# PERFORMANCE OF BOTTOM ASH TREATED PEAT SOIL IN IMPROVING SHEAR STRENGTH

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PERFORMANCE OF BOTTOM ASH TREATED PEAT SOIL IN IMPROVING SHEAR STRENGTH

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# ABSTRAK

Tujuan kajian ini adalah untuk meningkatkan kekuatan ricih tanah gambut dengan menstabilkan abu bawah dan campuran Simen Portland Biasa. Pemahaman terhadap sifat tanah yang stabil adalah yang paling penting untuk menstabilkan reka bentuk penempatan atau asas di tanah gambut untuk pembinaan bangunan. Beberapa eksperimen makmal dan medan konvensional telah dilakukan untuk menentukan hubungan antara sifat-sifat kejuruteraan tanah gambut dan kekuatan ricih yang tidak dapat direkodkan, dan untuk menentukan hubungan antara abu bawah dan kekuatan mampatan yang tidak terkonfigurasi tanah gambut yang lebih baik. Untuk mencapai matlamat tersebut, kajian ini mengkaji kesan abu bawah sebagai penstabil untuk meningkatkan kekuatan ricih tanah gambut selepas tempoh pengawetan tertentu dengan jumlah kuantiti yang berlainan abu bawah (5%, 10%, 15% dan 20%). Spesimen gambut yang stabil telah diuji menggunakan ujian mampatan yang tidak terkandung, had atterberg, hidrometer, kandungan organik, kandungan serat, analisis ayak dan ujian kebolehtelapan. Bukti yang ketara mengenai kesan positif campuran pada penstabilan tanah gambut telah ditemui dari penyiasatan ujian makmal kajian. Hasil daripada penyiasatan menunjukkan bahawa penambahan campuran tersebut dapat meningkatkan kekuatan mampatan yang tidak terkonfigurasi dan mengurangkan mampatan tanah gambut dibandingkan dengan gambut yang tidak dirawat.

# ABSTRACT

The aim of this study is to improve the shear strength of peat soil stabilized by addition of Bottom ash and mixture of Ordinary Portland Cement. An understanding of the stabilized soil properties is the most importance for the design stabilization of settlement or foundation in peat land for building construction. Some conventional laboratory and field experiments were done to determine the relationship between engineering properties of peat soil and undrained shear strength, and to determine the relationship between bottom ash and unconfined compressive strength of improved peat soil. To achieve such purpose, the study examined the effect of bottom ash as stabilizer to increase the shear strength of peat soil after specific period of curing with different proportion amount of bottom ash (5%, 10%, 15% and 20%). The stabilized peat specimens were tested using unconfined compressive test, Atterberg limit, hydrometer, organic content, fiber content, sieve analysis and permeability test. Significant evidence on the positive effects of the admixture at stabilizing peat soil was discovered from laboratory testing investigation of the study. Result from the investigation indicated that addition of the admixture was able to increase unconfined compressive strength and reduce compression of peat soil as compared to those of untreated peat.

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| | |
|---|---|
| $G_s$ | Specific gravity |
| $M_{DS}$ | Mass of the dry soil |
| $M_{AC}$ | Mass of the ashes |
| $M_{OC}$ | Mass of organic content |
| OC | Organic content |
| LL | Liquid limit |
| PL | Plastic limit |
| PI | Plastic index |
| $C_u$ | Undrained Shear Strength |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| OPC | Ordinary Portland Cement |
| BA | Bottom ash |
| UCS | Unconfined Compressive Strength |
| ASTM | American Society of Testings and Materials |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Peat soil has been identified as one of the major groups of soil found in Malaysia, which covers approximately 3 million hectares or 8% of the total land area (Kolay, 2011). On the other side, Sarawak has the largest peat land area in Malaysia which is about 16.5 $km^2$ or 13% of the state, of which about 90% of the peat is more than 1 m in depth (Mutalib AA, 1991). Peat or highly organic soil is a major problem in the infrastructure development of the coastal areas of Sarawak. The peat soil is classified as problematic soil due to its natural properties of high compressibility, low shear strength, high initial water content. Peat soil is considered as unsuitable for supporting foundations in its natural state. Based on test conducted on peatland in Peninsular, Malaysia it was found that the water holding capacity of this peat was very high and brown in colour and the soil was classified as H4 according to Von Post classification system (S.Islam, 2008). Besides, research conducted in West Malaysia about the water content of peat soil is in between 200% to 700% and the unit weight of inorganic soils is high compared to peat soil. Peat is an organic soil where the organic content is higher than 75%. Peat has certain characteristic that sets it apart from mineral soils and it also requires special consideration. These special characteristics include high natural moisture content (up to 700%), high compressibility including significant secondary and tertiary compression, low shear strength (typically 5-20 kPa), high degree of spatial variability and potential for further decomposition as a result of changing environmental conditions (Sadek Deboucha, 2008). Moreover, the normal depth of peat soil is 0.5 metre where usually contains organic materials. The organic contents classified as peat are basically of plant whose rate of accumulation is faster than the rate of decay and the content of peat soil differs in terms of locations due to factors such as temperature and degree of humification (Sadek Deboucha, 2008). Based on this problem, to improve organic soil and peat soil, many methods had been introduced such as preloading, deep stabilization, piling, surface reinforcement, vertical drain and chemical stabilization. Besides that, in validating peat soil strength it also involve several laboratory test which is required before, during and after the test such as unconfined compressive strength, Atterberg limit test, hydrometer, sieve analysis test and permeability test. This in-situ stabilization method involves the mechanical mixing of cementitious compound such as Ordinary Portland Cement (OPC).

## 1.2 Problem statement

Peat soil or peatland is classified as problematic soils which have low shear strength, high compressibility and high initial water content. The initial water content of peat soil is in the range of 200% to 700% with higher than other organic soil (S.Islam, 2008). Laterally, the peat soil can be found in the mangrove swamp area where the soil is good for plantation, agriculture and water ecosystem. On the other hand, peatland will be the last option for the engineer and developer to be selected because of its natural characteristic involved a lot of cost and modification. Besides that, in term of peat soil problem, construction project involving building, road and foundation are not recommended because soil issues like secondary settlement and stability problem may occur when the structure is built on the peat soil susceptible to instability such as localized sinking, slip failure, massive and long-term settlement when subject to even moderate load increase (Kolay, 2011). Moreover, in this globalization era, there are rapid grows of construction whether in urban or rural area that may take a lot of space and land use. In this development may cause a limited land use which needs to be solved effectively to make the area ready towards advance the city. Hence, by improving and strengthening the peat soil is the best solution to overcome lacking land use issues apart from to create better future the country development.

As a result, there are many steps and methods have been introduced to improve the peat soil. However, some of them require huge amount of budget and yet the effectiveness of the ground improvement method is questionable. Hence, elements like environment friendliness, cost, effectiveness, reliability and durability should be considered in selecting the best method of ground improvement.

Bottom ash stabilization is a new approach to be introduced for improving strength and stabilize peat soil. Abundant of bottom ash produced in Tanjung Bin power station produce 180 tonnes per day and 1,620 tonnes per day of fly ash from 18,000 tonnes per day of coal burning alone make it neglected and useless (Abdulhameed Umar Abubakar, 2012). To overcome this problem, bottom ash will be acted as stabilizer in improving peat soil because of economically- friendly and high accessibility aspect.

## 1.3 Research Question/Hypothesis

To overcome the said problems and existing gaps in this issue, this study aims to address the following research questions.

1. What is the effect of peat soil which consisting of different proportion of bottom ash towards the shear strength of peat soil?
2. What is the curing process effect of peat soil toward the shear strength improvement of peat soil?

## 1.4 Objectives and Aims

### Overall Objective

The main purpose of this research is to study the effectiveness of bottom ash treated peat soil in increasing the shear strength of soil in East Coast of Peninsular Malaysia (Pekan Peat).

### Specific Aims

1. To determine the relationship between engineering properties of peat soil and undrained shear strength.
2. To determine the relationship between bottom ash and unconfined compressive strength of improved peat soil.

## 1.5 Scope of work

1. The peat soil for this research was limited to Pekan Peat, Pahang.
2. The type of cement used in this research is Ordinary Portland Cement (OPC) and Bottom Ash (Ash).
3. Every sample was mixed with different amount of bottom ash which is 5%, 10%, 15% and 20%.
4. The sample was cured in the laboratory for 7, 14 and 21 days prior to the test.

## 1.6 Thesis Structure

Chapter 1

This chapter contains the introduction to the issues in which the research is concerned with the aims and objectives of the study and the scope outlined, research approach as well as the structure of the thesis. The background and history highlights empirical foundations of research. The purpose of the background or history section to give the relevant facts about the topic and research site so that material or case in the proposal and how it links to the questions posed can be understand. Besides, in any research need to provide a clear problem statement. The purpose statement should provide a synopsis of the purpose of the study, briefly define and delimit the specific area of the research, identify the unit of analysis in the study and foreshadow the hypotheses to be tested or the questions to be raised. A problem may be stated in term of a verbal statement.

Chapter 2

A review of relevant literature is the second step and is of great significance. The literature review helps relate the proposed study to the larger ongoing discourse in the literature about a phenomenon, filling in gaps in the literature and extending earlier studies. The literature review is neither a chronological summary of related works nor a mere catalogue of previous studies published in the field. Literature conceptually integrated within the logic of the proposed investigation. Literature review will show whether other researchers have studied the same or similar problems before, from what perspectives have these studies been conducted and whether these researches have been theoretically or empirically adequate.

Chapter 3

This chapter describes and explains the materials as well as the research methodology used in the study. The sub-topics for this chapter include the key research questions, the research design and the research procedures adopted. It may also, where appropriate, indicate sampling methods and research instruments. The purpose of this is to inform the reader on the method used to collect the data and generate the findings reported.

Chapter 4

In this chapter it will be discussed about the result and analysis. Analyses of the data for determine the shear strength and details was discussed in this chapter.

Chapter 5

This chapter contain conclusion and recommendation section. The summary and conclusions of major findings of this research and recommendation for future work on the topic related to the present study was included here.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Background of peat

Peat is a mixture of divided natural material shaped in wetland under suitable climatic and topographic conditions and it is gotten from vegetation that has been artificially changed and fossilized. Peat is by and large found in thick layers in restricted regions, has low shear strength and high compressive deformation which regularly result in challenges when development work is attempted on the deposit.

When the soil was extruded on squeezing which is passing between fingers, it was observed that the soil was somewhat pasty with muddy water squeezed out and the plant structure was not easily identified (Islam, 2008). Besides that, the soil can be classified as fibrous peat mixed with vegetal fibre, wooden chips inside and root appears top layer.

## 2.2 Peat

### 2.2.1 Distribution of Peat

On this time, 30% of Earth covered by the land and the remaining 70% fully blue by sea water. Only 5% to 8% of land surface consist of peat soil which organic soil. Peat can be found throughout the world. The country land for both Canada and Russia is covered with 150 million hectares of peat areas. A summary of peatland area distribution around the world is shown in Table 2.1 and Figure 2.1. Besides, in Malaysia, there is around 3 million hectares or approximate 8% of the land is covered with peats which include 14 state of Malaysia. In detail, state of Sarawak, there is 1.66 million of the land is covered with peat soil (Huat B. , 2004).

**Table 2.1: Peatland area distribution around the world** (Mesri, 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 |

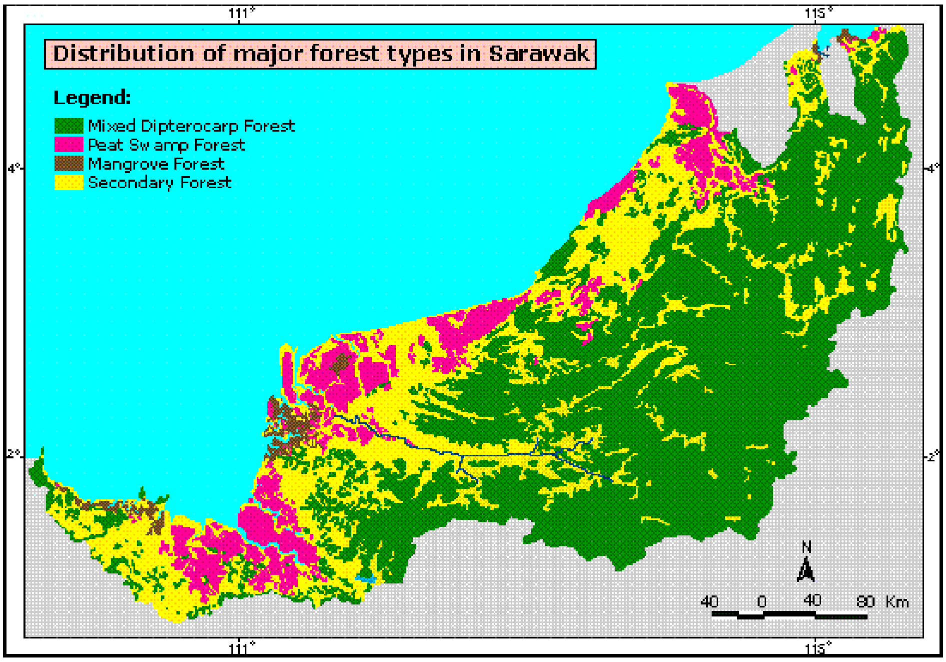


**Figure 2.1: Peat distribution in Sarawak (Osman, 2017)**

### 2.2.2 Engineering Characteristic of Peat

Peat is consisting of liquid, gaseous, and solid state matter. Peat soil which has high water content classified peat water into four types which are physically bound water, chemically bound water, free water in pore spaces and permeable bound water.

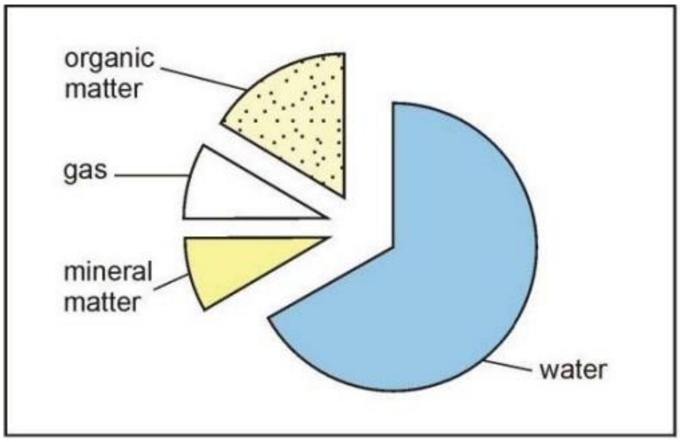


Figure 2.2: The composition of peat soil.

