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ROCK SLOPE ASSESSMENT USING KINEMATIC AND NUMERICAL ANALYSES

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Graphical abstract

Abstract

This paper presents stability assessment of rock slopes at Jalan Kuari, Cheras, Kuala Lumpur. The site is a disused quarry slope where a low cost residential area of Pangsapuri Intan was built very close to it, frequent instability at the rock slope have been reported. A detailed discontinuity assessment was carried at the site, then, the kinematic and numerical analyses were performed in order to determine the stability of the rock slope. The kinematic analysis was carried out using DIPS 5.0 software and the results showed that about 19% is the percentage of the wedge failure that is encountered for the rock slope. Meanwhile, the finite element method of analysis in Phase^2 showed that the slope is in stable condition, with the Strength Reduction Factor (SRF) of 2.0. The difference between the results of the kinematic and the finite element analyses is because, the kinematic analysis considered the discontinuities volume and orientations with regards to the slope face, while the finite element, analysed the slope with respect to strength properties. Since the slope is a disused quarry, where previous blasting work had produced fractures on the rock face, these discontinuities and fractures are more influencing the instability and the result from kinematic analysis shows a good agreement with the field observation.

Keywords: Rock slope stability; finite element method; Phase^2; DIPS 5.0 software

Abstrak

Kertas kerja ini membentangkan penilaian kestabilan cerun batuan di Jalan Kuari, Cheras. Kuala Lumpur. Lokasi tapak merupakan cerun kuari yang sudah tidak digunakan lagi, di mana ianya terletak berhampiran dengan kawasan perumahan kos rendah, Pangsapuri Intan. Beberapa kejadian ketakstabilan telah dilaporkan berlaku di cerun batuan. Penilaian ketakselanjaran secara terperinci telah dilakukan di tapak, kemudian,analisis kinematik dan analisis berangka telah dijalankan bagi mengenalpasti kestabilan cerun batuan. Analisis kinematik telah dilakukan mengunakan perisian DIPS5.0 dan keputusan menunjukkan bahawa 19% adalah peratusan kegagalan baji yang didapati di cerun batuan. Sementara itu, analisis kaedah unsur terhingga dalam perisian *Phase*^{2} menunjukkan bahawa cerun berada dalam keadaan stabil dengan *Strength Reduction Factor (SRF)*sebanyak 2.0. Terdapat perbezaan keputusan dari analisis kinematik dan kaedah unsur terhingga kerana analisis kinematik hanya mengambilkira jumlah dan orientasi ketakselanjaran terhadap muka cerun, manakala kaedah unsur terhingga, menganalisis cerun terhadap kekuatan batuan. Memandangkan cerun tersebut merupakan bekas kuari, di mana kerja-kerja letupan terdahulu telah menghasilkan rekahan pada mukacerun, rekahan-rekahan dan ketakselanjaranini adalah lebih mempengaruhi ketakstabilan cerun dan keputusan dari analisis kinematik menunjukkan persetujuan dengan pemerhatian di tapak.

Kata kunci: Kestabilan cerun batu; kaedah unsur terhingga; Phase^2; perisian DIPS 5.0

1.0 INTRODUCTION

As the need of urban areas is growing rapidly, many rock abandoned quarry sites have become real estate for residential living areas. Building residential structures in areas close to unstable rock quarry slopes without prior appropriate investigation will lead to unsatisfactory setbacks and loss of lives and properties. Over breaking from previous blasting work has caused instability of the rocks forming the slope in the area, hence, it is essential and necessary to carry out an appropriate assessment prior to the development in such area [1].

This paper presents stability assessment of rock slopes at Pangsapuri Intan, Jalan Kuari, Cheras, Kuala Lumpur. Both kinematic and finite element method of analyses were employed to assess the stability of the slope, and a comparison was made between these approaches.

