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Research Paper

Evaluation of Rock Slope Deterioration Based on Granite and Schist Rock Slopes

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A B S T R A C T

The problems of slope instability can be related to the terrain factors and weather. In Malaysia, slope failures and landslides are very common due to prolonged monsoon rainfalls. The consequences of slope instability can be hazardous to life including economic damages and costly repairs. The study was aimed to determine the physical and mechanical properties of the rock slope material from selected sites. Several tests including field observations were performed to analyze the engineering characteristic and physical properties of this Schist rock slope and Granite rock slope. The rock samples were classified into various weathering grades based on variations in these properties. Scan line methods were applied to obtain the measurement data. Direct discontinuity surveys were carried out in interval of 10 m. Laboratory tests on the samples were done that include two cycles of slake durability, Schmidt hammer test, point load test, petrography test, density test and direct shear box test. The analysis on each rock types showed that the amphibolite Schist at Putrajaya has the highest rock strength with a uniaxial compressive strength (UCS) 487.97 Mpa which is classified as extremely strong rock. By comparison, the UCS value of Granite was 267.28MPa and classified as strong rock.

1. Introduction

Slope failure due to rainfall is very common throughout the world and Malaysia is among the countries in South East Asia that experience high intensity rainfalls especially during the monsoon seasons (Saadatkhah et al. 2015). Rock slope areas are prone to landslides due to a variety of causing factors that result in the downslope movement of materials such as rocks, soil or fill material. Such slope movements can impose a detrimental impact on human and environment. Some of the rock slope failure is large and rapid. Slope stability problems are influenced by the topography and geology of the area, and the amount of rainfall and its distribution (Acharya et al. 2016).The stability of rock slopes depends on the weathering profiles in rock, the lithological characteristics, the relict structures in the rock and the ground water regime (Abad et al.2016).

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Rock is a naturally occurring organics and inorganics solid substance that contain one or more minerals or other solid substances. There are three group of rock types; igneous, sedimentary and metamorphic rock based on the process of the rock form (Schön, 2015). Igneous rock is formed by a crystallization of the molten rock or substances or magma. Sedimentary rock is formed by the fractured rock that is weathered, eroded, transported, deposited and lithified or cemented at earth's surface. Metamorphic rock is formed by the process of the recrystallization of the existing rock by the action of pressure, heat and fluids activities. Rock is different from other engineering materials because it has discontinuity. In rock engineering, the rock properties and its characterization and classification can be divided into two parts; physical properties and mechanicals properties. Rock material is determined based on the porosity, hardness, durability, point load strength, uniaxial compressive strength (UCS), sound velocity, and permeability of the rocks (Aladejare et al., 2017).The characteristics of the rock depend on the properties of discontinuities, *in-situ* sound velocity, and properties obtained from the rock material itself. The shear strength of the rock material and rock mass, the UCS, and the stiffness of discontinuities also need to be considered (Barton and Bandis., 2017).

Malaysia has a tropical environment which is humid and warm. This condition will cause the rock materials experience weathering easily (Mohamad et al., 2016). Subsequently, this weathering process will result in the decrease of dry density of the rock materials, its uniaxial compressive strength, point load strength index and Brinell hardness index. On the other hand, porosity, swelling coefficients and friability of the rock materials increase with the increasing of weathering grade (Raj, 2018). These phenomena can cause the erosion of the rock mass and depositions of the rock materials at the the slope which is described as rock slope deterioration. Cut slopes in rock masses will then begin to deteriorate after excavation due to stress relief and weathering.

The main objectives of this research were to identify the characteristics (physical and mechanical properties) of the rock slope materials, to interpret the correlation between the content of the mineral inside and the rock strength, and to justify the influence of mineral composition and weathering grade to the rock slope deterioration.

2. Study area

2.1 Granite cut slope in Kajang SILK Highway

The study area was located at KM17 along Kajang SILK Highway, Kajang, Selangor (**Fig. 1**). This highway cut slope was cut in steep stage with the slope angle 60º to 80º in the direction of 100ºN. It was a Granite cut slope with grade weathering I to grade III. The color was partially discoloration and the texture of the rock remains. The material from this site was hard and unbreakable by hand. Most were superficial indent with ringing sound.

