# UNIVERSITI TEKNOLOGI MALAYSIA

**DECLARATION OF THESIS / UNDERGRADUATE PROJECT PAPER AND COPYRIGHT**

Author's full name : **MOHAMED FAUZI BIN MD ISA**

Date of birth : **07 OCTOBER 1985**

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

Academic Session : **2010/2011**

I declare that this thesis is classified as :

| | | |
|---|---|---|
| ☐ | **CONFIDENTIAL** | (Contains confidential information under the Official Secret Act 1972)* |
| ☐ | **RESTRICTED** | (Contains restricted information as specified by the organization where research was done)* |
| ✓ | **OPEN ACCESS** | I agree that my thesis to be published as online open access (full text) |

I acknowledged that Universiti Teknologi Malaysia reserves the right as follows:

1. The thesis is the property of Universiti Teknologi Malaysia.
2. The Library of Universiti Teknologi Malaysia has the right to make copies for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:

**SIGNATURE** | **SIGNATURE OF SUPERVISOR**

851007-10-5055
**(NEW IC NO. /PASSPORT NO.)**

DR HJ. EDY TONNIZAM BIN HJ. MOHAMAD
**NAME OF SUPERVISOR**

Date : 20 JUNE 2011

Date : 20 JUNE 2011

**NOTES :** * If the thesis is CONFIDENTAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

"We hereby declare that we have read this thesis and in
our opinion this thesis is sufficient in terms of scope and
quality for the award of the degree of
Master of Engineering (Geotechnics)"

Signature : ....................................................
Name of Supervisor : DR. HJ. EDY TONNIZAM BIN HJ. MOHAMAD
Date : 20 JUNE 2011

Signature : ....................................................
Name of Co-Supervisor : ASSOC. PROF. MOHD FOR BIN MOHD AMIN
Date : 20 JUNE 2011

# 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.

| | | |
|---|---|---|
| Signature | : | …………………………………… |
| Name | : | MOHAMED FAUZI BIN MD ISA |
| 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*

My Teammates
*Undergraduate Students (Rohayati Razali, Ain Naadia Mazlan,Hanis Hazirah)*
*for their continuous support*

My Members
*Postgraduate Students (Fahmi Sabri, Fauzi Mazuki, Ikhwan Khalid, Azizi Aziz, Hanapi Azizol, Rohman Ahmad, Ariff Rahmat )*
*for their continuous support*

## ACKNOWLEDGEMENT

First and foremost, gratitude and praises to ALLAH s.w.t because with his bless, I have been able to pass the obstacle that stood in my way while doing this study. Secondly, I would like to thank Dr. Hj. Edy Tonnizam Mohamad for giving me the chance to complete my study under his supervision. His abundant knowledge of civil and geology field is a benefit for a postgraduate like me. A word of thanks also goes to Assoc. Prof. Mohd. For Bin Mohd. Amin for his help and guidance during my course of study.

I also would like to thank to technicians (Mr. Zulkifli, Mr. Hidayat, Mr. Azlan, Mr. Ikhsan, Mr. Nizam and Mrs. Ros) and academic staff in the Department of Geotechnics and Transportation, Faculty of Civil Engineering UTM and Research Management Centre (RMC) as well as Dr Hj Edy Tonnizam's undergraduate students for their assistance in this study. My fellow friends should also be recognized for their view and tips during this course.

Last but not least, my gratitude and thank go to my family for their support and motivation. I would like to end by saying that the people mentioned above will forever hold dear in my heart and will never be forgotten. Thank you all.

