PERFORMANCE OF BOTTOM ASH TREATED PEAT SOIL IN IMPROVING BEARING CAPACITY

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DEDICATION

To my beloved family for all support and love

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ABSTRAK

Tanah gambut dengan kekuatan ricih rendah, kebolehmampatan tinggi dan kandungan air permulaan yang tinggi, dianggap tidak sesuai untuk proses pembinaan. Oleh itu, campuran tanah dengan Simen Portland Biasa (OPC) adalah salah satu kaedah yang biasa digunakan untuk merawat tanah gambut. Walau bagaimanapun, disebabkan kos yang tinggi kaedah ini masih bukan kaedah terbaik yang disyorkan untuk tujuan ini. Dalam industri loji kuasa, abu bawah (Bottom Ash) dianggap bahan sisa dengan tempat untuk dilupuskan dan tiada nilai guna semula. Kajian terdahulu menunjukkan campuran abu bawah dengan serbuk simen dijangka dapat menstabilkan tanah gambut dengan mengubah sifat semula jadi. Kajian ini bertujuan untuk mengkaji kapasiti galas dan indeks kumpulan tanah gambut tropika yang stabil di Pantai Timur Semenanjung Malaysia dengan mencampurkan sebahagian simen OPC yang sama dan pelbagai abu bawah. Juga kajian ini akan membincangkan tingkah laku tanah gambut dengan atau tanpa abu bawah dan penstabilan simen. Sebahagian tetap pengikat OPC dan pelbagai bahagian abu bawah (bahan pozzolanic) dalam satu siri ujian makmal telah dijalankan. Semua sampel telah mengalami 3 hari direndam dalam pengalaman air untuk sampel direndam. Sampel tak terbakar telah diuji selepas pencampuran. Peningkatan kapasiti galas sedang dinilai menggunakan ujian California Bearing Ratio (CBR). Keputusan menunjukkan bahawa selepas mencampurkan dengan abu bawah kapasiti galas peningkatan tanah gambut dengan meningkatkan peratusan abu bawah dalam tanah gambut.

ABSTRACT

Peat soil with low shear strength, high compressibility and high initial water content, is deem unsuitable for construction process. Hence soil mixing with Ordinary Portland Cement (OPC) is one of the methods commonly used to treating the peat soil. However due to high cost this method is still not the best method recommended for this purpose. In power plant industry bottom ash considered waste material with nowhere to dispose and no reuse value. Previous research shows bottom ash mix with cement powder is expected to stabilise the peat soil by changing it natural properties. This research aims to study the bearing capacity and group index of stabilized tropical peat soil of East Coast of Peninsular Malaysia by mixing same proportion of OPC cement and various proportion of bottom ash. Also this study will discuss the behaviour of peat soil with or without the bottom ash and cement stabilization. A fixed proportion of OPC binders and various proportion of bottom ash (pozzolanic material) in a series of laboratory test were conducted. All samples have undergone 3 days soaked in water experience for soaked sample. Unsoaked sample was tested after mixing. The improvement in bearing capacity was being evaluated using California Bearing Ratio (CBR) test. The results shows that after mixing with bottom ash the bearing capacity of peat soil increase with increase the bottom ash percentage in peat soil.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

MW	Mega watt
ha	Hectare
%	Percentage
km^2	Kilometre square
mm	millimetre
N	North
E	East
°	Degree
m	Meter
ml	Millilitre
$kN\text{-}m/m^3$	Kilonewton- meter per meter cube
Kg/m^2	Kilogram per meter square
m/s	Meter per second
cm	centimetre
kN/m^3	Kilonewton per meter cube
cm^3	Centimetre cube
g	Gram
m^2	Meter square
cm^2	Centimetre square
cm/s	Centimetre per second
g/cm^3	Gram per centimetre cube
kg	kilogram

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
Al_2O_3	Aluminium Oxide
ASTM	American Standard Test Method
BA	Bottom Ash
BaO	Barium oxide
BS	British Standard
CaO	Calcium Oxide
CBA	Coal Bottom Ash
CBR	California Bearing Ratio
C_C	Coefficient of Curvature
C_U	Coefficient of Uniformity
DMM	Dry Mixed Method
DMJ	Dry Jet Mixing
ESA	Equivalent Standard Axles
FA	Fly Ash
JKR	Jabatan Kerja Raya
K_2O	Potassium Oxide
LL	Liquid Limit
MDD	Maximum Dry Density
MgO	Magnesium Oxide
Na_2O	Sodium Oxide
OMC	Optimum Moisture Content
PA	Pond Ash
P_2O_5	Phosphorus Pentoxide
PI	Plasticity Index
PL	Plastic Limit
RHA	Rick Husk Ash
SEM	Scanning Electron Microscopy
SiO_2	Silicon Dioxide
SO_3	Sulphur Trioxide
TiO_2	Titanium Dioxide
UCS	Unconfined Compression Strength
USCS	Unified Soil Classification System
XRF	x-ray fluorescence

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Peat soil contains a high amount of decomposed and disintegrated plant remains under condition of incomplete aeration and high water content. Around the world there are 400 million ha of peat soil. In Malaysia there are some 3 million ha covered in peat. Table 1.1 shows the proportion of peat soil in Malaysia.

Table 1.1 : Proportion of peat soil in Malaysia (Jon Davies et al., 2010)

State	Area (ha)
Peninsular	642 918
Sabah	111 965
Sarawak	1697 847

Peat soil has unfavourable characteristic such as low bearing capacity, low specific gravity, medium to low permeability, high compressibility, high content of natural water, high water holding capacity, high rates of creep and difficult accessibility (Venuja et al., 2017)

When using peat soil for construction, problem such as instability, slip failure, localized sinking and long term settlement (Venuja et al., 2017) will occur and therefore it is very difficult to use. However due to increase in population and scarcity of good land for development, peat soil is in demand for construction purpose. Generally there are two ways to improve peat soil i) mechanical method and ii) chemical method. It depends on the engineer's justification or sometimes on client's budget to choose the best method to improve peat. Some will cut and replace the peat, others will treat the soil or just completely avoid from using the soil for construction (which is not the best option). Typically mechanical method consists of 'cut and fill' method, stage construction, preloading, stone columns, piles, vertical drains and lightweight fill and as for chemical method there are deep in-situ mixing and surface stabilization had been introduced to improved expansive soil (clay, peat soil, etc). Among all deep soil mixing is one of the commonly used methods for soil stabilization. This in- situ method involves mechanically mixing of cementitious compound like Ordinary Portland Cement or lime.

For centuries coal has been used as one of the most important energy sources. Approximately 40% of electricity production in the worldwide is based on coal. In Malaysia, 7 of its power plant use coal as a raw material in generating electricity since the year 1988. Table 1.2 shows summarizes of capacity coal power plant in Malaysia.

Table 1.2: Summarizes the capacity of coal powered plant in Malaysia (Marto & Tan, 2016).

Power plant	Commissioning year	Capacity (MW)
Jimah, Negeri Sembilan	2009	1400
Manjung, Perak	2002	2295
Kapar, Selangor	1988	2420
Tanjung Bin, Johor	2006	2100
Mukah, Sarawak	2009	270
PPLS, Sarawak	2006	110
Sejingkat, Sarawak	1997	100

From these power plants Fly ash (FA) and Bottom ash (BA) are generated as one of the waste product. Fly ash has been used in cement industry meanwhile there are still some doubts on how to utilize bottom ash in the industry. Previous studies show that the bottom ash is highly potential in the construction industry as an alternative to existing materials. Therefore to check and validate the benefit involving bottom ash, this research is mainly focused to improve peat soil properties. Bottom ash will work with pozzolanic material in the soil mixing method. Using OPC as the binder, there will be a pozzolanic reaction when these two substances mixed together. In this study, 5% of OPC (binder) and 5% to 20% of Bottom ash was used to mix tropical peat soil.

1.2 PROBLEM STATEMENT

Due to its low shear strength, high compressibility and high initial water content, peat soil is unsuitable for construction process (Venuja et al., 2017). Therefore it is best to avoid because of the instability and settlement problem occurrence if any structures are to be built on it. However due to increasing in development and population, demand of land used for construction is unavoidable. Thus various method and solution are suggested to improve and strengthen peat soil properties. Previous researcher comes with many ways that can be categorized into two

i. Mechanical method
ii. Chemical method

Some of approaches are highly costly and the effectiveness is still questionable. So in order to find the best method, these factors should be considered

- Environmental friendliness
- Cost
- Effectiveness
- Reliability and durability

Mechanical method like cut and replace involve too much time and costly makes many reluctant to choose this method. While chemical method such as deep mixing stabilization appears to be cheap, but it is not very environmental friendly.

Material like OPC is highly regarded in soil stabilization since it can be obtained easily and cheap. However OPC emit carbon dioxide to environment during production process which will eventually cause greenhouse effect (McLellan et al., 2011). Besides that bottom ash from the power plant waste product will cause several environmental problems if not disposed properly.

1.3 RESEARCH QUESTIONS/ HYPOTHESIS

To overcome the research problem and the existing gaps in the research, the proposed study aims to address following questions

1. What is the engineering property of peat soils and bottom ash?
2. What is the effect of bottom ash in improving bearing capacity of peat soil?
3. What is relationship of group index and bearing capacity of improved peat soil?

1.4 OBJECTIVES

Main objective

This study aim is to determine the effectiveness of bottom ash as admixtures to stabilized peat soil and increasing bearing capacity of peat soil of East Coast Peninsular Malaysia (Pekan peat).

Specific aims

1. To determine the properties of tropical peat soil and bottom ash.
2. To find the relationship between bottom ash and bearing capacity improved peat soil.
3. To determine the relationship of Group Index (plastic limit, liquid limit, plasticity index and type of soil) and bearing capacity of treated peat soil.

1.5 SCOPE OF STUDY

1. Peat soil used in this research was obtained from Pekan which is located in the East Coast of Peninsular Malaysia.
2. This research work has only Ordinary Portland Cement (OPC) and Bottom Ash (BA) as material to stabilise peat soil.
3. Sample with 5 different ratios of cement and bottom ash proportion (0% BA + 5% OPC, 5% BA + 5% OPC, 10% BA + 5% OPC, 15% BA + 5%OPC, 20% BA + 5% OPC) was used.

1.6 THESIS OUTLINE

This thesis has 5 chapters; there are introduction, literature review, materials and methods, result and conclusion and conclusion.

In introduction chapter, find all related journal about peat soil and bottom ash. Then find the problem related to peat soil and how bottom ash can used to overcome the problem. The importance of peat soil and bottom ash toward construction industry is explained in this chapter. Lastly is finding the research questions and the objective of the study.

For literature review chapter, we done the overview of the research based on previous related research. This to finding what we understood based on previous research and applied the knowledge into this research. The previous research will act as guidelines for this research and we will cite the previous research in this chapter.

In materials and methods, we will elaborate about how the materials use in this research taken. Peat soil is taken from 0.5 m an open excavation at Pekan. Bottom ash is taken from Tanjung Bin, Johor and it undergo oven dried before seal in plastic bag. Ordinary Portland cement is bought from local store. Laboratory test are conducted to determine the engineering properties of peat soil and bottom ash. As for bearing capacity, it conducted for both unsoaked and soaked conditions for all sample.

Next is result and discussion, in this chapter we mainly elaborate about the result and discuss our finding here. All the result is analyzed and present in graph or table. From the result we can know about the solution to the problem statement. The relationship between bearing capacity and bottom ash, the relationship between group index and bottom ash and also the engineering properties of peat soil and bottom ash will discuss and elaborate more in this chapter.

From conclusions chapter, we will discuss about the finding and draw the conclusions about whether this thesis success or not. At this chapter we will answer the objectives of this research.

CHAPTER 2

BACKGROUND AND SIGNIFICANCE

2.1 Distribution of Peat

Peat soil formed by decomposed of organic material that accumulated over time. It can be identifying by its brownish-black colour. Lacking oxygen and under waterlogged conditions promote it formation. Basically peat soil contains 65% organic matter.

Tropical peat can be found in river valleys and creeks. Peat covers a few areas in Africa and parts of Central America. However 60% of peat lands of world exist at South- East Asia. Most of tropical peat swamp can be found on the islands of Borneo. Total area of peat in Malaysia is about 2.6 million hectares ($26000km^2$), which 13% at Peninsular Malaysia, 80% at Sarawak and about 5% At Sabah (Adon, Bakar, Wijeyesekera, & Zainorabidin, 2013).

Table 2.1 : Peat land area distribution around the world (Adon et al., 2013)

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

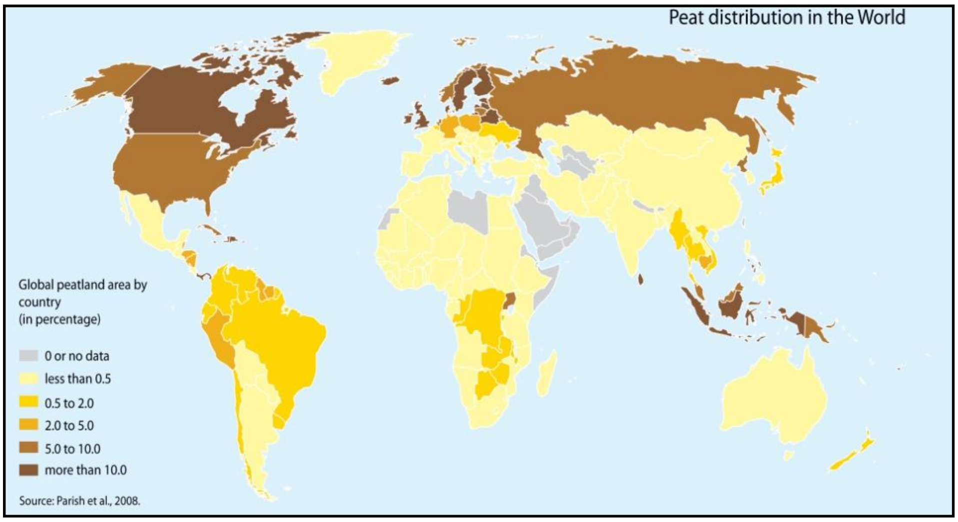

Figure 2.1: Peat distribution around the world (Adon et al., 2013)

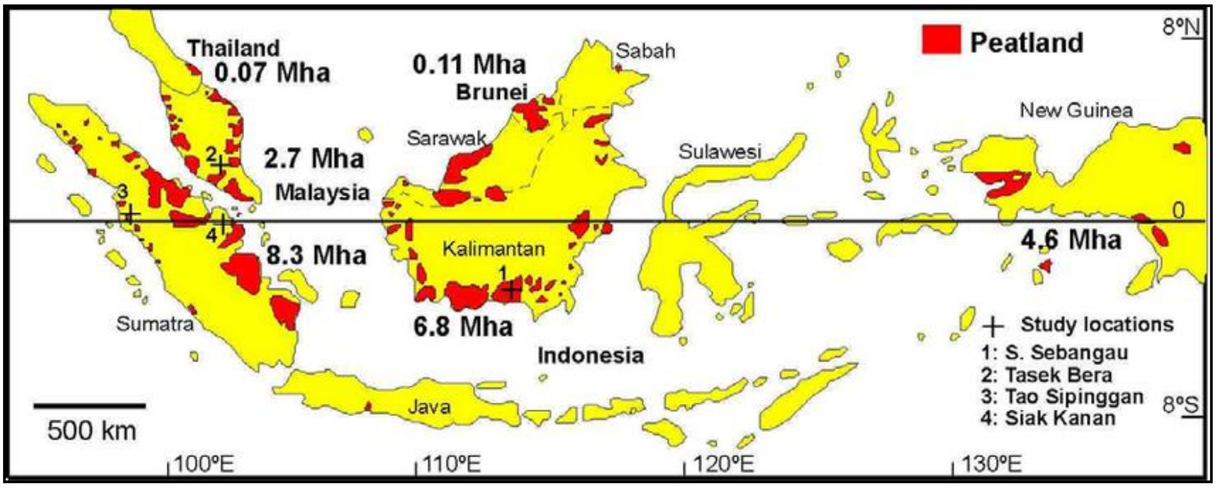

Figure 2.2: Distribution of peat lands in South East Asia (Adon et al., 2013)

2.2 Classification of Peat soil

Using several methods such as Radforth system, ASTM and Von Post Scale to classified peat soil. Radforth system is based on physical texture and botanical composition of peat soil as shown in Table 2.2 below. Peat also classified based on several criteria such as fiber content (ASTM 2013), ash content (ASTM 2014), pH value (ASTM 1998) and absorbency (ASTM 2000) of peat soil. ASTM classification is shown in Table 2.3. Table 2.4 shown Von Post Scale to classified peat soil. It the most common method use and it classified peat based on degree of humification (decomposition), botanical composition, water content, content of fine and coarse fibres and woody remnants.

