THE EFFECT OF TROPICAL WEATHERING ON THE STRENGTH AND ANISOTROPY INDEX OF WEATHERED SHALE

OLUMORIN MICHAEL MAIYE

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Civil-Geotechnics)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JANUARY 2014

To my sweet heart wife Adeola and my children Ayomide and Adebola

ACKNOWLEDGEMENT

First and foremost, I express my utmost gratitude to God Almighty who has been with me always in terms of protection and provision of knowledge to complete this research successfully. May all glory and honour be returned unto God.

My appreciation is extended to my supervisor Associate Professor Dr. Edy Tonnizam Bin Mohamad for his encouragement, valuable input and suggestions towards the successful completion of my research and the program. His contribution of wealth of knowledge has greatly assisted me a lot and will continue to be useful in my lecturing work and professional practice. I would also like to express my profound gratitude to my lecturers Dr. Rini Asnida, Professor Dr. Aminaton Marto, Madam Fauziah Kasim, Engr. Dr. Mua'zu Mohammed, Assoc. Prof. Ir. Dr. Ramli Nazir, Assoc. Prof. Mohd For Mohd, Assoc. Prof. Ir. Dr. Azman Kasim, Assoc. Prof. Dr. Nazir Ali and others in the Faculty of Civil Engineering, Universiti Teknologi Malaysia for their useful knowledge impacted in me during the course of study. Similarly, I appreciate other laboratory Technicians for their assistance during all the laboratory tests and the Universiti Teknologi Malaysia for given me the opportunity to study in this great institution. My unreserved gratitude goes to the management of Kaduna Polytechnic for approving my sponsorship to study Master of Civil Engineering program in Malaysia.

I would also like to thank my colleague Engr. (Dr.) Oyeleke Raifu Brown who has encouraged me in the pursuance of this program in Malaysia and for his unquantifiable input in the academic program for me to excel. I am also grateful to Engr. (Dr.) Sulaimon Shodiya, Engr. Gambo Yunsa Haruna, my course mate Elfira Warni, my friends in Malaysia and other well-wishers for their prayers, encouragements and support.

Finally, I would like to appreciate my lovely wife Adeola Olumorin for her fervent prayers, immense support and care at home and even while away. I also express my gratitude to my children Deborah Ayomide Olumorin and Precious Adebola Olumorin for their understanding while in thousands Kilometres apart and their prayers for me to excel and come back home safely.

ABSTRACT

Sedimentary rocks to be specific shale as it is the rock being studied can be adversely affected by weathering action; hence the alteration of its engineering properties is incontestable. The manipulation of the engineering properties of shale becomes more significant as it possesses fine lamination structures which tend to split unevenly, parallel to the weakness plane. It becomes so severe when the rock material is subjected to structural loads, slope cut and higher weathering process in tropical region. This study focus on the effect of weathering on the strength, and anisotropy index $Ia_{(50)}$ of shale of fresh to highly weathered (grades I–IV) shale collected at Nusajaya,west of Johor Baharu, Malaysia. A total of 96 samples representing various weathering grades were collected from the field and tested using 24 samples for each different weathering grade at varying moisture by immersing them in water at different duration of time ranging from 15, 30 and 60 minutes. Point load tests for the determination of the strength index $Is_{(50)}$ of the rock were measured at 0^o and 90^o orientations. For weathered shale (grade I to IV), the mean initial moisture content ranges from 0.12% to 10.69 respectively, while the initial mean strength index has maximum of 7.78 MPa and 0.4 MPa respectively. The results revealed that there is a significant relationship among weathering grades, moisture absorption, strength and anisotropy index of shale. The moisture absorption is dependent on the amount of clay minerals present in the rock material which indirectly affects the strength. In addition, the result shows a unique pattern on the range of anisotropy index for various weathering grades. In conclusion,this study also indicates that shale with higher moisture content and increase in weathering grade exhibits wider range of anisotropy index with lower strength values.

