EFFECT OF MOISTURE CONTENT ON SIGNIFICANT PARAMETERS TO THE SURFACE EXCAVATION PERFORMANCES

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

The influence of moisture content on weathered rock arise frequent issues related to excavation works. It should be taken into consideration as unique features in tropical climate. Therefore, the need for an effective assessment on excavation works related to the moisture content is demanding. A systematic approach of field and laboratory assessments were structured with geological data collection and field trials at Sedenak, Bentong and Ulu Kinta sites. First, the field study includes geological mapping and discontinuity survey in order to characterize the weathering state, followed by thirty-six excavation trials were carried out during sunny day and after rainy days. Then, the physical properties of rock materials were determined by laboratory works including point load test, jar slake, moisture content, slake durability and petrographic analysis on forty rock samples of sandstone, shale and granite respectively. Rock masses recorded joint spacing of 0.1-2 m with maximum of four joint sets during field investigation. Sandstone and shale exhibit bedding as major type of discontinuity as compared to granitic rock which only characterized by the joints and faults. Block size shows a decreasing trend, ranges from 1-0.1 m^3 with weathering degree of slightly to completely weathered. From petrographic study, it is revealed that percentage of clay in slightly weathered in sandstone, shale and granite is 2.1%, 2.7% and 0% respectively. Meanwhile, the percentage of clay in moderately weathered is found to be 36%, 45% and 10% for the similar rock types. Clay content increase in the highly weathered state with 49%, 55% and 75%. Furthermore, for completely weathering state, sandstone and shale consist of 95% of clay and granite is 90%. The incremental of clay content has been found as one of the major factors in reducing the rock material strength. It was established that reduction strength of slightly weathered sandstone and granite ranges from 5-12% and 8-10% respectively. Whereas, in moderately weathered sandstone reduced 16-20%, while in granite is 33% to 37%. The strength reduction become more significant in highly weathering state which ranges from 50-60% in sandstone and shale, while 50-57% for granite. The result shows that the block size more than 0.6 m^3 could not be excavated. The case was different when it involves block size ranges from 0.15-0.5 m^3 with productivity less than 15 m^3/h for all type of rock for slightly weathered rock mass. In highly weathering state, block size which ranges from 0.1-0.8 m^3 resulting the productivity increase between 10-45 m^3/h. The case is different in completely weathered, where block size ranges 0.1-0.8 m^3 does not influenced much on the productivity resulting 25-50 m^3/h. It was found that increment of moisture content help to increase the productivity when the block size measured less than 0.3 m^3 for all types of rocks. The productivity increased by 20-50% when excavated after heavy rain on moderately and highly weathered sandstone and shale. This study prove that moisture content could affects the performance of excavation significantly on highly weathered rock mass. The effects are minimal for completely weathered, slightly weathered and moderately weathered rock masses. The block size does not become important factor in controlling the excavation performance in the slightly and completely weathered zone.

