UNIVERSITI PUTRA MALAYSIA

THE EFFECT OF WETTING ON THE COLLAPSIBILITY AND SHEAR STRENGTHS OF TROPICAL RESIDUAL SOILS

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MASTER OF SCIENCE
UNIVERSITI PUTRA MALAYSIA

April 2008

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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April 2008

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In Malaysia, almost 80% of its land is covered with residual soils, especially sedimentary and granitic residual soils. It is believed that these types of soil have a high possibility to collapse when wetted. The high rate of collapsibility is influenced by the climatic tropical factor, hot and high humidity throughout the year. Therefore, the main objective of this study is to identify the effect of wetting on the collapsibility and shear strength of the tropical residual soils. Two major tests employed in the study were the Double Oedometer and Double Shear Box tests. For each test, two different samples were tested; the first samples were the soils in their natural moisture condition and the second were inundated in water. The samples tested using the double oedometer test were allowed to be inundated in water for a few days under applied load until they achieved a steady state (the dial gauge reading remained constant) before another load was added. There

were 20 samples in the situation *before* and *after* the inundated condition for the two major tests. Other than the rate of collapsibility and shear strength of these soils, other parameters such as void ratio, porosity, particle size distribution, dry density and bulk density were also observed. Other test such as the Scanning Electron Microscopic and X-Ray Diffraction Analysis were also carried out. From the result obtained, both type of soil collapse due to wetting however, calculated collapse potential indicates that the granitic residual soil is higher and having wider range as compared to sedimentary residual soil. After collapsing due to wetting, result from SEM analysis indicate that the soils sample structure become more compacted and voids between structure become smaller. On the other hand, result from shear strength test showed shear strength reduced vigorously after inundated especially in Granitic residual soil because the cohesion and friction angle reduced to more than 50% whereas much lesser in Sedimentary residual soil i.e. in the range of 30% to 40%.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

Kesan kelembapan terhadap kebolehruntuhan dan kekuatan ricih tanah baki tropika

Oleh

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Malaysia diliputi hampir 80% tanah baki terutamanya tanah baki sedimen dan tanah baki granit. Kedua – dua tanah baki ini dipercayai mempunyai kadar kebolehruntuhan yang tinggi apabila basah atau lembap. Kebolehruntuhan tanah yang tinggi ini dipengaruhi oleh keadaan iklim tropika, panas dan lembap sepanjang tahun. Oleh itu, objektif kajian ini dilakukan adalah untuk mengenalpasti kesan kelembapan terhadap kebolehruntuhan dan kekuatan ricih tanah baki tropika. Dua ujian utama dalam kajian ini adalah Ujian Oedometer Berganda dan Ujian Kotak Ricih Terus Berganda. Bagi setiap ujian, terdapat dua keadaan sampel yang diuji dalam ujian ini iaitu yang pertama sampel dalam keadaan kelembapan semulajadi dan yang kedua sampel direndam di dalam air. Sampel yang diuji menggunakan ujian oedometer berganda dibiarkan terendam di dalam air selama beberapa hari di bawah beban kenaan tetap sehingga mencapai keadaan tetap sebelum beban kenaan tetap ditambah. Sebanyak 20 sampel telah diuji dalam keadaan sebelum dan selepas direndam

bagi kedua – dua ujian. Selain daripada, peratus kadar kebolehruntuhan, dan kekuatan ricih bagi tanah – tanah ini, parameter – parameter lain seperti nisbah lompang, keliangan, saiz agihan partikel, ketumpatan kering dan ketumpatan pukal turut dikaji. Selain dua ujian utama tersebut, ujian seperti *Scanning Electron Microscopic* dan *X-Ray Diffraction analysis* turut dilakukan. Daripada kajian ini, didapati bahawa kedua-dua jenis tanah baki runtuh disebabkan oleh kelembapan. Walaubagaimanapun, pengiraan potensi kebolehruntuhan menunjukkan tanah baki granit lebih tinggi dan mempunyai julat yang lebih besar berbanding tanah baki sedimen. Keputusan analisis SEM bagi kedua – dua jenis tanah menunjukkan perubahan terhadap struktur tanah sebelum dan selepas sampel direndam. Struktur tanah tersebut menjadi lebih halus akibat liang – liang antara tanah menjadi lebih kecil dan padat. Selain daripada itu, hasil keputusan ujian kekuatan ricih berganda, didapati bahawa bagi tanah baki granit berlaku pengurangan 50% dalam kekuatan ricih selepas sampel direndam dalam air. Berbanding tanah baki sedimen, pengurangan dalam kekuatan ricih terhadap kelembapan dalam lingkungan 30% ke 40%.

