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Application of Schmidt hammer rebound test for weathering profile classification of granite, Paya Terubong, Penang, Malaysia

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Abstract: Weathering profile characterization is one of the significant information in the interpretation of the condition of rock. In addition, the tropical climate in Malaysia causes the deep–seated weathering phenomena of granitic rock. The identification of weathering profile of granite can be made using in–situ Schmidt hammer rebound test which is one of the non–destructive tests (NDT) that is widely used. In this study, the test is carried out on granitic rock in Paya Terubong, Pulau Pinang. Based on the study conducted, the value for each of weathering grade of granite can be identified. The value for fresh granite (Grade I) is greater than 55, slightly weathered granite (Grade II) is ranging from 35 – 55, moderately weathered granite (Grade III) is ranging from 17 – 35 and highly weathered granite (Grade IV) is less than 17. Completely weathered granite (Grade V) and residual soil (Grade VI) do not have any Schmidt hammer rebound values. This method can be used as a very useful method in the field to determine the degree of weathering of rock outcrops.

Keywords: Granite, weathering grade, weathering profile, Schmidt hammer rebound test

Abstrak: Pencirian luluhawa adalah salah satu informasi penting dalam menafsir keadaan suatu singkapan batuan. Malaysia yang mempunyai iklim tropika yang telah menyebabkan fenomena luluhawa yang tebal dan dalam bagi batuan granit. Pengenalpastian profil luluhawa granit boleh dilakukan dengan menggunakan kaedah ujian lantunan tukul Schmidt in-situ yang merupakan salah satu kaedah ujian tanpa musnah (NDT) yang sering digunakan. Dalam kajian ini, ujian lantunan tukul Schmidt dijalankan ke atas batuan granit di Paya Terubong, Pulau Pinang. Berdasarkan kajian yang telah dijalankan, nilai lantunan tukul Schmidt bagi setiap gred luluhawa batuan granit dapat dikenalpasti. Nilai bagi batuan granit segar (Gred I) adalah melebihi 55, bagi batuan granit sedikit terluluhawa (Gred II) adalah dalam lingkungan 35 – 55, bagi batuan granit terluluhawa sederhana (Gred III) adalah dalam lingkungan 17 – 35, dan bagi batuan granit terluluhawa tinggi (Gred IV) adalah kurang daripada 17. Manakala, bagi batuan granit terluluhawa keseluruhan (Gred V) dan tanah baki (Gred VI), tidak memberikan nilai lantunan tukul Schmidt. Kaedah ini boleh dijadikan sebagai kaedah yang sangat berguna di lapangan bagi menentukan tahap luluhawa singkapan batuan.

Kata kunci: Granit, gred luluhawa, profil luluhawa, ujian lantunan tukul Schmidt

INTRODUCTION

According to Moye, 1955 and Ruxton & Berry, 1957, weathering profiles in rocks are derived from the geological classification for engineering applications. Weathering profiles are characterized according to their classified weathering grades. There are some properties to be considered in classifying weathering grades. Indeed, in volcano and sedimentary formations there are significant lateral as well as vertical variations, where the original rock type greatly influences the rate of weathering, according to the view by Nahon (1986). According to Umar & Ibrahim (1997), the range of velocities representing grades and indices of weathered rocks and soils can be determined from the in situ seismic surveys at the field. Weathering is an essential process that reduces the mechanical strength of rock material and rock mass at shallow depths from the surface through chemical and physical weathering, as stated by Arikan & Aydin, 2012.

However, defining weathering profile of an outcrop requires identification and judgement of the geologist

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on site and can differ according to each individual's observations. When conducting engineering works, this is important information for the desk study for engineering planning which involves slope stability as well as other engineering purposes. Slope failures, erosion, and landslides often happen in areas that are strongly affected by weathering, and weathering is an environmental factor that impacts recent as well as historical sites (Arikan & Aydin, 2012). In granites, the weathering profile is always much deeper when compared to sedimentary and metamorphic rocks. Most of the proposed weathering profile models are concerned with granitic rocks according to Koita *et al.*, 2013.