ABSTRAK

Pengaruh kandungan kelembapan pada batuan terluluhawa sering menjadi isu dalam kerja pengorekan. Perkara ini perlu diambil serius sebagai ciri unik di iklim tropika. Penilaian parameter efektif diperlukan bagi mencapai kos efektif bagi kerja pengorekan. Penilaian yang sistematik yang dijalankan merangkumi kerja lapangan dan makmal merangkumi pengumpulan data dan percubaan lapangan di Sedenak, Bentong dan Ulu Kinta. Pertama, kajian lapangan meliputi pemetaan geologi dan survei ketakselanjaran untuk mencirikan keadaan luluhawa, diikuti tiga puluh enam ujian pengorekan dijalankan pada waktu panas dan selepas hujan. Kemudian, penentuan sifat fizikal batuan telah dijalankan di makmal seperti ujian beban titik, ujian dalam balang, kandungan kelembapan, pemeroian batuan dan analisis petrografik pada empat puluh sampel batu pasir, syal dan granit. Jarak ketakselanjaran direkod antara 0.1-2 m dengan maksimum empat set kekar melalui kajian lapangan. Batu pasir dan syal mempamerkan perlapisan sebagai ketakselanjaran utama berbanding granit ang hanya dicirikan oleh kekar dan sesar. Saiz blok menunjukkan tren menurun daripada 1-0.1 m^3 daripada jasad batu terluluwa rendah hingga terluluhawa lengkap. Daripada kajian petrografi, peratus lempung dalam batu pasir, syal dan granit terluluhawa rendah ialah 2.1%, 2.7% dan 0%. Manakala, bahan batuan terluluhawa sederhana merekodkan lempung 36%, 45% dan 10% pada batuan yang sama. Kandungan lempung semakin tinggi pada keadaan luluhawa tinggi dengan 49%, 55% dan 75%. Tambahan lagi, pada keadaan luluhawa lengkap, batu pasir dan syal mengandungi 95% lempung dan granit ialah 90%. Peningkatan kandungan lempung merupakan salah satu faktor dalam pengurangan kekuatan bahan batuan. Pengurangan pada batu pasir, syal dan granit terluluhawa rendah daripada 5-12% dan 8-10%. Sementara, batu pasir dan syal terluluhawa sederhana berkurang 16-20%, manakala granit ialah 33-37%. Pengurangan kekuatan semakin penting dalam keadaan terluluhawa tinggi berjulat antara 50-60% untuk batu pasir dan syal, manakala 50-57% untuk granit. Hasil menunjukkan bahawa saiz blok lebih daripada 0.6 m^3 tidak boleh dikorek. Berlainan kes apabila melibatkan saiz blok julat 0.15-0.5 m^3 dengan produktiviti kurang daripada 15 m^3/j untuk semua jenis batuan terluluhawa rendah. Dalam keadaan luluhawa tinggi, saiz batuan berjulat 0.1-0.8 m^3 menyebabkan produktiviti meningkat antara 10-45 m^3/j. Kes berlainan terhadap keadaan luluhawa lengkap di mana siza blok berjulat 0.1-0.8 m^3 tidak banyak mempengaruhi produktiviti dari 25-50 m^3/j. Peningkatan kandungan kelembapan ditemui membantu dalam meningkatkan produktiviti apabila saiz blok kurang daripada 0.3 m^3 untuk semua jenis batuan. Produktiviti meningkat antara 20-50% apabila dikorek selepas hujan pada batu pasir dan syal terluluhawa sederhana hingga tinggi. Kajian ini membuktikan bahawa kandungan kelembapan mempengaruhi prestasi pengorekan pada jasad batu terutamanya terhadap jasad batu terluluhawa tinggi. Untuk jasad batu terluluhawa lengkap, rendah dan sederhana, kesannya sedikit. Saiz blok tidak menjadi faktor mempengaruhi prestasi pengorekan dalam zon terluluhawa rendah dan lengkap.

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LIST OF ABBREVIATIONS

2D	-	Two-Dimensional
ASTM	-	American Society for Testing and Materials
EISR	-	Excavation Index for Sedimentary Work
ISRM	-	International Society for Rock Mechanics
JKR	-	Jabatan Kerja Raya
JMG	-	Jabatan Mineral dan Geosains
Q-system	-	Rock Mass Quality
RMR	-	Rock Mass Rating
RQD	-	Rock Quality Designation
UCS	-	Uniaxial Compressive Strength
UTM	-	Universiti Teknologi Malaysia

LIST OF SYMBOLS

R_{dj} - Joint spacing
% - Percentage
° - Degree
°C - Degree celcius
g - Gram
Id_2 - Slake durability second cycle
Is_{50} - Point load strength index
J_a - Joint alteration number
J_n - Joint number
J_r - Joint roughness number
m - Meter
m^3 - Meter cube
m^3/h - Meter cube per hour
MPa - Megapascal
Q - Excavation production rate
R_{oj} - Joint orientation
V_b - Block volume
R_{dj} - Joint spacing
% - Percentage
° - Degree
°C - Degree celcius
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Id_2 - Slake durability second cycle
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J_a - Joint alteration number

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CHAPTER 1

INTRODUCTION

1.1 Introduction

A tropical country with sunny exposing all year around incorporate with moisture content from air and high volume of rain (Thomas *et al.*, 1994). With these combination characteristics, humid climate in Malaysia is the best condition that trigger the exogenic process especially in chemical weathering process where great intensity and high temperature will encourage the weathering process. The presence of water enhances the chemical weathering where the exposure of the mineral to the surface, the minerals become unstable.

Moisture content is an important agent in reducing the strength of rock mass. Frequent of changing rock temperatures and moisture condition resulting physical weathering of rock mass. These mechanisms cause rock to alternate between contraction and expansion condition will associate to compressive and tensile stresses. Moisture content of rock mass cause a significance change in the internal energy and cause geological disasters such as landslides that usually occur after heavy rains (Lu *et al.*, 2019). Many geotechnical and dynamic failure of rocks involve and associate much with influence of moisture content. When the moisture content increases, water creates tension inside crack and micropores in the rock.

Weathering state for sandstone and shale are heterogenous depending on the lithology and its structural nature. The weathering of rock mass was classified into six grades. Grade I indicate fresh rock where the rock condition in unaltered state and becomes more weathered as the weathering state increases until become residual soil. Grade III (moderately weathered) to V (completely weathered) are always indefinite in ripping assessments (ISRM, 1988). The classification excavation proposed by

Pettifer and Fookes (1994) do not suitably address the weathering profile and nature of rock in tropical climate in Malaysia (Jamaluddin and Sundaram, 2000; Amin and Mohamad, 2003 and Jamaluddin and Yusoff, 2003).

