Characterization of Tropical Kenny Hill Weathered Sandstone using Non-Disruptive Testing of Pundit and Resistivity Testing

Noorfaizah Hamzah
School of Civil Engineering, College of Engineering,
Universiti Teknologi MARA, 40450, Shah Alam, Malaysia

*Nur'Ain Mat Yusof**
School of Civil Engineering, College of Engineering,
Universiti Teknologi MARA (Pahang), 26400, Bandar Tun Abdul Razak,
Jengka, Pahang, Malaysia
**nurainyusof@uitm.edu.my*

ABSTRACT

Rock characterization of tropical Kenny Hill weathered sandstone have been an effort to be explored by using non-disruptive testing of pundit and resistivity testing to undertake sustainability issues and providing technical approach in exploration of weak rock materials solving. The purpose of this research is to determine the relationship between resistivity and uniaxial compressive strength of the most problematic rock type in Malaysia, namely Kenny Hill weathered sedimentary rocks, more usually referred to as sandstone. According to earlier study, sandstone has degraded in quality and has a tendency to disintegrate due to the tropical climate. Sandstone has a higher strength feature as compared to shale from Bandar Nusa Rhu, Shah Alam. Series of uniaxial compression were carried out to obtain the strength for rock samples. The strength properties of weathered sandstone are studied to quantify the weathering impact to these materials. Resistivity test and Pundit test were laboratory method conducted on the rock samples for verification of the correlation between resistivity and uniaxial compression. Results from the test were analyzed and their relationship with weathering grade was established. It signifies that sandstone strength increasing with the weathering grade.

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Introduction

The knowledge of development due to weathered rock is still at lower level although many problems related to geotechnical were determined in these zones. The profile of weathering and the mass properties of rock in tropical climate are different from other climates. Based on previous researcher report, tropical climate is being affected by heavy rain flow conditions, high temperature and humidity within a year which make the rock decay slowly, but the presence of moisture content hastens the rate of decay [1, 2]. Malaysia is one of the countries which located at tropical weathering region. Tropical Kenny's Hill weathered rock of sedimentary rock can be found in this region. Sandstone is one of the rocks which could be found in Malaysia [3, 4]. Many researchers have highlighted that the strength of sandstone is harder than shale. Besides that, sandstone has lost in quality (degradation) and have tendency to break up into a pieces (disintegration) due to the tropical climate [3, 5]. The strength of tropical weathered rock also can be determined by using other method. Resistivity is measurement of the voltage and current allows determination of the average subsurface resistivity in a volume greatly found by the separation of the electrodes. Resistivity measures subsurface resistivity and can also to be used to map depth weathering, stratigraphy, and structures such as faults, dykes, and fracture zones. By using the resistivity technique, a current is transmitted into the ground by two current electrodes and resulting secondary voltage is measured by two separate potential electrodes. Resistivity allows the mapping of the lateral and depth variation in subsurface resistivity and can thus be used to discriminate between geological units of different resistivity [4]. Resistivity also can be used to detect unnatural or irregulaties in the soil, concentration of minerals deposits and so on.

Other than resistivity test, there is another test can be used to determine the strength of the rock. Seismic velocity test or known as Pundit test is non-destructive and easy to apply either in laboratory or field. In this research, this test is carried out in laboratory. Based on previous researcher, Seismic velocity test will be measured by P-wave velocity. The P-wave of rock velocity is similar to the intact properties of rock. It is also measuring the velocity in rock media questions for the rock structure and texture [6].

Generally, the rock strength is tested in laboratory using uniaxial compressive strength (UCS) tests. Uniaxial compressive strength is the most basic parameter of rock strength to be determined. The uniaxial compressive strength is obtained by compressing a trimmed cylindrical specimen in the longitudinal direction. The uniaxial compressive strength of the rock materials has been preferred as an input parameter for prediction of the elastic modulus

of the rock material or rock mass by some empirical approaches due to the strong relation between the uniaxial compressive strength and the elastic modulus [7]. Based on the previous studies, the uniaxial compressive strength is used to determine the strength of the rock.

