A STUDY OF THE INFLUENCE OF ACTIVATION TEMPERATURE OF PRESS MUD ON THE ENGINEERING PROPERTIES OF PEAT SOIL

LAI QIN YAO

UNIVERSITI TUNKU ABDUL RAHMAN

A STUDY OF THE INFLUENCE OF ACTIVATION TEMPERATURE OF PRESS MUD ON THE ENGINEERING PROPERTIES OF PEAT SOIL

LAI QIN YAO

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering

Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

May 2022

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : _________________________

Name : Lai Qin Yao

ID No. : 1702959

Date : 13 May 2022

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"A STUDY OF THE INFLUENCE OF ACTIVATION TEMPERATURE OF PRESS MUD ON THE ENGINEERING PROPERTIES OF PEAT SOIL"** was prepared by **LAI QIN YAO** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : 

Supervisor : Dr. Lee Foo Wei

Date : 13 May 2022

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"In order for the light to shine so brightly, the darkness must also be present.", said Francis Bacon. I am also grateful to my best friend and research mate, Ms. Hor Joe Yin for her editing help, late-night feedback sessions and moral support. I would be remiss in not mentioning my family, especially my parents and sisters. They belief in me has kept my spirits and motivation high during this process.

ABSTRACT

Peat soil covers 8% of the land area in the world and is an expansive soil which normally classified as problematic soil due to its geotechnical drawback characteristics. Press mud (PM) is the residue of filtration of sugarcane juice from the sugar manufacturing industry that can be used in soil stabilisation. This study proposes an investigation of the influence of stabiliser and activation temperature on the engineering properties of peat soil. The stabilisers used in this study are lime and press mud, and the designed stabilisers proportion is 3% and 5.5% for lime and 0.0%, 0.25%, 0.50%, 1.0% and 2.0% for press mud. Lime was mixed with different percentages of press mud and peat soil in the mixing process to carry out laboratory tests: Standard Proctor Test and Unconfined Compressive Strength Test. Standard Proctor Test was conducted to determine the effects of mixed proportions of lime and press mud on the optimum moisture content and maximum dry density of treated peat soil. Meanwhile, the Unconfined Compressive Strength Test was conducted to determine the effects of mixed proportions of lime and press and the influences of activation temperature on the unconfined compressive strength of treated peat soil. The optimum moisture content and maximum dry density of treated peat soil were obtained at 5.5% lime and 0.25% press mud stabilised peat soil specimen. The optimum moisture content and maximum dry density have an inverse relationship where increases in optimum moisture content will lead to a decrease in maximum dry density. The addition of lime is to neutralise the peat soil and improve its load bearing capacity and PM was added to accelerate the reaction but both lime and press mud did not showed a significant effect. The unconfined compressive strength of treated peat soil showed a significant early strength development by 5.5% lime and 0.25% press mud stabilised peat soil. Lime improve the soil by improving its workability and load bearing capacity which are the important properties for flocculation while PM accelerate the strength development at the beginning stage. The warm activator accelerates the early strength gain of treated peat soil but affects the strength gain negatively in the long period as the continuous high temperature is detrimental to the soil structure and thus, reduces the strength development.

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LIST OF SYMBOLS / ABBREVIATIONS

M_d	Soil sample mass in dry condition, kg
M_w	Soil sample mass in wet condition, kg
ρ_m	Soil sample moist density, kg/m^3
C_u	Shear strength, kPa
G_s	Specific gravity
M_{cs}	Moist compacted soil mass, kg
S_u	Undrained shear strength, kN/m^2
w_{opt}	Optimum moisture content, %
ρ_d	Compacted soil dry density, kg/m^3
ρ_m	Soil sample moist density, kg/m^3
ρ_{max}	Maximum dry density, g/cm^3
σ_u	Unconfined compressive strength, kN/m^2
ΔL	Change in soil sample length, m
A	Average soil sample cross-sectional area, m^2
A_0	Initial average soil sample cross-sectional area, m^2
L_0	Initial soil sample length, m
v	Mould volume, m^3
P	Applied axial load at failure, kN
e	Axial strain
w	Natural moisture content, %

C-S-H	Calcium silicate hydrate
LL	Liquid limit, %
OPC	Ordinary Portland Cement
PL	Plastic limit, %
PM	Press mud
Si-O-Al	Aluminosilicate
UCS	Unconfined compressive strength

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Kolay and Rahman (2016) stated peat soil could be found worldwide as it covers 8% of the land area in the world. However, it is an expansive soil and is classified under problematic soils due to its geotechnical drawback characteristics like high compressibility, high water content and water-holding power, low bearing capacity, low specific gravity and moderate permeability. All these geotechnical properties are detrimental to engineering structure and the worst outcome is building collapse (Kolay and Taib, 2018).

Press mud (PM) is the residue of filtration of sugarcane juice from the sugar manufacturing industry. Waste materials can be reused as the stabiliser and the common agents, lime or cement in soil stabilisation, thus contributing to waste management. Fly ash, rice husk ash, eggshell, and palm oil fuel ash are successful in waste material adaptation in soil stabilisation, whereas PM is still new and rare to be used in the industry (James and Pandian, 2016).

Activation temperature is the relative temperature of activation energy. Activation temperature can increase the reaction rate and thus decrease the time needed for the process and increase the effectiveness of the reaction. In this study, the influences of different activation temperatures on the engineering properties of peat soil will be discussed.

1.2 Importance of the Study

The construction industry was forced to carry out development on peatland to fulfil the market demand brought by the rapid development. However, peatland is unfavourable for development due to its engineering properties leading to serious construction. The engineering properties of peat soil can be enhanced through soil stabilisation. The stabiliser used in this study is PM which is the waste material from the sugar manufacturing industry. This study showed the effects of different percentages of mixed proportions of stabiliser and the influence of activation temperature of PM on the engineering properties of peat soil. The stabilised soil can be used in construction to ease the unstable engineering structure shown in the case of development on peatland and maximise the use of land for development to fix the market demand, and last, improve the waste management of PM.

1.3 Problem Statement

The study of stabilising problematic soil with waste materials and lime as stabilising agents is still under investigation, while PM is potential but still new in the field and yet to be studied.

Peat soil is not suitable for construction due to its natural properties but the construction on peatland has become unavoidable because of the rapid urbanization and population growth (Kolay and Rahman, 2016). The construction on peatland has the possibility of leading to construction failure as the unacceptable peat soils settlement increases together with the increase of period time (Raghunandan and Sriraam, 2017).

James and Pandian have studied the engineering properties of PM in the year 2016 and 2020, and they proved that PM can be used to stabilise expansive soil. However, the effects of different percentages of mixed proportions of stabiliser on the peat soil engineering properties are still unclear. Moreover, the influences of activation temperature of PM on the peat soil engineering properties have yet to be explored and understood. Few samples are proposed with different percentages of mixed proportions of stabilisers and with different activation temperatures to study their influences on the engineering properties of peat soil.

1.4 Aim and Objectives

This study proposes an investigation of the influence of stabilisers on the engineering properties of peat soil. The specific objectives of this research were to:

- Study the engineering properties of treated and untreated peat soil.
- Compare the effects of different percentages of mixed proportions of stabiliser on the optimum moisture content, maximum dry density, and unconfined compressive strength of peat soil.
- Investigate the influence of different activation temperatures on the unconfined compressive strength of peat soil.

1.5 Scope and Limitation of the Study

The focus of this study was the engineering properties of peat soil before and after soil stabilisation. The soil stabilisation using PM and lime as stabilisers was studied to investigate the impacts of different percentages of mixed proportions of stabiliser on the peat soil engineering properties. In addition, the influence of activation temperature on the peat soil engineering properties is one of the focuses of this study. The changes in peat soil engineering properties before and after soil stabilisation were determined by a few parameters such as liquid limit (LL), dry density, moisture content, and unconfined compressive strength (Chittaranjan et al., 2021 & James and Pandian, 2016). This study is to understand the properties of PM on soil stabilisation to improve the peat soil engineering properties. PM can be used wisely by the industry if the study is valid and lead to better PM waste management.

This study's limitations are insufficient research studies regarding soil stabilisation using PM as PM is still new in the field. Besides, the activator uses to investigate the effects of activation temperature is hard to design because the activator must have the capability to stabilize the soil meanwhile not detrimental to the peat soil structure.

1.6 Contribution of the Study

The finding of this study contributes as a reference to further studies of limitations and recommendations to the lime and PM stabilised peat soil, and determination of laboratory test.

1.7 Outline of the Report

Chapter 1 Introduction discourses the general introduction, importance of the study, problem statement, aim and objectives, scope and limitation of the study and contribution of the study.

Chapter 2 Literature Review reviews the engineering properties of treated and untreated peat soil, PM stabiliser mixtures, the raw materials involved in this study and the influences of activation temperature on the engineering properties of peat soil. All the information stated in this chapter is referred to professionals' research papers, studies and journals.

Chapter 3 Methodology and Work Plan explains the methodology of laboratory tests and the work plan of this study. The laboratory tests such as Standard Proctor Test and Unconfined Compressive Strength Test and their laboratory procedures and calculations, materials preparation and mixing processes are involved in this chapter.

Chapter 4 Result and Discussion discusses the results collected from laboratory tests regarding the lime and PM stabilised peat soil. The effects of different percentages of mixed proportions of lime and press mud on the optimum moisture content, maximum dry density, and unconfined compressive strength of peat soil and the influence of different activation temperatures on the unconfined compressive strength of peat soil were studied based on the experimental results obtained.

