SOIL PROPERTIES COMPARISON OF LIME TREATED SOFT CLAY

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Report submitted in fulfilment of the requirements for the award of the degree of

Bachelor of Engineering (Hons) in Civil Engineering

Faculty of civil Engineering and Earth Resources

UNIVERSITI MALAYSIA PAHANG

JANUARY 2015

ABSTRACT

The main objectives of this research are to determine the plasticity properties and the shear strength properties of lime treated soft clay. The physical properties and shear strength properties of lime treated soft clays are investigated by conducting laboratory test such as atterberg limit test and unconfined compression test. Atterberg limit test have been carried out for 7 days of curing period for the treated clay with the optimum lime content. For unconfined compressive test, the test have been carried out for 7, 14, and 28 days of curing period. For atterberg limit, there is an increment in both plastic and liquid limit of the lime treated soft clay and untreated soft clay. The liquid limits for untreated soil is 66.5% then increase into 73.30% when 20% lime is added. The plastic limit for untreated soil sample is 34.9% before it increase to 38.68% for 20% lime added respectably. This resulted an increment in plasticity index from 31.55% for untreated sample to 34.62% at 20% lime. For unconfined compressive test, the result have shown that there is an increment for the axial stress based on the curing days. The maximum axial stress for the untreated clay is initially 158.47 kN/m^2. After added with 20% of lime content, the maximum axial stress is increased to 209.21 kN/m^2 for 7 days of curing while for 14 and 28 days, the maximum axial stress are 231.19 kN/m^2 and 352.02 kN/m^2. It can be conclude that, lime stabilization method can be used as a soil treatment program for soft clay especially for road construction.

ABSTRAK

Objektif utama kajian ini adalah untuk menentukan sifat-sifat keplastikan dan sifat-sifat kekuatan ricih tanah liat lembut yang di rawat menggunakan kapur. Ciri-ciri fizikal dan kekuatan ricih tanah liat lembut yang di rawat dengan kapur boleh ditentukan dengan menjalankan ujian makmal seperti ujian had atterberg dan ujian mampatan tak terkurung. Ujian had atterberg telah dijalankan untuk tempoh pengawetan selama 7 hari terhadap tanah liat yang dirawat dengan kandungan kapur yang optimum. Ujian mampatan tak terkurung telah dijalankan untuk 7, 14, dan 28 hari dari tempoh pengawetan. Untuk ujian had Atterberg, terdapat kenaikan dalam kedua-dua plastik dan had cecair terhadap tanah liat lembut yg dirawat kapur dan tanah liat lembut yang tidak dirawat. Had cecair bagi tanah yang tidak dirawat adalah 66.5% kemudian meningkat menjadi 73.30% apabila ditambah dengan 20% kapur. Had plastik untuk sampel tanah yang tidak dirawat adalah 34.9% sebelum ia meningkat kepada 38.68% untuk 20% kapur ditambah. Ini mengakibatkan kenaikan dalam indeks keplastikan daripada 31.55% bagi sampel yang tidak dirawat ke 34.62% pada 20% kapur yang digunakan. Untuk ujian mampatan tak terkurung, hasilnya menunjukkan bahawa terdapat peningkatan bagi tekanan paksi maksium berdasarkan hari pengawetan. Tekanan paksi maksimum bagi tanah liat yang tidak dirawat pada mulanya 158.47 kN/m^2. Selepas ditambah dengan 20% daripada kandungan kapur, tekanan paksi maksimum meningkat kepada 209.21 kN/m^2 selama 7 hari pengawetan manakala bagi 14 dan 28 hari pengawetan, tekanan paksi maksimum adalah 231.19 kN/m^2 dan 352.02 kN/m^2. Ia boleh di simpulkan bahawa, kaedah penstabilan kapur boleh digunakan sebagai program rawatan tanah untuk tanah liat lembut terutamanya untuk pembinaan jalan raya.

