STRENGTH OF KAOLIN STABILIZED WITH VARIOUS PERCENTAGE OF LIME AND 4% SILICA FUME

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ABSTRACT

Clay soil as known as soft soil present difficulties to geotechnical engineer due to its complex nature and also contain variable materials. This type of soil can be categorized as problematic soil due to its weak properties. As the preliminary stage, soft clay soil did not meet the requirement for construction purpose. This is because the entire load from the top of the building will be transferred to the underlying soil. As we know the strength of soil is weak, without proper design, modification and earthwork, construction problem such as cracking, settlement of building may be occur and the building may collapse within its design life. It is very risky if the construction is still continuing on this type of soil without any remediation or improvement on the soil itself. Therefore, a proper modification for the soil itself is required to alter the soil become stronger; hence meet the requirement to use in construction industry. There are various methods to improve the soil. This research proposes about soil stabilization method that is soft clay soil Kaolin S300 stabilized with various percentages of lime and 4% silica fume. Percentages of lime used are 3%,5%,7% and 9%. While the percentage of silica fume used is fixed that is 4%. The main objectives in this research is to conduct the improvement of undrained shear strength of soft clay soil mixed with various percentages of lime and 4% silica fume. The improvement will be observed based on different percentage of lime. Other physical and mechanical tests that involves in this study are Atterberg Limit, Falling Head, Standard Compaction, Hydrometer, and Specific Gravity, The properties of soil was compared between the kaolin only and different percentages of lime mixed with 4% silica fume. The main test in this research is unconfined compressive test that is to determine the undrained shear strength. From the study, the optimum amount value of lime is 5%. This is because at 5% lime content, the maximum stress achieve is 29.37 kPa which is optimum compared to others percentage. It is shown that, the strength of soft clay is improved by 14.28%. Based on laboratory test result, it can be concluded that soil stabilization by using lime and silica fume can improved the strength of soft clay. Lastly, after all the tests had been done, correlation equation and cohesion value for each test were list out in graph and tabular form as well.

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ABSTRAK

Tanah liat yang juga dikenali sebagai tanah lembut mendatangkan banyak masalah kepada jurutera geoteknik berikutan sifat semulajadinya yang unik dan mengandungi pelbagai bahan asli di dalam tanah tersebut. Tanah lembut ini dapat dikategorikan sebagai tanah yang banyak mendatangkan masalah disebabkan sifat semulajadinya yang lemah. Sebagai permulaan, tanah lembut ini tidak memenuhi kriteria dan syarat untuk digunakan dalam industri pembinaan. Ini disebabkan, seluruh beban dari atas bangunan akan dipindahkan kepada permukaan bawah tanah. Seperti yang kita tahu, kekuatan tanah itu sangat lemah. Oleh yang demikian, tanpa kerja tanah, reka bentuk dan modifikasi, masalah pembinaan akan berlaku sebagai contohnya keretakan, dan juga pemendapan bangunan ke dalam tanah. Secara tidak langsung akan menyebabkan sesuatu bangunan itu untuk runtuh lebih awal daripada waktu yang sepatutnya bangunan itu runtuh. Sekiranya pembinaan diteruskan di atas permukaan tanah lembut ini, ianya sangat berisiko tinggi tanpa usaha untuk meningkatkan kekuatan tanah itu sendiri. Oleh sebab itu, pengubahsuaian yang betul terhadap tanah lembut amat penting untuk membuatkan tanah lembut itu berubah menjadi lebih baik dan menpunyai sifat yang kuat menampung beban. Pengubahsuaian yang betul boleh melayakkan tanah lembut ini untuk digunakan dalam industri pembinaan kelak. Terdapat pelbagai cara untuk meningkatkan kekuatan tanah tersebut. Kajian ini memfokuskan kepada penstabilan tanah di mana tanah liat S300 distabilkan dengan pelbagai peratus kapur dan 4% serbuk silica. Peratus kapur yang digunakan dalam kajian ini ialah 3%,5%,7% dan 9%. Manakala peratus bagi serbuk silica adalah tetap iaitu 4%. Tujuan utama kajian ini adalah untuk mengurus dan memantau peningkatan kekuatan ricih tanah lembut yang distabilkan dengan pelbagai peratus kapur dan 4% serbuk silica. Peningkatan kekuatan tanah dipantau berdasarkan peratus kapur yang berbeza dan 4% serbuk silica. Antara ujian fizikan dan mekanikal yang terlibat dalam kajian ini adalah Had Atterberg, ujian kebolehtelapan, ujian pemadatan tanah, ujian serakan (Hidrometer), dan ujian graviti tentu. Setelah ujian ini dilakukan, sifat tanah liat lembut ini dibandingkan antara satu sama lain dimana tanah liat sahaja dan tanah liat distabilkan dengan pelbagai peratus kapur dan 4% serbuk silica. Ujian paling utama dalam kajian ini adalah ujian ricih tanah. Tujuan utama ujian ini adalah untuk mengenalpasti kekuatan ricih tanah. Berdasarkan kajian yang dibuat, nilai jumlah optimum kapur adalah sebanyak 5%. Ini disebabkan,pada kadar 5% kandungan kapur, tekanan maksimum yang dicapai ialah sebanyak 29.37 kPa, dimana kekuatan ricih tanah yang paling tinggi berbanding dengan kadar peratus kapur yang lain. Ini menunjukkan kekuatan tanah liat lembut ini meningkat sebanyak 14.28%. Kesimpulannya, berdasarkan kesuluruhan ujian makmal yang dibuat, penggunaan kapur dan serbuk silca mebuktikan dapat meningkatkan kekuatan tanah lembut. Akhir sekali, setelah semua ujian makmal siap, kesemua persamaan korelasi dan nilai perpaduan disenaraikan dalam bentuk graf dan jadual.