Chapter 5 Conclusion and Recommendation concludes the project findings with an analysis and discussion of the laboratory results obtained. The conclusion of this study is made according to the objective to be achieved and the laboratory results obtained. Recommendations for the future study are also being discussed in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The engineering properties of raw materials and admixtures and the effects of admixtures on the engineering properties of the soil will be discussed in this chapter. The tests to determine the engineering properties of the soil will also be reviewed in this chapter.

2.2 Peat Soil

Peat soil is a type of soft soil made up of leaves, roots, and other fibres that have been fossilised when exposed to water (Moayedi and Nazir, 2018). It is dark brown to black, and a clay-like slurry will flow between fingers and leave the plant residues on the hand when peat soil is squeezed between fingers. It contains high organic matter due to no microbial activity in the acidic environment during plant decomposition and it can be found in both low-lying and high-lying areas (Rahman et al., 2016). According to research done by Rahman et al. (2016), Malaysia has 2.7 million ha of peatland which is 8% of Malaysia's total land area and the peatland is distributed near the seaside area. Sarawak is the state with the most peatland which is 1.66 million ha or known as 13% of its total land area (Rahman et al., 2016). The same statement regarding the distribution of peat soil in Malaysia is reported by Kolay and Rahman (2016), Raghunandan and Sriraam (2017) and Kolay and Taib (2018).

Peat soil is not suitable for construction due to its natural properties but the construction on peatland has become unavoidable due to the rapid growth in development and population (Kolay and Rahman, 2016). The construction on peatland will cause construction failure as the unacceptable peat soils settlement will increase with the increase of period time (Raghunandan and Sriraam, 2017).

Table 2.1: The Area of Peatland in Malaysia (Mahmod et al., 2016).

State	Area (ha)	Percentage (%)
Sarawak	1,697,847	69.08
Selangor	164,708	6.70
Pahang	164,113	6.68
Johor	143,974	5.86
Sabah	116,965	4.76
Terengganu	84,693	3.45
Perak	69,597	2.83
Kelantan	9,146	0.37
Negeri Sembilan	6,245	0.25
Federal Territory	381	0.02
Total	**2,457,669**	**100**

2.2.1 Engineering Properties of Untreated Peat Soil

Peat soil has been categorised as problematic soil because of its engineering properties and fell between H_5 and H_6 according to the von Post classification. Peat soil has a high moisture content that can reach up to 800% resulting in its highly compressible and low bearing capacity. Moayedi and Nazir (2018) and Kolay and Rahman (2016) have the same observations on the moisture content of peat soil. Rahman et al. (2016) stated in the research paper, that the peat soils found in Peninsula Malaysia have high water holding capacity due to their high moisture content. The high water holding capacity of peat soil found in Peninsula Malaysia was also reported by Zainorabidin, Musa and Mohamad (2016) and (Kolay and Taib, 2018). Based on the observation of a scanning electron microscope, the high compressibility and low strength of untreated peat soil are controlled by its sheet-like particles as shown in Figure 2.1 (Rahman et al., 2016).

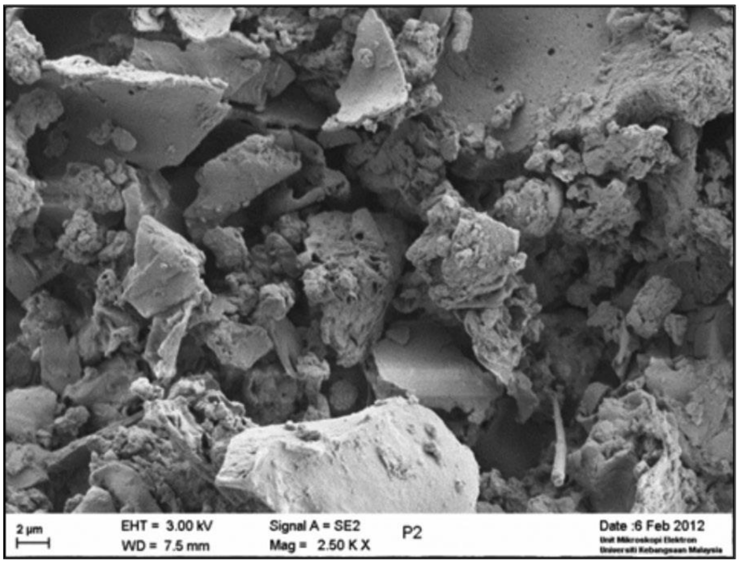

Figure 2.1: Scanning Electron Microscope Micrographs of Untreated Peat Soils (Rahman et al., 2016).

The peat soil's basic properties are shown in Table 2.2. Peat soil is highly acidic soil with a pH value of 3.51. The acidity of peat soil is caused by the organic and humic acids secretion from the organic content's decomposition in plants and the organic matters inside peat soil can exceed 95% of its composition. The statement that peat soils contain more than 95% of organic matter is supported by Zainorabidin, Musa and Mohamad (2016), who claimed that peat soil contains 65 to 97% of organic matter. It has a low specific gravity value of 1.25 and high moisture content (exceeding 100%). Raghunandan and Sriraam (2017) stated the organic content in peat soil is affecting its specific gravity directly and the increase in organic content will lead to a decrease in the specific gravity of peat soil. This statement is also reported by (Kolay and Taib, 2018). The organic content of peat soil allows water molecules to move freely and increases the water absorption capacity of peat soil (Raghunandan and Sriraam, 2017 & Kolay and Rahman, 2016). It is a non-plastic soil due to the existence of large amounts of plant leftovers, hence, the plastic limit is not determined. The results of the compaction test of untreated peat soil showed that peat soil is low in both maximum dry density and optimum moisture content and these have resulted in low shear strength of 11 kPa (Rahman et al., 2016). Moayedi and Nazir (2018) claimed the range of unconfined shear strength of peat soil fell between 3 to 17 kPa.

Table 2.2: Basic Properties of The Untreated Peat Soil (Rahman et al., 2016).

Property	**Peat**
pH	3.51^{α}
Particle size distribution	-
Specific gravity, G_s	1.25^{α}
Organic content (%)	97.42^{α}
Grade of decomposition	$H_5 - H_6$
Natural moisture content, w (%)	470 – 560
Liquid limit, LL (%)	184
Plastic limit, PL (%)	-
Maximum dry density, ρ_{max} (g/cm^3)	0.61^{α}
Optimum moisture content, w_{opt} (%)	63.5^{α}
Shear strength, C_u (kPa)	13.8

Remarks: α represents Mean value.

Kolay and Rahman (2016), Raghunandan and Sriraam (2017) and Kolay and Taib (2018) claimed the soil is categorised based on its organic content in the soils. The soil with 3 to 20% organic content is categorised as slightly organic while the soil with 20 to 75% organic content is considered ~~as~~ organic and the soil with more than 75% organic content is peat soil. However, soil scientists claimed that peat soil is soil with more than 35% of organic content and geotechnical engineers reported that peat soil is the soil that contains more than 20% organic matter (Zainorabidin, Musa and Mohamad, 2016). The categories of soils of different locations in Malaysia fell in are ~~as~~ shown in Figure 2.2.

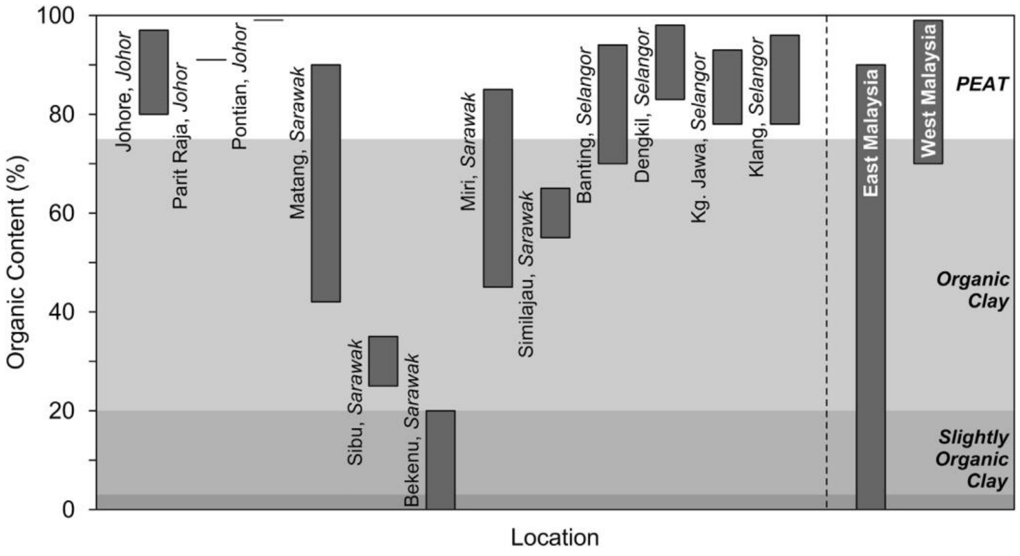

Figure 2.2: Organic Content and Categorisation of Soil of Different Locations in Malaysia (Raghunandan and Sriraam, 2017).

2.2.2 Engineering Properties of Treated Peat Soil

Moayedi and Nazir (2018) have discussed in their study that cement, quick lime and fly ash are workable in stabilising peat soil with correct proportions (6 - 20%). The peat soil stabilisation is done by mixing the wet or dry binder with correct proportions. Peat soil needs more stabiliser for stabilisation compared to that of clay as the solid particles in peat soil are lesser. Sand is one of the filler choices to increase the solid particles, but filler will not enhance the unconfined compressive strength, it will only make the soil stiffer.

