection. The null hypothesis (H_0) of this study is “no significant difference of DA data between the conventional and TLS”. Meanwhile, the alternative hypothesis (H_1) is “there is significant difference of 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 difference with values of 607.29 and 669.93 respectively. Table 2 shows the t-test result for this study.

The p-value for two tail analysis is 0.42 which is larger than 0.05 thus implies that there is no significant difference between data collected through conventional and TLS method. Fig 7 shows 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 the difference is not significant, which indicates the accuracy of data collected from both methods are acceptable.

Table 1
 Discontinuities data collection through conventional and TLS method

Site	TLS DA (degrees)	Conventional
1	20	25
2	75	70
3	49	45
4	29	25
5	88	85
6	41	40
7	84	90
8	20	15
9	42	40
10	26	25
11	36	30
12	26	20
13	75	80
14	47	45
15	14	10
16	25	20
17	84	90
18	62	65
19	36	25
20	63	50
21	10	15
22	26	25
23	27	20
24	57	55
25	17	5
26	74	70
27	9	5

Site	TLS DA (degrees)	Conventional
28	80	85
29	45	70
30	17	10
31	19	15
32	77	70
33	63	60
34	41	40
35	15	10
36	84	75
37	35	40
38	42	40
39	65	60
40	85	75
41	84	85
42	30	10
43	24	20
44	29	25
45	18	5
46	25	15
47	89	85
48	45	40
49	78	65
50	11	10
51	80	70
52	26	35
53	32	35
54	21	20

Site	TLS	Conventional	Site	TLS	Conventional
DA (degrees)			DA (degrees)		
55	21	20	83	40	45
56	30	25	84	10	9
57	21	20	85	77	80
58	24	20	86	59	60
59	41	35	87	72	85
60	44	35	88	70	80
61	50	55	89	72	85
62	29	30	90	41	40
63	43	40	91	72	85
64	8	10	92	76	70
65	32	25	93	26	20
66	70	60	94	18	10
67	71	70	95	8	10
68	26	15	96	47	35
69	65	60	97	59	55
70	21	20	98	31	80
71	21	20	99	32	35
72	60	50	100	75	80
73	40	35	101	45	35
74	89	85	102	26	25
75	65	55	103	26	25
76	91	80	104	70	80
77	22	15	105	47	45
78	44	45	106	70	80
79	92	80	107	75	70
80	67	55	108	21	15
81	26	15	109	24	20
82	88	70	110	24	20

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	

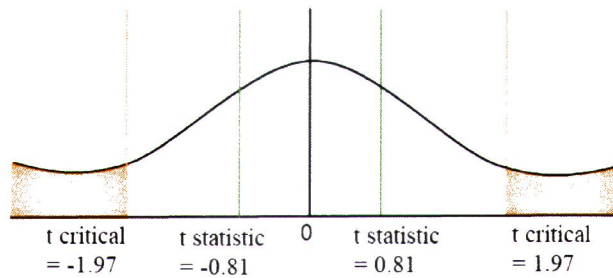


Fig. 7. Schematic drawing of t-test result distribution

4.2 Stability Analysis of Bukit Gemilang Slope Using Stereonet: Rocscience Dip Software

4.2.1 Planar Failure Analysis

Fig 8 shows the discontinuities contour plot of Bukit Gemilang for planar failure analysis. There are four density concentrations regions were identified which indicate there are four dominant joint set exist on the Bukit Gemilang rock slope, namely F1, F2, F3 and F4. The pink area indicates the potential failure zone in normal slope. Based on this research, the slope face direction $80^{\circ}/145^{\circ}$ (indicates by green line) is paralleled with discontinuities F2 plane $12^{\circ}/92^{\circ}$ (in red line) and slightly fall into potential failure region. The analysis shows that planar failure is the most prominent failure can occur at the Bukit Gemilang slope with percentage of 16.16%. Fig 9 (a) shows two locations of potential planar failure identified at site within chainage number 30m to 40m. Fig 9 (b) explained the discontinuities joint, F2 paralleled with the slope face [19].

