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Slope stability assessment in opencast quarry – an UAV approach

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Abstract: Evaluation on the stability of rock slope is a prime, interesting and formidable aspect in environmental issues. The mechanics of instability depend commonly on nature, strength, and structures of the rock mass. In this research, the structure of rock mass was studied using a technological advanced tool, Unmanned Aerial Vehicle (UAV) to determine the stability of the selected quarry face. To achieve this, photogrammetric mapping and kinematic analysis were carried out consequently at Hume Cement Quarry in Gopeng. The results indicate that the quarry slope has ten (10) major discontinuity sets and there are two (2) possible modes of failure consist of wedge and toppling failure. The UAV approach in determining the stability of rock slope have a lot of advantages and the usage of UAV could be wider as it can be used in many sector.

Keywords: Discontinuities, UAV, photogrammetric mapping, quarry, Kinta Limestone formation

INTRODUCTION

The unfavourably oriented discontinuities with respect to the slope cutting orientation may results in instabilities or rock slope failure. The role of geology parameters on slope problems and assessment is variable, depends on the subsoil constituent and structures itself. Rock slope stability is a condition where slopes are stabilized against the possibility of instability for both cut and natural slope (Kamaruszaman & Jamaluddin, 2016).

The quarrying activities can cause various type of instabilities, especially when the development schemes do not depend on scientific process (Guadri *et al.*, 2015; Hadji *et al.*, 2016). In mining industries, main used methods to assess the slope stability of rock mass in open cast mines are rock mass classification system followed by kinematic analysis and limit equilibrium calculation. The methods are controlled by mechanical parameter, geological conditions, geometrical design, and discontinuities characteristics (Brady & Brown, 1993).

The purposes of this study are to determine the properties of major discontinuity set based on the 3D model from photogrammetric mapping and to assess the stability of the limestone quarry slope based on kinematic analysis.

GEOLOGICAL SETTING

Hume Cement Quarry is an open pit quarry located in Gopeng, Perak (Figure 1) that excavate limestone and process it into cement for multi-purpose. This limestone is part of Kinta Valley Formation or known as Kinta Limestone. Kinta Valley is characterized by remnant limestone hills sandwiched by the Triassic granitic batholiths (Cobbing *et al.*, 1992) of the Kledang Range in the west and the Main Range in the east. There are three major facies in Kinta Valley; carbonate facies, argillaceous facies and arenaceous facies (Ingham & Bradford, 1960). The carbonate facies is known as Kinta Limestone Formation (Foo, 1983). The Kinta Limestone spanned from Silurian to Permian age and due to being exposed for a very long period of time, it is only visible as limestone hills or karst.

MATERIALS AND METHODS

For this study, a combination of two methods have been conducted to assess the slope stability of open pit quarry; the photogrammetric mapping and kinematic analysis. The first approach consist of data acquisition, along the selected rock section. The length of rock section investigated is about 55 m (Figure 2). The quarry face is almost vertical, with height of 15 m and was labelled as Window A. Data were collected by photogrammetry mapping using Unmanned