The rock-soil characteristics of materials or 'hard mass' always become an issue in determining the best excavation method and cost. A thick weathering profile consists of several weathering grade sub-classification based on the characteristics of each material. The best excavation machines for each material can be introduced to increase the excavation efficiency. In mechanical excavation, energy generated by excavator transferred into the ground.

Besides, effective excavation requires precise interpretation of different characteristic for thick weathering profile. In this relation, there is an essential to evaluate the excavation performance by adding the effects of moisture content for pre-liminary works. The complexity of subsurface condition, boulders, presence of discontinuities such as faults, bedding, joint and foliations prominently influence the excavation performance. On the other side, moisture content of rock mass highly depends on complexity of subsurface conditions and the presence of discontinuities. Disagreement in excavation method are common problems in civil engineers especially when confront with hard material. Hard material primes to the complication because the properties often too weak to be blast and too strong to be excavated (Amin, 1995; Kavvadas, 1998; Kanji, 2014)

1.2 Problem Background

In tropical climate region, the issues related to weathering process such the functionality of moisture content's presence in reducing the rock strength reduction of rock material and mass, discontinuity characteristics and clay content in rock material should be taken into consideration as unique features. Moreover, climate condition in tropics significantly decomposed and disintegrated rock mass which resulting the production of the thick weathering profile. One of the issues in surface excavation works is related to mainly in the highly and completely weathered rock mass which make it difficult to predict the excavation performance. Thus, it is important to highlight the significant features in determining the differences of excavation in different weathering state.

Most of the existing excavation assessments were not developed specifically to handle the tropics issues. For example, the rock mass from Bewick (2021) indicate that it underestimates the difficulty of excavation. Mechanical properties of rock materials highly dependents on the association between the particles and minerals present in it and cementations materials. Rock mass that has been undergo weathering process literally altered the rock materials. In addition, the comparison of geomechanical characteristics between each weathering state can be identified. Many cases have been reported to be very difficult to be excavated, however it becomes very easy to excavate after rain. This issue has caused confusion and arguments.

A major problem confronting geotechnical engineers in tropical climate is how to characterize the lithologies and the performance of the excavation. A reliable geotechnical characterization of the rock mass due to the influence of moisture should be established to enhance the excavation productivity. Fowell (1993) stated that geological properties and the parameter of machines are the major elements in affecting the mechanical excavation performance. Geological properties that influenced the excavation works can be divided into two categories which are rock mass and material properties. As the mechanical excavation, geological properties of rock masses play significant role in determining the performance of machine (Singh *et al.*, 1987). Rock masses considered to be a function of number of measurable parameters, with respect to their geomechanical properties display in massive and actual form.

1.3 Research Objectives

The objectives of the research are:

(a) To determine relevant physical properties of rock material and rock mass and its weathering state of the studied sites.

(b) To analyse the effect of moisture to the excavation performance for various weathering state rock types namely sandstone, shale and granite.

(c) To propose a simple and suitable assessment parameters of rock mass for excavation in relation to moisture influence based on lithology and weathering state.

1.4 Scope of Study

This research is focused on identifying the effect of moisture content on the parameters of surface excavation. This research involves the analysis of data between field works and laboratory works in order to propose the suitable parameters for surface excavation.

The research was carried out by selecting suitable studied sites namely Sedenak in Johor, Bentong in Pahang and Ulu Kinta in Perak. These sites were selected due to the good exposure of weathering profiles and current earthworks. Geological field mapping was carried out to establish the weathering profiles and characteristics of the rock masses. The variation of lithology and weathering states and joint spacing are recorded. Trial excavation was carried out using Excavator EX300 to obtain the production rate during sunny day and after rain. The results and discussion of geological field mapping are presented in Chapter 4.

Laboratory works are performed on rock materials to obtain their physical properties such as moisture content, point load strength test, jar slake, slake durability and petrography analysis. Correlation between the changes of physical properties effected by moisture content and the excavatability is analysed and the suitable assessment parameter for excavation is proposed to provide more reliable assessments in tropically weathered climate.

The research was carried out based on the study at sandstone and shale rock masses in Sedenak, Johor and Bentong, Pahang and granitic rock masses in Ulu Kinta, Perak. The locations and geology of the sites are shown in Figure 1.1.