Table 2.2: Classification of peat (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 a mound 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 -	12	Woody, coarse-fibrous peat

fibrous	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 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 (ASTM)

ASTM standard	Criteria	Designation
Fiber content (D 1997)	>67% fibers	Fibric ($H_1 – H_3$)
	33%- 67% fibers	Hemic ($H_4 – H_{10}$)
	<33% fibers	Sapric ($H_7 – H_{10}$)
Ash content (D 2974)	<5% ash	Low ash
	5%-15% ash	Medium ash
	15%-25% ash	High ash
Acidity (D 2976)	pH < 4.5	Highly acidic
	4.5< pH < 5.5	Moderately acidic
	5.5< pH < 7.0	Slightly acidic
	pH > 7.0	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 (Von Post Scale)

Symbol	Description
H1	Completely undecomposed peat which, when squeezed, releases 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 still easily identifiable. No amorphous material present.
H3	Very slightly decomposed peat which, when squeezed, releases 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 is passed 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 a very small amount of amorphous granular peat escaping between the fingers. The structure of the plant remains is quite indistinct although it is still possible 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 fingers. The residue is very pasty but shows the plant structure more distinctly than before squeezing.
H7	Highly decomposed peat. 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 dark and almost pasty.
H8	Very highly decomposed peat with a large quantity of amorphous material and very indistinct plant structure. When squeezed, about two-thirds of the peat escapes between the fingers. A small quantity of pasty water may be released. The plant material remaining in the hand consists of residues 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 a 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

2.3 Characteristics of Bottom ash (BA)

BA can be divided into 2 main categories dry bottom ash or wet bottom ash, depending on boiler used in power plant. Dry bottom ash is produced in solid state while wet bottom ash (boiler slag) in molten state. During combustion process BA accumulating coarser material compared to fly ash (FA). BA has a rough surface texture and angular and irregular shape. Its colour ranges from grey to black and glossy for some particles (Marto & Tan, 2016).

2.4 Size particle distribution

Bottom ash is compared to river sand and figure 3 is shown the result. The result show that the curve is a smooth curve revealing that the particle size distribution of bottom ash was in the range with natural river sand. Besides bottom ash has a grain size that similar to coarse to fine grains and part of it was sand like material (Ramzi, Shahidan, Maarof, & Ali, 2016).

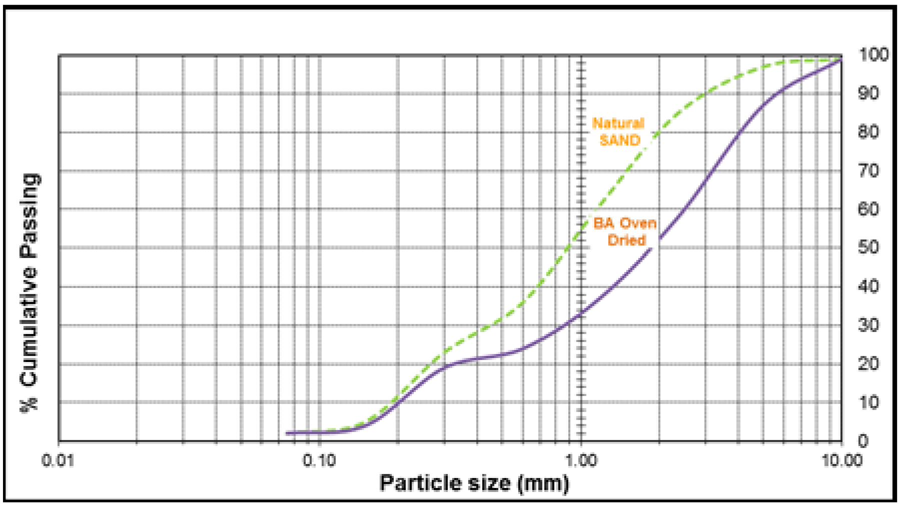

Figure 2.3: Particle size distribution between Natural River sand and bottom ash

2.5 Physical properties

Specific gravity of a material is often depending on two elements, which are chemical composition and particle structure. From previous studies by other researchers around the world, the specific gravity of bottom ash lies between 2.0 to 2.6. The popcorn like structure of BA will go to as low as 1.6. According to Das the presence of iron content in coal ash will lower down the value of specific gravity. The falling head permeability test was conducted to determine the permeability of BA. BA has high permeability value due to high porosity of BA material. Its allow BA to be a backfill material in the construction of road embankment, besides as subgrade material. Due to high porosity, BA could provide good drainage system. According to Siddique (2013) self-compacting concrete mix, that has bottom ash as replacement of sand show high permeability at age 90 days (Marto & Tan, 2016).

Table 2.5: Physical properties of bottom ash in some power plant (Marto & Tan, 2016).

Properties	Tanjung Bin
Specific gravity	1.99-2.44
Coefficient of uniformity, Cu	16.56

Coefficient of curvature, Cc	1.01
Permeability at maximum compaction	0.172-6.88 $\times 10^{-3}$

2.6 Morphological properties

Awang et al. (2012) used the scanning electron microscopy (SEM) of model ZEISS SUPRA 35- VP to obtain the micrograph of Tanjung Bin BA. Only BA with size finer than 0.075mm was utilised to observe the morphological properties at a magnification of 500, due to test limitations (Marto & Tan, 2016).

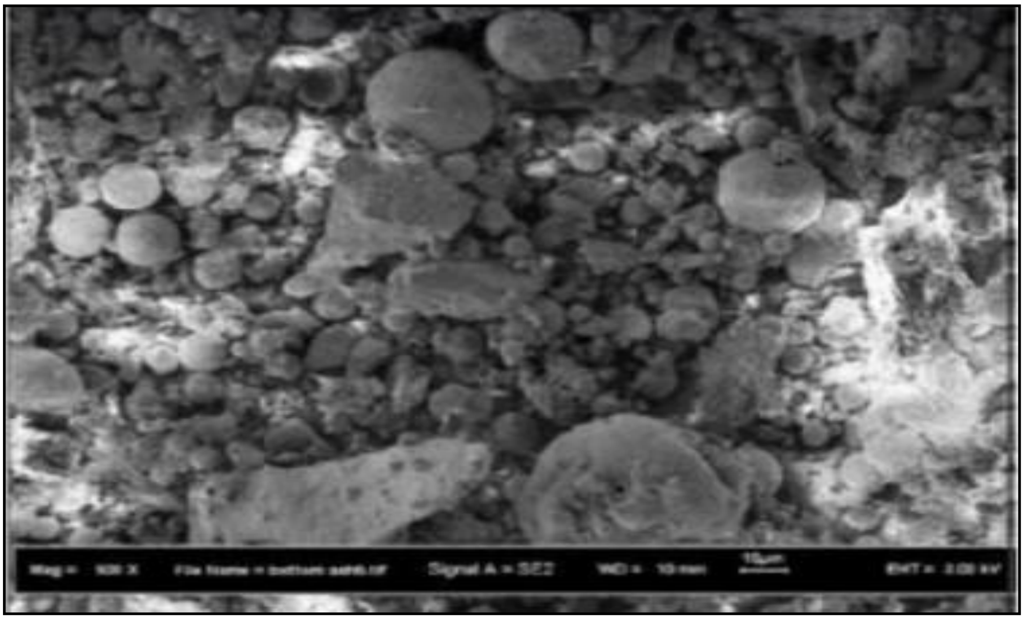

Figure 2.4: Photomicrograph of Tanjung Bin bottom ash (Marto et al., 2016)

2.7 Chemical properties

To obtain chemical composition X-ray Fluorescence (XRF) of model Bruker AXS S4 Pioneer was used. Results indicated that major content of bottom ash Tanjung Bin is silica, alumina, iron oxide and calcium oxide. Limiting chemical content of magnesium, kalium, barium, potassium, sodium and titanium oxides are also presence in BA (Marto & Tan, 2016).

Table 2.6: Chemical composition of Bottom ash and Natural river sand (Ramzi et al., 2016).

Formula %	Natural River Sand	Coal Bottom Ash (Tanjung Bin)
SiO_2	51.00	33.70
Al_2O_3	6.83	12.90
Fe_2O_3	0.32	6.98
CaO	0.48	6.34
K_2O	0.40	1.19
TiO_2	0.58	0.89
MgO	-	0.65
SO_3	-	0.90
Na_2O	-	0.59
P_2O_5	-	0.30
BaO	-	0.22

2.8 Sustainable method to overcome Peat problem

There are few method that exist to stabilize the soils including density treatments (compaction and preloading), pore pressure reduction techniques (dewatering or electrolysis), bonding of soil particles (ground freezing, grouting and chemical stabilization) and reinforcing elements (geotextiles and stone columns) (Otoko, 2014).

Summarizes a number of construction options that can be applied to peat and organic soil (Adon et al., 2013);

a. **'Cut and Fill' or replacement:**

   The oldest or conventional method by replace the poor soil with suitable imported fill material but this method is very expensive.

b. **Soil stabilization**

   Start popular about 40 years ago and widely used last 20-25 years in alternative ways to deal with soft soil. Comprehensive trials and fields work had been carried out where cement with different binders has shown improved the mechanical properties (shear strength and compressibility).

c. **Preloading**

Method involving placed a surcharges fills on top of the soil that requires consolidation. Then once sufficient consolidation has taken place, the fill can be removed and construction takes place. Surcharges fills are typically 10-25 feet thick and generally produces settlement of 1 to 3 feet. It must remain in place for months or years, thus it will delay the construction.

d. Vertical drain and preloading

Preloading principle was adopted with the idea to minimize post construction settlement. The basis of preloading is to place a temporary fill over the construction site that is thicker than the final design fill. This causes settlement to occur more rapidly than would have occurred under the final fill design height. The preload is ideally left in place until it has settled more than the total amount that the design fills is expected to settles in its design life (Duraisamy, Huat, & Aziz, 2007b).

e. Prefabricated vertical drain

Geosynthetics used as a substitute to sand columns. It is installed by being pushed or vibrated into the ground. Most are about 100mm wide and 5mm. the function of prefabricated vertical drain (PVD) is to allow drainage to take place in both vertical horizontal directions over a much shorter drainage path so that the rate of consolidation time can be reduced.

f. Deep stabilization method

Widely used for stabilization organic soil. Originally developed in Sweden and Japan more than thirty years ago and becoming well established now. In the Japanese Geotechnical Terminology Dictionary," generic term for soil improvement involving mixing by force together with chemical stabilizers such as lime or cement within the deep ground on site". According to Yang et al; Dry Mixing Method (DMM) and Dry Jet Mixing (DJM) methods are more effective for peat stabilization instead of wet mixing method. Research had been done to study the effect of cement column on the compressibility of peat soil. When a cement column is installed in peat, its compressibility is reduced because of the hardened skeleton matrix formed by cement particles bonding with adjacent soil particles in the presence of pore water (Duraisamy et al., 2007b).

In this research will focus more to soil stabilization/ chemical stabilization. Chemical stabilization involves mixing chemical additives with natural soils to remove moisture and improve strength of the soil by either reinforcing of the bonds between the particles or filling of the pore spaces (Otoko, 2014).

There are few material that can be used for soil stabilization (Otoko, 2014).

1. **Lime stabilization**

   Qubain et al. (2000) incorporated the benefits of sub-grade lime stabilization into the design of a major interstate highway pavement in Pennsylvania. For clayey sub-grade such as experienced in the project, lime improves the strength of clay by three mechanisms; hydration, flocculation and cementation. Qubain et al. (2000) investigation showed significant increase in strength by introduction of lime; which when introduced into design, reduced the pavement thickness and resulted in substantial saving.

   White (2005) investigated the effect of curing and degree of compaction on loam stabilized with different additives. At the ambient temperature lime continues react on cured specimen. The behaviour of the stabilized specimens was affected by the degree of compaction, which led to brittle failure behaviour at maximum densities.

   Ismaiel (2004) studied material and soils from some part of Germany. He stabilized these materials with lime (10%), cement (10%), and lime/cement (2.5%/7.5%). He concluded that the optimum moisture content was inversely proportional to the maximum dry density, while strength parameter was directly proportional to the stabilizing content. Ampera & Aydogmust (2005) treated clayey soil with lime and cement. They concluded that the strength of cement-treated soil was generally greater than that of lime.

2. **Fly ash stabilization**

Fly ash increases compacted dry density and reduces the optimum moisture content. Rapid strength gain of soil-fly ash mixtures occurs during the first 7 to 28 days of curing, and a less pronounced increase continues with time due to long-term pozzolanic reactions. Fly ash effectively dries wet soils and provides an initial rapid strength gain, which useful during construction in wet, unstable ground conditions. Fly ash also decreases swell potential of expansive soils by replacing some of the volume previously held by expansive clay mineral and by cementing the soil particles together.

UCS increases with the curing period after stabilized with fly ash and gypsum. When pond ash (PA) added to peat soil UCS is changed. Optimum Moisture Content (OMC) decreases and Maximum Dry Density (MDD) increases as the PA increased. This is due to consumption pore water by PA to form cementitious product during hydration process. UCS is increased with PA addition due to flocculation and hydration.

3. **Cement stabilization**

Portland cement is hydraulic cement made by heating limestone and clay mixture in a kiln and pulverizing the resulting material (Kowalski et al., 2007). It required calcium for the pozzolanic reaction to occur. The cement already has silica, therefore independent of the soil properties process; need only water for hydration process to begin.

4. **Rice husk stabilization**

According to Musa Alhassan (2008) there are general decrease in the maximum dry density and increase in the optimum moisture content with increase in rice husk ash (RHA). With increase RHA content there are slight improvement in the CBR and UCS.

Brooks (2009) said UCS increase 97% and CBR improved 47% when the content RHA increased.

5. **Scrap tyre**

The re use tyres depending on how tyres are processed. Basically including shredding, removing of metal reinforcement and further shredding till desired material achieved (Carreon, 2008).

Akbulut et al. (2007) concluded that using scrap tyre rubber and synthetic fibres improved the strength properties and dynamic behaviour clayey soils.

6. **Soil reinforcement method**

Use natural or synthesized additives to improve the soil. This method can be divided into categories as shown at figure 5 and figure 6. Some of it may be ineffective and/or expensive (Hejazi et al., 2012).

