A STUDY OF SOIL STABILIZATION BY HYDRATED LIME AT KAMPUNG KEDAIK ASAL, ROMPIN, PAHANG

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ABSTRACT

Soil such as soft clay is a material with low strength and easily affected by water but it will be strong in dry condition. When water is added to the clay, it will flow like liquid. Unstable clay soils often create problematic situations for engineers as the soil do not provide enough strength to support the loads of the constructions upon them. Therefore, lime stabilization is one of the commonest methods of soil stabilization. A little addition of lime percentages can stabilize the clay soil by enhancing the engineering properties of the soil to improve the construction materials. This study involves the clay sample which is taken from Kampung Kedaik Asal, Rompin site and evaluation of its properties in natural state and after lime stabilization. The main objective of this paper is to estimate the optimum hydrated lime content (OLC) needed to stabilize the soil by using Eades-Grim pH Test, to determine the optimum moisture content (OMC) and maximum dry density (MDD) of the treated soil by Standard Proctor Test and also the strength value of the soil specimens with different percentages of lime content corresponding with different curing period by Unconfined Compressive Strength (UCS) Test. From this study, the optimum amount to stabilize the clay soil and minimum amount of lime required to stabilize the soil pH level to 12 is 5%. The results showed that addition of lime decreased the maximum dry density (MDD) and increased the optimum moisture content (OMC). Unconfined compressive test on 48 sets of samples has been carried out for 7, 14 and 28 days of curing with different lime contents such as 5%, 7% and 9%. The highest unconfined compressive strength (UCS) achieved is 321 kN/m^2 for clay stabilized with 9 % lime content cured at 28 days. From the test results, it was found that the longer the immersion of curing period with higher lime content, the greater the compressive strength of the specimen.

KEYWORDS | *Lime Stabilization, Soil Improvement, Maximum Dry Density, Optimum Moisture Content, Unconfined Compressive Strength*

ABSTRAK

Tanah seperti tanah liat adalah sangat lembut dan mudah dijejaskan oleh air tetapi ia akan menjadi kuat apabil dalam keadaan kering. Apabila air ditambah dengan tanah liat, ia akan mengalir dalam keadaan cecair. Tanah liat yang tidak stabil sering membawa masalah kepada para jurutera kerana tanah liat tidak dapat menapung dan menyokong beban bangunan di atas tapak pembinaan. Oleh itu, penggunaan kapur adalah salah satu kaedah yang sering digunakan untuk menstabilkan tanah. Penambahan sedikit peratusan kapur boleh menstabilkan tanah liat dengan mempertingkatkan sifat-sifat tanah bagi mempertingkatkan kualiti tanah di tapak pembinaan. Kajian ini melibatkan sampel tanah liat yang diambil dari Kampung Kedaik Asal, Rompin dan penilaian tanah liat dibuat dalam keadaan semula jadi dan selepas menambahkan kapur. Objektif utama untuk kertas ini adalah untuk menentukan kepekatan larutan kapur yang optimum bagi menstabilkan tanah (OLC) dengan menggunakan Eades-Grim pH Test, untuk menentukan kandungan lembapan optimum (OMC) dan ketumpatan kering maksimum (MDD) tanah yang dikaji oleh Standard Proctor Test dan juga menilai kekuatan tanah sampel dengan peratusan kandungan kapur dalam tempoh pengawetan yang berbeza oleh Unconfined Compressive Strength Test. Ujian-ujian lain yang terlibat adalah Atterberg Limit, Standard Proctor Test dan Unconfined Compressive Strength (UCS) Test. Dalam kajian Eades-Grim pH Test, jumlah optimum untuk menstabilkan tanah liat dan jumlah minimum kapur yang diperlukan untuk menstabilkan tahap pH 12 ialah 5%. Dalam hasil kajian menunjukkan bahawa penambahan kapur menurun ketumpatan kering maksimum (MDD) dan meningkatkan kandungan lembapan optimum (OMC). Ujian mampatan tak terkurung (UCS) dijalankan dengan 48 sets sampel untuk 7, 14 dan 28 hari dan dirawat dengan larutan kapur yang berbeza seperti sebagai 5%, 7% dan 9%. Kekuatan tidak terkurung tertinggi mampatan (UCS) yang dicapai adalah 321 kN/m^2 bagi menstabilkan tanah liat dengan 9 % larutan kapur pada hari ke-28. Secara keseluruhan keputusan ujian, didapati bahawa semakin lama pencelupan tempoh pengawetan dengan kandungan larutan kapur yang lebih tinggi, lebih besar kekuatan mampatan yang dapat dicapai oleh sampel tanah liat.