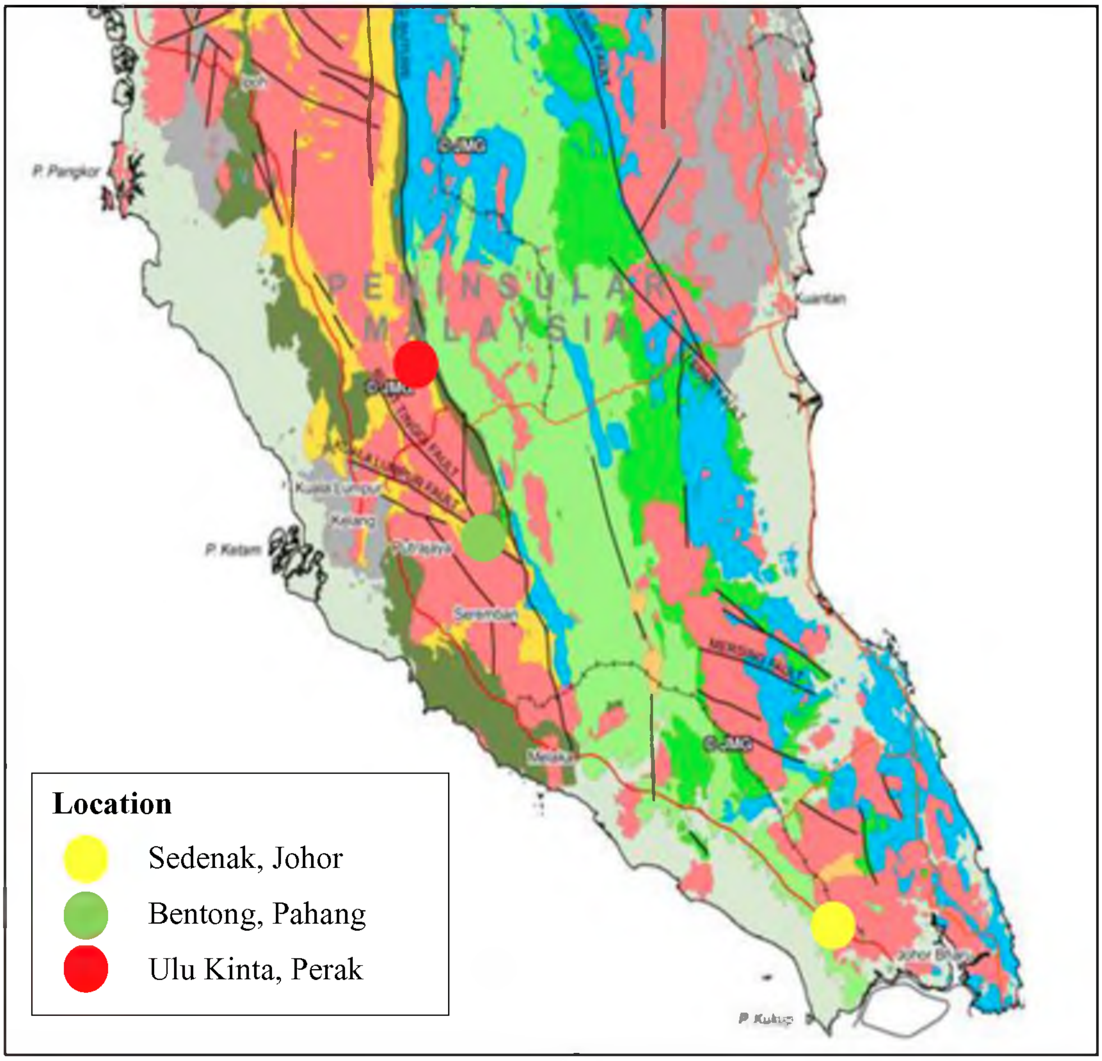

Figure 1.1 Geological map of the sites (Mineral and Geosciences of Malaysia, 2012)

1.5 Significance of the Study

The economic grow is taking important part in a developed country as in Malaysia. The findings of this study contributed to a cost efficient of excavation works in construction industry. Furthermore, the parameters that are classified in this study can be used as a reference or guideline in geotechnical and geological works in tropically climate area. Thus, it can improve the performance of excavation for construction purposes in a variety of materials. Tropical region is characterized by complex subsurface issues such as heterogeneities of ground, thick weathering profile, decrease of strength due to moisture and unclear interface boundary between soil and rock. By understanding the influence of the excavated rock mass, will assist in the excavation assessment. It is also expected this study to massively contribute in enhancing the knowledge and understanding of the tropical engineering field.

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LIST OF PUBLICATIONS

Mariatul Kiftiah Ahmad Legiman, Edy Tonnizam Mohamad, Eka Kusmawati, Nurul Amaniyah Romanah, Vynotdni Rathinasamy & Fazleen Slamat. (2021). Mechanism of moisture content in reducing strength of weathered rock in Malaysia. Proceedings of International Geo Engineering 2020, 233-240.