According to Abad *et al.*, 2014, one of the most important challenges in the study of slope stability, foundation, and excavation in rocks is understanding the weathering grades. This issue is especially important in tropical climates, where intense weathering produces thick weathering profiles. Therefore, describing the weathering profile involves an understanding of the weathering process of rock exposures of an area. Therefore, many studies have been conducted to achieve the classification of weathering grades. Abad *et al.* (2014) stated that weathering classification schemes are mostly proposed based on some important factors such as the condition and appearance of the rock material (e.g., its friability), the weathered materials engineering properties, the condition of individual minerals (e.g., the extent of micro-cracking), the degree of staining of joint surfaces and/or the extension of the staining from joints into the rock, and alterations to the mineral composition (e.g., the appearance of new minerals and disappearance of existing ones).

A study estimating the degree of weathering of metamorphic rocks from Malaysia using Schmidt hammer rebound test was conducted by Arifin *et al.* (2009) in which the quantification of the weathering grade of rock material is explained, and the linear relationship to the degree of weathering is determined. Goh *et al.*, 2017 states that a mean of quantification of rock material strength can be identified using the Schmidt hammer rebound test.

This study aims to estimate the degree of the weathering grade of granite based on Schmidt hammer rebound tests at Paya Terubong, Pulau Pinang. The area covered is located on Penang Island, a northern island of Malaysia. In this study, the Schmidt hammer rebound values were used to estimate the grade of weathering. The results of the study presents Schmidt hammer rebound test values for the different degree of weathering grades within the weathering profile of granite, as well as demonstrating a useful method for the determination of the degree of weathering in the field.

OVERVIEW OF STUDY AREA

The study area is located at Paya Terubong, Pulau Pinang with coordinate of N 5° 21' 8.24", E 100° 16' 33.16". Based on the Department of Mineral and Geoscience Malaysia (JMG) map of year 2006, the granitic rock in Paya Terubong is composed of medium–grained to coarse–grained biotite granite with microcline. The geology of Paya Terubong forms part of the South Penang Pluton (SPP) and comprises of coarse–grained and medium–grained porphyritic muscovite–biotite granite. Figure 1 shows the geological map of Penang Island modified after JMG, 2006. Figure 2 shows the

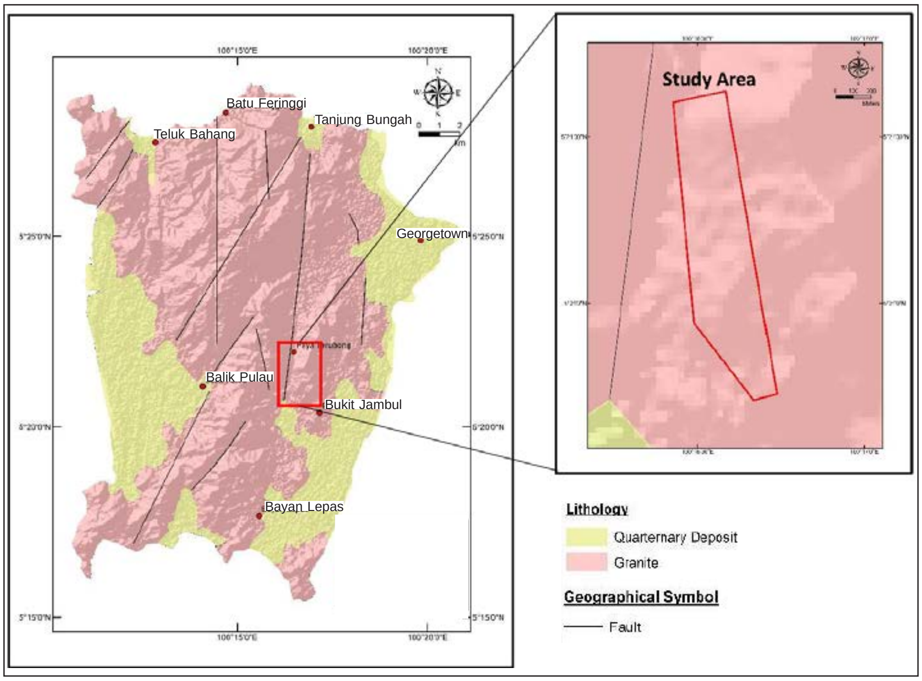

Figure 1: Geological map of Penang Island (modified after Department of Mineral and Geoscience Malaysia (JMG), 2006).