Fig. 1. Granite cut slope in Kajang SILK Highway at location 2.961250°N, 101.719436°E

2.2 Phyllite-Schist in Putrajaya

The area was a *Phyllite-Schist* cut slope with grade weathering II to grade III located at Putrajaya at location 2.961250ºN, 101.719436ºE (**Fig. 2**). The color was partially to completely change and the texture of the rock remains. The material was strong and firm. Most were superficial indent with ringing sound.

Fig. 2. *Phyllite-Schist* cut slope in Putrajaya at location 2.994701°N,101.832291°E

3. Methodology

The research was divided into four parts. First, the base map data were collected such as the geology and topography maps. All the discontinuity data such as orientation, aperture, persistence, and spacing were collected in the standard form of geological mapping. The weathering classification was also collected. Several rock samples were collected for laboratory test that include uniaxial compressive strength (UCS), point load strength test, second cycles of slake durability and petrography test analysis. The specimen slides of the rock samples were prepared before the petrography test. The conditions of individual minerals were observed such as degree of pitting and micro-cracking and changes in mineral composition. The data collected in field work will be compared with previous data and analyzed for fundamental geological influences on rock slopes in different rock masses. The analysis will show the value of the deterioration rate of the site location based on its characteristics. The discontinuity data was analyzed for potential failure of the site area using streonet analysis method. The mineral composition, rock matrix and grain size were determined by the petrography test that will be correlated to the uniaxial compressive strength results. Finally, the influences of mineral compositions and weathering grades to the rock slope deterioration will be identified.

Schmidt Hammer (ISRM, 1985) was used to measure the strength of rocks through empirical correlation between rebound readings and compressive strength determined from the standards tests. Samples of rock material were brought back to the laboratory. For the laboratory testing, 100 readings were taken for each sample of rock. These samples were used to perform Schmidt Hammer Test for specific sample observation. The specification of the test was set that 100 readings are taken at each different point of different sides. If the readings vary above 7MPa, it will be discarded, and only consistent readings were considered. Point Load Test (ISRM, 1985) was used to determine the rock strength indexes. Basically this test involves compressing a rock sample between conical steel plates until failure occurs. The apparatus contains a set of rigid steel frame, two point load platens, a hydraulically activated ram with pressure gauge and a device for measuring the distance between the loading points. Direct shear box (ASTM D4554) was performed to estimate the shear strength of a rock mass. It applies principal of friction whereby a cylindrical core sample with a length of minimum 100cm and 5.5cm diameter need to be prepared first before this test could be conducted. For the execution of the experiment, two sides of loading were required. Normal stress loaded in the direction perpendicular to shear stress. After completing the setup, load can be applied through the jacks. Normal stress was jacked before applying shear stress. The displacement was then recorded through the dial gage which is fixed at the side.

Both sides of the pressure in normal stress and shear stress were then released before repeating it over again. The test was repeated with three intervals of normal stress to obtain the stress-strain line. The tests for density and moisture content were carried out in accordance with the International Society of Rock Mechanics (ISRM) Standard Procedures (Brown,1981).

4. Results and Discussion

4.1 Geological Mapping and Discontinuity Data

Scan line method was used to conduct the discontinuity surveys. These discontinuities are predominantly in the form of joints which is generally tight, with planar to slightly undulating surface. The measurement of the distance was about 30 m to ensure that the survey representing the measurement is continuous over the distance. Geological mapping was applied to create an overview layout through the perspective of geology by utilizing stereographic projection. Three types of failure occurring in the study areas namely toppling failure, wedge failure and plane failure were observed. The stereographic projection of Granite rock slope at Kajang, Selangor showed that the slope will experience plane and wedge failure based on 73 data measured on site and scan line method discontinuity survey (**Fig. 3**). The stereographic projection of Phyllite-Schist rock slope at Putrajaya facing 350ºN showed that the slope will experience toppling and wedge failure based on 36 data measured by scan line method and discontinuity survey (Figure 4). From the results obtained, most chainage of the slope were not stable.