ACKNOWLEDGEMENTS

All praise and gratitude is due to Allah, the Lord and Sustainer of the universe, for without him, everything will cease to be.

I wish to express my profound gratitude and special thanks to my supervisor Prof. Dr. Bujang Bin Kim Huat, and to the committee members, Ir. Azlan Abdul Aziz for their excellent supervision, valuable guidance as well as very helpful comments at the commencement of the project, patience and endurance over the years.

The same appreciation and deepest thanks to the laboratory technician in the Geotechnical Engineering Laboratory, Mr Razali Abdul Rahman and also laboratory technician in the Geology Engineering Laboratory Mr Nik Mohd Faiz Nik Yahaya. Deepest thank to Mr Ahmed H. B Mohammed, Ms Ernaliza Mahsum, Mr Youventharant A/L Duraisamy and Mr. Mohd. Shahfarin Selamat for their valuable information and to all who helped direct and indirect.

I would also like to extend my deepest love and appreciation to my parents and family for their prayers and moral support throughout my study.

I certify that an Examination Committee met on 10th September 2008 to conduct the final examination of **Nor Azwati Bt Azmi** on the **degree of Master of Science** thesis entitled **Effect of Wetting on The Collapsibility and Shear Strengths of Tropical Residual Soils** in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the degree of Master Science. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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DECLARATION

I declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently submitted for any other degree at Universiti Putra Malaysia or at any other institution.

NOR AZWATI BT AZMI

Date: 25th April 2008

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The collapsible soil phenomenon is found widely all over the world. This phenomenon has been given a great attention by geotechnical engineers and researchers. Residual soil has peculiar or distinctive characteristics and is hard to understand. Some attempts have been made in order to understand the mechanism and its susceptibility to collapse, including case study and experimental study to predict this collapse.

In fact, Northey (1969) emphasized that the mechanisms of collapse and methods to assess the potential of soil collapsing were inadequately understood. Examples of past study on the collapsibility of residual soils are shown in Table 1.1

Table 1.1: Studies conducted on the collapsibility of residual soil phenomenon by researchers of three different countries

Country	Researchers	Titles	Reference
Malaysia	B. B. K. Huat, F. Hj Ali, F.N. Choong (2006)	Collapsibility and volume change of unsaturated residual soil	Journal of Geotechnical & Geological Engineering
Brazil	M. Vargas (1973)	Structurally unstable soils in Southern Brazil	Proceeding vIII International Conference Soil Mechanics & Foundation Engineering
	R.C Ferreira, L.B Monteiro (1985)	Identification and evaluation of collapsibility of colluvial soils that occur in Sao Paulo state	1st Internatioanal Conference on Geomechanics in Tropical Lateritic & Saprolitic Soils
	H. F. Pereira, D. G. Fredlund (2000)	Volume change behaviour of collapsible compacted gneiss soil	Journal of Geotechnical and Geoenvironmental Engineering
India	Yudhbir (1982)	Collapsing behaviour of residual soils	Proceedings of the Seventh Southeast Asian Geotechnical Conference
	S.M Rao, K. Revanasiddappa (2002)	Collapse behaviour of residual soil	Journal of Geotechnique
	S.M Rao, K. Revanasiddappa (2000)	Role of matrix suction in collapse of compacted clay soil	Journal of Geotechnical and Geo-environmental Engineering

1.2 Problem Statement

Malaysia is one of the countries which have a humid tropical climate, characterized by high temperatures and heavy rainfalls. Beside the wide distribution of residual soil in Malaysia, the climatic factor is also a main reason which leads to a very active formation process of residual soil in the region. Malaysia is also suffering from the combined effects of deeply weathered rock profiles and very high seasonal rainfall. It is believed that the collapsibility phenomenon has an inter-relation with the behaviour of residual soils.

Residual soils have peculiar characteristics; and these are depending on whether their formation is formed from sedimentary, igneous or metamorphic rocks (Blight, 1997). Instead of the soil formation, one of the significant characteristics of residual soils is the existence of bonds between the particles. These bonds are a component of strength (which can be reflected as apparent cohesion,c') and initial stiffness that is independent of effective stress and void ratio/density. The bonding is also contributed to the 'apparent' overconsolidated behaviour of the soils (Tan & Chow, 2004).]

