IOP Conf. Series: Earth and Environmental Science **971** (2022) 012025 doi:10.1088/1755-1315/971/1/012025

Correlation between Uniaxial Compressive Strength and Point Load Strength of Penang Island Granites

J D Mohamad[1], D Z Abang Hasbollah[2*], A Mohd Taib[3], M F Md Dan[4], S N Jusoh[1], K N Mat Said[1],

[1] School of Civil Engineering, Faculty of Engineering Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia
[2] Centre of Tropical Geo-engineering, School of Civil Engineering, Faculty of Engineering Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.
[3] Department of Civil Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia
[4]Department of Infrastructure & Geomatic Engineering, Faculty of Civil and Built Environment, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor
*Corresponding author: dzulaika@utm.my

Abstract. Uniaxial compressive strength (UCS) is one of the most widely used strength parameters in geotechnical design. The value is obtained through direct testing method, carried out through careful procedures of testing in a laboratory setting. As such, it is relatively more expensive, more tedious and requires longer time to complete. Considering that UCS is highly important, Engineers often utilize indirect methods, namely the Point Load Test, to obtain the Point Load Index Strength (Is(50)). From this test, the results are correlated in order to predict the UCS value. One of the general correlations is provided by ISRM where UCS=20-25 Is(50). However, it is highly contested as it is not universal for all types of rocks. The main focus of this research is to find the correlation of UCS and Is(50) in the Penang Island area. This research would also attempt to classify the granites according to strength. This study showed that the Penang Island Granites are "weak to very strong" granites with UCS values between 24.76 to 156.82MPa. The granites from the North Pluton are classified as "medium strong to very strong" with UCS values between 37.11 to 156.82MPa. The granites from the South Pluton are classified as "weak to very strong" with UCS values between 24.76 to 141.59 MPa. The recommended correlation between UCS and Is(50) are (1) Overall: 8.385 Is(50) + 30.016 (2) North Pluton: 7.93 Is(50)+ 35.606 (3) South Pluton: 9.03Is(50)+20.138.

1. Introduction

Reliable estimates of the strength and deformation characteristics of rock masses are required for almost any form of analysis used for the design of slopes, foundations and underground excavations. As such, a Geotechnical Engineer should have a proper understanding of the rock mass behavior and strength. In order to achieve this, qualitative measurements of the intact rock strength parameters are commonly carried out both in the laboratory and in-situ. Uniaxial Compressive Strength (UCS) and Point Load Index Strength (Is (50)) are among the most important intact rock strength properties. A reliable and good testing program and results could help Engineers and Geologists to classify the rock properly as well as predicting the behaviour of the rock mass and the performance of our design. This paper is aimed to classify Penang Island Granites based on the UCS and Is(50) as well as to establish the correlation between UCS and Is(50) of the Penang Island granite samples.

2. Problem background

In order to obtain the UCS value, the test involved is expensive, time-consuming, and requires high-quality samples [1-4]. Because of these drawbacks, UCS is a bit more hassle to carry out at the site. Not only that, in sites where the rock is highly weathered, the rocks are harder to prepare as the rock would crumble, resulting in failure to comply with the testing standard size as per ASTM and ISRM Standards. In order to overcome this, Engineers often utilize indirect testing methods to obtain rock strength parameters as they are simpler, cheaper, quicker and easily adaptable to the field [5-6]. One of the popular indirect methods used for this purpose is the Point Load Test (PLT). From this, Point Load Index Strength (Is(50)) is obtained. Previously multiple researchers attempted to predict the UCS values by correlating the Is(50) values with UCS values. From this, the correlation factor, (k) is obtained. Many studies had produced correlation between these two parameters for various types of rocks. Among the most renowned studies was by Broch and Franklin [7] giving a correlation factor of 24 x Is(50), for samples referred to a standard size of 50mm. According to the International Society of Rock Mechanics [8], the correlation factor recommended is between 20 Is(50) to 25 Is(50). Subsequent studies found that k=24 is not applicable for all types of rocks, instead, there appeared to be a broad range of correlation factors.

3. Literature review

3.1 Uniaxial Compressive Strength

Generally intact rock strength is divided into two, compressive strength and tensile strength. Compressive strength is the ability of a rock sample to withstand a compressive force applied axially on the rock. It is the maximum load applied to the rock before being fractured. When a rock fails in compression, it means that the compressive stress has exceeded the compressive strength of the rock. On the other hand, tensile strength is the maximum tensile stress a rock material can bear. Rocks is often assumed to have zero tensile strength since the test results for tensile strength are usually extremely low. One of the most important intact rock strength parameters is the uniaxial compressive strength (UCS). It is one of the important parameters when determining rock mass strength [9]. UCS gives the Engineers a rough index and some indication on the likely issues to occur during construction [10]. At the very basic level, the UCS is used as part of the Basic Geotechnical Description [11-13]. Other than that, UCS is also as one of the important parameters in rock mass classifications such as the Rock Mass Rating [14], Rock Mass Quality (Q) [15], Mining Rock Mass Rating (MRMR) [16] Geological Strength Index (GSI) [17] and Rock Mass Index (RMI) [18]. UCS could also be used to predict the shaft friction resistance in rock sockets [19-27]. Based on the various applications of the UCS mentioned above, it can be concluded that the UCS of a rock is undoubtedly very important. It is indeed versatile as it could help Engineers to obtain a lot of parameters for geotechnical design.