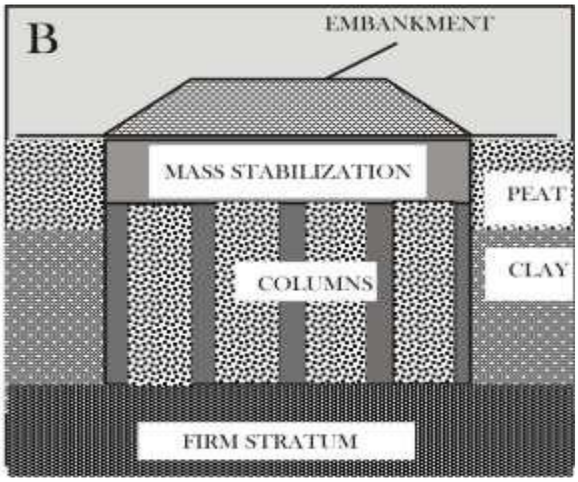

Figure 2.5: Combines mass and column stabilization (Otoko G.R, 2014)

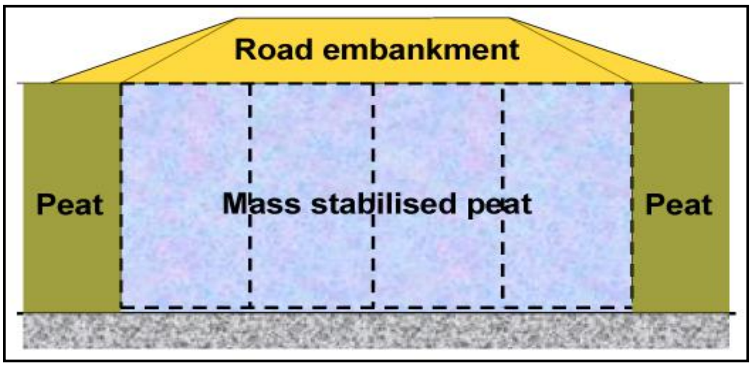

Figure2.6: Mass stabilization (retrieved from: http://www.roadex.org/e-learning/lessons/roads-on-peat/types-of-construction/)

2.9 Stabilization of peat soil using bottom ash and Ordinary Portland cement

In this research bottom ash are uses for stabilization of peat. Previous researcher study how bottom ash can be used in stabilised peat soil. Bottom ash reduced the liquid limits while plastic limit were increased. Plastic index are reduced by adding bottom ash. The swollen potential of cohesive soil got diminished with the addition of admixtures. It is well seen that bottom ash admixture showed better results when compared to cohesive soil without admixtures. The strength of soil also improved when added bottom ash (Durairaj, 2016). Reaction between OPC and hydration water in peat shows that OPC is the most practical additive for controlling water content during peat treatment. BA is not suitable for dehydration agent but suitable for filler. The pozzolanic reaction will occur when BA mix with peat (Rahman & Chan, 2014).

When a fibrous peat soil reinforced with cement columns, it show a reduction in compressibility by increasing the diameter of cement columns, increasing the number of cement column and increasing the amount of cement in cement columns (Duraisamy, Huat, & Aziz, 2007a).

When peat treated using BA and coconut shell powder, the unconfined compression strength value increasing but in the mix BA 15% + CSP 15% there are decreasing. The absorption mechanism of coconut shell powder is more likely to bond to clay content and the result is higher in the shear strength. There is reduction in liquid limit when there are increase of BA and CSP content whereas plastic limit is increased. Plasticity index is reduced due to cation exchange reaction and flocculation aggregation of more presence of BA and CSP. Therefore this causes significant decreases in swell potential (A.T.Manikandan et al., 2017).

Adding Coal Bottom Ash (CBA) to subgrade soil increases CBR value and decreases the swelling potential. In addition a decrease in MDD upon addition of CBA to the soil was registered due to lower specific gravity of the CBA. CBA also effectively used for mechanical stabiliser for the subgrade soil on the pilot field stretch and that 30% by weight of CBA added to the subgrade soil yielded the highest unsoaked and soaked CBR value of 140% and 95%, respectively (Cadersa, Seeborun, & Chan Chim Yuk, 2014).

Peat soils originally higher in water content indicated larger voids, requiring more stabilizers (Axelsson et al., 2002). BA can act as a filler to fill the voids in peat soils, while ordinary cement can be binder agents for hydration process.

The characteristics and strength of a highly expansive soil can be improved by Coal ash (fly ash + bottom ash) stabilization. Liquid limit and Plasticity index are decreased with percentage Coal ash added. The California Bearing Ratio can be increased 1.34 times approximately to the initial strength of the soil (Rajakumar & Meenambal, 2015).

2.10 California Bearing Ratio

California Bearing Ratio (CBR) value of sub grade is used for design of flexible pavements. It is important soil parameter for design of flexible pavements and runaway of air fields. It also used for determination of sub grade reaction of soil by using correlation. It is one of the most important engineering properties of soil for design of sub grade of roads. CBR value of soil may depends on many factors like maximum dry density (MDD), optimum moisture content (OMC), liquid limit (LL), plastic limit (PL), plasticity index (PI), type of soil, permeability of soil etc. Besides soaked or unsoaked condition also affect the value (Choudhary & Joshi, 2014).

CHAPTER 3

METHODOLOGY

3.1 Introduction

There were stages in this research work. Each stage represents the process of preparing samples and testing that was carried out to determine the objectives that had been outlined. It also to obtain all the data that we need to prove that bottom ash can use in treated peat soil. Sample was tested using various laboratory tests. The comparisons were made between control sample and sample with various percentage of bottom ash. Stage one involving within determining the engineering properties of peat soil and bottom ash. Stage two comprised of mixing the peat soil with different proportions of bottom ash. Stage three involved with the final test which is to determine the bearing capacity of treated peat soil.

3.2 Research Design

Study flow of this research is shown in Figure 3.1. From here it can be clearly seen the entire process that was carried out in this research. Each process was described in detail in this section. It is important to know the detail of each process so that it can be referred by others in the future.

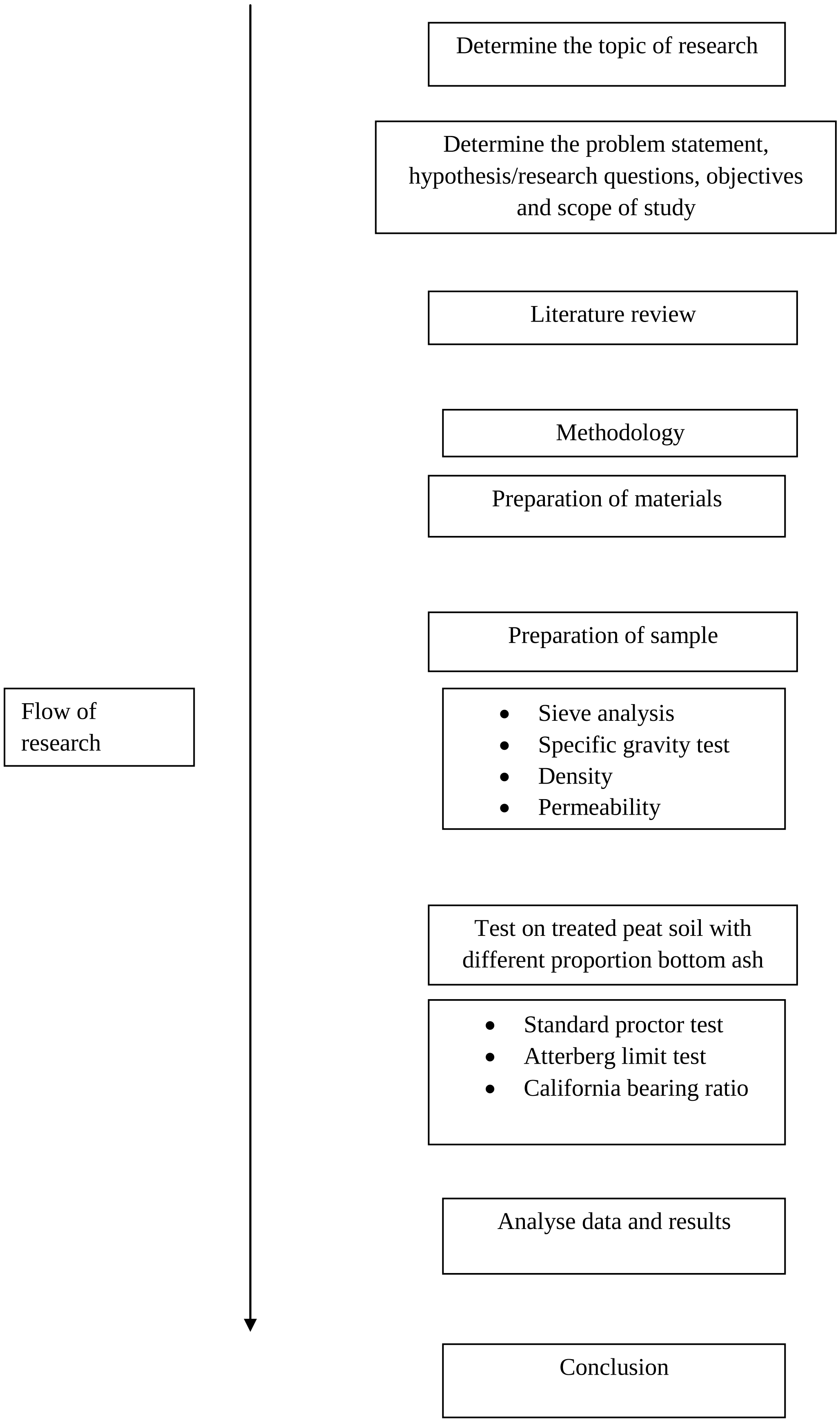

Figure 3.1: Study flow chart

3.3 Study Location

All tests and research was conducted at Geotechnical laboratory, Universiti Malaysia Pahang, Gambang Campus.

3.4 Sample Collection and Preservation

Sample collection and preservation will described more in this part. All the sample is either taken from outside or buys from outside.

3.4.1 Peat soil

Peat soil was taken from Pekan, Pahang at coordinate 3.678007 N 103.290031 E. Peat soil is taken from an open excavation between 0.3-0.5 m depths. It preserves in original condition which is wet condition. Peat soil then put in box so that it still retains its original condition. Some of peat was oven dried to remove the moisture content before sealing it in the plastic bag. This was done in accordance with the requirement of some of the laboratory test such as sieve analysis.

Figure 3.2: Location where peat sample was taken.

Figure 3.3: Shovel was used to obtain peat sample from the site.

3.4.2 Bottom ash

Bottom ash was taken from one of the waste site which belongs to the coal power Tanjung Bin, Johor. Bottom ash is a waste material from coal combustion and it does contain silica, alumina and iron, small percentages of calcium, magnesium, sulphates and other compounds. Bottom ash was oven dried and sealed in the plastic bag.

3.4.3 Ordinary Portland cement (OPC)

OPC that was used in this research are from YTL Company and in powdered forms. Each sample will needed 5% of ordinary Portland cement from peat soil weight.

3.4.4 Sample preparation

Sample preparation was conducted at Geotechnical engineering laboratory. A different proportion of bottom ash was mixed with peat soil for California Bearing

Ratio test, Atterberg's Limit test and Standard Proctor test as shown in Table 3.1. For bearing test the sample is soaked in water for 3 days before testing.

Table 3.1: Proportion of bottom ash and OPC in peat soil

Sample	Bottom ash %	OPC %
P1	0	5
P2	5	5
P3	10	5
P4	15	5
P5	20	5

3.5 Laboratory test

Several experimental were conducted with untreated peat soil a sample and treated sample with various percentages of bottom ash as shown in Table 3.1. This experimental test was conducted according to standard procedure and references.

3.5.1 Sieve analysis (ASTM D 422)

The objective of this test is to determine the percentage of different grain sizes contained within a soil. The sieve analysis is performed to determine the distribution of the coarser, larger – sized particles, and the hydrometer method is use to determine the distribution of the finer particles.

Apparatus:

Figure 3.4: Sieve set

Figure 3.5: Cleaning brush

Figure 3.6: Balance

Figure 3.7: Sieve shaker

Figure 3.8: Measuring cylinder

Figure 3.9: Stopwatch

Figure 3.10: Beaker

Figure 3.11: Hydrometer

Procedure:

Figure 3.12: Putting the sample into sieve shaker

a. Sample and empty sieve was weighted
b. Sieves are assembling according to size and sieve for 10 minutes and each sieve and its retained soil within it was weighted and recorded.
c. The fine soil at the bottom pan are soaked for 10 minutes in 125ml dispersing agent (sodium hexametaphosphate)
d. The sample then put into cylinder and filled with water until the marking level. The cylinder was secured and turned upside down for a few minute. Then the cylinder put in water bath and hydrometer was put into cylinder after ten seconds. Reading was taken according to time interval at 2, 5, 8, 15, 30, 60 minutes and 24 hours.

3.5.2 Moisture, fibre and organic content (ASTM D 2216- Standard Test Method for Laboratory Determination of Water (moisture) Content of Soil, Rock and Soil-Aggregrate Mixtures, ASTM D 2974 – Standard Test Methods for Moisture, Ash and Organic Matter of Peat and Organic Soils, ASTM (1997)- Standard Test Methods for Fibre Matter of Peat and Organic Soils)

Organic content test performed to determine the organic content of soils. The organic content is 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.

Fibre content test performed to determine the fibre content of organic soils. The fibre content is 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.

Apparatus:

Figure 3.13: Sodium Hexametaphosphate

Figure 3.14: Oven

Figure 3.15: Sieve set

Figure 3.16: Balance

Figure 3.17: Spatula

Figure 3.18: Evaporating dish

Procedure:

Figure 3.19: Sample in porcelain dish

a. For organic content, empty container and dried sample are weighted and put in furnace for 24 hour. After that the mass of dried sample are recorded.
b. As for fiber content 100 g are loosen using dispersing agent for 24 hours. Wet sieving the sample using 125µm size of sieve until clear water exiting the sieve. Then oven dried the remained sample and the weight was recorded.
c. For moisture content, the empty containers are weighted and wet sample were put into the container before weight it again. Oven dried the sample for 24 hours. Weight the sample after oven dried.

3.5.3 Permeability (ASTM D 2434- Standard Test Method for Permeability of Granular Soils (Constant Head), Falling Head Test Method is not standardised.)

The purpose of this test is to determine the permeability or hydraulic conductivity of a sandy soil by the constant head test method. The constant head test method is used for permeable soils where k is more than 10^{-4} cm/s

Apparatus:

Figure 3.20: Falling head

Figure 3.21: Stopwatch

Figure 3.22: Measuring cylinder

Procedure:

Filter paper placed at bottom of sample. Bottom of sample is attached to water and top is attached to vertical pipe. Are of pipe is measured. Times taken for water level to drop from h1 to h2 are taken. Water flow is constant.

3.5.4 Specific gravity (BS1377: Part 2: 1990:8.3- Standard test of Specific Gravity for fine grained soil using density bottle)

This test is performed to determining the specific gravity of soil using a density bottle. Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the volume of gas-free distilled water at a stated temperature.

Apparatus:

Figure 3.23: Density bottle

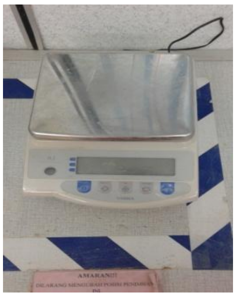

Figure 3.24: Balance

Figure 3.25: Vacuum pump

Figure 3.26: Funnel

Procedure:

Figure 3.27: Specific gravity performed using density bottle

10 g sample passed through no. 10 sieve in density bottle. Kerosene are added about half to ¾ of density bottle. Put in vacuum for 1 hour and filled with kerosene until full. Weight the sample and density bottle

3.5.5 Standard proctor (ASTM D 698 – Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (600KN-m/m³) or ASTM D 1557- Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (2700 KN-m/m³)

Test is performed to determine the relationship between the moisture content and the dry density of soil for a specified compaction effort. The compaction effort is the amount of mechanical energy that is applied to the soil mass.