The solid component of peat consists of mineral matter and organic matter. Organic matter is the main component of the solid phase of peat, including humus and plant debris which did not decompose fully. Humus, accounting for 20 to 70% of the organic matter of peat, is an organic chemical complex with a complicated structure which arose during the peat-forming process. Plant debris comprises the main part of organic matter of peat and also the most valuable part and it includes plants' roots, stems, leaves, fruits, seeds, spores, and pollen. The mineral matter of peat consist of two types which are material that was carried into peat by running water and wind during the accumulation process, or material that was formed by the decomposition of plant debris.

The classification of peat soil can be determined by several methods included ASTM, Radforth system and Von Post Scale. The Radforth classification system is based on virtual identification of texture and botanical composition as shown in Table 2. According to American Society of Testings and Materials (ASTM), the peat can be classified based on few criteria which are 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 3.

The most common method in classifying the peat soil is the Von Post Scale as shown in Table 2.4. In this classification system, the peat soil is classified according to the degree of humification (decomposition), botanical composition, water content, content of fine and coarse fibres and woody remnants. There are 10 degrees of humification (H1 to H10, with H1 being the least and H10 being the most decomposed) in the von Post classification system that are determined based on the appearance of peat water that is extruded when the soil is squeezed in the hand.

**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 framework |
| | 6 | Peat, predominantly amorphous-granular containing woody fine fibres, held in a woody, coarse-fibrous framework |
| | 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 amount of coarse fibres |
| | 9 | Woody, fine fibrous peat held in a woody, coarse-fibrous framework |
| | 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 a coarse fibrous framework |
| | 15 | Woody mesh of fibres and particles and 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 (H1-H3) |
| | 33% - 67% fibers | Hemic (H4-H10) |
| | <33% fibers | Sapric (H7-H10) |
| 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 | Moderately 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% | Moderately Absorbent |
| | W < 300% | Slightly Absorbent |

**Table 2.4: Classification of Peat according to Von Post Scale**

| Symbol | Description |
|---|---|
| H1 | Completely undecomposed peat which, when squeezed, release almost clear water. Plant remains easily identifiable. No amorphous material present. |
| H2 | Almost entirely undecomposed peat which, when squeezed, releases clear or yellowish water. Plant remains stills easily identifiable. No amorphous material present. |
| H3 | Very slightly decomposed peat which, when squeezed, released muddy brown water, but from which no peat passes between the fingers. Plant remains still identifiable and no amorphous material present. |
| H4 | Slightly decomposed peat which, when squeezed, releases very muddy dark water. No peat passes between the fingers but the plant remains are slightly pasty and have lost some of their identifiable features. |
| H5 | Moderately decomposed peat which, when squeezed, releases very muddy water with small amount of amorphous granular peat escaping between the fingers. The structure of the plant remains is quite indistinct although it is quite indistinct to recognize certain features. The residue is very pasty. |
| H6 | Moderately highly decomposed peat with a very indistinct plant structure. When squeezed, about one-third of the peat escapes between the fingers. The residue is very pasty but shows the plant structure more distinctly than before squeezing. |
| H7 | Highly decomposed which contains a lot of amorphous material with very faintly recognizable plant structure. When squeezed, about one-half of the peat escapes between the fingers. The water, if any is released, is very dark and almost pasty. |
| H8 | Very highly decomposed peat with a large quantity of amorphous material and very distinct plant structure. When squeezed, about two-third of the peat escapes between the fingers. A small quantity of pasty water may be released. The plant material in the hand consists of residue such as roots and fibres that resist decomposition. |
| H9 | Practically fully decomposed peat in which there is hardly any 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 moisture content |
| B3 | Moderate moisture content |
| B4 | High moisture content |
| B5 | Very high moisture content |

**Table 2.5: Organic soils and peat section of the Malaysian Soil Classification System for Engineering Purposes (from BS5930: after Jarrett 1995; Huat 2004; Engineering Geology Working Group 2007)**

| Soil groups | Subgroup and laboratory identification | | | | | | |
|---|---|---|---|---|---|---|---|
| | Description | Group symbol | Subgroup symbol | Liquid limit % | Degree of humification | Subgroup name | Field identification |
| Organic soils and peats | | | | | | | |
| Slightly organic soils (organic content 3–20 %) | Slightly organic silt | Mo | Mo | | | Slightly organic silt (subdivide like Co) | Usually very dark to black in color, small amount of organic matter may be visible. Often has distinctive organic smell |
| | Slightly organic clay | Fo | CLo | <35 % | | Slightly organic clay of low plasticity | |
| | | | Clo | 35–50 | | Slightly organic clay of intermediate plasticity | |
| | | Co | Cho | 50–70 | | Slightly organic clay of high plasticity | |
| | | | Cvo | 70–90 | | Slightly organic clay of very high plasticity | |
| | | | CEo | >90 | | Slightly organic clay of extremely high plasticity | |
| Organic soils (organic content 20–75 %) | Organic soils | O | | | | Subdivision of organic soil is difficult, as neither the plasticity tests nor the humification tests are reliable for them. As such, the best attempt is the probable outcome of subdivision leading to descriptions such as "fibrous organic soils" or "amorphous organic soils of intermediate plasticity" | |
| Peats (organic content more than 75 %) | Peat | Pt | Ptf | | H1–H3 | Fibric or fibrous peats | Dark brown to black in color. Material has low density so seems light. Majority of mass is organic, so if peat is fibrous, the whole mass will be recognizable plant remains. If highly humified, the peat will more likely to smell strongly |
| | | | Pth | | H4–H6 | Hemic or moderately decomposed peats | |
| | | | Pta | | H7–H10 (von Post humification scale) | Sapric or amorphous peats | |

1. When describing soils, the name of the soil group should always be given, supplemented if required by the group symbol, although for some additional applications (e.g., longitudinal applications), it may be convenient to use the group symbol alone

2. Where appropriate, gravel and sand may qualify as sandy gravel and gravelly sand

3. If laboratory methods have not been used for identification, the group symbol or subgroup symbol should be placed in parentheses, e.g., (GC)

4. When it is not possible or not required to distinguish between silt, M or clay, C, the designation "fine soil" or "fines," F, may be used

5. If more than 50 % of coarse material is of gravel size, the term "gravelly" is used. The descriptive term "sandy" is used if more than 50 % of the coarse material is sand-sized

6. A material that passes below the A-line on the Casagrande plasticity chart, has a restricted plastic range in relation to its liquid limit, and has a low cohesion, is termed a "silt," M. Slightly organic soils also usually plot below the A-line on the plasticity chart and are termed "slightly organic silts," Mo

7. Materials that pass above the A-line on the plasticity chart, and are fully plastic in relation to their liquid limits, are classified as "clay," C

## 2.3 Bottom ash

Bottom ash is a side product form from burning of coal in thermal power plant. Bottom ash was introduced because of economic, environmental friendly and technical advantage. Other use of Bottom is to replace expensive sand for peat soil foundation as a fine aggregate in high-performance footing (I Kula, 2002). The first two are justified by the use of a waste with no commercial value. The chemical properties of bottom ash it has hollow nature structure which cover the technical advantage. Basically, BA mainly determined by its physical characteristic such as grain size distribution, staining potential and dark in color. Hollow grain structure of bottom ash functions to absorb water and dissolve foreign elements. Regarding the chemical aspect, bottom ash can represent a source of alumina for ettringite formation in the same way as fly ash (C.A. Luz a, 2006).

**Table 2.6: Chemical composition of bottom ash (C.A. Luz a, 2006)**

Chemical composition of raw materials

| Elements | Dry GS | BA | Sulfoaluminate cement | |
|---|---|---|---|---|
| | | | Phosphogypsum | Clinker |
| Oxides (%) | | | | |
| $Al_2O_3$ | 5.7 | 26.7 | 0.2 | 31.2 |
| CaO | 20.9 | 0.8 | 32.5 | 43.2 |
| $SiO_2$ | 16.7 | 56.0 | 0.2 | 7.7 |
| $Fe_2O_3$ | 1.6 | 5.8 | – | 8.3 |
| MgO | 1.6 | 0.6 | – | 0.6 |
| $Na_2O$ | 0.4 | 0.3 | 0.2 | 0.1 |
| $K_2O$ | 0.6 | 2.6 | – | 0.2 |
| $P_2O_5$ | 0.7 | 0.2 | 0.2 | – |
| $TiO_2$ | 0.3 | 1.3 | | 1.0 |
| $SO_3$ | 1.5 | 0.2 | 44.9 | 6.8 |
| LOI | 35.4 | 4.6 | 20.2 | 0.6 |
| $CO_2$ (total) | 33.9 | 14.0 | – | – |
| C (organic) | 1.9 | 3.8 | – | – |
| Minor (ppm) | | | | |
| As | 1.7 | 11 | – | 42.9 |
| Ba | 205 | 469 | 836 | 123 |
| Cd | 1.0 | 1.0 | 0.8 | 0.4 |
| Cr | 85460 | 176 | 7 | 250 |
| Cu | 29570 | 31 | 6 | 21 |
| Ni | 9571 | 43 | 6 | 39 |
| Pb | 112 | 70 | 3 | 8 |
| Sr | 549 | 124 | 12090 | 2084 |
| Zn | 110 | 358 | 15 | 54 |

**Table 2.7: Chemical properties of Bottom ash (Malkit Singh, 2012)**

| Chemical composition (%) | Yuksel and Genc (2007) | Andrade et al. (2009) | Bai et al. (2005) | Kasemchaisiri and Tangtermsirikul (2007) | Sani et al. (2010) | Ghafoori and Bucholc (1997) |
|---|---|---|---|---|---|---|
| $SiO_2$ | 57.90 | 56.0 | 61.80 | 38.64 | 54.80 | 41.70 |
| $Ai_2O_2$ | 22.60 | 26.70 | 17.80 | 21.15 | 28.50 | 17.10 |
| $Fe_2O_3$ | 6.50 | 5.80 | 6.97 | 11.96 | 8.49 | 6.63 |
| CaO | 2.00 | 0.80 | 3.19 | 13.80 | 4.20 | 22.50 |
| MgO | 3.20 | 0.60 | 1.34 | 2.75 | 0.35 | 4.91 |
| $Na_2O$ | 0.086 | 0.20 | 0.95 | 0.90 | 0.08 | 1.38 |
| $K_2O$ | 0.604 | 2.60 | 2.00 | 2.06 | 0.45 | 0.40 |
| $TiO_2$ | – | 1.30 | 0.88 | – | 2.71 | 3.83 ($P_2O_5$, $TiO_2$, etc.) |
| $P_2O_5$ | | | 0.20 | – | 0.28 | |
| $SO_3$ | | 0.10 | 0.79 | 0.61 | – | 0.42 |
| LOI | 2.40 | 4.60 | 3.61 | 7.24 | 2.46 | 1.13 |

The bottom ash have different particles size and texture such as irregular, angular and have rough surface texture and the range size from fine gravel to fine sand. Bottom ash more brittle and lighter as compare to natural sand and have interlocking characteristic. The specific gravity of the bottom ash varies from 1.39 to 2.33 depending upon its chemical composition (Malkit Singh, 2012). A worldwide investigation has been carry on to produce specific gravity of various bottom ashes based on table 2.1 above.

The low specific gravity of bottom ash is explained by its low iron oxide contents. It is believed that for iron content greater than 10%, the specific gravity value is directly proportional to iron content but for lime content greater than 15%, the specific gravity value is more irrespective of iron content. Bottom ash with a low specific gravity has a porous texture that readily degrades under loading or compaction. Bottom ash derived from high sulphur coal and low rank coal is not very porous and is quite dense. Bottom ash is usually a well-graded material although variations in particle size distribution may be encountered from the same power plant.

## 2.4 Curing Condition

The curing condition is focused on the curing time that is selected and done before testing pf the sample.

### 2.4.1 Curing time

The curing days for sample was 7, 14 and 21 days. Esrig (1999) stated that most strength gain occurs within the first 28 days after mixing and strength continues to increase at a slower rate thereafter. Based on Koley (2010), it shows that the UCS increase with the curing period after the peat has been stabilized with fly ash and gypsum separately.

### 2.4.2 Curing temperature

Many variables affect curing temperature. Proper curing temperature for site-specific samples is quite uncertain, resulting in variable laboratory test procedures, typically ranging from 20°C (room temperature) to 75°C. Whatever curing temperature used, the specimen should be proper spaced and fans or pumps should be used to ensure that all the specimens cure at the same temperature (Sehn, 2001)

### 2.4.3 Humidity for Storage

The percentage for the humidity for storage of peat is set to 100% and in 18 to 22°C temperature. The peat is stored in controlled humidity to ensure the peat has not experienced any lost on moisture, strength and so on. No load is applied during storage. Based on den Haan (2000), recommends several methods for controlling the humidity in the curing environment such as curing sample is sealed, airtight tubes, curing underwater, or placing sample inside an insulating jacket. Hampton (1998) found that providing the samples access to water while applying a confining pressure during curing, which may imitate field conditions more accurately, reduces strength.

## 2.5 Index properties of peat soil.

Peat soil contents an organic material which has high water content exceeding 75%. The content of peat soil has different properties according the location and the factor of surrounding such as temperature, weather and degree of humification. Humification involves the loss of organic matter either in gas or in solution, the disappearance of physical structure and change in chemical state.

**Table 2.8: Properties of In-situ peat soil (Alwi, 2008)**

| Properties | value |
|---|---|
| Bulk density ($\gamma_b$) | 1.059 Mg/ m$^3$ |
| Dry density ($\gamma_d$) | 0.112 Mg/ m$^3$ |
| Moisture content ($w$) | 700-850% |
| Void ratio ($e$) | 10.99 |
| Fiber content | 84.99% |
| Degree of saturation ($S$) | 100 |
| Specific gravity ($G_s$) | 1.343 |
| Classification /Von Post | H4 |
| Linear Shrinkage | 5.58% |
| Liquid limit | 173.75% |
| Plastic limit | 115.8% |
| Plasticity Index | 57.95% |
| pH | 4.6 |
| *Scanning Electron Microscopy* | |
| Loss on Ignition | 98.46 % |

**Table 2.9: Physical properties of peat soil (Islam, 2008)**

| Index properties | Range | Average |
|---|---|---|
| Natural moisture content (%) | 414-674 | 555.000 |
| Specific gravity | 0.95-1.34 | 1.240 |
| Initial void ratio | 7.999-9.646 | 9.329 |
| Fiber content (%) | 90.25-90.49 | 90.390 |
| Organic content (%) | 88.61-99.06 | 96.450 |
| Ash content (%) | 0.94-11.39 | 3.550 |
| Bulk density (kg m$^{-3}$) | 1035.66-1040.41 | 1037.720 |
| Linear shrinkage (%) | 29.81-30.14 | 29.990 |
| pH of peat | - | 3.510 |
| pH of ground water | - | 4.070 |
| Liquid limit (%) | 202.30-220.65 | 208.390 |
| Classification/von post | | $H_4$ |

Besides that, based on research for undisturbed and reconstituted Parit Nipah peat showed the moisture content were 545% and 328% and for liquid limit undisturbed peat shows the highest value which was 360% followed by reconstituted peat at 362% (A T S Azhar, 2016). (Kolay, 2010), stated that sample contains a lot of fibers resulted in high water absorption capacity. The specific gravities of undisturbed peat were 1.49 and 1.33 for reconstituted peat. The fiber content of undisturbed peat was 66.56 % while for reconstituted peat was 51.12 %. The result of physical properties is within the range of the previous study as shown in Table 2.10.

Table 2.10: Physical Properties of Typical

| Parameter | Undisturbed peat | Reconstituted Peat Passing 3.35mm | Past Researcher |
|---|---|---|---|
| Moisture content (%) | 545 | 328 | 200-1000 |
| Liquid limit (%) | 360 | 326 | 190-360 |
| Specific Gravity ($mg/m^3$) | 1.49 | 1.33 | 1.38-1.80 |
| Fiber Content (%) | 66.56 | 51.12 | 33-77 |

### 2.5.1 Water content

In the peat soil area, ground water table was being determined about 0.3 m from the ground surface. According to high ground water table showed that peat have a very high water retention capacity and can be assumed to be fully saturated soil. Based on Kolay, P.K., Sii, H.Y and Taib, S.N.L (2011), natural moisture content of the peat soil is quite high around 599%. In other side, peat soil indicated that the soil was dark brown in colour by using visual observation. Based on previous research, the natural water content of peat in West Malaysia ranges from 200% to 700% and organic content is in the range of 50% to 95% (Huat, 2004).

| **Past researcher** | **Water content (%)** |
|---|---|
| Kolay, P.K, Sii, H.Y and Talib | 599% |
| Huat | 200% - 700% |

### 2.5.2 Organic content

Peat soil has soft soils texture which can classify as highly organic. Based on Kolay, P.K., Sii, H.Y and Taib, S.N.L (2011), the organic content of peat soil in Sarawak area is around 90%. In fact, peat mainly composed of fibrous organic matters and has partly decomposed plant such as leaves, root and stems. Mostly organic residues of plant in peat soil incompletely decomposed through lack of oxygen. Therefore, it has been said that peat shows unique geotechnical properties in comparison with those of inorganic soils such as clay and sandy soils which are made up of only soil particles (Sadek Deboucha, 2008).

| Past researcher | Organic content (%) |
|---|---|
| Kolay, P.K, Sii, H.Y and Talib | 90% |
| Huat | 50% - 95% |

### 2.5.3 Fibre content

The specific gravity ($G_s$) value of peat is very low because it contains a lot of fiber around 79%. Besides, the tropical peat soil rich with fiber such as deadwood and leaves. The dry weight of peat soil fiber content can be determine on ASTM sieve no. 100 over the total oven dried mass sample as according to ASTM D 1997-91 (Kolay P. S., 2011)

| Past researcher | Fibre content (%) |
|---|---|
| Kolay, P.K, Sii, H.Y and Talib | 79% |

### 2.5.4 Liquid limit

Regarding to the properties of peat soil which have higher fiber, the liquid limit is also higher and has high water absorption capacity. Based on Kolay, P.K., Sii, H.Y and Taib, S.N.L (2011), peat test in this study are non-plastic and has lower pH value and acidic. Furthermore, (Huat, 2004) reported based on the study the liquid limit of peat soil in the range of 200% to 500%. Besides, result from the researcher show that the liquid limit of the tropical peat was in the range from 150% to 400% which was the liquid limit of this tropical peat increase with increase in organic content (Youventharan Duraisamy, 2009). Moreover, in the case of temperate peat, the liquid limit of fen peat ranges from 200 – 600% and bog peat from 800-1500% (Hobbs, 1986).

| **Past researcher** | **Liquid limit (%)** |
|---|---|
| Youventharan Duraisamy | 150% |
| Huat | 200% - 500% |
| Hobbs | 200% - 600% |

### 2.5.5 Density and specific gravity.

Peat soil has low specific gravity. According to Den Haan (2006), the specific gravity of organic or peat is affected by the organic constituents, cellulose and lignin which are having lower specific gravity approximately 1.58 and 1.4 which causes the reduction in specific gravity of peat. Consequently, the specific gravity (Gs) of the peat depends on the organic and fiber constituents. The specific gravity of peat soil can be determine using pycnometer method based on procedures stated in ASTM D 422 63 (Kolay P. S., 2011).

| **Past researcher** | **Specific gravity (%)** |
|---|---|
| Den Haan | 1.58 and 1.4 |

### 2.5.6 Unconfined Compressive Strength

Shear strength is a concern both during construction for supporting construction equipment as well as at the end of construction in supporting the structure. Low shear strength and high compressibility of peat soils however confine them in a problematic category. Accuracy in determining the shear strength of these soils is associated with several variables which are origin of soil, water content, organic content and degree of humification (Huat B. B., 2004)

Based on research by Sina Kazemian (2011), the effectiveness of using different ratios of cement-sodium silicate system grout compound with kaolinite on the mechanical and micro structural properties of peat after it for 3 and 30 days provide the shear strength increased until the net charge of the sample changed to zero and thereafter it decrease with any further increase of calcium chloride because of the deflocculating of the larger particle and the reverse trend in the moisture content.

According Behzad Kalantari (2014) analysed the effect of various curing techniques such as air curing, moist curing and moist curing with surcharge load adopted for the stabilization of peat and cement. The highest percentages increase in the Unconfined Compressive Strength (UCS) was obtained under moist curing with surcharge with a 50% of OPC addition. (Wong Leong Sing, 2008), evaluated the strength characteristics of stabilized peat and found the economical mix in peat stabilization through laboratory tests. The results show that well graded siliceous sand largely contributed to gain early a higher strength as it enables cementation bonds at the contact points. Sodium chloride accelerated the rate of cement hydration in saturated peat by increasing the initial strength. Ali Dehghanbandaki (2013) conducted a study to find the optimum amount of natural filler that will provide a higher shear strength using OPC as the binder. The optimum filler content for the higher compressive strength was found to be 125 $kg/m^3$ of well graded sand.

Besides, soil permeability, shear strength and compressibility affected due to the size of peat, shape, fabric and packing of the soil particle (Wong, 2009). Based on Mitchell (1993), in determine the value of properties such a strength, permeability and compressibility, there are several factors that contribute which are size and shape of soil particles, the arrangements and the forces between particles. Thus, it can be concluded that the size and shape of peat can affect the water content, void ratio and fiber content, and thus affect the shear strength properties.

According to the result obtained from Parit Nipah peat in Johor, for comparison purposes the shear strength properties for reconstituted peat were higher than undisturbed peat if the reconstituted peat has passed 3.35 mm opening size of a sieve and compressed with 100 kPa preconsolidation pressure (A T S Azhar W. N., 2016).

Table 2.11: Triaxial Summary Results in Parit Nipah Peat, Johor (A T S Azhar W. N., 2016)

| Sample | Initial water content, w (%) | Initial Void Ratio, $e_o$ | Fiber content (%) | Undrained Shear Strength Properties | |
|---|---|---|---|---|---|
| | | | | c' (kPa) | θ' (°) |
| Undisturbed peat | 545 | 8.36 | 66.56 | 10 | 16 |
| Reconstituted peat | 328 | 5.74 | 51.12 | 21 | 41 |

Through the research by S.Venuja (2017), the variation of UCS from each types of sample show an increase with the addition fly ash up to 10% by weight and beyond that value and the UCS will be reduces as more fly ash is added to mix. Based on this peat result, optimum mix proportion of fly ash has been found which is 10% by weight.

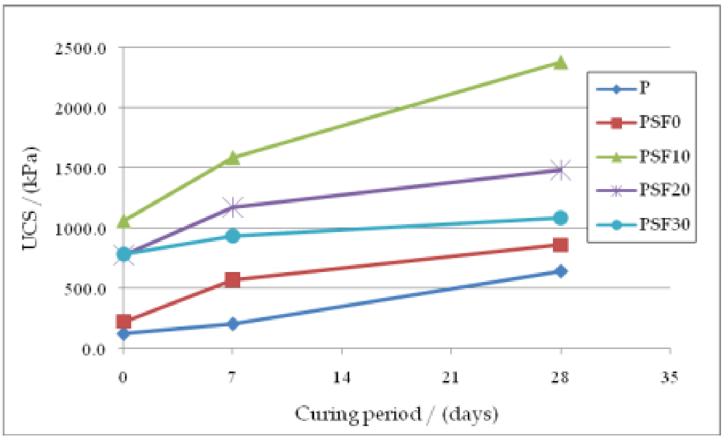


Figure 2.3: UCS variation with curing period

# CHAPTER 3

# METHODOLOGY

## 3.1 Overview

This research was conducted in 3 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. At the same time, the properties of the Bottom Ash was tested and identified. In Stage 2, the undrained shear parameters were obtained using UCS test. The samples which comprises of different proportion of peat soil and bottom ash were tested. The sample was be cured for 7, 14 and 21 days. In stage 3, the undrained shear parameters were used to calculate the theoretical bearing capacity of peat soil after stabilization work.

## 3.2 Study Location

The research was carried out in Geotechnical laboratory, Universiti Malaysia Pahang, Gambung Campus.

## 3.3 Site Selection and Classification of Peat

The undisturbed peat samples were collected from Pekan, Malaysia at a depth of 0.5-1m depth from ground surface.


Figure 3.1: Location of Pekan, Pahang

The sample will be tested by a series of laboratory test such as classification, Atterberg Limit Test, Permeability Test, Organic Content, Fiber Content, Moisture Content in order to determine natural properties of peat. The tests were carried out according ASTM and British Standard as shown in 3.1.

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, ’(degree) | BS 1377/ ASTM D4767 |
| Optimum Moisture Content (%) | ASTM 1557 |
| Maximum Dry Unit Weight ($kN/m^3$) | ASTM 1557 |
| UCS-undisturbed (kPa) | ASTM D2166 |

### 3.3.1 Sampler

Moreover, for the sampling purpose, excavation of trial pits was done to a depth of 0.5 m below the ground surface in order to get both undisturbed peat samples. Ground water table was found to be about 0.3 m from the ground surface. The high ground water table suggested that the peat had a very high water retention capacity. Visual inspection on the soil indicated that the soil was dark brown in colour.

Figure 3.2: Peat sampling method

Figure 3.2 shows the sampling method in providing undisturbed sample by excavate 0.5m depth of peat soil.

### 3.3.2 Degree of decomposition

Von post scale for assessing peat degree of decomposition was represented by symbol H1 until H10. To perform the test, the sample of peat or organic soil is squeeze in the hand. The colour and form of fluid that be extruded between the fingers was observed together with the pressed residue remaining in the hand after squeezing.

Figure 3.3: Von Post Scale identification

Figure 3.3 shows the Von Post Scale identification through the colour of the water dissipates out when the soil is squeezed. Thus it gives early prediction on the degree of decomposition of peat.

### 3.3.3 Repose angle

The material was poured through a funnel to form a cone. The tip of the funnel should be held close to the growing cone and slowly raised as the pile grows, to minimize the impact of falling particles. Stop pouring the material when the pile reaches a predetermined height or the base a predetermined width. Rather than attempt to measure the angle of the resulting cone directly, divide the height by half the width of the base of the cone. The inverse tangent of this ratio was the angle of repose.

Figure 3.4: Repose angle of bottom ash

## 3.4 Engineering Properties of Peat

Engineering properties of peat categorization was done with preliminary laboratory test to the peat. In this research, the categorization of peat were done with test of fiber content to find content of the fiber in peat soil, liquid limit as to find the Atterberg limit, moisture content of unstabilized peat, organic content of peat that is to find the content of organic and specific gravity of peat.

### 3.4.1 Fiber Content (ASTM D1997)

This test was performed to determine the fibre content of organic soils. The fibre content was the ratio, expressed as a percentage of the mass of fibre matter in a given mass of soil to the mass of the dry soil solids.

The standard reference of fibre content was ASTM (1997) which was Standard test Methods for Fibre Matter of Peat and Organic Soils.

Fibre matter influences many of the physical, chemical and biological properties of soils. Some of the properties influenced by fibre matter include soil structure, soil compressibility and shear strength. The equipment that be used are oven, 5% sodium hexametaphosphate and sieve N0. 100 (125 μm).

The calculation of fibre content will be as follow:

$$Fc = (M_{FIBRE}/ M_{SAMPLE}) \text{ X } 100\%$$

Figure 3.5: Fiber content test

Figure 3.5 shows the sieve that is used to determine the fiber content of peat.

### 3.4.2 Moisture Content (BS 1377)

Soil specimens were weighted as received then oven-dried at 105°C for 24 hours and weighed again. They are six samples that be tested in determine moisture content of peat which are original state, 0% ,5%, 10%, 15% and 20% of bottom ash by adding 5% of OPC and binder reagent. The difference in weight was assumed to be the weight of the water driven off during drying. The difference in weight was divided by the weight of the dry soil, giving the water content on a dry weight basis. To expedite the testing program, moistures were often determined using the microwave drying method.

### 3.4.3 Organic Content (ASTM D2974)

This test was performed to determine the organic content of peat soils. The organic content was the ratio, expressed as a percentage of the mass of organic matter in a given mass of soil to the mass of the dry soil solids.

Through this test, loss of ignition method was conducted and the standard reference of organic content test was ASTM D 2974 which was Standard Test Methods for Moisture, Ash and Organic Matter of Peat and Organic Soils.

There are several equipment that be used in this test which are muffle furnace, balance, porcelain dish, spatula and tongs.

The organic contents of these soils were determined by first oven drying a sample at 105°C for 24 hours and recording the moisture content. The sample was placed in a muffle furnace, heated to $440^0$C and when constant mass was achieved, the sample was weighted. Weight loss due to ignition divided by initial dry weight produces the ash content. The organic content was calculated as one minus the ash content.

The calculation of organic content will be as follow:

Mass of the dry soil, $M_{DS} = M_S - M_D$

Mass of the ashes, $M_{AC} = M_C - M_D$

Mass of organic content, $M_{OC} = M_{DS} - M_{AC}$

Organic content, $OC = (M_{OC}/M_{DS}) \times 100\%$

Figure 3.6: Organic content

Figure 3.6 shows the crucible in furnace for organic content determination.

### 3.5 Laboratory Test

The summary of laboratory test that was carried out was listed out in table 3.2.

Table 3.2 Summary of laboratory test

| Properties | Code of Practices |
|---|---|
| Unconfined Compressive Shear Strength | ASTM D2166 |
| Atterberg's Limit | ASTM D4318 |
| Relative Density | ASTM D4253 |
| Sieve Analysis | ASTM D422 |

#### 3.5.1 Unconfined Compressive Strength (ASTM D2166)

Unconfined Compression Strength tests have been conducted on the undisturbed peat soil as well as stabilized peat soil with OPC and fiber. Disturbed samples used for the stabilized peat soil UCS test were the peat soil samples at their natural state moisture content. Specified amounts of OPC and bottom ash were added to screened peat soil and mixed well for their homogeneity. 0%, 5%, 10%, 15% and 20% of bottom ash with 5% constant OPC based on the weight of the peat soil were added with peat soil prepared for 15 samples with 3 different time curing. Besides that, there are 3 samples which were prepared in natural state as a constant to compare with other sample. Total sample be uses were 18 samples. There are 3 different time curing which are 7, 14 and 21 days. Then the mixture has been placed in three layers in UCS mould having inside diameter of 38 mm and 76 mm height.

The equipment that involve in the Unconfined Compressive Strength test which were compression device, load and deformation dial gauges, sample trimming equipment, balance and moisture can.

In handling this test, extrude the soil sample from Shelby tube sampler. Cut a soil specimen so that the ratio (L/d) is approximately between 2 and 2.5. Where L and d which are length and diameter of soil specimen, respectively. Then, the exact diameter of the top of the specimen at three location 120° apart and then make the same measurements on the bottom of the specimen. Average the measurement and record the average as the diameter on the data sheet. After that, measure the exact length of the specimen at three locations 120° apart, and the measurements and record the average as the length on the data sheet. Then, weight of the sample and average length data was recorded. The deformation can be calculated, ΔL corresponding to 20% strain (ε).

Strain, $\varepsilon = \Delta L / L_o$

$L_o$ = Original specimen length

Placed the specimen in the compression device and centres it on the bottom plate. Adjust the device so that the upper plate just make contact with the specimen and set the load and deformation dials to zero. Apply the load so that the device produces an axial strain at a rate of 20 second and then record the load and deformation dial readings on the data sheet.

Keep applying the load until the load (load dial) decreases on the specimen significantly which the specimen be cracked/break or the load holds constant for at least four deformation dial reading.

Figure 3.7: Sample preparation

Figure 3.8: Sample was cured for specific period

Figure 3.9: Unconfined compressive strength test

### 3.5.2 Atterberg Limit (ASTM D4318)

The objective of this test is to obtain the basic index information about the soil used to estimate strength and settlement characteristics as Plasticity Index, Plastic Limit, Liquid limit, and Shrinkage Limit.

### 3.5.2.1 Liquid Limit (ASTM D 4318)

### (Cone Penetrometer Method)

In order to estimate the plasticity of the soils, the liquid limit and plastic limit values were determined. The Atterberg limits device was used to determine the liquid limit.

The apparatus that involve in this cone penetrometer test are flat glass plate, metal cups, spatula, moisture content tins and distilled water.

Firstly, take a sample of the soil of sufficient size to give a test specimen weighing at least 300gm which passes the 425μm test sieve and place it on the glass plate. Add some water and mix the paste for at least 10 minutes using the two spatulas. Push a portion of the mixed soil against the side of the cup to avoid trapping air. With the penetration cone locked in the raised position, lower the supporting assembly so that tip of the cone just touch surface of the soil.

Lower the stem of dial gauge to contact the cone shaft and zero reading. Set the timer to 5s, and then press the release button. After 5s, the controller will lock the cone shaft. Record the dial reading to the nearest 0.1mm. Record this reading as the cone penetration. Lift out the cone and clean it carefully. The moisture content sample of about 10g from the area penetrated by the cone be taken using the tip of small spatula.

Placed in a numbered moisture content container, which was weighed, oven dried and weighed and determines the moisture content. The amount of water added shall be such a range of penetration values approximately 15mm to 25mm covered by the three the addition of water. Repeat procedure for difference sample of bottom ash proportion which are 0%,5%,10%,15% and 20%.

From the graph, the moisture content corresponding to a cone penetration of 20mm is read off to the nearest 0.1%, the result is reported to the nearest whole number as the liquid limit (cone test).

Figure 3.10: Liquid limit test

Figure 3.10 shows the liquid limit apparatus to determine the liquid limit of peat.

#### 3.5.2.2 Plastic Limit Test

Apparatus that be used in this test are glass plate, a separate glass plate for rolling of threads, spatulas, and moisture content apparatus.

Firstly, take about 20g of the prepared soil paste and spread it on glass mixing plate so that it can partially dry. Mix occasionally to avoid local drying out. Then divide this sample into two sub-samples of about 10g each. Divide each sub-samples into four more.

Mould the soil in fingers to equalize the distribution of moisture content, then from the soil into a thread about 6mm diameter between the first finger and thumb of each hand. It is important to maintain a uniform rolling pressure throughout and do not reduce pressure as the thread approaches 3mm diameter. As soon as the crumbling stage is reached, gather the crumbled threads and place them into a weighed moisture content container. Replace the lid immediately.

Repeat procedure for the other pieces of soil, and place in the same container. Weighted the container and soil and dry in the oven overnight, cool and weigh dry, as in the standard moisture content procedure. Repeat procedure on the other set of four portions of the soil, using a second moisture content container.

Calculate the moisture content of the soil in each of the two containers. Take the average of the two results. If the differ by more than 0.5% moisture content, the test should be repeated.

The difference between the liquid limit and the plastic limit and the plastic limit is calculated to give the plasticity index (PI) of the soil:

$$PI = LL - PL$$

This test is repeated for 6 difference samples which are natural peat, 0% BA, 5% BA, 10% BA, 15% BA and 20% BA.

Figure 3.11: Plastic limit test

Figure 3.11 shows that the soil be rolled into a threat in between 6mm diameter and placed in the container for one night oven dry to get it moisture content result and plasticity condition.

### 3.5.4 Specific Gravity (ASTM D4253)

The objective of this test is to determine specific gravity of soils consisting of clay, silt, and sand-sized particles.

The apparatus that need such as four specific gravity bottles (pycnometer bottle) with stopper, vacuum desiccators (desiccators containing anhydrous silica gel), balance, drying oven (105ºC - 110ºC) and Kerosene.

Firstly, clean the density bottle and stopper. Dry and weight the bottle with the stopper. Take some soils from sample that has been oven dried at temperature of 105 - 110ºC. Sample is cooled inside the desiccators. Take about 5-10g sample of soil that passes through BS 2mm sieve and transfer the specimen to the density bottle. Weight the bottle, contents and stopper. Kerosene should be added not more half of density bottle.

Place the bottle and content without stopper in the vacuum desiccators. Leave the bottle in the desiccators for at least one hour or continue until no further loss of air is apparent. Then shake the bottle carefully. Add in kerosene to make it full. Wipe dry the surface of the bottle. Then leave for about an hour in room temperature.

Place the stopper. Wipe dry the surface of the bottle and weight it together with its content and stopper. Then remove soil and water from the bottle. Clean the bottle and refill it with kerosene only until full. Leave it for about one hour, topping up the kerosene if necessary. Place the stopper and wipe dry the surface. Weight the bottle, stopper and its content (water). Repeat test at least twice for the same soil sample.

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

The calculation of specific gravity will be as follow:

$$G_s = \frac{w_2 - w_1}{(w_4 - w_1) - (w_3 - w_2)}$$

Where: $w_1$ = Weight of bottle and stopper in g

$w_2$ = Weight of bottle, stopper and dry soil in g

$w_3$ = Weight of bottle, stopper**,** water and soil in g

$w_4$ = Weight of bottle, stopper and water in g

Figure 3.12: Specific density test

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 Introduction

The results are analysed based on the classification of peat, engineering properties of peat and effects of bottom ash mixed to peat. This result was discussed by cross referring the results from other researchers.

On the classification of peat, analysis of results is on the undrained shear strength from unconfined compressive strength and characteristics of peat from von post degree of decomposition test.

On the characterization of engineering properties of peat, the properties of peat is focused on the getting the natural moisture content from moisture content test, Atterberg limit from liquid limit test, specific gravity from specific gravity test, content of fibre from fibre content test and content of organics from organic content test.

The effects of percentage of bottom ash to the engineering properties of peat from the addition of peat with stabilizers is discussed on the improved undrained shear strength and moisture contents results from unconfined compressive strength test, Atterberg limit from liquid limit test and plastic limit test.

## 4.2 Classification of Peat

Classification of peat is done by referring to some basic test that shows the characteristic of peat. Degree of decomposition is done to classify the peat on its properties from Von Post Scale.

### 4.2.1 Degree of Decomposition

From the Von Post Scale on result of peat soil was moderately highly decomposed peat with a very indistinct plant structure. When squeezed, about one-third of the peat escapes between the fingers. The residue was very pasty but shows the plant structure more distinctly than before squeezing.

The soil was on H6 where the Pekan peat results show that Pekan peat is either fibric or hemic peat that has fiber content higher than 36.64%. Pekan peat was classified as fibrous peat with degree of decomposition test.

## 4.3 Engineering Properties of Peat

Preliminary laboratory work done for categorization of engineering properties of peat to be analysed are focused on fiber content, liquid limit, moisture content, organic content and specific gravity.

### 4.3.1 Fiber Content

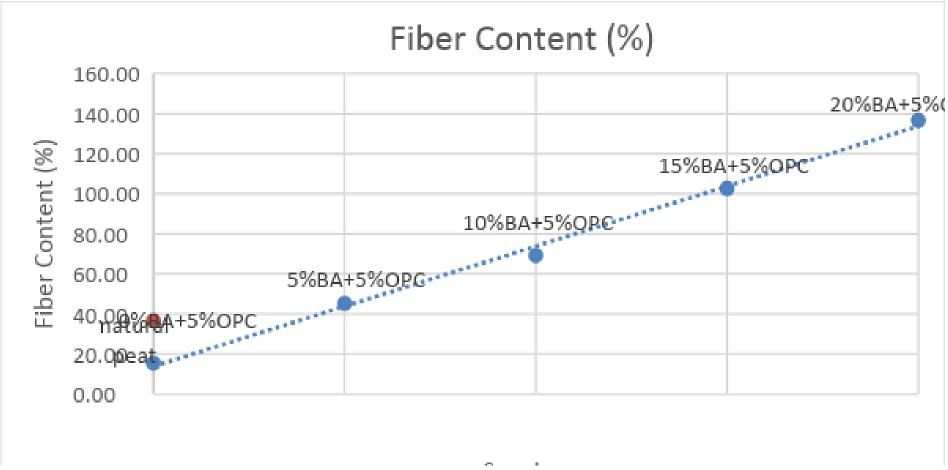


Figure 4.1: Fiber content of peat soil stabilized with bottom ash

Figure 4.1 shows the fiber content of Pekan peat at the natural state was 36.64%. Based on the reference in the literature review, fiber content in table 2.9 is in between 90.25 - 90.49%. The result was highly different because of the amount of sample be tested during fibre content test which less fibre otherwise more soil.

Besides that, effect of addition of bottom ash as stabilizer and Ordinary Portland Cement (OPC) make the graph directly proportional increase from 5% until 20% of BA. Treated peat has more fiber than untreated peat which is 15.39%, 45.20%, 69.12%, 102.57% and 136.63%.

### 4.3.2 Liquid Limit

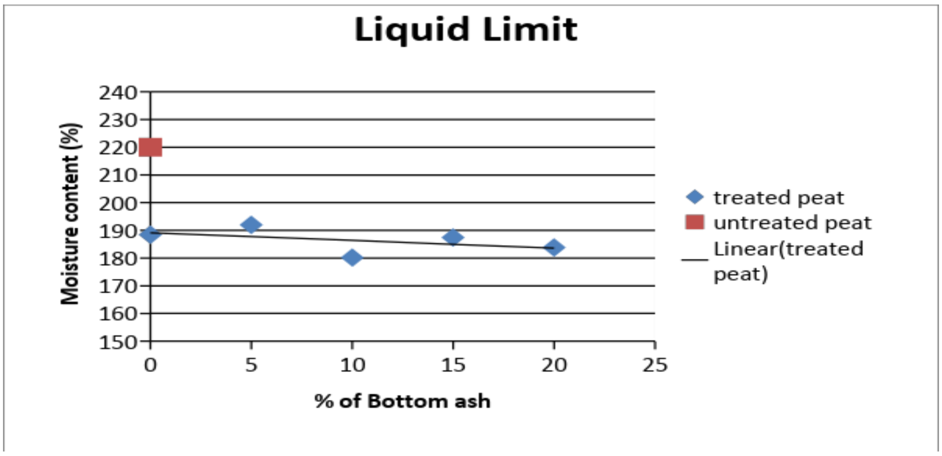


Figure 4.2: Liquid limit of Pekan Peat stabilized with bottom ash

Figure 4.2 shows the result of Pekan peat to determine the liquid limit through Atterberg limit test. Based on the reference in the literature review, liquid limit in table 2.9 is in the range of 220.30-220.65%. Table 4.2 shows the result of natural peat was 220% which was same as in reference.

From the literature review, research study by A T S Azhar et al. (2007) for undisturbed and reconstituted Parit Nipah show the moisture content were 545% and 328% and for liquid limit undisturbed peat shows the highest value which was 360% followed by reconstituted peat at 362%. On the other side, research studied by Duraisamy et al. (2007) on Sungai Buaya in west coast of Peninsular Malaysia the natural moisture content of 241% that is the lowest also shown the lower value of liquid limit that is 275% and the highest value of natural moisture content of 350% shows the highest value of liquid limit that was 398%.

Moreover, there were changes in addition of bottom ash as stabilizer and Ordinary Portland Cement (OPC) make the graph trend decrease from 5% until 20% of BA. Treated peat less liquid limit than untreated peats which were 188.40%, 192%, 180.2%, 187.42% and 183.8%. This is because of influence of the bottom ash act as stabilized which can make the soil less moist and having pozzolanic reaction by adding of OPC as binder.

### 4.3.3 Moisture Content

Peat usually has very high natural water content due to its natural water holding capacity. The soil has high water content because it has low bulk density and low bearing capacity as a result of high pore volume and buoyancy.

Based on S.Islam (2008), West Malaysia about the water content of peat soil is in between 200% to 700% and the unit weight of inorganic soils is high compared to peat soil. For Pekan peat soil, water content was obtained to be 220% which was reasonable for peat. High water content was become low bearing capacity and low bulk density as result of high buoyancy and high pore volume.

### 4.3.4 Plastic Limit

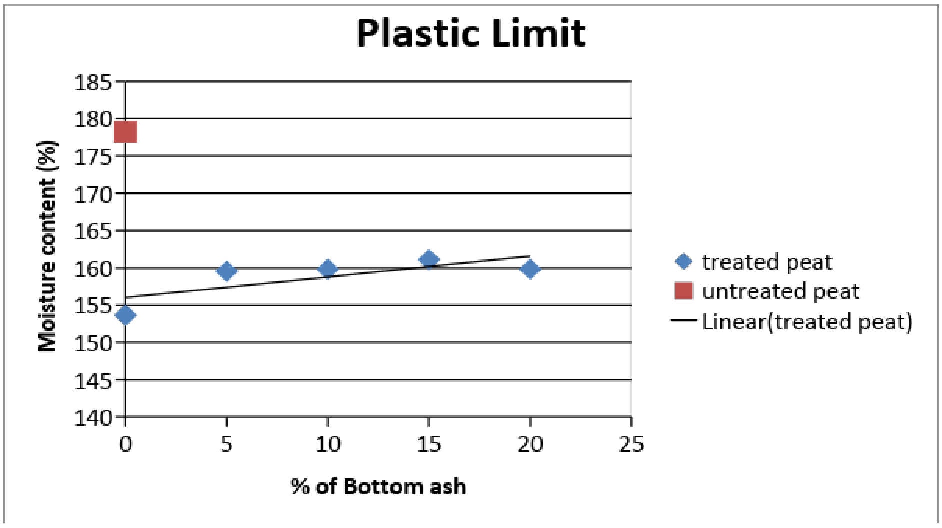


Figure 4.3: Plastic limit of Pekan Peat stabilized with bottom ash

Figure 4.3 shows the liquid limit that carry out from the Atterberg limit test to know either Pekan peat was plastic or opposite. At the natural state was 178.22% which higher than reference in the literature review, liquid limit in table 2.8 which was 115.8%. The result was significantly different when mix with bottom ash and OPC which were 153.65%, 159.54%, 159.81%, 161.09% and 159.81%.

### 4.3.5 Organic Content

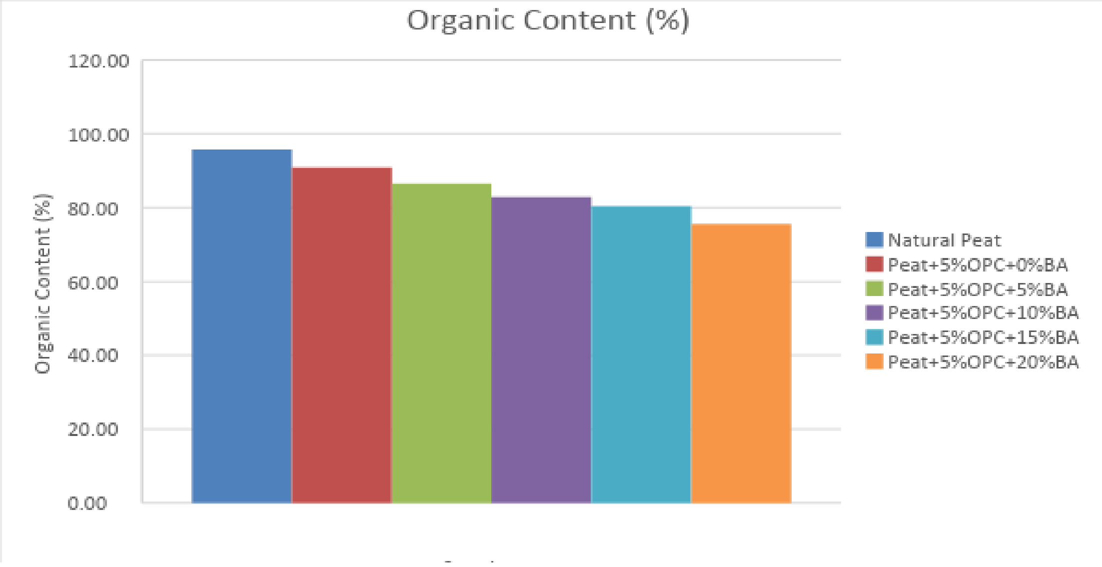


Figure 4.4: Organic content of Pekan Peat stabilized with bottom ash

Soil that has organic content above 75% is considered as peat from Table 4.4. Referring to figure 4.4, natural peat was the higher percentage of organic content compared to treat peat by addition of BA and OPC.

Besides that, addition of bottom ash and OPC from 5% to 20% shows the decreasing trend of the organic content.

### 4.3.6 Specific Gravity

From table 2.10, the bog peat has specific gravity value of 1.4 – 1.6, on the other hand for fen peat is 1.8. At west coast of Peninsular Malaysia, the range is from 1.38 to 1.7. Pekan peat had higher value compared with west coast of Peninsular Malaysia peat with specific gravity which is in range of 1.4 – 1.8 which is 1.44.

## 4.4 Relationship between Engineering Properties with Undrained Shear Strength

The shear strength of peat can be defined as the maximum stress applied on any plane in a peat mass at some strain considered as a failure. By plotting stress- strain relationship and bottom ash percentage relationship, the unconfined shear strength can be determined. Hence, the effectiveness of shear strength properties (c' and Ø') can be measured through this study.

### 4.4.1 Liquid limit effect to Undrained Shear Strength

Table 4.5 show the stress- strain relationship that has been performed between untreated and treated peat to determine the maximum value of deviator stress, $\sigma^d$ max versus axial strain, ϵa during the shearing stage. The $\sigma^d$ max for untreated and treated peat gradually increased when σ' increased. On the other hand, the liquid limit showed, (%) of bottom ash versus (%) of moisture content was performed in Figure 4.2 for untreated and treated peat soil. Based on the results, the (%) BA increased along with (%) moisture content but in the end of 20% bottom ash, the values are slightly dropped.

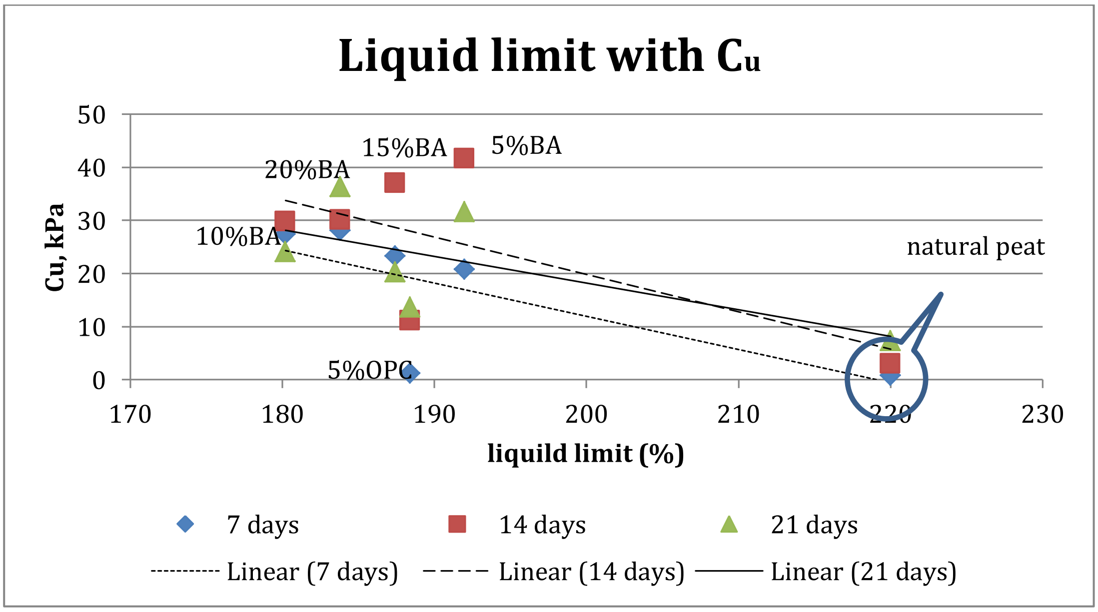


Figure 4.5: Relationship between Liquid limit with Cu

Table 4.14 shows the result of Pekan peat shows a decreasing of liquid limit if compare with the natural peat which has been added with the stabilizer which was bottom ash for 5%, 10%, 15% and 20% from the sample weight. From figure 4.5, the entire sample shows in trend of decreasing liquid limit except for natural peat where if the value of percentage stabilizer which was bottom ash was high, the higher the decreasing of liquid limit.

Referring to figure 4.12, results obtained on the undrained shear strength, Cu from the all curing period with different amount of BA was plotted. Sample with addition of 20% bottom ash on the 21 days curing show the highest reading of Cu if compare with other sample in 21 days curing. Besides that, it also in trend of increasing compared to natural peat. The undrained shear strength of peat with 20% BA shows the lower reading of liquid limit which was 183.8% prove the addition of high percentage of BA will increase the Cu.

This statement shows the results of peat having lower liquid limit when having lower moisture content and strengthen the statement of why Pekan peat increase in undrained shear strength and decrease of moisture content and liquid limit.

### 4.4.2 Curing period effect to Undrained shear strength

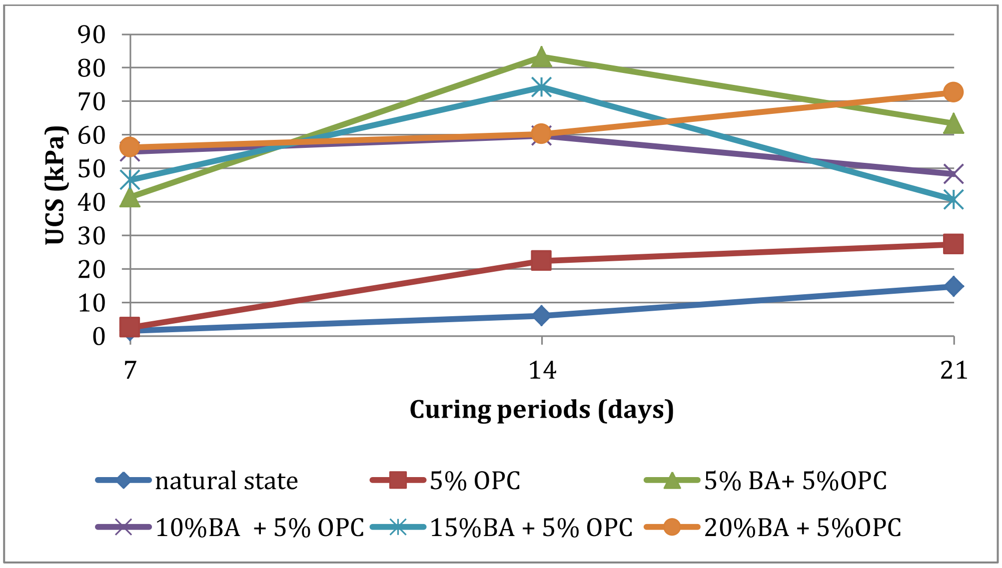


Figure 4.6: Relationship between curing period with unconfined compressive strength (UCS)

UCS test was done for all six different samples which were cured over three different curing periods. Figure shows UCS variation with curing period for all types of samples. From the figure, an increasing trend with the curing period can be observed in the UCS. The highest undrained shear strength reading was at 14 days curing period which was at 5% BA and 5% OPC. Otherwise, declination trend at the curing period 21 days show that the optimum curing period for treated peat was 14 days. This is because of the increased pore water consumption by bottom ash from peat as time passes on during the curing period to form cementing product during the hydration process.

### 4.4.3 Plastic limit effect to Undrained shear strength

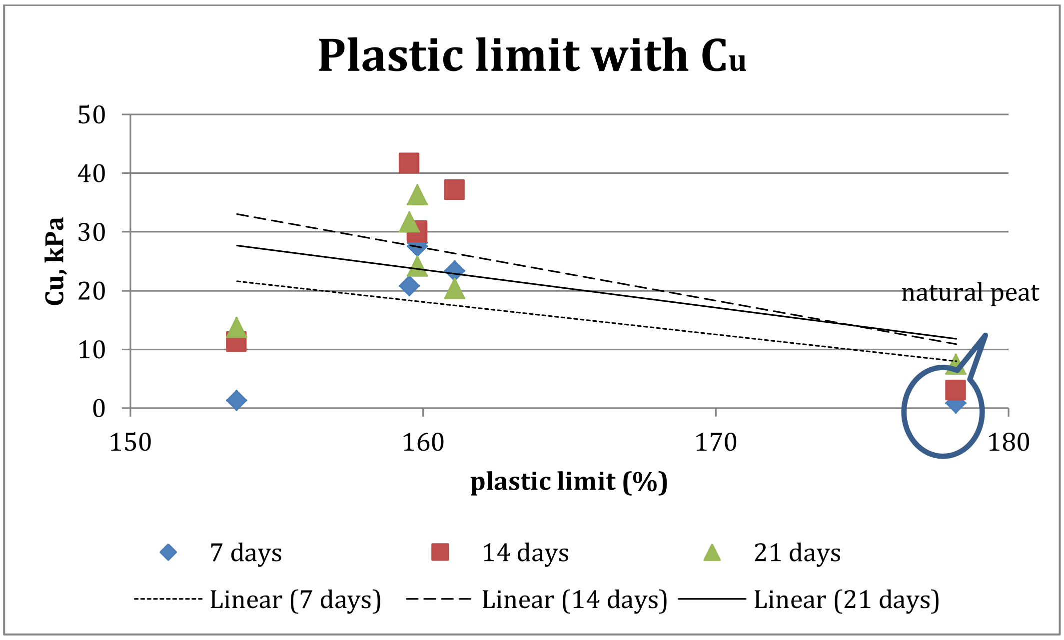


Figure 4.7: Relationship between plastic limit with undrained shear strength (Cu)

Based on the graph, the trend of the plastic limit and Cu was seen decreasing by addition of bottom ash. The result is highly different when mixed with bottom ash and OPC which are 153.65%, 159.54%, 159.81%, 161.09% and 159.81%. Hence, then decreasing trend of Cu with plastic limit show that the addition of BA will increase the undrained strength (Cu) by lowering the plasticity behaviour of peat. In other words, it was the percentage moisture content at which a soil changes with decreasing wetness from the plastic to the semi- solid consistency influence the strength of peat.

### 4.4.4 Plastic index effect to Undrained shear strength

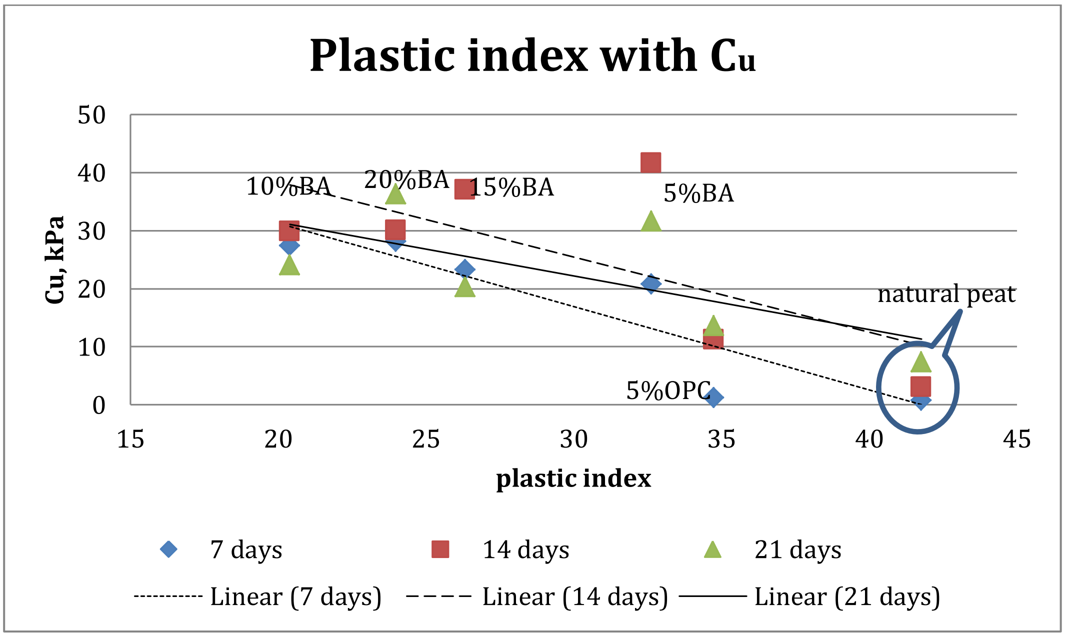


Figure 4.8: Relationship between plastic index with undrained shear strength (Cu)

Figure 4.8 shows, the graph trend of the plastic index and Cu was decreasing by addition of bottom ash.The plasticity index (PI) is a measure of the plasticity of a soil. The plasticity index is the size of the range of water contents where the soil exhibits plastic properties. The PI is the difference between the liquid limit and the plastic limit (PI = LL-PL). By addition of bottom ash, the treated peat stabilized with decreasing of plastic index of the soils was 41.78% from untreated peat. Hence, the decreasing trend of Cu with plastic index shows that the addition of BA will increase the undrained strength (Cu) by lowering the plasticity. Even the soil was been stabilized from 41.78% to 23.99%, the soil still in range high plasticity. Besides that, it also because of chemical reaction (pozzolanic) that takes place during curing process which the moisture content of sample tend to loss due to increase of temperature and hydration process.

### 4.4.5 Organic content effect to Undrained Shear Strength

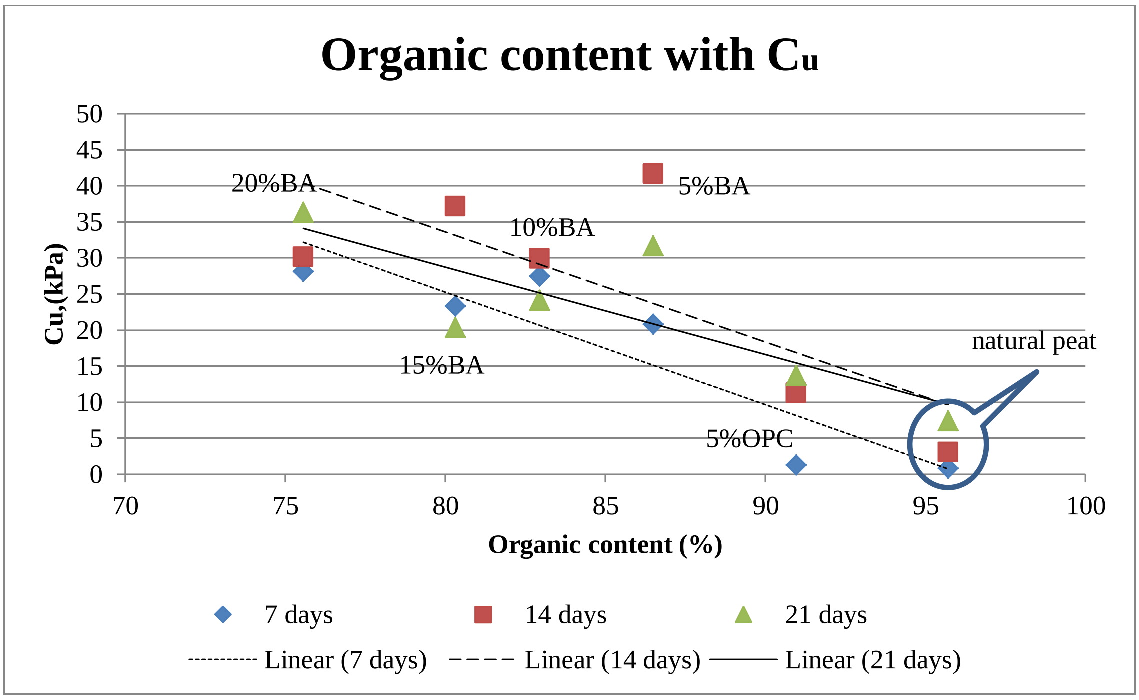


Figure 4.9: Relationship between organic content with undrained shear strength ($C_u$)

From the graph it shows, the organic content and the undrained shear strength was in decreasing trend. The lower the organic content was, the higher the undrained shear strength recorded. This is because the peat mainly composed of fibrous organic matters and has partly decomposed plant such as leaves, root and stems. Mostly organic residues of plant in peat soil incompletely decomposed through lack of oxygen. The decreasing in organic content of peat soil cause by the rate of the pozzolanic reaction controlled by external factors such as the mix proportions of bottom ash, the amount of water and space available for the formation and growth of hydration products and the temperature of reaction

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#### 4.4.6 Fiber content effect to Undrained Shear Strength

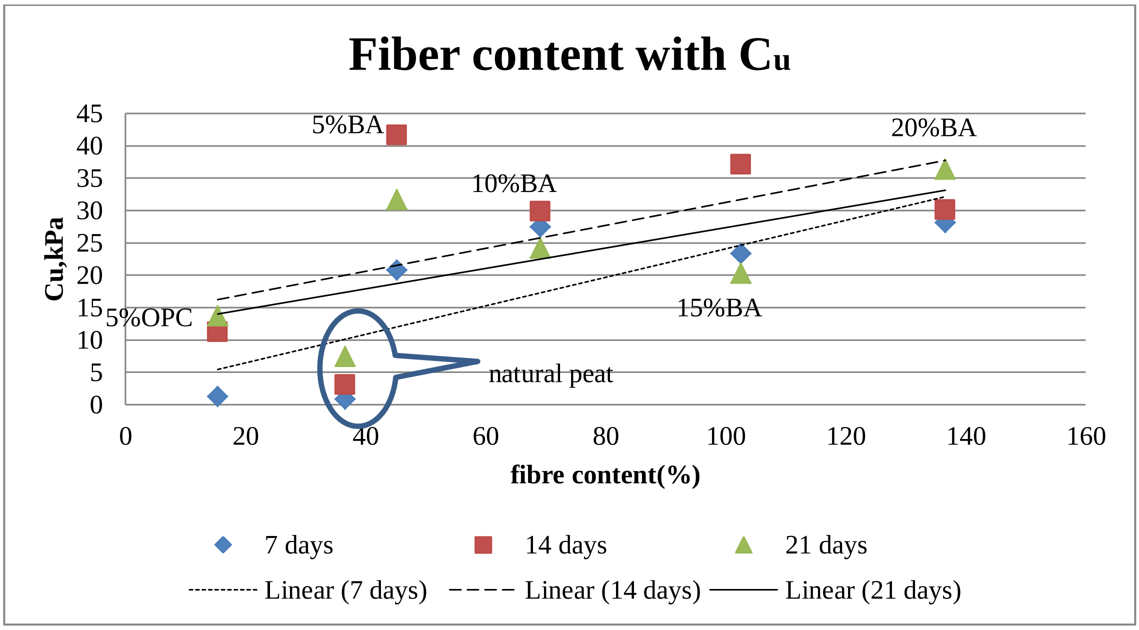


Figure 4.10: Relationship between fiber content with undrained shear strength ($C_u$)

Based on the graph, the trend of the fiber content and Cu is increasing by addition of bottom ash. The fiber content for natural peat was happened to be lower because of the amount of sample tested during fibre content test was not representative enough of the whole batch of soil. Besides, the fiber content increase influent of amount bottom ash added into the peat soil and not because of pozzolanic reaction. The increase was partly because of the method used in the measuring fiber content in this study.

### 4.5 Effect of Bottom Ash amount to Unconfined Compressive Strength.

The effects of bottom ash are focused on amount of stabilizer to be mixed with peat and the result of unconfined compressive strength.

### 4.5.1 Unconfined Compressive Strength Result

Table 4.1 shows the average unconfined compressive strength result of Pekan peat with its curing days and the amount of bottom ash added.

Table 4.1: Unconfined compressive strength of Pekan Peat

| Curing day | Bottom ash (%) | OPC (%) | Shear strength (kPa) |
|---|---|---|---|
| 7 days | Natural peat | 0 | 1.62 |
| | 0 | 5 | 2.51 |
| | 5 | 5 | 41.53 |
| | 10 | 5 | 54.90 |
| | 15 | 5 | 46.60 |
| | 20 | 5 | 56.22 |
| 14 days | Natural peat | 0 | 6.04 |
| | 0 | 5 | 22.44 |
| | 5 | 5 | 83.26 |
| | 10 | 5 | 59.70 |
| | 15 | 5 | 74.19 |
| | 20 | 5 | 60.18 |
| 21 days | Natural peat | 0 | 14.77 |
| | 0 | 5 | 27.32 |
| | 5 | 5 | 63.32 |
| | 10 | 5 | 48.27 |
| | 15 | 5 | 40.62 |
| | 20 | 5 | 72.63 |

### 4.5.2 Effect of Bottom Ash stabilized peat soil to Curing Period.

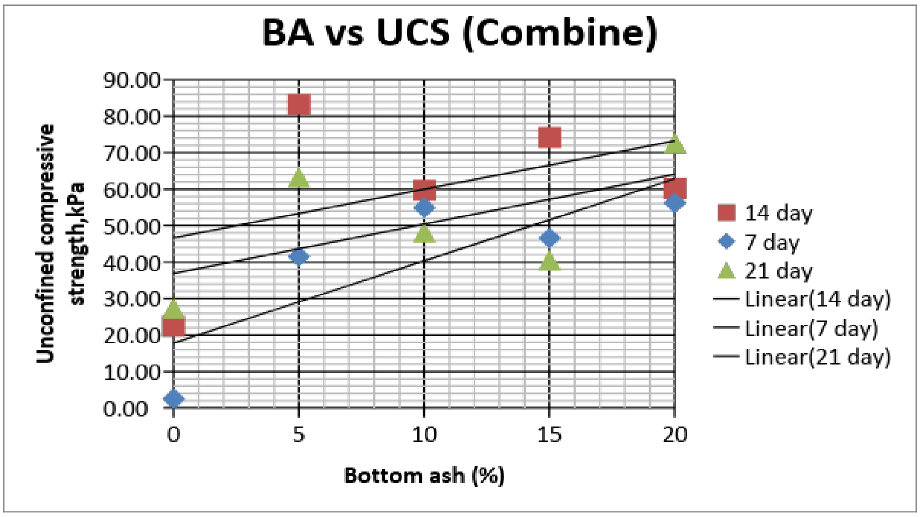


Figure 4.11: UCS result of mixing bottom ash with different curing period

Studies are carried out to examine the effect of bottom ash on the unconfined compressive strength of the Pekan peat soil samples, namely to examine the percentages of bottom ash and curing period, as well as the influence of organic content on the unconfined compressive strength of the soil samples.

Figure 4.11 shows the plot of unconfined compressive strength with percentages of bottom ash. It also shows the influence of curing period on the unconfined compressive strength of the sample.

As shown, the bottom ash increase the unconfined compressive of the soil samples. Similarly higher strength is obtained from samples that have been cured 21 days compared with the 7 days cured samples.

### 4.5.3 Relationship between Bottom ash with Undrained Shear Strength

Undrained shear strength ($C_u$) is equal to half of Shear Stress ($q_u$)

$$C_u = \frac{1}{2} \times q_u$$

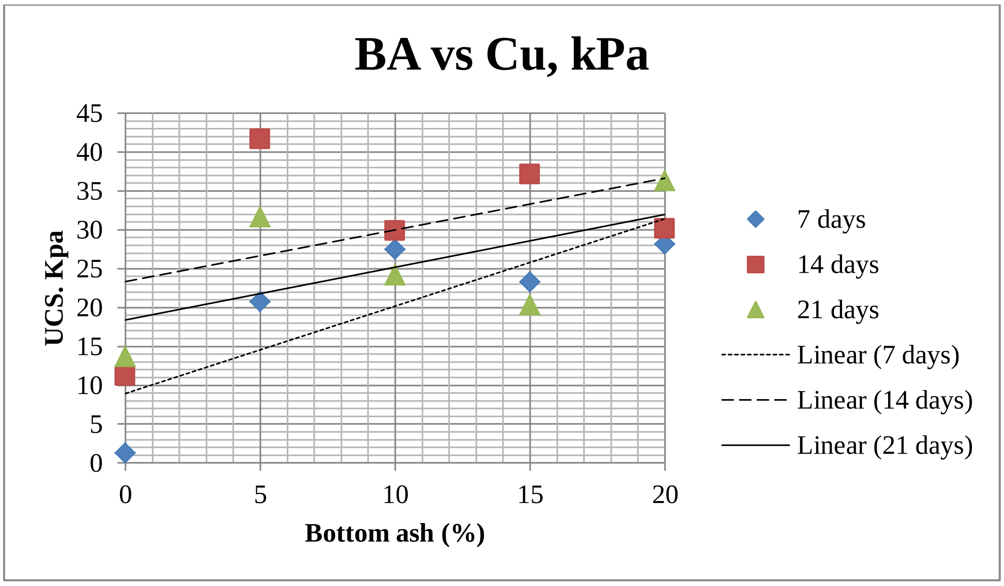


Figure 4.12: Undrained shear strength result of mixing bottom ash

Figure 4.12 shows result of undrained shear strength peat on treat and untreated peat. The highest increment of peat was at 5% bottom ash cured for 14 days and mix with 5% of Ordinary Portland Cement.

From above, produce the undrained shear strength development of stabilized peat specimens over percentages of bottom ash in varying composition of cement. Generally, the stabilized peat specimen of all composition of bottom ash and cement show significant improvement in undrained shear strength after curing 21 days.

### 4.5.4 Relationship between Bottom ash with Bearing Capacity

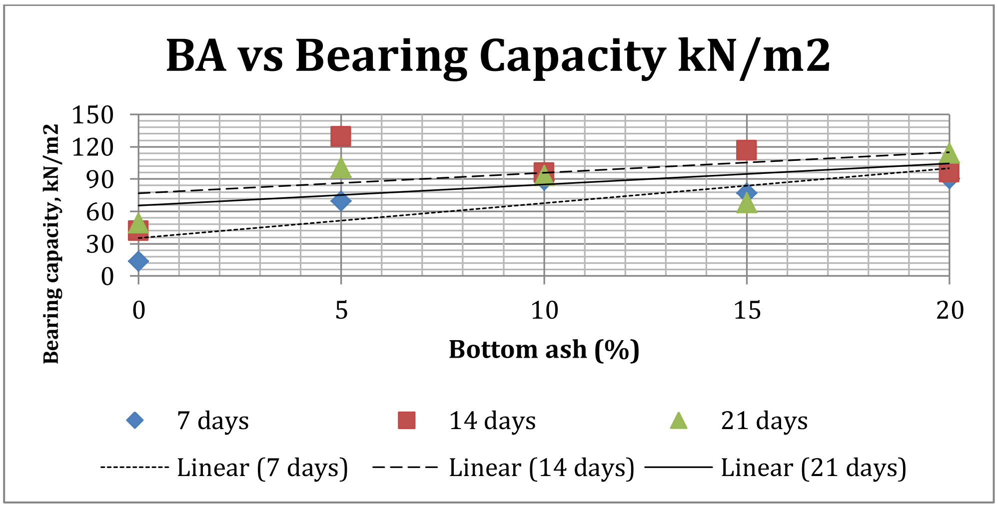


Figure 4.13: Bearing capacity result of mixing bottom ash.

Based on Terzaghi's bearing capacity theory, load is resisted by shear stresses at edges of three zones under the footing and the overburden pressure, q (=γD) above the footing. The first term in the equation is related to cohesion of the soil. The second term is related to the depth of the footing and overburden pressure. The third term is related to the width of the footing and the length of shear stress area. The bearing capacity factors, Nc, Nq, Nγ, are function of internal friction angle, φ.

Terzaghi's Bearing capacity equations:

Strip footings: $Qu = c\ Nc + \gamma\ D\ Nq + 0.5\ \gamma\ B\ N\gamma$ [1.1]

Square footings: $Qu = 1.3\ c\ Nc + \gamma\ D\ Nq + 0.4\ \gamma\ B\ N\gamma$ [1.2]

Circular footings: $Qu = 1.3\ c\ Nc + \gamma\ D\ Nq + 0.3\ \gamma\ B\ N\gamma$ [1.3]

Where:

C: Cohesion of soil

γ : unit weight of soil

D: depth of footing

B: width of footing

Nc, Nq, Nr: Terzaghi's bearing capacity factors depends on soil friction angle, φ.

$Nc=\cot\varphi(Nq - 1)$ [1.4]

$$Nq=e^{2(3\pi/4-\varphi/2)\tan\varphi} / [2\cos^2(45+\varphi/2)] \quad [1.5]$$

$$N\gamma=(1/2)\tan\varphi(Kpr/\cos^2\varphi - 1) \quad [1.6]$$

Where:

Kpr=passive pressure coefficient.

Figure 4.13 shows the bearing capacity relationship that has been performed between percentages of bottom ash to determine the maximum value of allowable bearing capacity, Qu max. The Qu max for untreated and treated peat gradually increased when BA increased.

Figure 4.13 shows result of bearing capacity of peat on square footing by stabilized and unstabilized peat. From figure 4.13, shows the highest value of the bearing capacity for 7 days period was 90.4 $kN/m^2$ when using 20% of bottom ash. Moreover, the highest reading increment of peat bearing capacity was at 5% bottom ash cured for 14 days and mix with 5% of Ordinary Portland Cement which was 129.19 $kN/m^2$. Hence, the highest bearing capacity reading for 21 days curing was at 20% of bottom ash with 113.94 $kN/m^2$. From figure 4.13, all sample shows in trend of increasing bearing capacity except for natural peat where if the value of percentage stabilizer which was bottom ash was high, the higher the increasing of bearing capacity.

Besides that, in figure 4.13 it indicates the bearing capacity of stabilized peat specimens over percentages of bottom ash in varying composition of cement provide positive improvement and increase trend of the graph. In other side, natural peat soil shows lower value bearing capacity in all curing period compare stabilized peat specimen of all composition of bottom ash and cement which show significant improvement after curing period.

# CHAPTER 5

# CONCLUSION & RECOMMENDATION

## 5.1 Conclusion

Based on the laboratory investigation on effect of Bottom Ash and Ordinary Portland cement in stabilizing Pekan peat soil as filler and binder finally provides the conclusion. The classification of Pekan peat which is completely undecomposed peat is H6 which is moderately highly decomposed peat with a very indistinct plant structure.

One unique characteristics of peat soil is high liquid limit. Liquid limit was calculated in this soil in natural state using liquid limit test was 220%. Other significant properties of peat soil its organic content, fibre content and specific gravity which were 95.72%, 36.64% and 1.44 respectively. After stabilizing the peat soil, there was a different result compared to the natural state of the peat soil. There is a significant improvement and positive result that can benefit the construction industry. The undrained shear strength test shows, the increasing of Cu of stabilized peat depends on the liquid limit, the plastic limit, organic content and fiber content in improving untreated peat.

On the other hand, unconfined compressive strength of natural peat soil was very low and from UCT test it was found that the strength were 1.62, 6.04 and 14.77 kPa for 7, 14 and 21 days curing period. As improvisation step was taken the changes in unconfined compressive strength of peat soil sample was namely to examine the effect of additives content and the suitable curing period as shown in figure 4.5 clearly provide an indication that unconfined compressive strength with bottom ash showing the influences of curing period of the soil samples. Similarly higher strength was obtained from samples that had been cured for 14 days compared with 7 days and 21 days cured sample. Otherwise, addition of Ordinary Portland cement may carry out pozzolanic reaction which increase in strength of cement stabilised with increase time curing, so, the suitable mature period for pozzolanic reaction was 14 days.

Besides, through this Unconfined Compressive Strength test produce the bearing capacity of the Pekan peat soil with different dosages of bottom ash which were 5%, 10%, 15% and 20%. In choosing the best addition of bottom ash to stabilize peat soil in strength, the higher bearing capacity been chosen to carry heavy load of building construction on the peat area. The undrained shear strength of stabilized and cured for 14 days with addition of 15% of bottom ash and 5% OPC shows that the stabilized peat has gain strength with high value of undrained shear strength and bearing capacity which were 37.095 kPa and 116.18 kN/$m^2$ compare to unstablized peat soil.

## 5.2 Recommendation

In this era, building and house construction development was very extremely huge and need a lot of new area to be explore. One of the new areas to be developed was at swamp peat locations which have around Peninsular Malaysia especially in Pekan, Pahang.

Peat soil has unique characteristics and there was a tendency in construction industry to avoid this type of problematic soil. In other to overcome this problem, proper soil stabilisation method which was economical and consume less time can overcome this type of problem. Some methods have been taken to become more effective, there are some approach and recommendation for future research in improving this method in better way.

First, I recommend doing this research using different types of soil to know the workability on that soil and for improvising purpose. This approach is to make sure this bottom ash stabilization can be used on other type of soil such as clay, silt and sand. If it has positive result and improvement on that soil which mean this method is flexible and valid to be applied.

Lastly, I recommend carrying out direct shear test to compare and check the current result with the new result for validation purpose. It is because in this bottom ash stabilization method is directly used unconfined compressive strength to find the shear strength. In making the result strongly valid, comparison between this tests need to perform to know relation and different of both test.

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## APPENDIX A

### TEST RESULTS

Table 4.1: Fiber Content of Pekan Peat

| Sampel | Fiber content (%) |
|---|---|
| Natural peat | 36.64 |
| Peat + 5% OPC | 15.39 |
| Peat + 5% bottom ash + 5% OPC | 45.20 |
| Peat + 10% bottom ash + 5% OPC | 69.12 |
| Peat + 15% bottom ash + 5% OPC | 102.57 |
| Peat + 20% bottom ash + 5% OPC | 136.63 |

Table 4.2: Liquid limit of Pekan Peat

| Sampel | Liquid limit (%) |
|---|---|
| Natural peat | 220 |
| Peat + 5% OPC | 188.4 |
| Peat + 5% bottom ash + 5% OPC | 192 |
| Peat + 10% bottom ash + 5% OPC | 180.2 |
| Peat + 15% bottom ash + 5% OPC | 187.42 |
| Peat + 20% bottom ash + 5% OPC | 183.8 |

Table 4.3: Plastic limit of Pekan Peat

| Sampel | Plastic limit (%) |
|---|---|
| Natural peat | 178.22 |
| Peat + 5% OPC | 153.65 |
| Peat + 5% bottom ash + 5% OPC | 159.54 |
| Peat + 10% bottom ash + 5% OPC | 159.81 |
| Peat + 15% bottom ash + 5% OPC | 161.09 |
| Peat + 20% bottom ash + 5% OPC | 159.81 |

Table 4.4: Organic content of Pekan Peat

| Sampel | Organic content (%) |
|---|---|
| Natural peat | 95.72 |
| Peat + 5% OPC | 90.96 |
| Peat + 5% bottom ash + 5% OPC | 86.50 |
| Peat + 10% bottom ash + 5% OPC | 82.94 |
| Peat + 15% bottom ash + 5% OPC | 80.31 |
| Peat + 20% bottom ash + 5% OPC | 75.57 |

Table 4.5: Liquid limit with Undrained shear strength

| Sample | Liquid limit (%) | Cu (kPa) | | |
|---|---|---|---|---|
| | | 7 days curing | 14 days curing | 21 days curing |
| Natural peat | 220 | 0.81 | 3.02 | 7.385 |
| Peat + 5% OPC | 188.4 | 1.255 | 11.22 | 13.66 |
| Peat + 5% bottom ash + 5% OPC | 192 | 20.765 | 41.63 | 31.66 |
| Peat + 10% bottom ash + 5% OPC | 180.2 | 27.45 | 29.85 | 24.135 |
| Peat + 15% bottom ash + 5% OPC | 187.42 | 23.3 | 37.095 | 20.31 |
| Peat + 20% bottom ash + 5% OPC | 183.8 | 28.11 | 30.09 | 36.315 |

Table 4.6: Plastic limit with Undrained shear strength

| Sample | Plastic limit (%) | Cu (kPa) | | |
|---|---|---|---|---|
| | | 7 days curing | 14 days curing | 21 days curing |
| Natural peat | 178.22 | 0.81 | 3.02 | 7.385 |
| Peat + 5% OPC | 153.65 | 1.255 | 11.22 | 13.66 |
| Peat + 5% bottom ash + 5% OPC | 159.54 | 20.765 | 41.63 | 31.66 |
| Peat + 10% bottom ash + 5% OPC | 159.81 | 27.45 | 29.85 | 24.135 |
| Peat + 15% bottom ash + 5% OPC | 161.09 | 23.3 | 37.095 | 20.31 |
| Peat + 20% bottom ash + 5% OPC | 159.81 | 28.11 | 30.09 | 36.315 |

Table 4.7: Organic content with Undrained shear strength

| Sample | Organic content (%) | Cu (kPa) | | |
|---|---|---|---|---|
| | | 7 days curing | 14 days curing | 21 days curing |
| Natural peat | 178.22 | 0.81 | 3.02 | 7.385 |
| Peat + 5% OPC | 153.65 | 1.255 | 11.22 | 13.66 |
| Peat + 5% bottom ash + 5% OPC | 159.54 | 20.765 | 41.63 | 31.66 |
| Peat + 10% bottom ash + 5% OPC | 159.81 | 27.45 | 29.85 | 24.135 |
| Peat + 15% bottom ash + 5% OPC | 161.09 | 23.3 | 37.095 | 20.31 |
| Peat + 20% bottom ash + 5% OPC | 159.81 | 28.11 | 30.09 | 36.315 |

Table 4.8: Fibre content with Undrained shear strength

| Sample | Fibre content (%) | Cu (kPa) | | |
|---|---|---|---|---|
| | | 7 days curing | 14 days curing | 21 days curing |
| Natural peat | 36.64 | 0.81 | 3.02 | 7.385 |
| Peat + 5% OPC | 15.39 | 1.255 | 11.22 | 13.66 |
| Peat + 5% bottom ash + 5% OPC | 45.2 | 20.765 | 41.63 | 31.66 |
| Peat + 10% bottom ash + 5% OPC | 69.12 | 27.45 | 29.85 | 24.135 |
| Peat + 15% bottom ash + 5% OPC | 102.57 | 23.3 | 37.095 | 20.31 |
| Peat + 20% bottom ash + 5% OPC | 136.63 | 28.11 | 30.09 | 36.315 |

Table 4.9: Unconfined compressive strength of Pekan Peat

| Curing day | Bottom ash (%) | OPC (%) | Shear strength (kPa) |
|---|---|---|---|
| 7 days | Natural peat | 0 | 1.62 |
| | 0 | 5 | 2.51 |
| | 5 | 5 | 41.53 |
| | 10 | 5 | 54.90 |
| | 15 | 5 | 46.60 |
| | 20 | 5 | 56.22 |
| 14 days | Natural peat | 0 | 6.04 |
| | 0 | 5 | 22.44 |
| | 5 | 5 | 83.26 |
| | 10 | 5 | 59.70 |
| | 15 | 5 | 74.19 |
| | 20 | 5 | 60.18 |
| 21 days | Natural peat | 0 | 14.77 |
| | 0 | 5 | 27.32 |
| | 5 | 5 | 63.32 |
| | 10 | 5 | 48.27 |
| | 15 | 5 | 40.62 |
| | 20 | 5 | 72.63 |

# APPENDIX B

## BEARING CAPACITY CALCULATIONS

### Terzaghi's Theory of Bearing Capacity

**Peat soil for 7 days**

Gross ultimate bearing capacity

1) **Peat soil + 5% OPC**

c'= 1.255 kN/$m^2$ Ø = $3^o$ Fs = 3

Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/$m^3$

q = 1.5 x 14.126

= 21.189 kN/$m^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = $1.3(1.255)(6.62) + (1.5 \times 14.126)(1.35) + 0.4(14.126)(2)(0.06)$

qu = 40.09 kN/$m^2$

$q_{all}$ = qu/Fs = $\frac{40.09}{3} = 13.36$ kN/$m^2$

Q = $q_{all}B^2 = 13.36 \times 4$ = 53.45 kN

**2) Peat soil + 5% OPC + 5% Bottom ash**

c'= 20.765 kN/$m^2$ Ø = 3º Fs = 3

Assume, Df = 1.5 m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/$m^3$

q = 1.5 x 14.126
= 21.189 kN/$m^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = 1.3(20.765)(6.62)+(1.5×14.126)(1.35)+0.4(14.126)(2)(0.06)
qu = 207.99 kN/$m^2$

qall = qu/Fs = 207.99/3=69.33 kN/$m^2$
Q = qall$B^2$ = 69.33×4 = 277.32 kN

**3) Peat soil + 5% OPC + 10% Bottom ash**

c'= 27.45 kN/$m^2$ Ø = 3º Fs = 3

Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/$m^3$

q = 1.5 x 14.126
= 21.189 kN/$m^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = 1.3(27.45)(6.62)+(1.5×14.126)(1.35)+0.4(14.126)(2)(0.06)
qu = 265.52 kN/$m^2$

qall = qu/Fs = 265.52/3=88.51 kN/$m^2$
Q = qall$B^2$ = 88.51×4 = 354.03 kN

**4) Peat soil + 5% OPC + 15% Bottom ash**

c'= 23.3 kN/$m^2$ Ø = 3º Fs = 3
Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/$m^3$

q = 1.5 x 14.126
= 21.189 kN/$m^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = 1.3(23.3)(6.62)+(1.5×14.126)(1.35)+0.4(14.126)(2)(0.06)
qu = 229.81 kN/$m^2$

qall = qu/Fs = 229.81/3=76.60 kN/$m^2$
Q = qall$B^2$ = 76.60×4 = 306.41 kN

**5) Peat soil + 5% OPC + 20% Bottom ash**

c'= 28.11 kN/$m^2$ Ø = 3º Fs = 3
Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/$m^3$

q = 1.5 x 14.126
= 21.189 kN/$m^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = 1.3(28.11)(6.62)+(1.5×14.126)(1.35)+0.4(14.126)(2)(0.06)
qu = 271.20 kN/$m^2$

qall = qu/Fs = 271.20/3=90.40 kN/$m^2$
Q = qall$B^2$ = 90.40×4 = 361.61 kN

## 6) Natural state of peat soil

$c' = 0.81\ kN/m^2$ $\quad\quad Ø = 3^o \quad\quad Fs = 3$

Assume, $Df = 1.5m \quad\quad b \times h = 2m \times 2m$

**$qu = 1.3c'Nc + qNq + 0.4\gamma BN\gamma$**

$y = (1.44 \times 9.81)/1000 = 14.13\ kN/m^3$

$q = 1.5 \times 14.126$

$= 21.189\ kN/m^2$

$Nc = 6.62 \quad Nq = 1.35 \quad N\gamma = 14.1264$

$qu = 1.3(0.81)(6.62)+(1.5\times14.126)(1.35)+0.4(14.126)(2)(0.06)$

$qu = 36.27\ kN/m^2$

$qall = qu/Fs = 36.27/3=12.09\ kN/m^2$

$Q = qallB^2 = 12.09\times4 = 48.36\ kN$

**Terzaghi's Theory of Bearing Capacity**

**Peat soil for 14 days**

<u>Gross ultimate bearing capacity</u>

1) **Peat soil + 5% OPC**

c'= 11.22 kN/m$^2$ Ø = 3$^o$ Fs = 3

Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/m$^3$

q = 1.5 x 14.126

= 21.189 kN/m$^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = $1.3(11.22)(6.62) + (1.5 \times 14.126)(1.35) + 0.4(14.126)(2)(0.06)$

qu = 125.85 kN/m$^2$

$q_{all}$ = qu/Fs = $\frac{125.85}{3} = 41.95$ kN/m$^2$

Q = $q_{all}B^2 = 41.95 \times 4$ = 167.80 kN

## 2) Peat soil + 5% OPC + 5% Bottom ash

c'= 41.63 kN/$m^2$ Ø = 3º Fs = 3
Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/$m^3$

q = 1.5 x 14.126
= 21.189 kN/$m^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = 1.3(41.63)(6.62)+(1.5×14.126)(1.35)+0.4(14.126)(2)(0.06)
qu = 387.56 kN/$m^2$

qall = qu/Fs = 387.56/3=129.19 kN/$m^2$
Q = qall$B^2$ = 129.19×4 = 516.74 kN

## 3) Peat soil + 5% OPC + 10% Bottom ash

c'= 29.85 kN/$m^2$ Ø = 3o Fs = 3
Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/m3

q = 1.5 x 14.126
= 21.189 kN/$m^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = 1.3(29.85)(6.62)+(1.5×14.126)(1.35)+0.4(14.126)(2)(0.06)
qu = 286.18 kN/$m^2$

qall = qu/Fs = 286.18/3=95.39 kN/$m^2$
Q = qall$B^2$ = 95.39×4 = 381.57 kN

**4) Peat soil + 5% OPC + 15% Bottom ash**

c'= 37.095 kN/$m^2$ Ø = 3º Fs = 3
Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/$m^3$

q = 1.5 x 14.126
= 21.189 kN/$m^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = 1.3(37.095)(6.62)+(1.5×14.126)(1.35)+0.4(14.126)(2)(0.06)
qu = 348.53 kN/$m^2$

qall = qu/Fs = 348.53/3=116.18 kN/$m^2$
Q = qall$B^2$ = 116.18×4 = 464.71 kN

**5) Peat soil + 5% OPC + 20% Bottom ash**

c'= 30.09 kN/$m^2$ Ø = 3º Fs = 3
Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/$m^2$

q = 1.5 x 14.126
= 21.189 kN/$m^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = 1.3(30.09)(6.62)+(1.5×14.126)(1.35)+0.4(14.126)(2)(0.06)
qu = 288.24 kN/$m^2$

qall = qu/Fs = 288.24/3=96.08 kN/$m^2$
Q = qall$B^2$ = 90.40×4 = 384.33 kN

### 6) Natural state of peat soil

c'= 3.02 kN/$m^2$ Ø = $3^o$ Fs = 3
Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/$m^3$

q = 1.5 x 14.126
= 21.189 kN/$m^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = 1.3(3.02)(6.62)+(1.5×14.126)(1.35)+0.4(14.126)(2)(0.06)
qu = 55.29 kN/$m^2$

qall = qu/Fs = 55.29/3=18.43 kN/$m^2$
Q = qall$B^2$ = 18.43×4 = 73.72 kN

**Terzaghi's Theory of Bearing Capacity**

**Peat soil for 21 days**

Gross ultimate bearing capacity

1) **Peat soil + 5% OPC**

c'= 13.66 kN/m$^2$ Ø = 3$^{\circ}$ Fs = 3

Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/m$^3$

q = 1.5 x 14.126

= 21.189 kN/m$^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = $1.3(13.66)(6.62) + (1.5 \times 14.126)(1.35) + 0.4(14.126)(2)(0.06)$

qu = 146.85 kN/m$^2$

$q_{all}$ = qu/Fs = $\frac{146.85}{3} = 48.95$ kN/m$^2$

Q = $q_{all}B^2$ = $48.95 \times 4$ = 195.80 kN

**2) Peat soil + 5% OPC + 5% Bottom ash**

c'= 31.66 kN/$m^2$ Ø = $3^o$ Fs = 3
Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/$m^3$

q = 1.5 x 14.126
= 21.189 kN/$m^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = 1.3(31.66)(6.62)+(1.5×14.126)(1.35)+0.4(14.126)(2)(0.06)
qu = 301.76 kN/$m^2$

qall = qu/Fs = 301.76/3=100.59 kN/$m^2$
Q = qall$B^2$ = 301.76×4 = 402.34 kN

**3) Peat soil + 5% OPC + 10% Bottom ash**

c'= 29.135 kN/$m^2$ Ø = $3^o$ Fs = 3
Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/$m^3$

q = 1.5 x 14.126
= 21.189 kN/$m^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = 1.3(29.135)(6.62)+(1.5×14.126)(1.35)+0.4(14.126)(2)(0.06)
qu = 280.03 kN/$m^2$

qall = qu/Fs = 280.03/3=93.34 kN/$m^2$
Q = qall$B^2$ = 93.34×4 = 373.37 kN

**4) Peat soil + 5% OPC + 15% Bottom ash**

c'= 20.31 kN/$m^2$ Ø = 3º Fs = 3
Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/$m^3$

q = 1.5 x 14.126
= 21.189 kN/$m^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = 1.3(20.31)(6.62)+(1.5×14.126)(1.35)+0.4(14.126)(2)(0.06)
qu = 204.08 kN/$m^2$

qall = qu/Fs = 204.08/3=68.03 kN/$m^2$
Q = qall$B^2$ = 68.03×4 = 272.10 kN

**5) Peat soil + 5% OPC + 20% Bottom ash**

c'= 36.315 kN/$m^2$ Ø = 3º Fs = 3
Assume, Df = 1.5m b x h = 2m x 2m

**qu = 1.3c'Nc + qNq+0.4γBNγ**

y = (1.44 x 9.81)/1000 = 14.13 kN/$m^3$

q = 1.5 x 14.126
= 21.189 kN/$m^2$

Nc = 6.62 Nq = 1.35 Nγ = 14.1264

qu = 1.3(36.315)(6.62)+(1.5×14.126)(1.35)+0.4(14.126)(2)(0.06)
qu = 341.82 kN/$m^2$

qall = qu/Fs = 341.82/3=113.94 kN/$m^2$
Q = qall$B^2$ = 113.94×4 = 455.76 kN

### 6) Natural state of peat soil

$c' = 7.385\ kN/m^2$ $\quad\quad$ $Ø = 3^o$ $\quad\quad$ Fs = 3

Assume, Df = 1.5m $\quad\quad$ b x h = 2m x 2m

**$q_u = 1.3c'N_c + qN_q + 0.4\gamma BN_\gamma$**

$y = (1.44 \times 9.81)/1000 = 14.13\ kN/m^3$

$q = 1.5 \times 14.126$

$= 21.189\ kN/m^2$

$N_c = 6.62 \quad N_q = 1.35 \quad N_\gamma = 14.1264$

$qu = 1.3(7.385)(6.62)+(1.5\times14.126)(1.35)+0.4(14.126)(2)(0.06)$

$qu = 92.845\ kN/m^2$

$qall = qu/Fs = 92.845/3=30.948\ kN/m^2$

$Q = qallB^2 = 30.948\times4 = 123.79\ kN$