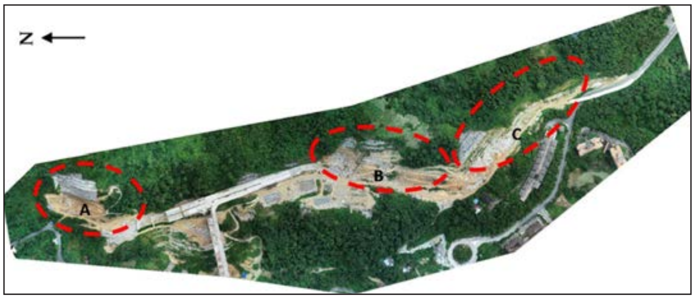

Figure 2: Aerial photo of the study area. Circled areas indicate the locations of *in-situ* Schmidt hammer rebound test done on granitic rock.

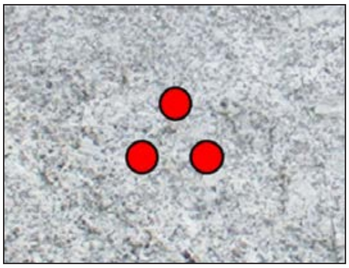

Figure 3: Three blows of *in–situ* Schmidt hammer rebound test done repeatedly at each point.

aerial photo of the study area taken using unmanned aerial vehicle (UAV).

The study area is divided into 3 locations named as location A, location B and location C. The rock outcrop at location A is 150 meters long with a width of 12 meters, at location B it is 95 meters long with a width of 10 meters and at location C, is 70 meters in length and width is 8.5 meters.

METHODOLOGY

The weathering grades of granite in the study area is defined through observation based on the weathering grade classification system of ISRM, 2015 as shown in Table 1. The weathering profile is divided into six (6) weathering grades and classified based on the state of weathering, the rock discoloration, and joint conditions.

Schmidt hammer test is a non–destructive method to estimate the uniaxial compressive strength (UCS) of rock material. According to Aydin & Saribiyik (2010), the rebound hammer test is classified as a hardness test based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges.

The *in–situ* Schmidt hammer rebound test were conducted three times for each point in every grade of weathering to obtain more accurate data. Figure 3 shows the typical procedure in collecting the Schmidt hammer rebound data.

Previous studies had proposed the approximate range values of Schmidt hammer rebound test to determine the weathering grade classification of granite. Table 2 shows the comparison between each range of values proposed.

RESULTS AND DISCUSSION

The results comprise of weathering profiles of the ourcrops in the study area and the *in–situ* Schmidt hammer rebound values of every weathering profile.

Weathering profile of the study area

The results of the tests on rock outcrops in the study area can be divided into 4 weathering zones. The analysis was carried out by constructing several graphs

Table 1: Weathering grade classification system suggested by ISRM (2015).

Term	Class	Description
Sound rock (SR)	I	No visible sign of matrix weathering; some rock discoloration may be presented along main discontinuities.
Slightly weathered rock (SW)	II	Discoloration of rock indicates beginning of rock matrix weathering and along discontinuity surfaces. All rock matrices can be discoloured by weathering and can be slightly softer externally than in sound condition.
Moderately weathered rock (MW)	III	Less than half of rock matrix is decomposed or disintegrated to soil conditions. Sound or discoloured rock is present forming discontinuous zones or as corestones.
Highly weathered rock (HW)	IV	More than half of rock matrix is decomposed or disintegrated to soil conditions. Sound or discoloured rock is present forming discontinuous zones or corestones.
Completely weathered rock (CW)	V	All rock matrices are decomposed or disintegrated to soil conditions. Original structure of rock mass is commonly preserved.
Residual Soil	VI	All rocks are transformed into soil. Geological structure of rock mass is destroyed. There is a great volume of variation but no significant soil transport is present.

Table 2: Comparison of weathering grade classification based on Schmidt hammer rebound values.

