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EFFECTS OF MOISTURE CONTENT ON THE STRENGTH OF WEATHERED GRANITE IN TROPICAL CLIMATE

MOHAMED FAUZI BIN MD ISA

A thesis submitted in fulfillment of the requirements for the award of the degree of Master of Engineering (Geotechnics)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JUNE 2011
I declare that this thesis entitled “Effects of Moisture Content on the Strength of Weathered Granite in Tropical Climate” is the result of my own study except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : 20 JUNE 2011
Specially Dedicate To…

My Inspiration
Mom, Dad, Nazrin Hamzah and all family members

My Supervisor
Dr. Hj. Edy Tonnizam Mohamad for his guidance

My Co-Supervisor
Assoc. Prof. Mohd. For Bin Mohd. Amin

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ABSTRACT

This study deals with the effect of moisture content on strength properties of weathered coarse grained granite. Common knowledge suggests that higher moisture content affect most aspects of physical and mechanical properties of rock, however its effect on various weathering grade is still not fully understood. A total of 300 rock samples were collected and tested ranging from fresh (Grade I) to completely weathered (Grade V) state. The field study including the weathering identifications, Schmidt hammer and impact index test were performed at the site. The newly introduced impact test performed at the site suggested that it correlates well with the strength of weathered rock. In the laboratory, samples were analyzed for durability, point load index, moisture content and density. In addition, X-Ray Diffraction Test and Petrographic Analysis were carried out to examine the mineralogy of the rock material. Specimen preparation and testing were performed in accordance to the ISRM, 1981 and 1985 standards. The results revealed that degree of alteration of feldspars and amount of clay minerals are good indicator for weathering grade identification. Amount of fresh feldspar reduced from 72% in grade I to 0% in grade V with increasing from 0% to 60% of altered feldspar and clay mineral. The presence of feldspar and mica minerals above 1 percent tended to increase the susceptibility of rock to the influence of water. It was also found that reduction in strength becomes greater with the increase of the weathering grade. In addition, the discolouration of rock material from greyish to brownish red also can be a good indicator for the strength reduction due to moisture content. The extent of strength reduction depends upon the weathering grade, petrographic constituent and duration of water immersion. It was also found that the point load index reduced by 138% with the increase of only 21.40% of moisture content for highly weathered granite (grade IV). However, in a lower weathering grade, a strength reduction of only 21.4% was noted with increase of moisture of 0.27%, although samples have been immersed for 60 minute. This study concludes the magnitude of the strength reduction due to presence of water is very much dependent on the weathering grade of rock material.
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LIST OF SYMBOLS

\( \theta \) - Angle of incidence of the X-ray beam

\( \sigma_c \) - Compressive strength

\( \sigma_t \) - Tensile strength

\( \lambda \) - Wavelength of the incident X-ray beam

\( a \) - Acceleration

\( A \) - Cross-Sectional Area

\( A \) - Mass of the drum plus sample

\( B \) - Mass of the drum plus retained portion of the sample after cooling in first cycle

\( B \) - Biotite mineral

\( C \) - Mass of the drum plus retained portion of the sample after cooling in second cycle

\( d \) - Distance between adjacent planes of atoms

\( D \) - Mass of a cleanly – brushed drum

\( F \) - Feldspar mineral

\( F \) - Force

\( K \) - Potassium

\( m \) - Mass

\( n \) - Order of the diffracted beam

\( N \) - Climate index

\( P \) - Applied point load

\( R \) - Rebound value

\( W \) - Sample width

\( w \) - Water content
Ca - Calcium
CM - Clay mineral
Mg - Magnesium
Na - Sodium
Ej - Evaporation during hottest month
$F_{net}$ - Force net
$I_{d1}$ - First cycle slake durability index
$I_{d2}$ - Second cycle slake durability index
$I_f$ - Fracture spacing index
$I_{fr}$ - Microfracture index
$I_{mp}$ - Micropetrographic index
Is - Uncorrected strength
$I_{s_{50}}$ - Point load strength index
MC - Moisture content
Pa - Annual rainfall
WG - Weathering grade index
PLT - Point load test
RSR - Rock-soil ratio
RQD - Rock quality designation
SHV, N - Schmidt hammer value
UCS - Uniaxial compressive strength
CHAPTER 1