## 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 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.

# ABSTRAK

Kajian ini adalah berkenaan pengaruh kandungan air pada sifat kekuatan granit terluluhawa berbutir kasar. Pengetahuan am umumnya, menunjukkan bahawa kandungan air yang lebih tinggi akan mempengaruhi sebahagian besar aspek sifat fizikal dan mekanikal batuan, tetapi kesannya terhadap pelbagai darjah luluhawa masih belum difahami sepenuhnya. Sebanyak 300 sampel bahan batuan telah diuji meliputi keadaan segar (Kelas I) kepada tahap luluhawa sepenuhnya (Kelas V). Kerja lapangan meliputi pengenalpastian tahap luluhawa, pemerhatian lapangan, ujian tukul *Schmidt* dan ujian impak dilakukan. Keputusan daripada ujian impak di lapangan menunjukkan bahawa ujian index ini dapat menghasilkan hubungkait yang baik dengan kekuatan batuan terluluhawa. Data ujian di makmal dianalisis untuk ujian keperoian, ujian beban titik, kandungan lembapan dan juga ketumpatan batuan. Selain itu, ujian *x-ray diffraction* dan analisis petrografik dilakukan untuk mengenalpasti kandungan mineralogi bahan batuan tersebut. Penyediaan spesimen dan ujian dilakukan mengikut speksifikasi bersesuaian dengan ISRM, 1981 dan 1985. Keputusan kajian menunjukkan bahawa darjah kandungan felspar terubah dan mineral lempung yang terhasil merupakan penunjuk yang baik untuk pengenalpastian darjah luluhawa. Jumlah mineral feldspar yang segar berkurangan daripada 72% bagi gred I kepada 0% bagi gred V dengan peningkatan feldspar terubah dan mineral lempung daripada 0% kepada 60%. Kehadiran mineral feldspar dan lempung sebanyak 1 peratus cenderung untuk meningkatkan kebolehupayaan batuan terhadap air. Kajian juga mendapati bahawa pengurangan kekuatan batuan menjadi lebih besar dengan peningkatan darjah luluhawa. Selain itu, perubahan warna bahan batuan dari kelabu menjadi merah kecoklatan juga boleh menjadi penunjuk yang baik untuk penurunan kekuatan batuan disebabkan oleh kandungan air. Pengurangan kekuatan bahan batuan didapati bergantung kepada gred luluhawa, konstituen petrografik dan tempoh rendaman air. Kajian juga mendapati bahawa indeks beban titik berkurangan sehingga 138% dengan kenaikan hanya 21.40% kandungan air bagi gred IV (terluluhawa gred tinggi). Walaubagaimanapun, bagi gred I (segar), pengurangan kekuatan hanyalah 21.4% daripada keadaan asal dengan nilai kandungan air 0.27% walaupun telah direndam selama 60 minit. Kajian ini merumuskan magnitud pengurangan kekuatan akibat kehadiran kandungan air adalah sangat bergantung kepada tahap luluhawa bahan batuan.

# TABLE OF CONTENTS


| CHAPTER | TITLE | PAGE |
|---|---|---|
| | **TITLE** | **i** |
| | **DECLARATION** | **ii** |
| | **DEDICATION** | **iii** |
| | **ACKNOWLEDGEMENTS** | **iv** |
| | **ABSTRACT** | **v** |
| | **ABSTRAK** | **vi** |
| | **TABLE OF CONTENTS** | **vii** |
| | **LIST OF TABLES** | **xi** |
| | **LIST OF FIGURES** | **xiv** |
| | **LIST OF APPENDICES** | **xviii** |
| | **LIST OF SYMBOLS** | **xix** |
| **1** | **INTRODUCTION** | **1** |
| | 1.1 Background of Study | 1 |
| | 1.2 Problem Statement | 3 |
| | 1.3 Objective of Study | 4 |
| | 1.4 Significance of Study | 5 |
| | 1.5 Scope of Study | 5 |
| **2** | **LITERATURE REVIEW** | **7** |
| | 2.1 Introduction | 7 |
| | 2.2 Tropical Weathering | 9 |