3.2 Uniaxial Compression Test (UCT)

The UCS value of a rock is obtainable via a direct strength test called the Unconfined Compression Test (UCT). The testing procedures are standardized by the International Society of Rock Mechanics (ISRM) as well as the American Society for Testing and Materials (ASTM). Rock samples are cut into the standard sizes of right circular cylinders before being crushed between two steel platens, with the load applied axially until the sample fails. The diameter preferably not lesser than NX core size, about 54mm [28-29]. Thuro *et al*. [30] noted that there are no significant effects by the sample diameter size on the UCS value. The length-to-diameter ratio (L:D) varies depending on which testing standard we follow as the ISRM recommends L:D between 2.5:1 and 3:1, while ASTM recommends L:D between 2.0:1 and 2.5:1. It is also noted that the measured strength would increase if the ratio is lesser than 2. Chiu and Johnston[31] pointed out that increased strength with a shorter specimen is due to lateral restraint at the ends of the specimen, caused by the platens, which may result in non-uniform stress distributions under compression [32]. Considering this, it is common practice that the ratio is typically 2:1. UCS value can be calculated using the following simple equation:

$$UCS= F/A \tag{1}$$

where F and A are maximum applied load and specimen cross sectional area, respectively.

3.3 Point Load Test (PLT)

PLT is carried out to obtain the point load strength index (Is (50)) of an intact rock. PLT is a popular method, used together with UCS in rock classification [33]. PLT is carried out by compressing rock samples (applying point load) between two conical steel platens (radius of 5mm, conical angle of 60˚) until failure occurs. It is noted that only failures where one or more extensional planes developed through the whole body of the sample, below the conical platens are considered as valid tests. Samples which chipped to the sides or where the failure plane did not go through directly below the conical platens are considered invalid. Typical failure patterns, as well as the valid and invalid tests are shown in Figure 1.

ASTM has established the basic procedure for conducting and calculation of point load strength index (ASTM D5731-08). In practice, there are three main types of PLT; axial, diametral and lump or block. Axial and diametral types are performed on rock core samples, while lump or block tests are carried out on rock samples with irregular shapes. The point load strength index determined by PLT must be corrected to the standard equivalent diameter (De) of 50mm [34], and is denoted by Is(50). The suggested equation for Is(50), by ASTM is as the following:

$$Is(50) = (De / 50)\ 0.45 \times Pu / De^2 \tag{2}$$

where Pu and De are the failure load and the equivalent diameter which is the core diameter. The load configurations and specimen shape requirement for PLT is as shown in Figure 2.

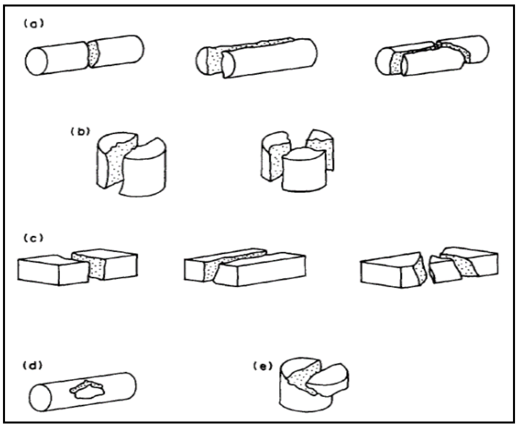

Figure 1. Typical Modes of Failure for Valid and Invalid Tests (a) Valid diametral tests; (b) valid axial tests; (c) valid block tests; (d) invalid core test; and (e) Invalid axial test.

IOP Conf. Series: Earth and Environmental Science **971** (2022) 012025 doi:10.1088/1755-1315/971/1/012025

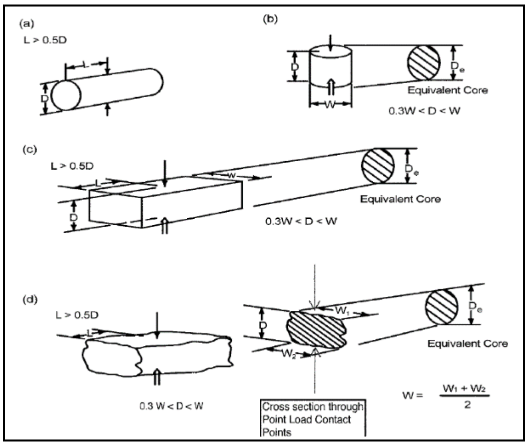

Figure 2. Load Configurations and Specimen Shape Requirement for (a) the Diametral Test, (b) the Axial Test, (c) the Block Test, and (d) the Irregular Lump Test Legend: L = distance between contact points and nearest free face, and De = equivalent core diameter.

Point Load Index Strength is considered as an index property of the rock. Tan and Chan[35] defined index properties as the physical or mechanical property of a rock, which are determined through a method that is relatively easy but still bears a significant relationship to its engineering properties.

3.4 UCS vs Is(50)

This method is highly popular, as there are literally hundreds of this method carried out by multiple researchers in the past, with various (k) values. As such, only past studies related to granites are included as shown in Table 1.

Table 1. Suggested correlations between UCS and Is(50) for granites.

Reference	Correlation	No.s of sample	R or R^2
Basu and Aydin [36]	UCS =18 Is(50) MPa	40	R^2=0.97
Ghosh and Srivasta[37]	UCS=16 Is(50) MPa	22	-
Tuğrul and Zarif [38]	UCS=15.25Is(50) MPa	19	R=0.98
Tan [39]	UCS= 7 to 17 Is(50) MPa	-	-

3.5 Previous studies in Penang Island area

Based on the Geology Map Sheet 28 by published by the Director General of the Malaysian Geological Society in 1994, the main island of Penang is underlain by two granite plutons of different magma origins namely the North Pinang Pluton and the South Pinang Pluton with sedimentary rocks of Mahang Formation and recent Quaternary deposits [40].