ABSTRAK

Batuan sedimen terutamanya jenis syal berupaya terjejas kualitinya dengan tindakan cuaca dan luluhawa. Justeru itu perubahan sifat kejuruteraan baginya adalah sangat penting untuk diramalkan. Sifat kejuruteraan batu syal adalah unik kerana ia mempunyai struktur laminasi halus yang cenderung kepada pecahan tak sekata, selari dengan satah kelemahan. Ia menjadi lebih teruk apabila bahan batuan ini tertakluk kepada beban struktur, potongan cerun dan proses luluhawa yang tinggi di rantau tropika. Fokus kajian tentang kesan luluhawa kepada kekuatan dan indeks anisotropi $Ia_{(50)}$ batuan segar kepada luluhawa tinggi (gred I-IV) syal diperolehi dari Nusajaya, Johor Bahru, Malaysia. Sebanyak 96 sampel yang mewakili pelbagai gred luluhawa dikumpulkan dari kawasan dan diuji menggunakan 24 sampel bagi setiap gred luluhawa pada kelembapan yang berbeza-beza dengan merendamkannya ke dalam air pada tempoh masa 15, 30 dan 60 minit. Ujian beban titik bagi penentuan indeks kekuatan batu $Is_{(50)}$ telah diukur pada orientasi 0 ^{o} dan 90 ^{o}. Hasil kajian mendapati syal terluluhawa (gred I hingga IV), mempunyai kelembapan min awal antara 0.12% kepada 10.69%, manakala indeks kekuatan min awal adalah 7.78 MPa dan 0.4 MPa masing-masing. Keputusan kajian menunjukkan terdapat hubungan di antara luluhawa gred, penyerapan kelembapan, kekuatan dan indeks anisotropi syal. Penyerapan kelembapan adalah bergantung kepada jumlah mineral tanah liat di dalam bahan batuan yang secara tidak langsung memberi kesan kepada kekuatan. Di samping itu, keputusan menunjukkan corak unik pada julat indeks anisotropi bagi pelbagai gred luluhawa. Kesimpulannya, syal dengan kandungan lembapan yang lebih tinggi dan peningkatan dalam gred luluhawa menghasilkan indeks anisotropi yang berjulat besar dengan nilai indeks kekuatan yang lebih rendah.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

A	-	The Minimum Cross-Sectional Area
β	-	The Orientation Angles to the Direction of Loading
CO_2	-	Carbon Dioxide
cm	-	Centimeter
D	-	Depth
D_e^2	-	The Distance between the Loading Points
F	-	A Size Correction Factor
$Ia_{(50)}$, AI	-	Anisotropy Index
$Is_{(50)}$, I_s	-	Strength Index
$Is_{(50)\perp}$	-	Perpendicular Point Load
$Is_{(50)//}$	-	Parallel Point Load
ISRM	-	International Society for Rock Mechanics
$I\sigma_c$	-	Uniaxial Compression Strength Index
$I\sigma_{c(90)}$	-	Uniaxial Compression Strength at 90° from Axial.
$I\sigma_{c(30)}$	-	Minimum Uniaxial Compression Strength at 30^o
kN	-	Kilo Newton
kN/m^3	-	Kilo Newton per Cubic Meter
L	-	Length, mm
M/C	-	Moisture Content
Min	-	Minutes
mm	-	Millimeter
MN	-	Mega Newton
MN/m^2	-	Mega Newton per Square Meter
Mpa	-	Mega Pascal
OMC	-	Original Moisture Content
P	-	Point Applied Load on Sample
UCS, σ_c	-	Uniaxial Compressive Strength

W	-	Width
W_1	-	Upper Width, mm
W_2	-	Lower Width, mm
WG	-	Weathering Grade
W (%)	-	Moisture Content
π	-	Pi = 3.142
°C	-	Degree Celsius
%	-	Percent

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Weathering can be described as process involving mineral alteration on the rock structure caused by exposure of the rock to the denudation agents such as water, wind and organic fluids in order to be more stable material in natural environment. Water is a triggering factor which plays a major role in both physical and chemical weathering of rocks especially in tropical climate. This leads to significant changes in most of the engineering properties of rocks, particularly in slope, foundation and excavation works. Vasarhelyi et al., (2006) reported that weathering in rock structure would affect the engineering properties of rock, such as porosity, degree of saturation, and strength. All rock engineering activities are conducted either on the surface of the Earth or within a relatively shallow depth beneath it. This thin mantle of the top crust is the zone where the processes of weathering, erosion, transportation and deposition are active (Price, 1995).

It is worth noting that the response of a rock mass to weathering is directly related to its internal surface area and average pore size (Bell, 2007). He further stressed that coarse-grained rocks generally weathered more rapidly than fine-grained ones. Also the amount of water that a rock contains influences mechanical breakdown and this action adversely affect the strength of rocks. Furthermore, the degree of interlocking between component minerals is also particularly important textural factor, since the more strongly a rock is bonded together, the greater is the resistance to weathering. The closeness of interlocking of grains governs the porosity of the rock. This, in turn, determines the amount of water it can hold, and this signifies that, the more porous the rock, the more it is susceptible to chemical attack.