The geological map of Jalan Kuari shows that this area is a granite formation, Figure 1[2].The study slope is a disused granite quarry, previous blasting and quarry works that took place in that area had caused fracture to the rock forming the slope (Figure 2) [3]. Fractured and jointed rock slope may fail at any time, causing major damages to properties and loss of lives. As a result of the lack of awareness, i.e. by assuming that the rock is safe and strong, residential units were built near to the steep slope with only on 8 m the buffer zone (Figure 3). From conversations with the residents at Pangsapuri Intan, a frequent instability have been occurring at this slope, yet it is not documented. The worst situation was reported in the news, when there was a big boulders that hit a taxi that park under the slope [4,5].

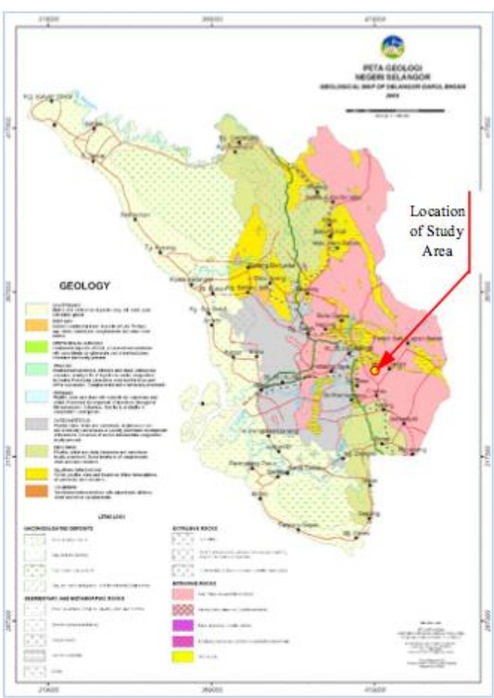


Figure 1 Geological map of Selangor [2]

Figure 2 Disuse quarry face layout at Apartment Intan, Taman Bukit Permai, Cheras, Selangor [3]

Figure 3 PangsapuriIntan was built close to the unstable rock slope. (note: the rockfall signboard)

2.0 FIELD WORK

The surrounding rock mass of the slope was investigated carefully.It can be seen, that wiremesh and rock bolt have been installed at certain places on the slope (Figure 4), showing that remedial measure has been carried out at the slope face.

The rock mass forming the slope is fractured granite that exhibit a very high roughness and slightly weathering state. The rock slope can be classified as completely wet because there was evidence of water flow appearing on the rock surface. From the site observation, some parts of the slope face were supported with netting and rock bolt, while the other parts were left unsupported.

The field work involves the determination of the rock parameters, study on the surrounding natural and man-made factors. For the purpose of gathering or collecting data, a few visits were incurred to the site and some observations were drawn such as the slope geometry. Due to the instability involved on site, the field work was carried out with caution and no sampling was undertaken. However, some index tests were performed to gather the rock properties. The following tests and methods have been used to perform the field study and collect the required data such as Schmidt Hammer test, dip and dip direction measurement, and discontinuity assessment.

Figure 4 Wire mesh and rock bolt installed on site

Schmidt Hammer Test was carried out in order to evaluate the strength of the granite rock forming the slope. By averaging the rebound valuesthe compression strength (UCS) of the rock can be estimated. A Clar compass (Figure 5) was used for the measurements of the dip and dip direction of the rock discontinuities orientation at the slope site.

