Geomechanical strength of carbonate rock in Kinta Valley, Perak, Malaysia

T L Goh*1, S S Ailie2, M Nur Amanina1, M M R Ainul1, R Abdul Ghani3, S Norbert1, and K E Lee4

1Centre for Earth Sciences and Environment, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor Darul Ehsan, Malaysia
2School of Engineering, Faculty of Computing, Engineering and Technology, (FCET), Asia Pacific University of Technology & Innovation, Technology Park Malaysia, Bukit Jalil, 57000 Kuala Lumpur, Malaysia
3Engineering Geology Advisory, 11, SS21/12, Damansara Utama, 47400, Petaling Jaya, Selangor, Malaysia.
4Institute for Environment and Development (LESTARI), Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia.

*Corresponding author email: gdsbgoh@gmail.com

Abstract. The geomechanical strength of rock materials plays a significant role in influencing the stability of both cut rock slopes and underground openings. The strength characteristics are influenced by both material characteristics and the condition of weathering. This paper presents a systematic approach to quantify the rock material strength characteristics for material failure and material & discontinuities failure by using uniaxial compressive strength, point load strength index and Brazilian tensile strength for carbonate rocks. The mean value of compressive strength, point load strength index and Brazilian tensile strength for material failure and material & discontinuities failure were 76.8±4.5 and 41.2±4.1 MPa respectively. The Point load strength index for material failure and material & discontinuities failure were 3.1 ± 0.2 MPa and 1.8 ± 0.3 MPa respectively. The Brazilian tensile strength with material failure and material & discontinuities failure were 7.1 ± 0.3 MPa and 4.1 ± 0.3 MPa respectively. The results of this research revealed that the geomechanical strengths of rock material of carbonate rocks for material & discontinuities failure deteriorates approximately ½ from material failure.

1. Introduction

The geomechanical strength of rock materials plays a significant role in influencing the stability of both cut rock slopes and underground openings. The strength characteristics are influenced by both material characteristics and the condition of weathering. The material strength of rock were influenced by material itself and discontinuities.

[1] and [2] has classified failure mode into various pattern which take into account the presence of microcracks that give microstructural differences in the same lithologies. In understanding the failure mode of rock material, [3] stated that the rock failure will occur by the development of fractures by several micro cracks. According to [4], the fracture initiation started when the tensile stress on the boundary of elliptical shaped flaws exceeds the local tensile strength of the rock material. The strength reduction in rock material due to the presence of discontinuities were broadly discussed by [5], [6], [7] and [1].
The literature study revealed that less research studies were conducted on quantification of the strength of limestone. The local researchers were focused on rock mass classification [8], landslide [9], [10] and [11], rock fall [12] and prediction of uniaxial compressive strength using ultrasonic [13], [14], [15] and [16]. However, [17] investigated the influenced of conditions of weathering to the geomechanical strength of Granites and Schists.

In this study, the geomechanical strengths of carbonate rock with material failure and material & discontinuities failure were characterized by employing the uniaxial compressive strength test, point load test and Brazilian tensile test.

1.1 Geological setting
The Kinta Valley is situated in the middle of the Perak state in the direction of NE-SW of Peninsular Malaysia. It is dominated by limestone hills with alluvium scattered around the hills forming a beautiful karst landscape. In general, the Kinta Valley area is dominated by Upper Paleozoic limestone. [18] classified the Kinta Valley area into three main facies; carbonated facies, argillite facies and arenite facies. [19] named every limestone unit in the Kinta Valley as Kinta Limestone. In term of age determination, Kinta Limestone aged from Silurian until Permian [19]. The metamorphism process that had occurred in the Kinta Valley converted limestone into marble, while shale and sandstone was metamorphosed into schist and quartzite. Kinta Limestone was underline by Kinta Valley Schist in Late Permian. The schist was poorly exposed and poorly stratified. The schist was observed in a cave that is located at the Gunung Rapat area and at the bottom of a massive limestone body, [12]. In Late Triassic, both Kinta Limestone and Kinta Valley Schist were intruded by Kledang Range in Main Range Granite province, [20].