The degree of weathering varies from region to region as a result of changes in climatic conditions. In tropical region, high temperature is usually being experienced and in dry air, rocks decay very slowly but the presence of moisture hastens the rate of decay. Shale is one of the fine-grained sedimentary rocks that has fissility structures or fine lamination that are built parallel to the weakness plane. These cause shale rocks to be easily broken into flakes and tend to split unevenly under applied loads or influence of weathering agents, especially water (Abhijit, 2010). There is no doubt that it is critically important to understand the effect and influence of extent of weathering on the engineering properties of rock material, particularly on the strength and anisotropy index. Shale is universally recognized as an anisotropic rock. Palmstrom (1995) defined anisotropy in rock material is mainly caused by schistosity, foliation or bedding and the different in properties is determined by the arrangement and amount of flaky and elongated mineral.

The strength and anisotropy behaviour of rock is considered to be a major importance in a number of key geotechnical structures, for example, the design of tunnels, dams, underground space and the stability of rock slopes. Consideration must be made to take into account the effect of water such as groundwater table or rainfall on the geotechnical structure especially in terms of strength and anisotropy index of the rock material. Strength and strength anisotropy index of weathered shale influence by water are the main parameters studied in this research. It is critical to understand the correlation and influence of moisture content to the engineering properties of rock especially in term of strength index and strength anisotropy index.

1.2 Problem Statement

In rock engineering project, the effect of weathering is an important issue and therefore requires special attention in dealing with slope stability safety and underground openings. It has been discovered that, most of the present studies focused on the influence of water to the strength of sandstone (Vasarhelyi et al., 2006; Edy Tonnizam et. al., 2008; Kwasniewski et. al., 2009) and metamorphic rock (Saroglou et al., 2004; Eduardo et al., 2006). (Sarout et al., 2006; Sung et al., 2002) studied the anisotropy index of Shale but no reference can be made for the study in influence of various water content to the strength anisotropic index of weathered shale. Meanwhile, Ajalloeian et. al., (2000) study on strength anisotropies in mud rock whereas he was focused on correlation between strength index and anisotropies of siltstone and siltshale but not correlated with influence of water. For these reasons, experimental programs are proposed with the primary objectives of investigating the effect of moisture content to the strength index and the effect of weathering to the anisotropy index under various moisture contents.

1.3 Aim and Objectives

The aim of this research is to investigate the effect of weathering to the strength and anisotropy index of rock material. In this study, two objectives have been identified.

i. To investigate the effect of moisture contents to the strength index of shale.
ii. To study the effect of weathering stages on the anisotropy index of shale.

1.4 Scope of the Study

In order to achieve the goal of this project, the scope of this work need to be specified. The scopes of this research include the analyses of the effect of tropical weathering to the strength index on shale materials using the point load test in the laboratory and changes to anisotropy index, then finally develop a guideline on the strength and anisotropy index of shale under different degree of weathering.

1.5 Significance of the Study

Most weathered rocks strength has been altered because of weakness plane or lamination formation when compared with the parental rock strength. For this reason, the behavior of laminated rock such as shale as it is the focus on this study requires strength and anisotropy index determination. The results obtained will be established as guideline for design in geotechnical structures such as tunnels, slope stability of rock as well as underground space work.

REFERENCES

Abhijit, N. (2010). *Shale rock.* Retrieved on October 20, 2013 from http:/www.buzzle. Com/articles/shale-rock.html.

Ajalloeian, R. & Lashkaripour, G. R. (2000). Strength anisotropies in mudrocks. Springer- Verlag; *Bull Eng Geol Env*., pp. 59: 195–199.

Anon. (1995). The description and classificatioin of weathered rocks for engineering purposes. *Quartly Journal Eng Geol.,* 28**,** 207-242. .

Bell, F. G. (2007). *Engineering Geology*.(2^{nd} ed.), Elsevier, UK. PP, 77-81.

Bieniawski, Z. T. (1975). *The point load test in geotechnical practice.* Engineering Geology, pp 1-11.

Bland, W. & Rolls, D. (eds.) (1998). *Weathering: An Introduction to the Scientific Principles.,* London; Arnold Publishers,.