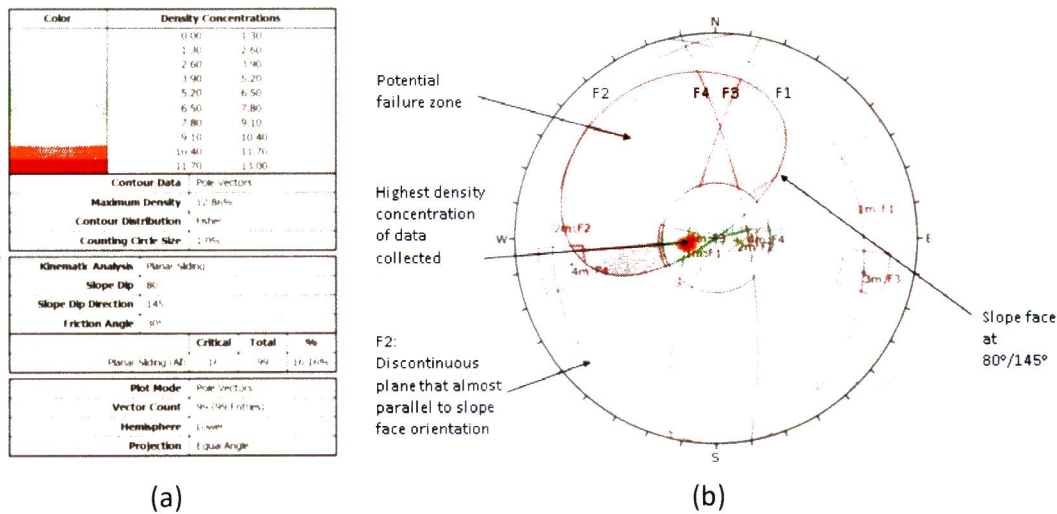


Fig. 8. Contour plot of poles to discontinuities (a) Density concentration (b) Planar sliding analysis

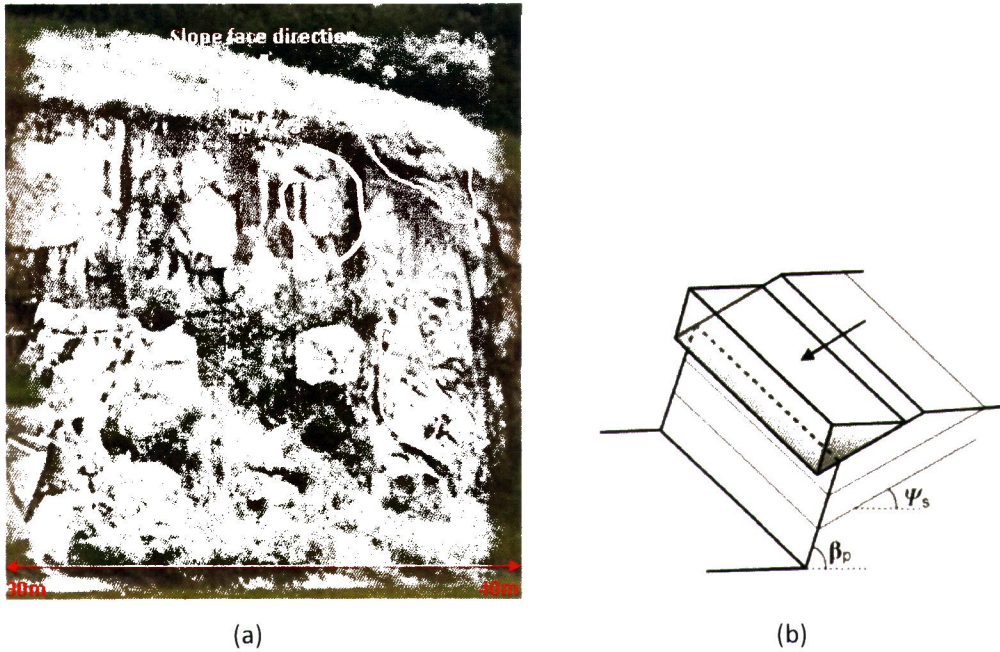


Fig. 9. (a) Location of potential planar failure on Bukit Gemilang (b) Schematic illustration of planar failure

