Stability of weathered cut slope by using kinematic analysis

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Stability of weathered cut slope by using kinematic analysis

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Abstract. Rock slope engineering involves the designing of safe and stable rock slopes for a certain lifespan. Different rock slopes exhibit different strengths of material that reacts differently to external forces. Rock strength can decrease over time due to weathering process. In addition, the presence of discontinuity can lead to structurally controlled slope failure. The study focuses on a large exposed rock slope in Sri Jaya area, where the exposed granitic rock was cut by several sets of discontinuities. In addition to the discontinuities, the slope exhibited several weathering grades. The objective of this study is to map the weathering and discontinuity of the rock slope, in order to determine the stability of the slope. Schmidt rebound hammer tests were carried out to determine the extent of the weathering grade of the slope material. The collected field data were then analysed using the kinematic analysis to determine potential mode(s) of failure. From the analysis, it is predicted that there is significant percentage for toppling failure and wedge failure to occur in the weathered rock material.

Keywords: Weathering, Weathered rock, Kinematic analysis, Rock slope stability, Dips 7.0

1. Introduction

Weathering is the breakdown of soils, rocks, and minerals that are in contact with earth's atmosphere, water and air. Weathering rocks take place over long period of time, with rocks on earth's surface experiencing the process faster than rock buried underground. Weathering is one of the process that lead to soil formation. There are different types of weathering that affect rocks, which includes physical/mechanical, chemical and biological weathering. For physical/mechanical weathering, this process will breaks down the rocks into bits. Weathering also not only effect strong rocks but weak masses, which included weathered material from original fresh rocks that now forms soil. Chemical weathering is more or common and occurs faster in tropical regions, such as Malaysia, due to heat and abundant water from rain [1]. Weathering reduces the strength of rock, which can then affect the cut slope stability. In rock slopes, several methods are available to assess the stability. Kinematic analysis is one of the conventional method of analysis of slope stability, alongside limit equilibrium analysis and rock fall simulators [2]. It is in basic terms a geometric analysis, which examines the modes of slope failure that are feasible in a given rock mass, which can be applied to both slopes that are already excavated or proposed rock slopes. The analysis was developed by [3], with subsequent modification by [4-5] commonly used in modern analysis. In a kinematic analysis, it is the orientation of the sets of discontinuities and the slope face, together with friction, that are examined to determine if certain modes of failure can occur. The analysis is commonly conducted with the stereographic representation of the planes and lines of interest. It is a popular choice of slope stability analysis among local engineer working on rock slopes [6]. This study sets out to investigate the effect of weathering of rocks to the stability of cut slope. Large exposed rock slope along Sri Jaya area was selected as a case study, where several stage of weathering can be observed on the slope faces. The relationship between the weathering condition and stability of the rock slope was studied.

2. Methodology

2.1. Fieldwork

In this study, the main objective is on finding the stability of weathered rock cut slope by using kinematic analysis. The data needed for the analysis would include the Schmidt rebound hammer test readings and discontinuity mapping (scanline mapping) of the rock slope. Fieldwork was carried out in order to determine the extent of the weathered rock, and ultimately to study its effect to the potential failure of the slope. The study area takes place in Sri Jaya, Pahang, where large exposed cut slope is found (Figure 1). The weathering condition of the slopes means that there are potential for the weakening of the slope, which could lead to failures. The rock mass along the slope consist of granitic rocks.

Figure 1. View of the exposed cut slope at Sri Jaya

2.2. Schmidt rebound hammer test

Schmidt rebound hammer test is a simple test used in determining the surface hardness of the weathered material of the rock slope (Figure 2 – Figure 3). The test was carried out an interval of 5m along scanline of the slope face. For every interval, the test was repeated 10 times in order to get the average value of the rebound number. This is following the suggested method by [7]. The values can be used to determine the weathering grade of the rock.

Figure 2. The Schmidt rebound hammer used to identify weathering grade *along the scanline* of the slope

Figure 3. Close up of measurement using the Schmidt rebound hammer

2.3. Discontinuity data

The scanline method was carried out in order to get the measurements of dip and dip direction of the discontinuity for the purpose of kinematic analysis. Discontinuity mapping is a method that based on fieldwork that collect data, and is one of component to calculate rock mass classification in rock engineering. This method is a reliable method to measures and describe the discontinuity, which refers to fracture or breakage in the rock, such as joints, faults, beddings, and foliations. The discontinuity mapping is characterized by measurement of the number of discontinuity sets, size, spacing intercept, location, orientation and mean density. The discontinuity data from the mapping were used as input for software to analyse the rock slope condition, where the potential of failure of the rock slope could be predicted. The software used is Dips [8], which is capable of calculating the percentage of potential modes of failure of a slope.