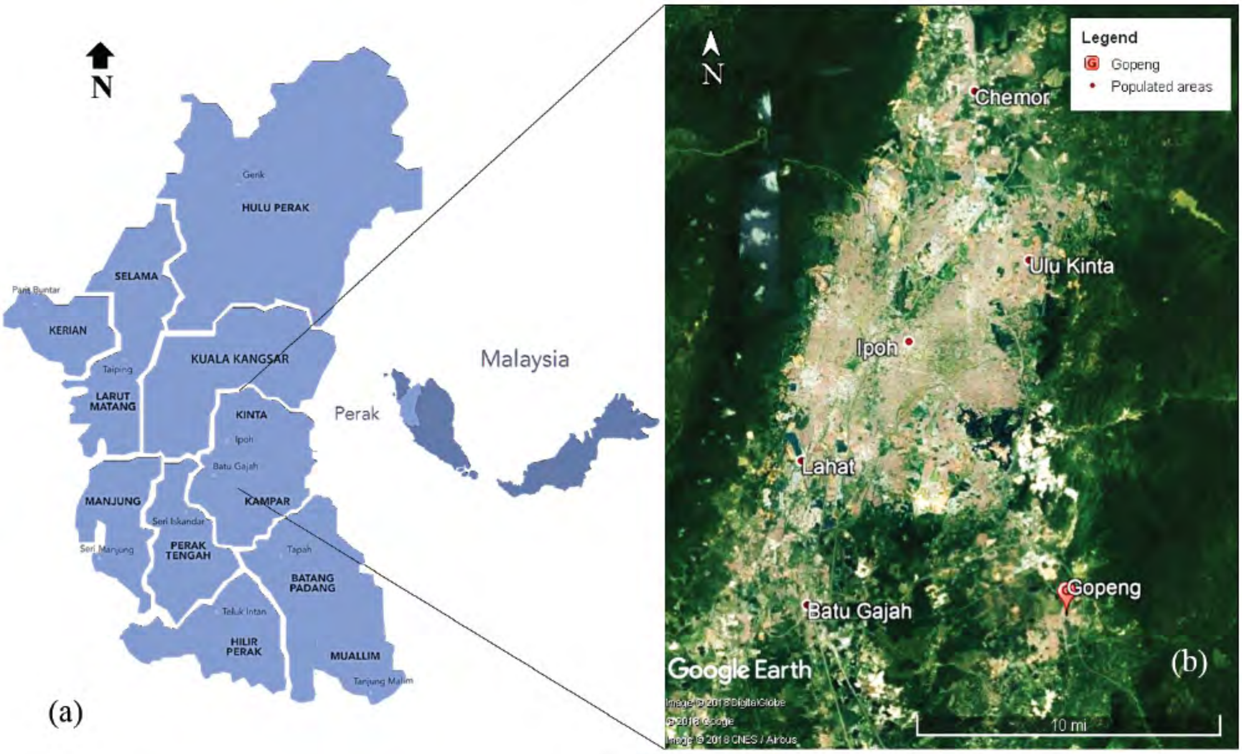

Figure 1: Maps of (a) distribution of Perak district; (b) location of Gopeng, Perak, Malaysia from Google Earth.

Figure 2: The quarry face of study area, Window A.

Aerial Vehicle (UAV) or drone. The gathered data were interpreted and analysed using software to obtain the 3D model and major joint set. The images taken at the site are first transferred to Agisoft Photoscan software to be modelled. The process in Agisoft Photoscan are using point cloud from the images taken. Discontinuity Set Extractor is used for kinematic analysis of discontinuities using stereographic projection method based on the information from the interpretation data of photogrammetric mapping. This analysis is applied to determine the stability of the rock section and possible mode of failures by using Dips 7.0.

RESULTS AND DISCUSSIONS

Drone mapping were done at Window A and 67 images were captured with different angles, so that the data collection are well presented. 3D model of Window A were constructed from all the images taken and are presented in Figure 3. From the 3D model, the discontinuities were analysed using Discontinuity Set Extractor (DSE) (Riquelme *et al.*, 2014) program. The program extracted the discontinuities from the model and present it in term of sets. Table 1 shows the properties of each discontinuity set that had been extracted from Window A. Stereographic projection of the discontinuity sets mentioned are plotted in Figure 4. From the table and figure below, J1 (237/34) shows the highest density and the most dominant orientation while J10 (321/65) has the lowest density of occurrence and the least dominant orientation for Window A. This results show similarities when compare with manual mapping, which have the most dominant orientation of 238/34 and so prove that the drone mapping is reliable to use. The collected discontinuity sets are projected in DSE program to discriminate each of the set and are presented in Figure 5.

The discontinuity sets obtained from photogrammetry mapping further used to study the kinematic properties of Window A. Results of kinematic analysis indicate that Window A have two potential mode of failures, which are wedge failure and toppling failure. Each discontinuity set is distinguished by different colour and symbol in the stereographic projection.