2.2.2.1 Engineering Properties of Cement Treated Peat Soil

The plastic index was not determined in this study as peat soil is non-plastic as stated previously. Rahman et al. (2016) stated the plastic index for non-plastic peat soil is around 0 to 3. The peat soil has a high-water limit due to its high organic content. Its high organic content increased its capacity for water absorption. This proved that the increase in the organic content of peat soil results in an increment in its liquid limit (LL).

Cement treated peat soil has a lower LL due to the pozzolanic reaction caused by cement hydration. Rahman et al. (2016) investigated the reaction of different Ordinary Portland Cement (OPC) amounts on the LL of peat soil. The results of the study as shown in Figure 2.3 showed the peat soil LL decreased when the amount of OPC added to the peat soil increased.

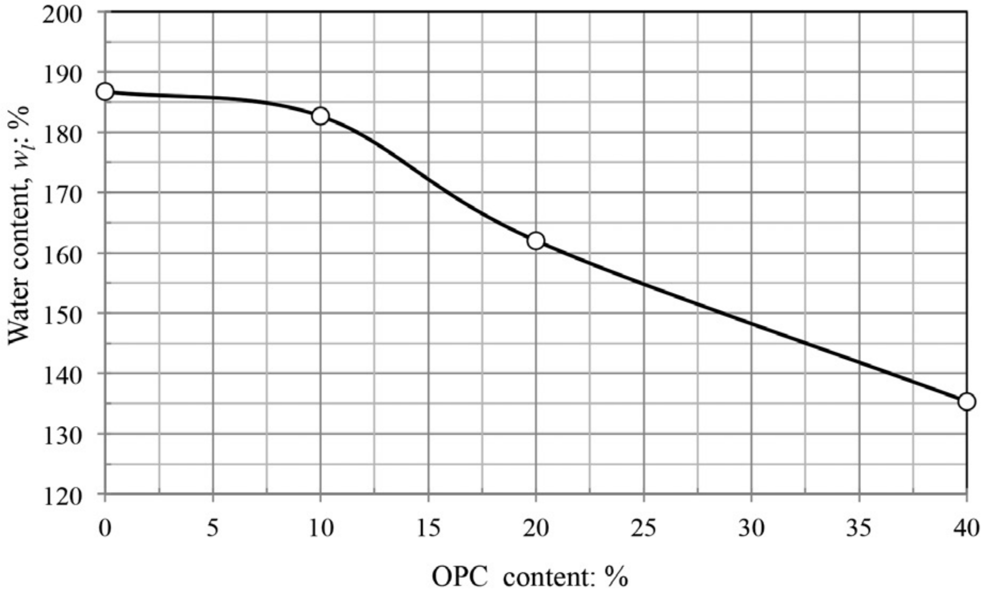

Figure 2.3: LL of OPC Treated Peat Soil (Rahman et al., 2016).

Cement treated peat soil showed an inclination on the maximum dry density and unstable values on the optimum water content in the research done by Rahman et al. in 2016. The compaction behaviour of OPC treated peat soil is shown in Table 2.3 and Figure 2.4. The peat soil is treated with four different OPC amounts, and it showed that its maximum dry density increased when the OPC amount increased but the optimum water content initially showed an increase and then started to decrease. The maximum dry density of OPC treated peat soil (0.62, 0.65 and 0.69 g/cm^3) larger than untreated peat soil (0.61 g/cm^3) explained the inner-particles space of peat soil was reduced due to pozzolanic reaction and being replaced by OPC, thus becoming a denser soil (Rahman et al., 2016).

Table 2.3: Compaction Behaviour of OPC Treated Peat Soil. (Rahman et al., 2016).

OPC content (%)	ρ_{max} **(g/cm^3)**	w_{opt} **, %**
0	0.61	63
10	0.62	70
20	0.65	64
40	0.69	62

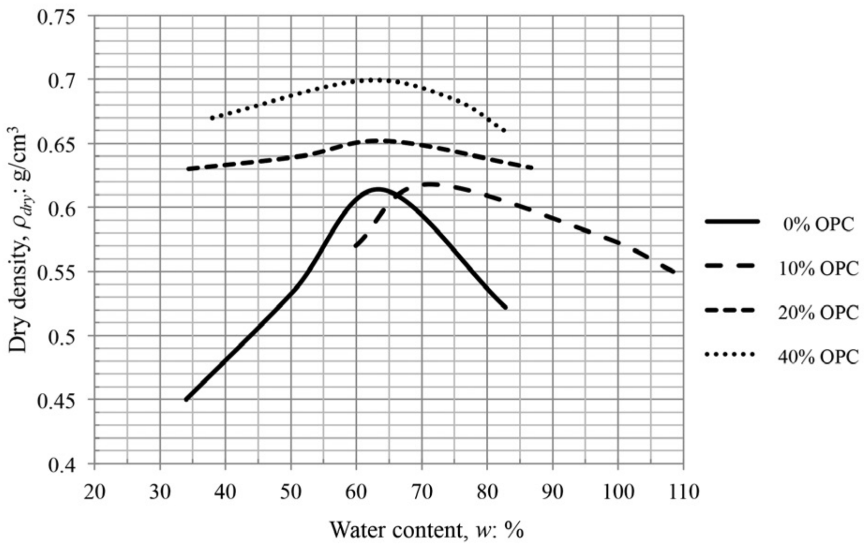

Figure 2.4: Compaction Behaviour of Untreated and OPC Treated Peat Soil (Rahman et al., 2016).

The cement effects on the unconfined compressive strength (UCS) of treated and untreated peat soil were shown in Table 2.4 and Figure 2.5. The results proved that the UCS of OPC treated peat soil has increased significantly as the OPC amount and curing period increased. This is also proved by Kolay and Taib (2018) in their study. The peat soil samples were treated with the same amount of OPC and the UCS on the 3 and 7 days curing period were recorded. The UCS values of OPC treated peat soil with a curing period of 3 days fell from 8.4 to 61.0 kPa, however, the UCS values of OPC treated peat soil cured at seven days was between 8.4 and 98.2 kPa (Rahman et al., 2016).

Table 2.4: Summary of The UCS Tests of Treated Peat Soil at Curing Period 3 and 28 days (Rahman et al., 2016).

OPC content (%)	**Unconfined Compressive Strength (kPa)**			
	3 days		**28 days**	
0	8.4		8.4	
10	17.0	103%	32.4	286%
20	30.0	256%	50.0	493%
40	61.0	627%	98.2	1072%

The UCS development shown in Figure 2.5 shows the correlation between OPC amount and the UCS values cured on 3 and 28 days curing period. The results gave the same conclusion as the UCS values obtained on the 3 and 7 days curing period. The UCS values of OPC treated peat soil increased when the OPC amount increased. This behaviour was the result of a pozzolanic reaction. The cement reacts with water and forms C-S-H gel through hydration has made the treated peat soil become denser, more brittle and thus, increasing its unconfined compressive strength (Rahman et al., 2016). The hydration process to produce C-S-H gel is controlled by the environmental condition including temperature and humidity, soil conditions including moisture content and also the quality and quantity of the stabiliser used (Kolay and Taib, 2018 & Kolay and Rahman, 2016).

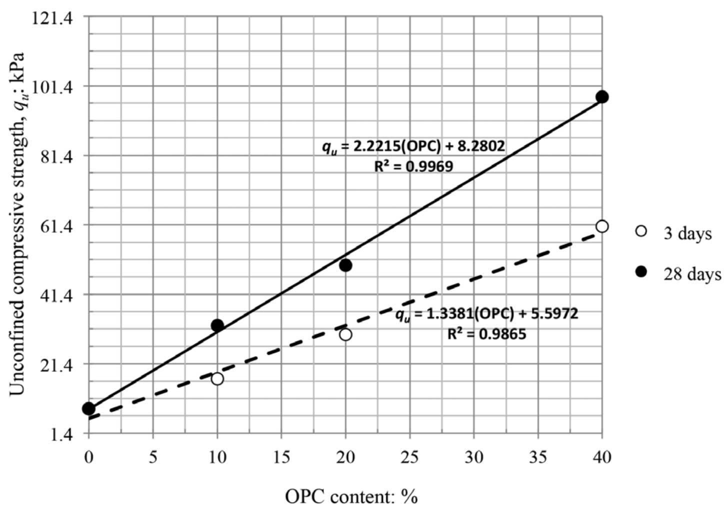

Figure 2.5: Results of UCS Tests on The OPC Treated Peat Soil at 3 and 28 days (Rahman et al., 2016).

2.2.2.2 Engineering Properties of Fly Ash, Quick Lime and Ordinary Portland Cement Treated Peat Soil

Kolay and Taib (2018) used class F fly ash as a stabiliser for peat stabilisation. The fly ash categorisation is based on ASTM C 618 standard and class F fly ash is the most common fly ash used by industry (Kolay and Rahman, 2016). Fly ash was mixed with quick lime in the peat stabilisation as class F fly ash is not capable of self-cementing. The mechanism of self-cementing is the process of hydration of cement components and secondary reactions triggered by hydration. The results shown in Figure 2.6 indicate the increase of quick lime and fly ash and the curing period results in the increase of UCS of peat soil. The results showed that all the samples achieved maximum UCS at 28 days but the addition of 6% quick lime showed a decrease in UCS during the whole curing period. The findings of UCS increase with the increase of fly ash amount and curing time and the 6 % lime decrease in the UCS has also been reported by Kolay and Rahman (2016). The UCS has achieved 70% with 6% lime and 20% fly ash combination compared to that of OPC 20% (Kolay and Taib, 2018). Cementitious hydrates, C-S-H gel and calcium aluminate hydrate (CAH) were the products of the reaction between the calcium from lime and fly ash and the fly ash and minerals in the clay. The main strength of the peat soil is contributed by the calcium aluminosilicate hydrates (Kolay and Taib, 2018). Similar results of using fly ash and OPC in soil stabilisation were observed by Kolay and Rahman (2016).