TABLE OF CONTENT

LIST OF TABLE

LIST OF FIGURE

LIST OF SYMBOLS

G_s	-	Specific Gravity
k	-	Hydraulic conductivity
kN	-	Kilo Newton
kPa	-	Kilo Pascal
Mg	-	Mega Gram
MN	-	Mega Newton
m/s	-	Metre per Second
mm	-	Milimetre
μm	-	Micrometre
q_{max}	-	Maximum deviator stress
q_u	-	Undrained Shear Strength
I_P	-	Plasticity index
w_L	-	Liquid limit
w_P	-	Plastic limit
w	-	Moisture Content
w_{opt}	-	Optimum Moisture Content
ρ_d	-	Dry Density
$\rho_{d(max)}$	-	Maximum Dry Density
ϕ	-	Internal Friction Angle
%	-	Percent
R^2	-	Cohesion value

LIST OF ABBREVIATIONS

ASSHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
BA	Bottom Ash
BS	British Standard
BSCS	British Soil Classification System
K	Kaolin
L	Lime
LL	Liquid Limit
OL	Low plasticity organic clay
PI	Plastic Index
PL	Plastic Limit
SF	Silica fume
SL	Shrinkage Limit
UCS	Unconfined compressive strength
UCT	Unconfined Compression Test
US	United States
USCS	Unified Soil Classification System

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Clayey soils are usually categorized as expansive soils. Other names of these soils are soft soils or fine-grained soils. These types of soils are known lead to critical damage to structures resting on them. Normally in construction industries, the structures that constructed on clay soils are tend to trigger the soil when exposed to additional load as well as external impact. This deformation could potentially cause significant failure to foundation and structures. Besides, the construction of roadway on the soft soils also encountered the same problem. This is because the soils do not have enough physical properties for construction application. It is very risky if the construction is still continuing on these types of soils without any remediation or improvement on the soils. As a general knowledge, the common approach when facing this difficulty is to remove all the soils and replace it with stronger soils or material like crushed rocks. The excessive expenses regarding the soils replacement cause the researcher to explore another method to make the cost become more reasonable.