2. Methodology
Core samples preparation and geomechanical testing were carried out according to the recommendations by [21] are uniaxial compressive strength test, point load strength index test and Brazilian tensile strength test. Both irregular lump and core were used in point load test. A standard testing machine (UNIT TEST SYSTEM DHR2000), Figure 1 were used for uniaxial compressive strength test and Brazilian tensile strength test. Point load strength index test were tested using the CXDZ-50 Rock Point Load Test Equipment (Figure 2). Rock blocks of different sizes for fresh rock material at all sites were collected using hand tools such as chisels, picks and geological hammers. The results of geomechanical strength were analysed using SPSS-statistical version 16 at 95% confident level. Independent-samples-T test was used to determine the average differences of geomechanical strength based on material failure and material & discontinuities failure. If P value obtained from independent-samples-T test is less than 0.00, alternative hypothesis (ha) is accepted. This indicates that the difference between material failure mode and material & discontinuities failure mode is significance. Hypothesis null (ho) is accepted when the P value is higher than 0.00. This indicates that the differences between material failure mode with material & discontinuities failure mode is not significance. The hypotheses for the result of geomechanical strength were as follow:

Null hypothesis (ho):
Average geomechanical strength with material failure = average geomechanical strength with material & discontinuities failure

Alternative hypothesis (ha):
Average geomechanical strength with material failure ≠ average geomechanical strength with material & discontinuities failure
3. Results and Discussion
A total of 60 of uniaxial compressive strength tests, 95 of Brazilian tensile strength tests and 102 of point load strength index (Is$_{50}$) tests were conducted on fresh rock material samples. The study areas covered Kinta Valley limestone hills. The study areas are at Gunung Lang, Gunung Rapat, Gua Kandu, Gua Tempurung, Gua Naga Mas and Gunung Mesah. The locations of each test site were shown in Figure 3. The geomechanical strength were determined according to the failure mode of the samples; material failure and material & discontinuities failure. The results were analysed using SPSS at 95% confidence level. The box plots for uniaxial compressive strength, Brazilian tensile strength and point load strength index were shown in Figure 4, Figure 5 and Figure 6. The P value obtained from T-test for all test conducted were 0.000. The summary of mean, standard deviation, median, skewness and mode
were displayed in Table 1. Negative skewness represents a condition in which more result have higher value (>50%) than the mean value of R. Positive skewness represents a condition in which more result have lower value (>50%) than the mean value of R. The result indicates that the differences in determination of uniaxial compressive strength, Brazilian tensile strength and point load strength index, (Is50) based on material failure and combination failure are significant at 95% confidence level.

**Figure 3.** Location of the study areas

**Figure 4.** Boxplots of Uniaxial compressive strength according to material failure mode (M) and material & discontinuities failure mode (MD).
Figure 5. Boxplots of Brazilian tensile strength according to material failure mode (M) and material & discontinuities failure mode (MD).

Figure 6. Boxplots of point load strength $I_{s(50)}$ according to material failure mode (M) and material & discontinuities failure mode (MD).
Table 1. Summary of statistical result of uniaxial compressive strength test, Brazilian tensile strength test, and point load strength index test, Is$_{(50)}$.

| Geomechanical test                  | Failure mode               | Number of test | Standard deviation (MPa) | Median (MPa) | Skewness | Mean (MPa) | P value |
|-------------------------------------|---------------------------|----------------|--------------------------|--------------|----------|------------|---------|
| Uniaxial compressive strength       | Material                  | 48             | 15.2                     | 71.5         | Positive | 76.8 ± 4.5 | 0.00    |
|                                     | Material & discontinuities| 12             | 6.5                      | 42.5         | Negative | 41.2 ± 4.1 | 0.00    |
| Brazilian tensile strength          | Material                  | 76             | 1.4                      | 7.1          | Positive | 7.1 ± 0.3  | 0.00    |
|                                     | Material & discontinuities| 20             | 0.6                      | 4.3          | Negative | 4.1 ± 0.3  | 0.00    |
| Point load strength index, Is$_{(50)}$ | Material                  | 79             | 0.9                      | 3.0          | Positive | 3.1 ± 0.2  | 0.00    |
|                                     | Material & discontinuities| 23             | 0.6                      | 1.7          | Positive | 1.8 ± 0.3  | 0.00    |