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w_L	Liquid Limit
w_P	Plastic Limit
I_P	Plasticity Index
^{o}C	Degree Celsius
σ_3	Confining Pressure
σ	Total Major Principle Stress

LIST OF ABBREVIATIONS

CaO	Calcium Oxide
Ca[OH]2	Calcium Hydroxide
CaCO3	Calcium Carbonate
ASTM	American Society for Testing and Materials
BS	British Standard
OLC	Optimum Lime Content
ICL	Initial Consumption of Lime

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

This study is focused on the plasticity characteristics and shear strength properties of lime treated soft clay. Soft clay is said give a lot of trouble for the Civil Engineers and Geotechnical Engineers. The problem that often occurs due to the soft clay is like deposition and low bearing capacity. Nowadays, many projects are rapidly develop due to the population growth and economics progress. Most construction projects undertaken focused on the soft clay area including rural area, coastal area and etc. However, this area actually becomes a great challenge to the engineers due to the existing soils that is soft clays are generally weak and high compressible in nature and also it exhibits moderate swelling when comes in contact with moisture. This behavior is due to the presence of clay minerals with expanding lattice structure. The soft clay is very hard when it is dry but loses its strength on wetting. As a geotechnical engineer, it is necessary to them to improve the behavior of this soil by using any of the available ground improvement techniques such as lime treatment, cement-mixed and other. So, to overcome these problems, lime stabilization can be adopted for this study (Maniam, S. V., 2012).

The application of lime to improve the engineering behavior of fine grained soils is not new and it is an age-old method. As we know, the field of highways and air-field pavements were proved successfully treated by using the lime stabilization. Indirectly, this method now being extended for deep in-situ treatment of clayey soil to improve their strength, and minimize the compressibility (Rajasekaran, G. and Roa, S. N., 2005).

There are two types of lime that can be used to treat the soils, quicklime and hydrated lime. Hydrated lime and quicklime are both calcium compounds (www.odimate-inc.com). Lime in the form of quicklime (calcium oxide – CaO), hydrated lime (calcium hydroxide – Ca[OH]2), or lime slurry can be used to improve the behavior of the soils. Hydrated lime is created when the quicklime chemically reacts with water. It is hydrated lime that reacts with particles of clay and permanently transforms them into a strong cementious matrix. However, the hydrated lime is more suitable for this study due to the its behavior that is already neutralized, so it will not undergo oxidation and can be used with water, for water ph control, lime slurry addition, lime slurry mixes, soil rehabilitation and more. Almost all fine-grained soils can be modified by using the hydrated lime including the most dramatic increase occurred in the clay of medium to high plasticity. Modification occurred because calcium cations supplied by hydrated lime replace the cations normally present on the surface of clay minerals. The structure of clay particles modified by particle flocculation/agglomeration will produce several benefits like plasticity reduction, increasing in the shear strength and bearing capacity, reduction in the susceptibility to swelling and shrinkage, and ability to construct a solid working platform. (Carmuese).

1.2 PROBLEM STATEMENT

In generally, soft clay usually living in coastal or marine area and rural area where the existing soils are weak and more deformative. This area usually become a great challenge to civil engineering to design suitable foundation or make any of construction. The soft clays have low strength, low permeability and weak confining pressure. The soft clays also are highly compressible soft clays and it exhibits moderate swelling when comes in contact with moisture. This behavior is due to the presence of clay minerals with expanding lattice structure. The soft clay is very hard when it is dry but loses its strength on wetting. These characteristics will give the problems for the structure or foundation because of the shear failure or different settlement and it is become more serious in the future because of the damage that will be happen either in slow or fast condition. Therefore, it is necessary to improve the behavior of this soil by using any of the appropriate soil stabilization techniques such as lime treatment that will be done for this study.

1.3 OBJECTIVES

The aim of the study are:

i. To determine the effect of lime stabilization on plasticity characteristics soft clay.

ii. To determine the unconfined compressive strength of lime treated soft clay.

