INVESTIGATION ON THE UNDRAINED SHEAR STRENGTH OF SOFT CLAY MIXED WITH VARIOUS PERCENTAGES OF LIME AND 6 % OF SILICA FUME

LEONG KAH SENG

A report submitted in fulfilment the requirements for the award of the degree of

B. Eng. (Hons.) of Civil Engineering

Faculty of Civil Engineering & Earth Resources

UNIVERSITI MALAYSIA PAHANG

JUNE 2015

ABSTRACT

Soil stabilization can make the soils becoming more stable. This method is applying admixture on the soil. Lime stabilization enhances engineering properties of soil, including reducing the soil plasticity, increase in optimum moisture content, decrease in maximum dry density and improvement in compaction of soil. Silica fume is utilized as a pozzolanic material in the application of soil stabilization. Silica fume was once considered as non-environmental friendly. Now, it has been adopted as a binder material with cement materials for the application of the soil stabilization. In this research, the materials required are kaolin grade S300, lime and silica fume. The focus of the study is the determinations of the physical properties of the soils tested and the strength of kaolin mixed with 6 % of silica fume and various percentages (3.0 %, 5.0 %, 7.0 % and 9.0 %) of lime. Unconfined compression test is carried out on the kaolin and the mixtures of soil-lime-silica fume to investigate the effect of lime stabilization with silica fume additives on the unconfined compressive strength of the mixtures. Based on the results obtained, all soil samples are indicated as soils with medium plasticity. From 0 % to 9.0 % of lime with 6.0 % of silica fume, the decrease in the maximum dry density is by 5.92 % and the increase in the optimum moisture content is by 23.5 %. Decreases in the coefficient of permeability of the mixtures occur if compared to the coefficient of permeability of kaolin soft clay itself. The optimal percentage of lime-silica fume combination is attained at 5.0 % of lime and 6.0 % of silica fume in order to improve the shear strength of kaolin soft clay. The improvement in shear strength of this stabilized mixture is 29.83 % if compared to the shear strength of the kaolin sample. It can be concluded that lime-silica fume mixture was an effective stabilizer for improving the geotechnical properties of clayey soils.

ABSTRAK

Penstabilan tanah membolehkan tanah menjadi lebih stabil. Kaedah ini menggunakan bahan tambah pada tanah. Penstabilan kapur meningkatkan sifat-sifat kejuruteraan tanah, termasuk mengurangkan keplastikan tanah, meningkatkan kandungan kelembapan optimum, mengurangkan ketumpatan kering maksimum dan peningkatan dalam pemadatan tanah. Silica fume digunakan sebagai bahan pozzolanic dalam permohonan penstabilan tanah. Silica fume pernah dianggap sebagai mesra bukan alam sekitar. Kini, ia telah diterima pakai sebagai bahan pengikat dengan bahan-bahan simen bagi permohonan penstabilan tanah. Dalam kajian ini, bahan-bahan yang diperlukan adalah gred S300 kaolin, kapur dan silica fume. Fokus kajian ini adalah penentuan sifat-sifat fizikal tanah diuji dan kekuatan kaolin dicampur dengan 6.0 % daripada silica fume dan pelbagai peratusan (3.0 %, 5.0 %, 7.0 % dan 9.0 %) daripada kapur. Ujian Mampatan Tak Terkurung dijalankan pada kaolin dan campuran tanah-kapur-silica fume untuk mengkaji kesan penstabilan kapur dengan bahan silica fume ke atas kekuatan mampatan tak terkurung daripada campuran. Berdasarkan keputusan yang diperolehi, semua sampel tanah dinyatakan sebagai tanah dengan keplastikan sederhana. Dari 0 % hingga 9.0 % kapur dengan 6.0 % silica fume, pengurangan dalam ketumpatan kering maksimum adalah sebanyak 5.92 % dan peningkatan kandungan lembapan optimum adalah sebanyak 23.5 %. Penurunan dalam pekali kebolehtelapan campuran berlaku jika dibandingkan dengan pekali kebolehtelapan tanah liat kaolin lembut sendiri. Peratusan optimum kapur-silica fume dicapai pada 5.0 % kapur dan 6.0 % silica fume bagi meningkatkan kekuatan ricih tanah liat kaolin lembut. Peningkatan dalam kekuatan ricih campuran ini adalah 29.83 % jika dibandingkan dengan kekuatan ricih sampel kaolin ini. Kesimpulannya, campuran kapur-silica fume merupakan penstabil yang berkesan untuk meningkatkan ciri-ciri geoteknik tanah liat.