Nowadays, there are many methods to improve the soils. From time to time, researchers make use of soils stabilization technique to enhance the geotechnical characteristics of clay soil to maintain roadways, control foundation settlement, prevent structures from collapsing, as well as avoid any kind of related failure. Various soil stabilization techniques are suitable for stabilization involving expansive clayey soil. These kinds of methods consist the application of chemicals, soil replacing, rewetting, moisture control, compaction control, surcharge loading and thermal methods (Chen, 1988; Nelson and Miller, 1992; Yong and Ouhadi, 2007). Instead of using chemical product, recycled or reused materials usually are might offer more economical options for a variety application of soil stabilization. As an example we can use lime and silica fume to improve the soil characteristics and also the performance of the soil. Preservation with the aim of getting rid of all environmental considerations is really a series issue (Edil & Craig, 2007). All these methods may have their advantages and disadvantages of being ineffective and also costly. Therefore, new methods are still being research to improve the strength properties in order to reduce the swell potential of expansive soils.

As an example, cement was initially utilized as a stabilizing agent in the beginning of the 20^{th} century. It had been combined with the soils in order to create road materials and was used in a wide range of applications worldwide. Since then, many other materials such as lime, fly ash, silica fume, organic polymers and other mixtures have been used as stabilizing agent. Among the stabilizing agent that have been identified, lime and silica fume have been selected in this research because these types of materials have good characteristics to improve its stability, increase the bearing capacity and reduce settlement and lateral deformation of the clayey soil. Type of clay use is Kaolin S300. As a general knowledge, kaolin is a clay mineral with the chemical composition $Al_2Si_2O_5(OH)_4$ (Weaver & Pollard, 1973). Kaolin has a minimal shrink swell capacity and low cation exchange capacity. It is easy to absorb water and will shrink as water is drawn away. This kind of clayey soil contains clay mineral that have the possibility of swelling and shrinkage under transforming water content.

Lime provides an economical as well as powerful way of chemical improvement. The standard utilization of lime stabilization is in the treatment of clay subgrade to create improved road foundation without necessity for large amounts of imported granular aggregates. In United States and Europe, lime stabilization is actually popular regarding improving traffic ability, loading capacity of foundations of road and embankment and also for erosion control (Perry *et al.,* 1977). Contrary to lime modification, lime creates long lasting improvements in soils characteristics offering structural benefits. Other than improving roadways, lime also treat foundations and embankment. Silica fume is very fine dust of silica from a blast furnace produce during silicon metal production and it has historically recently been considered as a waste product. Based on the previous study, it is indicating that silica fume help to improves geotechnical properties of the fine-grained soils for example hydraulic conductivity, swelling behavior, and unconfined compressive strength (Aiticin *et al.,* 1984). In addition, silica fume also have the ability to reduce the effects regarding freezing and also thawing cycles on the strength as well as permeability within the landfill liner and cover systems. Among the pozzolanic materials, silica fume has becomes the most effective by-product due to its extremely energetic and higher pozzolanic property (Atis *et al.,* 2005).

1.2 Problem Statement

Clay present difficulty to geotechnical engineer due to its complex nature and also contains variable materials. In the preliminary stage, the soils do not have enough physical properties for construction purpose. This is because; marginal soils which include soft clays, loose sand, and organic are not satisfactory materials for construction applications. However, this type of soils are very important in geology, construction, and also for the environmental applications because of their wide consumption as impermeable along with containment barriers inside landfill areas and other environmentally applications (Kayabali *et al.,* 1997). As an example, during the site investigation process, if the soil at any particular locality is unsuitable entirely or partially based on the engineer requirements a fundamental decision must therefore be generated whether to be able to remove the site materials and replace with a superior materials or just accept as it is and design to standard sufficient to meet the constraints by its recent quality or the last choice is to alter the properties of existing soil to become better and meet the engineer requirement.