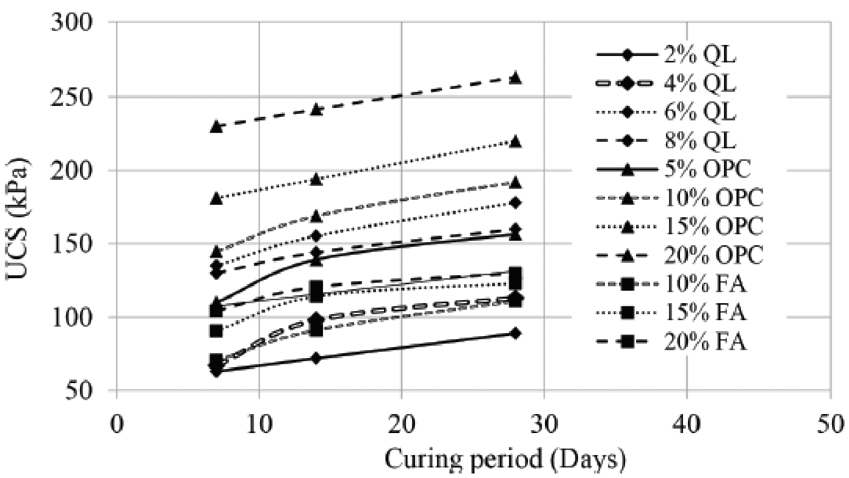

Figure 2.6: UCS Test Results of Peat Soil with Quick Lime, Fly Ash and OPC after curing for 7, 14 and 28 days (Kolay and Taib, 2018).

2.3 Press Mud

The production of industrial waste is increasing year by year and this has made industrial waste management become a public controversy. Geotechnical engineers and researchers claimed that some of the industrial waste can be applied to soil stabilisation. Examples of industrial waste that have already been adopted by industry in soil stabilisation are fly ash, eggshell, rice husk ash, oil palm ash and cement kiln (James and Pandian, 2016).

Press mud (PM) is the industrial waste of the sugar manufacturing industry. India is the second greatest sugarcane producer all over the world (James, 2020) and has produced 342.56 million tonnes of sugar from 2011 to 2012. This indicates there are tonnes of waste being produced. The industrial wastes from the sugar manufacturing industry are PM, spent wash, bagasse, sugarcane trash and bagasse fly ash. PM is the leftover sugarcane juice filtration. The sugarcane juice undergoes the clarification process to separate the juice and mud. The clear juice is sent for manufacturing and the mud sink in the bottom is collected and sent for filtration to filter out the suspended materials (Chittaranjan et al., 2021). The production rate of PM in carbonation sugar industries and sulphonation industries are 7% and 3% respectively which indicates that the waste produced by carbonation sugar industries are double that of sulphonation industries (James and Pandian, 2016).

2.3.1 Properties of Press Mud

James and Pandian (2016) observed that PM from carbonation sugar industries can be used as lime for building after undergoing calcination due to its 40 to 45% calcium oxide content. This proved that PM has the potential in stabilising soil. The chemical properties of PM are shown in Table 2.5.

Table 2.5 Chemical Properties of PM (Chittaranjan et al., 2021).

Oxides	Percentage (%)
Silicon Dioxide, SiO_2	25.5
Aluminium Oxide, Al_2O_3	2.4
Calcium Oxide, CaO	18.5
Iron Oxide, Fe_2O_3	5.8
Potassium Oxide, K_2O	1.3
Magnesium Oxide, MgO	3.1
Sodium Oxide, Na_2O	0.1
Phosphorus Pentoxide, P_2O_5	7.2
Titanium Dioxide, TiO_2	0.2
Sulphur Trioxide, SO_3	0.4

2.3.2 Effects of Press Mud on Soil Stabilisation

2.3.2.1 Effects of Press Mud and Lime on Unconfined Compressive Strength of Soils

James and Pandian (2016) have investigated the addition of different percentages of PM (0.25, 0.50, 1.0 and 2.0%) to 3% and 5.5% lime stabilised soil. The 3% lime-stabilised experienced a drop in UCS with the increase of press mud content at the early stage. However, the PM admixed 3% lime stabilised soil has achieved the UCS value similar to the UCS value achieved by pure lime stabilised soil. The results of the effects of PM on 3% lime stabilised soil are shown in Figure 2.7.

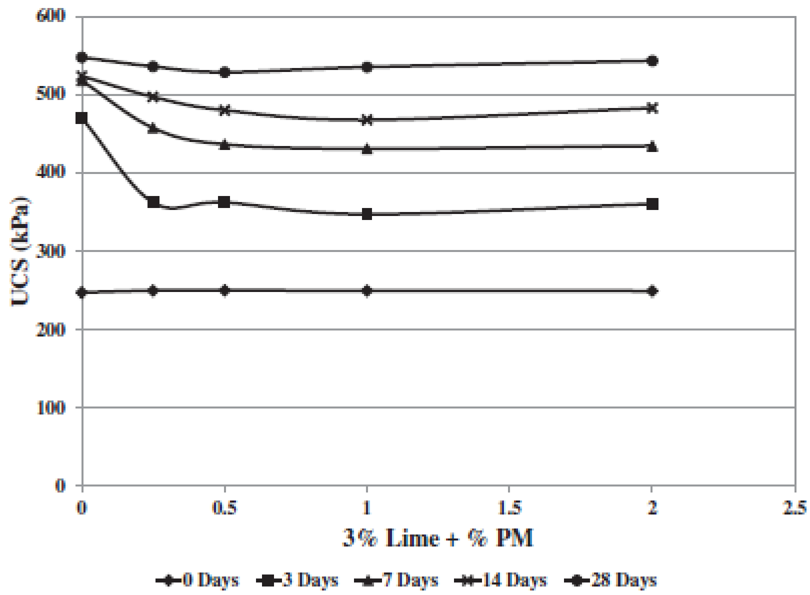

Figure 2.7: UCS Gained with Different Percentages of Press Mud (0.25 - 2%) for 3% Lime Stabilised Soil (James and Pandian, 2016).

The effect of PM on the 5.5% lime stabilised soil showed that the UCS has only been improved with the addition of 0.25% PM. Other than 0.25% PM, all the percentages experienced a reduction in UCS. The results shown in Figure 2.8 showed the early UCS of lime stabilised soil has been enhanced with the addition of PM. However, only the UCS of 5.5% lime stabilised soil with the addition of 0.25% PM has been maintained at 28 days of curing. This observation was also reported by other researchers (James and Pandian, 2016). Same findings have also been observed by James (2020). James (2020) claimed that the finding has shown that PM can accelerate the strength gain in the early stage compared to that of pure lime stabilised soil. James (2020) also suspected the calcium humic acid formation from PM reduced the soil strength and thus, reduced the strength gain availability of lime.

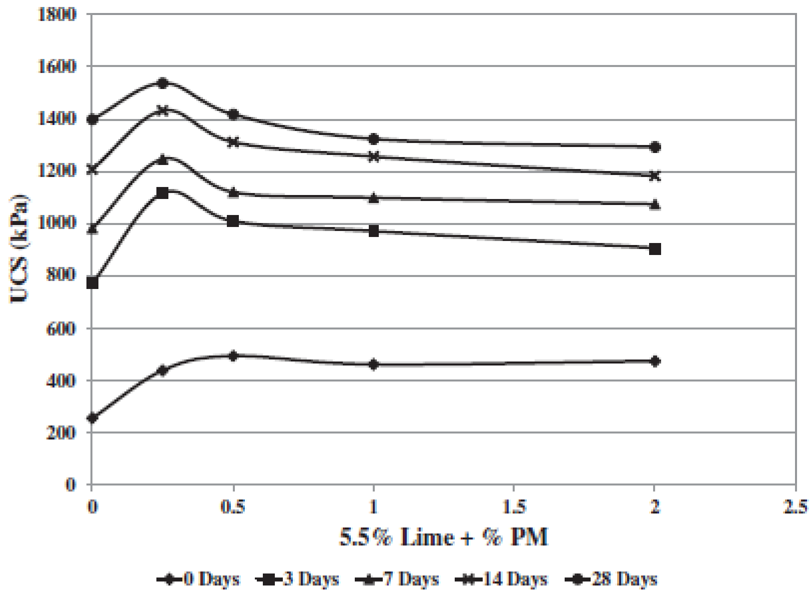

Figure 2.8: UCS Gained with Different Percentages of PM (0.25 - 2%) for 5% Lime Stabilised Soil (James and Pandian, 2016).