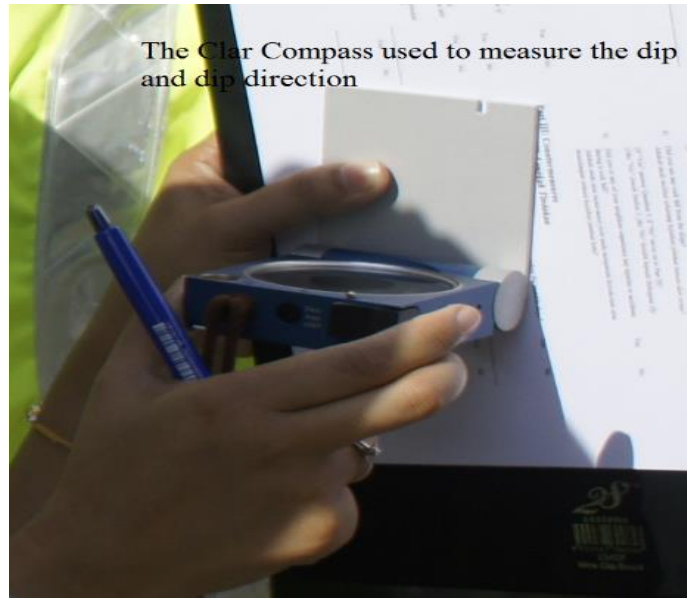


Figure 5 Clar compass used to measure the dip and dip direction

Discontinuity assessment was performed to assess the nature of the rock discontinuities. The shear strength of the joint depends on the roughness of its wall. Furthermore the roughness becomes less important, when the aperture width and the displacement increase. The discontinuities were assessed throughout a scan line by collecting the required data such as aperture width, spacing, surface roughness, nature of filling and water flow. The slope was observed from the top and a noticeable number of loose boulders were appearing on the surface and the existence of tree roots were detaching and breaking the rock.

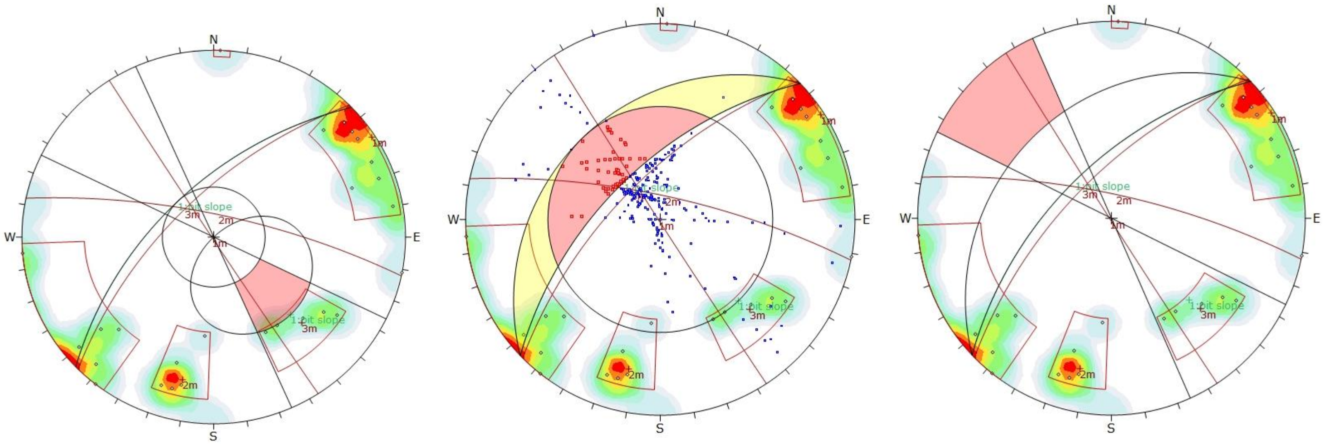
3.0 ROCK SLOPE STABILITY ANALYSIS

3.1 Kinematic Analysis

The data collected from the slope site for the rock discontinuities dip and dip direction was tabulated in Table 1, and similar discontinuity sets data are grouped together. The slope face has a dip angle of 60° and a dip direction of 316°. Kinematic analysis has been performed using DIPS 5.0 software [6]. By incorporating the slope and discontinuities data as in Table 1, Figure 6 was plotted to show three kinematic analyses which are planar, wedge and flexural toppling.