| | | | |
|---|---|---|---|
| | 2.3 | Weathered Rock Classification | 14 |
| | 2.4 | Rock Weathering | 17 |
| | | 2.4.1 Product of Weathering | 18 |
| | | 2.4.1.1 Weathering of Granite | 19 |
| | | 2.4.1.2 Changes of Mineralogy in Weathered Granite | 20 |
| | | 2.4.2 Effects of Weathering | 22 |
| | | 2.4.3 Engineering Properties of Weathered Rock Material | 23 |
| | | 2.4.4 Weathering Profile Characterization | 29 |
| | | 2.4.5 Classification of Weathered Rock for Engineering Purposes | 30 |
| | 2.5 | Rock Material Characteristics | 35 |
| | | 2.5.1 Physical Characteristics | 36 |
| | | 2.5.1.1 Mineralogical Composition | 36 |
| | | 2.5.1.2 Colour | 43 |
| | | 2.5.1.3 Rock Texture | 45 |
| | | 2.5.1.4 Porosity and Moisture Content | 47 |
| | | 2.5.1.5 Material Density | 51 |
| | | 2.5.2 Mechanical Characteristics | 52 |
| | | 2.5.2.1 Hardness | 53 |
| | | 2.5.2.2 Durability | 56 |
| | | 2.5.2.3 Strength | 57 |
| **3** | **METHODOLOGY** | | **60** |
| | 3.1 | Introduction | 60 |
| | 3.2 | Field Investigation | 64 |
| | | 3.2.1 Geological Background of the Site | 65 |
| | | 3.2.2 Weathering Identification of Rock Material | 66 |
| | | 3.2.3 Index Test | 68 |
| | | 3.2.3.1Schmidt Hammer Test | 68 |
| | | 3.2.3.2 Impact Test Method | 70 |

| | | |
|---|---|---|
| 3.3 | Sample Collection | 73 |
| 3.4 | Laboratory Tests | 74 |
| | 3.4.1 Petrographical Analysis | 74 |
| | 3.4.2 X-Ray Diffraction Method | 76 |
| | 3.4.3 Density Test | 78 |
| | 3.4.4 Slake Durability Test | 78 |
| | 3.4.5 Moisture Content | 80 |
| | 3.4.6 Point Load Test | 82 |
| 3.5 | Interpretation of Results | 85 |
| **4** | **CHARACTERISTICS OF TROPICAL WEATHERED GRANITE** | **88** |
| 4.1 | Introduction | 88 |
| 4.2 | Weathering Zone Profiling | 89 |
| | 4.2.1 Friability/Relative Strength | 89 |
| | 4.2.2 Discolouration | 91 |
| | 4.2.3 Rock Soil Ratio (RSR) | 93 |
| | 4.2.4 Joints | 94 |
| | 4.2.5 Boulders | 95 |
| | 4.2.6 Schmidt Hammer Test Results | 97 |
| | 4.2.7 Impact Test Results | 98 |
| 4.3 | Summary of Field Investigation | 104 |
| | 4.3.1 Panel 1 | 108 |
| | 4.3.2 Panel 2 | 109 |
| | 4.3.3 Panel 3 | 110 |
| | 4.3.4 Panel 4 | 111 |
| | 4.3.5 Panel 5 | 112 |
| | 4.3.6 Panel 6 | 113 |
| | 4.3.7 Panel 7 | 114 |
| | 4.3.8 Concluding Remarks | 115 |
| 4.4 | Laboratory Test Results | 117 |
| | 4.4.1 Petrographical Analysis | 117 |
| | 4.4.2 Mineral Composition (X-Ray Diffraction) | 124 |

4.4.3 Material Density 128
4.4.4 Slake Durability 130
4.4.5 Moisture Content 132
4.4.6 Point Load Index 134
4.4.7 Concluding Remarks 135

**5 EFFECT OF MOISTURE CONTENT ON STRENGTH 136**

5.1 Introduction 136
5.2 Absorption of Moisture Content 137
5.3 Influence of Moisture Content on Point Load Index 143
5.4 Strength Reduction with Respect to Weathering Grade 151
5.5 Concluding Remarks 154
5.6 Discussion 156