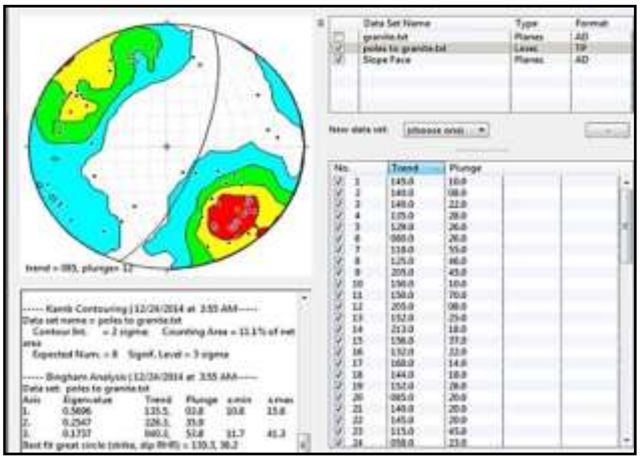

Fig. 3. Stereographic projection of Granite rock slope at Kajang, Selangor

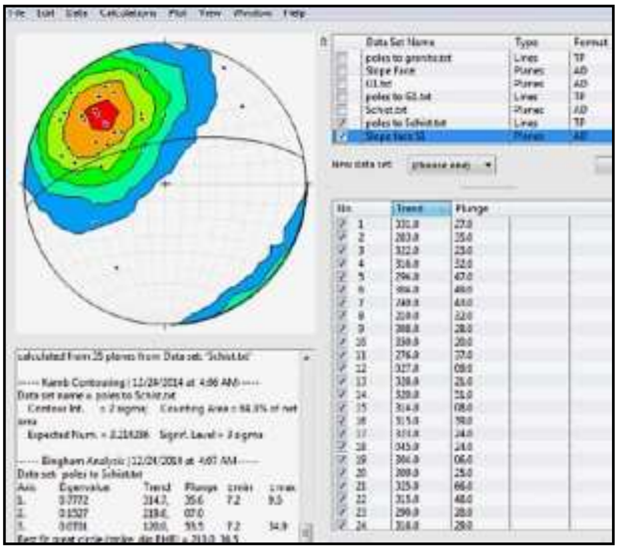

Fig. 4. Stereographic projection of Phyllite-Schist rock slope facing 350^{o}N at Putrajaya

4.2 Uniaxial Compressive Strength

The Schmidt Hammer Test was applied to estimate the uniaxial compressive strength (UCS) of a rock specimen by using a rebound hammer. The hammer was held vertically downwards and at right angles to horizontal faces of large rock blocks. The test was accomplished by L-type Schmidt hammer with impact energy of 0. 735Nm. 100 readings were collected at each study area. The uniaxial compressive strength was calculated using equation UCS = 4.24exp [0.059N]. The results showed that the uniaxial compressive strength Granite slope ranged from 39.91MPa to 76.37MPa. Only the mean UCS value was selected to represent that particular sample in order to achieve the highest accuracy. **Table 1** shows the range of Granite falls between moderate to medium strength for intact rocks. Based on the classification by ISRM (1978), it can be concluded that the UCS of Granite at Kajang ranged from medium to high strength.

Table 1. UCS values of granitic samples

Sample	Mode	Median	Mean	Minimum UCS Value (MPa)	Maximum UCS Value (MPa)	Mean UCS Value (MPa)
G1	46	46	44	24.89	102.57	56.86
G2	39	43	38	29.71	102.57	39.91
G3	35	38	38	29.71	60.31	39.91
G4	50	50	49	44.91	129.81	76.37
G5	37/39	37	38	16.47	129.87	39.91
G6	46	46	45	35.47	129.87	60.31

Based on the reading acquired for the Schist samples at Putrajaya, the UCS of Schist ranged from 63.98Mpa to 164.44MPa. According to the strength classification by ISRM, the strength of Schist was medium for intact rocks (**Table 2**). On a more detailed classification, the Schist can be categorized as high strength.

Table 2. UCS values of Schist samples

Sample	Mode	Median	Mean	Minimum UCS Value (MPa)	Maximum UCS Value (MPa)	Mean UCS Value (MPa)
M1	45	49	48	33.43	137.77	71.99
M2	52	52	54	71.99	185.04	102.57
M3	45	45	46	31.52	164.44	63.98
M4	49/51	49	50	33.43	220.87	81.01
M5	50	50	49	28.49	155.02	76.37
M6	60	62	50	102.57	263.63	164.44

4.3 Direct Shear Test

This test which is usually done on soil can also be performed on rocks. From this test, input parameters such as peak shear stress, friction angle and cohesion can be produced after interpretation of results. By plotting a graph of shear stress against displacement, the peak shear strength value can be obtained from the peak curve of the graph shear strength versus displacement. The angle of friction can be obtained by conducting the test through varying normal stress with shear stress which can be obtained from the graph of shear strength against normal stress. The angle between the horizontal axes against the inclined plotted line is the angle of friction. Finally, the third parameter obtained is cohesion. **Table 3** and **4** show the summary of cohesion for Granite and Schist rock slopes.