1.4 SCOPE OF STUDY

This study focuses on the laboratory study on the plasticity characteristics and shear strength properties of lime treated soft clays. The untreated clay were being collected at Chenor, Maran, Pahang (3° 27' 21" North, 102° 40' 44" East). Preliminary tests will be conducted to determine the suitability of the soil for the lime stabilization based on the physical and chemical properties before we start the main laboratory to know whether the untreated soil can shown the engineering properties of soft clay or not. The main test will be conducted such as Atterberg Limit, in order to determine the plasticity of the lime treated soft clay; and Unconfined Compressive tests, to define the unconfined compression strength of lime treated soft clay. The tests will be performed on samples after curing periods of 7, 14, and 28 days.

1.5 SIGNIFICANCE OF PROPOSE STUDY

This researched will be carried out to find the solution to improved the plasticity characteristics and shear strength of the untreated soft clays that can be a suitable soil as construction field. As we know, untreated soft clay is not recommended for any construction because of the instability. So, this is important to carried out this research. Other than that, this research also will study the different between the untreated and treated soft clay in term of plasticity and strength.

CHAPTER 2

LITERATURE REVIEW

2.1 CLAY

The word “clays” was assigned early to fine grained material in geological formations (Agricola, G., 1546) or soils (de Serres 1600). In the beginning of the 19th century, clays have been found as mineral species in the production of ceramic materials (Brongniart, A., 1844). Clay mineral is not suitable to defining it as "any mineral which occurs in clay" since, among several reasons, it would include many accessory minerals that are not characteristic of clay (Mackenzie, R.C., 1963). The definition of clay to fine-grained phyllosilicates (Bailey, S.W., 1980). In additional complication, the conceptual problem of combining particle size requirements of clay constituents with mineralogy. Clay are classified as all the fine-grained mineral components that give plasticity after hydration to rocks or materials which harden after drying or burning or in others word, the fine-grained is the dominating condition. That means that the mineral components involved can be any other mineral species than phyllosilicates (Stephen, G. and Martin, R. T., 1995).

The common characteristics usually that have been found in all clay minerals derive from their chemical composition, layered structure, and size. Clay minerals have a great affinity for water and some of it also swell easily. This condition may be can affect in thickness that can cause its double thickness when wet. Furthermore, most of the clay have the ability to soak up ions (electrically charged atoms and molecules) from a solution and release the ions later when conditions change. Clay minerals surfaces usually will attract the water molecules. A slurry forms have been happen when a little clay is added to water because of the clay distributes itself evenly throughout the water. The process by which some clay minerals swell when they take up water is reversible. Swelling clay expands or contracts in response to changes in environmental factors (wet and dry conditions, temperature). Hydration and dehydration can vary the thickness of a single clay particle by almost 100 percent (for example, a 10angstrom-thick clay mineral can expand to 19.5angstrom in water (Velde, 1995). Many structures likes houses, offices, schools, and factories built on soils containing swelling clays may be subject to structural damage caused by seasonal swelling of the clay portion of the soil.

Soft clays were a type of fine-grained soils which change volume when different from elastic deformation, consolidation and secondary compression. Clay is known as fine-grained soil due to its particles content are too small. Generally, this type of soil is usually dominated by clay particles with a size less than 0.002 mm and the circumstances that can change shape. It is formed from a combination of clay and mud and silt content in it almost 50%. Clay rarely exists in a pure state, but usually it is mixed with silt, fine sand and colloids (< 0.001 mm). Clay structure can be identified in the delocalized state, flocculent, and the cohesive soil naturally. Clays have a relatively large surface and importantly to determine the composition of the pieces of clay during sedimentation. Study on clay in Peninsular Malaysia have been conducted on the west coast and east coast by researchers such as Tin & Ooi (1977), Abdullah & Chandra (1987), the Board Highway (1989), Kobayashi et a /. (1990), Aziz (1993), Ramli et al. (1994), and Hussein (1995).