The soil particles stick together because of cohesion, which this cohesion is a result of bonding and cementation of fine particles. Fine particles especially clay have an electrostatic bonding which they tend to have an overall charges. Whereas, water (most natural water) has ions on it, the water molecules and clay particles would attract to one another because of this electrical charges and resulting in cohesion. Meant, as more water added to clay rich soils particle become farther apart and the strength of attraction decreases (Huat & Singh, 2004).

The distinctive behaviour of residual soil may cause the study of collapsibility more difficult to identify. Collapsible soils, which are also known as meta-stable soils, will remain strong and stable as long as they remain dry. However, if they become wet, they will quickly collapse, and thus will generate unexpected settlement. The process of collapsibility, in almost all cases, is instantaneous or of short duration processes (Aitchison, 1973). In general, the evaluation of collapsible phenomenon, particularly in residual soils, should consider some other aspects such as the soil criteria, causative factors, and adequate testing methods.

1.3 Objective

The main objective of this study is to determine the effect of wetting on the collapsibility and the shear strength parameters of tropical residual soil. To be specific, the purposed is to determine the collapse potential of granitic and sedimentary residual soil due to wetting as well as to determine the effect of wetting on the shear strength of tropical residual soil.

1.4 Scope of the Study

1.4.1 This study will be focussed into two major points namely the collapsibility of residual soil due to wetting and the effect of wetting on the shear strength.

1.4.2 The types of soils that will be used in this study are weathered granitic residual soil and weathered sedimentary residual soil. These two types of soil represent the major portion of Malaysian soil types.

1.4.3 The main laboratory testing used were standard oedometer test and shear box test. The standard oedometer test is used in this test to calculate the collapse potential of soil and the shear box test to determine the shear strength parameters of soil.

1.4.4 For engineering properties and classification purposes, a few test done such as Atterberg limits, particle size distribution and moisture content test. Whereas, the additional test applied in this study were Scanning Electron Microscopic (SEM) and X-Ray Diffraction analysis (XRD).

1.5 Limitations of the study

1.5.1 All tests applied in this study were carried out only via laboratory tests.

1.5.2 The two types of soil sample used are taken from two particular places namely Bentong, Pahang for granitic residual soil type and UPM Serdang Campus, Selangor for sedimentary residual soil type.

1.5.3 The elements or factors to be discussed would be the void ratio; the Atterberg limits result, shear strength parameters and additional factors that contribute to the collapsibility of residual soil.

1.6 Benefits of the Study

In Malaysia, the vast majority of its land is largely covered with residual soils. A better understanding of this type of soil is very important to enable the future developments and constructions are successfully carried out. Standard development programmes in such areas to be executed with special precautions and measures, as well as application of appropriate technologies in order to reduce the inherent risks of the unexpected huge settlement due to the collapse. Wetting-induced collapse may also explain the slumping phenomenon seen in some shallow slope failures (Blight, 1997).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Malaysia is a humid tropical climate country with high temperature and abundant moisture in this region. It provides an optimum environment for weathering processes, mainly the chemical weathering. Climate plays an important role in the residual soil forming processes. Therefore, the processes are still very active in this region.

Residual granitic soil and sedimentary soil can be found extensively in Malaysia. These types of soil cover more than 80% of the land area. Yet, not much research has been carried out on these materials (Ali & Rahardjo, 2004).

As mentioned earlier, it is believed that the collapsible soil phenomenon in Malaysia has an inter-relation with the behaviour of residual soils. However, most of the collapsible soil phenomena generally emphasize on the loess soil (Aeolian deposits) as compared to residual soil. Based on Figure 2.1, it is proposed that this emphasis should be given on the study of residual soil, since it is also classified as a collapsible soil. A classification of collapsible soils is shown in Figure 2.1 below. The three highlighted words are the major deposits which are classified as collapsible soils.