INTRODUCTION

1.1 Background of Study

Granite is a common and widely occurring type of intrusive igneous rock consisting of quartz, orthoclase feldspar and plagioclase feldspars, biotite, mica, and varying amounts of ferro-magnesium minerals such as hornblende. It is one of the strongest and most durable of rocks, but, when exposed to air and other agents of weathering, the granite becomes a mass of more or less discrete. Physical and chemical weathering cause progressive changes in the rock fabric and mineralogy that govern physical attributes of rock especially the strength property (Butenuth, 2001). The physical weathering causes disintegration (or breakdown) of original fabrics and also imposes new fabric features. As the size of particle gets smaller, the chemical weathering begins to take place resulting in the discoloration of the affected rock and change in mineralogy. Among the first minerals to be attacked chemically are those high in iron and magnesium. A complex silicate of calcium, magnesium, iron, sodium, and aluminum such as hornblende is transformed into a mass of calcium, magnesium, and sodium carbonates, iron and aluminum oxides, and colloidal silica (Schultz, 1955).
The simplest definition of weathering is the processes of alteration of rocks under the direct influence of air and water. The water plays a dominant role of weathering process because rock absorb water through the capillary or pore within the rock particles. Weathering of primary minerals in tropical regions is more intense and occurs to greater depth than elsewhere (Fookes, 1997) due to wet condition associated with extreme temperature and heavy downpour; hence weathering process is more intensive. The wider variation of moisture content accelerate the changes in rock strength properties. In Peninsular Malaysia, The rock is subjected to damp tropical climate with daily temperature ranging 22°C to 32°C, average soil temperature, including sub surface water, of 28°C and yearly rainfall of greater than 1500 mm per year (Ibrahim Komoo, 1995a). Monthly variation of rainfall is in the range of 75-125 mm. The most obvious change in tropically weathered granite is the decomposition of feldspar grains, mostly to kaolin (Hencher et.al., 1990). Degree of feldspar decomposition has been used by many authors as quantitative index and as an important descriptive feature in characterizing the degree of weathering. A majority of engineering properties decreases with increasing weathering (Sadisun et al., 1999).

Several researchers have studied the effect of moisture content on the engineering properties of weathered granite. They reported that the interaction of rocks with water leads to a reduction in physical and mechanical properties, and this effect has always been a problem in designs related to rock engineering projects especially when dealing with highly weathered rock. Among the previous researches is the work by Broch (1974) who explained that the reduction of strength with increase of moisture content is due to the reduction in the internal friction and their surface energy. Furthermore, Moon (1993) reported that the presence of water soften the bonds or interact with mineral surfaces and alter their surface properties. Effect of water content in strength of rock was studied several researchers (Ibrahim Komoo, 1995a; Lashkaripour and Ajalloeian, 2000; Vasarhelyi and Van, 2006). They agreed that uniaxial compressive strength (UCS) and point load index (Is) decreases by increase of moisture content. Furthermore, Edy Tonnizam et al. (2008) noted that the water absorption of rock increases with weathering grade, thus the water has more significant effect on the strength of highly weathered rock. Erguler and Ulusay
(2008) also studied the trend of water absorption with time. They found that the moisture content increase for all type of rocks when subjected to a longer soaking period. They also noted that the rate of moisture absorption is higher during the first 24 hours before it remains constant.

Despite of research done on the effect of weathering on the strength of rock as well as the effect of moisture on strength of rock, there is limited research carried out on the most important issues in the tropical climate, i.e. the changes of engineering properties of rock material due to the moisture content from various weathering grades. Thus, a better understanding on the process of water absorption in granite of various weathering grade should enable the study on the effect of moisture on the strength of the granite itself. Application of this research on the designs related to rock properties such as stability analysis of slope and underground opening should be enhanced through study on field identification of weathering grade of the granite by simple procedures such as discoloration, Schmidt hammer test, friability, durability and others.