Soft clays defined as a disturbed cohesive soil whose water content is higher than its liquid limit; such materials display extremely low yield stresses and represent difficult construction conditions (Yusof, M., et al., 2006). Soft clay usually can be found in highly plastic fine grained soils with moderate to high clay fraction. They are characterized by high compressibility and low shear strength. Soft clay have a few typical characteristic such as it is predominately fined grained i.e. more than 50% of soil passing through 75µ IS sieve, high liquid limit and plastic limit values, high natural water content and even higher than the liquid limit, low material permeability but overall permeability can be more and low shear strength which usually varies with depth (Abdul Razzak, H., 2013)

2.1 SOIL STABILIZATION

For many years soil stabilization techniques have been used in land-based projects with a variety of applications. These techniques are more commonly practiced because it have provide an alternatives that are more affordable and require shorter construction periods than foundation (Hamidi., et al., 2013). Soil stabilization in its broadest sense is the alteration of existing site foundation soils to improve its engineering performances to be a suitable soil under design and operational loading conditions. Soil stabilization techniques have been used widely for a new project to allow any of construction at the poor subsurface conditions. (Hirkane S. P., et al., 2014). Soil stabilization techniques are given the utmost importance in present days to adapt weak soil into the appropriate competent stable ground for different civil engineering applications (Vidal H., 1960). Soil stabilization techniques are recommended in difficult ground conditions as mechanical properties are not adequate to bear the superimposed load of infrastructure to be built, swelling and shrinkage property more pronounced, collapsible soils, soft soils , organic soils and peaty soils, karst deposits with sinkhole formations, foundations on dumps and sanitary landfills, handling dredged materials for foundation beds, handling hazardous materials in contact with soils, using of old mine pits as site for proposed infrastructure (Tiwari S. K. and Kumawat N. K., 2014).

In recent years rapid development of infrastructures in metro cities compounded with scarcity of useful land and become a great challenge to the geotechnic engineers to improve the properties of soil to bear the load transferred by the infrastructure (Tiwari S. K. and Kumawat N. K., 2014). As we know, soil stabilization techniques is a best solution for geotechnical engineers to improve its engineering performance like increase the bearing capacity, reduce the magnitude of settlements and the time in which it occurs, retard seepage, accelerate the rate at which drainage occurs, increase the stability of slopes, mitigation of liquefaction potential, etc (Hirkane S. P., et al., 2014). Ground improvement usually can be classified into three groups, namely mechanical, physical and chemical stabilizations (Ingles, 1972). There are several engineering techniques of soil stabilization that commonly used in this day are removal and replacement, stabilization using chemical admixtures and reinforcement (Tiwari S. K. and Kumawat N. K., 2014).

2.3 LIME

The term 'lime' is use to define finely ground limestone, an agricultural lime. The ground limestone is very useful soil however not strong enough chemically for soil stabilization take place. There are two types of lime that can be used to treat the soils, quicklime and hydrated lime. Hydrated lime and quicklime are both calcium compounds (www.sodimate-inc.com). Calcium oxide (CaO), commonly known as quicklime, is a widely used chemical compound. It is a white, caustic and alkaline crystalline solid at room temperature. As a commercial product, lime often also contains magnesium oxide, silicon oxide and smaller amounts of aluminium oxide and iron oxide. Lime in the form of quicklime (calcium oxide - CaO), hydrated lime (calcium hydroxide – Ca(OH)2), or lime slurry can be used to improved the engineering performance of the soils. Quicklime is manufactured by chemically transforming calcium carbonate (limestone – CaCO3) into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water. It is hydrated lime that reacts with clay particles and permanently transforms them into a strong cementitious matrix. Usually, limes used for soil treatment are "high calcium" limes, which contain not more than 5 percent of magnesium oxide or hydroxide. Lime, either alone or in combination with other materials, can be used to treat a range of soil types (Sarkar, R., et al., 2012).

