STRENGTH TEST OF IMPACT STRENGTH INDEX, SLAKE DURABILITY INDEX AND UNIAXIAL COMPRESSIVE STRENGTH OF MICA GRANITE ROCKS AT NATM-4, PAHANG SELANGOR RAW WATER TRANSFER AT LANGAT, SELANGOR

Afikah Rahim*

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Abstract

The correlations of the three rock parameters, in relation to the construction of the Pahang-Selangor-State Raw Water Transfer (PSRWT) Project, were investigated during this undertaking. The purpose, of the Pahang-Selangor-State Raw Water Transfer Project (PSRWT), is to facilitate the transportation of raw water, from the Semantan River to the Selangor/Kuala Lumpur area, by way of a domestic and industrial transfer tunnel, to evade the occurrence of water shortages. From the study area in the Langat district of NATM-4, rock samples were obtained from 16 tunnel distances, for the execution of three tests: the impact strength test, the slake durability test, and the uniaxial compressive strength test. The objective of these tests is to determine the mechanical properties of the highly weathered granite rocks, and the correlation between the impact strength index, the slake durability index and the uniaxial compressive strength. According to the results from these tests, in terms of high impact loading durability, slake toughness and uniaxial compressive force, the slightly weathered rocks portrayed high strength, while the highly weathered rocks portrayed significantly lower strength. This investigation also revealed that the correlation between the impact strength index, the slake resilience index and the uniaxial compressive strength is directly proportional. The evaluation of rock strength, often calls for physical testing, as rock strength is closely related to the mechanical properties of the rocks concerned.

Keywords: **Empirical equations, joint venture, excavation, physico-mechanical relationship, sustainable development, water security**

Introduction

Water Tunnel Construction in Relation to Water Security for Sustainable Development

An ample supply of water is crucial for the general development and well-being of populations worldwide. The combination of climate change, rapid population growth, and accelerated economic developments, have led to a host of water scarcity issues (UN Chronicle, 2020). With the spread of

Department of Geotechnics & Transportation, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Malaysia. E-mail: afikahrahim@utm.my
* *Corresponding author*

urbanization, the demand for water, and disputes related to water resources, have grown increasingly more intense (UN Chronicle, 2020). This situation has led to an increase in water-related conflicts internationally. Malaysia ranks 68th out of 162 countries (4th among ASEAN countries) following five years of an ambitious UN Agenda (2030), comprising 17 sustainable development goals (SDG Index and Dashboard Report 2021).

This is an indication that for the major constituencies in Malaysia, such as Kuala Lumpur, Putrajaya and Cyberjaya, water security is crucial for economic development. In view of the current situation, it is timely that Malaysia's water-related plans and key water security concerns, be thoroughly discussed. Despite its status as the country's most economically developed region, Malaysia's capital, Kuala Lumpur, is not without its share of water insecurity woes, brought about by economic expansion on a grand scale. The definition for sustainable development is manifold. Generally, however, it is defined as 'development that meets present-generation demands, without jeopardizing future generations. This was put forward by the 1987 World Environment and Development Commission (Keeble, 1988). In 2015, the UN General Assembly established the sustainable development goals (SDGs), based on the agreement of 193 countries, to accomplish 17 goals by 2030. The framework of this endeavour integrates economic, social, and environmental sustainability considerations, to ensure that 'no one is left behind' (United Nations Committee for Development Policy, 2018).

Vladimirova's research on SDG 6, which focused on clean water and sanitation, revealed the remaining 16 SDGs to be crucial. Researchers and the government, regard SDGs a suitable framework, for evaluating various features, which can contribute to the successful movement of raw water from Pahang to Selangor, to consequently realize water security. This undertaking takes into consideration the local situation, practices, and opinions, which are often disregarded during investigations of this nature. Understanding and managing the linkages between water, and the economic as well as social situations, is vital for the crafting of policies, aimed at developing a more resilient and adaptable society (Newell *et al*., 2001).