The Non-Disruptive Testing (NDT) methods are typically associated with technologies usage, like inspecting weak points using computer or digital camera, which the usage in construction site are most common. It is important to note that NDT does not necessarily require the use of special tools, or any big machinery at all. For instance, when geotechnical engineers in construction site unable to review the site condition with their naked eye, that therefore need the NDT designation, since it designated and have capabilities to collect data on the status of the ground condition without damaging it. On the other hand, using a sophisticated tool like Pundit and Resistivity apparatus to assist in characterizing the tropical Kenny Hill weathered sandstone material without the needs of boring excavation that allow for sustainable and saving the extensive usage of natural materials [5, 8, 9]. Resistivity and Pundit test is one of the alternative ways to determine the strength of the rock. This project aims to establish laboratory data regarding Tropical Kenny Hill Weathered Sandstone's rock strength.

Materials and Testing Method

In this study, the strength will be tested. There are many methods can be used to tests the rock sample such as point load test, Brazillian test and uniaxial compressive strength test. However, for this study, uniaxial compressive strength test is used and other two alternative laboratory methods to be conducted that are resistivity and pundit test. The strength properties of weathered sandstone are investigated in order to quantify the impact of weathering on these materials. As rock material deteriorates, standard testing procedures will become more difficult [2].

Study area

Sample of sandstone have been found and collected from outcrop area at Bandar Nusa Rhu, Shah Alam, Selangor. These sample approximately size about 0.02 m3 with irregular block form. The sample of material is very weak. It’s tendency to fissile when exposed to the weathering.

Sample preparations

In order to handle the laboratory, the sample were cut to appropriate size where stated by ISRM 1981. This laboratory, to cut the sample coring machine will be used to get the circle shape of samples. The size of samples should be less than 55 mm for diameter, D and the samples shall be right circular cylinders having a height to diameter ratio of 2.0 – 3.0. In this research, 30 samples of

sandstone have been prepared. The classification of the samples chosen is based from the previous findings as shown in Figure 1 and Figure 2 show the raw materials that brought to the laboratory before work had been done.

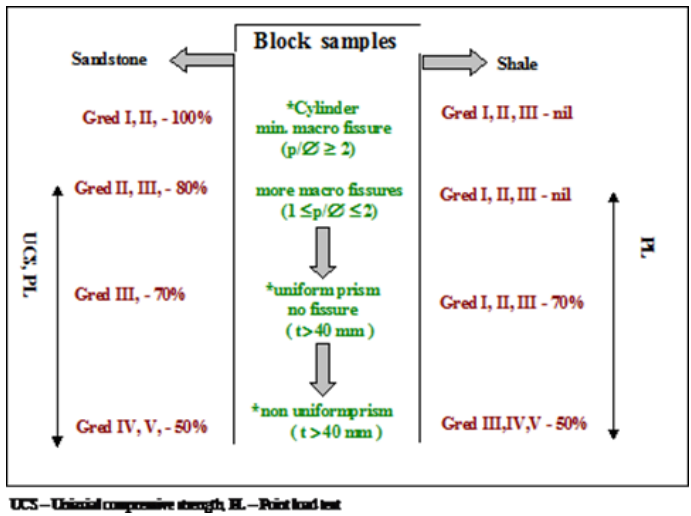

Figure 1: The laboratory strength test design for weathered shale and sandstone [2]

Figure 2: Sample preparation

Testing method

This study is fully conducted in laboratory. There are three main testing will have tested on the samples. In this study, the test will start with non-disruptive test by using resistivity test and followed by pundit test. After these two tests, Uniaxial Compressive Strength Test (UCS) will be the final method to be tested the strength of the sandstone because it would give harm to the samples. [10].

Rebound hardness test

Rebound hardness test is to determine the uniaxial strength of rock indirectly and quickly either in the field or laboratory [11]. For this test, Schmidt Rebound Hammer will be used. The samples that be tested can be in the form of rock mass or rock material. The rock samples which in the form material; it can be either in regular or irregular shapes. In this laboratory test, the hammer plunger is attached towards the rock surface and it is perfectly near to vertical before data is taken. Make sure the surface of the samples shall be smooth and flat over the area covered by the plunger. Attached hammer to the test surface and applied the pressure on the hammer. Pressed the button in its side to retain the reading, R. Repeated the test for 30 samples and the average of reading will be taken. Based on this test, the samples can be classified into the several grades. Figure 1 shows the classification of weathered rock sandstone and shale with related suitable testing method.

Resistivity test

The resistivity test is using Wenner's method. With the resistivity technique, a current transmitted into the ground by two current electrodes and a resulting secondary voltage is measured by two separate potential electrodes. Measurement of the voltage and current allows determination of the average subsurface resistivity in a volume greatly determined by the separation of the electrodes. The functions of distance are between electrodes, as well as the configuration between current and potential electrodes, and can be increased by increasing the electrode separation [12, 13].

Resistivity measurement involves applying a voltage into the ground through metal electrodes and measuring the resistance to the flow of the electric current. A typical system of resistivity survey consists of four equally spaced metal electrodes also called Wenner array insert into the soil [14].

The sample is placed at the center of the load cell machine. After that, LCR Meter (Figure 3) is connected to the load cell machine (Figure 4) by using the resistivity wire with the clipper. The frequency is setting and the currents are flowed to the samples. A resistance data is taken for three times for each sample for four different frequencies. This method is measuring the strength of rocks. The strength of rock material is identified by value of stress at the failure.

Figure 3: LCR Meter

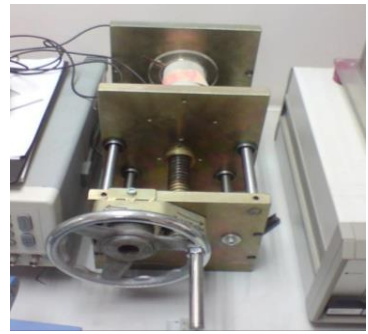

Figure 4: Load Cell Machine

In order to handle the laboratory, the sample were cut to appropriate size where stated by ISRM 1981. This laboratory, to cut the sample coring machine will be used to get the circle shape of samples. The size of samples should be less than 55 mm for diameter, D and the samples shall be right circular cylinders having a height to diameter ratio of 2.0 – 3.0. In this research, 30 samples of sandstone have been prepared. The classification of the samples chosen is based from the previous findings as shown in Figure 1 and Figure 2 show the raw materials that brought to the laboratory before work had been done.

Pundit test

The emitter and receiver wires were connected to the P-wave instrument (UPV). After that, connect the emitter and receiver to the sample [15, 16]. The adhesive grease is used to ensure the sample was connected properly to the emitter and receiver. The load is put on the top of the emitter because to ensure the UPV enable to provide the correct data. Data is taken for ten times for each sample. Figure 5 and 6 shown the P-wave instrument and the sample were connected to the UPV.

Figure 5: P-wave instrument (UPV)

Figure 6: The sample was connected to the UPV

Uniaxial compressive strength (UCS) test

Universal Testing Machine (UTM 500) as shown in Figure 7 has the persistent loading is around 500kN and is capable of bouncing the failure rock. This machine features 'servo control,' which simplifies and applies the testing procedure. Additionally, it provides a variable rate of loading with data that is accurate to two decimal places. Uniaxial Compression Strength is the most extensively used method for determining strength since it is the most standardised [10, 17, 18, 19]. The two loading faces of machine are parallel to each other. Place the steel plates in the form at the specimen ends.

One of the two platens should incorporate a spherical seat. The spherical seat should be placed on the upper of the specimen. The specimen, the plates and also the spherical shall be centered with respect to each other due to the machine. The scat surface of the curvature center should coincide with the center of the top end of the specimen. 30 samples were being prepared for this study. The dimension of one of the samples has been measured and the strain gauges were arranged on the cylinder's side to determine the changes in length for both in vertical and horizontal directions. The data logger and UTM 500 were connected to the strain gauges which the records and print out the result value of the loading action on the sample until 5 tests. This method is measuring the strength of rocks. The stress value at failure and the specified relationship are used to determine the rock material's strength [17].