Apparatus:

Figure 3.28: Set of sieve

Figure 3.29: Mould

Figure 3.30: Oven

Figure 3.31: Rammer

Figure 3.32: Balance

Figure 3.33: Straight edges

Figure 3.34: Container

Figure 3.35: Measuring cylinders

Figure 3.36: Standard proctor mixers

Figure 3.37: Trowel

Procedure:

Figure 3.38: Sample in mixing bowl

Samples were mixed with a small amount of water and moulds are weighted. Then sample are compacted in mould and excess are trimmed until it smooth. Next is mould and compacted sample are weighted and some sample is taken from below and upper compacted sample. Samples then oven dried before weight are taken. This repeated until 5 times.

3.5.6 Atterberg's limit (BS 1377: Part 2: 1990:43 – Standard Test Method for Liquid Limit, ASTM D 4318 – Plastic Limit, and Plasticity Index of Soils)

This test was performed to determine the plastic and liquid limits of a fine grained soil. The liquid limit (LL) is based on the measurement on penetration into the soil of a standardized cone of specified mass. At the liquid limit, the cone penetration is 20mm. the plastic limit (PL) is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2mm diameter threads without crumbling.

Apparatus:

Figure 3.39: Straight edges

Figure 3.40: Distilled bottle

Figure 3.41: Soil container

Figure 3.42: Glass plate

Figure 3.43: Oven

Figure 3.44: Liquid limit apparatus

Figure 3.45: Container

Figure 3.46: Balance

Figure 3.47: Spatula

Procedure:

Figure 3.48: Mixing the sample

a. For Liquid limit the sample are mixed with water until become paste then it pressed in cup without creating air. Top surface are smoothed. The cone and shaft must touch the upper surface of cup before release the button. Take a reading at different point and repeat this for 2 times.
b. As for Plastic limit, moisture can are weighted and ¼ of sample are taken for rolling at consistency before put in empty can and oven dried.

3.5.7 Bearing capacity test (CBR) (AASHTO T193-63, ASTM D 1883-73)

The California bearing ratio test is penetration test meant for the evaluation of sub grade strength of roads and pavements. The results obtained by these tests are used with the empirical curves to determine the thickness of pavement and its component layers. This is the most widely used method for the design of flexible pavement.

Apparatus:

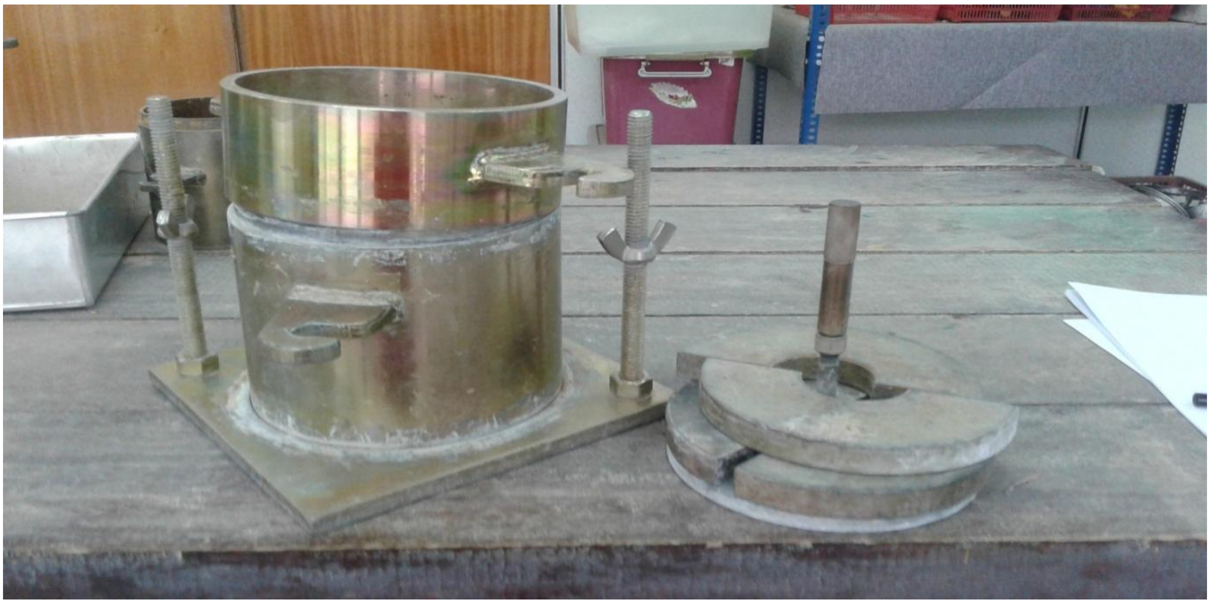

Figure 3.49: California bearing ratio mould

Figure 3.50: Rammer

Figure 3.51: CBR machine

Procedure:

Figure 3.52: Mixing process and compacted sample

Figure 3.53: Recording the reading

a. Mould is weighted and samples are mixed with uniform moisture water content. Then sample are compacted and the collar are removed and trimmed the sample until it smooth. Then both mould and sample are weighted before put it on CBR machine. Record the reading and make sure the plunger touched the surface of sample.
b. For soaked sample, sample are submerged for 24 hour and repeated the procedures.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, the relationships between the parameter will be further discussed. All the results are obtained from the same material and all other factors like temperature and humidity during the experiment were controlled as possible. The experiments were conducted in a room where temperature is range between 25- 27°C and dry humidity.

Soil sample used in this research was peat soil and other materials were bottom ash and ordinary Portland cement. The samples are mixed using percentage by weight as summarized in Table 3.1 in Chapter 3.

Laboratory experiments were carried out at Soil Mechanics and Geotechnical Laboratory of University Malaysia Pahang.

4.2 Natural properties of peat soil

Several experimental tests were done to determine the nature properties of peat soil. The results obtained were summarizing in the following table.

Table 4.1: Properties of peat soil

Properties	Value
Specific gravity	**1.44**
Density	**1440kg/m³**
Permeability	**0.0014m/s**
Plastic limit	**178.22%**
Shrinkage limit	**7.99**
Liquid limit	**220%**
Plastic index	**41.78%**
Fiber content	**36.64%**
Moisture content	**884.78%**
Organic content	**81.78%**
pH	**3.56**
Cu	**11.8**
Cc	**1.7**

Based on Radforth's system, this peat fall in fine fibrous peat in category 11 (woody and non-woody particles held in fine-fibrous peat). This peat has 36.64% fiber content so according to ASTM standard it a Hemic peat (H4-H10) and peat soil was highly acidic based on pH value.

Figure 4.1: Rubbing test of Van Post Scale

Figure 4.2: Muddy water comes out when squeezing the peat.

Based on Figure 4.1 above, it can be conclude that this peat is in H6 category of Van post scale. The peat is moderately highly decomposed with a very indistinct plant structure. When squeezed, about 1/3 of the peat escapes between fingers. The residue is very pasty and water comes out when squeezing is muddy in colour.

Table 4.2: Comparison between Peninsular (Pekan) peat and Sarawak peat

Properties	Pekan peat	Sarawak (Matang) peat
Moisture content (natural %)	884.78	598.5
Degree of composition	H6	H4
Fiber content (%)	36.64	79.33
Organic content (%)	81.78	90.47
Liquid limit (%)	220	200.2

Plastic limit (%)	178.22	Non-plastic
Specific gravity	1.44	1.21
pH	3.56	3.75

Table 4.2 above show some comparison of physical properties of peat. Each peat has a distinct feature compared to other place. Properties of peat can be influenced by age of peat swamp, decomposition of organic matter and humidity of peat swamp, thus resulting in difference of physical properties of different peat soil. Peat soil from Sarawak has a higher fiber content compared to Pekan's peat. Sarawak's peat also non-plastic compared to Pekan's peat and has a lower specific gravity. Both peats were same in terms acidity and liquid limit. Pekan's peat has a higher natural moisture content compared to Sarawak's peat. Both peats also differ in terms of degree of composition. In this research, it will focused more in Peninsular (Pekan) peat.

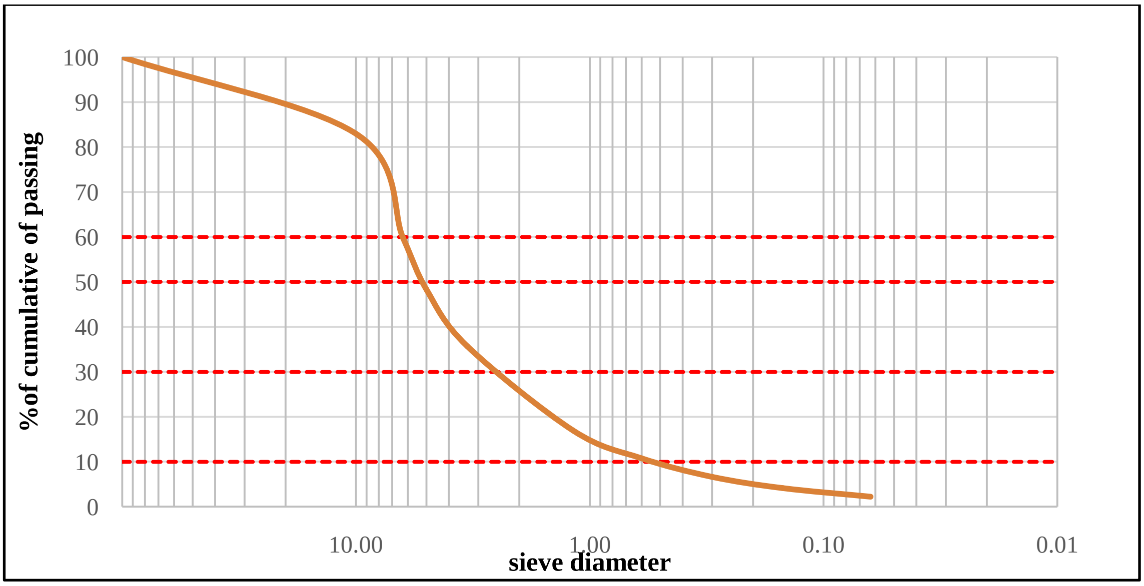

Figure 4.3 particle size distributions of peat soil

Figure 4.3 shows the particle size distributions of peat soil. From the graph we can determine the value of d_{60} is 6.5, d_{50} is 5.1, d_{30} is 2.5 and d_{10} is 0.55, while value of

Cu is 11.8 and Cc is 1.7 respectively. From Cc and Cu value the USCS classification the sample is indeed peat soil.

4.3 Natural properties of bottom ash

Series of experimental tests were carried out for bottom ash to determine the characteristics of bottom ash. The results were summarizing at Table 4.3 below.

Table 4.3: Physical properties of bottom ash

Properties	Value
Specific gravity	2.02
Density (kg/m³)	2020
Permeability(m/s)	0.001149
Cu	4.4
Cc	1.0
Angle of friction (°)	50
Repose angle (°)	21.5
e_{min}	0.93
e_{max}	1.44
pH	7.49
No. of angularity	5

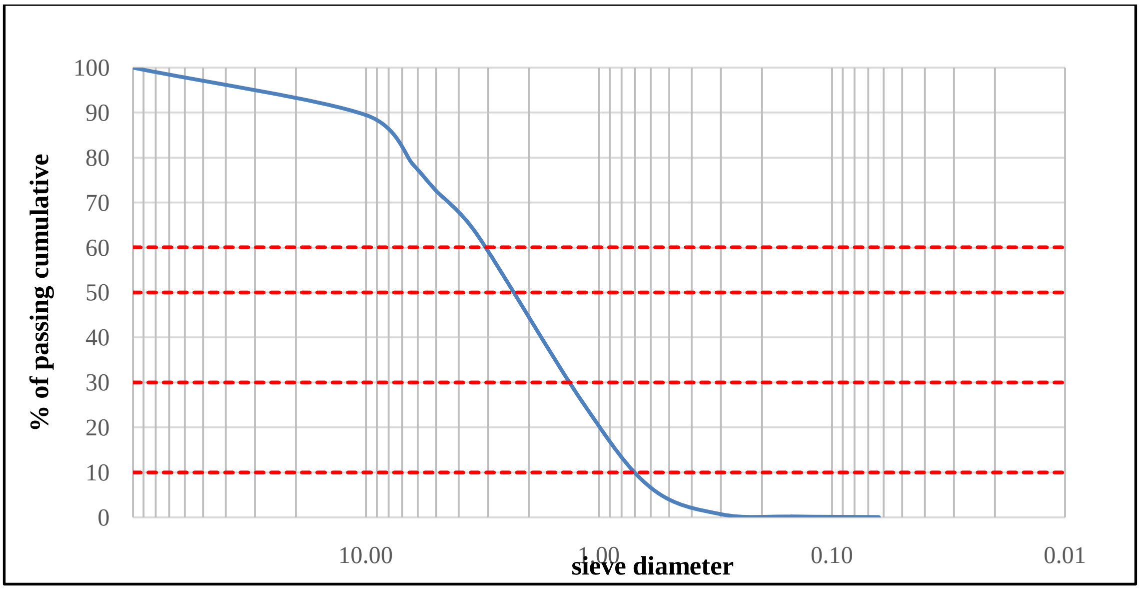

Figure 4.4: Particle size distributions of bottom ash

Figure 4.4 shows the particle size distributions of bottom ash. From the graph we can determine the value of d60 is 3.05, d50 is 2.4, d30 is 1.45 and d10 is 0.69, while value of Cu is 4.4 and Cc is 1.0 respectively. From Cc and Cu value it can be said that bottom ash similar to clean sand based on USCS classification.

Table 4.4: Comparison of physical properties between bottom ash and sand.

Physical properties	Bottom ash	Sand
Specific gravity	2.02	2.62
Density(kg/m³)	2020	2620
Permeability (m/s)	0.001149	0.00054
e_{min}	0.93	0.51
e_{max}	1.44	0.7
Cu	4.4	2.34
Cc	1.0	0.99

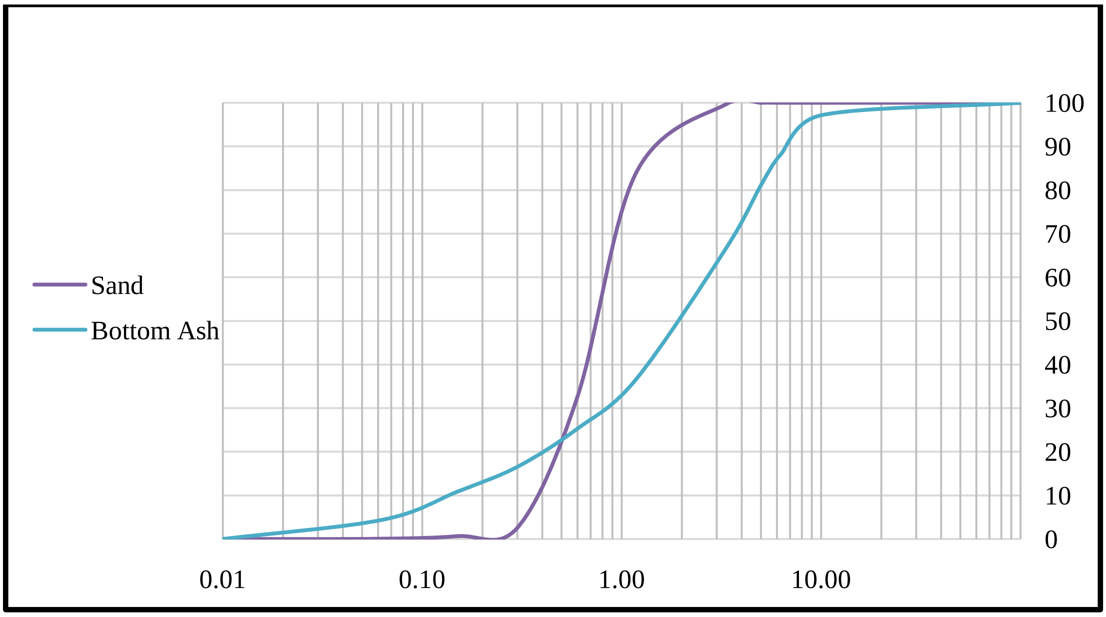

Figure 4.5: Particle size distribution for TC sand and bottom ash

Figure 4.5 above showed a comparison of particle size distribution curve between Teluk Cempedak sand and bottom ash. The curves showed a slightly similarities between bottom ash and Teluk Cempedak sand. As we can see at Table 4.4, the value of certain properties only a little bit different. Such as value of density of bottom ash and TC sand are 2020 kg/m³ and 2620 kg/m³ respectively. Specific gravity also has a slightly different, bottom ash (2.02) and TC sand (2.62) respectively. Value of Cc for bottom ash and TC sand showed a similarity which is 1.0 and 0.99 respectively. Figure 4.5, shows the particle size distribution between TC sand and bottom ash. The curve quite similar shows that bottom ash is slightly have a characteristic like TC sand. Since bottom ash has a similarity with TC sand, it can be used as a replacement for sand in concrete mixing. Beside bottom ash compatible with ordinary Portland cement due to pozzolanic reaction between these two materials. Bottom ash has angular and irregular in shape and has rough surfaces, those characteristics suitable to acts as aggregates in concrete mixing. According to Dilip Kumar et al. (2014), concrete that uses bottom ash as an aggregate has advantageous properties like improved workability and resistance to chemical attack.