Table 1 Dip and dip direction measurements

No	Dip angle	Dip direction
1	90	265
2	90	281
3	85	222
4	90	218
5	70	225
6	85	244
7	75	230
8	85	232
9	85	250
10	87	260
11	85	248
12	85	252
13	80	235
14	80	240
15	85	228
16	85	235
17	90	182
18	85	230
19	70	196
20	85	14
21	80	19
22	78	12
23	80	15
24	86	5
25	78	45
26	75	70
27	60	325
28	60	332
29	70	305
30	75	303
31	65	313



Kinematic Analysis	Planar Sliding		
Slope Dip	60		
Slope Dip Direction	316		
Friction Angle	30°		
Lateral Limits	20°		
	Critical	Total	%
Planar Sliding (All)	0	26	0.00%

(a) Planar sliding

Kinematic Analysis	Wedge Sliding		
Slope Dip	60		
Slope Dip Direction	316		
Friction Angle	30°		
	Critical	Total	%
Wedge Sliding	62	325	19.08%

(b) Wedge sliding

Kinematic Analysis	Wedge Sliding		
Slope Dip	60		
Slope Dip Direction	316		
Friction Angle	30°		
	Critical	Total	%
Wedge Sliding	62	325	19.08%

(c) Flexural toppling

Figure 6 Results of kinematic analyses

Table 2 summarises the kinematic analysis results, it was found that there is no possibility for planar and toppling failures to occur. The highest risk is due to wedge failure, with 19%. It indicates that there are 62 critical intersections out of a total of 325 mean set plane intersections. However, wedges do not necessarily slide along the line of intersection of two joint planes. Wedges can slide on a single joint plane, if one plane has a more favourable direction for sliding than the line of intersection. In this case, the second joint plane acts as a release plane rather than a sliding plane. This can occur in either the primary or the secondary critical region. As can be seen, there are possible wedge failures on the slope face as well (Figures 3 and 4).

Table 2 Summary of kinematic analysis results

Fieldwork Analysis	Percentage (%)	Critical of Joint Set
Planar	0	0
Wedge	19	62
Flexural Toppling	0	0

3.2 Finite Element Analysis

The finite element analysis has been performed using Phase^2 [7]. Table 3 summaries the rock parameters together with the required inputs for the analysis. These data are collected from the field tests and also based on the previous study [8].

For modelling purpose, the mesh was set using uniform mesh with six (6) node triangles for all Shear Strength Reduction analyses. The slope is meshed by selecting discretize and mesh option. Due to the previous quarry in the slope site, an excavated area in the model is selected to represent the formation of the slope. The discontinuities are defined in the modelling. The steps of modelling are presented in Figure 9. The slope was monitored in four stages as summarised in Table 4.

Table 3 Input parameter for finite element model.

Type of Data	Value
Rock Type	Granite
Slope Height	15 m
Uniaxial Compressive Strength (UCS)	140 MPa
Unit Weight of Rock	26kN/m^3
Geological Strength Index (GSI)	77
Hoek Brown Parameters	a =0.5, Mb=14, s =0.08
Modulus Ratio (E)	12000 MPa
Friction Angle	30°
Cohesion	5 MPa
Groundwater condition	Wet

