PERFORMANCE OF BOTTOM ASH TREATED PEAT SOIL IN REDUCING COMPRESSIBILITY

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ABSTRAK

Tanah gambut adalah tidak sesuai untuk tujuan pembinaan kerana sifat semulajadinya (kebolehmampatan tinggi, kekuatan ricih rendah dan kandungan air permulaan yang tinggi). Kajian ini dijalankan bagi mengenalpasti prestasi tanah gambut yang dirawat dengan Bottom Ash bagi mengurangkan kebolehmampatan. OPC digunakan sebagai pembolehubah yang dimalarkan iaitu sebagai pengikat kepada Bottom Ash dan juga simen. Bottom Ash digunakan sebagai pemboleh ubah manipulasi dalam setiap siri ujian makmal yang telah dijalankan. Kajian ini bertujuan bagi menentukan hubungan antara had pengecutan linear dan kandungan kelembapan tanah gambut sebelum dan selepas penstabilan, hubungan antara had pengecutan linear dan kandungan serat dengan kandungan organik dalam tanah gambut sebelum dan selepas penstabilan dan bagi mengukur kesan had penyusutan linear dalam mengurangkan penyelesaian sebelum dan selepas penstabilan. Beberapa ujian telah dilakukan bagi menentukan sifat kejuruteraan dan bagi mencapai objektif penyelidikan seperti ujikaji graviti tertentu, ujian nilai pH, kandungan air, kandungan serat, kandungan organik, dan had pengecutan linear. Hasilnya membuktikan bahawa Bottom Ash dapat digunakan sebagai salah satu agen penstabil dalam mengurangkan kebolehmampuan tanah gambut.

ABSTRACT

Peat soil is an unsuitable for construction purpose because of its natural properties (high compressibility, low shear strength and high initial water content). This research was done to study the performance of bottom ash treated peat soil in reducing compressibility. The specific amount of OPC (control variable) used as a binders and proportion of bottom ash (manipulate variable) in a series of laboratory test were conducted. This research aims were to determine the relationship between linear shrinkage limit and moisture content of the peat soil before and after stabilization, the relationship between linear shrinkage limit and the fiber content with organic content in peat soil before and after stabilization and to measure the effects of linear shrinkage limit in reducing settlement before and after stabilization. Several test has been done to determine the engineering properties and to obtain the objective of the research such as specific gravity test, pH value test, water content, fiber content, organic content, and linear shrinkage limit. The results proved that Bottom Ash could be used as one of the stabilization agent in reducing the compressibility of the peat soil.

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LIST OF ABBREVIATIONS AND SYMBOLS

ASTM	American Society for Testing and Materials
BA	Bottom Ash
BS	British Standard
Cc	Compression Index
$C\alpha$	Coefficient of Secondary Compression
FC	Fiber Content
LS	Linear Shrinkage
OC	Organic Content
OPC	Ordinary Portland Cement
δ_c	Settlement due to consolidation

CHAPTER 1

INTRODUCTION

1.1 Introduction and Background of Study

In Malaysia, Sarawak has the largest area of peat land which is about 1.66 million hectares (Huat, Kazemian, Prasad, & Barghchi, 2011). Whereas in Peninsular Malaysia, Pekan Forest Reserve has the largest peat block with an area of 59,097 ha (Lopez, 2010). Peat is an accumulation of partially decomposed and disintegrated plant remains under conditions of incomplete aeration and high water content (Kalantari & Prasad, 2014). Peat is an organic soil which consists more than 70% of organic matters (Duraisamy, Huat, & Aziz, 2007). The formation of peats is favourable when the area is waterlogged, with low permeability ground, excess rainfall and irrespective of altitude or latitude (Huat, Prasad, Asadi, & Kazemian, 2014). Its structure ranges from more or less decomposed plant remains to a fine amorphous, colloidal mass (Cumming & Finlay, 2006). The peat soil is classified as problematic soil. This is due to its natural properties of high water content, high compressibility, low shear strength, high degree of variability in the same location, and potential for further decomposition as a result of changing environmental conditions (Celik & Canakci, 2014). Usually peat area related with swampy and normally low shear strength region and high compressibility is significant and often related to problematic soil for construction purposes such as highly secondary settlement and stability problem may occur when the structure is built on the peat soil (Moayedi & Nazir, 2017). There are many methods to enhance the strength properties of the peat for future development in the country like Malaysia such as chemical stabilization, cement stabilization and fibre reinforcement. The main purposes here is only for construction reliability only and not considering the environmental effects. In this research, bottom ash was used to stabilize the peat soil. This stabilization method involves the mechanical mixing of cementitious compound such as Ordinary Portland Cement (OPC) with peat soil.

1.2 Problem Statement

Peat soil is considered as problematic soil due to its natural properties of high moisture content, high compressibility and water holding capacity, low specific gravity, low shear strength and medium to low permeability (Kolay, Sii, & Taib, 2011). It is unsuitable for the engineer to construct the structure like foundations and buildings on it. This is because construction poses problems like high secondary settlement and stability problem may occur when the structure is built on the peat soil. Usually, construction on peat soil is the last option for developer and also engineer as the effectiveness of existing treatment is still questionable and it is very costly. Unfortunately, due to the rapid development in country, lack of land for construction becomes problems. Hence, it is essential and important for the future of this country development by getting the right solution for the stabilization work and improving the peat soil. The properties of peat soil must be clearly understood in order to improve the properties of peat.

Nowadays, many methods have been introduced in order to stabilize and improve the soil such as mechanical stabilization (improving properties of the soil by changing its gradation) and stabilization by using different types of admixtures (such as Lime Stabilization, Cement stabilization, Chemical Stabilization and Fly ash Stabilization) (Afrin, 2017). However, some of them require high cost and yet the effectiveness of the ground improvement method is questionable. Thus, elements like cost, environmental friendliness, reliability, effectiveness and durability should be considered in selecting the best method of ground improvement.

Bottom ash used for the stabilization of the peat soil. It is one of the method for soft soil stabilization. In construction industry, OPC is combined with bottom ash for the peat stabilization because it has economically-friendly and good price-performance ratio. Unfortunately, OPC is highly not environmental friendly and it contributed to climate changes and global warming. For every tonne of cement production, its actually emit the same amount of carbon dioxide to the environment. The highest amount of carbon dioxide is actually from the production of cement which contributes to global warming (Damtoft, Lukasik, Herfort, Sorrentino, & Gartner, 2008).

1.3 Research Question/ Hypothesis

To overcome the already existing research problems and its gap, the proposed study aims to address the following research questions

- What is the effect of bottom ash toward the relationship of the linear shrinkage limit and moisture content of the peat soil before and after stabilization?
- What is the effect of peat consisting different proportion of OPC (5%) and Bottom Ash (5%, 10%, 15% and 20%) towards the relationship between linear shrinkage limit and fiber content with organic content in the peat soil before and after stabilization?
- What is the effects of linear shrinkage limit in reducing settlement before and after stabilization?

1.4 Overall Objective

The main purpose of this research is to study the performance of Bottom Ash treated peat soil in reducing compressibility

Specific Aims

1. To determine the relationship between linear shrinkage limit and moisture content of the peat soil before and after stabilization.
2. To determine the relationship between linear shrinkage limit and the fiber content with organic content in peat soil before and after stabilization.
3. To measure the effects of linear shrinkage limit in reducing settlement before and after stabilization.

1.5 Scope of Work

- The peat soil for this research is limited to Pekan Peat, Pahang.
- The peat soil in this research is comprised of Ordinary Portland Cement (5%) and bottom ash (5%, 10%, 15% and 20%).
- The peat soil has been prepared by vary method for different types of test.

1.6 Thesis Structure

This thesis is consisted of five chapters. Chapter 1 presented general information regarding background, problem statement, research question/hypothesis, objectives, scope of work, and thesis structure.

Chapter 2 is the literature review that provided the background of the research on different topics related to the research. In this chapter it was highlighted about the information and the general characteristics of peat, the definitions that relates to the research topic, and the methodology/experiments involve in general.

Chapter 3 described about the overall experimental program including laboratory tests in detail. The research methodology includes sampling of peat and laboratory soil tests performed to classify the soil and to determine the engineering properties of the peat. In this chapter also it was discussed about the detail set up and procedures of fiber content test, organic test, moisture content and linear shrinkage limit test.

Chapter 4 discussed about the results and analysis. Analysis of the data for determining the linear shrinkage limit, fiber content, moisture content, and organic content and discussion in detail was in this chapter.

Chapter 5 discussed about the conclusions and recommendations. It presented the summary and some major findings of this research and recommendations for future work on the topic related to the present study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction and Background

Peats are organic deposits made up of the partly decomposed remains of vegetation which have accumulated in waterlogged areas over for a long years (Celik & Canakci, 2014). Peats are generally partly decomposed biomass and they exhibit a huge range of degrees of decomposition (Tarmizi et al., 2013). Andriesse (1974) briefly summarizes the formation of peat as follows "During periods of low subsoil water, the formation of peat was a relatively short biochemical process carried on under the influence of aerobic in the surface layers of the deposits" (Tarmizi et al., 2013). As we know, peat were formed by limited decomposition and hence the accumulation of organic soil materials, which may consist of undecomposed, partially decomposed and highly decomposed plant remains (Tarmizi et al., 2013). Based on figure 2.1, tropical lowland peats usually contain undecomposed and partly decomposed branches, logs, and twigs (Tarmizi et al., 2013).

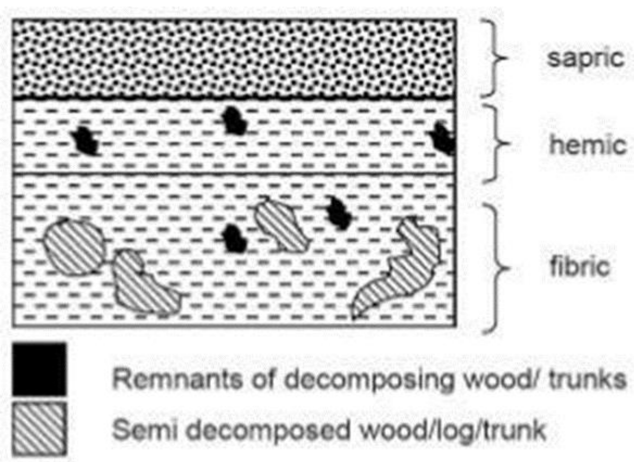

Figure 2.1 Morphology profile of drained peat soil
Source : Muttalib et al. 1991

2.2 Peat Soil

2.2.1 Distribution of Peat

Peat was found throughout the world except in the deserts and the arctic regions (Celik & Canakci, 2014). The most extensive areas are located in the northern hemisphere. The total area of tropical peat in the world is about 30 million ha (Celik & Canakci, 2014). On Earth, 70% is covered with sea water while the remaining 30% is covered by land. According to Mesri and Ajlouni (2007), peat occupy approximately 5% to 8% of land surface of earth.