Kata Kunci : *Penstabilan kapur , Penstabilan tanah, Ketumpatan kering maksimum (MDD), optimum kandungan lembapan (OMC), Kekuatan Mampatan Tak Terkurung (UCS)*

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
DMC	-	Dry Moisture Content
LL	-	Liquid Limit
MDD	-	Maximum Dry Density
OLC	-	Optimum Lime Content
OMC	-	Optimum Moisture Content
PI	-	Plastic Index
PL	-	Plastic Limit
UCS	-	Unconfined Compressive Strength
USCS	-	Unified Soil Classification System
WMC	-	Wet Moisture Content

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Ever since the availability of the construction site has been decreasing for the past several years, the necessity of soils for earthwork construction has been increasing which requires engineers to conduct tests to strengthen the ground at the construction site. Soil such as soft clay is a material with low strength and easily affected by water but it will be strong in dry condition. When water is added to the clay, it will flow like liquid. Due to the phenomenon, it creates a lot of problems at the construction site. Therefore, soil improvement methods have to develop in order to fulfil the demands of the society.

Soil stabilization is a very useful technique for civil engineering works. It is the modification of one or more soil properties by mechanical or chemical means, to create an improved soil material possessing the desired engineering properties. Regardless of the purpose of the soil stabilization, the desired results in the creation of a soil material or soil system that will remain in the place under the design use conditions for the design life of the project (Onyelowe & Okafor 2012).

The need for soil stabilization may arise if the natural soil to be built on in an area has poor engineering properties or the land is not suitable to support the foundation in its natural state. In some cases such as road pavement construction, the stabilization of pavement layers like the sub-grade, sub-base and the base can be carried out in order to reduce the cost of construction and improve the load carrying capacity (Ogundipe 2013).

1.2 PROBLEM STATEMENT

Geotechnical engineers mostly encountered problems at the construction site when the soil properties are unable to achieve the required specification. Normally the problems are soft soil such as clay. Soft soil such as clay on the construction sites cannot always be totally supported for the structures such as buildings, bridges, highways and etc. Soft clay is widely encountered in geotechnical engineering practice as the soil possesses low strength and high compressibility, thus forming great challenge to geotechnical engineers (Liu et al. 2010). Sometimes, the existing soft soil which is undesirable have to be removed and replaced with better modified soil in order to sustain the desired structural load.

Common construction site problem such as wet site condition can be proven as the main challenge as it causes the soil to become soft and muddy. The challenge increases when the site soil is used as structural fill and layers of soil have to be placed in order to raise the grade elevation of the specific area. It is also facing problem that is associated with clay soil which is due to high swelling (caused by high water absorption capability) and shrinkage of the soil, compaction difficulty and high plasticity of the soil. It becomes difficult for the engineers to reach for the soil moisture content and compaction a requirement which is established in the job specification.

Therefore, some researchers have proven that lime solutions can be used for drying, modifying and improving the construction site soil as lime can effectively dries out the wet soils and form it into a solid base for constructions. It is also proven that lime can reduce the plasticity of clay soils and improving the compaction characteristics. In addition, lime solutions will modify the soils continued to resist the moisture and softening throughout the construction process.

1.3 OBJECTIVES

The objectives of this study are:

i. To estimate the optimum lime content (OLC) needed to stabilize the clay soil.
ii. To determine the optimum moisture content (OMC) and maximum dry density (MDD) of the treated clay soil.
iii. To determine the strength value of the soil specimens with different percentages of lime content corresponding with different curing period.