The North Penang Pluton is subdivided into three units which are the Tanjung Bunga Granite, Feringgi Granite and Muka Head microgranite. The South Penang Pluton is further divided into two, namely the Batu Maung granite and Sungai Ara Granite.

The Batu Maung Granite is characterized by medium to coarse-grained biotite granite which occupies about 80% of microcline granite while the Sungai Ara Granite has the characteristics of a fine-grained biotite granite that occupies about 20% of the area underlain by the microcline granite. A fairly large area of altered granite occurs at the contact between these two granite plutons. Based on Lee *et al.* [41], the Batu Maung Granite subsoil mainly consists of silty SAND and sandy SILT.

The recent Quaternary deposits which consist of relatively recent unconsolidated sedimentary of Gula Formation and Beruas Formation are observed. According to Ong [42] the top one meter of recent alluvium deposits consists of light yellowish-brown clay with brownish spots. Below this is a thicker layer of brownish grey soft clay with abundant plant remains of greyish fine to medium grained sand. At the base of alluvium, a layer of coarse sand with some greyish clay or a layer of peat may occur. Figure 3 shows the Geological Map of the Penang Island while previous relevant studies carried out in the Penang Island Granites are compiled in Table 2.

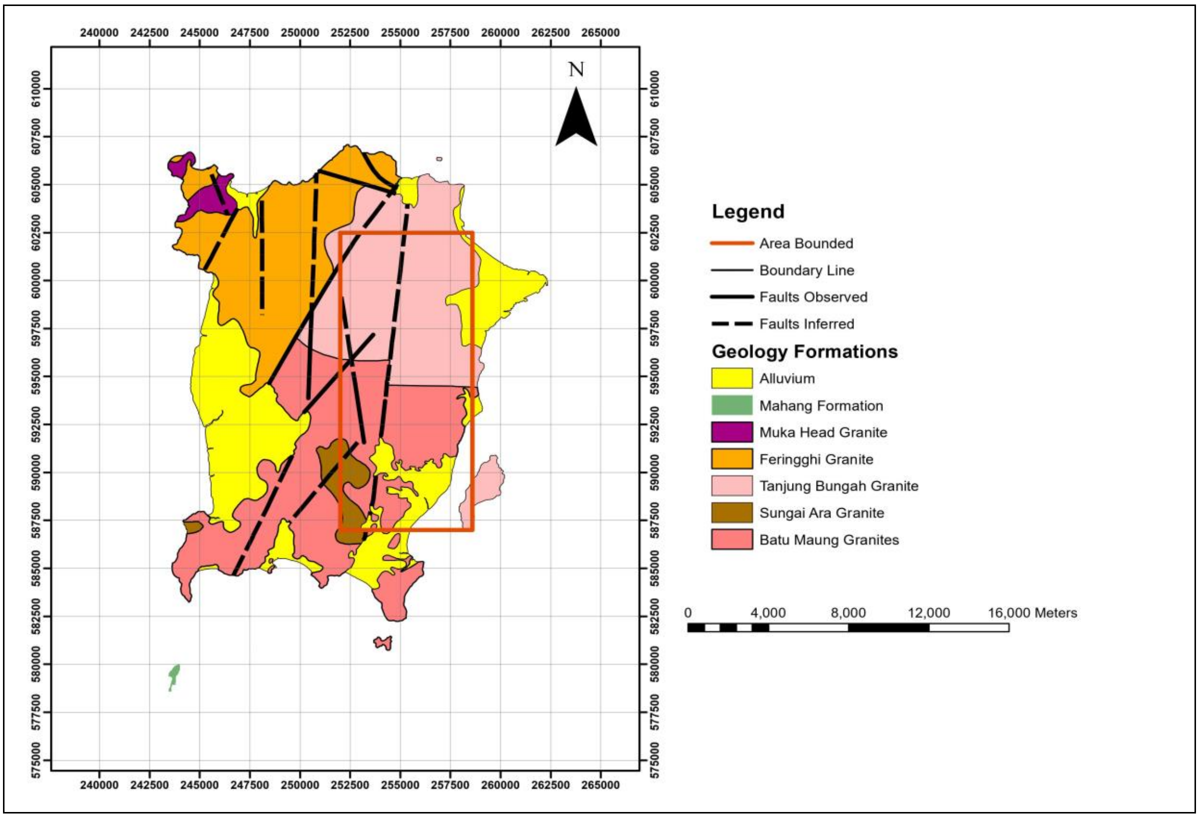

Figure 3. Geological Map of the Penang Island. Redrawn from [42]. Study area is marked with the red box.

IOP Conf. Series: Earth and Environmental Science **971** (2022) 012025 doi:10.1088/1755-1315/971/1/012025

Table 2. Previous relevant studies carried out in Penang Island area.

Reference	Geo-material studied	Properties studied	Gaps
Ong [42]	Geology and Engineering Geology of Penang Island	General Geology Engineering Geology (Aggregates)	Data on Engineering Geology not typically used in Geotechnical Engineering
Tan [39]	Soils Rocks and slope stability in Penang Island urban area. The study covered both North and South Pluton	i) Engineering properties of the granitic soils ii) Engineering properties of the granites iii) Slope stability. iv) Produced a correlation of UCS=7 to 17 Is(50)	Did not differentiate the two granites (The correlation is combined for the two plutonic groups)
Ahmad *et al.* [43]	North Pluton: (Batu Feringghi, Tg Bunga & Muka Head Microgranite) South Pluton: (Batu Maung Granite and Sungai Ara Granite.)	Soil Index Properties SPT-N Values Stiffness and Compressibility	No Rock Strength

4. Methodology

Given that the study takes place during the COVID-19 Pandemic, the data used for this study is secondary data. A total of fifty (50) Soil Investigation (SI) points from around the Penang Island area are gathered and analysed. The rock samples are distributed all around the Penang Island, mainly on the east coast of the Penang Island. Since there is a restriction on the exact locations of the boreholes by the data contributor, the authors will only include the approximate area bounded by SI points, which is summarized as shown in Table 3.