A summary of peatland area distribution around the world is shown in Table 2.1 (refer Appendix A). Based on Figure 2.2, Malaysia had around 3 million hectares or approximate 8% of the land is covered with peats. In state of Sarawak, 1.66 million of the land is covered with peat soil (Huat, Prasad, Asadi, & Kazemian, 2014). Consequence of population and economic growth, land use activities perceived increased intensely (Khaidir & Abu, 2016). As a result, suitable land for infrastructure development has decreased and become a problem in the future. Therefore, it was inevitable to construct on less favourable soils, like peat.

Figure 2.2 Peat locations in Malaysia
Source : Huat, Kazemian, Prasad, & Barghchi, 2011b

2.2.2 Classification of Peat

Peat was classified into two categories such as amorphous and fibrous peat. Peat with fiber content of less than 20% is classified as amorphous peat. While fibrous peat is defined as an organic soil that consists of more than 20 % (ASTM D4427, 1990). The behaviour of fibrous peat is different from mineral soil because of different phase properties and microstructure (Celik & Canakci, 2014). Duraisamy et al. (2007) reported that tropical fabric causes highest settlement and follow by hemic and sapric when subjected to load and over time period.

The peat soil was classified by some methods such as Radforth system, ASTM and Von Post Scale. The Radforth classification system is based on virtual identification of texture and botanical composition as shown in Table 2.2 (refer Appendix B). According to American Society of Testings and Materials (ASTM), the peat can be classified based on few criteria such as the fiber content (ASTM, 2013), ash content (ASTM, 2014), pH value (ASTM, 1998) and absorbency (ASTM, 2000) of the peat soil. The classification of peat soil according to ASTM is shown in Table 2.3 (refer Appendix B).

The common method in classifying the peat soil was the Von Post Scale as shown in Table 2.4 (refer Appendix B). In this classification system, the peat soil was classified according to the degree of humification (decomposition), botanical composition, water content, content of fine and coarse fibres and woody remnants. There was 10 degrees of humification (H1 to H10, with H1 being the least and H10 being the most decomposed) and the moisture regime of each peat sample is estimated using the above scale of 1 – 5 in the von post classification system that were determined based on the appearance of peat water that was extruded when the soil is squeezed in the hand.

2.2.3 Physical and Chemical Properties

Density

The bulk density (unit weight) of peat soil was both low and variable compare to mineral soils. The average bulk density of fibrous peat was around the unit weight of water (9.81 kN/m^3). Huat (2004) found that a range of 8.3 to 11.5 kN/m^3 was common for unit weight of fibrous peat in Peninsular Malaysia. When the water content increase, the unit weight were showed a sharp reduction, water content about 500%, the unit weight ranges from 10 to 13kN/m^3. Fibrous peat also had very low specific gravity of solids values, mainly attributable to cellulose and lignin which were the principal constituents of the organic matter. Low specific gravity of solids values were reflected in very low values of bulk density, typically between 9.5 and 11.5 kN/m^3 (Kelly, 2013).

Specific Gravity

Specific gravity of peat was affected by its composition and percentage of inorganic component. It was related to the degree of decomposition and mineral content of peat. Higher specific gravity showed that higher degree of decomposition and higher mineral content. The specific gravity of the East Malaysia peat is 1.1 – 1.6 (Huat, 2002; Chan, 2009; Tang, 2009). The specific gravity of peat which was an organic content greater than 75% has range between 1.3 and 1.8 with average 1.5 (Yulindasari, 2006). The specific gravity of peat ranges between 1.3 and 1.8 with average of 1.5 (Davis, 1997). If the specific gravity was lower, its show that it has lower degree of decomposition and low mineral content. Specific gravity of peat was greatly affected by its composition and percentage of the inorganic component (Nursyahidah binti Saedon, 2016).

pH Value

Peat usually were very acidic and low pH values, which was in range 4 and 7 (Yulindasari, 2006). In Peninsular Malaysia, peat was known to have very lower pH value ranging from 3.0 to 4.5, the acidity tends to decrease with depth, and the decrease may be large near the bottom layer depending on type of underlying soil (Yulindasari, 2006).

Water Content

Water content was one of the important properties of peat. It was depends on the origin, degree of decomposition and the chemical composition of peat. Basically, peat soil had very high natural water content due to its natural water-holding capacity (Huat, Kazemian, Prasad, & Barghchi, 2011a). The soil structure characterized by organic coarse particles which can hold a considerable amount of water had high natural water holding capacity since the soil fibers were very loose and hollow (Huat et al., 2011a). Based on Huat, (2004), The water content of peat researched in West Malaysia ranges from 200 to 700%. From the Table 4.3 (refer Appendix E), Duraisamy et, al (2007). showed the result of water content of the peat soil is 140-350%. High water content was because it has low bulk density and low bearing capacity as result of high buoyancy and high pore volume. Peat soil has high in moisture content which was may up to 1000% (Johari, Bakar, & Aziz, 2016). Naturally, peat had very high natural water content due to its natural water-holding capacity (Huat et al., 2011).

From the water content test, we got the result of water content about 220%. We can concluded that water content can also be influenced by the high cation exchange ability of the peat forming plants (particularly in the case of Sphagnum mosses), which governs the thickness and rigidity of the adsorbed water layer (Hobbs, 1986). This produces stronger adsorption complex and greater inter-particle adherence, which contributes to higher values of water content and also of liquid limit for fibrous peat (Hobbs, 1986; Huang et al., 2009; Huat et al., 2011).

Organic Content

Soils with high organic contents were generally highly compressible, with high rates of creep and, occasionally, unsatisfactory strength characteristics that increase the threat of unacceptable settlement and eventual failure as a foundation bearing material (Raghunandan & Sriraam, 2017). Based on Sina Kazemian and Bujang B. K. Huat (2009), all soils with organic content of greater that 20% was known as organic soil. Peat soil was an organic soil with organic content in the range of 50 to 95% (Huat et al., 2004). The organic content of the East Malaysia peat was 76% - 98% (Huat, 2002; Chan, 2009; Tang, 2009). Physical characteristic like high moisture content and organic content of more than 75% cause stability problem (Jarret, 1997).

According to BS 1377: Part 3: 1990, the organic content were determine the mass loss on ignition (Nursyahidah binti Saedon, 2016). Plant vegetation was broken down by microorganisms which use the decaying organic matter as both an energy source and building material. The process was one of biochemical oxidation since the end products of decomposition are generally carbon dioxide and water (Hobbs, 1986). The destruction of the plant remains and ensuing reductions in organic and fibre contents brought about by the decomposition process have a significant effect on the compressibility characteristics of peat (Wardwell et al., 1983; Farrell, 2012).

Figure 2.3 Furnace used in the organic content test

Fiber Content

Based on N.N. Johari, I. Bakar, and M. H. A. Aziz (2016), peat soil had high fiber content which poses serious settlement issue. The types of peat can be recognized from the Von Post classification system (H1 – H10) and the fiber content in the soil composition. ASTM standards has defined the organic soil that has organic content more than 75% is classified as peat and the type of peat can be recognized by the fiber content; fibric peat has more than 67% of fibers (less decomposed), hemic with 33% to 67% (moderately decomposed) and lastly was sapric with 33% of fiber content which highly decomposed.

Fibre of peat sample gives huge factors of the effect to the volume changes and shrinkage measurement (Nursyahidah binti Saedon, 2016). Depending on botanical composition and degree of decomposition, the main constituents were coarse fibres derived from plant stems and roots greater than 1 mm in diameter; fine fibres from plant leaves, stems and roots smaller than 1 mm in diameter and amorphous (structure-less) matter having a granular appearance (Hobbs, 1986).

Linear Shrinkage Limit

Linear Shrinkage test was mainly used for characteristics of soil resulting from shrinkage. Such characteristics were crucial in estimating the shrink/swell behaviour of the soil and also proper designing of building and other construction structures. The linear shrinkage value was considered a more reliable indicator of the 'Plastic behaviour' of soil than the 'Plasticity Index' for soil specimen with very low plasticity (Labs, 2017).

Linear shrinkage test conducted using standard linear shrinkage moulds of 140mm length in accordance to BS 1377: 1990 (Test 5). The test aimed to examine the reduction in linear shrinkage of stabilized peat in comparison to that untreated peat (Nur et al., 2017). Peat will extremely shrink when dried. It can shrink until reach 50% of the initial volume, but dried peat were swell up upon re-saturation because dried peat cannot absorb as maximum as initial condition, only 33% to 55% of the water can be reabsorbed (Yulindasari, 2006). The soil sample used for the test consists of particles less than or equal to 425µm by passing through sieve. Fibrous peat typically has a very high shrinkage capacity, reducing in volume by up to 50% on air drying (Huat et al., 2011).

The shrinkage potential in the vertical and horizontal directions is different since the plant structures tend to shrink more across the fibres than along their length (Hobbs, 1986), with the fibres often orientated in a general horizontal alignment in-situ

(Yamaguchi et al, 1985; Zhang and O'Kelly, 2013). Shrinkage of the thin-walled tissues and collapse of the cellular structure produces a reduction in the water holding capacity and particle porosity (Wong et al., 2008).

2.3 Bottom Ash

Coal bottom ash was usually a well-graded material and its particle size distribution was similar to that of river sand (Singh & Siddique, 2016). It had interlocking characteristics. It was lighter and more brittle as compared to natural river sand. It had low specific gravity had a porous texture that readily degrades under loading or compaction. Bottom ash composition reported in the literature usually contains 5-13% ferrous metals, 2-5% NFe metals, 15-30% glass and ceramics, 1-5% unburned organics, and 50-70% mineral fraction (Šyc et al., 2018). Previous researchers who made up with quite reassuring results when bottom ash was used partially or totally replacing sand in concrete because of its fine aggregate quality (Rafieizonooz, Mirza, Razman, Warid, & Khankhaje, 2016).

Based on Rafieizonooz et. al., 2016, coal bottom ash shows low density, high water absorption, irregular and spherical shaped and complicated texture typically high or It was divided into two major categories which was elastic/immediate and consolidation settlement of foundation take place during or immediate after the construction of the structure. Consolidation settlement occurs over time. Pore water was extruded from the void spaces of saturated clayey soils submerged in water. The total settlement of a foundation was the sum of elastic settlement and the consolidation settlement.