Table 3. Direct shear test for Granite rock slope

Rock Type: Granite	Chainage (m)	Average Peak Shear Stress (kPa)	Average Peak Friction Angle (°)	Cohesion (kPa)
G1	0 – 5	4460.00	28	1176.17
G2	15 – 30	4350.00	27	847.22
G3	30 – 40	3650.00	28	852.48
G4	40 – 45	4266.67	27	1366.67
G5	45 – 50	4266.67	26	1752.07
G6	50 – 60	4266.67	30	1296.73

Table 4. Direct shear test for Schist rock slope

Rock Type: Amphibolite Schist	Chainage (m)	Average Peak Shear Stress (kPa)	Average Peak Friction Angle (°)	Cohesion (kPa)
M1	0 – 10	3333.33	25	1092.33
M2	10 – 20	3283.33	26	847.22
M3	20 – 30	3350.00	27	852.48
M4	30 – 40	2933.33	27	1366.67
M5	40 – 50	3416.67	24	1398.6
M6	50 - 60	3250.00	29	1296.73

4.4 Slake Durability Test

The slake durability test was conducted to investigate the influence of weathering and degree of disintegration. It has complex mechanism but due to the length of test conducted on each sample, there was a high possibility only the wetting process occurs but this mechanism also depends on the porosity of the rock. The slake durability index was produced from the laboratory experiment. The results for all types of rock showed slake durability index that was more than 99% at the end of 1st cycle and 98% at the end of 2nd cycle. According to Gambles' Slake Durability classification, these rocks can be categorized as very high durability.

Table 5. Summary of slake durability index of Granite rock

Rock Type: Granite	Chainage (m)	$I_{d\ Average}$	Gambles' Strength Classification
G1	0 – 5	99.61953	Very High Durability
G2	15 – 20	99.55687	Very High Durability
G3	30 – 35	98.4037	Very High Durability
G4	40 – 45	99.4926	Very High Durability
G5	45 – 50	99.6117	Very High Durability
G6	55 – 60	99.78859	Very High Durability

Table 6. Summary of slake durability index of phyllite rock

Rock Type: Phyllite	Chainage (m)	$I_{d\ Average}$	Gambles' Strength Classification
M1	5 – 10	99.61953	Very High Durability
M2	15 – 20	99.55687	Very High Durability
M3	25 – 30	98.4037	Very High Durability
M4	35 – 40	99.4926	Very High Durability
M5	45 – 50	99.6117	Very High Durability
M6	55 – 60	99.78859	Very High Durability

Rocks that were from greater depth has higher overlying burden thus resulting in compaction which improves the bonding strength of the rocks. Besides this factor, binding materials and minerals within these types of rock may not be easily dissolved especially just by plain water.

4.5 Composition analysis

Mineralogy analysis was performed to investigate the deeper aspect of the rock samples to obtain a better understanding of the rock behavior through its mineral properties (Zhou et al., 2018). XRD test was carried out to verify the majority or significant types of minerals in the rock samples. The peaks obtained signify the highest count of minerals in that particular rock. The type of mineral is verified by matching the peak count in samples against the most similar peak in the standard database. The percentage of mineral was then measured by taking its peak count over the total number of peak counts for all minerals.

The XRD results showed that the Granite sample has majority of quartz minerals with the content ranged from 50.00% to 70.21%. Besides the quartz, other minerals such as muscovite, albite, orthoclase and clinochlore were also detected. On the other hand, the highest mineral content in the Schist sample was magnesiohornblende, ranging from 52% to 84%. This was followed by anorthite which ranged from 10% to 21%. Other minerals include traces of quartz, biotite, nimite and clinochore.