2.4 LIME STABILIZATION

Lime stabilization has been used in construction over 5000 years old ago. The Pyramids of Shersi in Tibet were built using compacted mixture of clay and lime (Rogers, C. D. F., et al., 2001). In modern era, highway and major airports, such as Dallas Fort Worth in Texas, United State of America (USA) have been built on lime stabilised clays. In civil engineering structures, lime is widely used such as in road construction, piles and foundation slabs. The first lime stabilization work in Malaysia was the construction of pavement of Kuala Terengganu airfield. 15cm (≈ 6 inches) lime stabilised base as main structural element of this construction. (Chan and Lau, 1973). Ever since ancient times, lime already used in construction as a binder for building structures. The earliest known example of soil improvement with lime is the Via Appia, which was built on lime-stabilized soil. This road dates from Roman times and is still in use (Lerat, M., 2008). Lime stabilization is a method of chemically transforming unstable soils into structurally sound construction foundations (Kaur, P. and Singh, G., 2012). Generally, the use of lime is to improves the behaviour of soils become a suitable soil for construction. The influence of lime stabilization on these soils was evaluated through determination of geotechnical properties such as liquid limit, plastic limit, swell, compressive strength, mineralogy, and microstructure. An optimum lime content beyond which the strength improvement decreased was found (Dash, S. and Hussain, M., 2012).

Lime in the form of quicklime (calcium oxide – CaO), hydrated lime (calcium hydroxide – Ca[OH]2), or lime slurry can be used to treat the soils. Hydrated lime is created when the quicklime chemically reacts with water. It is hydrated lime that reacts with particals of clay and permanently transforms them into a strong cementious matrix (Sarkar, R., et al., 2012). Lime stabilization occurs over a longer time period of curing. The effects of lime stabilization are usually measured after 28 days or longer. A soil that is lime treated additionally may experience the effects of soil drying and modification. When sufficient amount of lime is added to the soil, stabilization occurs (Samantasinghar, S., 2012). The soil-lime reaction can be cause of the improvements in the properties of soil (Clare and Cruchley., 1957; Ormsby and Kinter., 1973; Locat et al., 1990). The addition of lime results in flocculated type of fabric and the strength and the compressibility behaviour that has been improved cannot be attributed to the fabric changes alone as has been reported by many researchers (Nagaraj 1964; Yong and Warkentin., 1966; Barden and Sides., 1969). The decrease of plasticity of the soil with an increase in pH has been shown in the test result (Clare and Cruchley., 1957). There was a good improvement in the strength of lime treated soil with time and was mainly due to the formation of cementation compounds as has been specified in the rest report (Ingles 1964). Lime reacted with the clay minerals of the soil to form a tough water-insoluble gel of calcium silicate, which cemented the soil particles as has been recommended by (Ingles and Metcalf., 1972). A significant increase in the strength which caused by the lime stabilization of sensitive clay as has been shown in the laboratory investigation that been carried out by (Locat et al., 1990). The pH tests could be used to determine the optimum lime requirement of the soil as which has been proved in the results. (Eades and Grim., 1966). In recent times, the lime treatment techniques is extended to stabilize thick soft underwater marine clays (Yanase 1968; Okumura and Terashi., 1975; Narasimha Rao et al., 1992).

Lime stabilization is particularly important in the construction of highway for modifying subgrade soils, subbase materials, and base materials. The use of lime in the weak soil is intended to improve the engineering performance that will be provide important benefits to portland cement concrete (rigid) and asphalt (flexible) pavements (Kaur, P. and Singh, G., 2012). The stabilising effect depends on the reaction between lime and clay minerals. The main effects of this reaction are: An increase in the shear strength and bearing capacity of the soil; A reduction in the susceptibility to swelling and shrinkage; An improvement in the resistant to trafficking and to bad weather; and A reduction in the moisture content and an improvement in workability and compaction characteristics (Rogers, C. D. F., et al., 2001). The most substantial improvements in above said properties are seen in moderately to soils with high plasticity, such as heavy clays. Then soil stabilization occurs when lime is added to a reactive soil to generate long-term strength gain through a pozzolanic reaction. That reaction produces stable calcium silicate hydrates and calcium aluminate hydrates as the calcium from the lime reacts with the aluminates and silicates solubilised from the clay. This pozzolanic reaction can continue for a very long period of time, even decades -- as long as enough lime is present and the pH remains high (above 10). As a result of this, lime treatment can produce high and long-lasting strength (Kaur, P. and Singh, G., 2012).