1.4 SCOPE OF STUDY

The main purpose of this study is to improve the soil properties by using lime as stabilizer. Engineering properties of clay soil such as moisture content, Atterberg's Limit, specific gravity and pH were determined before Unconfined Compressive Strength Test (UCS) conducted. Lime that have been used in this study is calcium hydroxide $Ca(OH)_2$, also known as hydrated lime or slake lime. The concentrations of the hydrated lime used are 5%, 7% and 9% which performed on the samples for the curing periods of 7, 14 and 28 days. This study was conducted at Kedaik, Rompin, Pahang area and samples were collected in order to do some experimentation and testing.

CHAPTER 2

LITERATURE REVIEW

2.1 Clay Behaviour

Clay is a type of cohesive soil which is very weak with low strength and high compressibility and it is normally related to the changes when it is influenced by the water content in the soil. It is usually compact and cohesive but often poorly drained and aerated causing their large internal surface to store large amounts of water and mineral. This situation may be worsened by the presence of the water due to both of its softening effect on the soil and to the strength reduction it causes (Olugbenga et al. 2011).

Besides that, the clay type and content can be influenced the strength through their role as the water content will modify their cohesion. As the water content increase, the cohesion decreases. This is because increasing the water content can cause greater separation between the clay particles and resulting the softening of the soil properties.

Clay particles have a net electrical charge on them and usually a negative charge on their faces and a positive charge on their ends as shown in Figure 2.1(a); they are made up of clay minerals. The three most important clay minerals are Kaolonite, Illite and Montmorillonite. Because of the shape of the clay particles, they have a disproportionately large surface area in relation to their mass. Due to this reason, the particles are like that of colloids that is managed not only by gravity forces but also the electrical forces. This electrical charge gives a great attraction for the polar water molecule as shown in Figure

2.1(b) and in moist environment; the particle is surrounded by the water which is known as adsorbed water as shown in Figure 2.1(c). With enough amount of water in clay, it behaves like a liquid and with the water is removed; the clay will become solid form (Datta 2005). The orientation of water around the clay particles gives the clay soils their plastic properties. When the moisture is present, the engineering behaviour of the soil will change greatly as the percentage of clay mineral content increases (Braja 2010).

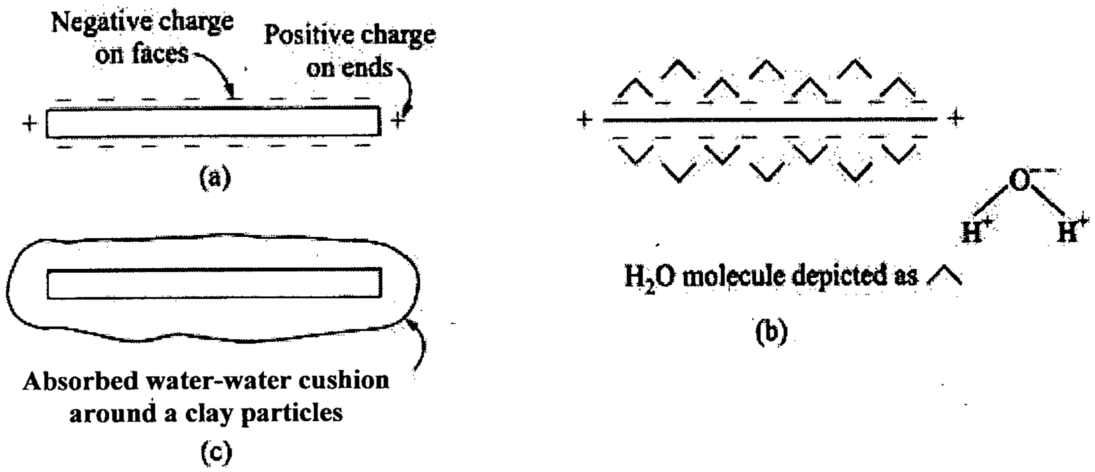

Figure 2.1: Charges on the clay particles

2.2 SOIL IMPROVEMENT

There are many soil improvement methods can be used to improve the soil engineering and physical properties. However, in most of the geotechnical projects, it is impossible to construct a construction project at the site without the soil modification to meet the design requirements. The current practice is to modify the engineering properties which have problematic soils meet the design specifications. Soils such as soft clays and organic soils can be improved to fulfil the civil engineering requirements.