Wedge failure may occur at the quarry slope with 17.79% critical intersections. Details of the failure mode shown in Figure 6 where 8 out of 45 intersections detected.

There are 15.56% possibility of direct toppling to happen at Window A which include 7 out of 45 intersections. The details of the toppling failure is shown in Figure 7.

CONCLUSION

Ten (10) major discontinuity sets had been found at Window A with J1 has the highest density and J10 has the lowest density. From the 10 major sets, kinematic analysis shows that wedge failure had most possibility to be occurred while there are also possibility for toppling. As the assessment had been done, it is shows that the rock slope for Window A has high potential for instability to happen. By using UAV approach in determining the stability of a rock slope, a lot of advantages are gained from it. It saves a lot of time and helps to take reading at unreachable places.

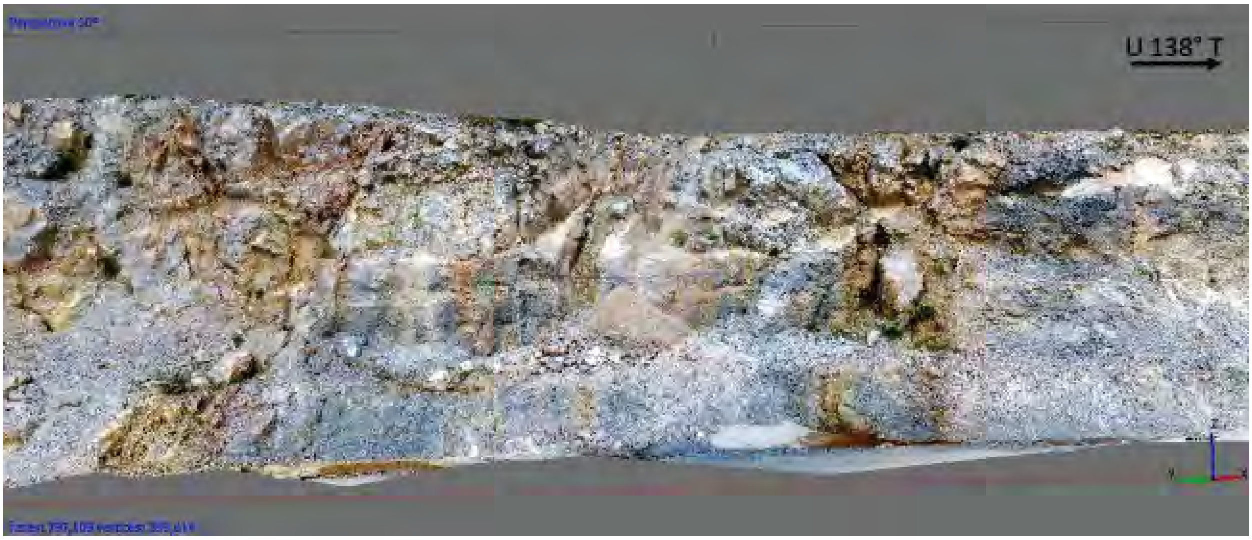

Figure 3: Model of Window A constructed from drone mapping.

Table 1: Properties of the 10 major discontinuity sets from DSE program.

Discontinuities joint set	Dip direction	Dip	Number of clusters	Number of points	Density
J1	237.52	34.49	495	430294	4.0755
J2	241.26	80.17	876	252696	0.9131
J3	65.32	88.21	597	175798	0.6382
J4	170.31	89.44	145	47771	0.4902
J5	195.75	87.94	707	41223	0.3743
J6	28.49	86.95	829	94509	0.3528
J7	185.19	76.54	583	80926	0.2802
J8	4.18	88.77	295	27113	0.2497
J9	33.11	66.35	442	42415	0.2432
J10	321.01	65.5	217	49348	0.1893