**6 CONCLUSION AND RECOMMENDATION 163**

6.1 Conclusion 163
6.2 Recommendation for Future Study 166

**REFERENCES 167**

**APPENDICES 178**

## LIST OF TABLES


| TABLE NO. | TITLE | PAGE |
|---|---|---|
| 2.1 | Laboratory tests and standard procedure for evaluation of rock properties | 8 |
| 2.2 | Climate grouping (after Strahler, 1970) | 11 |
| 2.3 | Rock Classification (Little, 1969) | 16 |
| 2.4 | Scheme of weathering profile classification for granite material in humid tropical terrain (Ibrahim Komoo *et al*., 1991) | 27 |
| 2.5 | Weathering grade for metamorphic rock based on the engineering rock material properties (Ibrahim Komoo and Jasni Yaakub, 1990) | 28 |
| 2.6 | Classification of weathered crystalline rocks (Irfan and Dearman, 1978) | 32 |
| 2.7 | Classification of weathered pelitic rocks in arid regions for engineering purposes (Dearman, 1978) | 33 |
| 2.8 | Rock: soil ratio for weathered crystalline rocks (Dearman, 1974) | 35 |
| 2.9 | Scale of decomposition of feldspars by grittiness test (Irfan, 1988) | 38 |
| 2.10 | Classification of weathering grades of granites in term of petrological changes in the rock material (Irfan, 1999) | 39 |
| 2.11 | Rock colour (Anon, 1972) | 44 |
| 2.12 | Description of grain size (Bell, 2007) | 47 |
| 2.13 | Particle shape (Anon 1979) | 47 |
| 2.14 | Classification based on porosity (Anon, 1979) | 48 |
| 2.15 | Moh’s scale of hardness (Terry, 1995) | 55 |

| | | |
|---|---|---|
| 2.16 | Characteristic properties of major rock-forming minerals (Pusch, 1995) | 56 |
| 3.1 | Summary of index and laboratory tests performed on samples | 63 |
| 3.2 | Typical characteristics and appearance of granite in this case study | 67 |
| 3.3 | Number of samples collected and panel involved with respect to weathering grade | 73 |
| 3.4 | Rock strength based Schmidt N hammer value (Look, 2007) | 85 |
| 3.5 | Weathering classification system for granite and volcanic rocks based on field characteristics (Hencher and Martin, 1982) | 86 |
| 3.6 | Gamble's slake durability classification (Gamble, 1971) | 86 |
| 3.7 | Proposed weathering profile classification for weathered rock based on slake durability (modified from Ibrahim Komoo and Jasni Yaakub, 1990) | 87 |
| 3.8 | $Is_{50}$ evaluation of rock strength (Look, 2007) | 87 |
| 4.1 | Summary of Schmidt hammer test from all panels | 97 |
| 4.2 | Results of Impact test | 103 |
| 4.3 | Summary of the results physical observation and in-situ tests each panel with respect to weathering zone | 105 |
| 4.4 | Summary of observation at studied panels | 107 |
| 4.5 | Results of microscopic study on the granite weathering grade I | 120 |
| 4.6 | Results of microscopic study on the granite weathering grade IV | 122 |
| 4.11 | Mean value of dry density | 129 |
| 4.12 | Range and mean value of slake durability index | 132 |
| 4.13 | Range and mean value of moisture content | 133 |
| 4.14 | Range and mean value of natural strength index | 134 |
| 4.15 | Rock material properties of granite for each weathering grade | 135 |
| 5.1 | Range and mean value of moisture content for different soaking time on each weathering grade | 139 |
| 5.2 | Mean differences of moisture content for each weathering grade | 142 |
| 5.3 | Range of differences on moisture content for different weathering grade | 143 |

| | | |
|---|---|---|
| 5.4 | Range of moisture content and strength index for each weathering grade in different soaking period | 144 |
| 5.5 | Comparison of tests result from this study with Irfan and Deaman (1978) | 151 |
| 5.6 | Percentage of strength reduction for weathering grade | 152 |
| 5.7 | Engineering properties of granite for each weathering grade | 155 |
| 5.8 | Characteristics of physical and mechanical properties of weathered granite rock | 158 |

