Experimental testing and ultrasonic pulse transmission technique of granite for sustainable rock testing approach at Rawang, Selangor

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Abstract. Advanced characterization technique which is Non-destructive Testing (NDT) technique are required to monitor the testing for physical and mechanical properties of rock. Using Non-destructive Testing technique, the information gather are much faster and easier without any disturbance to the sample test. In rock engineering, the key role in the long term stability are depending on the characteristics of rock and the rock masses. Since the finding of strength parameter are time consuming and very expensive, this research is conducted to perform experimental testing and ultrasonic pulse transmission technique on granite for a sustainable rock testing approach. Through this study, it enables to identify a simple way to predict these strength parameters especially and specifically for Unconfined Compression Strength (UCS) by using Point Load Test (PLT) and Ultrasonic Pulse Velocity (UPV) Test. From this study, the correlation can be made among UCS, point load index, and sound velocity which the empirical formula for point load and the ultrasonic pulse velocity test are $\text{UCS} = 20.8(I_{50}) + 2.2$ and $\text{UCS} = 144.68V_p - 684.37$ respectively. The ultrasonic pulse transmission technique methods can be used to predict the compressive strength of rock. It can be practically used in the field since the technique are portable and easy to use. By using the least-square regression method, the empirical formula formulated between UPV and UCS values signifies that the correlation coefficient ($R^2$) obtained for the equation is 0.9692 and indicates that both variables have a good agreement relationship.

1. Introduction

Identification of engineering parameters of rock is an important part of all rock engineering problems. A strong laboratory database of mechanical and engineering properties of rocks is very useful for site characterization and mining engineering applications. Owing to the discontinuous and variable nature of rock masses, it is difficult for rock engineers to directly obtain the specific design parameters of interest. As an alternative, they use empirical or theoretical correlations among various physical and mechanical properties of rocks to estimate the required engineering properties of rocks \cite{1}.

There is various problem that can be encountered when dealing with rock. There is rock crack, weak rock and easy to break due to weathering that can cause phenomenal disaster such as rockslide, rock fall and sinkholes.

In Malaysia, there is problematic rock condition in Malaysia that is commonly occurred as the condition difficult to predict the exact value of strength. This can lead to complication during construction process, or in attempting to protect the long existence of the constructions. Hence,
understanding the behaviour of weak rock by conducting the experimental work can be attempted to lead and providing information on identifying rock problem or issues.

This study can contribute for better understanding of the rock physical and mechanical behaviour by using experimental testing such as Point Load Test (PLT) and Ultrasonic Pulse Velocity (UPV) Test to estimate the uniaxial compressive strength (UCS) of intact rock. The obtained data can be used to lead the identification of rock and determine for its physical and mechanical characterization of rock mass. The determination of rock strength at in-situ is the mostly preferable and reliable method of testing to incorporate with the laboratory data. Besides, the data is useful to establish the relationship of UCS with Point Load index value. It is promising for geotechnical engineer to implement during the design stage of rock related in engineering works as to identify the uniaxial compressive strength by using Point Load Test.

In addition, engineers are enables to formulate and correlate information or data using the testing result. The rock behaviour must be consider either in designing planning and before the construction begin to ensure no problems occur in the future. It is desirable that the study can give a positive impact in rock excavation field. Thus, it can lead to proper prediction of the rock blasting during excavation. Moreover, the application of the non-destructive testing can prevent the disturbance occurred by excavation and preserve the sustainability of the ground condition as the original state.

2. Materials and testing method
In this study, uniaxial compressive strength test is used and other alternative laboratory method to be conducted that is the ultrasonic pulse velocity test or also known as pundit test. The strength properties of granite are studied to quantify the weathering impact to these materials. The standard testing procedures have become more difficult as rock material become weaker [2]. Sample of granite have been found and collected from rock quarry located at Sunway quarry in Rawang, Selangor.

2.1. Sample preparation
For laboratory work, the sample were cut to appropriate size where stated by ISRM [3]. This laboratory, to cut the sample coring machine will be used to get the circle shape of samples. The size of samples must be 50 mm for diameter, D and the samples shall be right circular cylinders having a height to diameter ratio of 2.0 – 3.0 by using Vernier Calliper as shown in Figure 1. In this research, 30 samples of granite have been prepared. The physical properties of the rock samples of granite are provided in Table 1.