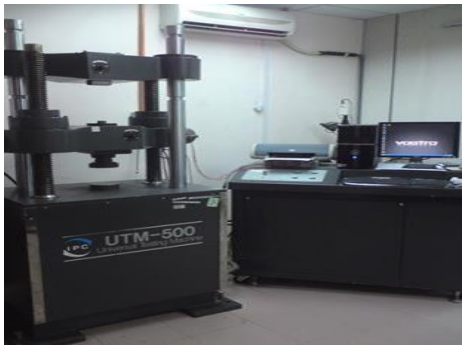

Figure 7: Universal Testing Machine (UTM 500)

Results and Analysis

It is important to define the hardness and the strength of the rock. It may be possible to relate the results. To evaluate the results, the linear regression techniques were used to examine the data of the laboratory test. The lacking of physical quality on sandstone because of the weathering grade was increased. From the laboratory test had been done, the analyses of the sandstone strength were done. There are several samples of sandstone obtained from Kenny Hill Formation were tested by three different methods.

Rebound hardness test result

It has approximately 30 samples of sandstone and the results are reported in the following subtopic. Table 1 showed the list of sandstone grade which tested by Rebound Hammer [11]. From this test, the sandstone was graded. Based on the test has done, the result shows the grade of sandstone were located between II to IV (as refer to Figure 1). More than 50% are classified as moderately decomposed rock, highly decomposed rock is about 27% and the other 20% are classified as slightly decomposed rock.

Resistivity test result

Resistivity is a method for determining the strength of a material that does not require disturbing the material's shape or conditions. All 30 samples of sandstones ranging from grade II to IV were tested using this method. Based on this laboratory result, shows that when the frequency is increased and the resistivity will decrease as shown in Figure 8.

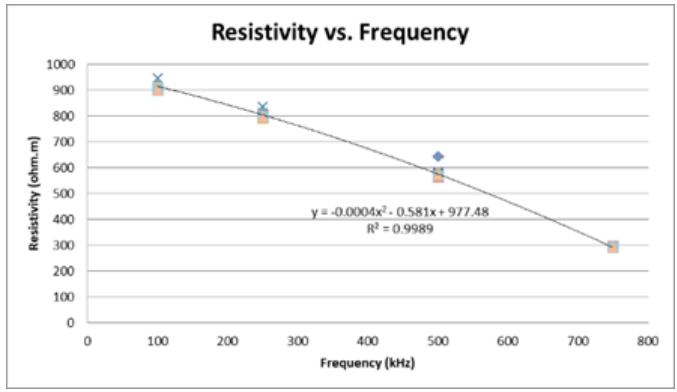

Figure 8: Relationship between resistivity and frequency of sandstone samples

From Figure 8, the result shows that the resistivity was decreased due to frequency [13, 16]. The graph also shows that the values of resistivity were closed to each other for every 30 samples of sandstones. Besides that, the ranges of resistivity of sandstones were located between 300 ohm.m to 1000 ohm.m. Hence, a very strong agreement of correlation whereby R2 = 0.9989 was discovered between the relationship of resistivity and frequency for sandstone. In this laboratory test, the frequencies ranges are already fixed by the equipment.

Pundit test result

This is another test that was conducted in the laboratory. It is also known as seismic velocity test and this test is also one of the undisturbed tests. The lowest reading is found at S14 which it is classify as grade IV. Grade IV is considered as weak rock in the rock mass classification system [17, 18].

For the highest reading, S3 specimen indicates the highest values. Figure 9 shows the relation between the velocities of P-wave over time result shows the longer time is taken, the velocity getting slower [15, 16]. Figure 9 shows the velocity of P-wave for 23 samples of sandstone ranging from above 2000 m/s to 4000 m/s and the other 7 samples were sorted below than 2000 m/s. Based on the graph, the percentage of velocity which located above 2000 m/s is 77% while the rest belongs to velocity of P-wave below than 2000 m/s. A very good agreement of correlation was found (R2 = 0.9949) for the tested sandstone samples.