Nowadays, the construction on soft soil is growing because of insufficient appropriate terrain for infrastructures as well as other developments. In this research, study is carried out by using kaolin S300 clay mixed with lime and silica fume. One of the well known waste industrial materials is silica fume. In western countries, it has recently become environmentally undesirable to produce the fume in to the atmosphere and thus it is collected (Aiticin *et al.,* 1983). Awareness is very important related to the harmful issue of the silica fume. Hence, we need to fully utilize the silica fume wisely as a stabilization material. Although silica fume is the waste product of industrial, the material has become the most valuable by-product among the pozzolanic materials because of its very active and also higher pozzolanic property (Atis *et al.,* 2005). According to Kalkan (2009) it absolutely was observed that silica fume improved much better the properties of clayey soil as well as make the clayey soil become more strength. In soil stabilization, binder material is very crucial to make each of the particles join and hold firmly. The binders is important to improve mechanical and chemical properties of the stabilize soil (Ancade, 2007). Some examples of the binders are lime, cement and other pozzolanic materials. In this research, lime treatment is carried out with the clayey soil considered inadequate amount in construction as well as recycle involving these kind of material will probably make environment become more friendly and also financial benefits by reducing expenses (Usman *et al.,* 2005). In addition, lime required less time to react with all the materials and also improved the chemical properties of soil in a more comprehensive technique (Osula, 1996). By utilizing waste product within soil stabilization purpose, retains these types of products from getting trashed directly into landfills. Therefore, conserving method is already using up landfill area.

Chemical stabilization of clay soil has been proved to be effective in increasing its strength and stiffness. Lime and silica fume provides one such means. As an extra advantage, make use of waste material in soil stabilization purpose, keeps these material from being dumped into landfills, thereby saving already the use of landfill space. For a successful stabilization, laboratory test followed up by field test is required in order to determine the engineering properties of soil. Therefore, in order to prevent the problems, it is important for engineers to stabilize the existing soil before starting the construction activities. By simply stabilizing the soil, it is expected that soil could be more suitable for any type of construction such as road or building construction. Thus, a suitable method to make sure strength of kaolin is improved is by mixing it with lime and silica fume as a stabilizer.

1.3 Objectives of Study

The objectives of this research are as follows:

I) To determine the physical characteristics of kaolin and kaolin mixed various percentage of lime and 4% silica fume

II) To determine the undrained shear strength of kaolin and kaolin mixed with various percentage of lime and 4% silica fume

III) To correlate the undrained shear strength of kaolin mixed with various percentage of lime and 4% silica fume.

1.4 Scope of Study

All testing was conducted in Geotechnical Engineering Laboratory, Universiti Malaysia Pahang (UMP). This research is mainly focused on stabilizing of kaolin clay (S300) using selected agents that were lime and silica fume. Laboratory testing methods will be conducted to test the strength, behavior and performance of stabilized soils.

The physical and mechanical properties of kaolin were determined from the following laboratory test:

I) Liquid Limit And Plastic Limit Test
II) Specific Gravity Test
III) Standard Compaction Test
IV) Falling Head Permeability Test
V) Hydrometer Test

The effective strength parameter of kaolin only and stabilized kaolin was determined from Unconfined Compression Test (UCT) with the following step:

I) Every batch of sample was produced by using compaction method by make sure that the size of the samples is same as well as exact size.
II) Diameter and height of each sample was 50mm and 100mm respectively.
III) After all the samples is well prepared, the UCT test is run and the data was analyzed.

1.5 Significance of Study

This research will be carried out to determine how far the performance of kaolin mixed with lime and silica fume. The work presented in this research is a contribution to the application of chemical stabilization techniques, for different concentration of lime and silica fume for kaolin clay. Therefore, this research provides insight into which stabilizers are most effective for stabilizing kaolin clay. This report can be used as a guide to select an appropriate stabilizer type and the amount of stabilizer based on the soil properties and the desired strength. All the problems regarding silica fume harmful can be solved by utilizing it as a stabilizing agent mixed with lime and kaolin. Therefore, the bearing capacity of clayey soil is increased and settlement of structure foundation is reduced. Hence, it increased the availability of marginal sites for small expenses and long term construction.