![Figure 1. Core samples of granite](image)

| Grade | Rebound No. (N) | Water Content (%) | Porosity (%) | Dry Density (kg/m³) |
|-------|----------------|------------------|--------------|---------------------|
| III   | 44             | 0.225            | 0.542        | 2416                |

Table 1. Physical properties of Granite samples from Rawang, Selangor
2.2. Testing method
Related testing to determine the strength of the rock is conducted at Rock Mechanic laboratory in Faculty of civil engineering, UiTM Shah Alam. Series of test such as unconfined compressive strength, point load, wave, durability and specific gravity are carried out. A few parameters are highlighted in this study for instance; uniaxial compressive strength, point load, rebound hammer value, sound velocity, water content, porosity and density of granite samples.

2.2.1. Rebound Hammer Test
The procedure of the laboratory testing is according to ISRM [3], suggested method for determination of the Schmidt hammer rebound hardness (a revised version). Firstly, for data gathering, 20 rebound values were recorded from single impacts separated by at least a plunger diameter. Several sets of isotropic rock readings were taken from different faces of blocks since the uniform specimens are not sufficient. The set of readings were given in the corresponding order and any consistent reduction from the first set of measurements were carefully monitored. Table 2 shows the classification of rock strength by using rebound hammer values based on Atterwell and Farmer [4].

| Strength classification | Strength range, (MPa) | Grade of rocks |
|------------------------|-----------------------|----------------|
| Very strong            | 160-320               | Granite grade I|
| Strong                 | 80-160                | Granite grade II|
| Medium                 | 40-80                 | Granite grade III|
| Weak                   | 20-40                 | Granite grade IV|
| Very weak              | 0-20                  | Granite grade V|

2.2.2. Water Content, Porosity and Density Test
The procedure for determining water content, porosity, density, absorption and related properties and swelling and slake-durability index properties - 1977 [EUR 4], ISRM [3]. For the procedure to determine water content, the container with its lid was cleaned and dried, and it’s mass, A determined. A representative sample comprised at least 10 lumps each having either a mass of at least 50 g. The sample was placed in the container, the lid replaced and then mass B, of sample plus container determined. The sample was placed in the container, the lid replaced and the mass B, of sample plus container determined. The lid was removed, and the sample dried to constant mass at a temperature of 105 degree Celsius. The lid was replaced, and the sample allowed to cool in desiccator for 30 minutes. The mass C of sample plus container was determined. Thus, the calculation for the test was:

\[
\text{Water content} = \frac{(\text{pore water pressure mass, } M_v)}{(\text{grain mass, } M_s)} \times 100\% \tag{1}
\]

\[
= \frac{(B-C)/(C-A)}{\times 100\%} \tag{2}
\]

Procedure to determine the porosity and density using saturation and buoyancy techniques is started by providing a representative sample having a mass of at least 50g and comprising at least 10 lumps irregular geometry. Secondly, to remove the dust, the sample was washed in water and was saturated by water immersion for a period of at least one hour. To determine its saturated-submerged mass \(M_{sub}\), the sample was transferred under water to the basket in the immersion bath. Then, its mass A was obtained with the sample container with its lid was cleaned and dried. The sample was carefully removed from the immersion bath and surface-dried with a moist cloth to remove only surface water and to ensure that no rock fragments are lost and remove only surface water. Next, the mass B of saturated-surface-dry sample plus container was determined by the sample is transferring the samples to the sample container and replaced the lid. Lastly, to get the mass C of oven dry sample plus container, the sample dried to constant mass at a temperature of 105°C for 24 hours as shown in Figure 2 with the removed lid. Then
the lid replaced followed with sample allowed to cool for 30 minutes in a desiccator. The calculation for the test was as follows:

\[ M_{sat} = B - A \] (3)
\[ M_s = C - A \] (4)
\[ V = \frac{(M_{sat} - M_{sub})}{\rho_w} \] (5)
\[ V_v = \frac{(M_{sat} - M_s)}{\rho_w} \] (6)
\[ n = \frac{100V_v}{V} \% \] (7)
\[ \rho_d = \frac{M_s}{V} \] (8)

2.2.3. Sound Velocity Test
The procedure of testing is according to upgraded ISRM[3] suggested method for determining sound velocity by ultrasonic pulse transmission technique. Before the test was conducted the Pulse Ultrasonic Velocity (PUV) equipment was calibrated using the calibrator and the reading must show the exact value of the velocity which is 42.5μs. Another name for this equipment is Portable Ultrasonic Non-destructive Digital Indicating Tester (PUNDIT). The procedures are beginning with a thin layer of grease oil was used to ensure efficient and uniform energy transfer from to the transducer. The transducer was positioned and aligned to produce an acoustic axis (centre beam) that was normal to both faces. Then 5 readings were being recorded and the average was calculated, and the procedures were repeated to the other 5 specimens.