The Pahang Selangor raw water transfer (PSRWT) project is a joint venture effort, under the patronage of the Malaysian government, which involves Japan's Shimizu Corporation and Nishimatsu Construction, as well as local enterprises IJM Corporation and UEM Builders Berhad (UEM Builder, 2018). The goal of this project is to transport raw water from the Semantan River to the Selangor/Kuala Lumpur region, via a household and industrial transfer tunnel, to mitigate potential water shortages in Selangor/ Kuala Lumpur, due to restricted water supplies. As indicated in Figure 1, water from the Semantan intake is transferred through a tunnel, to the water treatment facility.

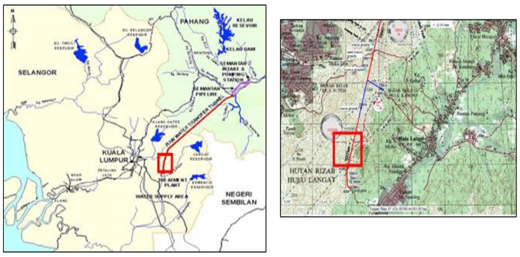

Figure 1. NATM-4 (study area). The Pahang Selangor state raw water transfer tunnel, from the Semantan intake to Selangor, is marked by the red box (United Nations Committee for Development Policy, 2018)

The length of the transfer tunnel, including the inlet connecting basin, inlet conduit, and output conduit, measures 44.6 km in length (Keeble, 1988). The tunnel runs through the main central mountain range, which reaches heights of over 1,200 m. The tunnel has a longitudinal slope of 1:1,900, and a diameter of 5.2 m. The excavation process involves three TBMs as well as four drilling and blasting sites. A tunnel boring machine (TBM) will be used to excavate the 35 km tunnel (Figure 2). The tunnel's upper and lower ends will be excavated using the new Australian tunnelling method (NATM). The inlet and output conduits are cut and cover culvers, with vertical walls in a horseshoe configuration. They are 4.0 m wide and 4.7 m in height.

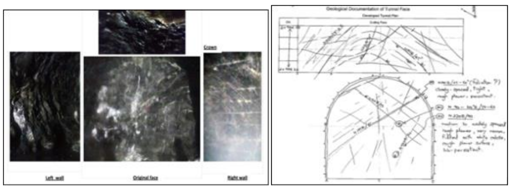

Figure 2. Left: New Australian tunnelling method (NATM-4), Right: Tunnel face mapping document (Newell *et al*., 2001)

Physico-Mechanical Relationship

There are several physico-mechanical tests available for assessing rock/aggregate quality. These tests classify rocks/aggregates according to test findings. However, a single rock/aggregate test cannot be considered conclusive. Several tests are recommended, and a combination of results from these tests is used, to estimate the rock/aggregate quality. Rock/aggregate strength and durability are the essential characteristics for predicting the actual performance of the geo-materials. Previous studies have revealed that the physical properties of geo-materials, such as water absorption, density, and porosity, are strongly associated to strength and durability (UN Chronicle, 2020).

Several researches have studied and evaluated the physico-mechanical properties of rock aggregates (Keeble, 1988; United Nations Committee for Development Policy, 2018; Newell *et al*., 2001; UEM Builder, 2018; Azit *et al*., 2017; Sharma and Singh, 2008; Sharma *et al*., 2011). The physico-mechanical properties of rocks, used as construction aggregates, are tested for their weathering conditions, strength, durability, and abrasion resistance, among others. These tests are performed, in compliance with available standards which include the American society for testing and materials (ASTM), the international rock mechanics standard (IRMS) and the British standard (BS). Other than correlating strength with durability, this undertaking also identifies the many regressions for predicting the empirical equations of different tests. Consequently, these empirical equations can be used for the calculation of rock mass attributes as input parameters.

Materials and Methods

Each segment of NATM-4 yielded sixteen (16) representative rock samples. There are extremely weathered granites in these 16 samples, which feature a contact zone with metamorphic rock, also known as meta-sedimentary rock. The relevance of aggregates/natural rocks (products of excavated rock), used as construction materials, was the basis for the sample collection. Figure 3 shows the detailed techniques employed, and the statistical data with regards to the physico-mechanical properties, of these extensively weathered rocks.