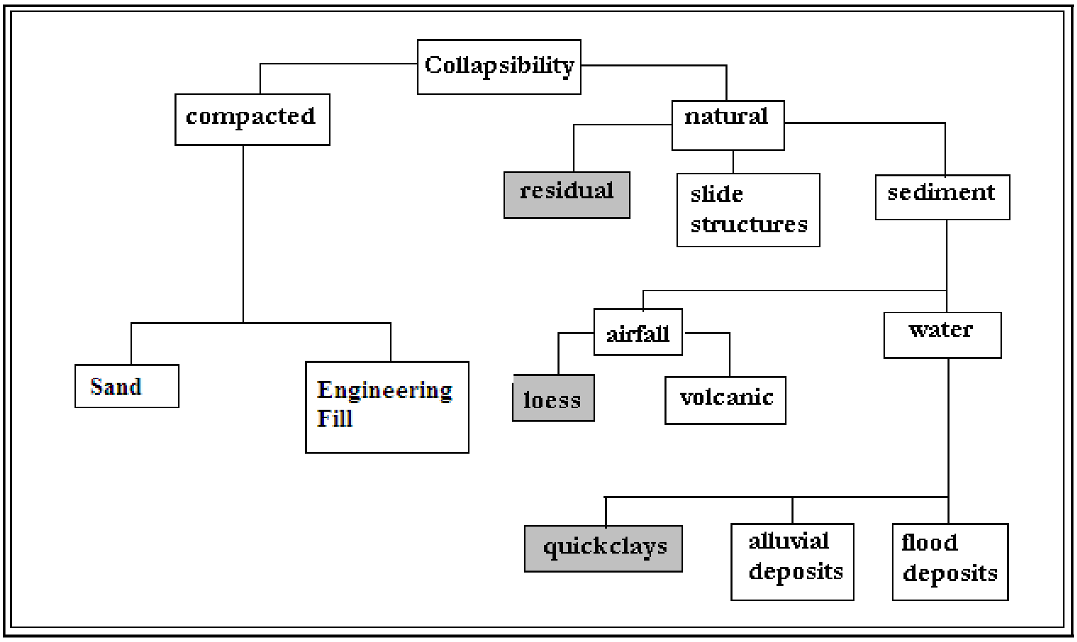

Figure 2.1: A classification of collapsible soils (Roger, 1995)

2.2 Definition of Residual Soil

Generally, residual soils are defined as products of the in-situ weathering of igneous, sedimentary and metamorphic rocks. In other words, residual soils form or accumulate and remain at the place where they are formed.

However, according to there is apparently no universal definition for residual soil. This shows that the definition of residual soil varies from one country to another. Some researchers, such as Brand & Phillipson (1985) defined residual soil as a type of soil formed by weathering in place, but with the original rock texture destroyed. The term is normally used for a soil that behaves like a soil in places such as Hong Kong, including the highly and completely decomposed rock.

Blight (1985), on the contrary, defined it as all material of a soil consistency that is located below the local ancient erosion surface, or that is below the pebble marker. However, this definition is given for the residual soil found in South Africa. Many people defined residual soil in the same ways as the definitions mentioned above.

Among others, a common definition of residual soil refers to it as the remaining depleted soil in which most soluble elements in the soil have been dissolved (Huat *et al*, 2004). This, in fact, implies that residual soils are normally undergoing extensive physical and chemical alteration through the processes known as 'natural weathering'. Weathering processes can result in various degrees of gradual degradation or breaking down of the parent rock material from fresh rocks to fine particles of clay sizes. Throughout these processes, physical characteristics of the soil such as bonding, strength, permeability and density, will change drastically (Liew, 2004).

2.3 The Formation of Residual Soil

Residual soils have peculiar characteristics because of the formation processes. They normally occur in most countries of the world, mainly in the humid tropical areas such as Malaysia. It is weathered to a considerable depth and degree of weathering which varies with depth. As a result, engineering properties of the residual soils are also varied along a soil profile. Residual soil properties vary from one region to another, due to their heterogeneous nature and highly variable degrees of weathering controlled by regional climatic, topographic conditions and nature of bedrock (Aung, 2001).

The formation of residual soil depends on a few factors which play important and influencing roles in its development. These factors give a great impact on the behaviour of the residual soil, either in terms of its characteristics or quality. The factors considered are simplified in Table 2.1 below, as cited from Huat and Singh (2004).

Table 2.1: Major factors affecting soil formation (Bergman & McKnight, 1993)

Factor	Description
Climatic	Refers to the effect on the surface by temperature and precipitation.
Geologic	Refers to the parent material (bedrock or loose rock fragments) that provide the bulk of most soils.
Geomorphic/ topographic	Refers to the configuration of the surface and is manifested primarily by the aspects of slope and drainage.
Biotic	Consists of living plants and animals, as well as dead organic material incorporated into the soil.
Chronological	Refers to the length of time over which the other four factors interact in the formation of particular soil.