Table 3. Area Bounded by the SI Points.

Axis	RSO Coordinates (meters)	
	From	To
Northing	587 000	602 500
Easting	252 000	258 600

5. Data Analysis

From the data sets, UCS and Is(50) results are extracted. A set of rock sample is when UCS and Is(50) is available for a given depth. Only rock samples that comply with the test requirements outlined by ISRM and ASTM were selected for this study. A total of forty-two (42) sets of rock samples are used for this study. Any inconsistencies between the records shown on the results sheet and the recorded dimensions of the rock sample is checked, and corrections are made accordingly. It must be noted that the laboratory tests were done at the respective laboratories, and the accuracy and reliability of the results are borne by the respective Soil Investigation Contractors. Table 4 summarized the available data for this study:

Table 4. Summary of the data available for this study.

No	Pluton Member	Geological Formation	Sample No.s
1	North	Tg, Bungah	19
2	South	Batu Maung	22
3	South	Sg. Ara	1

5.1 Strength Classification of the rock samples

The rock samples are classified based on its strength. The strength classification shall be based on the BS 5930. BS5930:2015 were used to classify the strength of the rock samples. Clause 36.2.1 is referred from BS5930:2015. The rock strength descriptions are summarized as Table 5 below:

Table 5. Terms for description of rock strength. Adapted from [12].

Term for use in field or based on measurement	Definition for field use	Definition on basis of Unconfined Compressive Strength measurements (MPa)
Extremely weak	Can be indented by thumbnail. Gravel sized lumps crush between finger and thumb.	0.6 – 1.0
Very weak	Crumbles under firm blows with point of geological hammer. Can peeled by a pocketknife.	1 – 5
Weak	Can be peeled by a pocketknife with difficulty. Shallow indentations made by firm blow with the point of geological hammer	5 – 25
Medium strong	Cannot be scraped with pocketknife. Can be fractured with a single blow of geological hammer.	25 – 50
Strong	Requires more than one blow of geological hammer to fracture.	50 – 100
Very strong	Requires many blows of geological hammer to fracture.	100 – 250
Extremely strong	Can only be chipped with geological hammer.	>250

From this, it is learned that in overall, the granites from Penang Island are categorized as “weak to very strong” rocks, with the UCS values between 24.76 to 156.82 MPa. The granites from the North Pluton are classified as “medium strong to very strong”, with UCS values between 37.11 to 156.82

MPa. The granites from South Pluton are classified as "weak to very strong" with UCS values between 24.76 to 151.59 MPa. The result from this stage of analysis is summarized in Table 6:

Table 6. Summary of the UCS value range and strength descriptions based on BS5930:2015.

Geology	UCS (MPa)	Strength description
North Pluton	37.11-156.82	Medium strong to very strong
South Pluton	24.76-141.59	Weak to very strong
Overall	24.76-156.82	Weak to very strong

5.2 Correlation between UCS values and Is(50) values

This stage of analysis aims to find out the correlation between the UCS value and the Is(50) values for the rock samples. In order to achieve this, a simple mathematical approach is employed. The UCS and Is(50) values are plotted into a graph using Microsoft Excel. An upper boundary line and a lower boundary line were drawn to limit the highest and the lowest value. Then, gradient for these two boundary lines shall be determined in order to find the formula. The formula UCS= x Is(50) will be derived from this exercise, where x is the gradient. Next, a line of simple linear regression is also obtained from the graph. The line is the best fit line. The equation of the line shall be the correlation between UCS and Is(50). The analysis is done for overall, North Pluton and South Pluton samples. The graph obtained for overall samples is as shown in Figure 4.

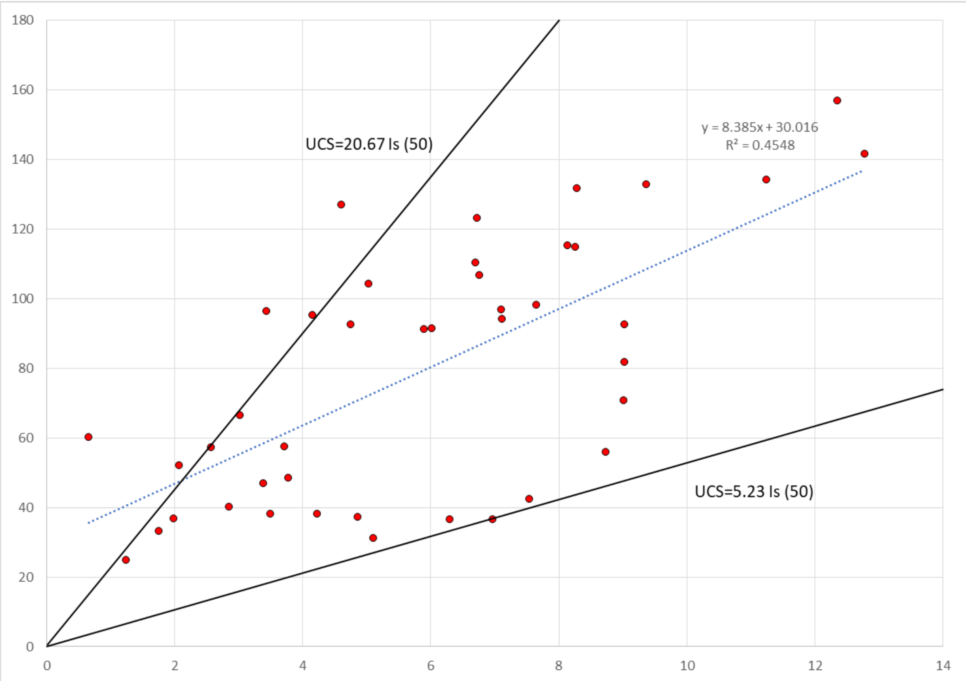

Figure 4. UCS vs Is(50) graph for Overall Samples.