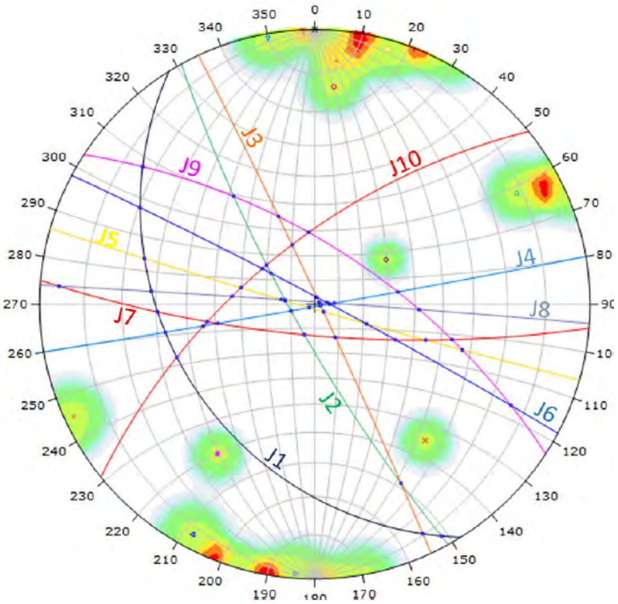

Figure 4: Stereographic plot of 10 major discontinuity sets found at Window A from the photogrammetric mapping.