## LIST OF FIGURES


| FIGURE NO. | TITLE | PAGE |
|---|---|---|
| 1.1 | Location map of the studied area (Mineral and Geoscience Department Malaysia, 1982) | 6 |
| 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) | 9 |
| 2.2 | The classic illustration of the rate and weathered product relationships with difference range of temperature and precipitation (Strakhov, 1967) | 12 |
| 2.3 | Relationship between climate and type of weathering (Fookes *et al*., 1971) | 13 |
| 2.4 | Weathering degree versus saturated uniaxial compressive strength (Fahimifar and Soroush, 2007) | 17 |
| 2.5 | Variation in void ratio with weathering grade (Cook *et al.,* 1996) | 18 |
| 2.6 | Variation of rock mass permeability with weathering grade (Zhoa *et al*., 1994) | 23 |
| 2.7 | Relationship between rock strength and weathering grade for certain igneous rock (Fookes *et al*., 1971) | 25 |
| 2.8 | Relationship between uniaxial compressive strength with weathering grade for various types of igneous rock (Ibrahim Komoo, 1995a) | 26 |
| 2.9 | Characteristics of rock material properties (Singh and Goel, 1999) | 35 |

| | | |
|---|---|---|
| 2.10 | Diagrammatic sketch showing (a) Single octahedral unit (b) Sheet structure of the octahedral units and (c) Schematic of the octahedral sheet (Terry, 1995) | 41 |
| 2.11 | Diagrammatic sketch showing (a) Single silica tetrahedron (b) Sheet structure of the tetrahedrons and (c) Schematic of the tetrahedral sheet (Terry, 1995) | 42 |
| 2.12 | Structure of clay minerals (a) Two-layer or t-o structure clay (b) Three-layer or t-o-t structure clay (Terry, 1995) | 43 |
| 2.13 | Effect of water content in strength of rock (Vasarhelyi and Van, 2006) | 50 |
| 2.14 | Correlation between uniaxial compressive strength and water content for mudrocks (Lashkaripour and Ajalloeian, 2000) | 50 |
| 2.15 | Variation in water content of different clay-bearing rocks with time: (a) Specimen stored in room and (b) Saturated sample (Erguler and Ulusay, 2008) | 51 |
| 2.16 | Uniaxial compressive strength versus dry and saturated bulk density (Irfan and Dearman, 1978) | 52 |
| 2.17 | Relation between average values of $\gamma_a R$ and ultimate compressive strength for rock in uniaxial compression (Miller, 1965) | 54 |
| 2.18 | Rock strength classification chart based on Schmidt`hardness using L Hammer (Miller, 1965) | 54 |
| 2.19 | Variation of point load strength with grade of weathering (Zhoa *et al.,* 1994) | 58 |
| 3.1 | Flow chart of major processes in involved in this study | 61 |
| 3.2 | Rock material with various weathering zone observed at the site | 64 |
| 3.3 | Location of the panels studied as marked as P1-P7 | 65 |
| 3.4 | Schmidt hammer test | 69 |
| 3.5 | Impact load test | 71 |
| 3.6 | Carl Zeiss axiocam | 75 |
| 3.7 | Slake durability test | 80 |
| 3.8 | Rock samples | 82 |
| 3.9 | Point load test | 84 |