Based on Figure 4, the correlation between UCS and Is(50) for overall Penang Island Granites is 8.385 Is(50) + 30.016, with a correlation coefficient (R^2) of 0.455 and R value of 0.674. This shows that the data is scattered around the fitted regression line, with a positive correlation. This also tells us that 45.5% of the variability of UCS value is affected by the Is(50) values.

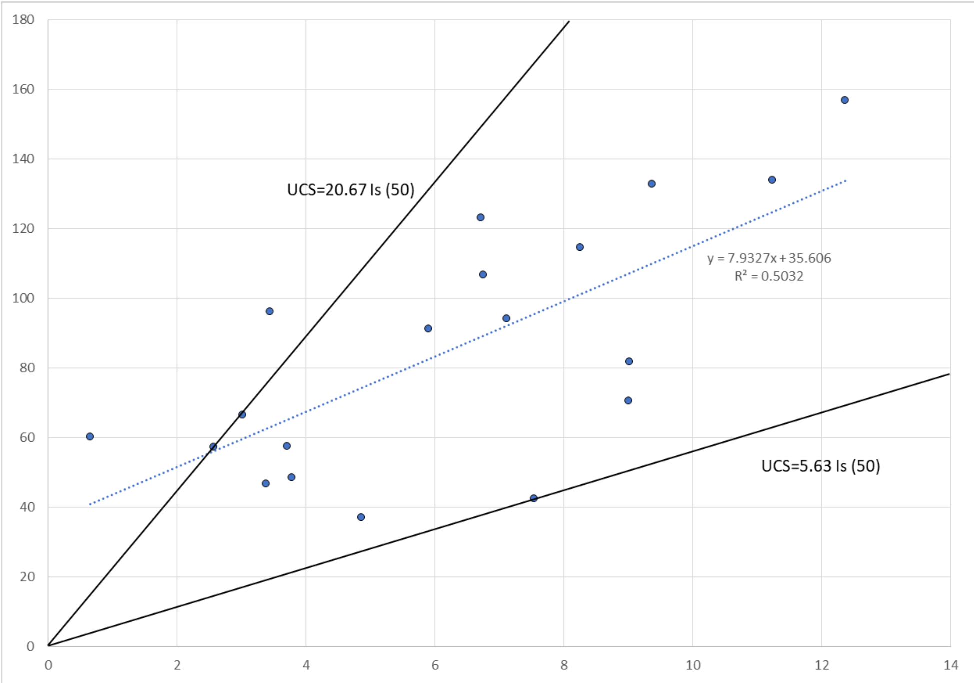

Figure 5. UCS vs Is (50) graph for North Pluton Samples.

Based on Figure 5, the correlation between UCS and Is(50) for North Pluton Granites is 7.93 $Is_{(50)}$+ 35.606, with a correlation coefficient (R^2) of 0.503 and R value of 0.709. This shows that the data is scattered around the fitted regression line, with a positive correlation. This also tells us that 50.3% of the variability of UCS value is affected by the Is(50) values.

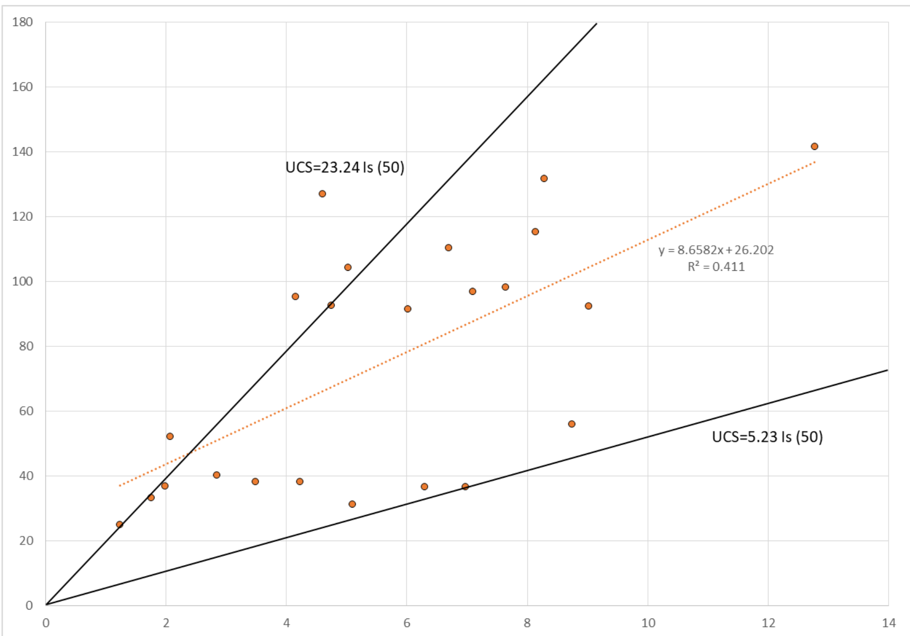

Figure 6. UCS vs Is (50) graph for South Pluton Samples

Based on Figure 6, the correlation between UCS and Is(50) for the South Pluton Granites is 9.03Is(50)+20.138, with a correlation coefficient (R^2) of 0.411 and R value of 0.641. This shows that the data is scattered around the fitted regression line, with a positive correlation. This also tells us that 41.1% of the variability of UCS value is affected by the Is(50) values. From graphs shown in Figure 4, Figure 5 and Figure 6, the following can be summarized, shown in Table 7.