(Source: Huat & Singh, 2004)

Residual soil is an important product of weathering. The formation process of the residual soil involves three types of weathering which work simultaneously in nature, i.e. physical, chemical and biological.

2.3.1 Weathering

Weathering involves physical breakdown and chemical alteration, or in other words, disintegration and decomposition of rocks at or near the Earth's surface. The existence of residual soil is contributed by the weathering process.

Weathering process is a combination of disintegration and decomposition of rocks which are exposed to the atmosphere for a sufficient length time. Disintegration is the breakdown of rocks into small particles by the action of denudation mechanical agents such as rain, wind and waves, all of which are helped by gravity. Decomposition is the breakdown of mineral particles into new compounds by the action of chemical agents, such as the acids in the air, rain and river water (Blyth, 1960).

2.3.1.1 Physical Weathering

Physical or mechanical weathering is accomplished by physical forces which break rock into smaller pieces without changing the rock's mineral composition. For this reason, physical weathering increases the amount of the existing surface area for chemical weathering (Frederick & Edward, 2003). The physical weathering involves a few different types of processes such as frost wedging, exfoliation, thermal expansion and contraction, and abrasion.

2.3.1.2 Chemical Weathering

Chemical weathering involves the chemical dissolution or alteration of the chemical and mineralogical compositions of minerals. In this process, minerals are broken down into new compounds by the chemical agents such as acid which is contained in the air or rain. The rock-forming minerals are vulnerable to attack by water, oxygen and carbon dioxide at the new surface environment they are exposed to, and tend to undergo chemical changes to form new stable minerals (Huat & Singh, 2004).

This also can be explained as the form of weathering brought about by chemical attack on rocks, usually in the presence of water. Chemical weathering involves the breakdown of the original minerals within a rock to produce new minerals (such as clay minerals, bauxite, and calcite). The breakdown of rocks occurs because of chemical reactions between the minerals in the rocks and substances in the environment, such as water, oxygen, and weakly acidic rainwater. Some chemicals are dissolved and carried away from the weathering source, while others are brought in (http://www.tiscali.co.uk/reference/encyclopaedia).

In other words, chemical weathering includes processes by which the internal structure of a mineral is altered by the removal and/or addition of elements. The common chemical processes contributing to chemical weathering are solution, oxidation (breakdown by the oxygen in air and water), hydration (breakdown by absorption of water), hydrolysis (breakdown by water), carbonation (breakdown by weakly acidic rainwater) and leaching. In addition, this process is also influenced by temperature and the amount of exposed surface.

2.3.1.3 Biological Weathering

Weathering is also contributed by the activities of organisms whereby they can act both as the chemical and/or physical agents of weathering. These organisms release acids which will react with rocks and mechanically break them up. A wide range of organisms ranging from micro-organisms to plants and animals can cause weathering to occur (Huat & Singh, 2004).

2.3.2 Weathering Product

The product of weathering can be classified into two categories: they are weathering products from rock–forming minerals and parent rocks. Minerals are naturally formed crystals composed of one or more chemical elements. They are distinguished from other minerals by their crystalline structure (Huat & Singh, 2004).

The rate of weathering process slightly depends on the stability of the mineral in the weathering environment. For instance, some minerals are readily soluble in slightly acidic water, whilst others are very resistant to weathering and sometimes remain for a long time without alteration.

The temperature of mineral forming is one of the crucial factors which determine the nature of mineral. At high temperatures and pressures, the minerals tend to become unstable and weather almost rapidly. This is because they are the furthest from the conditions under which they formed. Inversely, at lower temperatures and pressures, the minerals are most stable beneath the surface conditions.

On the other hand, rock weathering involves the weathering of their respective constituent minerals. The mineral-suite forming respective major rock types (igneous rocks, sedimentary rocks and metamorphic rocks) which determine the products of weathering from these rocks (Huat & Singh, 2004).

The parent rock plays an important role in determining the characteristics of residual soil. For example, residual soil on weathered granite will initially be sandy, having sand-sized particles of quartz, and partially-weathered feldspar are released from the granite. The partially-weathered feldspar grains will gradually and further completely weather it into fined-grained clay minerals over the time. As resistant quartz does not weather, the resulting soil will have both sand-sized quartz and clay (Huat & Singh, 2004).

Rocks can be composed of numerous grains of several different minerals. The example given above is composed of the minerals quartz, feldspar, hornblende and biotite. However, the influence of the parent rock decreases over the passage of time.