The effects of PM on UCS can be explained by PM containing 15 to 30% of fibre and sugars. Fibres can be used in reinforcing soil and improving soil strength with correct proportions. The researchers had proved that the addition of fibre into treated soil will increase in strength. Sugars have the function of enhancing soil strength and bonding of particles as it contains saccharides which enable a material to act as hydrocolloids (James and Pandian, 2016). James and Pandian (2016) stated adding small amounts of sugar to cement concrete will improve 12 to 15% cement concrete strength at 28 days of curing but sugar in the form of sucrose is detrimental to the strength development of cement stabilised soil. James (2020) has a similar explanation of the effects of the addition of PM to the lime stabilised soil.

The phosphorus pentoxide, P_2O_5 and hydrocolloid in PM have the capability to increase the soil strength with the correct quantity. The amount of hydrocolloid used for soil stabilisation is usually not more than 0.1% of the dry weight of soil. A large amount of PM added for soil stabilisation will not enhance the strength due to the increase in organic content caused by a large amount of PM (James and Pandian, 2016).

2.3.2.2 Effects of Press Mud and Lime on Atterberg Limits of Soils

The LL of lime stabilised soil is affected by the addition of PM. Results in Figure 2.9 showed the curve of 3% lime stabilised soil with the addition of PM is above the curve of 5.5% lime stabilised soil with the addition of PM. The curve of the 3% lime stabilised soil with the addition of PM does not have a big change in value and the change is small enough to be ignored, however, 5.5% lime stabilised soil showed an increment in LL. This indicates a higher amount of lime is more effective in reducing LL. The lime stabilised soil with higher lime content has lesser LL but the addition of PM into it will increase its LL. This can be explained by the LL of soil being affected by the PM water absorption capability (James and Pandian, 2016).

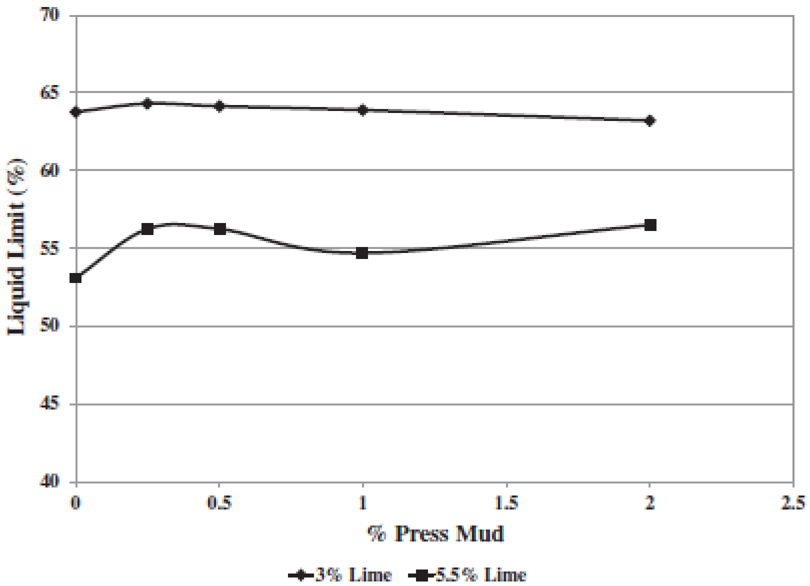

Figure 2.9: Effects of LL with Different Percentages of PM (James and Pandian, 2016).

The results in Figure 2.10 showed the addition of PM into 3% lime stabilised soil has reduced the plastic limit (PL) of soil while adding PM into 5.5% lime stabilised soil led to the increase of PL. The capacity of water absorption of the organic content causes the PL to increase when PM is added into the soil in large quantities. This can be explained by the reduction due to organic content induced aggregation is overcome by the water absorption capacity (James and Pandian, 2016).

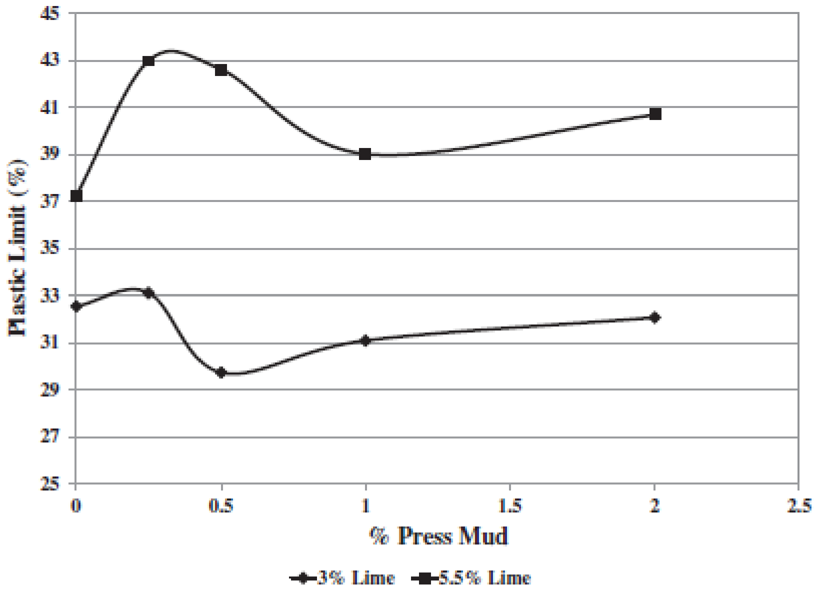

Figure 2.10: Effects of PL with Different Percentage of Press Mud (James and Pandian, 2016).

The researchers investigated that the soil with higher addition of PM is having higher pH value. The results in Figure 2.11 showed that the pH of PM admixed soil with lesser lime content has decreased to 9 and below. However, the PM admixed soil with higher lime content has maintained the pH at 9 and above (James and Pandian, 2016). The researchers also noted that when pH is 9 and above, the undrained shear strength will increase drastically. The rise in strength was greatest when 0.25% PM was added to 5.5% lime, as previously stated. The lower pH after adding 0.25% PM is due to more efficient lime and PM use in soil stabilisation, resulting in a lower pH (James and Pandian, 2016).

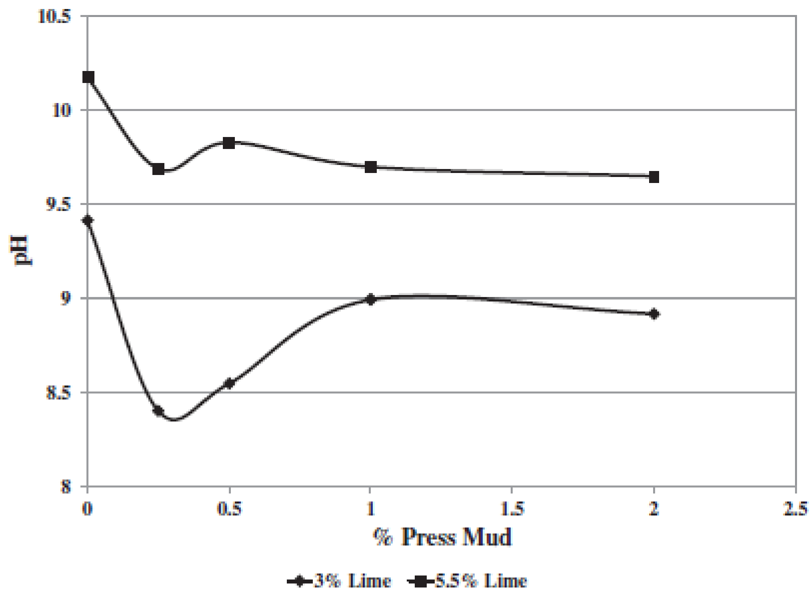

Figure 2.11: Effects of pH with Different Percentages of PM (James and Pandian, 2016).

The observation of the effect of maximum dry density with different percentages of PM is shown in Figure 2.12. The results indicated the increase in PM content had led to the decrease in the maximum dry density of soil. Chittaranjan et al. (2021) explained the results with the theory of flocculation.

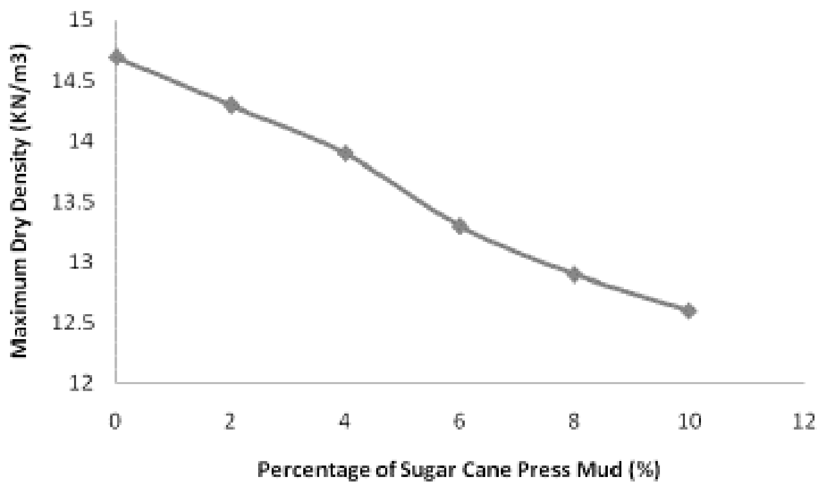

Figure 2.12: Effects of Maximum Dry Density with Different Percentages of PM (Chittaranjan et al., 2021).

2.4 Cement

Cement is one of the common stabilisers for soil. It can be used to stabilise various types of soils. The reasons cement are commonly used in soil stabilisation are they can stabilise the soil within a short period and short curing period and give a platform that does not leach for soil stabilisation (Rahman et al., 2016).