Table 7. Summary of the recommended correlations.

Data Set	Lower Boundary	Upper Boundary	Recommended Correlation	R^2	R	Equation No
Overall	5.23 Is(50)	20.67 Is(50)	8.385 Is(50) + 30.016	0.455	0.674	(3)
North Pluton	5.63 Is(50)	20.67 Is(50)	7.93 Is(50)+ 35.606	0.503	0.709	(4)
South Pluton	5.23 Is(50)	23.24 Is(50)	9.03Is(50)+20.138	0.411	0.641	(5)

5.3 Comparison with previous studies

One of the main goals of this study is to build upon the work by [39] Through this, existing knowledge on the Penang Islan Granites can be improved. [39] proposed the upper and lower boundary lines for Penang Island Granites. As such, the upper boundary and lower boundary is compared for the overall samples. Figure 7 shows the plotting from [39] and this study.

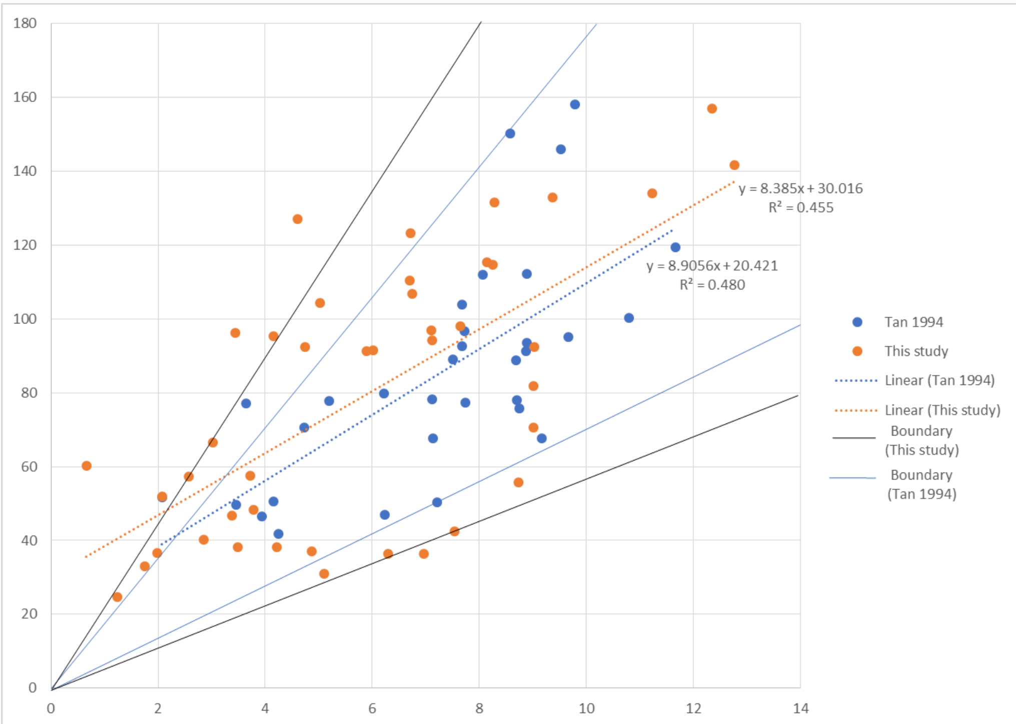

Figure 7. UCS and Is(50) values from Tan [39] and this study plotted together.

From Figure 7, it is learned that this study expanded the range of values of the lower boundary and the upper boundary. More data are added into the range proposed by Tan [39].This is something positive as more data is available, increasing the reliability of the proposed value by Tan [39]. Twenty-four (24) more data sets fall be between the 7-17 Is(50) proposed by Tan[39]. A similar result to [4] was also obtained where the R^2 value decreased when the sample number increases. The R^2 value for North Pluton (19 samples) are higher than the South Pluton (23 samples).

From the laboratory results, it is calculated that the average value for UCS for North Pluton Granites is higher than the South Pluton Granites. This was also observed for Is(50) values as well. This is thought to be as a result of the difference of (1) rock weathering condition and (2) difference of grain sizes of granite. This is in line with previous findings by previous granitic rock researchers which found that the petrological properties, texture, grain size, mineral composition and weathering grades affects the mechanical properties of a granite [44-46].

Equations 3, 4 and 5 were then compared with other correlations published. It is learned that the equations tend to underpredict the UCS values of the granites. Twenty-four (24) samples were underpredicted when the UCS is predicted using the proposed equations from this study, while the remaining eighteen (18) were overpredicted. This is expected since the R^2 values are relatively low.

6. Conclusion and recommendations

This study accomplished in classifying the Penang Island Granites based on UCS value and Is(50). Strength classifications were successfully made based on BS5930:2015. This study also proposed the correlation between UCS and Is(50) for the Penang Island Granites, as well as the upper boundary and the lower boundary lines. The correlations proposed as well as the strength classification were made for overall, North Pluton and South Pluton members of the Penang Island Granites. This study showed that the Penang Island Granites are “weak to very strong” granites with UCS values between 24.76 to 156.82MPa. The granites from the North Pluton are classified as “medium strong to very strong” with UCS values between 37.11 to 156.82MPa. The granites from the South Pluton are classified as “weak to very strong” with UCS values between 24.76 to 141.59 MPa. The recommended correlation between UCS and Is(50) are (1) Overall: 8.385 Is(50) + 30.016 (2) North Pluton: 7.93 Is(50)+ 35.606 (3) South Pluton: 9.03Is(50)+20.138.