The mean values of uniaxial compressive strength for material and material & discontinuities failure were 76.8 ± 4.5 and 41.2 ± 4.1 MPa with standard deviation of 15.2 and 6.5 MPa respectively. The mean difference between material failure with material & discontinuities failure is 35.6 MPa. This indicates that the mean value of material & discontinuities failure had decreased by 54% of the mean value for material failure.

The mean values of Brazilian tensile strength for material and material & discontinuities failure were 7.1 ± 0.3 MPa and 4.1 ± 0.3 MPa with standard deviation of 1.4 and 0.6 MPa respectively. The mean difference between material failure with material & discontinuities failure is 3.0 MPa. This indicates that the mean value of material & discontinuities failure had decreased by 58% of the mean value for material failure.

The mean values of point load strength index, Is$_{(50)}$ for material and material & discontinuities failure were 1.1 ± 0.2 MPa and 1.8 ± 0.3 MPa with standard deviation of 0.9 and 0.6 MPa respectively. The mean difference between material failure with material & discontinuities failure is 1.3 MPa. This means the mean value of material & discontinuities failure had decreased by 58% of the mean value for material failure. Rock material strength for rock that undergo material & discontinuities failure in uniaxial compressive strength test, point load test and Brazilian tensile test were reduced from 54% to 58% from material failure.

4. Conclusion
The result of t-test for uniaxial compressive strength test, Brazilian tensile strength test, and point load strength index, Is$_{(50)}$ test showed the difference in geomechanical strength based on material failure and material & discontinuities failure were significant at the confidence level of 95%. The results of this research revealed that the geomechanical strengths of rock material of carbonate rocks for material & discontinuities failure deteriorates approximately ½ (54% to 58%) from material failure. The results of this research revealed that the geomechanical strengths of rock material with material & discontinuities failure deteriorates approximately ½ from rock strength with material failure. The analytical results represent a mean of quantification for rock material strength according to the failure mode using uniaxial compressive strength test, point load strength index test and Brazilian tensile strength test.
5. References