4.2.2 Wedge Failure

Fig 10 shows the discontinuities contour plot of Bukit Gemilang for wedge failure analysis. The pink area indicates the potential of wedge failure region in normal slope. The result shows that there are no two joint sets had intersected each other, except for F3 and F4. The discontinuity joint F3 plane $74^\circ/103^\circ$ intersecting the discontinuities joint F4 plane $72^\circ/260^\circ$, however it does not lean on the potential failure zone. Therefore, the possibility of wedge failure can occur at the Bukit Gemilang slope is considered low with percentage value 7.84%. Fig 11 (a) shows the potential location of wedge planar failure identified at site within chainage 35m to 45m. Fig 11(b) shows the schematic drawing of how the wedge failure can occur if F3 and F4 joint set intersect each other and the direction is parallel with slope direction [20].

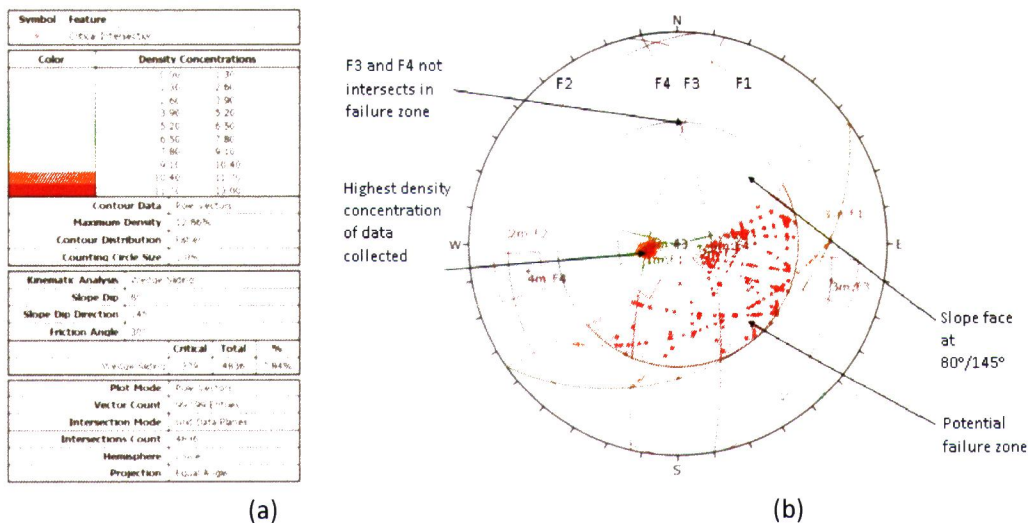


Fig. 10. Contour plot of poles to discontinuities (a) Density concentration (b) Wedge sliding analysis