2.2.4. Uniaxial Compressive Strength Test
This test was conducted using Universal Testing Machine (UTM-500). The procedure of this UCT testing is based on standard method for determining the uniaxial compressive strength and deformability of rock materials -1979 [EUR 4][3]. The procedure started when load on the specimen was applied continuously at a constant stress rate such that failure occurred within 5 – 10 minutes of loading, alternatively the stress rate shall be within the limits of 0.5 – 1.0 MPa/s. Then the maximum load on the specimen was recorded in kilonewtons and megapascal. The 3 specimens tested were determined the loads by the same procedures as stated above.

2.2.5. Point Load Test
The procedure for Point Load test is according to standard method for determining point load strength -1985 [EUR 4][4]. The sample were cylinder so the diametral test procedure can be opt for the sample testing. The test has used Universal Testing Machine (UTM-500). Before the test were conducted, the centre of the samples was marked for the contact to happen between the samples and UTM. The core specimens with length/diameter ratio greater than 1.0 are suitable for diametral testing. The specimen was inserted in the test machine and the platens closed to make contact along a core diameter, the distance between the contact points and the nearest free end was at least 0.5 times the core diameter. The load was steadily increased such that failure occurred within 10-60sec, and the failure load P was recorded and procedures above were repeated for the remaining specimens in the sample as pictured in Figure 2.
Figure 2. Sample testing a) centre of the sample was marked b) sample before the load c) sample after the load was applied

3. Results and discussion

The granite rock samples taken at Rawang has been determined its classification and it is found that the granite rock samples are of grade III. It shows a medium class range between 40 – 80 MPa. Despite that, for its moisture content, the value is 0.225 percent and the average porosity is 0.542 percent. For sound velocity (Vp), the values obtained are very high as recorded in the Table 3 which mostly stated more than 5 km/s range.

Table 3. The sound velocity (Vp) values

| Specimens | Vp (m/s) |
|-----------|----------|
| UCS1      | 5576     |
| UCS2      | 5199     |
| UCS3      | 5333     |
| UCS4      | 5416     |
| UCS5      | 5238     |

The analysis of the uniaxial compressive strength (UCS) with point load shows that uniaxial compressive strength (UCS) has higher values compared to point load values. It means to break down the granite in easy manner is by applying load at a point of the granite. While for the sound velocity (Vp) is the longer the time taken for the wave travel to another end of specimen the lesser amount of void exists in the specimen. Table 4 indicated data gathered for the strength properties of granite samples in this study.

Table 4. Strength properties of granite samples from Rawang, Selangor.

| UCS (MPa) | Point Load (MPa) |
|-----------|------------------|
| UCS1      | 120.822          | PLT1 9.646     |
| UCS2      | 64.256           | PLT2 11.307    |
| UCS3      | 85.122           | PLT3 8.635     |
| UCS4      | 104.861          | PLT4 9.259     |
| UCS5      | 77.593           | PLT5 10.613    |
Table 5. Water content for Granite in Turkey [5]

| Sample No | Water Content (%) |
|-----------|-------------------|
| Gr1       | 0.24              |
| Gr10      | 0.18              |
| Gr13      | 0.26              |
| Gr16      | 0.20              |
| Gr19      | 0.19              |

The value for the water content for the granite rock samples from Rawang, Selangor is 0.225 percent and to be compared with Table 5 is the value also in range. Thus, it means that water content for granite for both study area which are Rawang, Selangor and from Turkey have quite similar physical properties in term of water content for granite rock. As for the comparison, the result from the researcher showed that percentage of the porosity of the granite is 0.542 percent and the range of uniaxial compressive strength (UCS) obtained are 85 to 120 MPa. The dry density that obtained from the Granite at Rawang, Selangor was 2416 kg/m³ for range of sound velocity (Vp) from 5.199 – 5.333 km/s. The correlation between uniaxial compressive strength (UCS) against sound velocity (Vp) indicate that the higher the value of sound velocity (Vp) the higher uniaxial compressive strength (UCS). It means the less amount of void in the granite produce higher amount of load to break down the granite. The equation produce from the graph is that UCS = 144.68Vp – 684.37 to show the relationship between those two properties as in Figure 3. By using least-square regression method, the empirical formula can be formulated between UPV with the UCS values. From Figure 3, the correlation coefficient (R²) obtained for equation is very good for rock mechanics with the reading of 0.9692 which is approaching 1. It indicates that both variables have a good agreement relationship.