| | | |
|---|---|---|
| 4.1 | The highly weathered sample (grade IV) before testing | 90 |
| 4.2 | The highly weathered material (grade IV) breaks with strong hand pressure | 91 |
| 4.3 | Discoloration along the horizontal joints | 92 |
| 4.4 | Iron stained at the weathered material surfaces | 93 |
| 4.5 | Three sets of joints; horizontal, vertical and inclined | 94 |
| 4.6 | Occurrence of boulders in a mass of completely weathered zone 5 | 96 |
| 4.7 | Material found between two distinctive boulders | 96 |
| 4.8 | Occurrence of small boulders sliding at hillside | 96 |
| 4.9 | Ball diameter analysis on weathering grade | 99 |
| 4.10 | Diameter of ball | 99 |
| 4.11 | Before test on weathering grade III | 100 |
| 4.12 | After test on weathering grade III | 100 |
| 4.13 | Before test on weathering grade IV | 101 |
| 4.14 | After test on weathering grade IV | 101 |
| 4.15 | Before test on weathering grade V | 102 |
| 4.16 | After test on weathering grade V | 102 |
| 4.17 | Residual soil measurement | 103 |
| 4.18 | Pattern of ball diameter for each weathering grade | 104 |
| 4.19 | Rock face and illustration of weathering profile for panel 1 | 109 |
| 4.20 | Rock face and illustration of weathering profile for panel 2 | 110 |
| 4.21 | Rock face and illustration of weathering profile for panel 3 | 111 |
| 4.22 | Rock face and illustration of weathering profile for panel 4 | 112 |
| 4.23 | Rock face and illustration of weathering profile for panel 5 | 113 |
| 4.24 | Rock face and illustration of weathering profile for panel 6 | 114 |
| 4.25 | Rock face and illustration of weathering profile for panel 7 | 115 |
| 4.26 | Photomicrograph of granite (weathering grade I) | 121 |
| 4.27 | Photomicrograph of granite (weathering grade IV) | 123 |
| 4.28 | X-ray diffraction test for weathering grade II to V | 124 |
| 4.29 | Mineral content for different weathering grade | 127 |
| 4.30 | Pattern of dry density versus weathering grade | 129 |
| 4.31 | Pattern of $I_{d2}$ versus $Is_{50}$ | 130 |

| | | |
|---|---|---|
| 4.33 | Pattern of $I_{d2}$ versus weathering grade | 132 |
| 4.34 | Natural moisture content for each weathering grade | 133 |
| 4.35 | Natural strength index for each weathering grade | 134 |
| 5.1 | Pattern of mean value for moisture content versus weathering grade | 137 |
| 5.2 | Pattern of mean moisture content for different soaking time in every weathering grade | 138 |
| 5.3 | Pattern of moisture content versus time | 140 |
| 5.4 | Mean differences of moisture content for each condition | 142 |
| 5.5 | Pattern of strength index test versus moisture content | 146 |
| 5.6 | Mean value for strength index and moisture content for each weathering grade | 149 |
| 5.7 | Trend of cumulative percentage moisture content and strength reduction for each weathering grade. | 153 |
| 5.8 | Pattern of moisture content and strength index due to mineralogy content for each weathering grade | 160 |
| 5.9 | Pattern of durability index due to mineralogy content for each weathering grade | 161 |

# LIST OF APPENDICES


| APPENDIX | TITLE | PAGE |
|---|---|---|
| A | Results of X-Ray Diffraction (XRD) | 178 |
| B | Slake Durability Test | 187 |
| C | Laboratory Data and Results | 189 |

# 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 |
| $Is_{50}$ | - | 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 absorbtion 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 dominat factor affecting the weathering process. Thus some researchers (Ibrahim Komoo, 1995a; Lashkaripour and Ajalloeian, 2000; Vasarhelyi and Van, 2006) also studied the effect of water on the strength of the rock. These studies indicates that both weathering process and water have significant influence of 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.

