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Empirical Correlation of Weathering Grade and Rock Properties of Weathered Granitic Rock

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Abstract:
Rock mass in Malaysia seems to experience high rate of weathering due to its tropical climate. The understanding of weathering process in influencing rock mass behaviour is vital. Previous studies have found that many geotechnical characteristics such as weathering are controlled by the density and arrangement of fractures within the rock, but the relationships between fracture patterns and weathering grades are not typically considered. In this study, weathered granitic rock samples were assessed to determine the correlation of weathered rock characteristics namely mineralogy, weathering grade, joint characteristics with density, UCS and P-wave velocity. The results of the experiment showed that the weathering grade was found to have inverse impacts on all assessed joint characteristics parameters such as joint spacing, joint inclination except for frequency of joint set. Whilst, the rock strength such as R value, UCS and Vp appeared to decrease with increase of weathering grade.

Keywords: *weathered rock, rock characteristics, P-wave velocity, joint characteristics*

I. INTRODUCTION

Design procedure involving rock mass always requires detailed characteristics on rock joints especially when it involves bedrock. Underground rock exploration depends on the limited data obtained from site investigation where this requires for total reliance on core samples [1]. Moreover, the scale effects and other uncertainties such as weathering process always have huge variance if compared with surface mapping. Rock mass in Malaysia seems to experience high rate of weathering due to its tropical climate. The understanding of weathering process in influencing rock mass behaviour is very important. An assessment of engineering properties of rock mass with reference to weathering grade for igneous rock, sedimentary rock and metamorphic rock have found correlations between Schmidt Hammer value, unconfined compressive strength (UCS), P-wave velocity, and weathering grade [2-3]. Process of weathering of igneous rocks in humid tropical experiencing changes in microstructural where the process involves discolouration, and micro cracking, chemical alteration and mineral leaching followed lastly by collapsed of relict structural [4-5]. The quantification of weathering grade of rock can be conducted on rock mass outcrop or core sample. Quantification of weathered rock characteristics based on core samples can be made using visual inspection and observation as per conducted at field.

Numerous studies have demonstrated that many geotechnical characteristics such as weathering are governed by the density and arrangement of fractures within the rock, but the relationships

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between fracture patterns and weathering grades were not addressed typically [6]. Thus, this study presents the correlation of weathered rock characteristics namely mineralogy, weathering grade, joint characteristics with density, P-wave velocity and UCS. The variability of weathered materials is an important element in the geotechnical characterization of rock for engineering purposes. Most engineering rock mass classifications include weathering schemes that classify the weathering profile into zones or grades subjected to the engineering and geological properties of the rock.

The degree of rock weathering apparently has effects on the joint characteristics. The characteristics of vertical and steeply dipping joints in weathered granite are marked by changes in frequency, length and appearance of joints as the rock mass as weathering grade evolves [7]. The frequency of joint spacing within weathered rock mass appears to have wider spacing for fresh (Grade I) or slightly weathered (Grade II) but as the weathering process progresses the joint spacing becomes closer for moderately weathered (Grade III) granite and later progressively wider from moderate to highly (Grade IV) and completely weathered rock (Grade V).

Another study also had the same finding [8] that showed the causes were due to disintegration and physical changes in rock as weathering progresses which consequently changes its structural features (i.e. joints); especially in severely weathered rock (in the highly and completely weathered zones). Whilst, the changes in joint appearance starts with sharp-edged and straight joint and progressively becomes rounder and sinuous as well as discontinuous around mineral grains. Consequently, the disintegration of rock mass into individual grains and its movement into voids within the joint make the joint looked shorter of which this eventually will affect the rock mass classification. Another joint characteristic, joint inclination appears to be affected by the changes of weathering grade. As the weathering grade increases from fresh to completely weathered rocks, an increase trend was observed in percentage of horizontal joints which may affect excavability of rock [9-10].