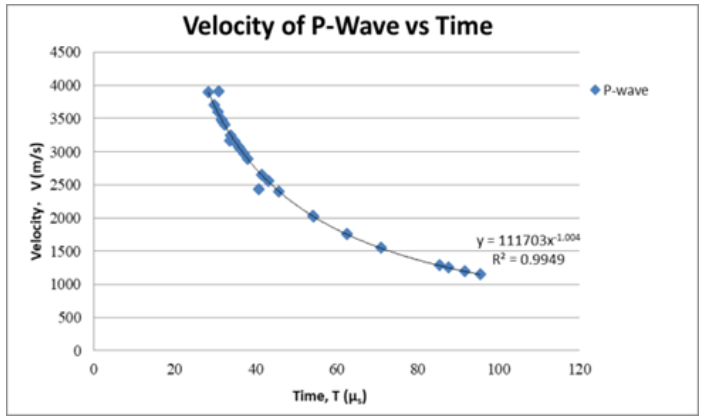

Figure 9: Relationship between P-wave and time of sandstone

Uniaxial compressive strength test result

The uniaxial compressive strength test is conducted to obtain the stress strain behavior of the tested rock samples. The testing can also indicate the quantitative value in determining the strength of the rock [18, 19, 20]. Overall result is summarized in Table 1. Based on the results, it indicated various values of UCS which the highest strength is on 80.19 MPa which specified as grade II. The various value of UCS obtained from 30 samples of sandstone tested ranges between 0 – 80 MPa. However, most of the sample tested was concentrated between the ranges 10 – 40 MPa.

Correlation of laboratory index test

Based on the laboratory work, the sample of sandstone that is found with different hardness although the samples were collected from the Kenny's Hill Formation area. The samples hardness grade is consisting of slightly, moderately and highly decomposed [16, 18, 21].

Correlation of resistivity and Pundit test

Table 2 shows a result of Resistivity and Pundit Test. Based on the table of result of laboratory test, most of the average of resistivity are ranging 640 ohm.m and above. From this result, the graph average of resistivity and velocity of p-wave of sandstones that shows in Figure 10 was plotted. It is shows the correlation between velocity of P-wave and resistivity of sandstone. The graph average of resistivity and velocity of P-wave of sandstones were plotted from the data taken. In this graph, it shows that the graph of average of resistivity was decreased due to the velocity of P-wave. Most of the data gathered are between 640 ohm.m and 650 ohm.m. From Figure 10, the graph indicates that when the resistivity is higher, the velocity of P-wave is increased.

In this laboratory test, a good correlation was found in between average of resistivity and velocity of P- wave of sandstones is R2 = 0.4074.

Table 1: List of sandstone grade, Rebound Hammer value and uniaxial compressive strength (UCS) test result of Kenny Hill weathered sandstone

Sample	Value of Rebound Hammer	UCS (MPa)	Grade	Sample	Value of Rebound Hammer	UCS (MPa)	Grade
S1	39.5	38.78	III	S11	40.0	29.20	III
S2	42.5	25.34	III	S12	38.5	16.28	III
S3	43.0	26.57	III	S13	22.5	6.25	IV
S4	45.5	30.92	II	S14	21.0	13.22	IV
S5	35.5	40.29	III	S15	23.0	9.59	IV
S6	34.0	22.27	III	S16	26.0	15.62	III
S7	31.4	18.11	III	S17	20.5	8.40	IV
S8	42.5	54.19	III	S18	18.7	6.06	IV
S9	34.0	14.28	III	S19	20.5	9.47	IV
S10	30.0	15.59	III	S20	17.0	27.25	IV
S11	40.0	29.20	III	S21	42.5	25.93	III
S12	38.5	16.28	III	S22	37.5	28.20	III
S13	22.5	6.25	IV	S23	13.0	11.23	IV
S14	21.0	13.22	IV	S24	45.5	39.53	II
S15	23.0	9.59	IV	S25	48.0	52.05	II
S16	26.0	15.62	III	S26	32.0	43.45	III
S17	20.5	8.40	IV	S27	37.5	18.94	III
S18	18.7	6.06	IV	S28	53.0	80.19	II
S19	20.5	9.47	IV	S29	47.0	70.23	II
S20	17.0	27.25	IV	S30	53.5	55.98	II