The main objective in this research is to evaluate the engineering properties of kaolin clay which is stabilized with different admixtures such as lime and silica fume. The improvement of soil is observed based on different percentage of lime and silica fume mixed with kaolin compared with kaolin only. A series of laboratory tests were carried out to prove that kaolin become more improved when mixed with stabilizing agents for soil stabilization technique. After the completion of this research, the problem related to strength of kaolin was solved with one solution. The usage of lime and silica fume as stabilizing agents was able to increase bearing capacity and shear strength of the clayey soil as well as reduced the waste of industrial waste of silica fume which currently disposed in large quantity into landfill. Apart from that, it can be considered as economic and environmental friendly since the silica fume is a waste generated during silicon metal production

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this literature review, there will be further explanation about the components of this study for any related issue and the definition in-depth. The sources are from various sources such as books, journals website and articles. This chapter will provide a clear understanding of the research objective, problem statement, and the significant of the study

2.2 SOIL TYPES

With regard to engineering purpose, soil is defined as the uncemented aggregate of mineral grains and also decayed organic and natural matter (solid particles) with liquid as well as gas inside the empty spaces between the solid particles. Soil may be split up into three very wide categories; cohesive, non-cohesive, and organic soil. As a general knowledge, organic soil is the organic and natural matter element of soil comprising of plant and animal residues at numerous phases of decomposition, ingredients synthesized by soil organisms, and cells and tissues of soil organisms (Groenigen *et al*., 2010). Non-cohesive soil has strength on their owned. Any free running kind of soil for example sand or gravel whose strength is depend on friction between particles. On the other hand, if sandy or gravely soil is geologically confined, they can produce strength properties but the strength is depending on the confinement not the materials itself.

Cohesive soil is (mostly clay, but also silty clay, and clay-sand mixtures with clay being main element). Most of these soils usually contain adequate amount of clay in order to success bind the actual mass together. In addition, they have the ability to be molded or shaped. This property is called ‘plasticity’. This type of soil possesses inner strength, can be compacted and compressed and usually suitable for foundation materials under optimum moisture conditions. According to Coduto (1999) clayey soil cannot easily be segregated by sieve analysis into size groups because no particle sieve made with small opening instead of the particle size may be determined by observing settling velocities of the particles in a water mixture.

Clayey soil generally has low shear strength and will become more easily to lose shear strength during wetting or any other physical disturbance. Plastic and compressible are their properties. The soil condition will shrink when dried and tend to get expand when wetted. When a constant load is applied to the cohesive soil, it can suddenly slip (deform plastically) when the shear strength reach it limit and will cause landslides to occur. In that condition, large lateral load is produce and the soil have low permeability (Coduto, 1999). The particle size in soil is varying from 100mm to less than 0.001mm. Table 2.1 below describes details about the size of particles between limits and also Table 2.2 that describe about the size of soils according to British Soil Classification System (BSCS).

Table 2.1: Soil types based on particle sizes

	Particle sizes (mm)			
Soil Types	British Standard (BS)	ASTM D422/ D635	USCS	AASHTO
Boulders	> 200	> 300	> 300	> 75
Cobbles	60 – 200	75 – 300	75 – 300	
Gravel	2 – 60	4.75 – 75	4.75 – 75	20 – 75
Sand	0.063 – 2	0.075 – 4.75	0.075 – 4.75	0.075 – 2
Silt	0.002 – 0.063	0.005–0.075	0.005 – 0.075	0.005 – 0.075
Clay	< 0.002	< 0.005	< 0.005	0.001 – 0.005
Colloids				< 0.001

Source: Gofar and Kassim (2005)

Table 2.2: British Soil Classification system

<table>
<tr><td rowspan="2">Very coarse soils</td><td colspan="2">BOULDERS</td><td>> 200 mm</td></tr>
<tr><td>COBBLES</td><td></td><td>60 – 200 mm</td></tr>
<tr><td rowspan="6">Coarse soils</td><td rowspan="3">G
GRAVEL</td><td>Coarse</td><td>20 – 60 mm</td></tr>
<tr><td>Medium</td><td>6 – 20 mm</td></tr>
<tr><td>Fine</td><td>2 – 6 mm</td></tr>
<tr><td rowspan="3">S
SAND</td><td>Coarse</td><td>0.6 – 2.0 mm</td></tr>
<tr><td>Medium</td><td>0.2 – 0.6 mm</td></tr>
<tr><td>Fine</td><td>0.06 – 0.2 mm</td></tr>
<tr><td rowspan="4">Fine soils</td><td rowspan="3">M
SILT</td><td>Coarse</td><td>0.02 – 0.06 mm</td></tr>
<tr><td>Medium</td><td>0.006 – 0.02 mm</td></tr>
<tr><td>Fine</td><td>0.002 – 0.006</td></tr>
<tr><td colspan="2">C
CLAY</td><td>< 0.002</td></tr>
</table>

Source: Gofar and Kasim (2005)

2.3 SOFT CLAY

From the past until now, many construction industries were facing with challenging soft clay soil construction. This is because of the soil itself engineering properties that are shape and size, type and strength of structural bonds, high compressibility, low shear strength and low permeability of soil (Das, 2006). All of these characteristics are dangerous because it leads to excessive settlement problem, and reduce bearing capacity. To construct on this type of soil, either specially design foundation or pre treatment of soil is compulsory with regard to low cost construction for develop houses and road infrastructure (Chan, 2006). Therefore, it is not practical to remove and replace the soft clay soil with another type of string soil because the process is very expensive and take a lot of time.

The treatment required the knowledge of physical properties of soft clay and their effect on the usage of soft clay in the field. According to Unified Soil Classification System (USCS), clay are categorized as fine grained soils with more than 50% by weight passing No. 200 US standard sieve (0.075mm. This dimension has larger surface areas compared to coarse grained soils. Generally, clayey soil is referred to clay mineral made up of a mass fine mineral particles as well as linked with certain quantity of water, it will revealed plasticity characteristics. There are three major minerals consisted in clay minerals. There are kaolinite, illite, and montmorillonite. Table 2.3 below describes general characteristics of clay minerals.

Table 2.3: General of clay characteristics

Mineral	Kaolinite	Illite	Montmorillonite
Typical thickness (nm)	50 – 2000	30	3
Typical diameter (nm)	300 – 4000	10000	100 - 1000
Specific surface (m^2/g)	10 – 30	50 – 100	200 - 800
Cation exchange capacity (meq/100g)	3	25	100
Activity (PL/ %clay)	0.3 - 0.5	0.5 - 1.3	1.5 - 7
Swell potential	low	medium	high

Source: Holtz and Kovacs (1981)

Soft clay soil can be yellow, red, brown, grey or various combinations of those colors (Steele, 1976). By testing most of the fined grain soil, they are known to be derived from in-situ weathering factor that is metamorphic rocks and igneous rocks and limestone continues to be non dispersive (Sherrad and Decker, 1977). Most of the soft clay particles have particles size lower than 2µm and the particles also are easily breakdown to this dimension (Liu and Evett, 2005). Table 2.4 below shows the soft clay classification according to their compressive strength. Based on Kempfert and Gebreselassie (2006), soft soil can be clay or silt depends on the geological young and also under a well balanced condition because of its own weight has not yet gone through significant secondary consolidation simply by its formation. However, there are possibilities in large deformation although the soft clay soil is able to carry its own overburden weight and any other imposed additional load.

According to British Soil Classification System (BSCS), clay soils composed of 35% to 100% fines in which the clay particles predominate to produce plasticity, cohesion and low permeability.