II. METHODOLOGY

Four types of weathered granitic rock core samples ranging from Grade I until Grade IV were used in this study as shown in Figure 1. All cylindrical rock core samples (50 mm x 100 mm) were brown/pinkish and light grey in colour. For classification of weathering grade, both observation and laboratory testing were conducted. Mineral identification was also conducted to deduce micro joint based on mineral arrangement. The joints were then separated into sets. A scanline method such as at field was adopted in this study to obtain strike and dip angle of from rock core samples [11-12]. To avoid any correction for orientation, joint spacing was measured perpendicular to strike for each joint set. The joints were classified according to dip for data analysis purposes: 0–25^o, horizontal joints; 26–69^o, dipping joints; and 70–90^o vertical joints.

Once the characteristics of rock were obtained, the strength of rock was determined using Schmidt hammer and unconfined compressive strength test (UCS). N type Schmidt hammer was used since it produces a lesser scatter in the data and is more efficient than the L hammer in predicting uniaxial compressive strength and Young's modulus. Portable Ultrasonic Non-Destructing Indicating Tester (PUNDIT) test was used to study the P-wave propagation across studied rock core samples. A correlation between physical and mechanical properties was then established to study weathered rock behaviour.

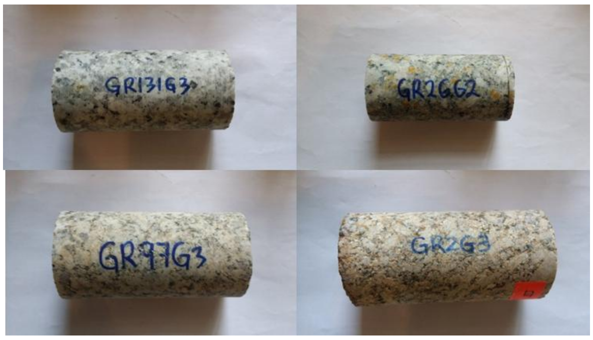

Fig. 1 Physical condition of rock core samples for

weathering grade (a) I, (b) II, (c) III and (d) IV

III RESULTS AND DISCUSSION

The results showed that the core samples consisted of common minerals found in granitic rock such as N plagioclase and K feldspar with trace of biotite, muscovite, quartz as well as amphibole (Table 1). According to statistical analysis of collected data, as the weathering grade increases from I to IV, the percentage amphibole, biotite, N plagioclase and K feldspar decreases. Whilst, in terms of joint spacing, as the weathering grade increase, the joint spacing become closer. Whilst, the inclination of the joints appears to decrease with increase of weathering grade from Grade I (fresh) to Grade IV (highly weathered).

TABLE 1

DISTRIBUTION OF MINERAL FOR WEATHERED GRANITIC ROCK

Sample mark	**Weathering Grade**	**Mineral (%)**					
		Amphibole	**Biotite**	**N Plagioclase**	**K Feldspar**	**Muscovite**	**Quartz**
GR36	I	4	5	90	-	-	1
GR44	I	12	2	-	85	1	-
GR131	I	1	7	91	-	-	1
GR2662	II	10	8	-	80	2	-
GR52	II	2	1	-	96	-	1
GR28	II	1.5	5	-	92.5	-	1
GR30	II	5	5	3	85	2	
GR31	II	5	3	78.5	12	-	1.5
GR162	II	7	-	89	4	-	-
GR52	II	3	1.5	76	18	1.5	-
GR49	II	3	1.5	90.5	4	1	-
GR51	II	3	1.7	85.3	10	-	-
GR46	II	3	-	92	4	1	-
GR160	II	3	1.7	86.3	8	-	1
GR97	III	1.7	-	65.6	30	1.7	1
GR105	III	15	3	76	5	-	1
GR76	III	15		5	80	-	-
GR145	III	3	1.5	25	70.5	-	-
GR41	III	10	5	74	10	1	-
GR148	III	-	-	-	100	-	-
GR96	III	3	1.5	95.5	-	-	-
GR104	III	3	2	96	-	1	-
GR36	III	2	-	89	8	-	1
GR35	III	2	-	89	8	-	1
GR133	IV	-	1.7	71.3	17	-	10
GR2	IV	1	1	55	43	-	-

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A. Effects of weathering grade on rock characteristics

Table 2 summarizes the effect of weathering grade on rock characteristics of 26 rock samples. It appears that the increase of weathering grade has inverse impacts on mineralogy, joint spacing and joint inclination except frequency of joint set. Since the strength of weathered rock mass depends on both intact rock properties and its discontinuities, quantitative data as tabulated in Table 3 were presented and analysed.