According to Muhmed and Wanatowski (2013), different methods are to improve the engineering properties of problematic soil such as densification, chemical stabilization, reinforcement and techniques of pore water pressure reduction. When there are some problematic soil occurs, much concern upon the appropriate methods to modify the properties have to take into consideration.

There are special stabilization methods that classified into three groups, namely mechanical, physical and chemical stabilizers. Mechanical and physical stabilization improves the soil properties by mixing other soil materials with the target soil to change the gradation and therefore change the engineering properties. It is based on decreasing the void rate by compacting or physically altering the grain size factions involving the adjustment of the particle size composition of soil (Olaniya et al. 2011).

Based on Onyelowe and Okafor (2012), mechanical stabilization produces by compaction of soil-aggregate particles. The grading of the soil- aggregate mixture must be such that dense mass is produced when it is compacted. The choice of methods should be based on the gradation of the material. Mechanical stabilization may be used in preparing soil to function as subgrades, bases and surface for road constructions. This is because it can help in increasing the drainability of the soil, increase the stability and reduce the volume changes of the soils to give the desired stability.

Chemical stabilization used the addition of pozzolanic materials to improve the soil properties. It is traditionally used in Portland cement, lime, fly ash and bituminous materials for chemical stabilization. These agents generally are potential binders and as such effectively bonds together with the soil aggregates to achieve properties binders and as such as improved load- carrying and stress- distributing characteristics and control of shrinkage and swell (Olugbenga et al. 2011).

There are some considerations need to be concern when selecting the suitable stabilizer additive and the factors are the types of the soil to be stabilized, type of soil quality to be improved, strength and durability requires to stabilize the layers, cost and environmental conditions.

The chemical stabilization of clays using lime is one of the commonest methods that can be used to upgrade the soils of poor properties to provide a workable platform for construction projects. Soil improvements by stabilization can increase in soil strength (shearing resistance), stiffness (resistance to deformation), durability (wear resistance), reductions in swelling potential of wet clay soils and other desirable characteristics. Therefore, soil improvement is a very important study in geotechnical engineering to avoid failure in construction.

2.3 LIME STABILIZATION

Lime stabilization is the most common method of improving the soil engineering properties. The addition of lime to the fine-grained soil has advantage effects on their engineering properties, including reduction in plasticity and swells potential, improved workability, increased strength and stiffness and enhanced durability. Lime has been used to improve the strength and stiffness properties of unbound base and sub-base materials. Lime can be used to treat the soils to varying degrees, depending upon the objectives. A greater degree of treatment supported by testing, design and proper construction techniques to produce permanent structural stabilization soils (Olugbenga et al. 2011).

Kaur and Singh (2012) stated that lime stabilization is a method of chemically transforming unstable soils into structurally sound construction foundations. It is important in the construction of highway for modifying subgrade soils, subbase materials and base materials. Lime stabilization creates a number of important engineering properties in soils which includes improved strength, resistance to fracture, fatigue and permanent deformation; reduced swelling and resistance to the damaging effects of moisture.

According to Onyelowe and Okafor (2012), lime reacts with medium, moderately fine and fine-grained soils to produce decreased plasticity, increased workability and strength and reduced swelling. Lime-soil mixtures should be scheduled for construction so that sufficient durability can gain to resist to any freeze-thaw cycles expected. It is stated that lime can be used either to modify the physical properties and improve the quality of a soil or to transform the soil into a stabilized mass which increases the strength and durability. The amount of lime additives depends on the soil whether to be remodify or stabilized.

The use of lime stabilization of clay in construction has been in various ways throughout their long history. There are some examples for the treatment of clay with lime particularly for the state highways and airports. One of the examples was the Dallas Fort Worth Airport at United Kingdom that were built by lime stabilised clays. It has been resulted not only saving in construction costs but also performed over 25-30 years period with minimal maintenance. Other than that, design of a major interstate highway pavement in Pennsyvlvania lime stabilization in order to safeguard against the potential softening of the clayey sub-grade due to rain.

2.3.1 Types of Lime

There are many types of lime can be used for lime stabilization. Lime can be divided into quicklime (calcium oxide) and hydrated lime (calcium hydroxide) which is burned from limestone (calcium carbonates). Below are the two most common types of lime used to stabilize the soil.