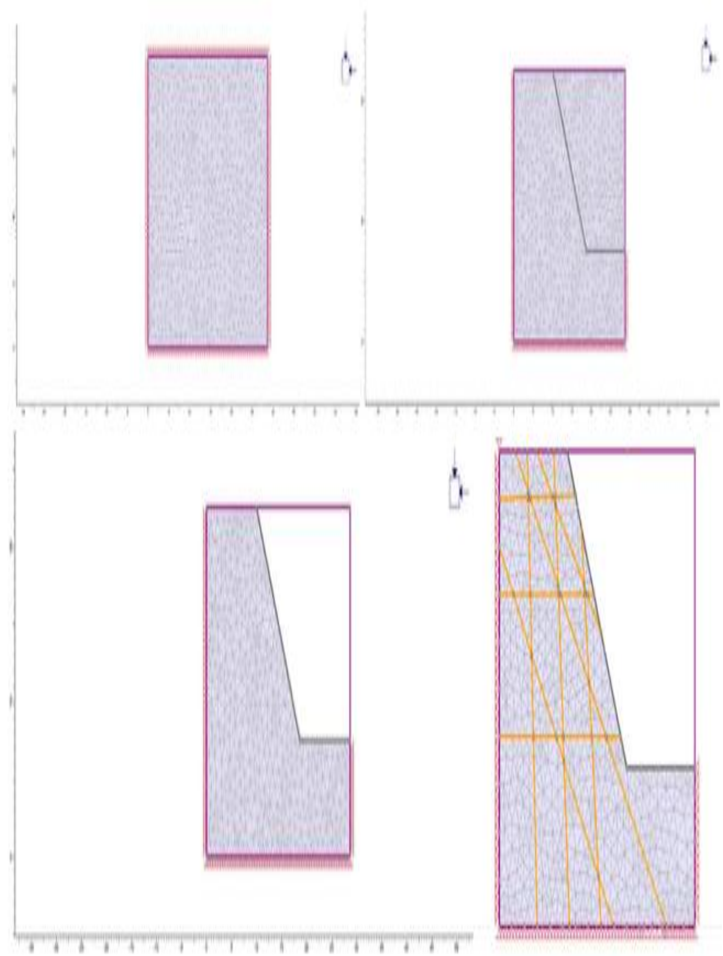
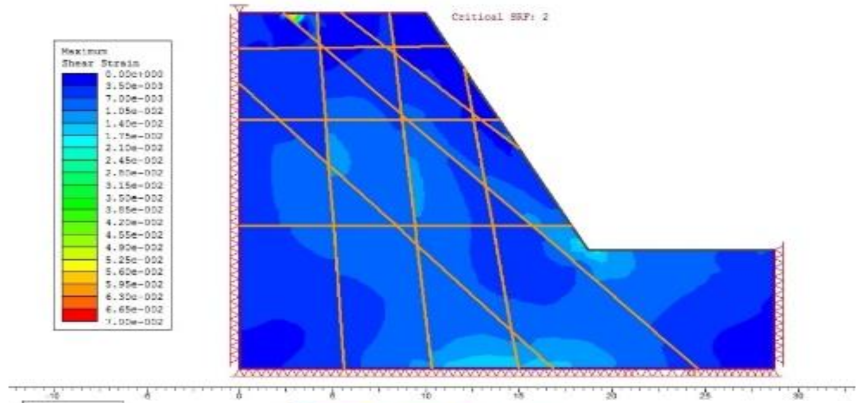
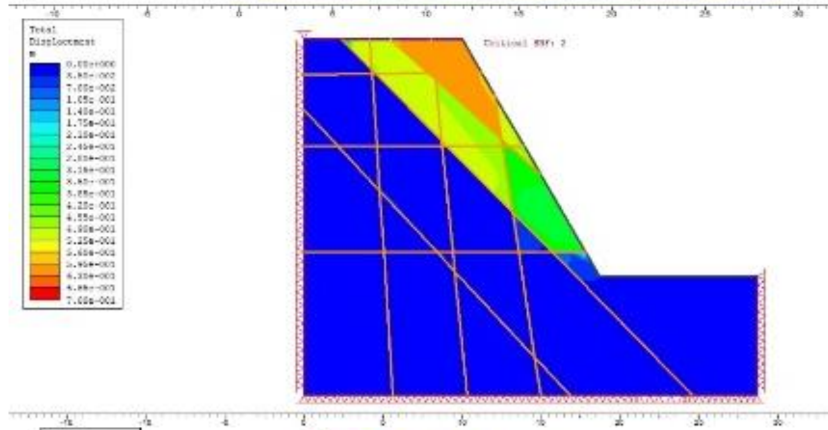
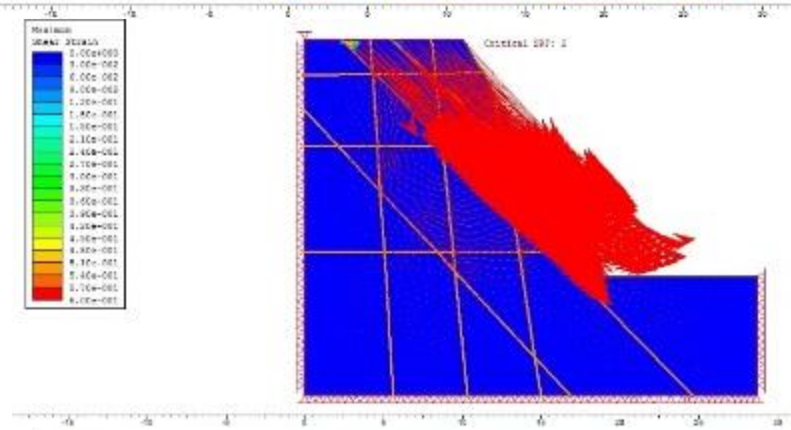
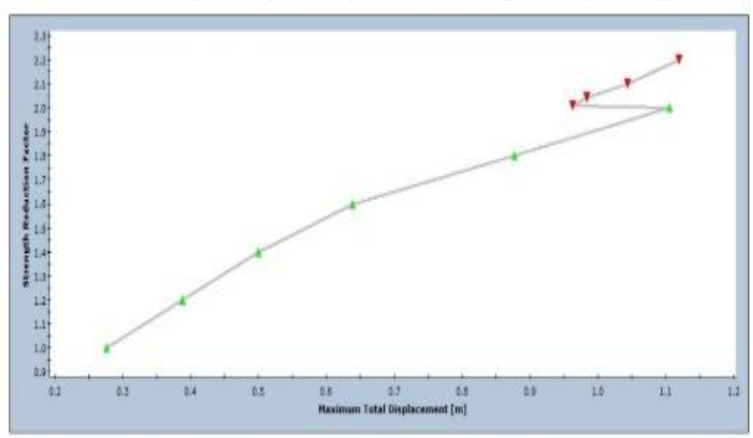