4.4 Maximum Dry Density

Maximum dry density is the moisture content of soil at the optimum. The consistency test was carried out using our sample with both wet and dry conditions. The results are shown in Figure 4.6 below.

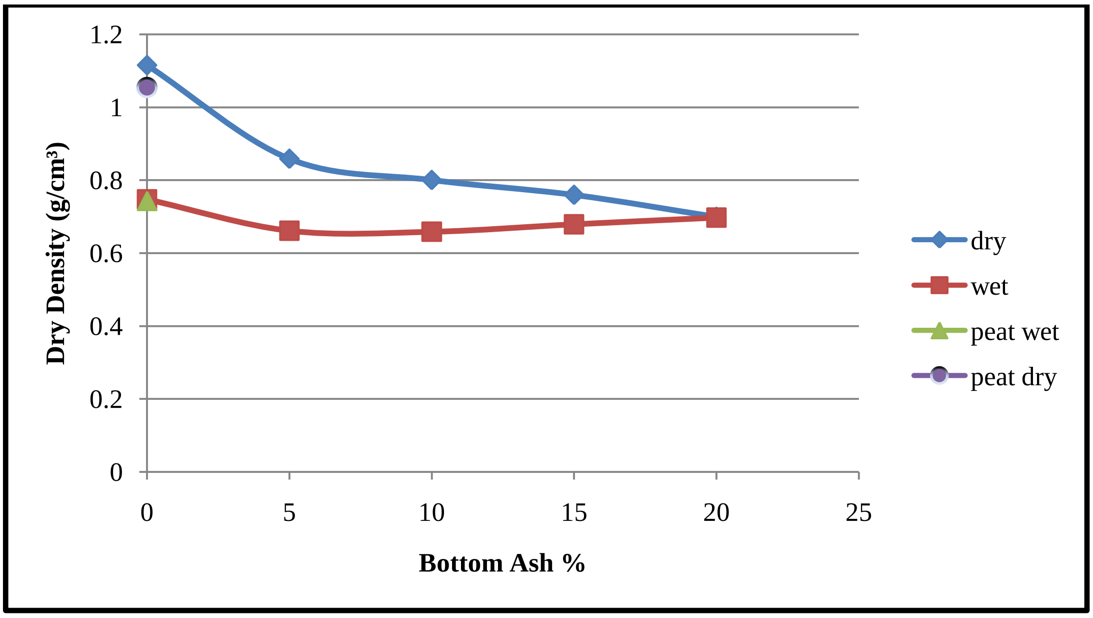

Figure 4.6: Maximum dry density with corresponding value of bottom ash.

Based on Figure 4.6, the value of MDD of original peat is 0.7426 g/cm³ and 1.0535 g/cm³ for wet and dry sample. For P1 is 0.7475 g/cm³ and 1.1153 g/cm³ for wet and dry sample, as for P2 is 0.6612 g/cm³ and 0.8585 g/cm³ for wet and dry sample, whereas for P3 is 0.6583 g/cm³ and 0.8002 g/cm³ for wet and dry sample, for P4 is 0.6789 g/cm³ and 0.7595 g/cm³ for wet and dry sample and P5 is 0.6972 g/cm³ and 0.6991 g/cm³ for wet and dry sample. Decreasing of MDD was due to higher specific gravity of bottom ash compared to peat soil. Beside that higher permeability of bottom ash also causes the reducing in MDD.

4.5 Liquid Limit

Liquid limit is the moisture content that defines where soil changes into viscous liquid state. It defines by calculate water content of each the liquid limit moisture cans after oven dried for overnight. Graph is plotted for water content (%) versus cone penetration (mm). Liquid limit is water content (%) at penetration at 20mm.

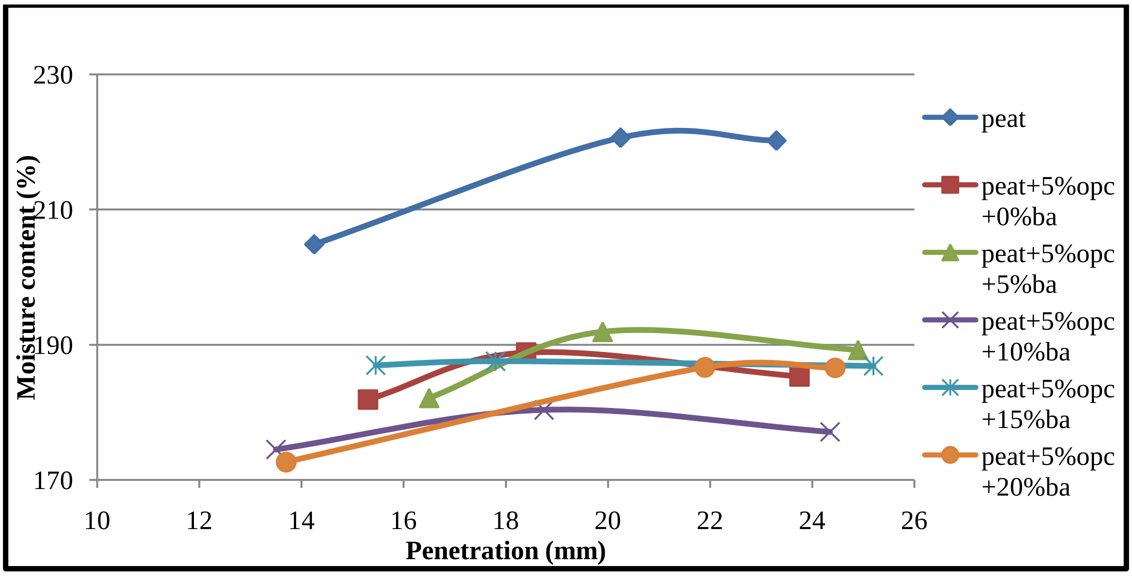

Figure 4.7: liquid limit value for untreated and treated sample.

Based on Figure 4.7, the value of liquid limit of untreated peat soil is 220% whereas P1 is 188.4%, P2 is 192%, P3 is 180.2%, P4 is 187.42% and P5 is 183.8%.

4.6 Plastic Limit

Plastic limit is moisture contents that corresponding to when soil changes into semi-solid to flexible (plastic) state. Plastic limit is determined by calculate the water content in the can by calculate the weight of sample before and after oven dried for 24 hours.

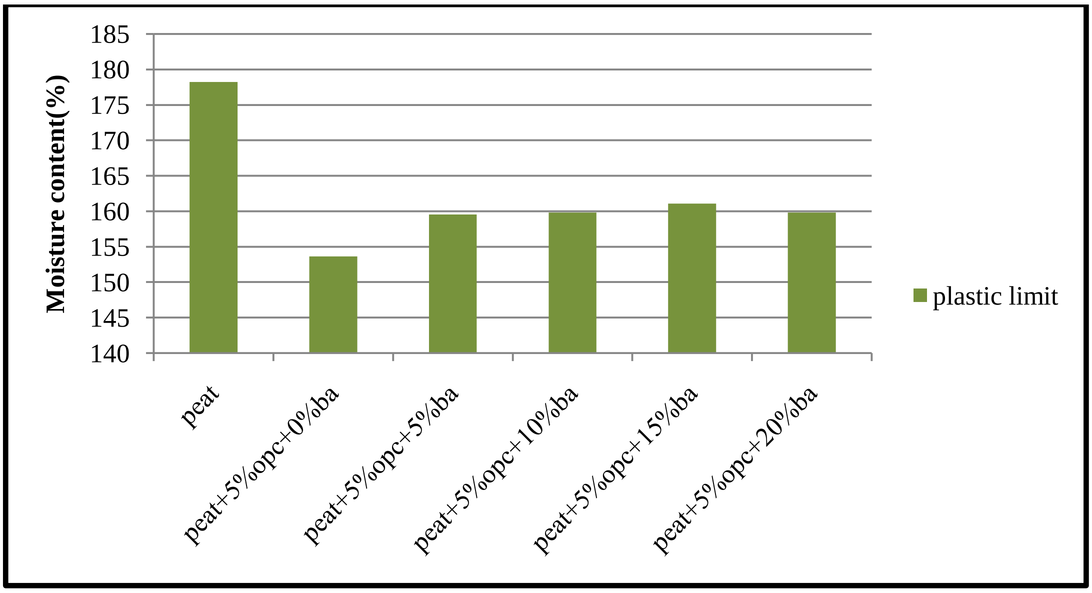

Figure 4.8: Plastic limit of treated and untreated sample

From Figure 4.8, the value of plastic limit of original is 178.22%, whereas P1 is 153.65%, P2 is 159.54%, P3 is 159.81%, P4 is 161.09% and P5 is 159.81%.

4.7 Effect of adding bottom ash on liquid limit of peat soil.

A consistent test for sample is tested to determine the liquid limit. These variations are shown in Figure 4.9.

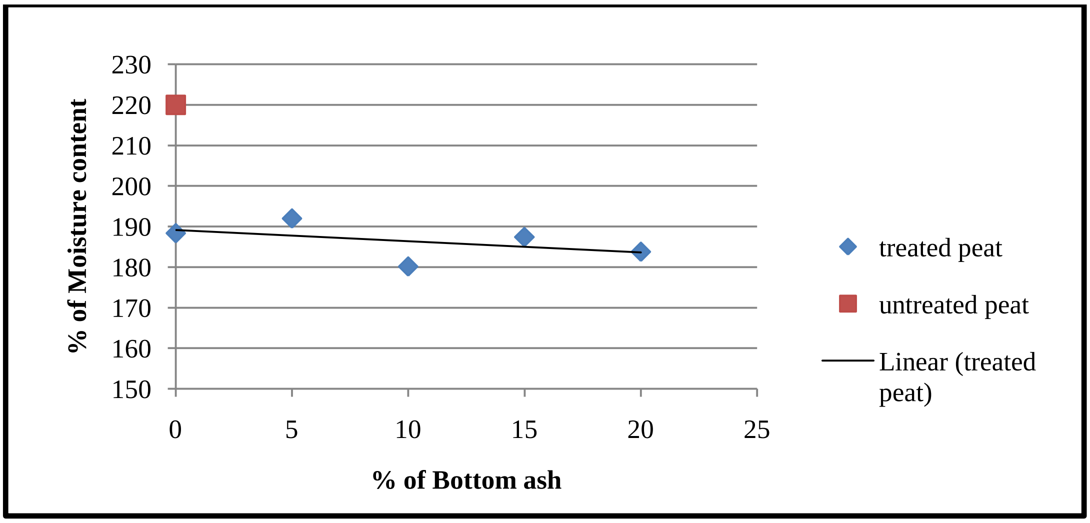

Figure 4.9: Liquid limit value of peat soil

Based on figure above, the liquid limit of peat soil shows a decreasing after adding bottom ash. Untreated peat show 220% liquid limit and while it treated with 5% OPC, the value decrease to 188.4%. Then we added 5%BA, 10% BA, 15% BA and 20%BA into peat+5%OPC respectively. The value of liquid limit of P1, P2, P3, P4 and P5 had shown a significant reduction. Peat originally has higher liquid limit due to abundant voids that exists in peat soils particles. The addition of coarser and irregular bottom ash particles filled the voids thus reduced the liquid limit of treated peat soil. The hydration process between OPC and peat soil contributed in reducing the liquid limit. This corresponding with what A.T Manikandan et al. (2017) said that upon addition BA there are reductions in liquid limit.

4.8 Effect of bottom ash on plastic limit of Peat soil.

A consistent test for sample is tested to determine the plastic limit. These variations are shown in Figure 4.10.

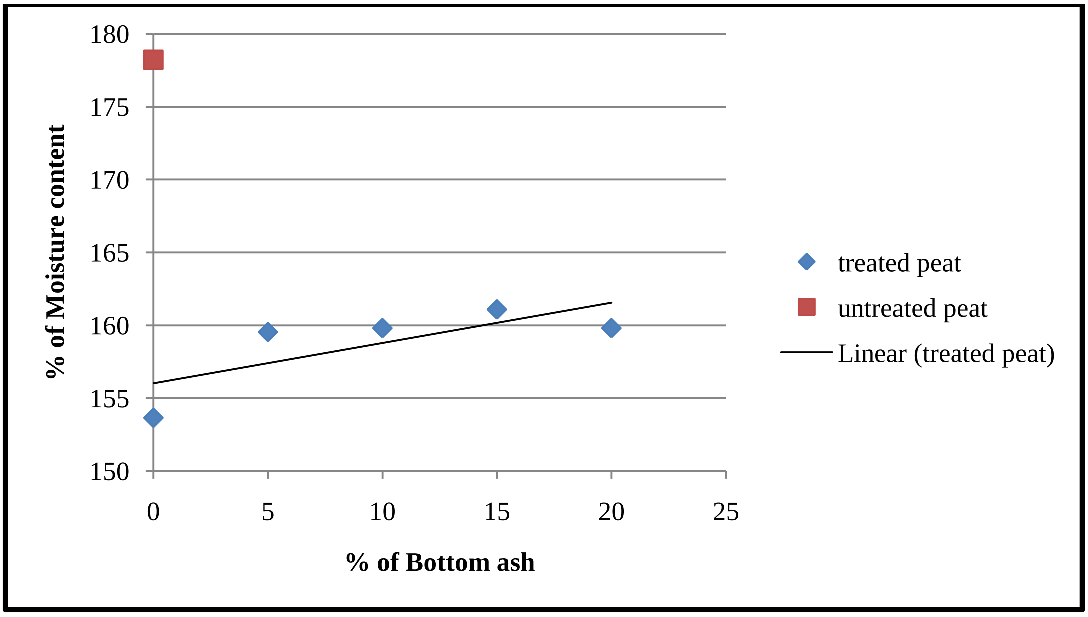

Figure 4.10: Plastic limit of peat soil (untreated and treated)

Figure 4.10 show a plotted graph for moisture content of plastic limit and corresponding percentage of bottom ash that added into peat. The value of plastic limit showed an increasing as the percentage of bottom ash increased. The value of plastic limit of original peat is 178.22% whereas P1 is 153.65%, P2 is 159.54%, P3 is 159.815%, P4 is 161.095% and P5 is 159.8%. Plastic limit of untreated peat higher compared to treated peat due to non-plastic characteristic of bottom ash. But as the percentage of bottom ash increases the plastic limit increases due to flocculation of peat and bottom ash particles. Bottom ash and peat soil formed cemented particles by pozzolanic reaction. This tally with what Rahman & Chan (2014) said about the pozzolanic reaction that happens when BA mix with peat.