OPC is a hydraulic cement which reacts with water to perform hydration in order to set and harden the concrete. Calcium sulphate is found in small amounts in OPC which is also known as gypsum. OPC is under the category of silty clay and its particle distribution is in the range of 5 to 15 µm. OPC is a pozzolanic-reactive mineral-based material which can help soil to gain its full strength in maximum of 28 days and make peat soil a denser structure to support more load (Rahman et al., 2016).

2.5 Lime

The soil pH is increased up to 10.5 which allows the clay particles to break down to occur and thus release the alumina and silica. The tricalcium silicate, C_3S in OPC reacts with water and forms the calcium silicate hydrate gel, C-S-H. The cementitious properties of C-S-H result in enhancing the engineering properties of problematic soils (Rahman et al., 2016). Lime helps in improving the strength and stiffness of soil through cementation and modifying the plastic index and swelling index of soil (Moayedi and Nazir, 2018).

2.6 Fly Ash

Fly ash is the by-product of coal burning. The production of fly ash in Sarawak has achieved more than 4.2 to 13 million metric tonnes and the fly ash is disposed of by pouring into ash ponds or lagoons which deteriorate the environment seriously. To tackle the environmental issue, fly ash is used as a stabiliser or filler in soil stabilisation due to its pozzolanic characteristic (Kolay and Rahman, 2016).

2.7 Admixtures

Soil stabilisation is needed for peat soils and the most common option is stabilised with cement and lime. The peat soils characteristics such as soil volume, soil stability, and strength of soil can be enhanced by adding additives to the soil to carry out chemical reactions (Rahman et al., 2016).

2.7.1 Cement and sand

Rahman et al. (2016) claimed that cement and sand can stabilise peat soils' and enhance peat soils maximum dry density and unconfined compressive strength (Rahman et al., 2016).

2.7.2 Cement and lime

The unconfined compressive strength of treated peat soils can be improved with the addition of cement and lime and the curing period. It found that the treated peat soil has better performance with a longer curing period (Rahman et al., 2016).

OPC is added into the peat soils with the amount of 0, 10, 20 and 40% of the peat soil sample's dry weight. The test carried out in this study to identify the engineering properties of peat soil are the Atterberg limit test, compaction test, permeability test and also shear strength test (Rahman et al., 2016).

The findings proved that lime and cement can improve the maximum dry density and unconfined compressive strength of peat soil and decrease the maximum dry density. OPC showed better performance when compared with lime (Moayedi and Nazir, 2018).

2.8 Activation Temperature

Alkali-activated material is material consists of aluminium oxide, Al_2O_3 and silicon oxide, SiO_2. It has the potential to replace cement in construction as it is capable to enhance the soil's mechanical properties. Cristelo, Glendinning and Pinto (2011) have done research on the potential of alkaline activated fly ash in soil stabilisation. Fly ash has the same properties as press mud, the waste material chosen for this study.

Geopolymerisation was introduced by Davidovits in 1976. Geopolymerisation is the process in aluminium oxide and silicon oxide undergoing polymerisation to produce a new material after the dissolution process under an alkaline environment. The alkali-activated material is the product of a material that contains a large proportion of aluminium oxide and silicon oxide and an alkaline solution which is known as Si-O-Al type structure. The Si-O-Al type structure is a new strong matrix in the forms of gels matrix and compounds of crystalline with good stability of chemical and strength of mechanical (Cristelo, Glendinning and Pinto, 2011).

Most of the aluminosilicates, Al_2SiO_5 are stable under all but extreme conditions as their physical state are in crystalline form. The raw materials of aluminosilicate will be sent to thermal treatment to create an extreme environment for alkaline activation and thus, improving the rate of polymerisation. The aluminosilicate will experience structural changes due to the water loss and coordination changes of oxygen and aluminium ions. Hence, alkaline activation is more suitable for raw materials that have thermal and calcination history (Cristelo, Glendinning and Pinto, 2011).

2.8.1 Preparation of Alkaline Activator Solution and Soil Samples

The alkaline activator solution used by Cristelo, Glendinning and Pinto (2011) is the mixture of sodium silicate, Na_2SiO_3 solution and sodium hydroxide, NaOH solution and the ratio of silicon dioxide to sodium oxide is 2:1 by mass. The sodium hydroxide with the value of specific gravity 2.13 is flake form at room temperature while the sodium silicate with the value of specific gravity 1.5 is liquid form at room temperature. The Type I OPC is used to prepare samples in the study.

The ratio of activator to sum of soil and fly ash remained constant in sample preparation where only the percentages of fly ash is manipulated. The ratio is important in maintaining the liquid content for effective mixing purposes while avoiding the excess liquidity. This is due to the reason there is no extra water added for mixing purposes except the water added to the alkaline activator solution (Cristelo, Glendinning and Pinto, 2011). Cristelo, Glendinning and Pinto (2011) proposed the ratio of activator to the sum of soil and fly ash between 0.40 to 0.50 is the ideal ratio while the sodium silicate solution to sodium hydroxide solution ratio is 2:1 by mass. The activator has to keep warm to prevent the crystallisation of the activator as the crystallised activator results in a viscous mixture at the end of the mixing phase.

The reaction between sodium silicate and sodium hydroxide solutions is greatly exothermic which releases a lot of energy during the reaction and eventually increases the temperature. The researchers highlighted the ratio of silicon to aluminium of aluminosilicate gel is affected by temperature and the ratio is important to the alkali-activated material's mechanical behaviour. However, Cristelo, Glendinning and Pinto (2011) observed the heat energy released in the laboratory mixing at the temperature of about 30°C is notably lower compared to the expectation for mixing in the large quantities in the field at 50°C and above. Three sets of 76 mm height and 38 mm in diameter samples were prepared for the UCS test and the sample was cured at ambient temperature under humidity conditions and buried in the sand with 20% moisture content and 20 cm below the ground.

2.8.2 Effects of Temperature on Unconfined Compressive Strength of Alkali-activated Soils

The rate of UCS development for samples prepared with cold and warm activators was similar. However, samples with cold activator achieved higher UCS starting from 90 days compared to that samples with warm activator and respective fly ash content (Cristelo, Glendinning and Pinto, 2011).

The potassium-based activator stabilised Class F fly ash experiences an increase in temperature due to the exothermic reaction is considered as warming the activator. This has made no contribution to the strength development as only the rise in temperature for a longer period will increase the strength gain. Some researchers claimed that the addition of water is needed for curing at an escalated temperature for more than 24 hours to cut down the cracking and keep the integrity of the structure. This is due to the reason curing at elevated temperature for a long period is detrimental to the soil structure.

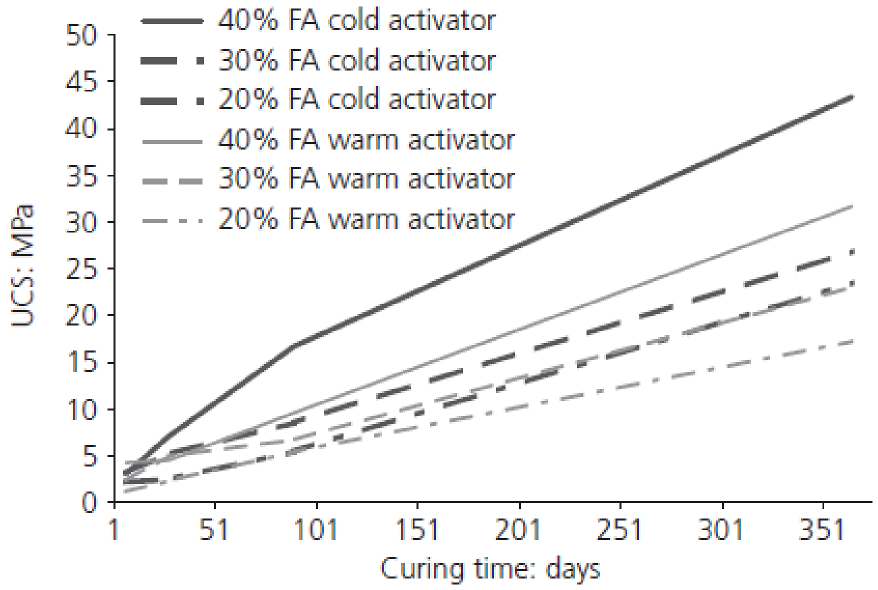

Figure 2.13: Comparison of UCS Between Different Percentages of Fly Ash Mixtures Prepared with Cold and Warm Activator (Cristelo, Glendinning and Pinto, 2011).

The UCS for 20, 30 and 40% of fly ash content for the same concentration of the 12.5 mol of mixture are shown in Figure 2.14. The results indicate that the mixture with greater fly ash content has better performance in UCS development for both normal and buried curing. The buried curing samples with 20 and 30% fly ash content gained more strength compared to normal cured samples with the same fly ash content after 90 days. However, normal curing samples showed double UCS values of buried curing at 365 days. The researchers explained this situation with the difference in temperature as the wet sand temperature was 2 to 5°C colder than the temperatures of surroundings (Cristelo, Glendinning and Pinto, 2011).