3. Results and discussion

3.1. Weathering grade classification

Table 1 show the result from the Schmidt rebound number from field mapping. Based on the result, it was found that most of the slope consists of rock material from weathering grade II (WG II). Based on the weathering classification on granite, it was determined that for WG II granite, the average value for Schmidt rebound hammer is more than 45 [9]. For rocks which does not give any rebound number, the weathering grade is classified as WG IV or lower.

Table 1. Summary of Schmidt rebound hammer test along the slope

Chainage (m)	Rock type	Average reading of Schmidt rebound hammer	Weathering grade	Chainage (m)	Rock type	Average reading of Schmidt rebound hammer	Weathering grade
0	Granite	0	IV	170	Granite	59.6	II
5	Granite	0	IV	175	Granite	38.8	III
10	Granite	44.6	III	180	Granite	59.2	II
15	Granite	0	IV	185	Granite	53	II

20	Granite	56.6	II	190	Granite	57.2	II
25	Granite	52.6	II	195	Granite	-	-
30	Granite	32.6	III	200	Granite	46.6	II
35	Granite	45.6	II	205	Granite	44.8	III
40	Granite	27	III	210	Granite	58.8	II
45	Granite	24.6	III	215	Granite	48.8	II
50	Granite	37.2	III	220	Granite	0	IV
55	Granite	62.2	I	225	Granite	62	I
60	Granite	60.4	I	230	Granite	59	II
65	Granite	38.8	III	235	Granite	64.4	I
70	Granite	47	II	240	Granite	68.4	I
75	Granite	48	II	245	Granite	37.8	III
80	Granite	51	II	250	Granite	56.4	II
85	Granite	47.2	II	255	Granite	42.4	III
90	Granite	48.2	II	260	Granite	59.8	II
95	Granite	52.4	II	265	Granite	50.8	II
100	Granite	56.4	II	270	Granite	43.4	III
105	Granite	53.8	II	275	Granite	50	II
110	Granite	55.2	II	280	Granite	38.8	III
115	Granite	55.8	II	285	Granite	44	II
120	Granite	65.2	I	290	Granite	53.8	II
125	Granite	52.4	II	295	Granite	42	II
130	Granite	53.2	II	300	Granite	52.8	II
135	Granite	64.8	I	305	Granite	54.4	II
140	Granite	62.2	I	310	Granite	63.8	I
145	Granite	49.8	II	315	Granite	57.2	II
150	Granite	52.4	II	320	Granite	59.8	II
155	Granite	67.4	I	325	Granite	43.2	II
160	Granite	56	II	330	Granite	54.2	II
165	Granite	46.6	II	335	Granite	39.2	III

3.2. Kinematic analysis

Data for the discontinuity of rock slope were processed in the software Dips, which requires the orientation of the discontinuities (joints) and slope face orientation. In the analysis, four types of plane failures could be calculated: planar sliding, wedge sliding, flexural toppling and direct toppling. The kinematic analysis was carried out along panels of the slope faces, separated into four panels: panel 1 (0-100 m), panel 2 (100-200 m), panel 3 (200-300 m) and panel 4 (300 – 334.8 m). The result of kinematic analysis for one of the selected panel shown in Figure 4(a) – Figure 4(d), with a summary of the result from the other panels shown in Table 2.