2.4 Experiments

Several test methods have been used to study the engineering properties and to achieve the objective by using different proportion of the bottom ash to mix with the peat soil. Specific gravity test, permeability test, moisture content test, atterbeg test, fiber content test and organic content test has been done. It was to achieved the objection of this research such as to determine the relationship between linear shrinkage limit and moisture content, to determine the relationship between linear shrinkage and fibre content with organic content in peat before and after the stabilization and also to measure the effects of linear shrinkage limit in reducing settlement before and after stabilization.

2.5 Sampling of Peat

There are two types of sample which was undisturbed and disturbed samples. It was quiet impossible to obtain undisturbed samples of any types of soil such as peat. A lot of difficulties related to the nature of the fibre. Sampling methods vary with the peat structure, moisture content, and the expected use the samples. Besides, disturbance can be minimized using certain sampling techniques. Therefore, there were a clear understanding of the causes of disturbance during sampling, handling of the samples, and transport.

2.6 Settlement Parameters of Peat

The settlement parameters of peat were determined by the compression parameters. The compression parameters that we used to determine the settlement which are compression index (C_c) and coefficient of secondary compression (Cα). This was because as we can saw from the equation 2.1 and equation 2.2. Its showed that the compression parameters were the function of settlement. When the compression index decrease, the settlement has highly potential to decrease.

Equation of compression index, C_c

$$\delta c = \frac{C_C}{1+e_0} H log(\frac{\sigma_{zf}}{\sigma_{z0}}) \quad 2.1$$

Where, δ_c was the settlement due to consolidation.,

C_c was the compression index,

e_0 was the initial void ratio, H was the height of the compressible soil,

σ_{zf} was the final vertical stress, σ_{z0} was the initial vertical stress.

Equation of Coefficient of Secondary Compression, Cα

$$\delta s = \frac{H_0}{1+e_0} C\alpha \, log(\frac{t}{t_{95}}) \qquad 2.2$$

Where, H_0 was the height of the consolidating medium,

e_0 was the initial void ratio,

Cα was the secondary compression index,

t was the length of time after consolidation considered,

t_{95} was the length of time for achieving 95% consolidation

2.7 Compression Index, c_c and Void Ratio, e

Based on Farrell et al. (1994), he was considered the empirical relationship between the compression index and the liquid limit suggest by Skempton for organic soils (equation 2.3) gives a reasonable approximation of this parameter.

$$c_c = 0.009 \, (LL - 10) \qquad 2.3$$

Based on Hobbs (1986), he estimated the compression index of temperate (fen) peat was about (equation 2.4), which give a bit lower value of c_c.

$$c_c = 0.007 \, (LL - 10) \qquad 2.4$$

Therefore, the average value of c_c of tropical peat however were a little higher than the above two relationships. The range for the value of $c_c$could be in range 5 to 10 compared with that clay of only 0.20 to 0.8.

Based on Azzouz et al, (1976) the following relationship for organic soil and peat,

$$c_c = 0.0115w \quad 2.5$$

Where, w is soil natural content in percentage.

Based on Al-Raziqi et al. (2003), the general trend for the graph void ratio against liquid limit was that the void ratio increase with increase in liquid limit. The void ratio of peat ranges between 9 for amorphous peat up to 25 for fibrous peat. For comparison, Malaysia marine clay for instance has an initial void ratio in the range of 1.5 to 2.5. The natural void ratios of peat indicate their higher capacity for compression. By referring the graph of initial void ratio and natural water content for Dutch peat. The best-fit line in the figure is express by:

$$e_0 = 30.65[\frac{w_0+0.88}{1.12}] - 30 \quad 2.6$$

In the case with liquid limit, void ratio increase with an increase in natural water content.

Based on Hobbs (1986), the trend of relationship between settlement parameters, Cc /(1+e_0) increase with the increase in natural water content.

Bulk density and void ratio may also be influenced by the presence of internal gases generated by the decomposition process, occurring either as free gas in the macropores or entrapped gas in micropores. These gases generate a buoyancy effect for submerged peat material (Huang et al., 2009)

The extreme compressibility of fibrous peat was strongly linked to its very high void ratio, typically ranging between 7.5 and 30, which had been mainly attributed to its comparatively large and highly porous particles (Mesri and Ajlouni, 2007; Huat et al., 2011; Farrell, 2012). This influences the permeability and sequential expulsion of water from macro- and micro-pores, which govern the rates of primary consolidation and creep settlements (Huat et al., 2011)

2.8 Coefficient of Secondary Compression, Cα

Peat and organic soils of high water, organic and fiber content tend to show rapid primary compression/consolidation (a few minutes in the laboratory) under the applied stress followed with significant secondary compression that continues for long time (well beyond 24 hours in the laboratory) (Huat, 2004). Thus, secondary compression was severe in such materials and cannot be ignored as had often been done when dealing with more firm inorganic soils (Edil, 1997).

Based on Sina Kazemian (2009), peat deposits were more significant with secondary compression and associated settlement compare to others materials. Primary consolidation and secondary compressions can took place simultaneously but it was assumed that the secondary compression was negligible during primary consolidation and was identified after primary consolidation was finished.

Based on Huat (2004), secondary compression or creep, as defined for one-dimensional compression of soils, a continuing volumetric compression under constant vertical effective stress. This time-dependent component of total settlement was typically taken occur after essential all of the excess pore pressure has dissipated, that was stage, which was considered to come after consolidation has ended. The associated settlement was called secondary compression or creep.

Based on Farrell et al. (1994), the following relationship between the laboratory determined coefficient of secondary consolidation Cα and initial water content up to water content, W_o 250% was generally close to empirical relationship,

$$C\alpha = 0.00018\ W_o \qquad 2.7$$

Where, W_o is water content.

Based on O'Loughlin and Lehane (2003) found that Cα increases with increasing organic content. Evidently, Cα also depends on W_o and consequently e_o.

2.9 Summary of Literature Review

Peat was an accumulation of partially decomposed and disintegrated plant remains under conditions of incomplete aeration and high water content (Kalantari & Prasad, 2014). Peat had some unique physical and chemical characteristic properties such as high moisture content. This high water content was the cause of buoyancy and high pore volume that results in low bulk density and low bearing capacity. Most of peat was reported to had an ash content of less than 10% which was showing a very high content of organic matter. Besides, the peat soils were acidic and the pH values are between 3.0 to 4.5. The peat commonly known had high holding capacity and varying degrees of decomposition. The electrical conductivity for peat soil was also low.

The behaviour and characteristic of peat like high compressibility and water holding capacity, very high void ratio, and low specific gravity lead to a serious problem in construction industry due to its long term consolidation settlement. When soil was loaded, it will undergo an elastic and plastic deformation which is resulted from reduction in the volume of void or decrease in void ratio. The term settlement was referring to the vertical displacement of the oil surface corresponding to the volume change at any stages of the process. Hence, in its natural state, peat was considered as not suitable to support the structure. The experimental work were carried out, the sample that were taken from area of Pekan, Pahang. This study consist of preparation of sample, determination of organic content, fiber content, specific gravity, liquid limit, shrinkage limit, moisture content, pH value test. Every preparation of soil sample and the method used in conducting this test was carried out using the procedures described in British Standard.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The research was conducted in 2 stages. First, the physical and engineering properties of the peat soil sample were tested in order to classify and identify the behaviour of the peat soil such as sieve analysis, specific gravity test, permeability test, Atterberg's limit test and repose angle test. At the same time, the properties of the peat soil were tested and identified.

The physical properties of peat were conducted along with Bottom Ash. The peat soil was mixed with different amount of Bottom Ash. Ordinary Portland Cement (OPC) acted as a binder material. The objective of this research were achieved when the sample undergo three test such as linear shrinkage limit test, fiber content and organic content.

3.2 Sampling

3.2.1 Location of Sampling

Undisturbed samples of peat soil were taken from one locations on the east coast of Peninsular Malaysia which was at the Pekan, Pahang. The coordinate of the location was 3.678007 N 103.290031 E. The research were carried out in Soil and Geotechnical laboratory, Universiti Malaysia Pahang, Gambang Campus.

Figure 3.1 Sampling location

3.2.2 Sampling Collection and Preservation

The samples were taken using a digger at the depth of 0.5m and being placed in a storage box. The distance from UMP Gambang to the locations was around 30.4 km. In-situ measurement of water content was not possible. Thus, sufficient cared was taken during the sampling of the peat in order to maintain the natural water content.

Figure 3.2 Peat storage box

3.3 Determination of Engineering Properties

The determination of engineering properties of peat soil such as natural moisture content, specific gravity and pH value were determined to establish the basic characteristics of the soil. The soil was classified based on von Post or degree of humification, fiber content, organic content, and ash content. We squeezed and scrubbed it using our hand to determine the decomposition of the peat and type of the peat. All tests were performed in accordance with the British (BS) and U.S. (ASTM) Standards as shown in Table 3.1 (refer Appendix D).

3.3.1 Determination of Specific Gravity

The specific gravity was determined using the density bottle method according to the procedures described in BS1377: 1975. The objective of this test was to determine specific gravity of soils consisting of clay, silt, and sand-sized particles. For this test, distilled water normally used as density bottle fluid, but if the soil contains soluble salt, an alternative liquid should been used. The usual liquid was kerosene (paraffin) or alternatively white spirit. The specific gravity of the liquid was measured separately.

Procedure

1. The density bottle with the stopper was prepared.
2. The soil sample was prepared.
3. The dry sample in bottle was weighted and recorded.
4. Kerosene was added and applied vacuum.
5. Stirred and repeated until air is removed.
6. Top up, transferred to temperature bath.
7. Bottle + soil + liquid were weighted and recorded.
8. Bottle + liquid were weighted and recorded.
9. SG values were calculated.
10. Reported the result.

If the results differ by more than 0.03 Mg/m^3, repeat the test.

The calculation of specific gravity will be as follow:

$$G_S = \frac{M_O}{M_O + (M_A - M_{B)}} \qquad 3.1$$

Where: M_O = Sample of oven-dry soil was weighted in g

M_A = Density bottle filled with water was weighted in g

M_B = Density bottle filled with water and soil was weighted in g

G_S = Specific Gravity

3.3.2 Determination of Water Content

The water content of peat samples was determined by referring the ASTM D2216. For peat and soils containing organic matter a drying temperature of 60ºC was been preferred to prevent oxidation of organic content.