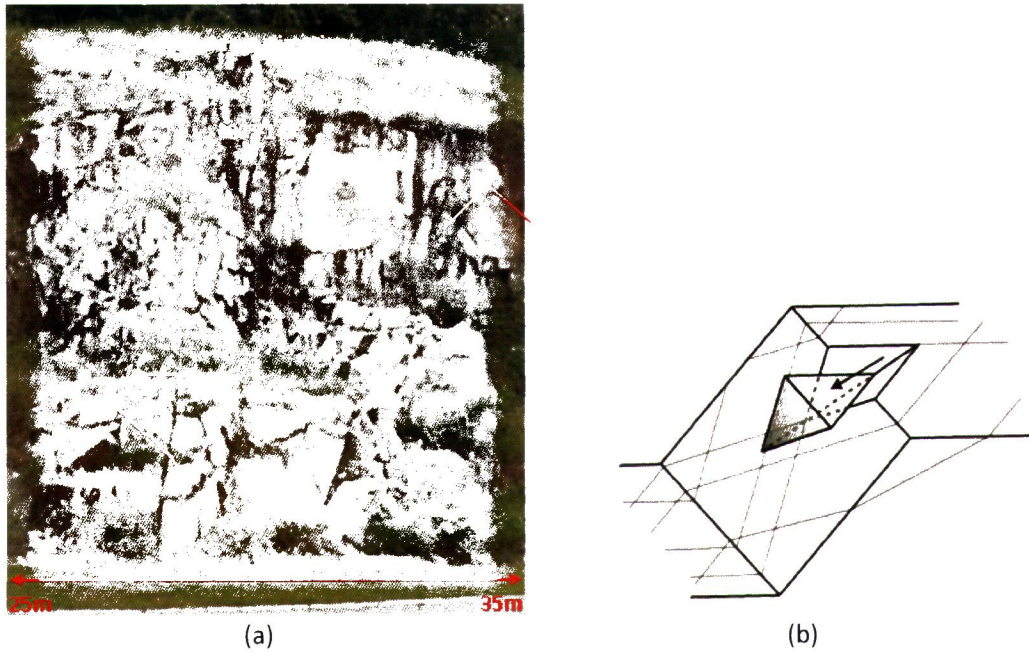


Fig. 11. (a) Location of wedge failure on Bukit Gemilang outcrop (b) Schematic illustration of wedge failure

4.2.3 Toppling Failure Analysis

Fig 12 shows the contour plot of discontinuities plane of Bukit Gemilang for toppling failure analysis. Based on this research, three out of four discontinuity planes which are F2 $12^\circ/96^\circ$, F3 $74^\circ/103^\circ$ and F4 $72^\circ/260^\circ$ were not opposed to the slope face direction $80^\circ/145^\circ$. However, F1 $18^\circ/256^\circ$ very slightly opposes the slope face direction. The analysis shows that a very low possibility of toppling failure can occur at Bukit Gemilang with a percentage value of 4.04%. Fig 13 (a) potential location of toppling failure identified at site within chainage 15m to 20m. Fig 13 (b) shows schematic drawing of the potential toppling failure can occur [21].

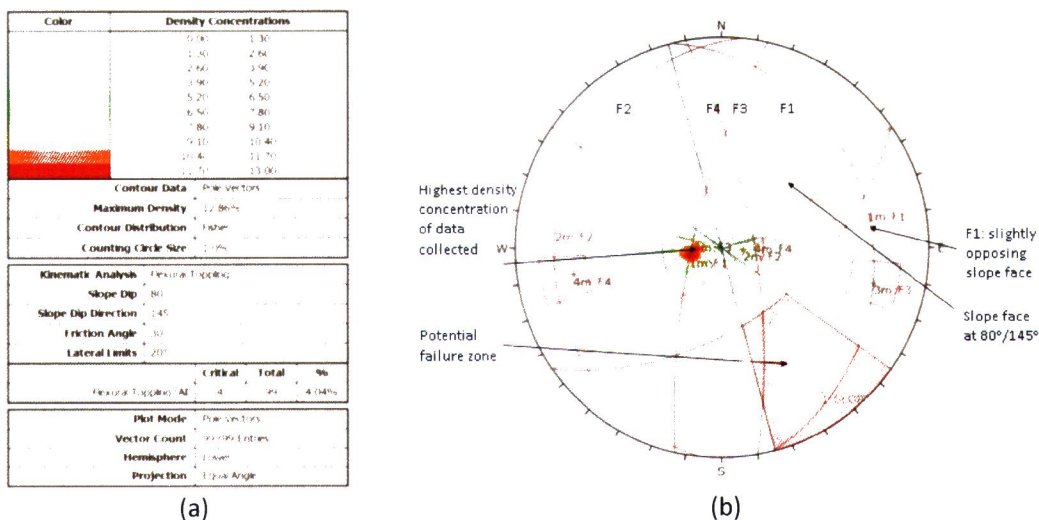


Fig. 13. Contour plot of poles to discontinuities (a) Density concentration (b) Toppling sliding analysis