TABLE OF CONTENT

LIST OF TABLE

LIST OF FIGURE

LIST OF SYMBOLS

cm	-	Centimetre
c	-	Cohesion
G_s	-	Specific Gravity
I_P	-	Plastcity index
kN	-	Kilo Newton
kN/m^3	-	Kilo Newton per cubic metre
kPa	-	Kilo Pascal
K_t	-	Coefficient of permeability
Mg	-	Mega Gram
Mg/m^3	-	Mega gram per cubic metre
m^2/g	-	Square metre per gram
m/s	-	Metre per Second
ml	-	Millilitre
mm	-	Milimetre
nm	-	Nanometre
s_u	-	Undrained shear strength
Δs_u	-	Percentage in undrained shear strength
w	-	Moisture content
w_L	-	Liquid limit
w_P	-	Plastic limit
w_{opt}	-	Optimum moisture content

γ_d	-	Dry Unit Weight
$\gamma_{d(max)}$	-	Maximum Dry Density
ΔL	-	Lime percentage
$°C$	-	Degree Celsius
ϕ_u	-	Undrained angle of internal friction

LIST OF ABBREVIATIONS

ASSHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BS	British Standard
BSCS	British Soil Classification System
EPA	Environmental Protection Agency
ICE	Inventory of Carbon & Energy
K	Kaolin
L	Lime
LL	Liquid Limit
PI	Plastic Index
PL	Plastic Limit
RMC	Recovered Mineral Components
SCM	Supplementary Cementitious Materials
SF	Silica Fume
UCT	Unconfined Compression Test
UCS	Unconfined compressive strength
USCS	Unified Soil Classification System

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

In Malaysia, with the increasing number of national road networks, areas underlain with very soft soils are used for building constructions. The soft soil has become a threat to the construction industry, especially in road construction. As we know, soft soil are highly compressible, low shear strength and low permeability. Usual construction issues in this deposit are unsatisfactory bearing capacity, extra post construction settlement and instability on soil removal and embankment forming. In order to construct geotechnical buildings like embankments, structure and roadwork, engineers have to study the soil's properties, cost-effective and environmental aspects.

In geotechnical engineering projects, satisfactory soil engineering characteristics play a major part. If a soil does not have sufficient properties, engineers have to find ways to fix the mechanical and chemical problems of local soil. In order to counter issues in geotechnical construction, engineers have to study the engineering properties of the soft clay. A variety of methods like displacement, replacement, reinforcement, and stabilization are the approaches practised for enhancing the properties of the weak soils (Nikraz, 2012). In Malaysia, the typical practised ground treatment methods are surface reinforcement, sand or stone column, preloading, prefabricated vertical drains, use of piles and chemical stabilization.

In this research, only chemical stabilization method is studied. Salmi (2010) reported soil stabilization by which a soil material become more stable. This method is applying admixture on the soil. Chemical stabilization methods are adopted in order to provide the soil strength improvement, total and differential settlements and permeability reduction. Soil stabilization is an economical and environmental method implemented to accustom the soils' mechanical and chemical characteristics by the pozzolanic reaction (Cuisinier *et al.*, 2011). There are diversified types of usable admixtures. The chemical reaction between soils and admixtures boosts the physical and engineering properties. Replacement of soft soil with suitable soil is still extensively utilized when construction has occurred on soft soil deposit. This approach leads to a costly design as large amount of suitable soil are required to be transported. When there is an addition of admixtures to the soil in the appropriate quantities, the properties of the soil can be improved. The types of admixtures applied for soil stabilization are dependable on the types of soils, the required properties, the environmental condition and the cost-effectiveness consideration.