1.2 Problem Statement

Due to climate condition in the tropics, rock mass was weathered significantly and produced thick weathering profile (Ibrahim Komoo, 1995b). The thick weathering profile can be classified into several weathering zones or grades depending on their physical and engineering properties.

The effect of weathering on the strength of rock has been the subject of many researchers such as Fookes et al., (1971); Cook et al., (1996) and Edy Tonnizam et al., (2008). Direct influence of air and water has been identified as the most dominant factor affecting the weathering process. Thus some researchers (Ibrahim Komoo,
1995a; Lashkaripour and Ajalloeian, 2000; Vascarhelyi and Van, 2006) also studied the effect of water on the strength of the rock. These studies indicate that both weathering process and water have significant influence on the strength. Furthermore, studied by Edy Tonnizam et al., (2008) indicated that the rock absorption of water increases with weathering grade while Erguler and Ulusay (2008) identify a relationship between water absorption with time.

This research was carried out to investigate the effect of moisture content on rock material properties of various weathering grade, focusing on their strengths which essential parameters in designing rock engineering structure. Besides the mechanism of water absorption as well as field identification of weathering grade was also part of this study.

1.3 Objective of Study

The research is aimed at identifying the effect of moisture on the change of engineering properties of weathered granite of various weathering grades. In order to achieve the aim of the study, the following specific objectives are set forth:

1. To investigate relationship between strength, durability, and mineral content with the degree of weathering of granite.
2. To evaluate the relative importance of factors affecting the extent of strength reduction especially the change in moisture content.
3. To determine the extent of reduction of strength of weathered granite due to change in moisture content.
1.4 Significance of Study

Rock material strength is significantly affected by weathering process and especially moisture content. Designing a structure in this rock of different weathering degree will create problems related to the variation in material properties. More understanding and accurate knowledge of the weathering profiles can help in optimizing the expenditure and increases the safety level of the in-progress or the future civil engineering works. The result from this research might provide guidance, information and knowledge that can be applied in the whole spectrum of civil and mining engineering fields. This research can develop the understanding of the weak rock masses behaviour and the establishment of a more suitable method to test the properties of the weak rock materials.

1.5 Scope of Study

The research study is bounded by the following scope and limitation:

i. The study focused on coarse grained biotite granite found in Masai Johor (Figure 1).

ii. The assessments of rock mass properties are mainly based on field observation i.e. the strength, texture, friability and discoloration. Schmidt Hammer Test and Impact Test perform in-situ.

iii. Rock material properties were assessed by laboratory experiment i.e. Density Test, Point Load Test, Slake Durability Test, Moisture Content, X-Ray Diffraction (XRD) Test and Petrographic Analysis to obtain their density, strength, durability, moisture, chemical composition and mineralogy of rock.
Combination of field exploration and laboratory experiment provide the information on mass and material properties which will be used to determine the rock classification due to the moisture content of rock.

Figure 1.1: Location map of the studied area (Mineral and Geoscience Department Malaysia, 1982)
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The subjects of weathered rocks are important in engineering due to significant problems involved with their existence. The rock that has been altered by weathering processes generally shows some anomalous engineering characteristic in comparison with fresh rock or residual soil. Neither rock mechanics nor soil mechanics concepts can be used to describe the behaviour of weathered rock. Thus, it is important to recognize the role played by weathering processes in the performance of rock in engineering application.

The weathered rock possess a wide range of index and engineering properties depending on their parent rock forming minerals, intensity of weathering, amount of rainfall and temperature (Ibrahim Komoo, 1995a). These factors are in turn governed by the geographical location and the prevailing weather conditions. Rock weathering results from a series of processes which produce by the alteration of the physical and the mineralogical nature of both the rock material and the rock mass. Most rocks exposed at the surface are the products of weathering processes which involved elevated pressure and temperature. Since physical and chemical conditions at the
surface are significantly different from those under which the rock was formed, the
fabric and minerals of the rock undergo changes in response to the new physico-
chemical regime (Beavis, 1985).