[1] Szwedzicki, T. A. 2006. A hypothesis on modes of failure of rocksamples tested in uniaxial compression. RockMech Rock Eng.40:97–104
[2] Basu, A., Mishra, D.A. & Roychowdhury. K. 2013. Rock failure modes under uniaxial compression, brazilianand point load tests. Bull Eng Geol Environ. 72:457–475
[3] Maji, V. B. 2011. Understanding failure mode in uniaxial and triaxial compression for a hard brittle rock. Proceedings of the 12th ISRM international congress on rock mechanics. 723–726
[4] Hoek, E. 1968. Brittle fracture of rock in Rock Mechanics in Engineering Practice. (Ed) K.G. Stagg and O.C. Zienkiewicz: London: J. Wiley
[5] Tsoutrelis, C.E. &Exadaktylos, G.E. 1993. Effect of rock discontinuities on certain rock strength and fracture energy parameters under uniaxial compression. Geotechnical and Geological Engineering.11(2) : 81 –105
[6] Szwedzicki, T., and Shamu, W. 1999. The effect of material discontinuities on strength of rock samples. Proceeding of Australasian Institute of Mining and Metallurgy. 304(1); 23–28
[7] Ming, C. K., Yong, M. T. &Chen, A. C. 2004. Study of failure process and failure modes of interstratified rock mass with an emphasis on specimen preparation and image scanning. North America Rock Mechanics Symposium. 6
[8] Norbert, S., Rodeano, R., Abdul Ghani, R., Goh, T.L., Noran, N.N.A., Kamilia, S., Nightingle, L.M., Azimah, H. and Lee, K.E. 2016. Rock Mass Assessment using Geological Strength Index (GSI) along the Ranau-Tambunan Road, Sabah, Malaysia. Research Journal of Applied Sciences, Engineering and Technology 12(1): 108-115
[9] Norbert, S., Michael, C., Mairead, d. R. and Abdul Ghani, R. 2013. Point based assessment: selecting the best way to represent landslide polygon as point frequency in landslide investigation. Electronic Journal Geotechnical Engineering 18 (d): 775-784.
[10] Norbert, S., Rodeano, R., Nightingle, L.M., Juhari, M. A., Abdul Ghani, R., Goh, T.L. 2014. Lineaments and Their Association with Landslide Occurrences Along the Ranau-Tambunan Road, Sabah. Electronic Journal Geotechnical Engineering 19 (c): 645-656.
[11] Norbert, S., Michael, C., Mairead, d. R., Abdul Ghani and R.Rodeano, R. 2015a. Time series assessment on landslide occurrences in an area undergoing development. Singapore Journal of Tropical Geography 36: 98-111.
[12] Norbert, S., Muhammad Fahmi, A.G., Goh, T.L, Abdul Ghani, R., Azimah, H., Rodeano, R. and Lee, K.E. 2015b. Assessment of rockfall potential of limestone hills in the Kinta Valley. Journal of Sustainability Science and Management 10(2) 24-34
[13] Goh, T.L., Abdul Ghani, R., Ailie, S.S., Azimah, H. and Lee K.E. 2016. Use of Ultrasonic Velocity Travel Time to Estimate Uniaxial Compressive Strength of Granite and Schist in Malaysia. SainsMalaysiana 45(2):185-193.
[14] Goh, T.L., Abdul Ghani, R., Ailie, S.S., Norbert, S., Lee K.E., and Azimah, H. 2015a. Empirical Correlation of Uniaxial Compressive Strength and Primary Wave Velocity of Malaysian Schists. Electronic Journal Geotechnical Engineering 20: 1801-1812.
[15] Goh, T.L., Abdul Ghani, R., Ailie, S.S., Norbert, S., Azimah, H. and Lee K.E. 2015b. Correlation of Ultrasonic Velocity slowness with Uniaxial Compressive Strength of Schists in Malaysian. Electronic Journal Geotechnical Engineering 20: 12663-12670.
[16] Goh, T.L., Abdul Ghani, R., Ailie, S.S., Norbert, S. and Lee K.E. 2014b. Empirical Correlation of Uniaxial Compressive Strength and Primary Wave Velocity of Malaysian Granites. Electronic Journal Geotechnical Engineering 19 (E): 1063-1072.
[17] Goh, T.L., Abdul Ghani, R., & Hariri, A. 2012b. Geomechanical Strength of Granites and Schists of Peninsular Malaysia. Sains Malaya 41(2):193-198.
[18] Ingham, F.T. & Bradford, E.F. 1960. The geology and mineral resources of the Kinta Valley, Perak. Federation of Malaya, Geological Survey District Memoir.9
[19] Foo, K. Y. 1983. The Paleozoic Sedimentary Rocks of Peninsular Malaysia-Stratigraphy and Correlation. Proceeding of the Workshop on Stratigraphic Correlation of Thailand and Malaysia, 1: 1-19.
[20] Lee, C.P. 2009. Paleozoic stratigraphy in Hutchinson, C.S & Tan, D.N.K (ed). Geology of Peninsular Malaysia, pp.55-86. Kuala Lumpur: University of Malaya and Geological Society of Malaysia.

[21] ISRM. 1981. International Society for Rock Mechanics: Rock characterization, testing and monitoring. In Brown, E.T. (Editor), ISRM suggested Methods. Pergamon Press, Oxford, U.K.

Acknowledgement
This publication is based on work supported by Universiti Kebangsaan Malaysia under internal grant GUP-2018-116 and sabbatical leave. The authors would also like to acknowledge the support of the staff and facilities at Geology Program and Faculty of Science and Technology, Universiti Kebangsaan Malaysia.