Reference	Weathering Grade	Schmidt Hammer Rebound Range Value (R)
Brand & Phillipson (1984)	I	N/A
	II	>45
	III	25 – 45
	IV	<25
	V	No Rebound from Schmidt hammer
	VI	N/A
Yunus *et al.* (2010)	I	>54
	II	37 – 54
	III	17 – 37
	IV	N/A
	V	N/A
	VI	N/A

to identify the degree of weathering of the exposed outcrops. The exposed outcrops in the study area show several weathering profiles, as the following:

a) Weathering profile of grade II – III;
b) Weathering profile of grade III – IV;
c) Weathering profile of grade IV – V;
d) Weathering profile of grade VI (residual soil).

Weathering profile of grade II – III

This profile shows slightly weathered to moderately weathered granite. The outcrop shows some discoloration at the joint surface and slight disintegration of minerals can also be seen. Figure 4 shows the weathering profile of grade II – III. Meanwhile, the graph in Figure 5 shows the *in*–situ Schmidt hammer rebound data collected at the profile. The maximum rebound value (R_{max}) and minimum rebound value (R_{min}) for this profile is 59 and 15 respectively.

Figure 5 is the result of the field test in which the values of Schmidt hammer rebound is plotted vs the position of blows in the study area, and it includes a total of 155 blow numbers at different points with an interval of 3 to 5 meters between each point.

Weathering profile of grade III – IV

This profile shows moderately weathered to highly weathered granite. Discoloration can be observed along the outcrop and disintegration of minerals can be seen. Figure 6 and 7 show the weathering profile of grade III – IV and graph of *in*–situ Schmidt hammer rebound data collected on the profile, respectively. The maximum rebound value (R_{max}) and minimum rebound value (R_{min}) for the profile is 39 and 11, respectively. The test was conducted at 98 locations to determine the degree of weathering.

Figure 4: Overview of weathering profile of grade II – III at circle A area of Figure 2.

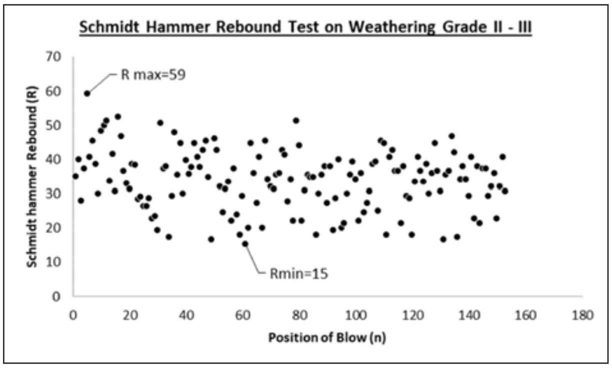

Figure 5: Graph of *in–situ* Schmidt hammer rebound test values vs position of blows, on weathering grade II – III; R_{max} = 59, R_{min} = 15.

Figure 6: Overview of weathering profile of grade III – IV at circle B area of Figure 2.

Figure 8: Overview of weathering profile of grade IV – V at circle C area of Figure 2.

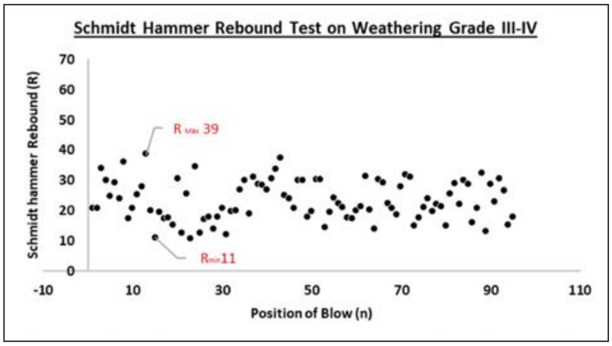

Figure 7: Graph of *in–situ* Schmidt hammer rebound test values vs position of blows, on weathering grade III – IV; R_{max} = 39, R_{min} = 11.