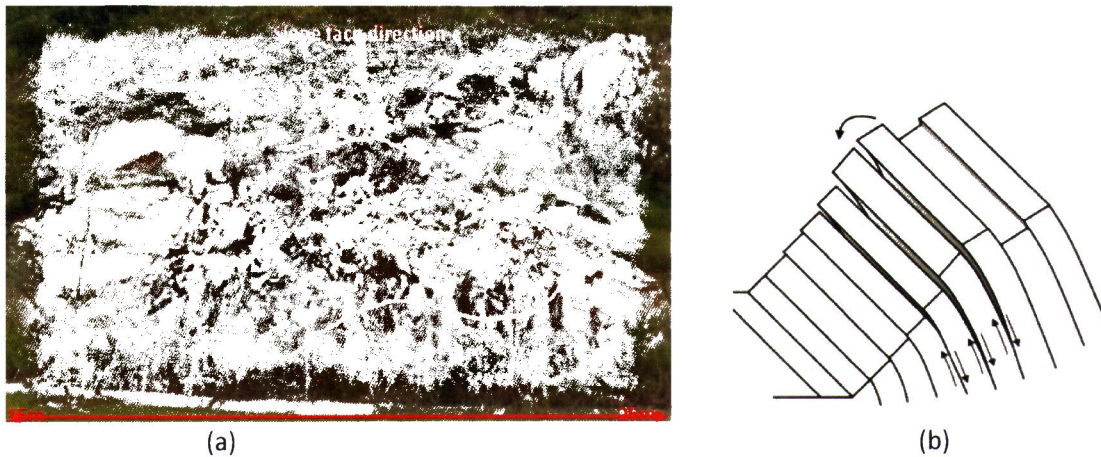


Fig. 14. (a) Location of toppling failure on Bukit Gemilang outcrop (b) Schematic illustration of toppling failure

5. Conclusions

It was found that the predominant factor affecting rock slope instability at Bukit Gemilang is joint set. A total of four predominant joint sets F1, F2, F3 and F4 exist on Bukit Gemilang slope which derived from 110 joint planes data collected for stability analysis through conventional and TLS method. The results of 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 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 conventional method with time difference of 15 minutes and 5 hours respectively. However, TLS has limitation which unable to measure some of the joint discontinuities under small exposure planes and being obscured by vegetation. Based on RocScience Dip analysis of the stability of Bukit Gemilang rock slope is considered stable with the possibility of planar failure, wedge failure and toppling failure occurred is low with 16.16% ,7.84% and 4.04% respectively.

Acknowledgement

The authors wish to express their gratitude to the National Defence University of Malaysia for funding and supporting this project under the grant with project code PS0056UPNM/2022/GPPP/TK/24.

References

- [1] Woodroffe, C. (2001). Geomorphology. Encyclopedia of Ocean Sciences, 1142–1148. Retrieved from <https://doi.org/10.1006/RWOS.2001.0093>
- [2] Tipol, F. H. et al (2011). Joint patterns in granite and its relationship with its slope failure: bukit lanjan rockslide revisited cite this paper joint patterns in granite and its relationship with its slope failure: bukit lanjan rockslide revisited.
- [3] Raghuvanshi, T. K. (2019). Plane failure in rock slopes—A review on stability analysis techniques. Journal of King Saud University-Science, 31(1), 101-109. <https://doi.org/10.1016/j.jksus.2017.06.004>
- [4] Weidner, L. et al (2021). Monitoring the effects of slope hazard mitigation and weather on rockfall along a Colorado highway using terrestrial laser scanning. Remote Sensing, 13(22). <https://doi.org/10.3390/rs13224584>
- [5] Undul, O., Tugrul, A (2012). The Influence of Weathering on the Engineering Properties of Dunites. Rock Mech Rock Eng 45, 225–239 <https://doi.org/10.1007/s00603-011-0174-1>
- [6] Riquelme, A., Cano, M., Tomás, R., & Abellán, A. (2017). Identification of Rock Slope Discontinuity Sets from Laser Scanner and Photogrammetric Point Clouds: A Comparative Analysis. Procedia Engineering, 191, 838–845. <https://doi.org/10.1016/j.proeng.2017.05.251>