In this research, a variety of experiments are conducted to analyse the effect of engineering properties of kaolin grade S300 blended with quicklime and silica fume. The main objective of this research is to study some important engineering properties of the soft soil tested and the effect of different percentages of silica fume and lime on soft soil in term of its change in shear strength. The laboratory tests conducted include specific gravity, Atterberg limits, compaction test, sieve analysis, hydrometer test, falling head permeability test and lastly unconfined compression test. Kaolin will be added with stabilizers which are silica fume and lime in a small percentage, thus improving the engineering properties of the soil. For each test, the optimal percentage of lime and silica fume combination were determined.

For shear strength determination (confirming the stability and improvement of kaolin), a number of kaolin samples have been remolded with different percentage of lime and silica fume, The unconfined compression test is conducted on the samples to evaluate the change in shear strength. Hence, the results of treated and control samples have been analyzed and conclusion drawn based on the objective of this research topic. In this research, the results of study on the shear strength characteristics are presented for both unstabilised and stabilised soil samples using unconfined compression test. From the test results, we can determine whether lime and silica fume stabilization will enhance the shear strength of clay or not and thus apply the findings to the construction site.

1.2 PROBLEM STATEMENT

Many constructions have encountered the issues of soil where the soil cannot fulfil the required specification such as bearing capacity of soft soil too weak to withstand any superstructure which is located on the soil. The soils used at construction sites must be entirely fitted in supporting structures such as buildings, bridges, highways and dams. The knowledge of engineering characteristics of soft soil should be understood by any relevant parties in this field.

Soft soil is chosen as a simple in this study due to their poor properties of the soils. Commonly, due to sedimentary process on various environments, there is an obvious variation in the engineering properties of the soils. They are high compressible, decreased strength, low permeable and compacted, and therefore exhibits low construction quality.

The problem of settlement is important when dealing with structure such as roads, housing and embankment constructions on soft soil. Due to the poor characteristic of soft soil, the structure may settle excessively due to high compressibility and low shear strength. Structures built on soft soil are subjected to settlement and some settlements cannot be avoided. This might be causing the occurrences of issues in the real situations and thus bringing lots of unnecessary and inconvenient affairs to be settled.

Civil engineering projects located in areas with soft soil is one of the most common problems in many parts of the world. The old usual method to soft soil stabilization is to remove the soft soil and replace it with stronger materials. The high cost of this method has driven the researches to look for alternative methods.

Furthermore, the result of previous works on lime stabilization showed that some type of soils may improve but some may not. This is due to the changes in clay fraction and minerals. To further study the pass research, lime as a soil stabilizer were tested. Addition of catalyst such as silica fume may improve the long term performance of lime stabilization due to the enhancement in the pozzolanic reaction. Optimum mix of lime and silica fume will be established for effective stabilization.

1.3 OBJECTIVES

Generally, the objectives of this study are:

i. To determine the physical characteristics of soft clay and soft clay mixed with various percentages of lime and 6 % of silica fume.
ii. To determine the undrained shear strength of soft clay and soft clay mixed with various percentages of lime and 6 % of silica fume.
iii. To correlate the shear strength and physical properties of soft clay and soft clay mixed with various percentages of lime and 6 % of silica fume.

1.4 SCOPE OF THE STUDY

The study emphasized on the shear strength characteristic of the soil by using unconfined compression test. The soil samples that have been used in this study are kaolin S500. Several tests that have been conducted on soil samples are to identify the engineering properties of samples. Lime used in this research is calcium hydroxide $Ca(OH)_2$, also called as quicklime. To extend this finding in application various proportion of lime with additives or silica fume were examined for soil stabilization. The concentration of lime are 3 %, 5 %, 7 % & 9 % whereas the silica fume is fixed to be 6 % respectively on samples. have also been conducted.