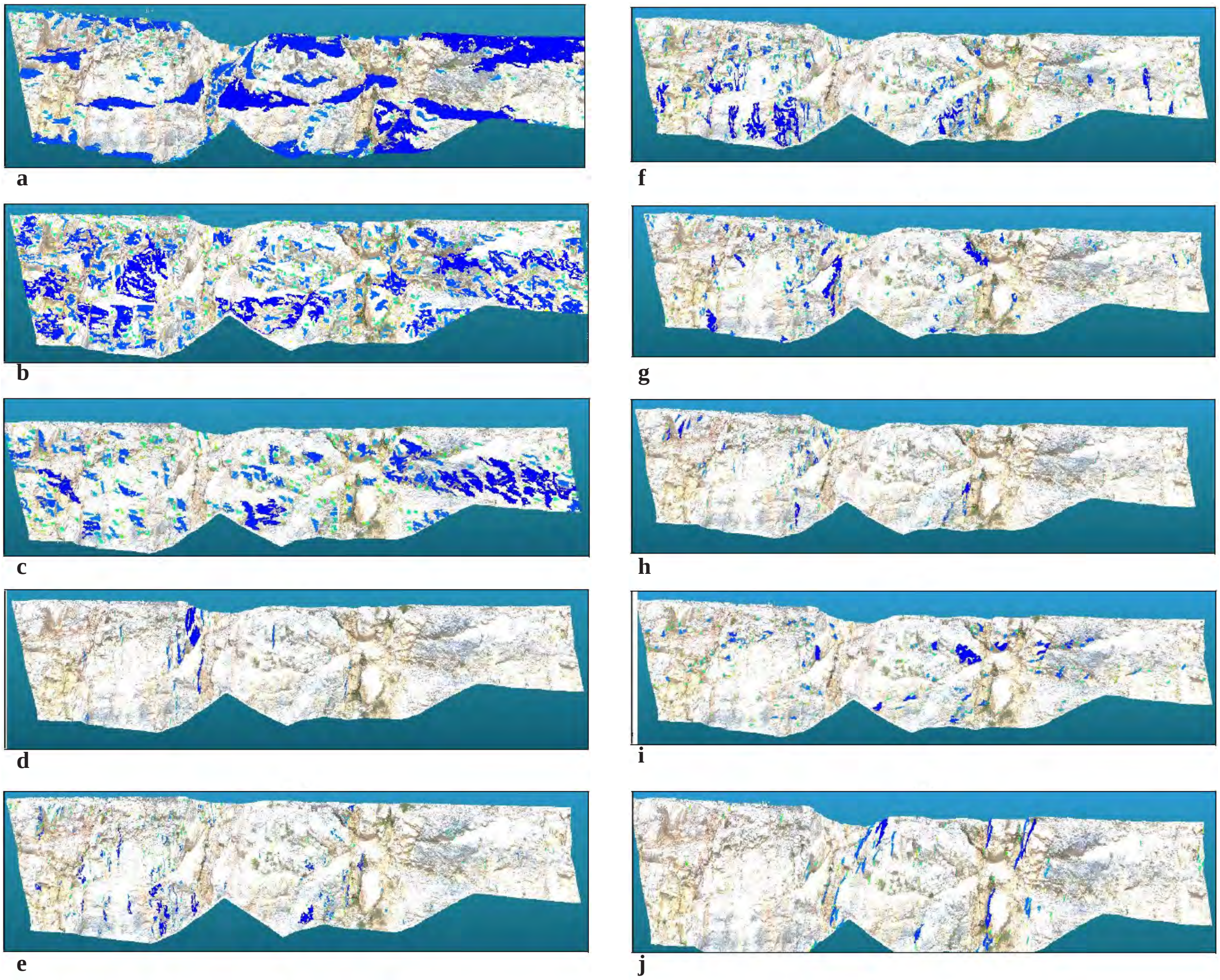

Figure 5: Each discontinuity sets interpreted by DSE program. The colors (blue and green) represent the discontinuity planes and difference of density for each set can be seen. (a) J1; (b) J2; (c) J3; (d) J4; (e) J5; (f) J6; (g) J7; (h) J8; (i) J9; (j) J10.

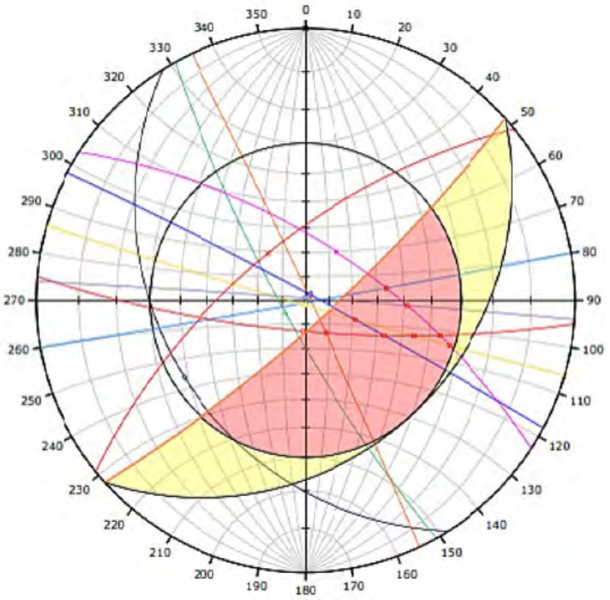

Figure 6: Kinematic analysis of wedge mode failure.

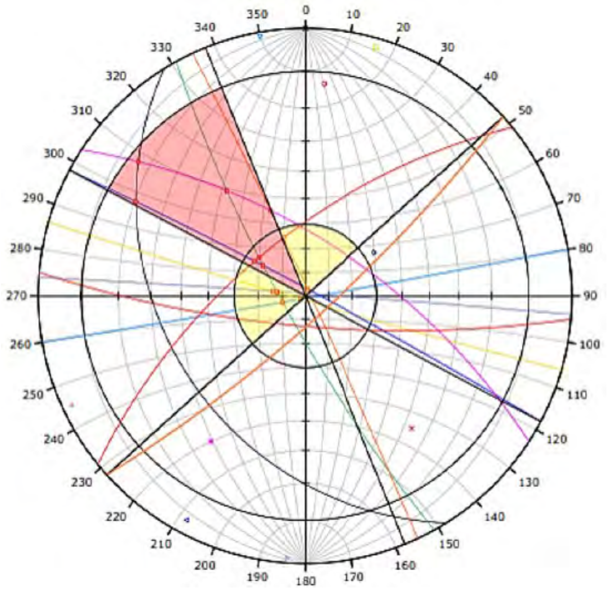

Figure 7: Kinematic analysis of toppling mode of failure.

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