TABLE 2

RELATIONSHIP BETWEEN SELECTED ROCK CHARACTERISTIC PARAMETERS WITH WEATHERING GRADE

Weathering Grade	Mineralogy (amphibole, biotite, Na Plagioclase, K Feldspar)	Joint spacing	Joint inclination	Frequency of joint set
I	↓ decrease	↓ decrease	↓ decrease	↑ increase
II				
III				
IV				

TABLE 3

ROCK PROPERTIES GRANITIC ROCK WITH WEATHERING GRADE I TO IV

Sample No.	Weathering Grade	R value	UCS (kPa)	Dry density (kg/m3)	Vp (m/s)	Range			
						R value	UCS (kPa)	Dry density (kg/m3)	Vp (m/s)
GR36	I	31	26.41	2608	3625.4	31-36	26.41-35.47	2591-2708	3625.4-5567.9
GR44		31	26.41	2591	4886				
GR131		36	35.47	2708	5567.9				
GR2662	II	33	29.71	2621	6397.3	30-40	24.89-44.91	2595-2671	3372-6397.3
GR52		35	33.43	2618	4429.5				
GR28		40	44.91	2685	6085.1				
GR30		38	39.91	2698	6256.7				
GR31		38	39.91	2666	6230.2				
GR162		31	26.41	2603	5608.8				
GR52		31	26.41	2618	4311.5				
GR49		31	26.41	2597	4775.8				
GR51		31	26.41	2595	3372				
GR46		30	24.89	2617	4773.1				
GR160		33	29.71	2671	6207.9				
GR97	III	33	29.71	2570	4915.1	27-33	20.85-29.71	2480-2635	2827.2-5242.3
GR105		30	24.89	2480	3422.2				
GR76		30	24.89	2542	3435				
GR145		30	24.89	2617	5242.3				
GR41		33	29.71	2635	4193.5				
GR148		30	24.89	2534	4796.4				
GR96		30	24.89	2585	5114.1				
GR104		31	26.41	2524	3398.1				
GR36		28	22.12	2519	2849.9				
GR35		27	20.85	2532	2827.2				
GR133	IV	30	24.89	2537	4608.4	21-30	14.64-24.89	2503-2537	1839-4608.4
GR2		21	14.64	2503	1839.4				

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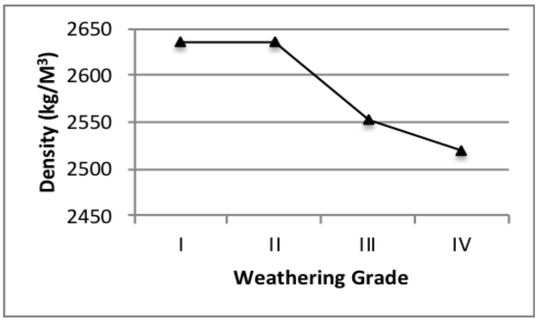

Fig. 2 Effect of weathering grade on density of rock sample

Figure 2 shows the reduction of density as the weathering grade increases. An apparent steep drop in density was recorded from Grade II to Grade III.

This counts for the disintegration of rock mass. Meanwhile, as the weathering grade increase from I to IV it was observed that the same trend of data were obtained for rebound hammer value (R), unconfined compressive strength (UCS) and P-wave velocity (Vp) where the values increase as the weathering grade increase from I to II and then reduce significantly beyond this and towards weathering grade IV as shown in Figure 3, 4 and 5 respectively. Previous study showed that linear and direct relationship was established between these parameters. However, the degradation of rock due to weathering into smaller fraction may have filled up the rock aperture, thus slightly increased of strength was observed as the weathering grade increased.