Procedure

1. Weight container.
2. Select soil sample.
3. Dry sample in oven.
4. Cool in desiccator.
5. Weight dried sample.
6. Calculate
7. Report

Based on this method, the water content, w was expressed as percentage of its dry soil and been calculated from the question 3.2.

$$w\ (\%) = \frac{M_S}{M_D} \text{ X } 100\% \quad 3.2$$

Where, w = water content or moisture content (%)

M_S = measured mass of moisture soil (g)

M_D = measured mass of dried soil (g)

3.3.3 Determination of Linear Shrinkage Limit

Linear shrinkage was the ratio in length of a soil sample when oven-dried, starting with a moisture content of the sample at the liquid limit over the initial length of soil.

Procedure

1. The wet soil was placed in the mould carefully to remove all air bubbles from each layer by lightly tapping the base of the mould. Slightly overfilled the mould and then levelled off the excess material with the spatula. All soil adhering was removed to the rim of the mould.
2. The initial length of the peat soil was measured.

3. The specimen was allowed to dry at room temperature for about 24 hours until a distinct change in colour been noticed. It was transferred into an oven and dry at between 105 °C and 110 °C.
4. The specimen was allowed to cool and then measured its dried length, L_d to the nearest millimetre. If the specimen cracks into pieces, firmly hold the separate parts together and measured the dried length. If the specimen curls in the mould carefully removed it and measured the length of the top and bottom surfaces.

The percentage of linear shrinkage (LS) of the specimen.

$$LS\ (\%) = \left(1 - \frac{Ld}{Lo}\right) X\ 100 \qquad 3.3$$

Where:

L_d = Length of the dry specimen was measured (mm)

L_o = Initial length of the specimen was measured (mm)

LS = Linear shrinkage

Figure 3.3 Shrinkage limit test

3.3.4 Determination of Fiber Content

Fiber matter influenced many of properties such as physical, chemical and biological properties of soils. Besides, it also affected the soil structure, shear strength and soil compressibility. ASTM D1997 standard procedure had been followed in order to determined fiber content of peat sample. The dry peat sample was sieve through 425µm sieve and the soil retained on the sieve is fiber content of peat sample which is expressed as percentages.

$$Fc = \frac{Mfibre}{Msample} x\ 100\% \qquad 3.4$$

Procedure

1. 100g of peat soil had been saturated approximately, Msample of known volume for 24 hours in a sodium hexametaphosphate to loosen the soil fibre before wet sieving began.
2. The sample was placed on number 100 sieve (125µm) and gently washed distilled water through the sieve to expel any fine particulates until the water exiting the sieve was clear.
3. The remaining particles larger than 125µm had been oven dried at 103ºC until a constant mass, mass of fiber, Mfibrer eached.

Figure 3.4 Moisture content tests

3.3.5 Determination of Organic Content

Organic matter influenced some of properties such as soil structure, soil compressibility and shear strength. Besides, it also affected the water holding capacity, nutrient contributions, biological activity and water and air infiltration rates. The organic content experiment referred the ASTM D 2974 – Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Organic Soils.

The determination of organic content was carried out by using the equation 3.5.

$$\text{OC} = \frac{\text{mass or organic content}}{\text{mass of dry soil}} \text{ x } 100\% \qquad 3.5$$

Where, OC = Organic Content (%)

Procedure

1. The mass of an empty, clean and dry porcelain dish had been recorded.
2. The entire oven-dried test specimen from the moisture content experiment in the porcelain dish has been placed and recorded the mass of the dish and soil specimen.
3. The dish was placed in a muffle furnace. The temperature was gradually increased to the 440°C and leaved in the furnace overnight.
4. The porcelain dish been removed carefully using tongs and allowed it to cool at room temperature.
5. The mass of the dish containing the ash had been determined and recorded.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the result of engineering properties of peat from laboratory test was presented. The result and analysis will answer the objective of the study as stated in Chapter 1.

One of the objective of the study was to determine the relationship of the linear shrinkage limit and moisture content of the peat before and after stabilization. In order to achieve the objective, linear shrinkage limit test and moisture content test has been done in the Soil Mechanics and Geotechnics Laboratory. The result from this test was compared with the published data from previous researcher.

Another objective of this study was to determine the relationship between linear shrinkage limit and the fiber content with the organic content in peat soil before and after stabilization. To achieve this objective, fiber content test and organic content test has been conducted to relate with the result of the linear shrinkage limit prior to this test. The result from the test was compared with other data from others researcher.

The last objective of this study is to measure the effects of linear shrinkage limit in reducing settlement before and after stabilization. To achieve this objective, the settlement of each sample from different proportion of bottom ash has to be found in order to measured the effects.

4.2 Soil Classification

From the test based on ASTM Standard for Fiber Content (D1997), the natural peat was classified as Hemic because it had 36.64% of fiber content.

Based on Van Post Scale, it was identified that the natural peat soil can be classified as H_6. Moderate highly decomposed peat with a very indistinct plant structure. When squeezed, about one-third of the peat escaped between the fingers. The residue was very pasty but show the plant structure more distinctly than before squeezed.

Based on Radforth's system, this peat was classified in fine fibrous peat in category 11(woody and non-woody particles held in fine-fibrous peat).

Figure 4.1 Van Post Scale test

4.3 Index and Engineering Properties

4.3.1 pH value

Based on Yulindasari (2006), peat is usually very acidic and low pH values, which is in range 4 and 7. In Peninsular Malaysia, peat was known to have very lower pH value ranging from 3.0 to 4.5, the acidity tends to decrease with depth, and the decrease may be large near the bottom layer depending on type of underlying soil. For this research, the pH value of peat soil was 3.56.

4.3.2 Specific Gravity

The composition and percentage of organic content was the main factor affecting the specific gravity. Lower the specific gravity of peat, lower the degree of decomposition and organic content. Based on Davis (1997), an organic content higher than 75%, the specific gravity was in range of 1.3 to 1.8 with average of 1.5. For this study, the specific gravity was 1.44 which in the range of previous researcher. From the Table 4.2 (refer Appendix E), Hashim, R. et, al. (2008) showed the result of specific gravity was in range of 0.95-0.1.34, while Duraisamy et, al. (2007) showed the result of specific gravity was in range 1.07-1.70. It can be concluded that when the specific gravity was lower, it showed that it had lower degree of decomposition and low mineral content.

4.3.3 Water Content

Peat usually has very high natural water content due to its natural water holding capacity. The soil had high water content because it had low bulk density and low bearing capacity as a result of high pore volume and buoyancy. Based on Huat (2004), East Malaysia had water content usually in the range of 200 to 700%. Peat soil had high in moisture content which was may go up to 1000% (Johari, Bakar, & Aziz, 2016). For this study, water content was obtained to be 220% which was reasonable for peat. High water content was because it had low bulk density and low bearing capacity as result of high buoyancy and high pore volume.

4.3.4 Linear shrinkage limit

Based on Yulindasari (2006), peat extremely shrinks when dried. It can shrink until reach 50% of the initial volume, but dried peat will swell up upon re-saturation because dried peat cannot absorb as maximum as initial condition, only 33% to 55% of the water can be reabsorbed.

4.3.5 Fiber Content

The test result from laboratory test showed that peat sample had fiber content. The natural peat had fiber content of 36.64% and it was placed in hemic group. Based on Duraisamy et al. (2007), it was in the range of 31-77%. Based on ASTM standard (ASTM D1997), Pekan peat could be classified as fibric peat with fiber content was higher than 67%. The value of fiber content was higher than the result found by Hashim, R. et al. (2008) and Wong et al. (2008).

4.3.6 Organic Content

The result that obtained for the organic content test was 95.72% and it was reasonable to accept because it was in the range of the result from others data. From the Table 4.4 (refer Appendix E), the result of organic content of peat soil by Hashim, R. et, al. (2008) showed 96.45%, by Wong et, al. (2008) showed the result of organic content of peat soil about 96.00%, and Duraisamy et, al. (2007) showed the result of organic content of peat soil about 50-95%. This showed that the organic content of the East Malaysia peat was 76% - 98% (Huat, 2002; Chan, 2009; Tang, 2009).

4.4 Relationship between linear shrinkage limit and moisture content

The natural peat soil has high water content because it has low bulk density and low bearing capacity as a result of high buoyancy and high pore volume.

OPC was used as a binder between peat and bottom ash. It produced a reaction which is known as Pozzolanic reaction that influence the water content.

From the Figure 4.2 and Table 4.6 (refer Appendix F), the trend of water content in peat with difference amount of bottom ash was reducing. When the proportion of bottom ash increased, the moisture content was decreased.

From the Figure 4.3 and Table 4.7 (refer Appendix F), there is a linear relationship between the linear shrinkage limit and the water content. When the water content of peat soil reduces, the linear shrinkage limit reduces.

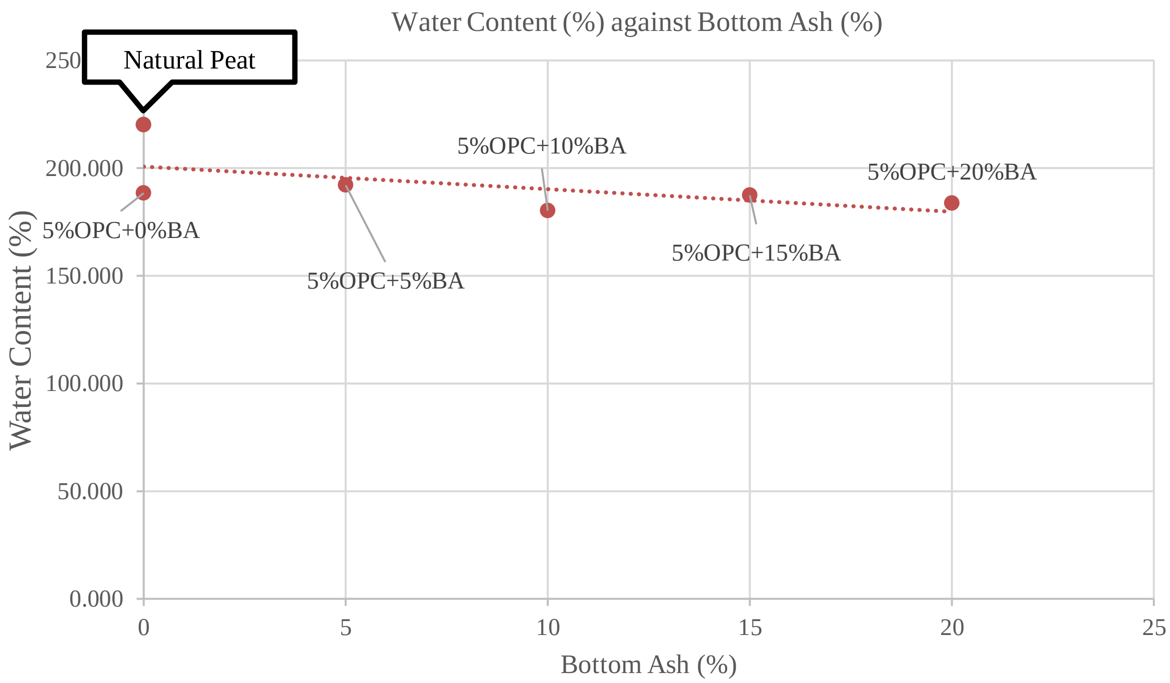

Figure 4.2 Water Content of (%) against Bottom Ash (%)