The greatest uniaxial compressive strength was recorded as 59.847 MPa. TD 2015.3 was used to collect these high-strength boulders from a tunnel distance. This location is preferable, as the rock at this tunnel distance is new. The trends of the uniaxial compressive strength values, are considerably different from those previously reported, as illustrated in the graph (refer to Figures 4, 5 and 6). With a value of 18.776 MPa, TD 2073.7 recorded the lowest value. This can be attributed to the presence of micro-cracks in the rock sample, even in a circumstance where the rock sample is only slightly weathered. Micro-cracks are a common occurrence in undamaged rocks.

Results and Discussion

Regression analysis was used to determine the relationship between the physico-mechanical properties. The relationship coefficient (R2), and the mathematical description of the best fit line, were estimated for the test outcome, with very low confidence levels of 4%, 5% and 2% percent, as shown in Figures 4, 5, and 6 respectively. The best fitted curves, for correlation between the impact strength index, the slake durability index, and uniaxial compressive strength of heavily weathered granite rocks, were generally observed to be overly scattered, nonlinear, and non-correlated.

The association between the slake durability index and the impact strength index was observed to be weak. Only a few samples passed through the 1.40 mm sieve, due to the high impact strength index values, and the rest were kept back in the pan. The variability of highly weathered rock, in the contact zone between granite and meta-sedimentary rock, is somewhat subjective, but the durability of the slake, when subjected to dry and wet processes, was observed to be high. This is an indication of the high resistance level of greatly weathered rocks. The impact strength index was observed to be unrelated to slake durability, impact strength was observed to be unrelated to uniaxial compressive strength, and the slake durability index observed to be unrelated to UCS. While these three factors are without a proportional relationship, they are moderately correlated (less than 5%) to each strength parameter. This is portrayed in Figures 4, 5, and 6.

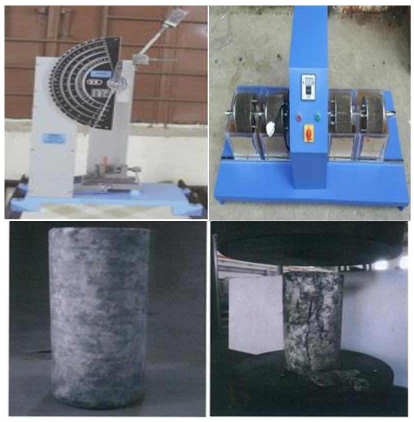

Figure 3. (a) Impact strength test, (b) slake durability test and (c) UCS sample at TD 2008

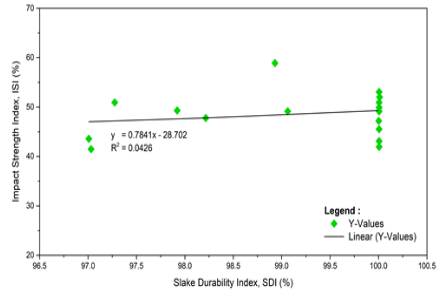

Figure 4. **Graph of impact strength index against slake durability index**

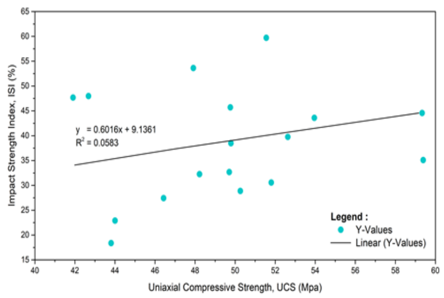

Figure 5. **Graph of impact strength index against UCS**

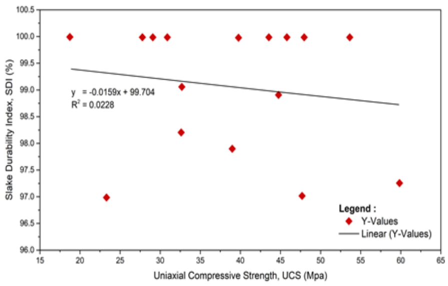

Figure 6. **Graph of slake durability index against UCS**

Table 1. **Empirical equations between UCS and slake durability**

Regression Expression	R value	T value	T critical value	F value	F critical	P Value A = 0.05
UCS = 4.2327 I_{D2} 13.638	0.53	>30	2.010	>30	1.624	0
UCS = 17.792$^{E0.0083Id2}$	0.62	5.140	2.002	8.995	1.624	0