2.3.1.1 Calcium Oxide (CaO)

Calcium oxide, CaO is also known as quicklime. The manufacture of quicklime involves the heating of excavated limestone in a lime kiln to temperatures above 900°C resulting the carbon dioxide released and calcium oxide being produced.

$$CaCO_3 \underset{\Delta}{\overset{900°C}{\rightleftharpoons}} CaO + CO_2$$

The calcium oxide is unstable and will spontaneously react with carbon dioxide from the air when it is stored in the storage for a long period. After a certain time, the calcium oxide will be completely changed back into calcium carbonate. This means that commercial quicklime will never be 100% of CaO.

The ability of quicklime is to form alkaline solutions and suspension in water is the key to its being able to modify certain soils in such a way that the end result is a benefit to road engineers.

2.3.1.2 Calcium Hydroxide, $Ca(OH)_2$

Calcium hydroxide, $Ca(OH)_2$ also called as slaked lime or hydrated lime. It is produced by the hydration process where the calcium oxide is mixed with water. At 350°C, the calcium oxide component of quicklime reacts with the water to produce hydrated lime as well as liberating heat.

$$CaO + H_2O \rightleftharpoons Ca(OH)_2 + heat$$

Calcium hydroxide has a lower content of lime comparing to calcium oxide and therefore it is more suitable to stabilize the soil with lower water content.

2.3.2 Mechanisms of Lime Stabilization

When lime is added to clay, there are three reactions occurring which is dehydration of the soil, cation exchange and flocculation- agglomeration and pozzolanic reaction. Lime will act as stabilizing agent for clay and produce a binder through slow chemical reactions mainly with silicates in the clay minerals. Throughout the hydration process, $Ca(OH)_2$ is formed when lime (CaO) is added to the soil. During the hydration process, heat is released as the temperature increase by resulting large amount of pore water is evaporated.

$$CaO + H_2O \longrightarrow Ca(OH)_2 + Heat$$

The addition of lime to a clay soil will produce calcium ions (Ca^{2+}) and magnesium (Mg^{2+}). These ions tend to displace other cations such as sodium ion (Na^{+}) or potassium ion (K^{+}). The replacement of the sodium or potassium ions with calcium will reduce the plasticity index of the clay. The exchange of ions between clay minerals and lime depends on the cation exchange capacity which will be affected by the pH value. This is because the addition of lime can increase the soil pH which is also increasing the cation exchange capacity. The flocculation-agglomeration reaction causes the clay particles to flocculate and agglomerate into large clumps which make the clay plasticity reduced and making it more workable without influence the strength of the clay.

$$(Ca^{2+}, Mg^{2+}) + \text{clay} \longrightarrow (Ca^{2+}, Mg^{2+}) \text{ exchanged with } (Na^{+}, K^{+})$$

As for the pozzolanic reactions, lime is added to a reactive soil to generate long-term strength gain. Kaur and Singh (2012) stated that pozzolanic reaction produces stable calcium silicate hydrates and calcium aluminate hydrates as the calcium from lime reacts with the aluminates and silicates solubilized from the clay. This reaction can continue for a very long period of time as long as enough lime is present and the pH remains high above 10. As a result, lime treatment can produce high and long-lasting strength.

2.3.3 Factors that Control Hardening Characteristics of Lime Treated Clay

i. Type of Lime

Hydrated lime is used for the assessment of lime effectiveness with soils in the laboratory. However, quicklime is the most commonly used on the site. In the laboratory, hydrated lime is used and the $Ca(OH)_2$ components determines the reaction with the pavement materials. As for quicklime, it is used in the field and slaked on the site to form hydrated lime. Hydrated lime is used most often because it is much less caustic than quicklime.

ii. Optimum Lime Content

The soil strength will increase as the lime content increase. On the other hand, when the lime content reach until a certain level, the rate of increase will lessen till no further strength gain occurs. Optimum Lime Content can be determined through Eades - Grim Test (ASTM D 6276). Figure 2.2 shows the theoretical plot of optimum lime content.