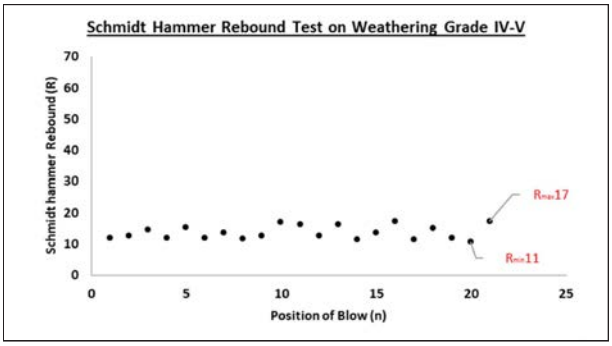

Figure 9: Graph of *in–situ* Schmidt hammer rebound test values vs position of blows, on weathering grade IV – V; R_{max} = 17, R_{min} = 11.

Weathering profile of grade IV – V

This profile shows highly weathered to completely weathered granite. Discoloration can be seen at most of the outcrop and the minerals are highly disintegrated. Dents on the surface of rock can be seen due to the impact of *in–situ* Schmidt hammer rebound test. Figure 8 shows the weathering profile of grade IV – V and Figure 9 shows the graph of *in-situ* Schmidt hammer rebound data collected on the profile. The maximum rebound value (R_{max}) and minimum rebound value (R_{min}) for the profile is 17 and 11, respectively. There were 22 point of blow that classify the degree of weathering in this zone.

Weathering profile of grade VI (residual soil)

This profile is identified as residual soil where all the rock has completely disintegrated into soil. Figure 10 shows the weathering profile of grade VI (residual soil). No graph is constructed as no *in–situ* Schmidt hammer rebound data can be collected at the profile.

Based on the graphs plotted for each of the weathering profile, the range values of *in–situ* Schmidt hammer rebound test are proposed for each weathering grade of granite. The values are interpreted based on the distribution of Schmidt hammer rebound data on the following weathering profiles. Several data that are considered as random error are ignored from the proposed values. Figure 11 shows the range of values of Schmidt hammer rebound data for weathering grades of granite.

Figure 10: Overview of weathering profile of grade VI (residual soil) at circle A area of Figure 2.

Previous researchers such as Brand & Phillipson, 1984 and Yunus *et al.*, 2010 have stated the results of similar studies as in Table 2. In addition, the determination of weathering degree has also considered field observations