Blatt, Harvey & Robert J. T. (1996). *Petrology: Igneous, Sedimentary and Metamorphic*.2nd ed. Freeman, pp. 281 – 289.

Broch E. & Franklin J.A. (1972). *The point load strength test*. Int. Journal Rock Mech., Min. Sci 9, pp 669-697.

Chigira, M., Mohamad, Z., Sian, L.C., Komoo, I. (2011). Landslides in weathered granitic rocks in Japan and Malaysia. *B. Geol Soc. Malaysia* 57, 1–6.

DE Mulder, E. J. F., Hack, H. R. G. K. & Van REE, C. C. D. F. (2012.). *Sustainable Development and Management of the Shallow Subsurface*. The Geological Society, London.

Eduardo, M., Sossai, F. & Santiago, L. O. R. (2006). *Weathering influence and weatherability evaluation of some metamorphic rocks from Brazil.* IAEG2006, 453

Edy Tonnizam Mohamad & Azman Kassim (2007). *Laboratory study of weathered rock for surface excavation works.* Faculty of Civil Engineering, University Of Technologi, Malaysia; vot 75055.

Edy Tonnizam Mohamad., Ibrahim, K., Kassim, K. A. & Gofar, N. (2008). *Influence of moisture content on the strength of weathered sandstone.* Malaysia Journal of Civil Engineering 20(1): 137-144(2008).

Farough, H. M. 1993. *Some aspects of the strength characteristics of intact and jointed rocks.* PhD Thesis, University of New South Wales, Australia.

Fookes, P. G., Gourley, C. S. & Ohikere, C. (1988). Rock weathering in engineering time. *Quarterly Journal Engineering Geology Hydroge*, 21**,** pp. 33-57.

Ghafoori, M., Carter, J. P. & Airey, D. W. (1993). Anisotropic behavior of Ashfield shale in the direct shear test. *Proc Int Symp on Geotechnical Engineering of Hard Soils*– Soft Rocks, Rotterdam. pp.509–515.

Ghiasi, V., Omar, H., Huat, B.K., 2009. A study of the weathering of the Seremban granite. *Electron J Geotech Eng.* Pp. 9- 14.

Gupta, A. S. & Rao, K. S. (2001). Weathering indices and their applicability for crystalline rocks. *Bull Eng Geol. Environ*. 60**,** pp. 201-221.

Gurocak, Z. & Kilic, R. (2005). Effect of weathering on geomechanical properties of the Miocene basalts in Malatya, Eastern Turkey. *Bull Eng Geol. Environ,* 6**,** 373-381.

Gutierrez, M., Oyno, L. E. & NYGA°RD, R. (2000.). Stress-dependent permeability of a de-mineralised fracture in shale. *Marine and Petroleum Geology* 17**,** 895–907.

Hachinohe, S., Hiraki, N., Suzuki, T., 2000. Rates of weathering and temporal changes in strength of bedrock of marine terraces in Boso Peninsula, Japan. *Eng Geol.* 55, 29-43.

Hencher, S. R. & Knipe, R. J. (2007). *Developments of rock joints with time and consequences for engineering.* Proceedings of the 11th congress of the International Society for Rock Mechanics, Lisbon. Taylor & Francis, pp. 223-226

Hoek, E. & Brown, E. T. 1980. *Underground escavation in rock,* Lodon, Institution of mining and metalurgy.

Hudson, J. J. & Harrison, J. P. 1997. *Engineering Rock Mechanics: an introduction to principles,* Amsterdam, Pergamon.

Huisman, M., 2006. *Assessment of rock mass decay in artificial slopes,* PhD, Eng Geol. University Delft/ITC, Delft/Enschede, p. 283.

Hunt, R. E. (2005). *Characteristics of geologic materials and formations, A field guide for geotechnical engineers* . CRC press; pp 40-41.

ISRM. (1985). Commission on testing methods; Suggested method for determining point load index strength (revised version). *Int. Journal Rock Mech. Min. Sci. & Geomech. Abstr.*, vol. 22, pp 51-60.

ISRM. (1981). *Rock characterization, testing and monitoring, ISRM suggested method.* Pergamon Press, Oxford, UK. Reference from 11th Congress of The International Society For Rock Mechanics, Vol. 1, Taylor & Francis.

Kevin, C. B. & Frederick, L. S. (2011). *Sedimentary rock. In Encyclopedia Britannica.* Retrived April 18, 2013, from http://www.britannica.com.