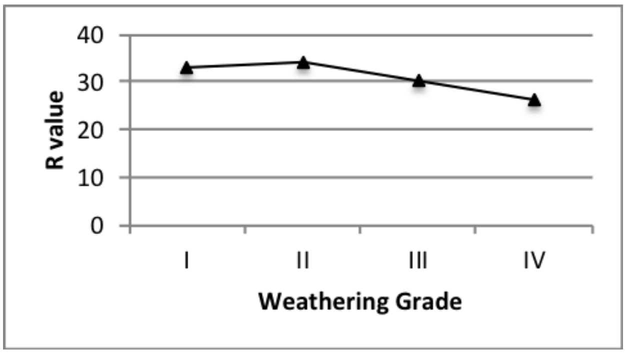

Fig. 3 Effect of weathering grade on rebound hammer value (R) of rock sample

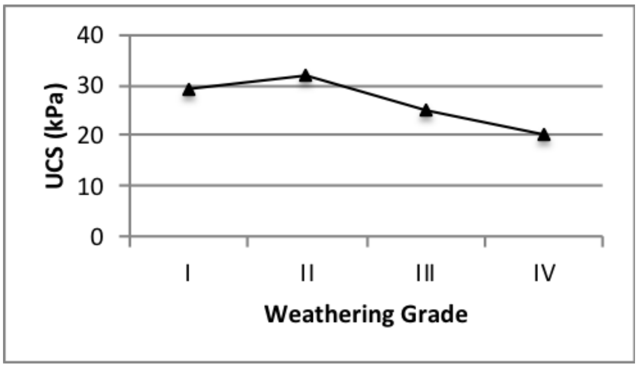

Fig. 4 Effect of weathering grade on unconfined compressive Strength value (UCS) of rock samples

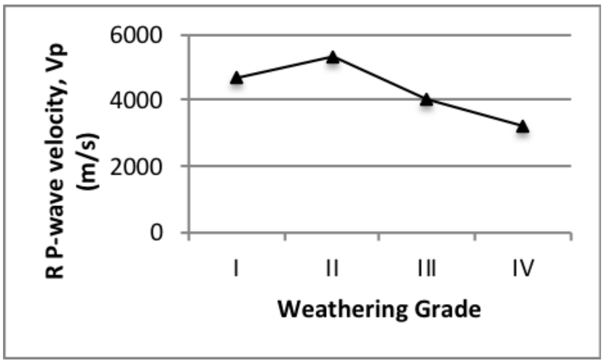

Fig. 5 Effect of weathering grade on P-wave velocity of rock samples

B. Effects of rock properties on P-wave velocity

The P-wave velocity (Vp) was also affected by density. According to Figure 6, correlation of density with Vp shows significant changes both weathering grade II and III. However, for weathering grade III, any changes to the density would have gradual impact on Vp.

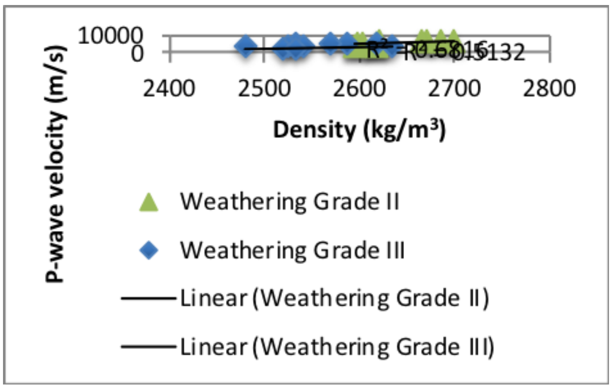

Fig. 6 Relationship of P-wave velocity, Vp (m/s) and rock density (kg/m^3)

Previous studies have shown that the wave propagation of elastic wave across jointed rock is useful in quantification of rock mass [11-12]. Nonetheless, correlation between P-wave velocity and engineering properties of rock is needed to determine the strength of rock. The presence of mineralogy such as quartz may increase the density and has inverse effect on P-wave velocity. However, very little amount of quartz were found in all samples, thus its effect towards density and V_p are somewhat requires further analysis at micro scale i.e. thin section sample.

Apart from mineralogy study, the P-wave velocity also relies on number of joint set as well as joint spacing as shown in Figure 6. Higher frequency of joint set produces lesser joint spacing and this increase attenuation and intrinsic loss of P-wave velocity (V_p) due to wave reflection, consequently lesser V_p was observed as shown in Figure 7. It is also observed that the relationship of V_p and joint set is hard to quantify for weathered rock grade II and III since there is no apparent relationship and bigger range, thus proves that other parameters of rock properties also contributed to its behaviour. However, if the overall degradation of rock quality from weathering grade I to IV is accounted, a reduction of V_p was observed.