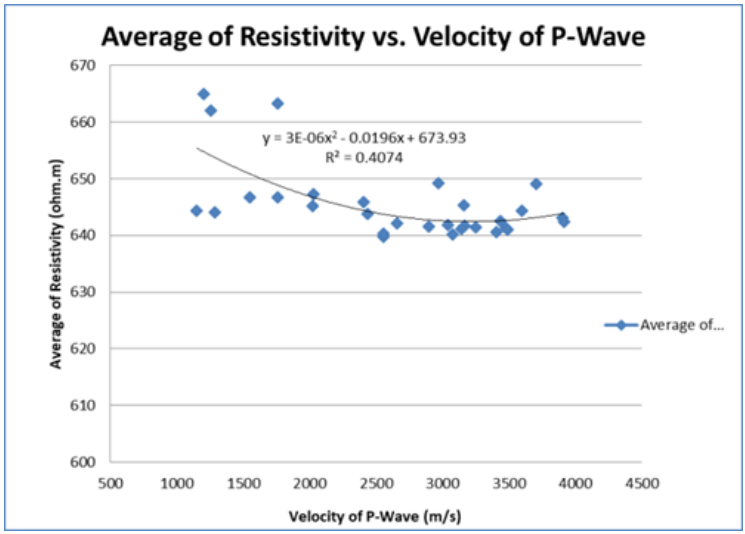

Figure 10: Relationship between average of resistivity and velocity of P-wave of sandstones

Table 2: Resistivity and Pundit test result of Kenny Hill weathered sandstone

Sample	P-Wave (m/s)	Average of Resistivity (ohm.m)	Sample	P-Wave (m/s)	Average of Resistivity (ohm.m)
S1	3477.30	641.304	S16	2023.20	645.127
S2	3900.90	643.086	S17	1760.70	646.790
S3	3915.90	642.460	S18	1759.50	663.280
S4	3437.50	642.497	S19	1254.30	661.995
S5	2404.40	645.910	S20	1287.50	644.085
S6	3167.60	641.768	S21	2556.40	639.776
S7	3599.70	644.393	S22	2555.40	640.305
S8	3074.70	640.138	S23	1549.20	646.763
S9	2433.20	643.853	S24	3250.90	641.369
S10	2968.00	649.171	S25	3487.90	641.061
S11	3042.30	641.855	S26	2656.00	642.125
S12	3163.50	645.370	S27	3706.40	649.106
S13	1201.10	665.024	S28	2896.40	641.623
S14	1151.80	644.414	S29	3144.10	641.223
S15	2031.30	647.308	S30	3403.20	640.640

Correlation of velocity of P-wave and uniaxial compressive strength

The velocity of P-wave and Uniaxial Compressive Strength (UCS) data of sandstone specimens were obtained to search for correlation between them. The graph that demonstrates the correlation between velocity of P-wave and Uniaxial Compressive Strength were plotted as shown in Figure 11. From the figure, it is shows that when the velocity of P-wave increased automatically the strength also increased. It means that the faster velocity could grow as the strength of sandstone increased [18, 21].

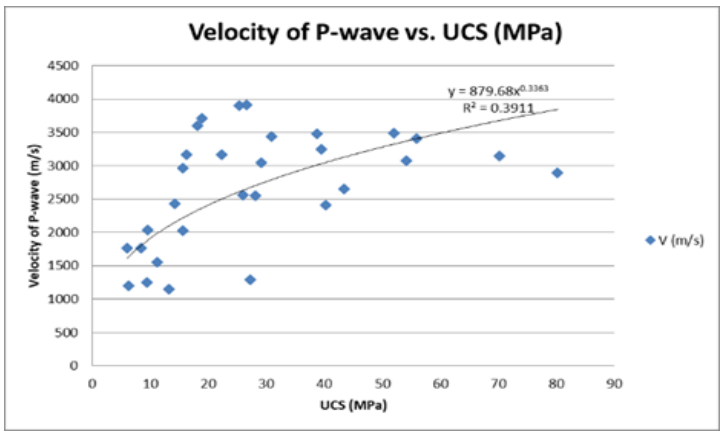

Figure 11: Relationship between velocities of P-wave and uniaxial compressive strength of sandstone