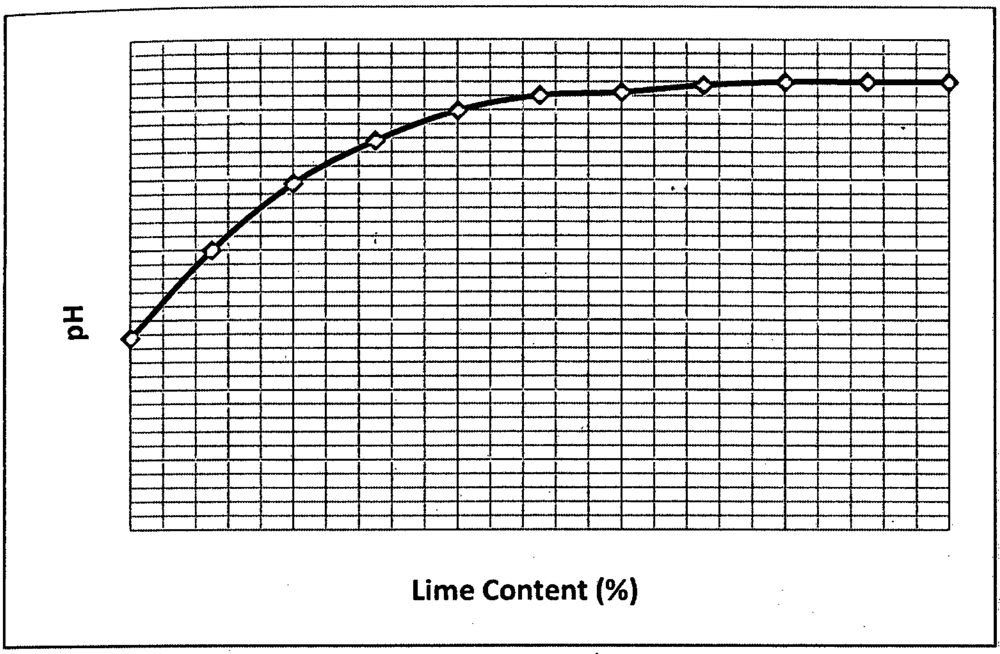

Figure 2.2: Theoretical plot of optimum lime content (*After Eades and Grim, 1960*)

iii Curing Period

By referring most of the similar researches, the soil specimen strength increase with the increasing length of curing time. Most of the strength is noticeable after 7 days when the pozzolanic reactions are started to become more active. The lime stabilized specimens increased about twice of the original strength after 28 days curing period (Muhmed & Wanatowski 2013).

2.3.4 Mixture Design and Strength Characteristics

The purpose of mixture designing is to determine the optimum lime content of soil in order to achieve the maximum strength required by using the lime stabilizer. The strength requirements depend to the intended use of the construction. For example, to improve the workability of the soil so they will be easier to compact. Therefore, there is wider range of lime content to be used to produce various results.

2.3.4.1 Eades-Grim pH Test

Optimum lime content for the soil specimens was determined by using the procedure given by Eades- Grim (1960) methods. The objective of conducting this test is to add sufficient lime to soil to ensure a pH of 12.4 for sustaining the strength-producing lime-soil pozzolanic reaction. The lowest percentage lime in soil that produces a laboratory pH of 12.4 is the minimum percentage for stabilizing the soil. The lowest lime content that provides a pH of 12.4 is then used as the starting point for determining the optimum lime content. The lime content design is usually based on the lime content effect on the engineering properties of the soil mixture. The purpose of lime treatment is depending on the different design of lime contents.

2.3.5 Benefits of Soil Stabilization

Soil stabilization is a very effective method of improving poor quality soil into a better quality soil. Due to the rising cost of construction, it has transformed into the most useful method to prepare all the construction site projects.

i. Substantial Savings

In order to stabilize the existing subgrade, the cost that need to be used to excavate the existing soil, remove it from the site and replace it with suitable materials can be eliminated. By doing so, it can result in substantial savings to the engineers.

ii. Reducing Weather Related Delays

For certain area where the weather conditions that will cause site work delaying, soil stabilization can be utilized to treat the unstable soils to reduce the work delays and able to continue site work. It still can continue the construction schedules and cost