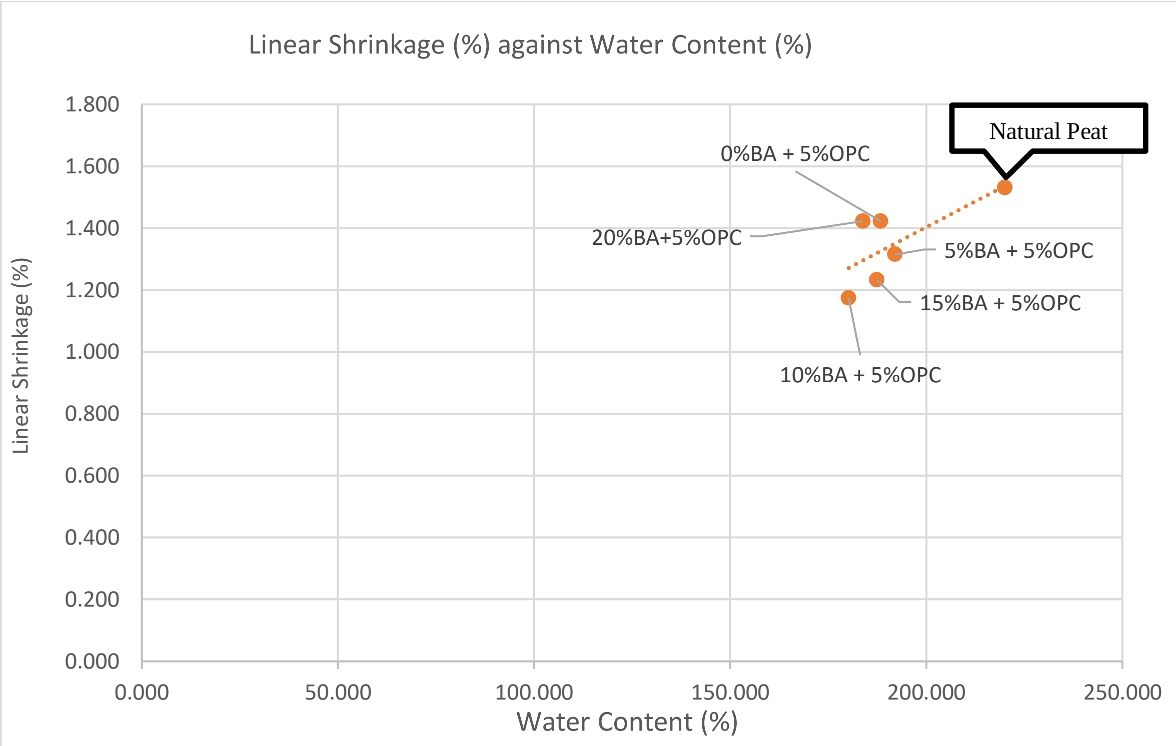

Figure 4.3 Linear Shrinkage (%) against Water Content (%)

4.5 Relationship between linear shrinkage limit and the fiber content with organic content

Based on the Figure 4.4 and Table 4.8 (refer Appendix F), there was an increasing trend in the graph of Fiber Content (%) against Bottom Ash (%). When the bottom ash added into the peat soil, the fiber content too increased.

This was due to the influence of the amount of bottom ash added into the peat soil and not because of the pozzolonic reaction. The increase is partly because of the method used in measuring the fiber content in this study.

Besides, from the Figure 4.5 and Table 4.9 (refer Appendix F), there was a linear relationship between the linear shrinkage limit and the fiber content. Fiber of peat sample gives huge impact on the effect of the volume changes and shrinkage measurement. When the fiber content increases, the linear shrinkage limit also decreases.

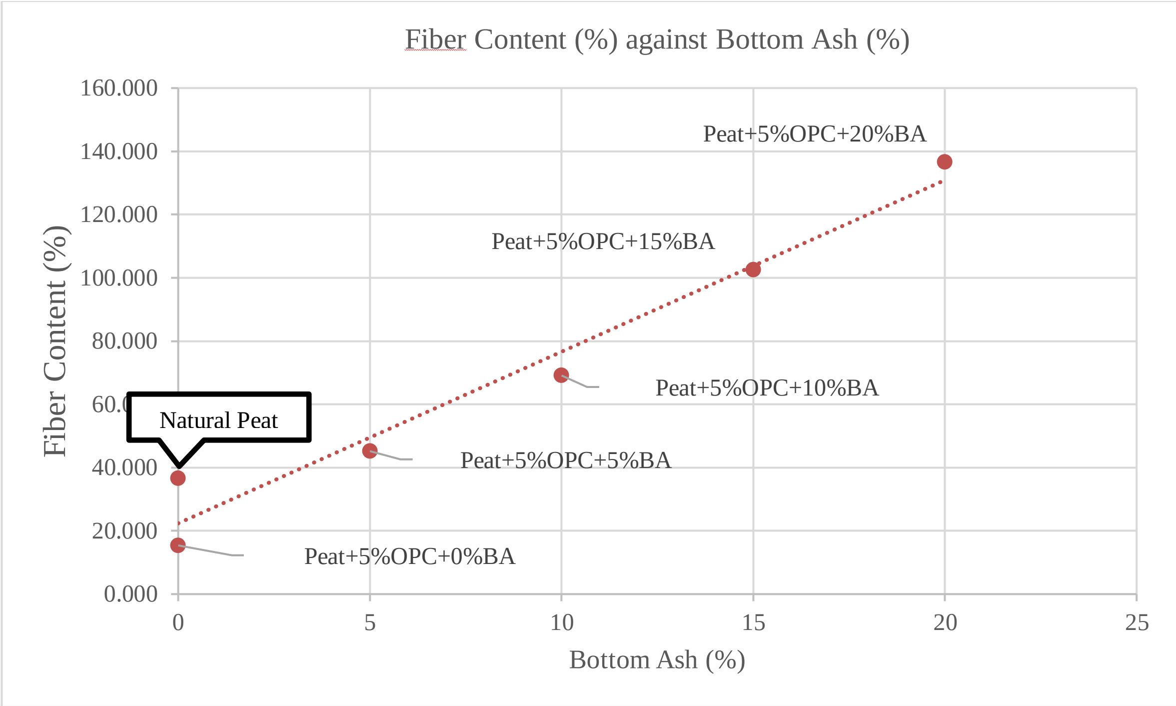

Figure 4.4 Fiber Content (%) against Bottom Ash (%)

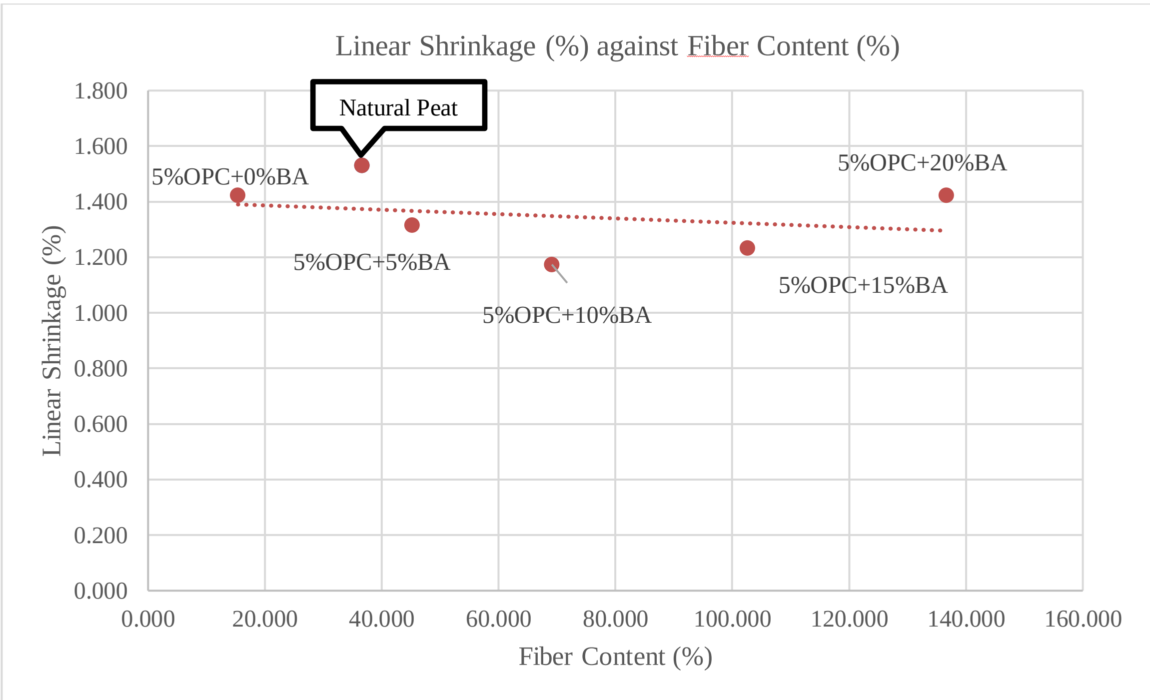

Figure 4.5 Linear Shrinkage (%) against Fiber Content (%)

From the Figure 4.6 and Table 4.10 (refer Appendix F), there was a decreasing trend for the graph of Organic Content (%) against Bottom Ash (%). When the proportion of bottom ash added into the peat soil increased, the organic content of the peat soil was decreased.

This happen because when there is a pozzolonic reaction between the bottom ash and the OPC. Hence some of the organic content was combusted in the chemical reaction that took place.

Besides, from the Figure 4.7 and Table 4.11 (refer Appendix F), the graph of the Linear Shrinkage Limit against the Organic Content shows decreasing trends. When the organic content was reducing, the linear shrinkage limit also was reducing.