Komoo, I. (1995). Syarahan Perdana Geologi Kejuruteraan Perspektif Rantau Tropika Lembap. *Universiti Kebangsaaan Malaysia., Universiti Kebangsaan Malaysia.*

Kwasniewski, M. & Oitaben, P. R. (2009). *Effect of water on the deformability of rocks under uniaxial compression; from rock engineering in difficult ground condition catalogue record.* edited by Ivan Vrkljan. Taylor & Francis Group, London; pp 271-276.

Mohamad, E.T., Komoo, I., Kassim, K.S., Gofar, N., 2008. Influence of moisture content on the strength of weathered sandstone. *Malaysian J. Civ. Eng* 20, 137-144.

Mohamed, Z., Rafek, A.G., Komoo, I., 2007. Characterization and classification of the physical deterioration of Tropically weathered Kenny Hill rock for civil works. *Electron J Geotech Eng* 12, 16.

Murthy, V. N. S. (2003). *Geotechnical Engineering. Principles and Practices of Soil Mechanics and Foundation Engineering*. Marcel Dekker, Inc. New York. PP. 6

Nicholson, D. T. (2004). Hazard assessment for progressive, weathering-related breakdown of excavated rockslopes. *Quarterly Journal Eng Geol. Hydroge.* , 37**,** pp. 327-346.

Nishiyama, K.-I. & Matsukura, Y., 2009. Weathering rates and mechanisms causing changes in rock properties of sandstone; paper 278, in: Culshaw, M.G., Reeves, H.J., Jefferson, I., Spink, T.W. (Eds.), 10th international congress International Association of Engineering Geology and The Environment

(IAEG2006); Engineering geology for tomorrow's cities. *Geological Society of London*, Nottingham, UK, p. 6 (CD).

Palmstrom, A. (1995). *A rock mass characterization system for rock engineering purpose.* PhD Thesis, Oslo University, Norway, pp 400.

Pauzi, N.I.M., Omar, H., Bujang, K.H., Misran, H., Yusoff, Z.M., 2011. Microcrack pattern propagations and rock quality designation of Batu Caves Limestone. *Electron J Geotech Eng* 16, 591–604.

Price, D. G. (1995). Weathering and weathering processes. *QuarterlyJournalof Engineering Geology*, 28**,** 243–252.

Raj, J. K., (1985). Characterization of the weathering profile developed over a porphyritic biotite granite in Peninsula Malaysia. *B. Eng Geol. Environ.* 32, 121-129.

Ramamurthy, T. 1993. *Strength and modulus responses of anisotropic rocks Comprehensive Rock Engineering Fundamentals*, Pergamon Press.

Santi, P. M. (2006). *Field methods for characterizing weak rock for engineering*. Vol. XII, Environmental & Engineering Geoscience, pp. 1 – 11.

Saroglou, H. and Tsiambaos, G. (2007). *Classification of anisotropic rocks. Vol.1, 11th congress of the international society for rock mechanics*, Taylor & Fracis group, London, pp 191-196.

Sarout, J., Molez, L., Gue'guen, Y. & Hoteit, N. (2006). *Shale dynamic properties and anisotropy under triaxial loading. Experimental and theoretical investigations*. Elsevier Ltd., physic and chemistry of the earth.

Semhi, K., Amiotte Suchet, P., Clauer, N. & Probst, J. L. (2000). *Impact of nitrogen fertilizers on the natural weathering-erosion processes and fluvial transport in the Garonne basin*. Appl. Geochem., 15**,** pp. 865-878.

Singh, J., Ramamurthy, T. & Rao, G. V. (1989). Strength anisotropies in rocks. *Indian Geotech J* 19**,** 147–166.

Vasarhelyi, B. & Van, P. (2006). *Influence of water content on the strength of rock.* Engineering Geology 84, pp 70–74.

West, T. R. (1995). *Geology Applied to Engineering*. Prentice Hall, Inc. New Jersey,U.S.A . PP.51, 58.

Yatsu, E., (1988). *The Nature of Weathering*: an Introduction. Sozosha, Tokyo, Japan. P. 624.

Yokota, S. & Iwamatsu, A., 2000. Weathering distribution in a steep slope of soft pyroclastic rocks as an indicator of slope instability. *Eng Geol.* 55, 57–68.

Zetty, S. M. & Edy Tonnizam, M. (2010). *Durability of granite and shale for various weathering grade.* Under graduate thesis. Universiti Teknologi Malaysia, pp 5-6.