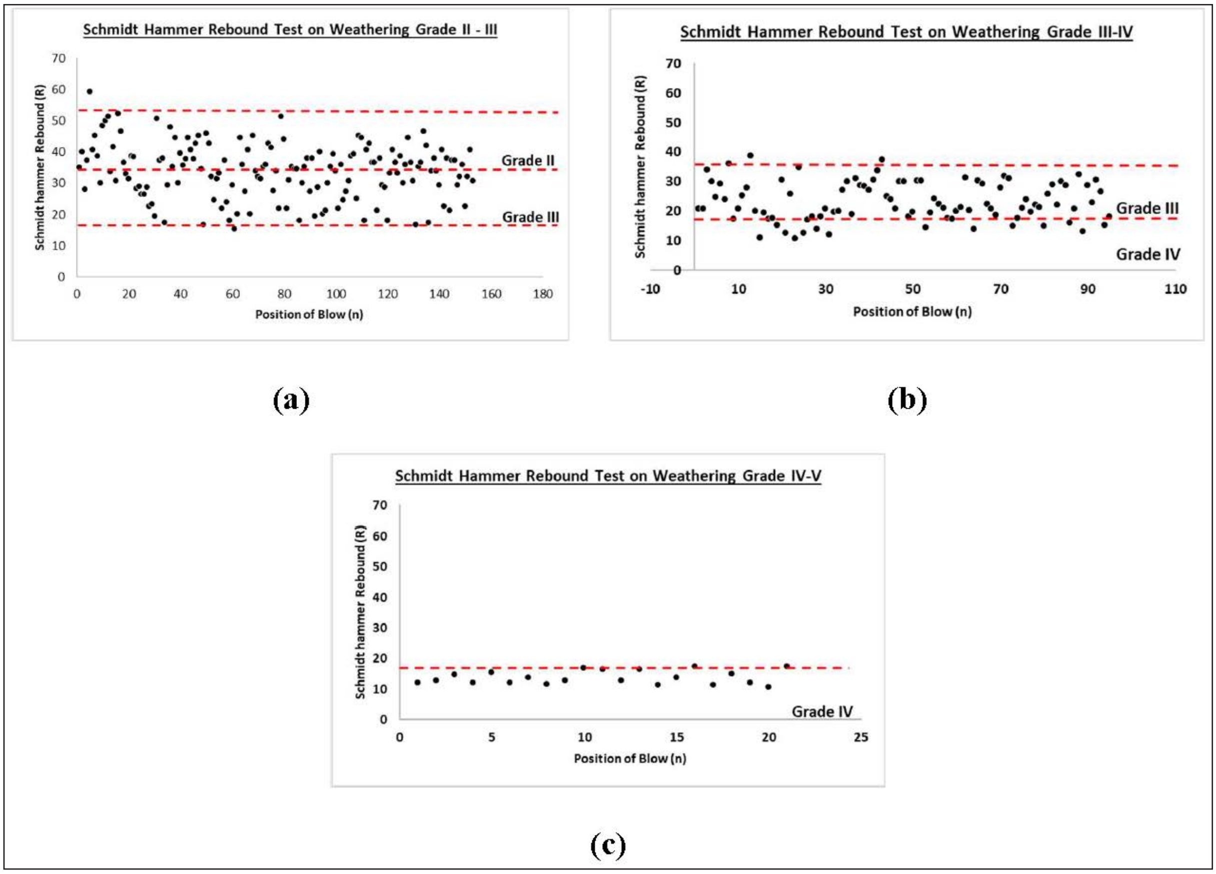

Figure 11: Graph showing the range value of *in–situ* Schmidt hammer rebound test (R) for the different weathering grades.

Table 3: Proposed values of *in–situ* Schmidt hammer rebound test for weathering grade classification for granite at Paya Terubong, Penang, Malaysia.

Term	Weathering Grade	Schmidt Hammer Rebound Test Value (R)
Fresh Granite (F)	I	>55
Slightly weathered Granite (SW)	II	35-55
Moderately weathered Granite (MW)	III	17-35
Highly weathered Granite (HW)	IV	<17
Completely weathered Granite (CW)	V	No rebound
Residual Soil	VI	N/D

N/D : Not determinable

and also the classification of weathering degree by ISRM, 2015 as in Table 1. The results of this study can be concluded that the Schmidth hammer rebound values for the different degrees of weathering in the study area are as follows:

(a) Weathering grade II – III,
R_{III} = 17 – 35, R_{II} = 35 – 55
(b) Weathering grade III – IV,
R_{IV} = 0 – 17, R_{III} = 17 – 35
(c) Weathering grade IV – V,
R_{IV} = 0 – 17
d) No rebound data for grade V.

Based on the range value of *in–situ* Schmidt hammer rebound test on the weathering profile, the proposed values of *in–situ* Schmidt hammer rebound test for each weathering grade of granite are shown in Table 3.

CONCLUSION

The results of this study have successfully determined the relationship between the value of Schmidt hammer rebound values with the degree of weathering of the study area. The results of this study can be used as a method to determine the degree of weathering of a rock outcrop. The degree of weathering of rock outcrops is one of the important elements in determining the level of rock slope stability. Apart from determining the degree of weathering by observation of the physical condition of the rocks and minerals in the rocks, Schmidt hammer rebound is an excellent method which can provide rock strength values. This paper determined the relationship between the *in–situ* Schmidt hammer rebound test and the weathering grades of a granite weathering profile. The results of this study indicate that Schmidt hammer rebound test for Grade I is greater than 55, Grade II is ranging from 35 – 55, Grade III is ranging from 17 – 35, and Grade IV is less than 17. For Grade V, there is no rebound data that can be collected and Grade VI is identified as residual soil.

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AUTHOR CONTRIBUTIONS

In this study, the geological field work was conducted by MSH together with MAG. MRU determined the general geology of the study area as well as the site specific geology. AGMR supervised the in-situ Schmidt hammer testing together with MAG. Interpretation of the results where a correlation of the weathering grades with the Schmidt Hammer rebound values was also conducted by AGMR and MAG. The first draft of the manuscript was prepared by MSH. The manuscript was reviewed by AGMR and MAG with input from MRU.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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