The investigations on the properties of soil are crucial in order to study the engineering behavior of soils (Mitchell, 2005). Different laboratory experiments are conducted on the unstabilized and stabilized soils to understand the properties of the soils. The laboratory tests needed are listed below.

1) Sieve analysis
2) Specific gravity of soil solids
3) Fine analysis/ Hydrometer analysis
4) Atterberg limits
5) Falling head permeability test
6) Standard proctor test
7) Unconfined compression test

1.5 SIGNIFICANCE OF STUDY

In this study, the purpose is to determine the improvement in the shear strength of soft clay after mixing with lime and silica fume. Thus, there are some experimental methodologies conducted to evaluate the suitability of lime and silica fume in replacing other normally used stabilizers such as fly ash. By applying small amounts of lime and silica fume in soft clay, problems of disposing large amount of silica fume in the landfills can come to a solution. Besides, the increase in shear strength can improve the bearing capacity of soft soil. Without question, this would increase importantly the availability of marginal sites for cost effective and long-lasting construction.

CHAPTER 2

LITERATURE REVIEW

2.1 FUNDAMENTAL OF SOIL BEHAVIOURS

The word 'soil' brings particular definitions for different fields. To the agriculturist, soil is the upper lean zone of earth within which is important for the growth of organic life. To the geologist, soil is the material in the upper lean layer within which roots exist. In the aspect of civil engineering, engineers are responsible with soil which encompasses entire earth materials, organic and inorganic, existing above the rock crust. Soil is interpreted as a natural aggregate of mineral grains that can be disaggregated in water by gentle agitation.

How a structure behaves is dependable on the properties of the soil materials on which the structure rests. The properties of the soil materials are dependable upon the properties of the rocks from which they are extracted. The formation of soils is through the means of physical and chemical weathering. The specific size of the component parts of the rock under weathering can range from the smallest state (colloidal) to the largest possible (boulders). This indicates that not all the weathered constituents of a parent rock are considered as soils. Soil particles are classified according to their grain sizes as cobbles, gravel, sand, silt and clay. There are coarse grained soils and fine grained soils. Gravel and sand are coarse grained soil whereas silt and clay are fine grained soils. In reality, soil masses are appeared in non-homogeneous states. The natural soils are in mixed grained which comprise of coarse grained and fine grained soils (Das, 2010).

2.2 CLAY

Clay is an aggregate of microscopic and submicroscopic particles. Clay are commonly formed over a long period of time from the chemical decomposition of rocks. Clay is composed of the fine grained fraction of soils. The soil particles are finer than 2 micron. These particles are invisible for the naked eyes. It is plastic within a moderate to wide range of water content. The permeability of clay is intensely low. The mineralogy and arrangement of molecule of a clay particle are intensely complicated and greatly variable. From the perspective of geotechnical engineering, clay is a form of cohesive soil which its strength will decrease by the impact of climate or water content in the soil (Das, 2010).

According to the clay mineral concept, clay minerals are essentially composed of extremely small crystalline particles of one or more members of a small group of minerals that are commonly known as clay minerals. The basic building blocks form tetrahedral and octahedral layers of clay minerals, different combinations of which produce a unit sheet of the various types of clays. Clay minerals are essentially crystalline in nature through some clay minerals do contain material which is non-crystalline. As shown in Figure 2.1, two basic building blocks are involved in the formation of clay mineral structures. In the diagram, the left structure is silicon-oxygen tetrahedron whereas the right structure is aluminium-hydroxyl octahedron (Craig, 2004).