4.9 Effects of bottom ash on plastic index of Peat soil

A variations of sample added with different percentage of bottom ash are tested for plastic index to find the correlation between parameter. Results are shown in Figure 4.6.

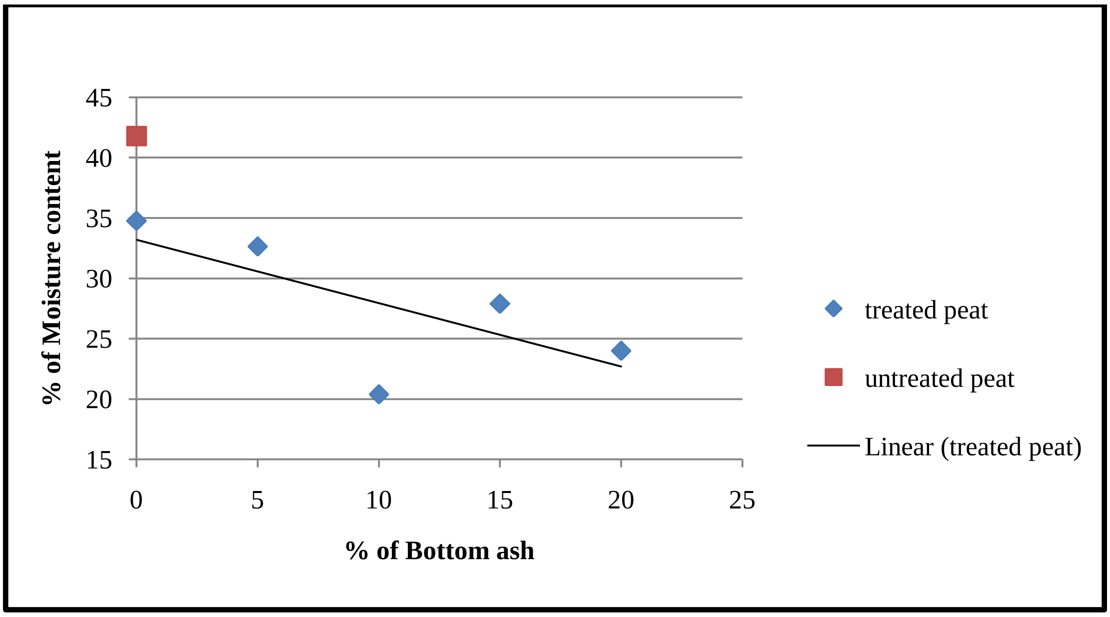

Figure 4.11 Plastic index value of peat soil

Based on Figure 4.11, the plasticity index is clearly shown a reduction when bottom ash are added into peat soil. The original peat plasticity index is 41.78% whereas P1 is 34.75%, P2 is 32.64%, P3 is 20.39%, P4 is 26.33% and P5 is 23.99%.

Based on this, bottom ash reduced the plasticity index of peat soil compared to original thus the swollen index of peat soil also diminishes. The cation exchanges between OPC and bottom ash and aggregations of flocculation of particles reduced the plasticity index. These finding corresponding with what A.T Manikandan et al. (2017) said about the cation exchange reaction and flocculation happen cause the plasticity index reduce.

4.10 California bearing ratio

Consistency test of California Bearing Test are conducted on peat soil samples and on samples treated with 0%,5%,10%,15% and 20% bottom ash plus with 5% ordinary Portland cement. The tests were carried out on samples prepared under compaction and in soaked and unsoaked conditions. Value of CBR at 2.5 mm and 5.0mm are taken as shown in figure

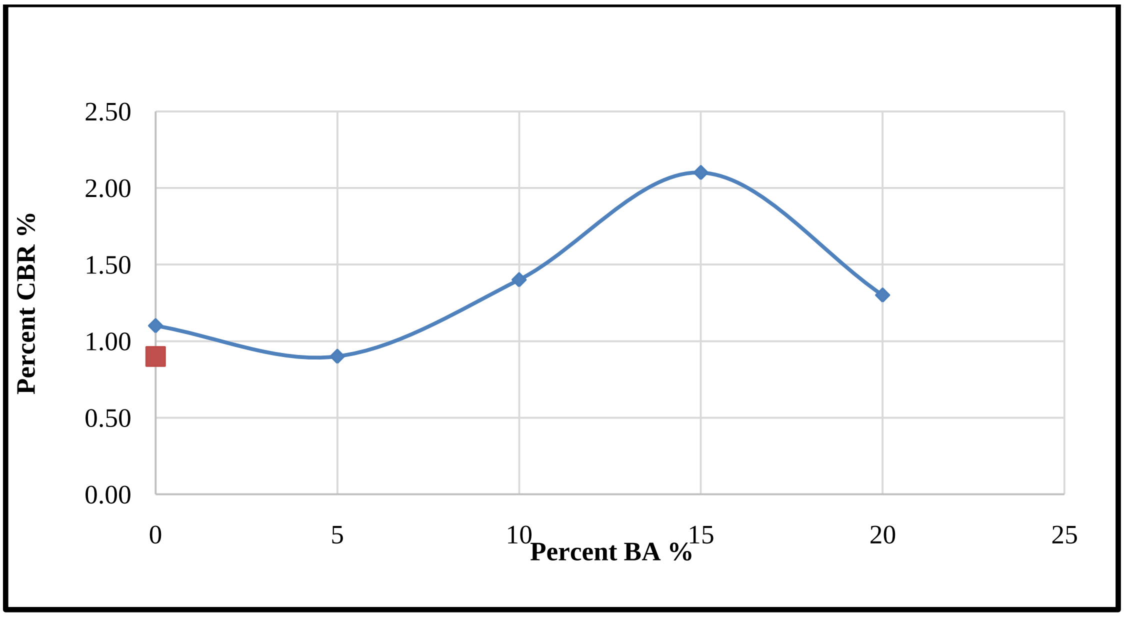

Figure 4.12: Unsoaked CBR at 2.5 mm.

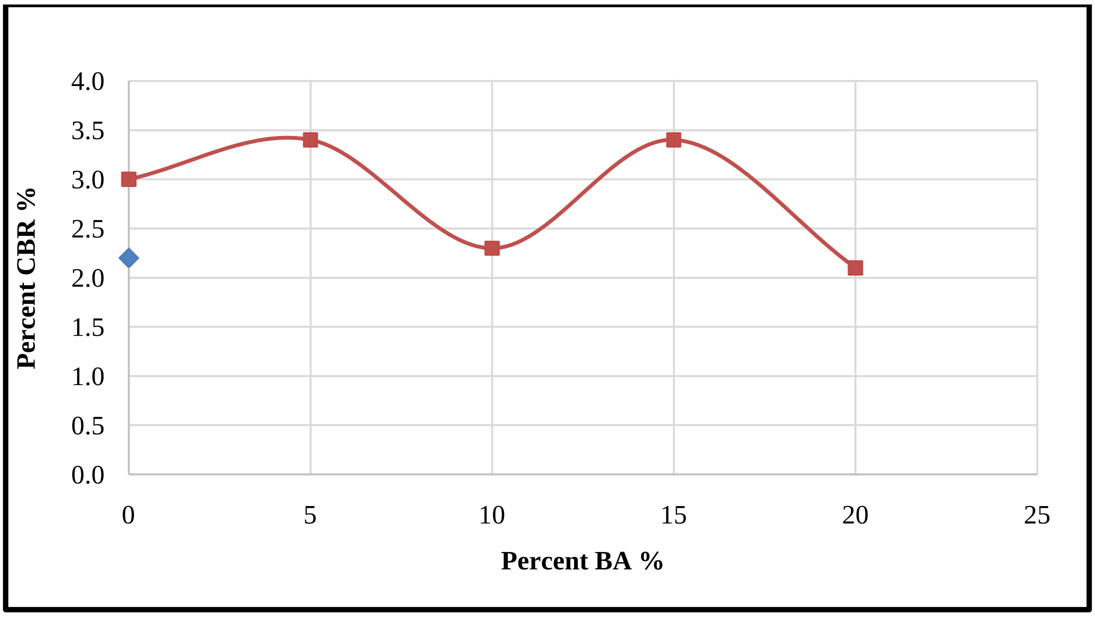

Figure 4.13: Soaked CBR at 2.5 mm.

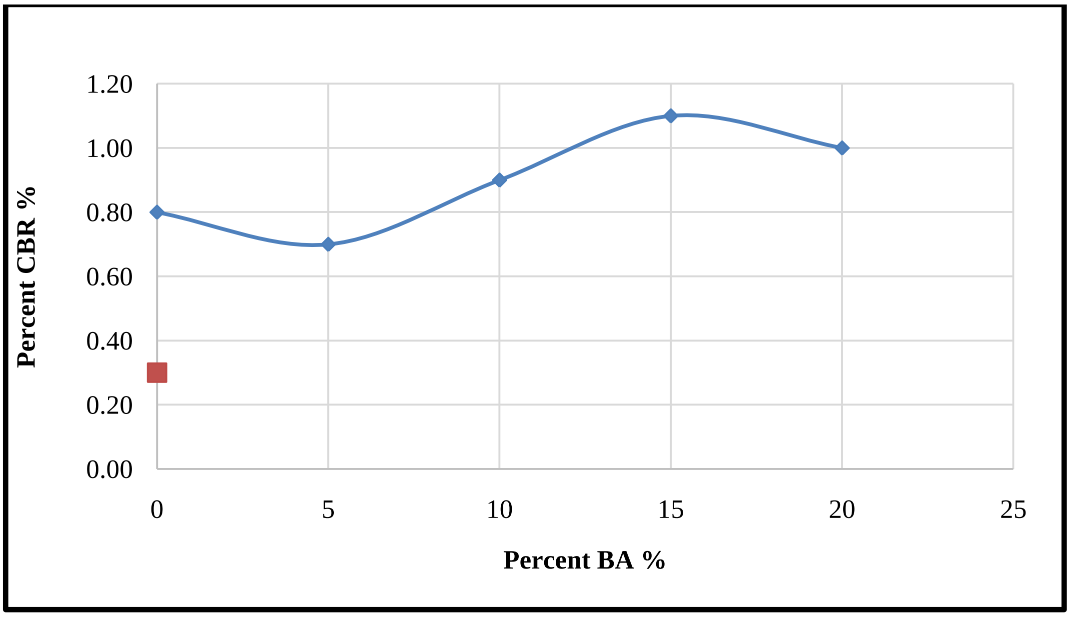

Figure 4.14: Unsoaked CBR at 5mm.

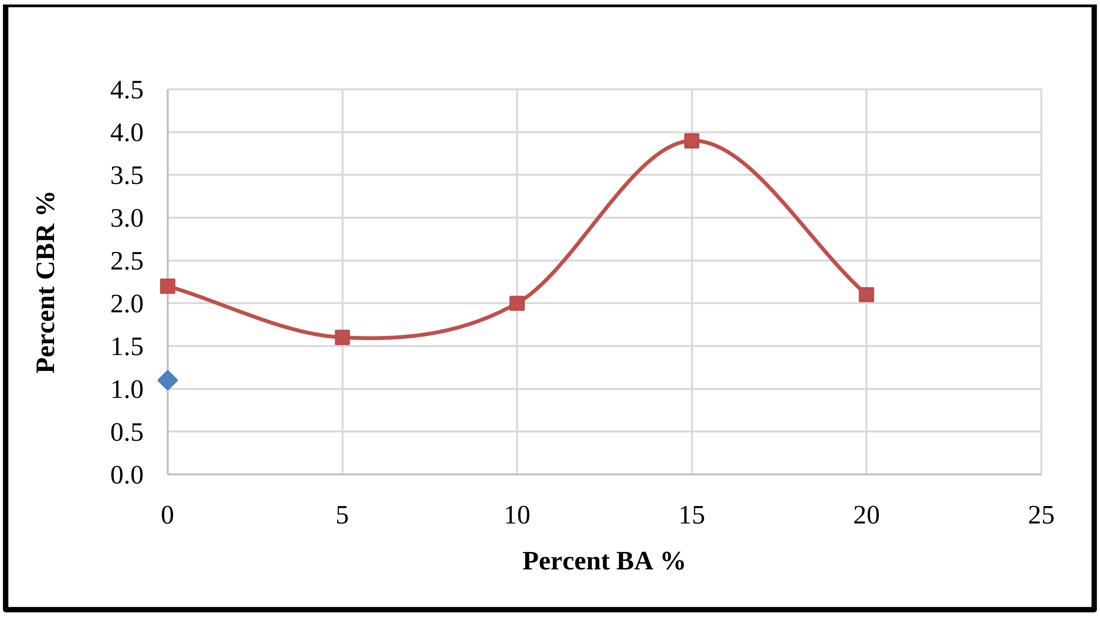

Figure 4.15: Soaked CBR at 5mm.

Based on Figure 4.12 and Figure 4.13 above, the values for unsoaked CBR at 2.5 mm is 1.1% for P1, 0.9% for P2, 1.4% for P3, 2.1% for P4 and 1.3% for P5. At 5mm the value of unsoaked CBR are 0.8% for P1, 0.7% for P2, 0.9% for P3, and 1.1% for P4 and 1.0% for P5.

As for Figure 4.14 it shown the value of soaked CBR at 2.5 mm is 3.0% for P1, 3.4% for P2, 2.3% for P3, 3.4% for P4 and 2.1% for P5. Figure 4.15 shown a value for soaked CBR and based from this, the value for P1 is 2.2%, for P2 is 1.6%, for P3 is 2.0%, for P4 is 3.9% and for P5 is 2.1%.

From these values, the smallest one will be chosen for CBR value of unsoaked and soaked sample for each sample.