With a projection of 95%, extrapolated to 50 samples, the empirical equations formulated between the extrapolated numbers of the slake durability test and UCS (predicted), are displayed in Table 1. The analytical graphs can be observed in Figures 7(a) and 7(b).

Linear and non-linear regression analyses, with a confidence level of 95% and a significance level of 0.05 (A = 0.05), were conducted for UCS-SDI parameter pairs (Figure 7(a)). Plot versus mean, and mean UCS to SDI, are portrayed in Figure 7(b). With a correlation value (R) of 0.53, the test results revealed a moderate association. The Id2 coefficient correlation was recorded as 0.62, while the t and F tests revealed a significant relationship between the parameters (UCS-SDI, UCS-Id2) and statistically significant R-values (Table 1). Thus, it can be surmised that comprehensive predicted data can be attained, by extrapolating the number of samples, with a confidence level of 95%.

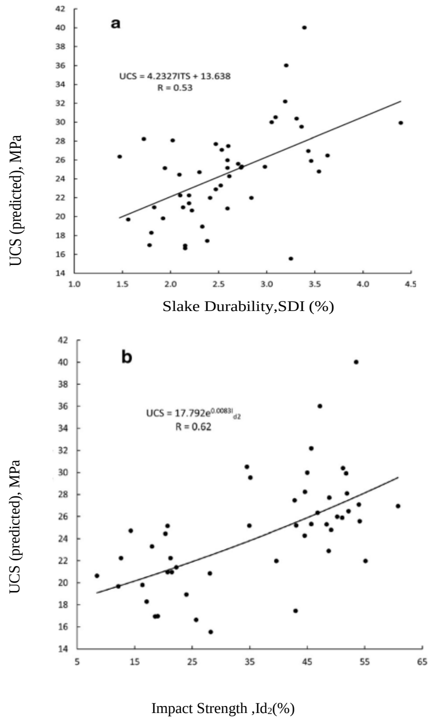

Figure 7. **(a) Estimated SLD in relationship to projected values in terms of UCS values of Langat granites, (b) Estimated I_{d2} in relationship to projected values in terms of UCS values of Langat granites**

Conclusions

This study was carried out to add on to the body of knowledge regarding the relationship between impact strength tests, slake durability, and UCS (or E) rock hardness testing. Information on this subject matter, particularly with regards to weathered granite rocks located at the meta-sedimentary contact zones region, is sorely lacking in relevant literature. Several hardness tests, as well as certain engineering features of rocks, were investigated during this undertaking. The findings, attained through regression analysis, are summarized as follows:

- The weathering states of the rock, creates low significant correlations, in the results of impact strength analysis, to slake durability, and impact strength test to UCS of 16 samples. These granites behave elastoplastically, with an overall volume compaction during UCS, till the onset of dilatancy at a high stress level, due to the presence of clay and micro-cracks. A single, or a few shear fractures form, as the peak stress is attained, resulting in a spontaneous internal force to failure. Under high minor confining stress values, damage and failure are suppressed.
- The slake durability index versus UCS yielded the weakest correlation. As such, the highest correlations for forecasting the UCS and E were detected at high slake durability levels, while low slake durability levels generated data dispersion.

The findings reveal that rock hardness tests are unreliable, as the low dependability renders the prediction of UCS and E (Young's modulus), for test data concerning rock quality, unattainable. However, as demonstrated in Table 1, correlation can be predicted through the extrapolation of the number of samples, together with the employment of statistical modelling. Informative details with regards to rock mass condition, rock type, failure mechanisms, materials, and micro-cracks, can be harnessed to establish a stronger correlation between data sets.

Acknowledgements

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