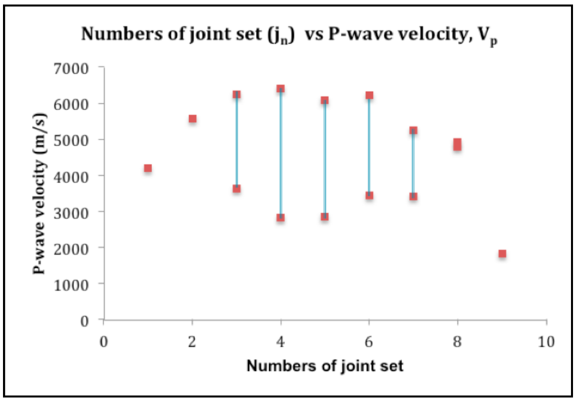

Fig. 7 Distribution of numbers of joint set with regards to P-wave velocity, Vp (m/s)

Since classification of weathering grade is greatly subjective, correlation with engineering properties such as compressive strength and rebound hammer values were established. According to Figure 8, both have identical trend as the effects of weathering grade on UCS and R-values. In a nutshell, a linear regression was observed between rock strength and weathering grade as shown in Figure 9.

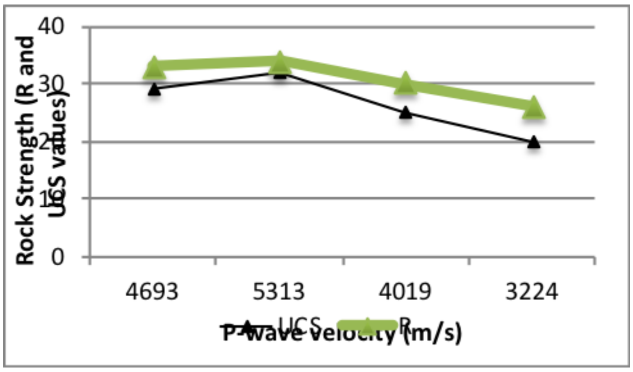

Fig. 8 Relationship between rock strength and P-wave velocity

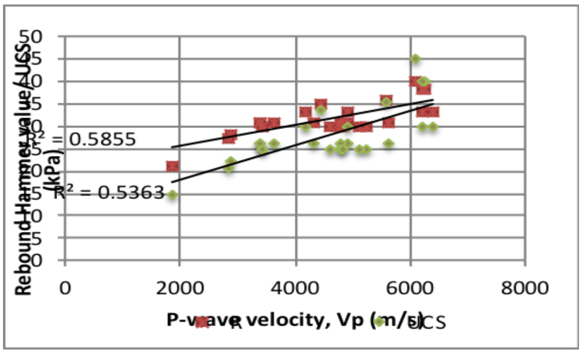

Fig. 9 Relationship of R value and UCS (kPa) with Vp (m/s)

IV CONCLUSION

In conclusion, Table 4 is presented as a summary of effects of weathering grade on rock and joint properties. This table can also be used to quantify the relation between studied parameters. It was observed that an increase of weathering grade may be represented by the visual and physical rock characteristics, where aside from increasing numbers of joint sets, the joint spacing and inclination decreases. Thus, affecting P-wave velocity and this may indicate the usefulness of NDT data in quantifying rock mass strength.

However to better understand the behaviour of weathered rock mass, further and detailed study of other parameters such as joint infilling is needed.

TABLE 4
ROCK PROPERTIES PERFORMANCE IN ACCORDANCE TO WEATHERING GRADE

Weathering Grade	Mineralogy (amphibole, biotite, Na Plagioclase, K Feldspar)	Joint Characteristic			Rock Properties			P-wave velocity
		Inclination	Joint set	Spacing	Density (kg/m^3)	UCS (kPa)	R value	
I	↓ decrease	↓ decrease	↑ increase	↓ decrease	↓ decrease	↓ decrease	↓ decrease	↓ decrease
II								
III								
IV								

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