4.11 Effects of adding bottom ash on CBR value of Peat soil

Table 4.5: Value CBR corresponding to sample (soaked)

Percentage BA	CBR
Peat	1.1
Peat +5%OPC	2.2
Peat+5%OPC+5%BA	1.6
Peat+5%OPC+10%BA	2
Peat+5%OPC+15%BA	3.4
Peat+5%OPC+20%BA	2.1

Table 4.6: Value of CBR corresponding to sample (unsoaked)

Percentage BA	CBR
Peat	0.3
Peat +5%OPC	0.8
Peat+5%OPC+5%BA	0.7
Peat+5%OPC+10%BA	0.9
Peat+5%OPC+15%BA	1.1
Peat+5%OPC+20%BA	1

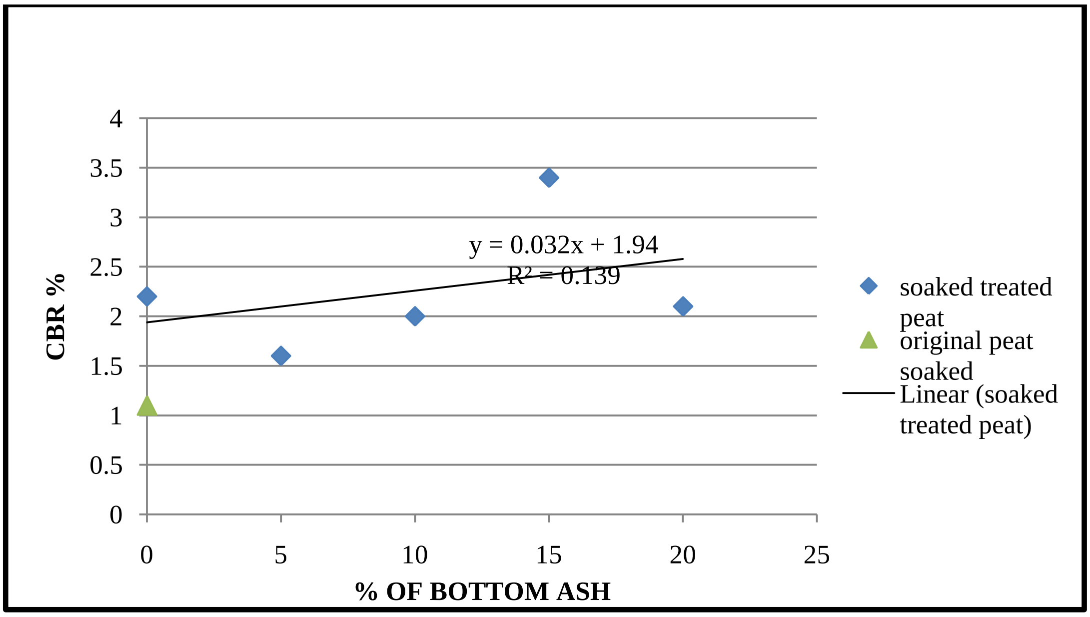

Figure 4.16: Comparison of CBR and % of BA

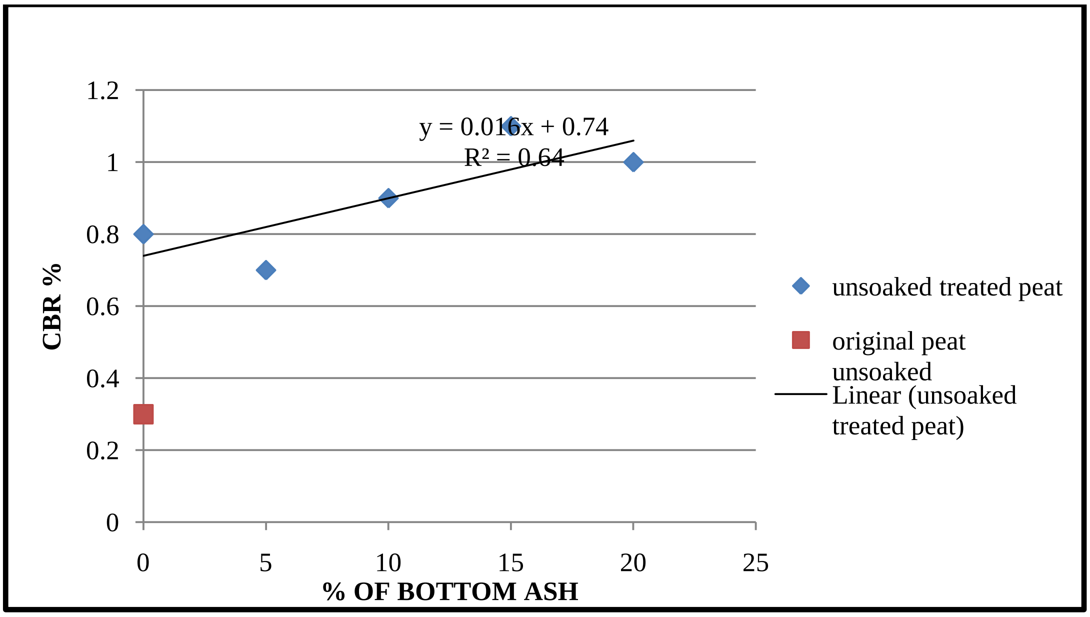

Figure 4.17: Comparison of CBR and % of BA

Table 4.5 and Table 4.6 are values for CBR that chosen from the smallest values from 2.5mm and 5mm value. From this value the graph at Figure 4.16 and Figure 4.17 are plotted. The value for CBR increases after adding bottom ash compared to original peat soil. It shows that by adding bottom ash into peat soil can increase the bearing capacity of peat soil. Original peat value is 1.1% for soaked and 0.3% for unsoaked. The value increases after adding 5% OPC that is 0.8% for unsoaked and 2.2% for soaked, for P2 the value is 1.6% for soaked and 0.7% for unsoaked. As for P3 the value of CBR for unsoaked is 0.9% and 2.0% for soaked sample. For P4 the value of CBR is 1.1% for unsoaked and soaked is 3.4% whereas for P5 is 1.0% for unsoaked and for soaked is 2.1%.

Adding bottom ash increased the fine and coarser particles contents in peat soils. During compaction of samples, bottom ash undergoes certain degree of crushing thus the particles packed closely together with peat soil. Bottom ash filled up more voids in peat soils and increasing the cohesion friction. Resulting an increasing in mechanical strength, reducing of voids ratio and eventually the bearing ratio also increases. A hydration process reduced the water content of peat soil also one of reason of increasing the bearing capacity.

These results can be supported by what Cadersa, Seeborun & Chan Chim Yuk (2014) said that by adding CBA to subgrade will increases CBR values and decreases swell potential. Besides that Rajakumar & Meenambal (2015) also said that adding Coal ash (fly ash + bottom ash) into highly expansive soil can increase the CBR value 1.34 times to the initial strength of the soil.

4.12 Effects of CBR value on pavement thickness design of peat soil

To calculate the pavement thickness, Arahan Teknik Jalan 5/85 Public Work Department are used and some conditions are assumed. For this research we assumed that;

Type of road: JKR05

Initial daily traffic volume: 6600

Percentage of commercial vehicle: 15%

Annual growth rate: 7%

Equivalence factor: 2.0

Rolling terrain

Design year: 10 year

Based on these assumptions, we calculate the following;

Initial annual commercial traffic for one direction VO = 180675

Total number of commercial vehicles for one direction VC= 2.5×10^6

ESA = 5×10^6

Table 4.7 Value of CBR and corresponding pavement thickness (mm)

Sample	CBR soaked	Pavement thickness (cm)	CBR unsoaked	Pavement thickness (cm)
Peat	1.1	35	0.3	37
Peat+5%OPC+0 %BA	2.2	32	0.8	35
Peat+5%OPC+5 %BA	1.6	34	0.7	36
Peat+5%OPC+10 %BA	2	33	0.9	35
Peat+5%OPC+15 %BA	3.4	29	1.1	34
Peat+5%OPC+20 %BA	2.1	32	1	35

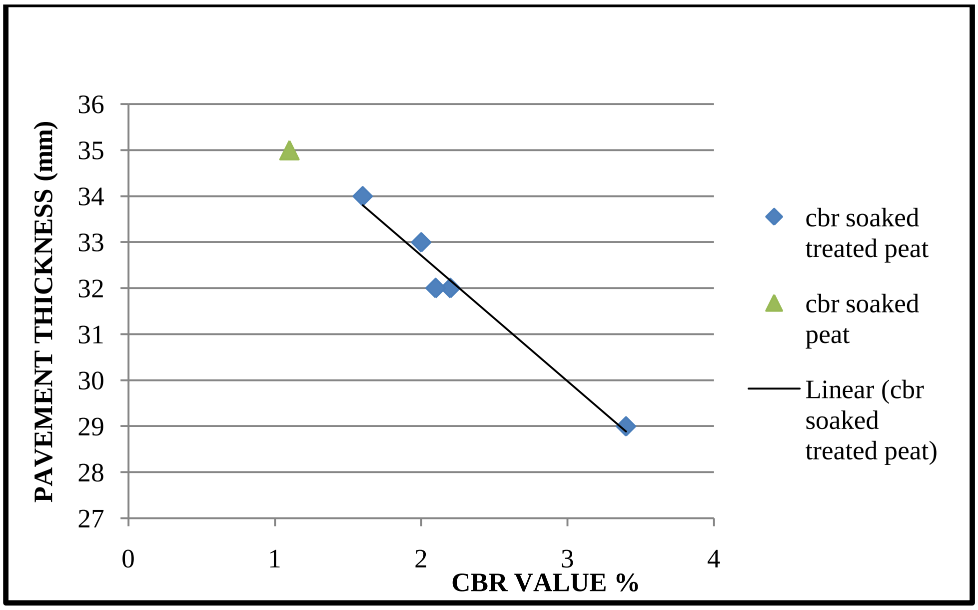

Figure 4.18 Comparison of CBR value (%) and pavement thickness (mm)

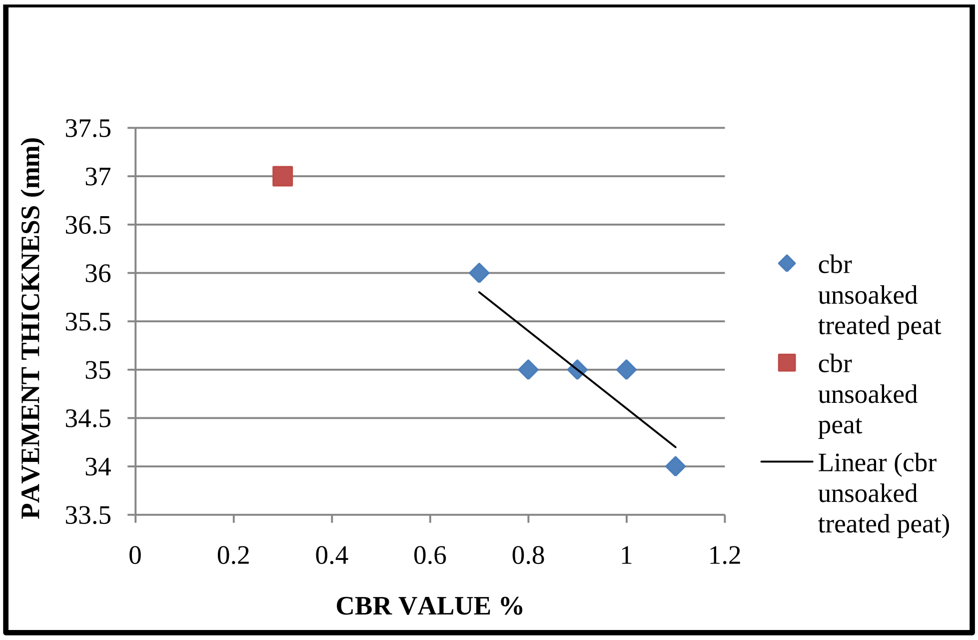

Figure 4.19: Value of CBR (%) for unsoaked sample and pavement thickness (mm).

Based on figure and table, it can be seen that increasing in CBR value can decreasing the pavement thickness. The original peat shows a thick pavement that is 35 and 37 mm for soaked and unsoaked conditions. But it started decreasing when peats are treated with bottom ash.

CHAPTER 5

CONCLUSION

5.1 Introduction

As we know peat soil is problematic soil that not suitable for construction industry. Based on this statement, we conducted a research to improvise peat soil by adding bottom ash. Bottom ash is waste product that we get after combustion of charcoal. A series of experiment are done to prove that bottom ash can improved peat soil. The series of data and analysis from Chapter 4 will be concluded here.

5.2 Conclusions

From this experiment we can determine the natural properties of both peat and bottom ash. The peat soils that we use in this research are Hemic peat. Based on Radforth's system, this peat fall in fine fibrous peat in category 11(woody and non-woody particles held in fine-fibrous peat). This peat has 36.64% fiber content so according to ASTM standard it a Hemic peat (H4-H10).This peat is in H6 category of Van post scale. The peat is moderately highly decomposed with a very indistinct plant structure. When squeezed, about 1/3 of the peat escapes between fingers. The residue is very pasty and water comes out when squeezing is muddy in colour.

For bottom ash it more or less like sand, based on particle size distribution test the bottom ash fall in category clean sand (USCS classification). Bottom ash is very angular coarse material. When bottom ash is added into peat soil, the MDD is decreased as the bottom ash percentage increase. Bottom ash provides initial rapid strength gain by cementing soil particles. MDD decreased due to water used up during hydration and flocculation of peat soil and bottom ash particles. Beside that bottom ash has higher specific gravity compared to peat soil. The permeability of peat soil also contributed in reducing the MDD.

Adding bottom ash into peat soil reduced the liquid limit of peat soil. The original peat soil has a high liquid limit which is 220%. This due to larger voids that existing in peat soil. After adding 5% OPC the value of liquid limit reduced into 188.4%. It can be said that the more BA added into peat soil, more decreasing the liquid limit. Because of hydration reaction between OPC and peat cause the reduction of liquid limit. When bottom ash and OPC is added into peat soil there is pozzolanic reaction happen while bottom ash filled the voids that exist in peat soil. The coarser and irregular shape of bottom ash increased the cohesion of particles thus peat soils and bottom ash particles will pack closely together. These factors contributed in reducing liquid limit of treated peat soils with bottom ash.

While liquid limit shown a reduction, the plastic limit shows an increasing in result. The plastic limit is the moisture content needed for soil to turned into flexible state. As for this case, peat already filled with bottom ash and hydration process cause by OPC there is restrain for peat to turn into flexible. Bottom ash has non-plasticity characteristic also one of factor that contributed into this condition. Plasticity index shows a reduction due to exchange of cation when reaction occurs between peat and OPC and also due to flocculation aggregation of more presence of bottom ash. This eventually led to significant reduction in swelling index of peat soil while cohesion increasing.

California bearing ratio has shown an increasing of value whether for unsoaked and soaked sample. As we know CBR is affected by liquid limit, plastic limit, plasticity index, maximum dry density, optimum moisture content, and type of soil and permeability of soil. By adding bottom ash into peat soil, the bearing capacity of peat soil increases due to less moisture content in the peat. The more presence of bottom ash in peat soils the less of moisture content thus a higher bearing capacity of peat soil. Beside that adding bottom ash increased a fine and coarser particles in peat soils particle thus enable bottom ash filled the voids. During process of compaction bottom ash undergoes certain degree of crushing thus it can filled more voids and increasing of cohesion between particles. The closely packed together particles increased the mechanical strength of soils. In nutshell adding bottom ash reduced the voids ratio and eventually the bearing ratio is increases.

Value of CBR is needed to design a flexible pavement for highway and field air construction. The higher the value of CBR the more suitable the soil uses in construction. In this case we can see that the value of pavement thickness decrease with the increase value of CBR. Original peat has 37 cm and 35 cm for unsoaked and soaked sample. After adding 5%OPC the value decrease into 35cm and 32 cm for unsoaked and soaked for sample. And decrease further after adding 5%, 10%, 15% and 20%BA respectively.

It can be concluded that by adding bottom ash into peat soils, the MDD is decreased. Adding bottom ash also reduced the liquid limit of peat soil while plastic limit increases and plasticity index is reduced. The CBR value is increases after adding bottom ash and the thickness of pavement is decreased when peat soils is treated with bottom ash. These show that bottom ash can be used as a mechanical stabiliser, where bottom ash as a filler and OPC as hydration agents.

5.3 Recommendations

The following or suggestions to expand or improve this research of Performance of Bottom Ash Treated Peat Soil in Improving Bearing Capacity

i. All laboratory tests should repeat at least 3 times to get the consistent results and average results.
ii. Bottom ash can be used in highway construction to improved bearing capacity of peat soil and in the same time reduce the cost of highway construction.
iii. Doing in-situ test also to prove that this research can be used in industry.

This research only provides a general idea and established the feasibility of the performance of bottom ash towards peat soil in improving the bearing capacity and increasing the strength of peat soil. In order to ascertain the feasibility, further research is needed for future application in actual industry.