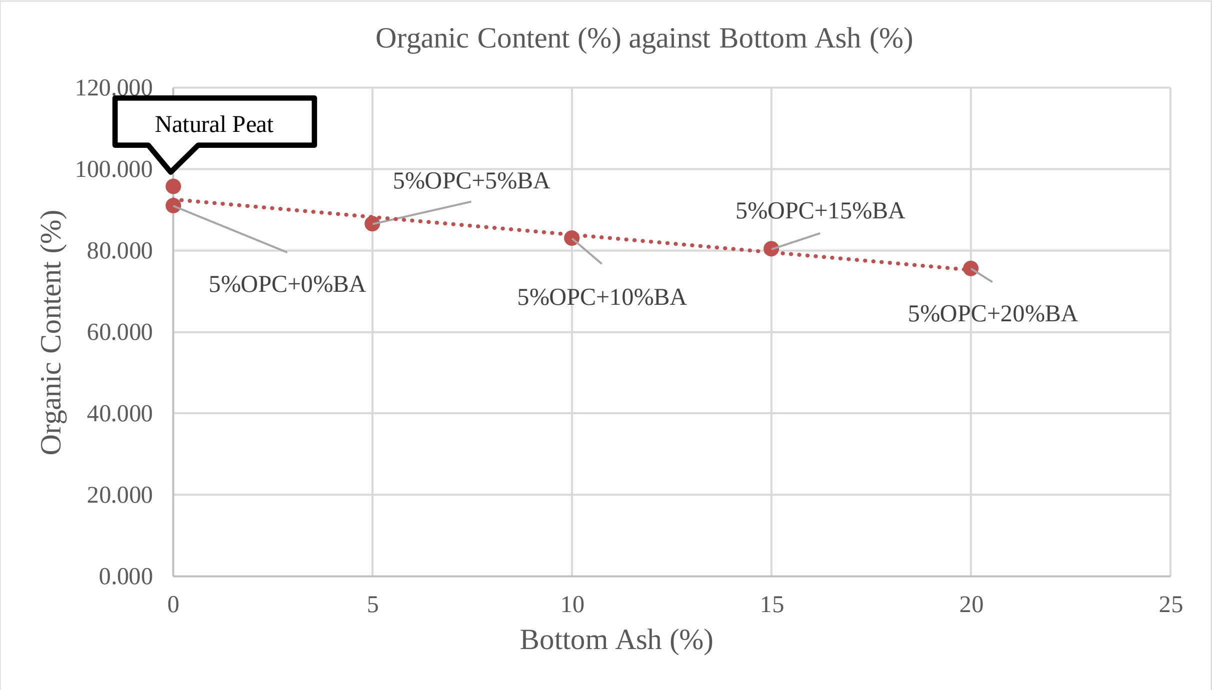

Figure 4.6 Organic Content (%) against Bottom Ash (%)

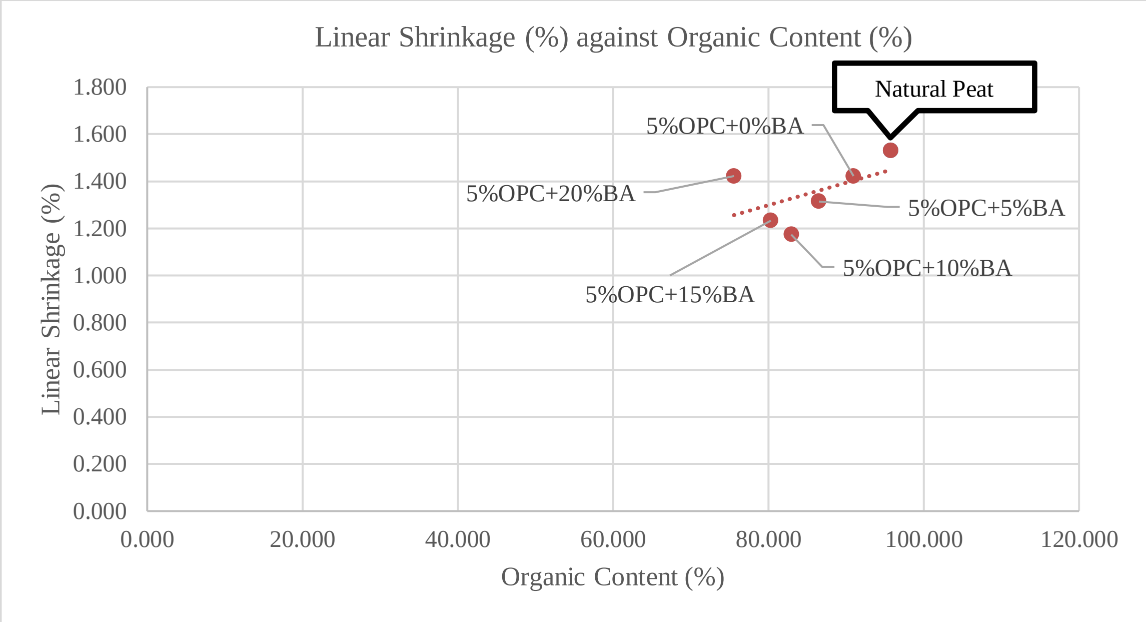

Figure 4.7 Linear Shrinkage (%) against Organic Content (%)

4.6 Effects of linear shrinkage limit in reducing settlement

4.6.1 Compression Index, C_c

From the Table 4.5 (refer Appendix F), when the proportion of bottom ash added into the peat soil increased, the linear shrinkage limit was decreased.

From the Table 4.14 (refer Appendix F) and Figure 4.9, when linear shrinkage limit decreased, the Compression Index (Cc) will also decreased.

We know from equation (4.1) below that the Compression Index (Cc) is a function of settlement therefore the settlement in peat soil is highly potentially to decrease.

$$\delta c = \frac{C_C}{1+e_0} H log(\frac{\sigma_{zf}}{\sigma_{z0}}) \quad 4.1$$

Where, δc is the settlement due to consolidation.

C_c is the compression index.

e_0 is the initial void ratio.

H is the height of the compressible soil.

σ_{zf} is the final vertical stress.

σ_{z0} is the initial vertical stress.

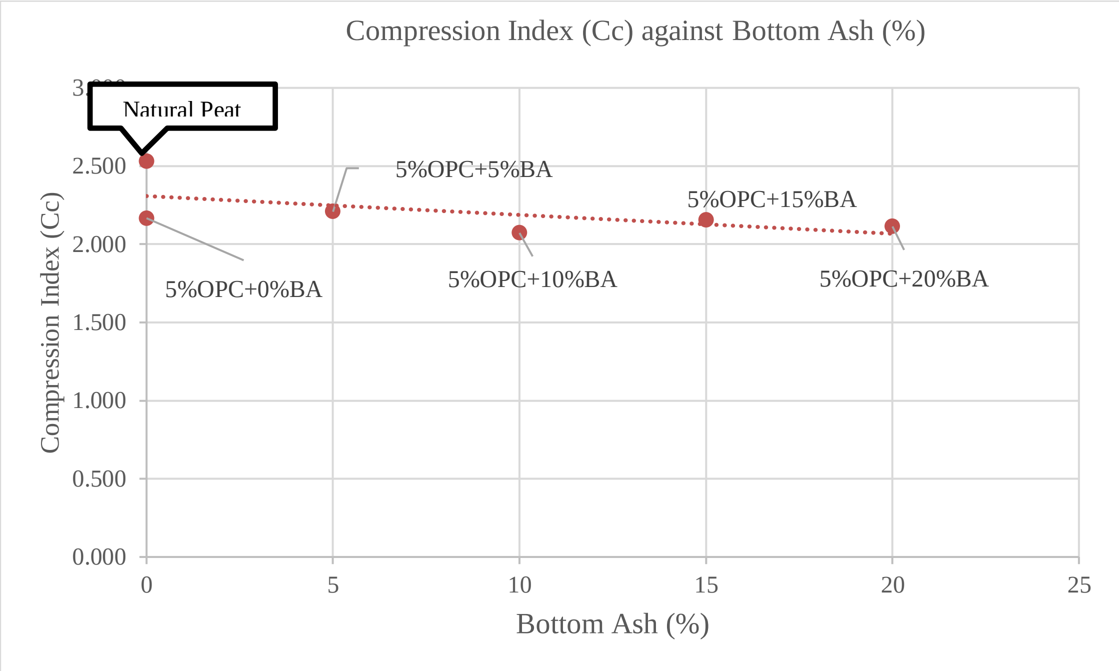

Figure 4.8 Compression Index (Cc) against Bottom Ash (%)

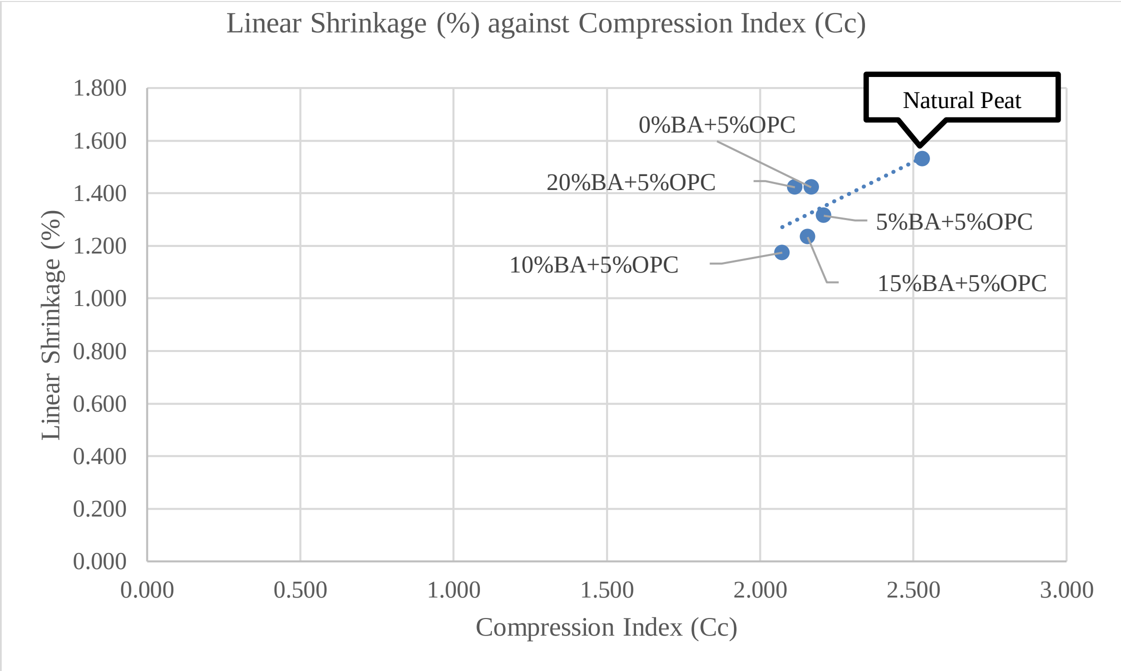

Figure 4.9 Linear Shrinkage (%) against Compression Index (Cc)

4.6.2 Coefficient of Secondary Compression, Cα

From the table 4.5 (refer Appendix F), when the proportion of bottom ash added into the peat soil increased, the linear shrinkage limit will decrease.