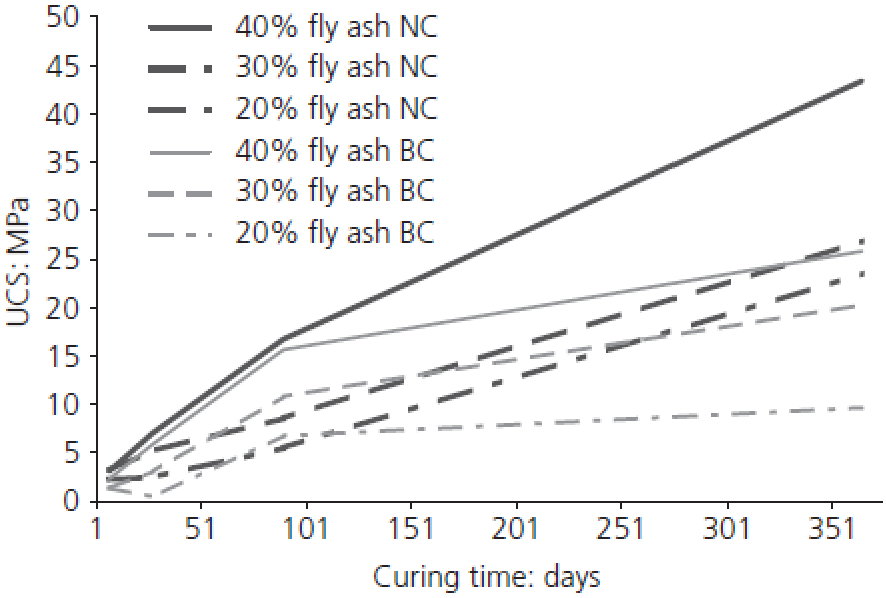

Figure 2.14: UCS for Different Percentages of Fly Ash for 12.5 Mol Mixtures and Normal Curing (NC) and Buried Curing (BC) (Cristelo, Glendinning and Pinto, 2011).

2.9 Test on Untreated and Treated Peat Soil

2.9.1 Standard Proctor Test

Standard Proctor Test was developed by Ralph R. Proctor in 1930 to study the dry density and moisture content of soil. The standard Proctor test is standardised for the gross energy input of 600 kNm/m³. The test is then modified to encourage the use of heavier compaction equipment in the field by increasing the gross energy input to 2703 kNm/m3. (Kodikara, Islam and Sounthararajah, 2018).

2.9.2 Unconfined Compressive Strength Test

UCS test is conducted according to ASTM D 2166 standard to study the unconfined compressive strength gained by the soil. The UCS test is then used to compute the unconsolidated undrained shear strength of clay under unconfined conditions.

The UCS is the maximum compressive stress sustained by the soil sample in a simple compression test. The strength is the maximum load successfully sustained per unit area at 15% axial strain, the exact value is depending on whichever occurs first during the test (Krishna, 2017). Jinping

(2017) said it is not suitable for dry sands and fragile clays as the materials will fall apart without lateral confinement.

2.10 Summary

Peat soil is classified under problematic soils due to its geotechnical drawback characteristics such as high-water content, high compressibility and water-holding power, low bearing capacity, low specific gravity and moderate permeability. The improvements in the geotechnical properties of peat soils with OPC, fly ash and lime are reviewed. The results obtained by researchers showed that the water content, compressibility and water adsorption capability are reduced and the bearing capacity is increased through soil stabilisation.

PM is the residue of filtration of sugarcane juice from the sugar manufacturing industry. The researchers have conducted research on the effects of PM on soil stabilisation. The research proved that the mixture of lime and PM can be used to enhance the engineering properties of expansive soils.

Activation temperature is the relative temperature of activation energy. Alkaline activation is studied to understand the effects of different activation temperatures on the engineering properties of peat soil. The research showed the exothermic reaction of activators released a lot of energy during the reaction and eventually increased the temperature. The strength development of soil with warm activator has gained lesser strength compared to that of cold activator at 90 days. This is explained by the continued rising of temperature for more than 24 hours will alter the soil structure and thus, affect the strength development of soil. Besides, the increase in the proportion of admixtures will result in a better performance in strength development.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

In this chapter, the methodology and work plan of this study will be discussed. This chapter will cover the preparation of soil samples and admixtures, the procedures of each test, and the related calculations

3.1.1 Experimental Methods

Tests were conducted during the study to achieve the objectives stated in Chapter 1. The tests planned to conduct are Standard Proctor Test and Unconfined Compressive Strength (UCS) Test.

For the UCS test with press mud admixed peat soils, the different percentages of mixed proportions of stabiliser used are 0.0%, 0.25%, 0.50%, 1.0% and 2.0% of press mud (PM) mixed with 3% and 5.5% of lime respectively, meaning that total 10 sets of peat soil samples were prepared for this study. The curing period proposed for this study is 0, 7, 14 and 28 days. The amount of lime is fixed at 3% and 5.5% of the dry peat soil while the amount of PM is 0.0%, 0.25%, 0.50%, 1.0% and 2.0% of the dry weight of peat soil. The peat soil, PM and lime are packed according to the designed amount. The peat soil, PM and lime are then poured into the mixing pan and mixed manually in a dry state until well mixed. The water was added based on the designed amount to the mixture and thoroughly mixed to achieve a consistent wet mix. The mixture is now well prepared for the Standard Proctor Test and Unconfined Compressive Strength Test.

For the UCS test of alkaline activation, the activator selected for this study is the mixture of sodium silicate solution and sodium hydroxide solution. The molarity of sodium silicate solution and sodium hydroxide mixtures is 12.5 mol while the ratio is 2:1 by mass. The molarity of 12.5 mol and ratio of 2:1 by mass is referred to in the research done by Cristelo, Glendinning and Pinto (2011). The peat soil samples are stabilised with 0.0%, 0.25%, 0.50%, 1.0% and 2.0% of press mud and cold and warm activator. The activators are well mixed before adding them to the peat soil samples. The peat soil samples with respective activators are then being cast and cured for 0, 7, 14, and 28 days under buried and normal curing conditions.

3.1.2 The flow of Work Plan

The flowchart of the overall study is shown in Figure 3.1.

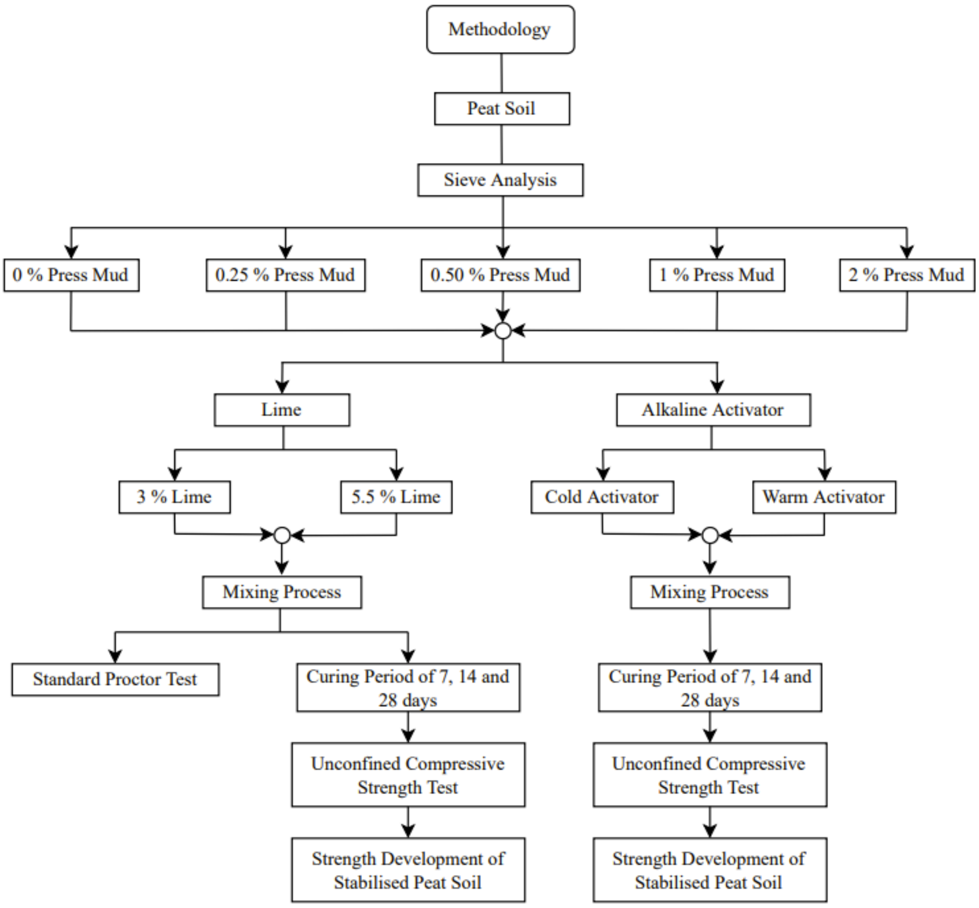

Figure 3.1 Flowchart of The Overall Study.

3.2 Materials

The raw materials used in this study include peat soil, PM, lime and water. The alkaline activator used in this study is made with sodium silicate solution and sodium hydroxide solution.

3.2.1 Peat soil

Peat soil collected from Sekinchan, Selangor Malaysia is used in this study. Peat soil is a problematic soil that is not suitable for development, but peatland development has become unavoidable due to rapid development. Hence, the stabilisation of peat soil became more vital, and this study is to study the engineering properties of peat soil.

3.2.2 Press Mud

PM used in this study was obtained from Sekinchan, Selangor Malaysia. PM is the residue of the sugar manufacturing process and it is cheap and produced in large quantities annually. For better waste management, PM is investigated to explore its hidden functions, and this study is proposed to study the stabilising ability of PM on peat soil.