4.6 Weathering grade

A comparison based on site observation and physical characterization was established on weathering grade for both Schist and Granite rock samples. The weathering grade was obtained from *in-situ* evaluation and later compared against physical characterization scheme for rocks. The weathering classification data from in-situ has been recorded such as the degrees of discoloration, the appearance and condition of the rock materials (e.g. whether or not it is friable), Schmidt hammer test, weathering grade, and the degree of staining on joint surfaces and/or the distance that staining extends into the rock from joints, and rebound hammer for compressive strength reading. **Table 7** and **8** showed some of the weathering grade differed from the prediction based on site whereas most of the rocks seemed to have lower grade of weathering compared to that of site prediction.

Table 7. Weathering grade for mechanical properties of Granite rock mass

Chainage (m)	0 - 5	5 - 10	10 - 15	15 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45	45 - 50	50 - 55	55 - 60
Weathering Grade (field observation)	III	II	II	II	III	III	II	II	III	II	II	III
UCS_{UU} (MPa)	56.86	56.86	56.86	39.91	39.91	39.91	39.91	76.37	39.91	39.91	60.31	60.31
UCS_{PLT} (MPa)	188.98	188.98	188.98	117.35	117.35	117.35	69.81	267.28	69.81	96.74	134.06	154.06
Cohesion, c (kPa)	1176.17	1176.17	1176.17	847.22	847.22	847.22	852.48	852.48	1366.67	1752.07	1752.07	1296.73
Peak Angle of Friction, Φ (°)	28	28	28	27	27	27	28	28	27	26	30	30
Peak Shear Strength, τ (kPa)	4460.00	4460.00	4460.00	4350.00	4350.00	4350.00	3650.00	3650.00	4266.67	4266.67	4266.67	4266.67
Slake Durability Index, I_D	99.62	99.62	99.62	99.56	99.56	99.56	98.40	98.40	99.49	99.61	99.79	99.79

Table 8. Weathering grade for mechanical properties of Schist rock mass

Chainage (m)	0 - 5	5 - 10	10 - 15	15 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45	45 - 50	50 - 55	55 - 60
Weathering Grade (field observation)	III	II	III	III	III	II	III	III	III	II	II	III
UCS_{UU} (MPa)	71.99	71.99	102.57	102.57	63.98	63.98	81.01	81.01	76.37	76.37	164.44	164.44
UCS_{PLT} (MPa)	340.14	340.14	169.23	169.23	309.97	309.97	218.38	218.38	207.04	207.04	487.97	487.97
Cohesion, c (kPa)	1092.33	1092.33	847.22	847.22	852.48	852.48	1366.67	1366.67	1398.6	1398.6	1296.73	1296.73
Peak Angle of Friction, Φ (°)	25	25	26	26	27	27	27	27	24	24	29	29
Peak Shear Strength, τ (kPa)	3333.33	3333.33	3283.33	3283.33	3350.00	3350.00	2933.33	2933.33	3416.67	3416.67	3250.00	3250.00
Slake Durability Index, I_D	99.62	99.62	99.56	99.56	98.40	98.40	99.49	99.49	99.61	99.61	99.79	99.79

From the analysis of the rock tests on each rock types, it was found that the Schist rock sample at Putrajaya is the most dominating rock based on the strength of the rock. When compared to Granite, Schist having the least weathering which make the Schist rock higher in strength. The data correlations concluded that the composition of quartz and average grain size play an important role in determining uniaxial compressive strength of rocks. The increased composition of quartz and average grain size will cause the uniaxial compressive strength to increase. The strength of a rock with large amount of matrix will have lower strength because matrix contains a lot of smaller grain size minerals and voids. A large number of voids in the rock will cause the rock to fail easily. From the correlation on shear strength and petrographic characteristics, the frictional angle has a positive correlation with composition of quartz and average grain size. However, the correlation is unclear when it is made in between cohesion and composition of quartz and average grain size but the correlation between same rocks type is considered good.

5. Conclusions

The objectives of this study were to determine the characteristic (physical and mechanical properties) of the rock slope materials and to interpret the correlation between the mineral composition and the rock strength. The analyzed data was used to justify the influence of mineral composition and weathering grade on rock slope deterioration. It was found that the orientation and alignment of rock mass such as dip and dip angle together with its in-situ condition plays an important role in influencing the stability.

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