There are a few suggestions that can be considered for future works such as to use primary data for analysis. Even though the majority of the fieldworks were supervised by the authors, as well as by experienced Geotechnical Engineers, ultimately the sampling and lab tests were carried out by a third party i.e., SI Contractors. The skill in drilling may affect the sample in which coring-induced fracture may occur, which in return would affect the strength. We could also better monitor the sample preservation. The samples in this study were stored in a wooden box, handled carefully. However, there could be some unknown accidents from the site to the laboratory. A poor sample preservation could also cause, loss of moisture over time may affect the rock quality eventually affecting the UCS results. The second suggestion is to increase the number of samples, in order to obtain better correlation and the boundary lines of the data. More data would give a more accurate simple linear regression line, and as a result, a more accurate correlation could be proposed. The third suggestion is to make the data uniform in terms of the testing standards followed. In this study, samples from ASTM and ISRM are combined. It would be beneficial if future study would be made up exclusively from one standard of testing. Not only that, there is also identified research gap in this area where the major difference in results between ASTM and ISRM standards can be explored.

7. References

[1] Aliyu M M, J. Shang, W. Murphy, J. A. Lawrence, R. Collier, F. Kong and Z. Zhao 2019 Assessing the Uniaxial Compressive Strength of Extremely Hard Cryptocrystalline Flint, *Int. J. of Rock Mech. Min. Sci*. **113** 310–321

[2] Basu A, N Ghosh and M Das 2012 Categorizing Weathering Grades of Quartzitic Materials and Assessing Brazilian Tensile Strength with Reference to Assigned Grades, *Int. J. of Rock Mech. Min. Sci.* **49** 148–155

[3] Cai M 2010 Practical Estimates of Tensile Strength and Hoek–Brown Strength Parameter m_i of Brittle Rocks, *Rock Mech. Rock Eng.* **43** (2) 167–184
[4] Momeni E, Nazir R, Armaghani D J and Mohamad E T 2015 Prediction of Unconfined Compressive Strength of Rocks: A Review Paper, *J. Tekno.* **77**(11)
[5] Aksoy C O, Ozacar V, Demirel N, Ozer S C and Safak S 2011 Determination of Instantaneous Breaking Rate by Geological Strength Index, Block Punch Index, and Power of Impact Hammer For Various Rock Mass Conditions, *Tunnel Underground Space Tech.* **26**(4) 534–540
[6] Gunsallus K L and Kulhawy F H 1984 A Comparative Evaluation of Rock Strength Measures, *Int. J. of Rock Mecha. and Min. Sci. and Geomech*. **21** 233-248.
[7] Broch E and Franklin J A 1972 The Point Load Strength Test, *Int. J. of Rock Mech. and Min. Sci. and Geomech.* **9** 669-697
[8] ISRM. International Society of Rock Mechanics Commission on Testing Methods 1985 Suggested Method for Determining Point Load Strength, *Int. J. of Rock Mech. and Min. Sci. and Geomech.* **22** 51-60
[9] Edelbro C 2004 *Evaluation of Rock Mass Strength Criteria* PhD Thesis (Sweden: Luleå University of Technology) pp 11
[10] Jahanger Z K and Ahmed A A 2013 Correlation Between Point Load Index And Very Low Uniaxial Compressive Strength Of Some Iraqi Rocks, *Australian J. of Basic and Appl. Sci.* **7**(7) 216-229
[11] Deere D U and Miller R P 1966 *Engineering Classification and Index Properties For Intact Rock*, Technical Report No. AFWL-TR-65-116 (New Mexico: Air Force Weapons Laboratory) pp 136
[12] British Standards Institute (BSI) 2015 *BS5930 Code of Practice For Site Investigations* (London: British Standard) pp 134
[13] Geotechnical Engineering Office (GEO) 2017 *Guide to Rock and Soil Descriptions* (Hong Kong: Geotechnical Engineering Office) pp 12
[14] Bieniawski Z T 1974 Geomechanics Classification Of Rock Masses And Its Application In Tunneling, *Proc. 3rd Int. Congress on Rock Mechanics* (Denver) 27-32
[15] Barton, N 2002 Some New Q-Value Correlations To Assist In Site Characterization And Tunnel Design, *Int. J. of Rock Mech. and Min. Sci.* **39** 185-216
[16] Laubscher D H and Jakubec J 2001 The MRMR rock mass classification for jointed rock masses. Underground mining methods: engineering fundamentals and international case studies eds. Hustrulid WA, Bullock RL (Littleton, CO: Society for Mining, Metallurgy, and Exploration, Inc) pp 475–481
[17] Hoek E (1994) Strength of Rock and Rock Masses ISRM News J. **2** (2): 4–16
[18] Palmstrøm A 1996 Characterizing Rock Masses by The RMi For Use in Practical Rock Engineering: Part 1: The development of the Rock Mass index (RMi), *Tunnel Underground Space Tech.* **11**(2), 175-188
[19] Horvath R G and Kenney T C 1979 Shaft Resistance of Rock Socketed Drilled Piers, *Proc. of a Symposium on Deep Foundations* (Atlanta, Georgia, USA) pp. 182–214
[20] Rosenberg P and Journeaux N L 1976 Friction and End Bearing Tests on Bedrock for High-Capacity Socket Design, *Canadian Geotech. J.* **13**(3): 324–333
[21] Rowe R K and Armitage H H 1987 A Design Method for Drilled Piers in Soft Rock, *Canadian Geotechnical Journal* **24**(1) 126–142
[22] Carter J P and Kulhawy F H 1988 Analysis and Design of Drilled Shaft Foundations Socketed into Rock. Final report, EPRI-EL-5918/Project 1493-4 (New York:Electric Power Research Institute Cornell University)
[23] Zhang L and Einstein H H 1998 End Bearing Capacity of Drilled Shafts in Rock, *J. of Geotech. and Geoenv. Engineering* **124**(7) 574–584
[24] Meigh A C and Wolski W 1979 Design Parameters for Weak Rock, *Proc. of the 7th Euro. Conf. on Soil Mech. and Foundation Eng.* (Brighton, UK) **5** 59–79