Weathering is a process of alteration of rocks under the direct influence of air
and water which leads to a decrease in density and strength, as well as increasing
deformability. A majority of engineering properties decreases with increasing
weathering (Sadisun et al., 1999). These properties can be gathered through the site
observation (at macroscopic level) and laboratory testing (at microscopic level).

Measurement of rock mass properties in not easily accomplished because of
the large volume of rock involved, hence laboratory testing can be performed to
determine the rock material properties. Laboratory tests have been carried out to
identify material properties i.e. strength, durability, moisture, surface hardness,
chemical composition and mineralogy of the samples. Table 2.1 presents the
common laboratory testing for determines of rock properties.

<table>
<thead>
<tr>
<th>Test Category</th>
<th>Laboratory Testing</th>
<th>Standard Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength Index, $I_{S_{50}}$</td>
<td>Point Load Strength Index Test</td>
<td>ISRM 1985</td>
</tr>
<tr>
<td>Slake Durability Index, $I_{d2}$</td>
<td>Slake Durability Test</td>
<td>ISRM 1981 Part 2</td>
</tr>
<tr>
<td>Water Content</td>
<td>Moisture Content</td>
<td>ISRM 1981 Part 2</td>
</tr>
<tr>
<td>Surface Hardness</td>
<td>Schmidt Hammer Test/ Rebound Test</td>
<td>ISRM 1981 Part 2</td>
</tr>
<tr>
<td>Density</td>
<td>Density Test</td>
<td>ISRM 1981 Part 2</td>
</tr>
<tr>
<td>Mineralogy</td>
<td>Petrographical Analysis</td>
<td>ISRM 1981 Part 2</td>
</tr>
</tbody>
</table>
2.2 Tropical Weathering

Weathering of primary minerals in tropical regions is more intense and occurs to greater depth than elsewhere (Fookes, 1997). Organic matter is rapidly degraded and forms a thin surface layer. Consequently weathering occurs mainly by hydrolysis in near-neutral conditions at depths well below the influence of acidic organic decomposition products. According to Fookes (1997), the alteration is often so intense that in an engineering sense, the rock materials behave quite differently from the parent material from which they were derived.

The tropical land extends between 10°N and 10°S of the equator (Figure 2.1). In the humid tropics, the average annual solar radiation is 7400MJ m\(^{-2}\) per year; water vapour pressure exceeds 25 \(\times\) 10\(^{-2}\) Pa and more than 80% relative humidity (Chai, 2008). It has sunny flux all the year (22-32°C), high amount of precipitation (>1200mm) and underground water of 28°C (Kassim and Edy Tonnizam, 2007).

Figure 2.1: World map of tropical humid region (WMO, 1993). This tropical region was limited in Southeast Asia, Middle Africa, and part of Brazil (Ibrahim Komoo, 1995a)
Climate has great influence to exogenic process especially to chemical weathering process where the high intensity of rain and high temperature accelerates the weathering process. Table 2.2 shows the climate described in term of both of the general governing conditions and the current and immediately preceding weather. The climatic description should be capable of quantifying annual rainfall (including intensities), seasonal and diurnal rainfall variations, seasonal and diurnal temperature variations and humidity.

Determining the local evaporation/transpiration ratios should be an end product of site climatic observations. For some projects it may prove useful to establish local climatic indices on the lines described by Weinert (1974). This climatic index, \( N \) is given by

\[
N = \frac{12E_j}{Pa} \quad [2.1]
\]

Where \( E_j \) is evaporation during the hottest month and \( Pa \) is the annual rainfall.

Weinert derived this index for use in Southern Africa as an aid to the assessment of road aggregate durability in response to weathering environments. Climate index value less than five indicate climatic condition conducive to a residual soil mantle.