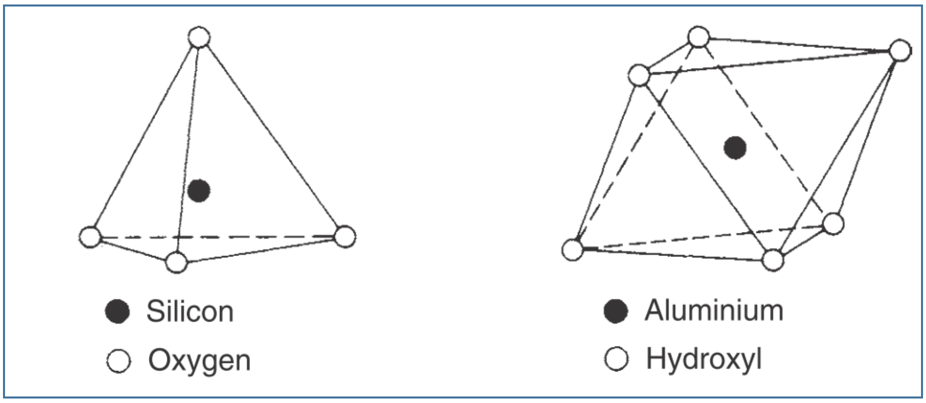

Figure 2.1: Basic building blocks in the formation of clay mineral structures (Craig, 2004)

Silicates (felspars), oxides (silica and iron), carbonates (calcium and magnesium) and sulphates (calcium) are the common minerals of clay. The mineralogical composition of clays range from kaolin (made up of individual particles which cannot be divided without difficulty, through iilites to montmorillonites and other non-sheet-clay minerals (Nagaraj, 2001). Kaolin is made up of individual particles which cannot be readily divided. Another crucial constituents of clay soils like Illite which have a crystal structure similar to the mica minerals but with less potassium; thus they are chemically much more active than other mica (Holtz, 1981).

According to the British Soil Classification System (BSCS), clay soil is made up of 35-100 % fines where the clay particles predominate to produce cohesion, plasticity and low permeability. The characteristics of clay soil are shown at Table 2.1. The characteristics of clayey soil is shown in Table 2.2.

Table 2.1: Clay Minerals (Murthy, 2002)

Name of Mineral	Structural Formula
1. Kaolin Group	
1. Kaolinite	$Al_4Si_4O_{10}(OH)_8$
2. Halloysite	$Al_4Si_4O_6(OH)_{16}$

Table 2.2 : Characteristics of Clay Soil (Meschyan, 1995).

CHARACTERISTICS OF CLAY SOIL	
Specific Gravity	2.55 – 2.75
Bulk Density (Mg/m^3)	1.50 – 2.15
Dry Density (Mg/m^3)	1.20 – 1.75
Liquid Limit (%)	> 25
Plastic Limit (%)	>20
Effective Cohesion (kPa)	20 - 200

2.3 KAOLINITE

Kaolinite is one of the most common clay minerals in sedimentary and residual soils. A unit sheet of kaolinite, which is approximately 0.7 nm thick, is composed of one aluminium octahedral layer and one silicon tetrahedral layer, joined together by shared oxygens. A typical particle of kaolinite consists of a stack of sheets forming a stiff hexagonal plate with flat-faced edges. It is about 100 nm in thickness with a breadth/ thickness of about 5 to 10, and a specific surface of 5 to 15 m^2/g (Terzaghi, 1996).

Kaolinite is a clay mineral with the chemical composition $Al_2Si_2O_5(OH)_4$. Kaolinite is made up of individual particles which cannot be divided with no difficulty and it is a layered mineral of silicate. The layered silicate mineral is with one tetrahedral sheet linked through oxygen atoms to one octahedral sheet of alumina octahedral. Rocks that are rich in kaolinite are china clay or kaolin. The shrink-swell capacity and cation exchange capacity are low. It is a white mineral which is produced by the chemical weathering of aluminium silicate minerals like feldspar (Budhu, 2010). The chematic diagram of kaolinite structure is shown in Figure 2.2.