The data that plotted on the graph shows that velocity of P-wave for sandstones ranging from 1000 m/s to 4000 m/s. Based on the findings, S2 specimen has the highest reading for velocity of P-wave and the lowest reading is belongs to S14 specimen. The best correlation was found between velocities of p-wave and uniaxial compressive strength of sandstone is about R2 = 0.3911.

Correlation of average of resistivity and uniaxial compressive strength

The data of Uniaxial Compressive Strength and average of resistivity were obtained and summarized in Figure 12. It shows that the graph of correlation between Resistivity and Uniaxial Compression Strength (UCS).

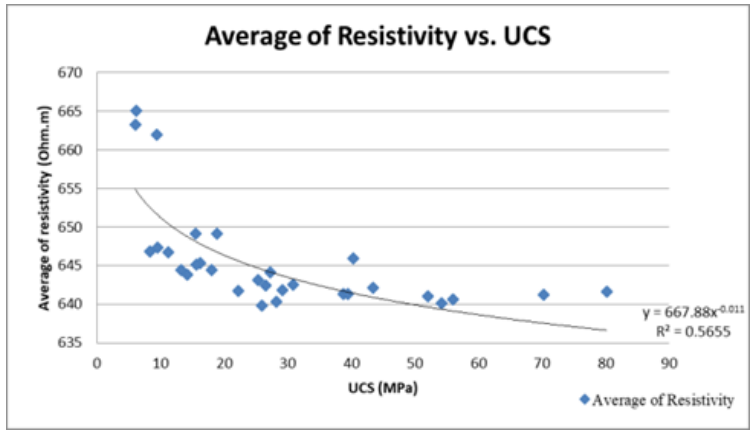

Figure 12: Relationship between average of resistivity and uniaxial compressive strength of sandstone

Based on the graph of relationship between Relationship between UCS, P-waves and Average Value of Resistivity of sandstone shows the very good correlation (R2 = 0.5655) was found between the relationship UCS and average value of resistivity. And the correlation (R2 = 0.3911) was found between the relationship UCS and P-wave.

Conclusion

From the result, it is shown that the strength and resistivity of sandstone deteriorates with increasing of weathering grade. Testing and analysis of the samples approach have given the attention of the weathered matter issue. In addition, the resolving the sampling problem for weak weathered rock especially sandstone to aspired data. Initially, technique of uniaxial strength test is the most appropriate to be done to evaluate weak rock mass properties. Based on these quantitative findings, the uniaxial compressive strength (UCS) of tropical weathered sandstone rock mass was defined and most of the data was concentrated between the ranges 10 – 40 MPa. The resistivity due to strength of tropical weathered sandstone rock mass was found through this research. The ranges of resistivity of tropical weathered sandstone are between 300 – 1000 ohm.m. The correlation between resistivity and UCS of tropical weathered sandstone was defined in this research as good agreement as shown in Figure 12.

After through all tests involve in this research, type of weathered need to support from field data was founded. The field data is significant, and the combination of field and laboratory result will ensure the correlation between

resistivity and uniaxial strength of weathered sandstone. This research has provided the correlation between the resistivity and uniaxial compressive strength of sandstone.

Based on this finding, the correlation between resistivity and UCS are discovered. In this study, the researcher used sandstone as the material that be tested. As for the future research, the attempting approach is to use other geomaterials such as granite, siltstone and so on. It is highly recommended to use other laboratory compressive strength test to define the strength and its correlation. In addition, the future researcher is recommended to approach different parameter from this present research. For example, defining the correlation between resistivity and moisture content or correlation between resistivity and S- waves can be considered.

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