![](image1)

**Figure 3. UCS (MPa) vs Vp (km/s)**

Figure 4 shows the previous researches about the relationship between uniaxial compressive strength (UCS) and sound velocity (Vp). According to the Figure 3, the researcher’s starting line is below than the other three lines. It means that the Granite rock at Rawang, Selangor has quite low of uniaxial compressive strength (UCS) at 5.2 km/s. Then, at the centre to end of line, the researcher’s line of graph has gone above Yagiz [6] which include that the higher of sound velocity (Vp) produce high increase of the uniaxial compressive strength (UCS). While for Tugrul and Zarif [5] and Sharma and Singh [7], their line of graph has higher uniaxial compressive strength (UCS) that the researcher at the same sound velocity (Vp).
Figure 4. Comparison of UCS (MPa) vs Vp (km/s) from previous researches

According to Figure 5, the graph shows that the increasing of point load index lead to increase of UCS. Although the value of point load index is relatively small but the UCS values are quite large. The diameter of the samples according to the core were 50 mm. To produce the point load index (Ip), the equation Ip = P/D^2 was used. P is point load failure value in Newton and the D is diameter of the sample in mm. The previous of research showed that the more accurate of relationship between UCS and Ip by indicating the graph in linear relationship. Thus, by demonstrating the linear relationship of UCS and point load having R² = 87% of confidence level between those two properties.

Figure 5: UCS vs Point Load Index, Ip

From Figure 6, the researcher’s line of graph is below 140 MPa of uniaxial compressive strength (UCS). The line of this study started at second highest and at the middle it has pass the previous highest line. Thus, the point load index for Granite rock at Rawang has highest point load strength between those other researchers above. For linear line of Tugrul and Zarif [5] is below other than researchers. It means that the Granite rock at Turkey is having quite low strength of the samples tested from point load test. Kahraman [8] has produce the linear such as in Figure 8 and shown that its lowest point load index is the highest as compared to other two results. It is considered that is quite high for strength of granite obtained by the point load test.
4. Conclusion
From the seven properties of rock properties tested, correlation can be made among uniaxial compressive strength, point load index, and sound velocity. The result for both point load and uniaxial compressive strength test are affected by the core length and diameter. The core diameter is preferably the 50mm diameter. The sound velocity for the Granite rock is categorized as very high. The prime objective for this research has been achieved which is to obtained the point load index value. The prime objective for this research has been achieved which is to obtained the point load index value.

From the lab test carried out from this study, the empirical formula for the point load index is $20.8(\text{Is}50) + 2.2$. While the other objective is to correlate the strength with the obtained properties of Granite samples. From lab tests that have been conducted, correlation can be made among uniaxial compressive strength, point load index, and sound velocity that will gives out the formula of $\text{UCS} = 20.8(\text{Is}50) + 2.2$ and $\text{UCS} = 144.68\text{Vp} – 684.37$ for point load and the ultrasonic pulse velocity test respectively.

In order to enhance the research a bit more, non-destructive testing should be considered in most site excavation activities that involves geomaterials. This helps in saving materials and loss of energy in preparing unnecessary samples. This also contribute a lot in saving the mother earth materials and highly recommended as an effective sustainability approach. With NDT such as ultrasonic pulse velocity test or also known as pundit test, correlation can be made with the other physical properties with using lesser number of samples. This technique can then be used to monitor the integrity of the structure along it design life.

5. References

[1] Szlavin, J 1974 Relationships between some physical properties of rock determined by laboratory tests Int. J. of Rock Mechanics and Mining Sci. & Geomechanics Abstract 11(2) 57-56
[2] Mohammad E T and Kassim A 2007 Laboratory study of weathered rock for surface excavation works Report under Research Management Centre (Johor: Universiti Teknologi Malaysia)
[3] ISRM 2007 The Complete ISRM suggested methods for rock characterization, testing and monitoring [1974-2006] In: Ulsay, R., Hudson, J.(Eds.)(Lisbon: International Society for Rock Mechanics and Rock Engineering)
[4] P.B. Attewell I W and Farmer 1973 Fatigue behaviour of rock International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts 10(1) 1-9
[5] Tuğrul A and Zarif I H 1999 Correlation of mineralogical and textural characteristics with engineering properties of selected granitic rocks from Turkey Eng. Geology 51(4) 303–317
[6] Yagiz S 2011 P-wave velocity test for assessment of geotechnical properties of some rock materials. Bulletin of Materials Science 34(4) 947–953
[7] Sharma, P.K., Singh, T.N 2008 A correlation between P-wave velocity, impact strength index, slake durability index and uniaxial compressive strength Bull. Eng Geol Environ 67 17–22
[8] Kahraman S 2001 Evaluation of simple methods for assessing the uniaxial compressive strength of rock Int. J. of Rock Mechanics and Mining Sci. 38(7) 981–994

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