From the Figure 4.11 and Table 4.15 (refer Appendix F), when linear shrinkage limit decreased, the coefficient of secondary compression (Cα) will also decrease.

We know from equation (4.2) below that the coefficient of secondary compression (Cα) is a function of settlement, therefore the settlement in peat soil is highly potentially to decrease.

$$\delta s = \frac{H_0}{1+e_0} C\alpha \, log(\frac{t}{t_{95}}) \qquad 4.2$$

Where, H_0 is the height of the consolidating medium

e_0 is the initial void ratio

C_α is the secondary compression index

t is the length of time after consolidation considered

t_{95} is the length of time for achieving 95% consolidation

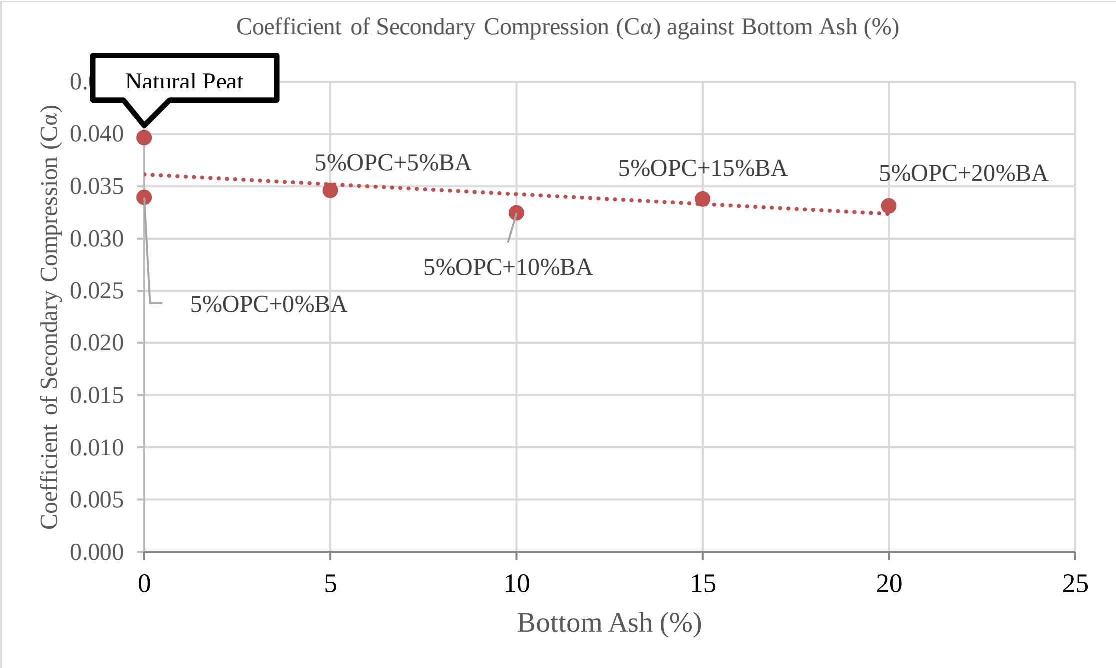

Figure 4.10 Coefficient of Secondary Compression (Cα) against Bottom Ash (%)

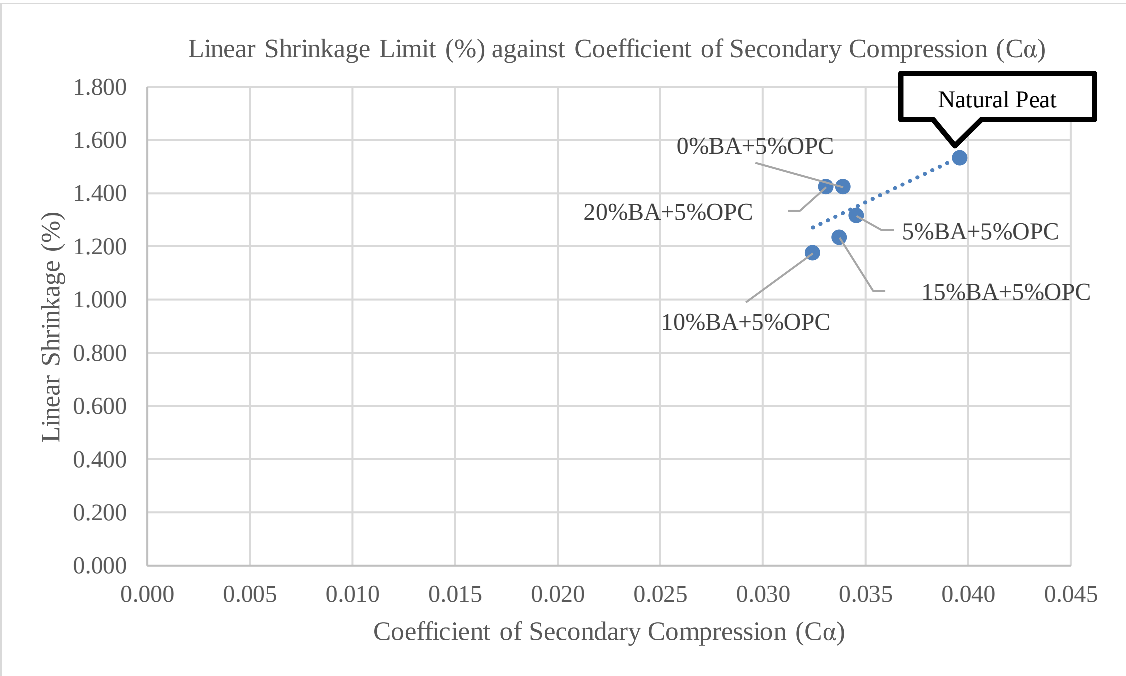

Figure 4.11 Linear Shrinkage Limit (%) against Coefficient of Secondary Compression (Cα)

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

There is a relationship between the linear shrinkage limit and the water content. When the proportion of bottom ash increased, the moisture content decreased. When the water content of peat soil reduce, the linear shrinkage limit was also reducing.

There is a relationship between the linear shrinkage limit and the fiber content. When the proportion of bottom ash added into the peat soil increased, the fiber content was increase. When the fiber content was increasing, the linear shrinkage limit was decreasing.

There is a relationship between the linear shrinkage limit and the organic content. When the proportion of bottom ash added into the peat soil increased, the organic content of the peat soil decreased. When the organic content was reducing, the linear shrinkage limit was also reducing.

There was the effects of linear shrinkage limit in reducing settlement before and after stabilization. Peat soil has a very high compressibility before treated with the bottom ash. When the proportion of bottom ash added to stabilized the peat soil increase, the shrinkage limit will decrease. When the linear shrinkage limit was decreased, the compression parameters will also decrease (C_c and C_α are the functions of settlement). When the compression index was decreased, the settlement also will be reducing.

As conclusion, Bottom Ash could be used as one of the stabilization agent in reducing the compressibility of the peat soil.

5.2 Recommendations

For the future research, I recommend that Oedometer or one dimensional consolidation test to be conducted so that the trends observed in this study can be validated. Next, for the future research, I also recommend that different parameter of the peat soil is investigated in order to improve other engineering properties of peat soil. Lastly, I recommend in the future research to relate the void ratio of peat soil with the settlement in order to validate the present data.

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APPENDIX A

PEATLAND AREA DISTRIBUTION

Table 2.1: Peatland area distribution around the world (after Mesri and Ajlouni,2007)

Country	*Peat land* (km^2)	*Percentage of land area*
Canada	1,500,000	18
USSR (former)	1,500,000	
USA	600,000	10
Indonesia	170,000	14
Finland	100,000	34
Sweden	70,000	20
China	42,000	
Norway	30,000	10
Malaysia	25,000	
Germany	16,000	
Brazil	15,000	
Ireland	14,000	17
Uganda	14,000	
Poland	13,000	
Falklands	12,000	
Chile	11,000	
Zambia	11,000	
26 other countries	220 to 10,000	
Scotland		10
15 other countries		1 to 9

APPENDIX B

CLASSIFICATION OF PEAT AND ORGANIC SOIL

Table 2.2: Classification of peat according to Radforth System

Predominant Characteristic	Category	Name
Amorphous-granular	1	Amorphous-granular peat
	2	Non-woody, fine-fibrous peat
	3	Amorphous-granular peat containing non-woody fine fibres
	4	Amorphous-granular peat containing woody fine fibres
	5	Peat, predominantly amorphous-granular, containing non-woody fine fibres, held in a woody, fine-fibrous frameworks
	6	Peat, predominantly amorphous-granular, containing woody fine fibres, held in a woody, coarse-fibrous frameworks
	7	Alternate layering of non-woody, fine fibrous peat and amorphous-granular peat containing non-woody fine fibres
Fine-fibrous	8	Non-woody, fine fibrous peat containing a mound of coarse fibres
	9	Woody, fine fibres peat held in a woody, coarse-fibrous frameworks
	10	Woody particles held in a non-woody, fine-fibrous peat
	11	Woody and non-woody particles held in fine-fibrous peat
Coarse-fibrous	12	Woody coarse-fibrous peat
	13	Coarse fibres criss-crossing fine fibrous peat
	14	Non-woody and woody fine-fibrous peat held in coarse-fibrous frameworks
	15	Woody mesh of fibres and particles enclosing amorphous-granular peat containing fine fibres
	16	Woody, coarse-fibrous peat containing scattered woody chunks
	17	Mesh of closely applied logs and roots enclosing woody coarse-fibrous peat with woody chunks