Figure 9 The modelling of the rock slope

Table 4 Results of the finite element analysis in Phase

Type of Output	Description	Graphic
1.The critical SRF	The critical strength reduction factor (SRF) equals to 2.0 which indicates that the slope is stable.	
2.Total displacement	The total displacement which clearly highlight the failure zone	
3. Deformation vector	The deformation vector is shown by the highlighted zone	
4. SRF versus the maximum deformation	When the slope starts to fail, deformations will increase rapidly and the finite-element analysis will not converge. It is the point of non-convergence that defines the critical SRF. The SRF result is 2.0 which indicate that the slope is stable.	

4.0 CONCLUSION

Based on the field visit and the slope stability analyses using kinematic and finite element methods, the following conclusions are derived:

1) The results from the kinematic analysis (DIPS) showed that the rock slope is stable and there is no expected planar or toppling failure. From the analysis, about 19% is the percentage of the wedge failure that is encountered for the rock slope. On the other hand, the output of the Finite Element analysis ($Phase^2$) provides that the slope is stable with 2.0 shear reduction factor (SRF) that is equivalent to factor of safety of 2.0.
2) The difference between the results of the kinematic analysis (DIPS) and the finite element analysis ($Phase^2$) because the kinematic analysis only considered the discontinuities orientations with regards to the slope face, while the finite element analysed the slope with respect to its strength properties.
3) Since the slope is a disused quarry, where previous blasting work had produced fractures on the rock face, these discontinuities and fractures are more influencing the instability and the result from kinematic analysis shows a good agreement with the field observation.

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