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APPENDIX A
SIEVE ANALYSIS

Table Appendix A1: Data of Sieve analysis of bottom ash

Weight of soil (g): 495.75 g

Sieve (mm)	Sieve wt (g)	Sieve + soil wt (g)	Soil wt. retained (g)	% wt. retained	Cumulative % wt. retained	Cumulative % passing
10	592.01	644.41	52.4	10.57	10.57	89.43
6.3	515.28	569.48	54.2	10.93	21.49	78.51
5.0	508.48	537.59	29.11	5.87	27.36	72.64
3.35	540.1	587.73	47.63	9.60	36.97	63.03
1.18	485.37	670.67	185.3	37.36	74.33	25.67
0.6	483.74	578.29	94.55	19.06	93.39	6.61
0.3	432.27	461.39	29.12	5.87	99.27	0.73
0.15	410.86	413.51	2.65	0.53	99.80	0.2
0.063	399.51	400.25	0.74	0.15	99.95	0.05
pan	243.28	243.53	0.25	0.05	100.00	0.00

Total = 495.75 Total loss% = 0.00%

Fill in from grain size curve

d_{60}= 3.05 Cu= $d60/d10$

d_{50}= 2.4 = 4.4

d_{30}= 1.45 Cc=$d30^2/d60 \times d10$

d_{10}= 0.69 = 1.0

USCS Classification= Clean Sand UCCS letter code = SP

Table appendix A2: Data of Sieve analysis of peat soil

Weight of soil (g): 420 g

Sieve (mm)	Sieve wt (g)	Sieve + soil wt (g)	Soil wt. retained (g)	% wt. retained	Cumulative % wt. retained	Cumulative % passing
10	592.25	663.77	71.52	17.03	17.03	82.97
6.3	515.59	613	97.41	23.19	40.22	59.78
5.0	508.61	556.72	48.11	11.45	51.68	48.32
3.35	540.14	592.98	52.84	12.58	64.26	35.74
1.18	514.36	593.2	78.84	18.77	83.03	16.97
0.6	391.11	417.03	25.92	6.17	89.20	10.80
0.3	431.36	448.7	17.34	4.13	93.33	6.67
0.15	421.51	432.23	10.72	2.55	95.88	4.12
0.063	399.08	407.03	7.65	1.89	97.77	2.23
pan	364.52	371.17	6.65	1.58	99.36	0.64

Total = 417.30 Total loss% = 0.64%

Fill in from grain size curve

d_{60}= 6.5 Cu= $d60/d10$

d_{50}= 5.1 = 11.8

d_{30}= 0.55 Cc=$d30^2/d60 \times d10$

d_{10}= 0.69 = 1.7

USCS Classification= Silt sand UCCS letter code = PT

APPENDIX B

SPECIFIC GRAVITY

Table Appendix B1: Data of specific gravity of bottom ash

Description	1	2	3
Density bottle no.	A	B	C
Weight of density bottle	22.26	21.54	21.99
Weight of density bottle + Stopper	27.29	26.56	27.18
Weight of density bottle + Stopper + Dry Soil	37.34	36.59	37.25
Weight of density bottle + Stopper + Dry Soil + Water	83.5	83.01	82.69
Weight of density bottle + Stopper + Water	78.39	77.94	77.63
Weight of Dry Soil	10.05	10.03	10.07
Weight of Water	51.1	51.38	50.45
Weight of Dry Soil + Water	61.15	61.41	60.52
Specific gravity	2.03	2.02	2.01
Average Specific gravity	2.02		

Table Appendix B2: Data of specific gravity of peat soil

Description	1	2	3
Density bottle no	P	Q	R
Weigh of density bottle	24.52	21.99	20.62
Weight of bottle + stopper	28.89	27.18	25.64
Weight of bottle + stopper + dry soil	33.8	31.98	30.34
Weight of bottle+ stopper +soil +kerosene	70.32	69.16	67.34
Weight of bottle +stopper +kerosene	68.81	67.63	65.98
Weight of dry soil	4.91	4.8	4.7
Weight of kerosene	39.92	40.45	40.34
Weight of soil +kerosene	36.52	37.18	37
Specific gravity	1.4441	1.4679	1.4072
Average specific gravity	1.4397		

APPENDIX C
PERMEABILITY

Table Appendix C1: Data of permeability test of peat soil

Diameter	0.07466	m
Length	0.125	m
Area	0.0043779	m^2

Manometer tube	Diameter (m)	Start level h1 (m)	End level h2 (m)	Time , t sec
T1	0.01618	1	0.9	0.093
T2	0.0073	1	0.887	0.093
T3	0.00818	1	0.925	0.093

Manometer tube	h1/h2	log (h1/h2)	Time, t sec	Radius manometer tube, r (m)	Area manometer tube, a (m^2)	A×t
T1	1.1111	0.0458	0.093	0.00809	0.000205611	0.0004
T2	1.1274	0.0521	0.093	0.00365	0.000041854	0.0004
T3	1.0811	0.0339	0.093	0.00409	0.000052553	0.0004

Permeability of soil, Kt average $= \frac{KI+K2+K3}{3}$

$$= \frac{0.0029+0.0007+0.0005}{3}$$

= 0.0014 m/s

Table Appendix C2: Data of permeability test of bottom ash

Internal diameter, d (cm)	7.5	Vertical height, h (cm)	32
Specimen height, L (cm)	21.5	Area (cm^2)	44.16

Temperature	20	25
Viscosity	0.01005	0.00894

Constant head (cm)	Elapsed time, t (s)	Volume overflow Q (cm^3)	KT (cm/s)	K20(cm/s)
30	30.03	250	0.1267	0.1127
50	29.64	250	0.1283	0.1142
60	29.29	250	0.1299	0.1155
70	28.85	250	0.1319	0.1173

APPENDIX D

STANDARD PROCTOR TEST

Table Appendix D1: Data of standard proctors test of peat soil (dry)

Sample	Peat soil dry	
Vol. of mould	1000	cm^3

Water content	300	600	900	1200	1500
Mass of mould +base (m1)	4130	4130	4130	4130	4130
Mass of mould + base + compacted specimen (m2)	5300	5510	5530	5500	5500
Mass compacted specimen g	1170	1380	1400	1370	1370
Bulk density ρ g/cm^3	1.17	1.38	1.4	1.37	1.37

Moisture container no	1	2	3	4	5	6	7	8	9	10
Container weight g	10.35	9.75	10.76	9.51	10.53	10.22	9.9	10.66	10.45	9.92
Wet soil + container g	12.78	13.82	16.5	17.25	17.26	19.16	26.77	30.62	36.36	37.12
Wet soil g	2.43	4.07	5.74	7.74	6.73	8.94	16.87	19.96	25.91	27.2
Dry soil + container g	12.37	12.97	14.73	14.84	14.74	15.91	19.65	22.18	24.52	24.86
Dry soil g	2.02	3.22	3.97	5.33	4.21	5.69	9.75	11.52	14.07	14.94
Moisture loss g	0.41	0.85	1.77	2.41	2.52	3.25	7.12	8.44	11.84	12.26
Moisture content %	16.87	20.88	30.84	31.14	37.44	36.35	42.21	42.28	45.70	45.07
Avg. moisture content %	18.88		30.99		36.90		42.24		45.39	
Dry density ρ(g/cm^3)	0.9842		1.0535		1.0227		0.9631		0.9423	
Dry unit weight (kN/m^3)	9.65		10.34		10.03		9.45		9.24	
Maximum dry unit weight (kN/m^3)	10.34									
Maximum dry density (g/cm^3)	1.0535									
Optimum moisture content	30.99									

Table Appendix D2: Data of standard proctors test of peat soil (wet)

Sample	peat soil wet	
Vol. of mould	1000	cm³

Water content	90	180	270	360	450
Mass of mould +base (m1)	4130	4130	4130	4130	4130
Mass of mould+ base + compacted specimen (m2)	5360	5360	5360	5360	5370
Mass compacted specimen g	1230	1230	1230	1230	1240
Bulk density ρ	1.23	1.23	1.23	1.23	1.24

Moisture container no	1	2	3	4	5	6	7	8	9	10
Container weight g	10.35	9.75	10.76	9.51	10.51	10.21	9.91	10.67	10.47	9.93
Wet soil + container g	21.47	26.23	18.53	29.7	29.96	27.52	31.08	25.15	36.06	35.85
Wet soil g	11.12	16.48	7.77	20.19	19.45	17.31	21.17	14.48	25.59	25.92
Dry soil + container g	14.12	15.49	13.42	16.23	16.91	15.8	16.77	15.27	18.47	17.88
Dry soil g	3.77	5.74	2.66	6.72	6.4	5.59	6.86	4.6	8	7.95
Moisture loss g	7.35	10.74	5.11	13.47	13.05	11.72	14.31	9.88	17.59	17.97
Moisture content %	66.10	65.17	65.77	66.72	67.10	67.71	67.60	68.23	68.74	69.33
Avg. moisture content %	65.63		66.24		67.40		67.91		69.03	
Dry density ρ (g/cm^3)	0.7426		0.7399		0.7348		0.7325		0.7336	
Dry density(kN/m^3)	7.28		7.26		7.21		7.19		7.20	
Maximum dry unit weight (kN/m^3)	7.28									
Maximum dry density (g/cm^3)	0.7426									
Optimum moisture content	65.63									

APPENDIX E
ATTERBERG LIMIT

Table Appendix E1: Data of atterberg limit of peat soil

Liquid limit

TEST NUMBER	1		2		3	
Cone penetration (mm)	14.5	14	20	20.5	23.5	23.1
Average penetration	14.25		20.25		23.3	
Container no.	1	2	3	4	5	6
Container weight (gm)	13.15	14.44	15.15	15.18	14.04	13.64
Wet soil + container (gm)	21.37	21.54	24.23	26.45	28.4	25.45
Wet soil (gm). Ww	8.22	7.1	9.08	11.27	14.36	11.81
Dry soil + container (gm)	15.8	16.81	17.97	18.71	18.56	17.3
Dry soil (gm), Wd	2.65	2.37	2.82	3.53	4.52	3.66
Moisture loss (gm), Ww-Wd	5.57	4.73	6.26	7.74	9.84	8.15
Water content (%),(Ww-Wd)/(Wd)	210.1887	199.5781	221.9858	219.2635	217.6991	222.6776
Average water content (%)	204.8834		220.6246		220.1884	
w%	215.2321201					
Liquid limit	220%					

Plastic limit

Container no	1	2
Container weight (gm)	15.23	15.59
Wet soil + container (gm)	22.45	23.32
Wet soil (gm) ,Ww	7.22	7.73
Dry soil + container (gm)	17.77	18.43
Dry soil (gm), Wd	2.54	2.84
Moisture loss (gm), Ww - Wd	4.68	4.89
Moisture content	184.252	172.1831
Average moisture content	178.2175	

APPENDIX F

CALIFORNIA BEARING RATIO

Table Appendix F1: Data of CBR of peat soil unsoaked

Material Type **Peat soil Wet**

No. of Blows		25
Mould No.		G
Mould +Sample	A	9740
Wt. of Mould	B	7240
Vol. of Mould	C	2300

Container		24C	54D
Cont. +Wet Sample	W	38.48	53.72
Cont. +Dry Sample	D	14.16	15.57
Container MC=(W-D)/(D-T)x100	T	10.07	10.66
Moisture Content	MC	594.6	777.0
	Average	685.80	

Wet Unit Weight	(A-B)/C	WD	1.087
Dry Unit Weight	100xWD/(100+MC)	DD	0.138

Test No.		**1** 25 Blows	
Penet . mm	Std. Load Kg	Reading	Load Kg
0.25		1	0.016
0.50		2	0.032
0.75		2	0.032
1.00		3	0.048
1.25		4	0.064
1.50		5	0.080
1.75		8	0.128
2.00		9	0.144
2.25		10	0.160
2.50		8	0.128
2.75		10	0.160

3.00		9	0.144
3.25		8	0.128
3.50		5	0.080
3.75		5	0.080
4.00		5	0.080
4.25		5	0.080
4.50		3	0.048
4.75		2	0.032
5.00		4	0.064
5.25		4	0.064
5.50		4	0.064
5.75		5	0.080

CBR @	**95%**	1.625

CBR =	0.3

Correction Loads		
Test No	1	
Penetration	2.5	5.0
Std. Load	13.7	20.6
Corr. Load	0.128	0.064
CBR %	0.9	0.3
MIN %	0.3	

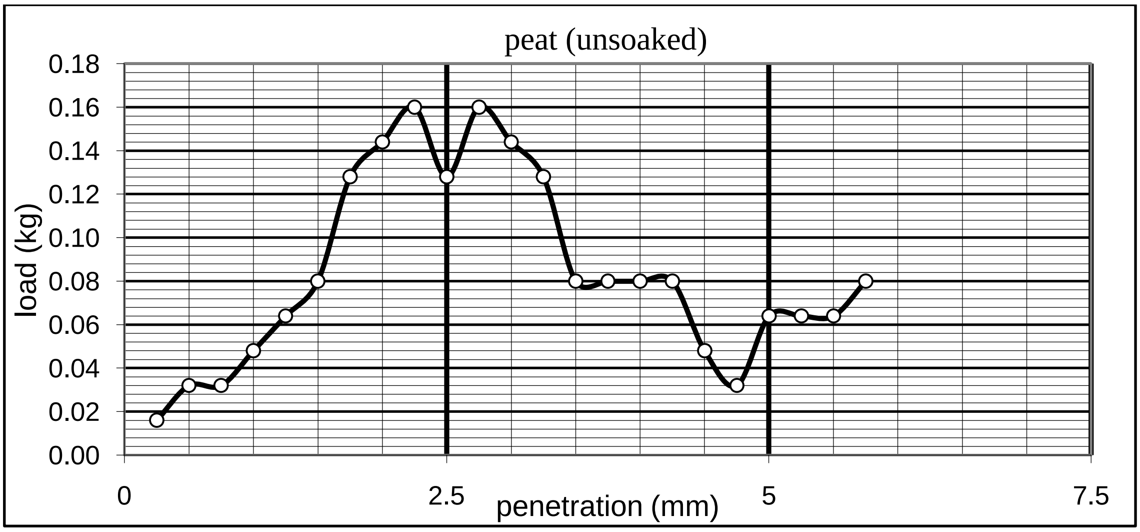

Table Appendix F2: Data of CBR of peat soil soaked

Material Type **Peat soil Wet**

No. of Blows		25
Mould No.		G
Mould +Sample	A	9260
Wt. of Mould	B	6860
Vol. of Mould	C	2300

Container		67 C	39D
Cont. +Wet Sample	W	35.83	54.01
Cont. +Dry Sample	D	16.2	13.97
Container MC=(W-D)/(D-T)x100	T	10.77	10.2
Moisture Content	MC	361.5	1062.1
	Average	711.79	

Wet Unit Weight	(A-B)/C	WD	1.043
Dry Unit Weight	100xWD/(100+MC)	DD	0.129

Test No.		**1** 25 Blows	
Penet . mm	Std. Load Kg	Reading	Load Kg
0.25		18	0.288
0.50		13	0.208
0.75		15	0.240
1.00		15	0.240
1.25		16	0.256
1.50		15	0.240
1.75		16	0.256
2.00		15	0.240
2.25		18	0.288
2.50		19	0.304
2.75		22	0.352
3.00		14	0.224

3.25		12	0.192
3.50		13	0.208
3.75		15	0.240
4.00		13	0.208
4.25		13	0.208
4.50		11	0.176
4.75		13	0.208
5.00		14	0.224
5.25		13	0.208
5.50		12	0.192
5.75		12	0.192

CBR @ 95% 1.625	**CBR =** 1.1

Correction Loads		
Test No	1	
Penetration	2.5	5.0
Std. Load	13.7	20.6
Corr. Load	0.304	0.224
CBR %	2.2	1.1
MIN %	1.1