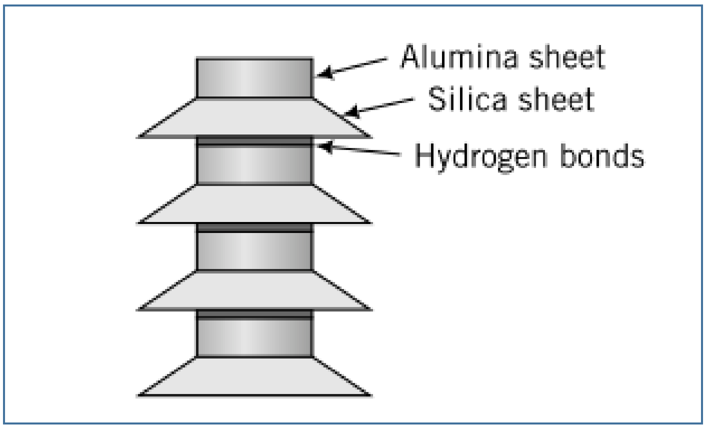

Figure 2.2: Schematic diagram of kaolinite structure (Budhu, 2010)

2.4 SOIL STABILIZATION

In the construction of road, it is not cost-effective for large volumes of unsuitable soils to be discarded and replaced with more suitable material. Hence, it is necessary to use other approaches like soil stabilization. Soil stabilization is a way of improving the weight of bearing capabilities and performance of in-situ subsoils sand and other waste minerals in order to strengthen road surfaces. The purpose of the soil stabilization is to make alternation or preservation of one or more soil properties to meet specific engineering requirements. These approaches are good in changing the characterization of soil in addition to an increase in shear strength, the reduction of soil compressibility, affecting permeability of the soil or to improve soil homogeneity (Kirch, 2005). Soil stabilization aims at improving soil strength and increasing resistance to softening by water through bonding the soil particles together, water proofing the particles or combination of two (Makusa, 2012). The simplest stabilization processes are compaction and drainage. The other way is by improving particle size gradation and further improvement can be achieved by adding binders to the weak soils (Makusa, 2012). Thus soil stabilization is crucial in geotechnical engineering to prevent construction failure.

Soil stabilization can be accomplished by several methods. Soil stabilization methods are divided into three categories, which are mechanical, physical and chemical stabilizers. Typically mechanical methods practised are vibroflotation technique, vertical drain and geotextile. They are practised to make soil improvement by adopting other materials that do not have effect on any property of contingent soil itself. The physical stabilizers, which modify the soil properties by heat and electricity, are such thermal stabilization and pressure stabilization. Based on study done by Sokolovich (1988), application of chemical method to stabilize organic clay is sufficiently reliable to modify the soil properties by means of some solid or liquid additive and in many cases it is the only possible measure for strengthening weak soil (Aziz, 2012).

Chemical soil stabilization favourably change soil-water interactions by surface reactions in such manner to make the behaviour of soil modified to its intended used. The physical properties of soil can often economically be improved by the use of admixtures. There are many types of chemical methods suggested for soils as well as organic clay are such as asphalt, portland cement, bitumen, calcium salts, lime or combination. The process of the soil stabilization involves the mixing with the soil a suitable chemicals which changes its property and then compacting the admixture. This method is applicable only for soils in shallow foundation or the base courses of roads, airfield pavement and many more. Soil stabilization depends mainly on chemical reactions between stabilizer (cementitious material) and soil minerals (pozzolanic materials) to achieve the desired effect. Through soil stabilization, unbound materials can be stabilized with cementitious materials (cement, lime, fly ash, bitumen or combination of these). The stabilized soil materials have a higher strength, lower permeability and lower compressibility than the native soil. The method can be achieved in two ways, namely; in situ stabilization and ex-situ stabilization. Note that, stabilization not necessary a magic wand by which every soil properties can be improved for better. The decision to technological usage depends on which soil properties have to be modified. For a successful stabilization, a laboratory tests followed by field tests may be required in order to determine the engineering properties. Although laboratory experiments may produce higher strength than corresponding material from the field, but will help to assess the effectiveness of stabilized materials in the construction site or field. Findings obtained from the laboratory tests, will enhance the knowledge on the choice of binders and amounts (Makusa, 2012). Depends on the suitability of the soil characteristics, different stabilization methods have been adopted.