2.4.1 Mechanism Of Lime Stabilization

The addition of lime to a fine-grained clay soil initiates several reactions.

2.4.1.1 Drying Out By Absorption And Evaporation

The moisture content of the natural soil can be reduced if quicklime is used for stabilisation rather than hydrated lime. The quicklime is capable to absorb up to one third of water from surrounding soil and transform as hydrated lime. There is also losses in moisture due to evaporation because this slaking reaction is highly exothermic process. An excessive drying of soil must be avoided because moisture is essential for lime treatment. So this essential to have proper or correct water add during mixing process. Any incorrect method could leads to decrease in strength of treated soil.

2.4.1.2 Physico-Chemical Reactions

Dehydration of soil, cation exchange and flocculation/agglomeration, and pozzolanic reaction are the several main reactions when the lime is added with a fine-grained clay soil. The addition of lime to expansive soils increases the plasticity properties of the soils, including a reduction in swell and shrinkage strains, an increase in shear strength and a reduction in the compressibility and permeability properties (Broms and Boman,. 1979; Little., 1987; Puppala, A., 1998). During the hydration process, larger amount of pore water evaporates because of the heavy heat release induced by an increase of temperature (Miura and Balasubramaniam., 2002). The dehydration reaction will occurs when a certain amount of lime is added to the soils. Calcium hydroxide is a product of the dehydration reaction. The dissociation of calcium hydroxide will increase the electrolytic concentration and the pH of the soil when it react with water. The calcium hydroxide dissociation is explained in the equation below (Sirivitmaitrie, C., 2009)

$$Ca(OH)_2 \longrightarrow Ca^{2+} + 2[OH]^-$$

where,

$Ca(OH)_2$: Calcium Hydroxide

Ca^{2+} : Calcium ions

$2[OH]^-$: Hydroxide ions

The released calcium ions will participate in the cation exchange reactions in soil and the following important processes occur in soils are due to the mentioned reactions. Reduction in susceptibility to water addition due to reduced thickness of electic double layer. (Rogers., 1997). In the presence of water, practically all fine-grained soil will display rapid cation exchange and flocculation - agglomeration reactions when treated with lime. The lime addition is the calcium source. Calcium cations preferentially replace commonly present monovalent soil cations such as hydrogen and sodium (a good indicator of abnormally high swell potential). Cation exchange is very effective in reducing PI and swell potential. Flocculation and agglomeration produce an apparent change in texture with clay particles (< 2-micron size) "clumping together" into larger-sized aggregates (more silt-sized) producing a "friable" soil structure. An apparent change in "workability" is easily noted (Thompson, M. R., 2005).

The soil that is added with lime will be alters the properties of soil and this is mainly due to the formation of various compounds such as calcium silicate hydrate

(CSH) and calcium aluminate hydrate (CAH) and micro fabric changes(Pozzolanic reaction).

$$Ca^{2+} + 2(OH)^{-} + SiO_2 \longrightarrow CSH$$

$$Ca^{2+} + 2(OH)^{-} + Al_2O_3 \longrightarrow CAH$$

Where,

Ca^{2+} : Calcium ions

$2[OH]^{-}$: Hydroxide ions

SiO_2: Silica

Al_2O_3: Aluminum Oxide

CSH: Calcium Silicate Hydrate

CAH: Calcium Aluminate Hydrate

(Babu, G. L. S., 2007). When the water and lime in soil mass produce a hugh pH system, which is sufficient for the solution of the clay mineral structure, that will make the pozzolanic reaction occurs. A proper lime-watersoil system would be designed at a normal paving temperature when the pH value is higher than 12 is obtained (Arabani, M. and Karami, M. V., 2007).

2.4.2 Lime Stabilization Properties

The characteristic and properties of lime treated soil is depending on several factors. Factors that affecting the properties are: