STABILIZATION OF PEAT SOIL BY USING EFFECTIVE MICROORGANISM (EM)

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by

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Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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September 2016

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NUR SYASALBILA BINTI SAMSUDDIN

ABSTRACT

Peat soil is one of the most soft soils ever exist around the world and classified as highly organic. Peat are well known for their high compressibility, natural moisture content, low shear strength and long term settlement. The aim of this study is to obtain the stabilized peat soils by using the Effective Microorganisms (EM). The volume of EM added and mixed with peat soils varied with 2%, 4%, 6%, 8% and 10% and then were cured for 7, 14 and 21 days after being compacted in the PVC mould with 5 blows for each layer for 3 layers. The experiment was done for uncontrolled and controlled moisture content which means that the uncontrolled moisture content does not have specific moisture content for the samples compared to controlled moisture content that have 50% of moisture content. The experiments carried out for the physical analysis of the samples are Sieve test, Oven-Drying Method, Pycnometer test and Cone Penetrometer test. The testing that has been carried out on the samples are Unconfined Compressive Strength test (UCS). From the results obtained, the mix design of uncontrolled moisture content does not shows increment compared to the raw samples, however, the mix design of the controlled moisture contents were showing promising results. Peat soil with 2% EM shows increment of 5.279 kPa, peat soil with 4% EM shows the increment of 6.028 kPa, peat soil with 6% EM give increment of 6.785 kPa and peat soil with 8% EM and 10% EM shows increment of 6.626 kPa and 8.241kPa respectively. The peat soil samples with 10% of EM shows the highest increase in UCS value and the percentage of increments are in the range of 44% to 65% after curing for 21 days compared to after only 7 days which prove that the EM is giving promising in improving strength of the peat soil as well as the other engineering properties.

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CHAPTER 1

INTRODUCTION

1.1 Background

In engineering construction, the problems with soil always occur even during construction or after construction. The problem occur because the soil cannot achieve the required specification such as the bearing capacity of soil is too weak to support superstructure above it (Hassan, 2015). The existing soil at a construction site are not always be totally suitable for supporting structures such as buildings, bridges, highways, and dams. Hence, if the building is constructed on the poor soil, many problems will occur after the construction finished. The building will be cracked because of the settlement of the soil (Hassan, 2015).

Peat soil is a best representation for the soft soils existed on the earth and it is classified as highly organic as it is composed of fibrous organic matters which are the partly decomposed plants such as the roots, leaves and stems (Lewis *et al.,* 2003). These condition happens due to lack of oxygen and it has been said that peat shows a very unique and distinct geotechnical properties in comparison with those of inorganic soils for instance clay and sandy soils which are made up of only the soil particles. Peat soil is found in all part of the world except the arctic and dessert regions. Sha'abani and Kalantari (2012) said that it is estimated that there are about 1 billion acres of peat land in the world or about 4.5% of total land areas. These soils are geotechnically problematic as they show high compressibility and low shear strength. Kazemian *et al.,* (2011) emphasize that the compressibility of soil generally comprises of three stages namely initial compression, primary consolidation and secondary compression. Initial compression occurs instantaneously right after the load is applied while primary and secondary compressions depend upon the length of time the load is applied. The initial compression occurs mainly due to the compression of gas within the pore spaces and also due to the elastic compression of soil grains. Primary consolidation observed during the increase in effective vertical stress caused the dissipation of excess pore water pressure. The compression of peat is much larger than that of other soils and the creep portion of settlement plays a more significant role in determining the total settlement of peat than of other soil types (Kazemian and Huat, 2009).

According to Kazemian *et al., (*2011), the peat usually has very low shear strength and the determination of shear strength is somehow a difficult job in geotechnical engineering because the difficulties will depend on factors such as the origin of the soil, its water content, organic matters and also on the degree of humification. During the sampling stage, the sample disturbance will also affect the evaluation of shear strength of peat.

1.2 Problem Statement

Generally, before any development can be done in the areas with peat soils, the engineers must come out with a solution to solve the soft soil issue. In other words, peat soil is an extremely soft soil which is subjected to the instability and it is not suitable to be develop because it is known as the problematic ground by the engineers. There are numerous methods used to improve the soft soil, however the common ways the engineers use in dealing with this problematic ground have been either to remove the peat deposits and replace those soils with stronger soils or to drive the piles (end bearing) into the peat layer to the more supportive soil layers below (Ibrahim *et al.,* 2014). However, those methods have high financial cost. Stabilization using microbes is a relatively new ground improvement method for the soft soils to increase the peat strength, improve the deformation properties and save costs.

1.3 Objectives and Scope of Study

1.3.1 Objectives

This study will be carried out based on the objectives to be achieve at the end of the study period. Basically, there are two objectives for this study which are:

i. Optimization of the Effective Microorganism (EM) concentration and curing time for the peat soil stabilization for the samples of uncontrolled moisture content and the samples of controlled moisture contents.

ii. Testing of the stabilized peat with uncontrolled and controlled moisture content using the Unconfined Compressive Strength test.

1.3.2 Scope of study

The study has been carried out using the peat soils sample taken from Sri Iskandar, Perak, Malaysia. The stabilizer used in this research are the Effective Microorganism (EM).

In order to determine the compressive strength of the soil, the testing has been conducted which is the Unconfined Compressive Strength test. The peat soils will be stabilized with different dosages of EM (2%, 4%, 6%, 8% and 10% (v/w)). There were two mix design has been carried out for the project which are the peat soils with uncontrolled moisture content and the peat soils with the controlled moisture content. The curing technique that will be used for the experiments is air curing for 7, 14 and 21 days.

CHAPTER 2

LITERATURE REVIEW

2.1 Peat Soil in Malaysia

Most of the lowland peatlands in Malaysia have developed along the coast, behind accreting mangrove coastlines, where sulphides in mangrove mud and water restrict bacterial activity, leading to the accumulation of organic matter as peat. Many peatlands which are now far inland developed along the former coastline such that some may be around 100 km inland such as the peat areas around Marudi in Sarawak. The age of the oldest inland peat areas has been estimated as 4,000-5,000 years. The peatlands formed along the coast do not form an unbroken area, rather, they develop as individual units on the alluvial plains between rivers flowing to the sea.

Johor has the largest area of coastal estuarine ecosystems in Peninsular Malaysia with varied wetlands types for instance sea grass beds , mangrove swamp forest, coral reefs, riparian fringes and peat swamp forest. Peat soils in Johor have developed on marine soils, marine clays, and acid sulphate soils. The Johor west coast peat overlies acid sulphate soil and the east coast peat overlies sand and clay.

According to Mutallib *et al.*, (1991), the peat deposits represent 8 % of the total land area of the country, which is approximately 2.6 million hectares of land area. Organic soils in particular, have an inhomogeneous and anisotropic structure that differs greatly from inorganic soils, resulting in their peculiar engineering properties (Kallioglou *et al.*, 2009), which are normally not favourable for load-bearing. Chan and Abu Talib (2008) reported that the Malaysian peat usually found at sites with high water levels throughout the years, thus providing very limited resistance against loading and settlement in short or long term. Even a moderate load can lead to a large change in volume in these soils (Huat, 2002).

2.2 Functions and Usage of Peat Soil

Peat is useful as an alternative to firewood for cooking and heating in temperate and boreal regions of Europe. The increasing use of gas and oil as cooking and heating fuels during the 20th century resulted in a diminishing use of peat for such domestic purposes. The high demand for electricity, however, locally stimulated the development of large electric power plants fuelled by peat. Recently, peat has been used for electricity generation in small units in the range of 20-1 000 kW. The carbon and hydrogen contents of peat are significant for its use as a fuel (FAO, 1988).

Other than that, peat is mixed with mineral soil in horticulture to increase the moisture holding capacity of sands, to increase the water infiltration rate of clayey soils, and to acidify soils for specific pot plants.

2.3 Properties and Chemical Composition of Peat Soil

Typically, in a sample of fresh peat about 80 to 90 % of the sample weight is accounted for by water. The organic residues present in peat are derived mainly from vegetative matter, and to a lesser extent from microbial sources. Peat contains an enormous number of organic compounds, thus, it should be appreciated that the chemical composition of peat is complex. In addition, the composition of the peat can vary considerably from bog to bog, and even within the same bog the chemical composition can change with depth (Jinming *et al*., 2003).

According to Delicato (1996) as the peat decomposes there is about a 10 % increase in its carbon content, from an initial value of about 50 % to about 60 %, due to microbial degradation of the vegetative matter. The percentage of oxygen decreases by about 10 % with increasing humification of the sample, from about 43 % to about 33%. There are smaller increases in the percentages of nitrogen and sulphur with increasing state of decomposition while the percentage content of hydrogen remains roughly static. The readily degraded materials, such as cellulose and hemicellulose, are the first to be attacked by the soil microorganisms, and it can be seen that the levels of these materials drops to almost nothing in the highly decomposed peats.

Ignoring water, the inorganic fraction of peat usually accounts for only 2 to 10 % of the dry weight of the sample, for the highly decomposed mucks this can increase to about 60 % of the dry weight. The total percentage ash content of peat samples taken from a bog site contained three peat layers, each at a distinct stage of decomposition, namely a muck (well decomposed sapnst peat) overlaid with a hemist peat layer and a fibrist peat layer respectively. the ash content of the peat increases with increasing state of decomposition of the peat in the order, fibrist peat (125 % ash), hemist peat (49 % ash) and sapnst peat (574 % ash) This trend is related to the cation exchange capacity of the peat (Delicato, 1996).

2.4 Problems Regarding to Peat Soil in Construction Site

Engineers have recognised that peat is a very problematic soil that is best avoided as far as possible. Peat or organic soil is a very soft soil that subjected to instabilities, such as localised sinking and slip failure, and to massive primary and long-term secondary and even tertiary settlement when subjected to even moderate load increases. In addition, there is discomfort and difficulty in access to the sites, tremendous variability in material properties and difficulties in sampling (Huat *et al.,* 2014).

These material may also change chemically and biologically with time. Further humification to the organic constituents would alter the soils mechanical properties, such as compressibility, shear strength and hydraulic conductivity. Lowering of ground water may cause shrinking and oxidation of peat, leading to humification and a consequent increase in permeability and compressibility.

2.5 Practical Solutions in Construction Sites

There are numerous applications has been used at the construction site to overcome the problems related to the problematic soils. Below are some of the solutions that has been taken into the considerations when the engineers encounter the problematic soils.

2.5.1 Installation of piles

The common foundations adopted for area with peat soils are installation of deep and closely spaced piles. While the piles serve the purpose well by transferring the load to a firm stratum deep down in the subsoil, the scale of machinery, materials, labour, costs and time involved are inevitably high (Chan *et al.,* 2010). Sometimes such approach is uneconomical and even unwise with over-designs to counter the poor soil quality. High safety factors may be used to ensure the performance of the foundation, hence leading to the installation of deep, closely spaced piles to mobilize optimal skin friction and end bearing capacities.

2.5.2 Floating foundations

Floating foundations have also been used successfully in the construction on soft soils. According to Murthy (2002), floating foundation is simply defined as a foundation of which the weight of the building is approximately equal to the full weight, including water, of the soil removed from the site of the building. The foundation could be a raft or a mat, typically cast as a continuous reinforced concrete pad under the entire building (Dunlop *et al.,* 2003). Alternatively, a backfill of suitable material, as in the mass replacement method, is an option for providing a firm foundation for development on soft soils. According to Magnan (2002) the depth should not exceed 6 m to ensure its effectiveness.

2.5.3 Stone column

According to (Murugesan & Rajagopal, 2009), the construction of stone column involves partial replacement and/or lateral compaction of loose subsurface soils with a compacted vertical column of stone aggregate. The presence of the columns creates a composite material which is stiffer and stronger than the original unsuitable soil. Stone columns have certain limitations when it is used in sensitive clays such as increase in the settlement of the bed because of the absence of the lateral restraint, and clay particles get clogged around the stone column thereby reducing radial drainage. In order to overcome these limitations, and to improve the efficiency of the stone columns with respect to the strength and the compressibility, stone columns are encased (reinforced) using geogrids/geocomposites (Mokhtari & Kalantari, 2012).

2.5.4 Geopier

Geopier is the foundation system which incorporates very stiff aggregate piers to reinforce weak and compressible peat and highly organic soils with a basic requirement that the peat and highly organic soil layer has to be penetrated completely (Allgood *et al.*, 2003). The method requires complete penetration of the peat and highly organic soil layer. However, the pier cavity usually lies within soft and compressible inorganic soils and does not have to extend to a good soil layer (Allgood *et al.*, 2003). It shows that geopier are technically feasible and are usually highly cost effective compared to massive excavation and replacement methods, deep foundation systems, or other soil improvement techniques.

2.5.5 Offloading

According to Munro (2004) this technique basically involves the removal of heavyweight material from an existing road construction and its replacement with something lighter. The aim of offloading is to produce a reduction in load on the underlying peat preferably to a level within its existing bearing capacity.

2.6 Research Attempt to Stabilize the Peat Soil

Several researchers have conducted laboratory experiments to study the effect of binders on the shear strength of peat. Skels *et al.,* (2013) conducted an experiment that aims to increase the bearing capacity and with that the compressibility and stability of the treated soil layers. It was observed during laboratory testing that the unconfined compression strength (UCS) of stabilized peat increased remarkably already after 7 days curing in water container and it enlarged continuously. In the study, the stabilization of peat with ordinary Portland cement showed a considerable strength increase to more than 20 times the strength of the natural peat and stabilized peat with 300 kg/m3 Portland cement dosage and 18 kPa surcharge. They reported an improvement in the engineering properties (unconfined compressive strength) of cement stabilized peat. Generally, the more cement that is added to the peat, the greater the strength. Research has also been carried out on the effect of binders and fillers on the strength of stabilized peat.

Wong *et al.,* (2008) reported on the use of sodium bentonite to maximize the filler and pozzolanic effects of peat stabilized with cement. When activated by cement, the pozzolan, which contains excess silica and alumina, is able to neutralize the acid and create an alkaline environment that enhances the secondary pozzolanic reaction within the cemented soil. This generates more secondary tobermorite gels that in effect, block the pores, reduce the permeability, and increase the strength of the cemented soil (Wong *et al.,* 2008). They conclude that the different type of peat reacts with different type of binder at certain binder dosage to achieve effective stabilization.

Aagnostopoulos and Chatzianglou (2008) reported that the stabilization of an organic soil such as peat is affected by a number of factors for instance water content, physical, chemical, and mineralogical properties, character and amount of organic content, and the pH of the pore water. Tremblay *et al.,* (2002), Ramirez (2005), Kalantari (2011) and Duraisamy *et al.*, (2007) has written that in most of the studies involving peat and cement (as binder), it is reported that the samples were mixed with desired amount of binder (cement in most cases) and cured for varying periods normally from 28–240 days.

2.7 Effective Microorganism (EM)

According to Golec *et al.,* (2006), there are primarily 5 types of bacteria used to prepare EM solution which are the photosynthetic bacteria, lactic acid bacteria, yeasts, *Actinomycetes* and fermenting fungi. Photosynthetic bacteria are independent self-supporting microorganisms. These bacteria synthesize amino acids, nucleic acids, bioactive substances and sugars, substances from secretions of roots, organic matter (carbon) by using sunlight and the heat of soil as sources of energy. Lactic acid is a strong sterilizer. It suppresses harmful microorganisms and increases rapid decomposition of organic matter.

Moreover, lactic acid bacteria enhances the breakdown of organic matter such as lignin and cellulose. Yeast synthesize antimicrobial and useful substances for plant growth from amino acids and sugars secreted by photosynthetic bacteria, organic matter and plant roots. Bioactive substances such as hormones and enzymes produced by yeasts promote active cell and root division. Their secretions are useful substrates for effective microorganisms such as lactic acid bacteria and *Actinomycetes*. *Actinomycetes* produces antimicrobial substances from amino acids secreted by photosynthetic bacteria and organic matter.

These antimicrobial substances suppress harmful fungi and bacteria. Fermenting fungi such as *Aspergillus* and *Penicillium* decompose organic matter rapidly to produce alcohol, esters and antimicrobial substances. These microorganisms are physiologically compatible with one another and can coexist in liquid culture. There is evidence that EM inoculation to the soil can improve the quality of soil, plant growth and yield (Kengo and Hui-lian, 2000).

In 1982, Dr.Higa at the University of Ryukyus, Okinawa Japan, discovered a specific group of naturally occurring beneficial microorganisms with an amazing ability to revive, restore, and preserve known as Effective Microorganism (EM). EM contains an unspecified amount of Lactobacillus sp., Rhodopseudomonas sp. and Streptomyces griseus (Daly and Stewart 1999).

Higa (2003) encounter that studies conducted indicate that EM may influence development conditions for microorganisms living in a given soil, thus affecting plant growth and development.

2.7.1 Advantages of EM

There are a lot of advantages of the EM. That is the reason why EM has been widely used in the industry especially in the farming sector. One of the reason is the EM can act as the measure against stained/polluted/contaminated water. Higa (1999) emphasize that when EM is applied and propagated at the source of pollution, such as toilets and a sewage treatment system, water will be cleaned enough for recycling for agriculture, aqua-culture, and even household uses.

Other than that, EM is one of the measure against problems associated with energy consumption and solid wastes. EM and EM ceramics not only improve the efficiency of combustion engines including automobiles, boats, and farm machines, resulting in better fuel mileage and cleaner emission, but also protect them from aging, such as rusting, resulting a longer life. This helps us to reduce the consumption of energy, the pollution from exhaust gases, and reduce the waste of raw materials (Higa, 1999).

Beside, one of the application that has been widely well-known is the Integrated Farming (Systemic-Comprehensive Farming). With EM it is possible to build an integrated farm with various practices for a farmer or for a community of farmers which themselves may be separate practices. That is, almost all industries not only the combination of cropping and livestock but also including aqua-culture, waste water and solid waste from food processing, of primary products, and sewage can be integrated into a system, which in turn provides opportunities for a wider range of industries to be integrated and recycled. If such a system is adopted widely and firmly in the society, most environmental problems which are attributed to a large amount of kitchen garbage and organic wastes, sewage, and excreta from livestock, can be resolved, and finally we can establish a farming characterized with “low input”, “high productivity”, “high quality”, and “sustainable” (Higa, 1999).

2.7.2 EM in construction industry

Addition of EM is still in early stage in construction field, hence detailed research needed to determine the actual effects on concrete. There are not much of the application of EM in the construction industry which is quite disappointed since the EM is very useful in certain ways.

One of the research has been done by Tan *et al.,* (2012) emphasize that the Effective Microorganisms for Concrete (EMC) is now being produced locally and has been used in the construction industry to promote sustainability. The main concept in EMC is the fermentation in which the process will not produce harmful substances. Previous works in Japan found that EMC improved the concrete strength and also durability. The aim of the research is to determine the optimum percentage of the EMC to be added into the concrete and to identify the ability of the EMC to enhance the mechanical properties of the concrete. A few samples been prepared with presence of EMC of 5% till 50%. Testing of compressive, tensile and flexural strength test were carried out throughout the project. The finding of the project shows that the addition of 5% of EMC gave the values for compressive, tensile and flexural strength of

143.90%, 25.23% and 19.17% of the design compressive strength respectively. However, the research also indicate that the addition of 25% of EMC and beyond will increase the tensile strength of the concrete. Therefore, the study concludes that the most economical and optimum percentage of EMC added into the concrete is 5% in which enhancing its design strength. Further study on the usage of the EM in the construction study shall be done in order to help to improve the presence weakness in the industry.

CHAPTER 3

METHODOLOGY

3.1 Sample Collection and Preparation

In this study, the peat soils were collected from Sri Iskandar area in the oil palm plantations area. At first, half of the samples was dried in the oven at 105ºC for 24 hours and the other half was kept in the container so that the moisture content will be preserved along the period. The EM was obtained from the supplier to be used as the stabilizer later on. The EM was kept in the closed plastic bottle and the bottle's cap was opened from time to time to allow the gasses produced in the bottle to be released. The apparatus and materials is being prepared before conducting any experiments.

3.2 Physical Analysis of Peat Soil

The experiments has been conducted to analyse the peat soils and to obtain the physical properties of the peat soil. The experiment for each of the properties of peat soil has been described as below.

3.2.1 Oven-Drying Method

For peat soils, the water content is an extremely important index used for establishing the relationship between the way a soil behaves and its properties. The water content is also used in expressing the phase relationships of air, water, and solids in a given volume of soil. The procedure will be started by cleaning the containers with lid dry it and weigh it (W1).

The sample was then put in the container and was weighted (W2). The container was kept in the oven to be dried with the temperature at 105°C possibly for 24 hours. The value obtained in the percentage shown the percent of moisture content in the sample. The Equation 1 will be used to calculate the moisture content.

$$\text{The natural moisture content, w (\%)} = \frac{w2-w3}{w3-w1} \times 100 \tag{1}$$

3.2.2 Specific Gravity Determination

The specific gravity (ρs) of the highly organic or peat soil is determined based on procedure stated in BS 1377: Part 2: 1990. In this test, ρs is determined by using small pycnometer which is used for the soils consisting of particle finer than 2mm. After receiving the soil sample it is dried in oven at a temperature of 105ºC to 115ºC for a period of 16 to 24 hours. Firstly, the pycnometer was dried and weighted with its cap (m_1). About 100g of the crushed oven dried soil was taken and put into the pycnometer as three samples and weighted again (m_2). Distilled water was added to cover the soil and was shaken so that the mixture was well mixed. The sample was put in the vacuum desiccator to remove the entrapped air for about 1 to 2 hours and then the sample was left in the desiccator for 24 hours. After 24 hours of removing air from the pycnometer, the pycnometer was filled with water and the weighted (m_3). The pycnometer was weighted and then filled with the distilled water and the weighted (m_4).

The Specific gravity of soil solids (ρs) is calculated using Equation 2:

$$\text{Specific Gravity, ρs} = \frac{(m2-m1}{((m4-m1)-(m3-m2))} \tag{2}$$

where m_1 is the empty weight of pycnometer, m_2 is the weight of pycnometer + oven dry soil, m_3 is the weight of pycnometer + oven dry soil + water and m_4 is the weight of pycnometer + water full.

3.2.3 Cone Penetrometer Method

This method will be used to determine the liquid limit (LL) of peat soil sample. The sample was dried in the oven at 105ºC and then crushed before undergo sieving process. The sample of 300g that passes 425µm test sieve was used. Distilled water was then mixed to the soil thus obtained in a mixing disc to form a uniform paste. Then the wet soil paste is transferred to the cylindrical cup of cone penetrometer apparatus, ensuring that no air is trapped in this process. Finally the wet soil is levelled up to the top of the cup and placed on the base of the cone penetrometer apparatus. The penetrometer was adjusted that the cone point just touches the surface of the soil paste in the cup and the initial reading is ready to be taken. The vertical clamp is then released allowing the cone to penetrate into soil paste under its own weight for 5 seconds. After 5 seconds the penetration of the cone is noted to the nearest millimetre. The test is repeated at least to have four sets of values of penetration in the range of 14 to 28 mm.

The exact moisture content of each trial is determined. A graph representing water content on Y – axis and the cone penetration on X – axis is prepared. A best fitting straight line is then drawn. The moisture content corresponding to cone penetration of 20 mm. is taken as the liquid limit of the soil.

3.2.4 Plastic Limit Determination

The objective of the experiment is to determine the plastic limit and the plasticity of the soil according to BS 1337: Part 2: 4.3/4.4. About 20g of the samples that passes 425µm test sieve was taken and placed on the glass plate. The distilled water was then added until the sample can be shaped into a ball. After that, the samples was then rolled to about 3mm diameter thread. The soil threads was transferred into the container and then dried in the oven for 24hours in 105ºC condition. The container was weighted to obtain the moisture content of the soil samples.

From the data of liquid limit and plastic limit, the plasticity index (*PI*) of the sample can be obtained using Equation 3.

$$PI = LL - PL \tag{3}$$

where PI is the plasticity index, LL is the liquid limit and and PL is the plastic limit.

Table 3.1: The number of samples for every test and analysis.

Number of samples	Test / Analysis
3	Oven-Drying Method
3	Specific Gravity Determination
3	Sieve Analysis
3	Liquid Limit
3	Plastic Limit
72	Unconfined Compressive Strength test

The Table 3.1 above shows the number of samples that has been used to do the testing and analysis. The amount of peat soils needed are according to the requirement of each of the experiments.

3.3 Uncontrolled and Controlled Moisture Content Mix Designs

The research has been done on 2 mix designs which is the uncontrolled moisture content and the controlled moisture content. As for the uncontrolled moisture content, the study used the peat soil samples with its original moisture content and the EM will be added according to the percentage of EM for each formulation. Therefore the samples will have different dosage of moisture in the samples and the samples with 10% EM will have the most EM and will be more flaccid since the EM is in the liquid form.

As for the controlled moisture content, the peat soil samples was dried at the first place at 105ºC in the oven for 24 hours. This mix design have the specific moisture content which is 50% including the percentage of EM that has been added. Therefore, the moisture content in each of the sample was the same with one another and gave more promising data.

3.4 Optimization of EM Concentration for Peat Soil Stabilization

The different concentration of the EM was used in the experiments which are 2%, 4%, 6%, 8% and 10% (v/w). The EM was mixed with the peat soil samples to get the by-product of the reaction between the admixtures and the peat soil.

3.5 Optimization of Curing Time for Peat Soil Stabilization

Air curing is a technique in which the mixture of peat and stabilizer is exposed to the air for curing, without any external water intruding into the stabilized samples (Denhaan, 1997). This air curing technique was adopted as the natural water content of the peat was very high. The samples were prepared in a mould, taken out after compaction and then wrapped in a thin plastic sheet and kept in the air at a room temperature of 30 ± 2 °C during the curing period. The stabilized peat soil will be cured for 7, 14 and 21 days.

3.6 Testing of Raw and Stabilized Peat Soil

The samples from the 2 mix designs has been tested using the Unconfined Compressive Strength test. The results obtained showing huge difference between the 2 mix designs.

3.6.1 Unconfined Compressive Strength Test

UCS tests will be conducted on the samples of mix design with uncontrolled moisture contents and mix design with controlled moisture contents that are stabilized with different dosages of EM (2%, 4%, 6%, 8% and 10 %(v/w)). Peat shall be screened using a 6.3 mm (0.3″) sieve in order to remove the larger size of vegetal fibers. As for the peat soil with stabilized peat using EM, specified amount of microbes then will be added to the screened peat and mixed well for homogeneity (Black et al., 2007). The mixing shall be done using a house hold mixer for five minutes. The mixture then place in three layers in the PVC mould and then compacted with 5 blows for each layer for 3 layer. The UCS tests for stabilized peat samples will be conducted after curing for 7, 14 and 21 days.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Physical Properties

The results of conducted experiments are presented below together with the explanations and discussions on the results obtained.

4.1.1 Moisture Content

Three sample of 30g from the peat soil is taken and dried in the oven. An average of the three determinations is taken. The sample calculation is shown in Table 4.1 below:

Table 4.1: The calculations for the moisture content.

No.	Description	Determination No.			
		I	II	III	Average
1	Weight of empty container (W_1) in g	21.10	21.12	18.66	20.29
2	Weight of container+ Wet soil (W_2) in g	51.78	51.22	48.72	50.57
3	Weight of container + Dry soil (W_3) in g	33.6	33.8	31.1	32.83
Calculation					
1	Weight of water= W_2-W_3	18.18	17.42	17.62	17.74
2	Weight of soil= W_3- W_1	12.5	12.68	12.44	12.54
3	Water content, w (%) = $\frac{w2-w3}{w3-w1} \times 100$	145.4	137.4	141.6	141.5

The average value for the moisture content of the peat soils is 141.5% which means that the water contents in the peat soils is about 141.5% of the total mass of the peat soil. The water content of the peat soil depend on the origin of the soil, the chemical composition of the soil itself and the degree of decomposition. Huat *et al.* (2011) emphasized that the peat soil has a very high natural high holding capacity because the soil structure characterized by the organic coarse particles (fibers) which means that they can hold a considerable amount of water since the soil fibers are very loose and hollow.

Other than that, the peat soil also has low bulk density and low bearing capacity resulting to the high buoyancy and high pore volume (Huat *et al.,* 2011). Generally, the water content of the peat soil may range from 200% to 2000% which is very different from clay and silt deposits which rarely exceed 200% (Ajlouni, 2000). In West Malaysia, the water content of the peat soil was reported ranges from 200 to 700% (Huat, 2004). The water content of the peat soil at Seri Iskandar does not exceed 200% which means that the decomposition's degree of the soil is quite low compared to the peat soil at the other location that is why it cannot store high percentage of water (Boelter and Verry, 1977).

4.1.2 Specific Gravity

Specific gravity is the ratio of the density of a substance to the density of a reference substance which is water. Substances with a specific gravity of 1 are neutrally buoyant in water. Those with specific gravity greater than 1 are denser than water and will, disregarding surface tension effects, sink in it. Those with an SG less than 1 are less dense than water and will float on it. The specific gravity, ρ_s of the soil are calculated using Equation 2.

The Table 4.2 shows the value that is obtained after conducting the experiments. The average of specific gravity obtained by using the Equation 2.

Table 4.2: The specific gravity of the soil.

Mass (g)	Sample		
	1	2	Average
Pycnometer + cap (m1)	31.2	30.5	30.85
Pycnometer + cap + soil (m2)	41.3	40.6	40.95
Pycnometer + cap + soil + water (m3)	85.3	84.5	84.9
Pycnometer + cap + water (m4)	81.7	81.9	81.8
Average of specific gravity of peat soil (Mg/m^3)			1.45

The average value of the specific gravity obtained is 1.45 Mg/m^3, which means that the peat soil density is denser than the water density. Specific gravity is an important soil property used in calculation of porosity and void ratio. Void ratio is often used in soil mechanics (Keller *et al.,* 2011), and reliable estimates are important in the interpretation of soil mechanical behaviour.

The particle density of soil depends on the composition of both the mineral and the organic soil components (Rühlmann *et al*., 2006). The specific gravity of clay particles was approximately 2.86 Mg m^{-3}, while that of sand + silt particles could be estimated to ≈ 2.65 Mg m^{-3}(Schjønning *et al.,* 2016). The value of specific gravity decreases with increasing content of soil organic matter (SOM) (Rühlmann *et al.*, 2006).

4.1.3 Plastic Limit

The plastic limit is the empirically established moisture content at which soil becomes too dry to be plastic. The plastic limit is defined as the water content of soil when the soil sample can be rolled to a diameter of 3 mm and it just begins to crumble. "Plastic index is the difference between the liquid limit and the plastic limit" (White, 1949). The Table 4.3 shows the data for the plastic limit after conducting the experiments on 3 samples of peat soils. The average of the 3 moisture content was calculated.

Table 4.3: The plastic limit of the soil.

PLASTIC LIMIT	Container		
Mass	1	2	Average
Container (g)	21.43	21.24	21.34
Wet soil + container (g)	31.85	32.45	32.15
Dry soil + container (g)	28.6	28.7	28.65
Moisture Content (%)	45.33	50.27	47.8%

The average of the moisture content obtained is 47.8%. The value also represent the plastic limit of the peat soil and it will be used to calculate the plasticity index of peat.

4.1.4 Liquid Limit

The liquid limit is the empirical established moisture content at which a soil passes from the liquid state to plastic state. The results for the liquid limit using the peat soil samples are shown in the Table 4.4.

Table 4.4: Liquid Limit data

LIQUID LIMIT	1		2		3	
Dial Gauge Reading(mm)	7.1	7.4	16.9	16.7	21.9	22
Average penetration(mm)	7.25		16.8		21.95	
Container no.	1		2		3	
Mass of wet soil+ container(g)	28		36		37	
Mass of dry soil+ container(g)	25.2		28.8		29.9	
Mass of container(g)	21		19		22	
Mass of moisture(g)	2.8		7.2		7.1	
Mass of dry soil(g)	4.2		9.8		7.9	
Moisture content (%)	66.67		73.47		89.87	

From the Table 4.4 above, the moisture content of the peat to obtain 7.25mm penetration is 66.67%. As the moisture content is at 73.47%, the penetration of the peat soil is 16.8mm while moisture content at 89.87%, the penetration goes to 21.95mm. The moisture content at penetration of 20mm will be taken as the optimum moisture content that the peat passes from the liquid state to the plastic state. A graph was plotted using moisture content data against the penetration data.

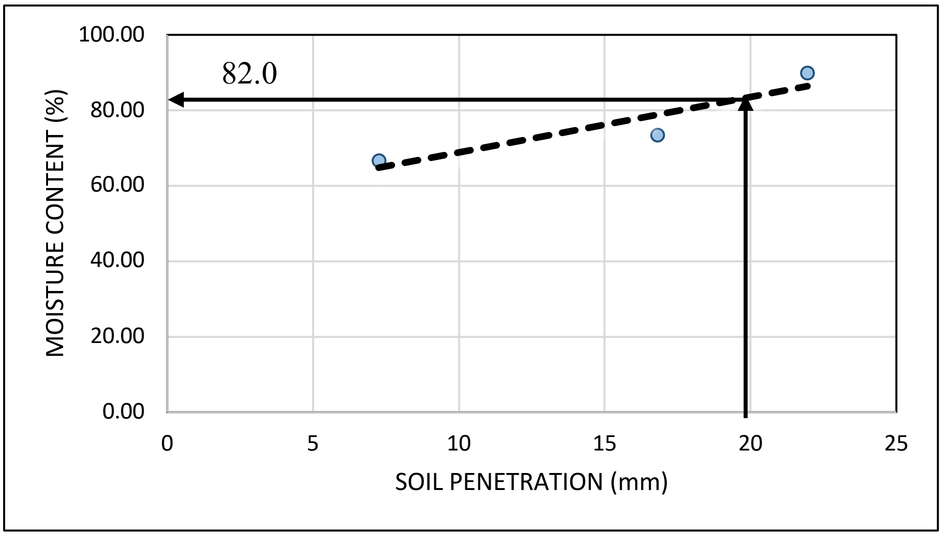

Figure 4.1: Moisture content against soil penetration.

From Figure 4.1 above, it can be observed that the penetration of the soil at 20mm, following the standard procedure, give moisture content of approximately 82% which is also act as the liquid limit for the peat soil sample. These data will be used to calculate the Plasticity Index (PI) of the peat soil to know the plasticity of the soil, where the water content within which soil achieves its plastic state.

4.1.5 Plasticity Index

Plasticity is defined as the property of a cohesive soil to change its mechanical behaviour with change of moisture content. The value for the plasticity index obtained from the values of plastic limit (PL) and liquid limit (LL). The calculation to get the plasticity index (PI) has been shown in Equation 3.

From the data that has been obtained, the PI for the peat soil sample is,

$$\begin{aligned} PI &= 70\% - 47.8\% \\ &= 22.2\% \end{aligned}$$

Asouli (2016) state that increase in plasticity index will increase the strength of the samples and compensate for the fact they are gap graded. The plasticity of the peat is medium therefore the strength also in the medium ranges. The plasticity index is also a measure of the cohesion ability of soils. Beata and Imre (2009) stated that the higher plasticity index usually means a higher expected value of cohesion (by the same compactness). The value of 22.2% of plastic index shows that the soil is medium plastic, means that the soil have medium value of cohesion which indicate that the peat soil is not strong enough to hold any big structure above it without any improvement.

4.2 Biofilm Formation on the Sample.

Figure 4.2: The formation of biofilm on the surface of the sample.

From the observation on the samples after 7, 14 and 21 days, a formation of the spider-web-like layer has been encountered, refer Figure 4.2. The formation is actually the by-product of the bacteria in the EM which is called biofilm. The biofilm can be either single or multilayer and contain the populations of the bacteria that has remain the matrix made from the extracellular polymeric substances secreted by component population of the biofilm. Costerton *et al.,* (1999) stated that the biofilm is the structured community of bacterial cells enclosed in a self-produced polymeric matrix and adherent to an inert or living surface.

In most biofilms formation, unicellular organisms come together to form a community that is attached to a solid surface and covered in an exo-polysaccharide matrix. The microorganisms account for less than 10% of the dry mass, whereas the matrix can account for over 90%. There are a variety of mechanisms by which different microbial species are able to come into closer contact with a surface, attach firmly to it, promote cell–cell interactions and grow as a complex structure (Breyers and Ratner, 2004). Maric and Vranes (2007) have classified the five simple generalized stages are shown for formation of biofilm. The first stage is that the planktonic cell attaches with the substrate by adhesion mechanism and then the cell starts adsorption and multiplication, after that, the early development of biofilm architecture take place before the production of cell-cell signalling molecule and finally produce firmly mature biofilm architecture with extracellular polymeric substances (EPS). The single cell biofilm will dispersed and then created the group of biofilm.

4.3 Testing of Raw and Stabilized Peat Soil

4.3.1 Unconfined Compressive Strength Test

The Unconfined Compressive Strength test has been tested to the samples with uncontrolled moisture content after being cured for 7 days, 14 days and 21 days in the room temperature for both mix design of uncontrolled and controlled moisture content.

4.3.1.1 Formulation with uncontrolled moisture content

The below Table 4.5 shows the summary of the compressive strength of the soil sample with uncontrolled moisture content varied with their EM concentrations. The values was obtained after conducting the testing on each of the sample for the mix design of uncontrolled moisture contents. The values of UCS was noted in kiloPascal (kPa).

Table 4.5: Unconfined compressive strength of soil for 7 days, 14 days and 21 days for mix design of uncontrolled moisture content.

EM Concentrations	Unconfined Compressive Strength (kPa)		
	7	14	21
Raw	33.986	30.997	34.819
2%	11.349	10.979	12.043
4%	3.197	5.799	6.410
6%	3.090	3.957	5.555
8%	3.904	3.726	4.396
10%	2.572	2.603	2.857

From Table 4.5 and Figure 4.3, generally the compressive strength for each of the different concentration is more like constant for all the sample. There are slight increase in the UCS value for peat soil with 2% of EM from 11.349 kPa to 12.043 kPa after 7 days and 21 days curing. Another obvious increase in the value of UCS is the peat soil with 4% of EM which increasing from 3.197 kPa to 6.410 kPa, showing 100% of increment comparing from 7 days to 21 days.

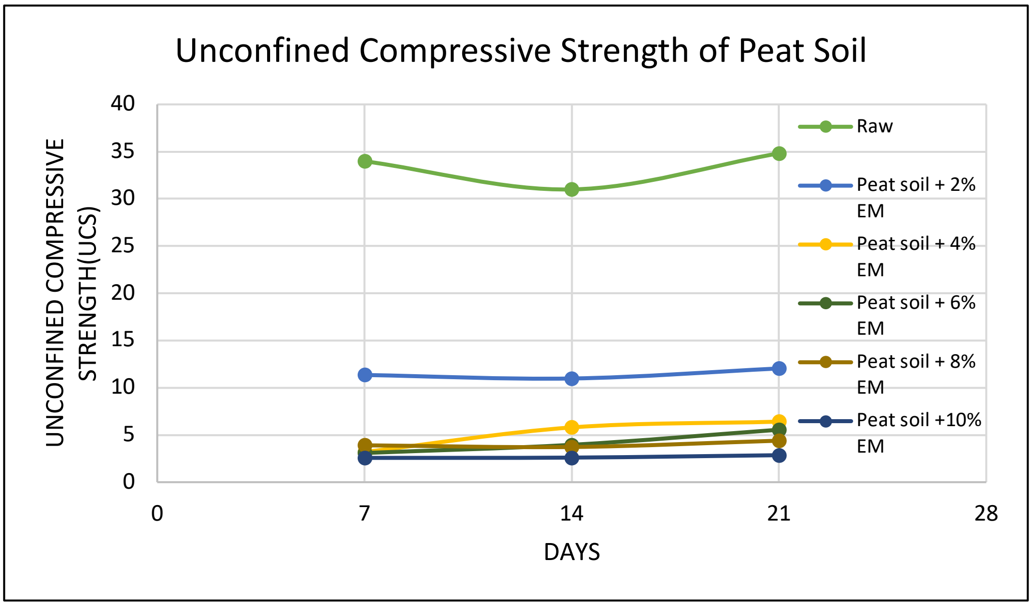

Figure 4.3: The unconfined compressive strength of the samples after curing for 7 days, 14 days and 21 days for mix design of uncontrolled moisture content.

It shows that the EM does gave increment in the UCS value which means that the strength of the peat will be improved if this method were to be implemented at the site whenever they encounter peat soil at the construction site. However, the drop in the value of the compressive strength from the raw and the other mix design is due to uncontrolled moisture content. Each of the mix design have different moisture content compared to others. The moisture content can affect the compressive strength of the samples. Figueroa *et al.,* (2015) explained that the strength of the wood increases again up to a maximum value, which can be explained by the decrease of the moisture content. The mix design that have 10% of EM concentration will have the most moisture content in the sample thus making the compressive strength of the sample was reduces even it shows the increment in the compressive strength on 21 days compared to 7 days. It shows that there are microbial reactions occur in the sample during the curing time if the moisture content to be ignored. Generally, the mix design of uncontrolled moisture content shows reduction in UCS values if it were compared to the raw sample.

4.3.1.2 Formulation with controlled moisture content

The below Table 4.6 shows the summary of the compressive strength of the soil sample with controlled moisture content varied with their EM concentrations. The values was obtained after conducting the testing on each of the sample for the mix design of uncontrolled moisture contents. The values of UCS was noted in kiloPascal (kPa).

Table 4.6: Unconfined compressive strength of soil for 7 days, 14 days and 21 days for mix design of controlled moisture content.

EM Concentrations	Unconfined Compressive Strength (kPa)		
	7	14	21
Raw	11.815	11.824	11.731
2%	11.961	13.150	17.240
4%	11.976	13.618	18.004
6%	12.020	14.247	18.805
8%	12.387	15.880	19.013
10%	12.672	16.365	20.913

From Table 4.6 and Figure 4.4, it can generally be concluded that the compressive strength for each of the different concentration is increasing impressively from 7 days to 21 days. The mix design with controlled moisture content are having the specific moisture content of 50% including the volume of EM added.

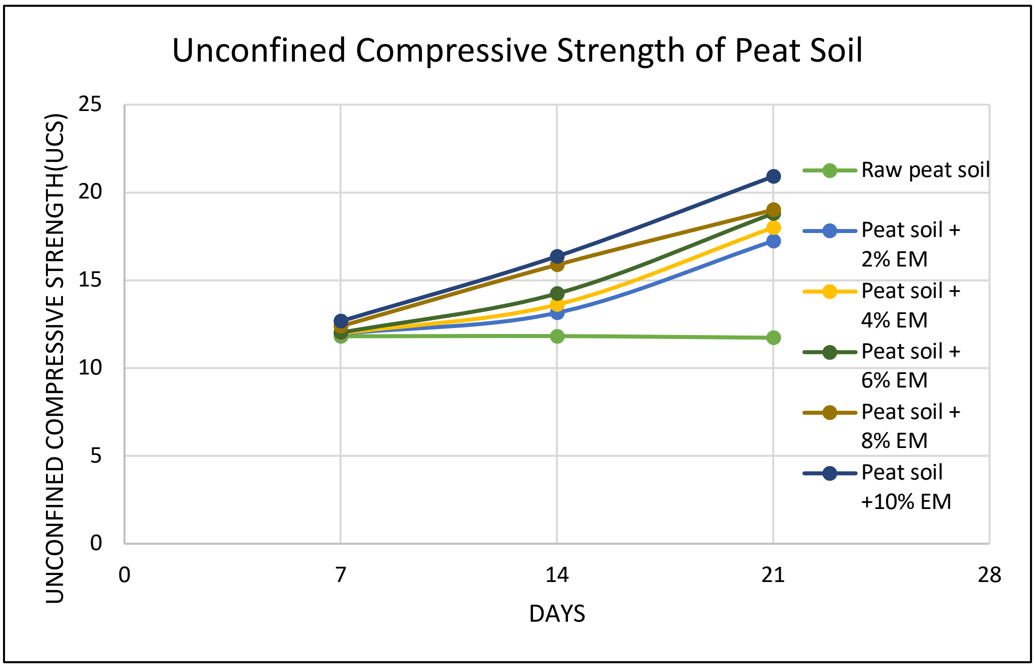

Figure 4.4: The unconfined compressive strength of the samples after curing for 7 days, 14 days and 21 days for mix design of controlled moisture content.

The highest increment of the peat soil was observed occurring to the peat soil with 10% EM with values increasing from 12.672 kPa to 20.913 kPa. The other formulation also showing impressive increment in the range of 44.14% to 64.57%. From the result obtained, it can be conclude that the higher the percentage of EM added to the sample, the higher the increment of the UCS values. The plasticity index of the soil are medium so the strength would be in the medium range. The strength of the sample are in the intermediate value, however, the values are increasing after curing for 21 days. The values might increase if the samples are cured for a longer time. The increment of the compressive strength is due to the biocementation process which is the generation of particle-binding materials through microbial processes in situ so that the shear strength of soil can be increased. The precipitation of material in between the spaces of the soil particles and the binding of the particle takes place in the process of improving the strength of peat soil (Karol, 2003).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Utilization of the EM as the additive to stabilize the peat soil has been investigated. The stabilizer used were studied for their effect on the strength of the stabilized peat samples. The stabilizer used is the EM which help increase the peat soil's strength from the results of their chemical reactions. The change in strength of the stabilized samples was evaluated by performing the UCS test on the sample after curing for 7, 14 and 21 days with the dosage of EM of 2%, 4%, 6%, 8% and 10% respectively. The result of the mix design of uncontrolled moisture content showing the negative result. The strength of the stabilized peat soil does not improved compared to the raw samples. However, if it were to be compared by itself, it does shows increments. The moisture content are affecting the strength of the peat soil samples.

As for the mix design of controlled moisture content, the result shows increment on the compressive strength of the soil samples compared to the samples with 78% increment after curing which means that the EM are reacting and in the process of stabilizing the soil sample. Other than that, it was observed that there were presence of biofilm on the surface of the sample which gave an idea that this project can give a positive results at the end if it were to be implement in the industry. The project will sure give significant impact to the construction industry because it can save cost of the replacement of the peat soil the site if ever the engineer encounter the peat soil at the site.

5.2 Recommendation

As for recommendation, in order to obtain the more reliable data, the morphology changes on the raw samples and the stabilized samples shall be done so that the observation on the samples can be made clearly. Other than that, the permeability test should be done also to the raw and stabilized samples to show how the EM affecting the permeability of the sample. The last recommendation is to obtain the constant grain size for the testing purpose. The peat soil samples should be sieved first and certain size of soil shall be use so that the data obtained will give the desired results.

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