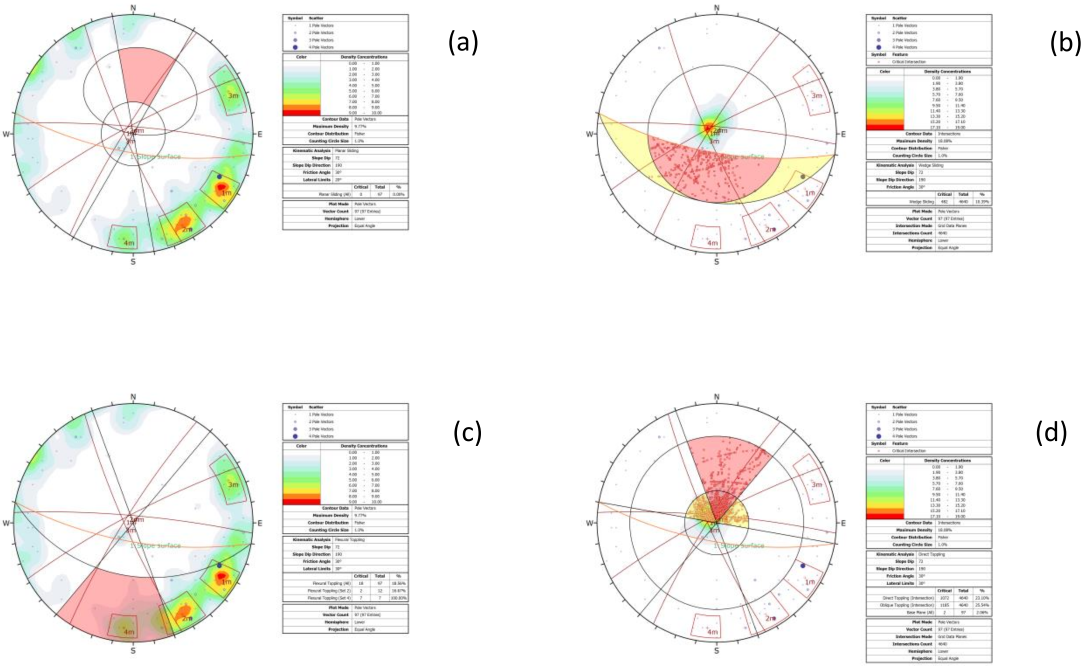

Figure 4. Kinematic analysis for Panel 1 (0-100 m): (a) planar, (b) wedge, (c) flexural toppling and (d) direct toppling

Table 2. Potential mode failure for each type of failure

Panel	Planar failure (%)	Wedge failure (%)	Toppling failure (%)	
			Flexural	**Direct**
Panel 1	0	10.39	18.56	23.1
Panel 2	0	6.52	9.18	24.97
Panel 3	0.70	20.48	11.27	19.54
Panel 4	0	21.08	10.77	19.38

From Table 2, it was found that there is very low possibility for planar failure to occur in all the panels of the slope, with a potential from 0% to 0.70%. In Panel 1 and Panel 2, the highest risk of failure are direct toppling, with a range of 23.1% to 24.97%, whereas for Panel 3 and Panel 4, there are high potential for both wedge failure (20.48% to 21.08%) and direct toppling (19.38% - 19.54%) to occur.
Mapping of the panels of the slope face shows that the weathering of the rocks of Panel 1 and Panel 2 ranges from WG II to WG IV, whereas rocks in Panel 3 and Panel 4 are mostly weathered to WG II to WG III.

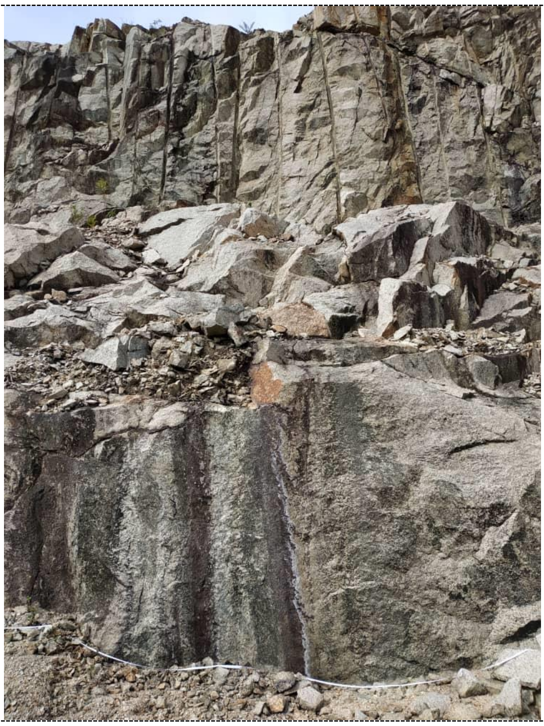

Figure 5. View of potential toppling failure on the slope (Panel 1)

Figure 6. View of potential wedge failure on the slope (Panel 4)

Due to the orientation of the joints to the way the slope surface was excavated, the potential of plane failure is low, as the joint are not oriented in a way that would facilitate the occurrence of planar sliding. However, with the orientation of the joint that dips towards the slope direction, together with the excavation of the slope to form high level berms, there is significant potential for toppling failure to occur. In addition, intersection of two or more sets of the joints in the rock slope could also lead to potential wedge failure, where there is weakening of the rock strength along more than one joint sets. However, kinematic analysis only provides the potential of slope failure based on discontinuity mapping of the slope. In order to further predict the stability of slope based on the weathered material, more detailed wider in-situ and laboratory testing of the weathered material is required [10]. This is to ensure proper protection measures could be undertaken for the slope.

4. Conclusion

Based on the study of the rock material of the slope, the weathering grade in the area are mostly in WG II, and are mostly strong and stable, as proven by the classification system on granite. The result for kinematic analysis and field study shows that there is potential for toppling failure and wedge failure along the slope, which would require undertaking some slope protection measures if there are plans of development near the slope's face. To improve the analysis for stability of rock slopes, other analysis such as Finite Element Method could be applied, which would require more parameters from the slope.

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