Table 2.3: Classification of Peat according ASTM

ASTM Standard	Criteria	Designation
Fiber Content (D 1997)	> 67% fibers	Fibric (H_1-H_3)
	33 - 67% fibers	Hemic (H_4-H_{10})
	< 33% fibers	Sapric (H_7-H_{10})
Ash Content (D 2974)	< 5% Ash	Low Ash
	5 - 15% Ash	Medium Ash
	15 - 25% Ash	High Ash
Acidity (D 2976)	pH < 4.5	Highly Acidic
	4.5 < pH < 5.5	Moderate Acidic
	5.5< pH < 7	Slightly Acidic
	pH > 7	Basic
Absorbency (D 2980)	w > 1500%	Extremely Absorbent
	800 < w < 1500%	Highly Absorbent
	300% < w < 800%	Moderate Absorbent
	w < 300%	Slightly Absorbent

Table 2.4: Classification of Peat according to Von Post Scale

Symbol	Description
H1	Completely undercomposed peat. When squeeze also release clear water. Plant remain easy to identifiable. No amorphous material present
H2	Almost entirely undecomposed peat which when squeeze release clear or yellowish water. Plant remain still easily identifiable. No amorphous material present
H3	Very slightly decomposed peat when squeezed it will release muddy brown water but from which when squeezed it will release muddy brown water but from which no peat is passes between the fingers. Plant still remain identifiable and no amorphous material present
H4	Slightly decomposed peat which when squeeze release muddy dark water. No peat is passes between fingers but the plant remain still slightly pasty and have lost some of their identifiable features
H5	Moderate decomposed peat. When squeeze release muddy water with a very small amount of amorphous granular peat escaping between the fingers. The residue is very pasty. The structure of the plant remains its quiet indistinct although it is still possible to recognize certain features.
H6	Moderate highly decomposed peat with a very indistinct plant structure. When squeeze, about one-third of the peat escape between the fingers. The residue is very pasty but show the plant structure more distinctly than before squeezing
H7	Highly decomposed peat. Contain a lot of amorphous material and very faintly recognizable plant structure. When squeeze, about one-half of the peat escape between the fingers. If water release, is dark and almost pasty
H8	Very highly decomposed peat with a large quantity of amorphous material and very indistinct plant structure. When squeeze, about two-third of the peat escape between the fingers. A small quantity of pasty water may release. The plant material remaining in the hand consist of residue such as roots and fibres that resist decomposition
H9	Practically fully decomposed peat in which there is hardly recognizable plant structure. When squeezed it is fairly uniform paste
H10	Completely decomposed peat with no discernible plant structure. When squeezed all the wet peat escapes between the fingers
B1	Dry peat
B2	Low
B3	Moderate
B4	High moisture content
B5	Very high moisture content

Note: The moisture regime of each peat sample is estimated using the above scale of 1-5 and symbol “B” (derive from Swedish blothet = wetness)

APPENDIX C

EXPANSION BASED ON LINEAR SHRINKAGE

Table 2.5: Category based on the linear shrinkage (Labs, 2017)

Category	Linear Shrinkage (% m/m)	Expansive Rating
Low	0-12	No-Critical
Medium	12-17	Marginal
High	17-22	Critical
Very High	More than 22	Very Critical

APPENDIX D

PROPERTIES AND TESTING METHODS

Table 3.1: Physical and chemical testing for peat

Properties	Code of Practices
Classification	BS 1377; ASTM D1997; USCS & Von Post Scale
Moisture Content (%)	BS 1377
Bulk Density (g/cm^3)	ASTM D2937-00
Atterberg Limit (%)	BS 1377
pH	BS 1377
Organic Content (%)	ASTM D2974
Fiber Content (%)	ASTM D1997
Permeability	ASTM D2434
Void ratio (initial), e_o	BS 1377
Compression Index, C_c	BS 1377
Recompression Index, C_r	BS 1377
Cohesion, C_u' (kPa)	BS 1377/ ASTM D4767
Friction angle, ϕ (degree)	BS 1377/ ASTM D4767
Optimum Moisture Content (%)	ASTM 1557
Maximum Dry Unit Weight (kN/m^3)	ASTM 1557
UCS-undisturbed (kPa)	ASTM D2166

APPENDIX E

COMPARISON OF RESULTS

Table 4.1 Result of natural peat soil properties

Properties	Value
Specific gravity	1.44
Density	1440kg/m³
Permeability	0.0014m/s
Plastic limit	52.64%
Shrinkage limit	7.99%
Liquid limit	220%
Plastic index	167.36%
Fiber content	36.64%
Natural Moisture content	884.78%
Organic content	81.78%
pH	3.56

Table 4.2 Comparison of results of specific gravity

Researcher	Specific Gravity
Present study	1.44
Hashim, R. et al. (2008)	0.95 – 1.34
Wong et al. (2008)	1.40
Duraisamy et al. (2008)	1.07 – 1.70

Table 4.3 Comparison of results of water content

Researcher	Water content (%)
Present study	220
Hashim, R. et al. (2008)	414 - 674
Wong et al. (2008)	668
Duraisamy et al. (2007)	140 – 350
Johari et al. (2016)	May up to 1000%

Table 4.4 Comparison of organic content results

Researcher	Organic content (%)
Present study	95.72
R. Hashim et al. (2008)	96.45
Wong et al. (2008)	96.00
Duraisamy et al. (2007)	50 - 95
Huat et al. (2002)	76 – 98

APPENDIX F

RESULTS OF PEAT SOIL WITH BOTTOM ASH

Table 4.5 Result of Linear shrinkage (%)

Specimen	Initial Length, Lo	Oven-dried Length, Ld	Linear Shrinkage (%)
Natural Peat	140.450	138.300	1.531
5%OPC+0%BA	140.600	138.600	1.422
5%OPC+5%BA	140.750	138.900	1.314
5%OPC+10%BA	139.700	138.060	1.174
5%OPC+15%BA	140.300	138.570	1.233
5%OPC+20%BA	140.600	138.600	1.422

Table 4.6 Result of Water content (%)

Specimen	Water Content (20mm penetration)
Natural Peat	220.000
5%OPC+0%BA	188.400
5%OPC+5%BA	192.000
5%OPC+10%BA	180.200
5%OPC+15%BA	187.420
5%OPC+20%BA	183.800

Table 4.7 Water content (%) against linear shrinkage (%)

Specimen	Water Content (20mm penetration),%	Linear Shrinkage (%)
Natural Peat	220.000	1.531
5%OPC+0%BA	188.400	1.422
5%OPC+5%BA	192.000	1.314
5%OPC+10%BA	180.200	1.174
5%OPC+15%BA	187.420	1.233
5%OPC+20%BA	183.800	1.422

Table 4.8 Result fiber content (%)

Specimen	mass of pan, g (m1)	mass of pan + sample passing, g (m2)	mass of 150µmm sieve, g (m3)	mass of 150µmm sieve + sample retained, g (m4)	m4 - m3	m2 - m1	Fiber Content (%)
Natural Peat	243.390	253.380	426.150	429.810	3.660	9.990	36.637
Peat+5%OPC+0%BA	367.220	384.180	421.120	423.730	2.610	16.960	15.389
Peat+5%OPC+5%BA	364.110	381.940	411.600	419.660	8.060	17.830	45.205
Peat+5%OPC+10%BA	367.220	385.580	421.120	433.810	12.690	18.360	69.118
Peat+5%OPC+15%BA	364.110	381.590	411.600	429.530	17.930	17.480	102.574
Peat+5%OPC+20%BA	243.810	261.800	425.740	450.320	24.580	17.990	136.631

Table 4.9 Linear Shrinkage (%) against Fiber Content (%)

Specimen	Linear Shrinkage (%)	Fiber Content (%)
Natural Peat	1.531	36.637
Peat+5%OPC+0%BA	1.422	15.389
Peat+5%OPC+5%BA	1.314	45.205
Peat+5%OPC+10%BA	1.174	69.118
Peat+5%OPC+15%BA	1.233	102.574
Peat+5%OPC+20%BA	1.422	136.631

Table 4.10 Result of Organic Content (%)

Specimen	Mcubical, g	Mbefore dry , g	Mbefore dry - Mcubical, g (m1)	Mafter dry, g	Mafter dry - Mcubical, g (m2)	m1 - m2	Organic Content (%)
Natural Peat	86.070	106.160	20.090	86.930	0.860	19.230	95.719
Peat+5%OPC+0%BA	96.210	117.900	21.690	98.170	1.960	19.730	90.964
Peat+5%OPC+5%BA	84.110	106.920	22.810	87.190	3.080	19.730	86.497
Peat+5%OPC+10%BA	73.320	97.060	23.740	77.370	4.050	19.690	82.940
Peat+5%OPC+15%BA	87.460	112.090	24.630	92.310	4.850	19.780	80.309
Peat+5%OPC+20%BA	77.720	103.380	25.660	83.990	6.270	19.390	75.565

Table 4.11 Linear Shrinkage (%) against Organic Content (%)

Specimen	Linear Shrinkage (%)	Organic Content (%)
Natural Peat	1.531	95.719
Peat+5%OPC+0%BA	1.422	90.964
Peat+5%OPC+5%BA	1.314	86.497
Peat+5%OPC+10%BA	1.174	82.940
Peat+5%OPC+15%BA	1.233	80.309
Peat+5%OPC+20%BA	1.422	75.565

Table 4.12 Result of Cc

Specimen	Cc
Natural Peat	2.530
Peat+5%OPC+0%BA	2.167
Peat+5%OPC+5%BA	2.208
Peat+5%OPC+10%BA	2.072
Peat+5%OPC+15%BA	2.155
Peat+5%OPC+20%BA	2.114

Table 4.13 Result of Cα

Specimen	Cα
Natural Peat	0.040
Peat+5%OPC+0%BA	0.034
Peat+5%OPC+5%BA	0.035
Peat+5%OPC+10%BA	0.032
Peat+5%OPC+15%BA	0.034
Peat+5%OPC+20%BA	0.033

Table 4.14 Linear Shrinkage (%) against Cc

Specimen	Linear Shrinkage (%)	Cc
Natural Peat	1.531	2.530
Peat+5%OPC+0%BA	1.422	2.167
Peat+5%OPC+5%BA	1.314	2.208
Peat+5%OPC+10%BA	1.174	2.072
Peat+5%OPC+15%BA	1.233	2.155
Peat+5%OPC+20%BA	1.422	2.114

Table 4.15 Linear Shrinkage (%) against Cα

Specimen	Cα	Linear Shrinkage (%)
Natural Peat	0.040	1.531
Peat+5%OPC+0%BA	0.034	1.422
Peat+5%OPC+5%BA	0.035	1.314
Peat+5%OPC+10%BA	0.032	1.174
Peat+5%OPC+15%BA	0.034	1.233
Peat+5%OPC+20%BA	0.033	1.422