[25] Williams A F and Pells P J N 1981 Side Resistance Rock Sockets in Sandstone, Mudstone, And Shale, *Canadian Geotechnical Journal* **18**(4) 502–513
[26] Kulhawy F H and Phoon K K 1993 Drilled Shaft Side Resistance in Clay Soil to Rock *Proc. of Conference on Design and Performance of Deep Foundations: Piles and Piers in Soil and Soft Rock* Geotechnical Special Publication **38** 172–183
[27] Hoek E and Brown E T 1980 Empirical strength criterion for rock masses. Jour. of the Geotech. Eng. Division, ASCE **106**(GT9): 1013–1035
[28] Bieniawski Z T and Bernede M J 1979 Suggested Methods for Determining The Uniaxial Compressive Strength And Deformability Of Rock Materials: Part 1. Suggested Method for Determining Deformability of Rock Materials in Uniaxial Compression, *Int. J. of Rock Mecha. and Min. Sci. and Geomech*. Abstracts **16**(2) 138-140
[29] ISRM. International Society of Rock Mechanics Commission on Testing Methods, (2007). The Complete ISRM Suggested Methods for Rock Characterization, Testing and Monitoring: 1974–2006. (Ankara:Int. Soc. for Rock Mechanics)
[30] Thuro K, Plinninger R J, Zäh, S and Schütz S 2001 Scale Effects In Rock Strength Properties. Part 1: Unconfined Compressive Test and Brazilian Test, *ISRM regional symposium, EUROCK* pp. 169-174
[31] Chiu H K and Johnston I W 1983 The Uniaxial Properties of Melbourne Mudstone, *5th Congress of the International Society for Rock Mechanics*, 209-214
[32] Matthews M C and Clayton C R I 1993 Influence of intact porosity on the engineering properties of a weak rock, *Geotechnical Engineering of Hard Soils – Soft Rocks*, pp. 693-701
[33] Bieniawski Z T 1975 The Point-Load Test in Geotechnical Practice, *Eng. Geol*. **9** 1-11
[34] Reese L C and O'Neill M W 1988 Drilled Shaft: Construction Procedures and Design Methods, Publication No. FHWA-H1-88-042 (Washington: US Department of Transportation-Federal Highway Administration
[35] Tan B. K and Chan S F 1980 Preliminary Studies on The Correlation of Index Properties and Engineering Properties of Malaysian Rocks, *Geol. Soc. Malaysia Bulletin* **12** 31-43
[36] Basu A and Aydin, A. 2006 Predicting Uniaxial Compressive Strength by Point Load Test: Significance of Cone Penetration, *Rock Mech Rock Eng.* **39** 483–490
[37] Ghosh D K and Srivastava M 1991 Point-Load Strength: An Index for Classification of Rock Material, *Bulletin of the Int. Assoc. of Eng. Geol.*, **44**(1), 27-33
[38] Tuğrul A and Zarif I H 1999 Correlation of Mineralogical and Textural Characteristics with Engineering Properties of Selected Granitic Rocks from Turkey, *Engineering Geology*. **51**(4) 303-317
[39] Tan B K 1994 Engineering Properties of Granitic Soils and Rocks of Penang Island, Malaysia. Geol. Soc. Malaysia Bulletin **35** 69- 77
[40] Chakraborty K R 1990 Granitic Rocks of Penang Island: Minor and Trace Element Variation Patterns and Implications. *Geol. Soc. of Malaysia Annual Geological Conference '90* (Ipoh)
[41] Lee P, Kwang K, Kasim K I B and Azhar A B 2019 Hand-Dug Caisson Piles In Granitic Formation, Penang, *1st Malaysian Geotechnical Society (MGS) and Geotechnical Society of Singapore (GeoSS) Conference* (Petaling Jaya, Malaysia)
[42] Ong W S 1993 The Geology and Engineering Geology of Pulau Pinang. (Kuala Lumpur: Jabatan Penyiasatan Kajibumi Malaysia)
[43] Ahmad F, Yahaya A S and Farooqi M A 2006. Characterization and Geotechnical Properties of Penang Residual Soils with Emphasis on Landslides, *Am. J. Env. Sci*, **2**(4) 121-128
[44] Irfan T Y 1996 Mineralogy, Fabric Properties and Classification of Weathered Granites in Hong Kong, *Quarterly J. of Eng. Geol. and Hydrogeo.*, **29**(1) 5-35.
[45] Brace W F 1961 Dependence of Fracture Strength of Rocks on Grain Size, *Penn. State Univ. Mineral Expt. Sta. Bulletin* **176** 99-103
[46] Yusof, N Q A M and Zabidi H. 2016 Correlation of Mineralogical and Textural Characteristics with Engineering Properties of Granitic Rock From Hulu Langat, Selangor. *Procedia Chemistry* **19** 975-980

Acknowledgments
Authors would like to acknowledge UTM Research Grant-Tier 2 (Vot No: Q. J130000.2651. 16J84) for financial support. Authors would also like to thank Mr. Andrew Tham and Mr. Devendran Arumugam and Mr. Yeoh Gim Heng for their assistance in this research.