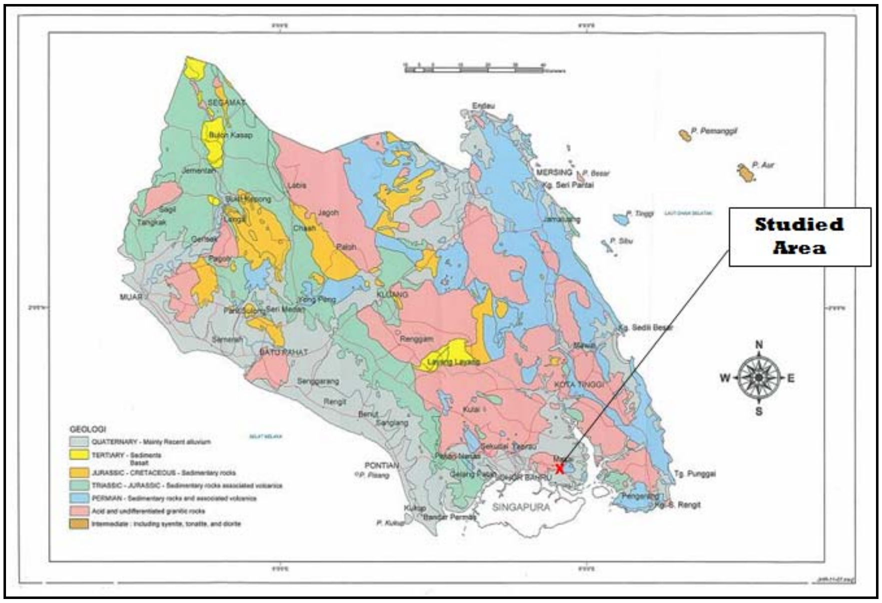


Figure 1.1: Location map of the studied area (Mineral and Geoscience Department Malaysia, 1982)

# 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 physic-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 2.1: Laboratory tests and standard procedure for evaluation of rock properties

| **ROCK TESTS** | | |
|---|---|---|
| **Test Category** | **Laboratory Testing** | **Standard Procedure** |
| Strength Index, $Is_{50}$ | Point Load Strength Index Test | ISRM 1985 |
| Slake Durability Index, $I_{d2}$ | Slake Durability Test | ISRM 1981 Part 2 |
| Water Content | Moisture Content | ISRM 1981 Part 2 |
| Surface Hardness | Schmidt Hammer Test/ Rebound Test | ISRM 1981 Part 2 |
| Density | Density Test | ISRM 1981 Part 2 |
| Mineralogy | Petrographical Analysis | ISRM 1981 Part 2 |

## 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 10ºN and 10ºS 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 (22-32ºC), high amount of precipitation (>1200mm) and underground water of 28ºC (Kassim and Edy Tonnizam, 2007).

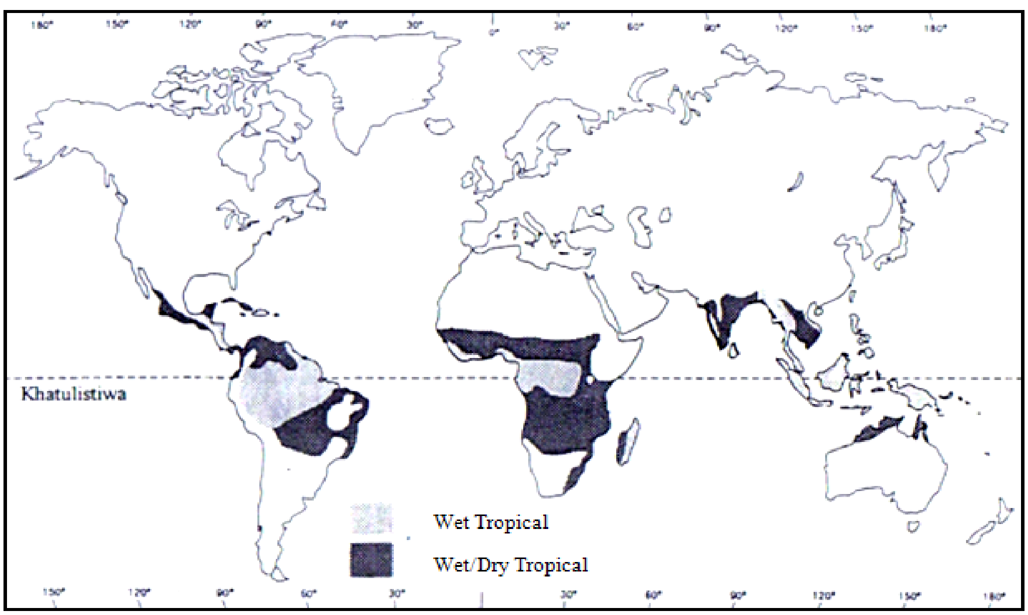


Figure 2.1: World map of tropical humid region (WMO, 1993). This tropical region was limited in Southeast Asia, Middle Africa, and part of Brazil (Ibrahim Komoo, 1995a)

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

$$N = \frac{12Ej}{Pa} \qquad [2.1]$$

Where *Ej* 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.