- [7] Jena, R., Pradhan, B., & Alamri, A. M. (2020). Geo-structural stability assessment of surrounding hills of Kuala Lumpur City based on rock surface discontinuity from geological survey data. *Arab J Geosci* 13, 95 <https://doi-org.libproxy.upnm.edu.my/10.1007/s12517-020-5057-x>
- [8] Shariati, M. et al (2021). Rock slope stability evaluation using kinematic and kinetic methods along the Kamyaran-Marivan road, west of Iran. *Journal of Mountain Science*, 18(3), 779–793. <https://doi.org/10.1007/s11629-020-6438-z>
- [9] Nagendran, S.K. et. al (2019). Integration of UAV photogrammetry and kinematic analysis for rock slope stability assessment. *Bulletin of the Geological Society of Malaysia*, 2019(67), 117–123. <https://doi.org/10.7186/bgsm67201913>
- [10] Roslan, R. et al (2019). Discontinuity mapping using terrestrial laser scanner and kinematic method. *International Journal of Engineering and Advanced Technology*, 9(1), 3640–3644. <https://doi.org/10.35940/ijeat.A2704.10911>
- [11] Gigli, G., Lombardi, L., Carlà, T., Beni, T., & Casagli, N (2022). A method for full three-dimensional kinematic analysis of steep rock walls based on high-resolution point cloud data. *International Journal of Rock Mechanics and Mining Sciences*, 157. <https://doi.org/10.1016/j.ijrmms.2022.105178>
- [12] Ismail, A., Ahmad Safuan, A. R., Sa'ari, R., Wahid Rasib, A., Mustaffar, M., Asnida Abdullah, R., Kassim, A., Mohd Yusof, N., Abd Rahaman, N., & Kalatehjari, R. (2022). Application of combined terrestrial laser scanning and unmanned aerial vehicle digital photogrammetry method in high rock slope stability analysis: A case study. *Measurement: Journal of the International Measurement Confederation*, 195. <https://doi.org/10.1016/j.measurement.2022.111161>
- [13] Jelani, J., Hah, M.S.A., Mohd Daud, M.N., Ahmad, N., Othman, M., Wan Mohamed Sabri, W.M.S. (2021). Stability Analysis of a Man-Made Slope: A Case Study on the UPNM Campus, Sg Besi, Kuala Lumpur. In: Jeon, HY. (eds) *Sustainable Development of Water and Environment. ICSDWE 2021. Environmental Science and Engineering*. Springer, Cham. https://doi.org/10.1007/978-3-030-75278-1_4
- [14] Jelani, J., Baharudin, S., Othman, M., Mohd Daud, M. N., Ahmad Ishak, A. S., & Yahya, M. A. (2021). Preliminary Investigation of the Effect of Surcharge Load and Distance on Non- Homogenous Man-Made Slope. *Jurnal Kejuruteraan SI*, 4(1), 101–107.
- [15] Hellmy, M. et al (2019). Rock slope stability analysis based on terrestrial LiDAR on karst hills in Kinta valley geopark, Perak, peninsular Malaysia. *Sains Malaysia*, 48(11), 2595–2604. <https://doi.org/10.17576/jsm-2019-4811-29>
- [16] Yiu K et al (2009). Stereonet data from terrestrial laser scanner point clouds. *Department of Land Surveying and Geo-Informatics, Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong*, 41(314), 324-338. <https://doi.org/10.1179/003962609X451573>
- [17] Beni, T. et al (2022). Route Stability Index (RSI): an Index for the Assessment of Rockfall-Related Hazards in Rock Slopes Equipped for Sport Climbing. *Geoheritage*, 14(3). <https://doi.org/10.1007/s12371-022-00715-7>
- [18] Sturzenegger et al (2009). Close-range terrestrial digital photogrammetry and terrestrial laser scanning for discontinuity characterization on rock cuts. *Engineering Geology*, 106(3–4), 163–182. <https://doi.org/10.1016/j.enggeo.2009.03.004>
- [19] Mebrahtu, T.K., Heinze, T., Wohnlich, S. et al. (2022). Slope stability analysis of deep-seated landslides using limit equilibrium and finite element methods in Debre Sina area, Ethiopia. *Bull Eng Geol Environ* 81, 403 <https://doi.org/10.1007/s10064-022-02906-6>
- [20] Tang et al (2022). Automatic Extraction of Rock Discontinuities from the Point Cloud Using Dynamic DBSCAN Algorithm. *Advances in Civil Engineering*, 2022. <https://doi.org/10.1155/2022/7754179>
- [21] Bolla, A. et. al (2020). Geomechanical Field Survey to Identify an Unstable Rock Slope: The Passo Della Morte Case History (NE Italy). *Rock Mechanics and Rock Engineering*, 53(4), 1521–1544. <https://doi.org/10.1007/s00603-019-01963-w>