3.2.3 Lime

Hydrated lime purchased from the hardware shop nearby Malaysia is used in this study. The lime serves as a stabilising agent to assist a soil in gaining long-term strength through pozzolanic reaction. The lime is fixed at 3% and 5.5% and mixed with different percentages of press mud for the peat soil stabilisation in this study.

3.2.4 Water

Water is added to the dry mixture to initiate the hydration process, thus binding the materials together. The water used in this study is the clean tap water obtained from the laboratory in UTAR.

3.2.5 Alkaline Activator

The alkaline activator is the mixture of sodium silicate solution and sodium hydroxide solution. The sodium silicate solution and sodium hydroxide solution proposed are obtained from the chemistry laboratory in UTAR.

3.3 Sieve Analysis

Sieve analysis is conducted according to the ASTM D 422 standard. Sieve analysis is carried out to determine the percentages of grain with different sizes contained in soil.

Each of the sieves is cleaned and weighed as well as the bottom pan and the readings will be recorded. The peat soil sample is weighed, and the weight will be recorded. The peat soil sample is then poured into the top sieve and covered the sieve with a cap. The sieve with the peat soil sample is then placed on the mechanical shaker and shaken for 10 minutes. The sieve is removed with care and weighed after 10 minutes of shaking.

3.4 Standard Proctor Test

Standard Proctor Test is carried out based on the ASTM D 698 standard to determine the Optimum Moisture Content and the Maximum Dry Density of soil.

The mould selection for the Standard Proctor test depends on the particle size of the soil sample. The 100 mm diameter mould is chosen for the test if the untreated peat soil sample remaining in the 4.7 mm sieve is less than 20% of the total weight of the untreated peat soil sample, otherwise, a 150 mm diameter mould is used. The mould is then cleaned and applying oil inside it to prevent soil from sticking to the mould wall. The mould is weighed and recorded for the calculations later. The peat soil sample is divided into 3 parts and filled separately into the mould. Each layer of the peat soil sample is around one-third of the mould and each layer needs to be compacted evenly by a rammer 25 times. The compaction needs to cover the entire mould area that is filled with peat soil samples. The extra peat soil sample is removed and smooths the mould surface. The mould with peat soil sample is weighed and recorded for calculations.

3.4.1 Calculations for Standard Proctor Test

The optimum moisture content is the highest moisture content while the maximum dry density is the largest dry density.

$$w = \frac{M_w + M_d}{M_w} \times 100\% \tag{3.1}$$

Where,

w = Natural moisture content, %

M_w = Soil sample mass in wet condition, kg

M_d = Soil sample mass in dry condition, kg

$$\rho_m = \frac{M_{cs}}{v} \tag{3.2}$$

Where,

ρ_m = Soil sample moist density, kg/m^3

M_{cs} = Moist compacted soil mass, kg

v = Mould volume, m^3

$$\rho_d = \frac{\rho_m}{1 + \frac{w}{100}} \tag{3.3}$$

Where,

ρ_d = Compacted soil dry density, kg/m^3

ρ_m = Soil sample moist density, kg/m^3

w = Moisture content, %

3.5 Unconfined Compressive Strength Test

Unconfined Compressive Strength (UCS) test is conducted according to the ASTM D 2166 standard to observe the effects of different proportions of stabiliser on the UCS of peat soil sample and the effects of different activation temperatures on the UCS of peat soil sample.

The sample is loaded between the upper and lower plates and in the UCS test's centre of the loading machine. The upper plate is adjusted to the height that is able to contact the peat soil sample and the deformation is set to zero. The test then begins with a steady axial strain of between 0.5 and 2.0% per minute and collects the load and deformation readings. The test is stopped when a decrease in load values happens or achieved 20% axial strain. The load and deformation values are recorded for calculations to obtain a load and deformation value.

3.5.1 Calculations for Unconfined Compressive Strength Test

The UCS is represented as the axial load at failure divided by the average cross-sectional area of the soil sample.

$$e = \frac{\Delta L}{L_0} \tag{3.4}$$

Where,

e = Axial strain

ΔL = Change in soil sample length, m

L_0 = Initial soil sample length, m

$$A = \frac{A_0}{(1 - e)} \tag{3.5}$$

Where,

A = Average soil sample cross-sectional area, m^2

A_0 = Initial average soil sample cross-sectional area, m^2

e = Axial strain

$$\sigma_u = \frac{P}{A} \tag{3.6}$$

Where,

σ_u = Unconfined compressive strength, kN/m^2

P = Applied axial load at failure, kN

A = Average soil sample cross-sectional area, m^2

$$S_u = \frac{\sigma_u}{2} \tag{3.7}$$

Where,

S_u = Undrained shear strength, kN/m^2

σ_u = Unconfined compressive strength, kN/m^2

3.6 Specimen Mixtures Combination

The stabilisers combination for soil samples in percentages for Standard Proctor Test and UCS Test were listed in Table 3.1, 3.2 and 3.3 respectively. The mixing process is then conducted based on the designed stabilisers combination to produce a complete specimen set for curing purpose and the curing period for UCS Test was set as 7, 14 and 28 days. The Standard Proctor Test will be conducted right after the mixing process while the UCS test will be conducted when each respective curing period is reached.

Table 3.1: Stabilisers Percentage Combination into Soil Samples for Standard Proctor Test.

Specimens	**Mixture Combination**		
	Lime (%)	**Press Mud (%)**	**Water Content (%)**
S0	3	0.0	10
S1			15
S2			20
S3			25
S4		0.25	10
S5			15
S6			20
S7			25
S8		0.50	10
S9			15
S10			20
S11			25
S12		1.0	10
S13			15
S14			20
S15			25
S16		2.0	10
S17			15
S18			20
S19			25

Table 3.1 (Continued).

S20			10
S21		0.0	15
S22			20
S23			25
S24			10
S25		0.25	15
S26			20
S27			25
S28			10
S29	5.5	0.50	15
S30			20
S31			25
S32			10
S33		1.0	15
S34			20
S35			25
S36			10
S37		2.0	15
S38			20
S39			25

Table 3.2: Stabilisers Percentage Combination into Soil Samples for UCS Test.

Specimens	**Mixture Combination**		
	Lime (%)	**Press Mud (%)**	**Curing Period (days)**
U0	3	0.0	0
U1		0.25	
U2		0.50	
U3		1.0	
U4		2.0	
U5		0.0	7
U6		0.25	
U7		0.50	
U8		1.0	
U9		2.0	
U10		0.0	14
U11		0.25	
U12		0.50	
U13		1.0	
U14		2.0	
U15		0.0	28
U16		0.25	
U17		0.50	
U18		1.0	
U19		2.0	

Table 3.2: (Continued).

U20		0.0	
U21		0.25	
U22		0.50	0
U23		1.0	
U24		2.0	
U25		0.0	
U26		0.25	
U27		0.50	7
U28		1.0	
U29		2.0	
U30	5.5	0.0	
U31		0.25	
U32		0.50	14
U33		1.0	
U34		2.0	
U35		0.0	
U36		0.25	
U37		0.50	28
U38		1.0	
U39		2.0	

Table 3.3: Stabilisers Percentage Combination into Soil Samples for Effects of Activation Temperature to UCS of Soil Samples.

Specimens	Mixture Combination		
	Activator	**Press Mud (%)**	**Curing Period (days)**
A0	Cold	0.0	0
A1		0.25	
A2		0.50	
A3		1.0	
A4		2.0	
A5		0.0	7
A6		0.25	
A7		0.50	
A8		1.0	
A9		2.0	
A10		0.0	14
A11		0.25	
A12		0.50	
A13		1.0	
A14		2.0	
A15		0.0	28
A16		0.25	
A17		0.50	
A18		1.0	
A19		2.0	

Remarks: Activator is a mixture of Sodium Silicate and Sodium Hydroxide Solution.

Cold Activator is stored at room temperature (26°C).

Warm Activator is keeping warm at 50°C.

Table 3.3: (Continued).

A20		0.0	
A21		0.25	
A22		0.50	0
A23		1.0	
A24		2.0	
A25		0.0	
A26		0.25	
A27		0.50	7
A28		1.0	
A29		2.0	
A30	Warm	0.0	
A31		0.25	
A32		0.50	14
A33		1.0	
A34		2.0	
A35		0.0	
A36		0.25	
A37		0.50	28
A38		1.0	
A39		2.0	

Remarks: Activator is mixture of Sodium Silicate and Sodium Hydroxide Solution.

Cold Activator is stored at room temperature (26°C).

Warm Activator is keeping warm at 50°C.

3.7 Summary

There are total of 16 mixed proportions of PM stabilised specimens in this study. Specimens with mixed proportions of 0.0%, 0.25%, 0.50%, 1.0% and 2.0% press mud and 3% and 5.5% lime were prepared to investigate the effects of different percentages of mixed proportions of stabiliser on the engineering properties of peat soil. To determine the influence of different activation temperatures on the engineering properties of peat soil, specimens stabilised with cold and warm activators and different PM content were prepared. The activator is the mixture of sodium silicate solution and sodium hydroxide solution with a molarity of 12.5 and a ratio of 2:1 by mass while the press mud content is 0.0%, 0.25%, 0.50%, 1.0% and 2.0% by mass.

Four tests were conducted for this study: Sieve Analysis, Standard Proctor Test and UCS Test. The sieve analysis is conducted according to the ASTM D 422 standard. Besides, the standard Proctor test was carried out based on the ASTM D 698 standard and the UCS test was conducted according to the ASTM D 2166 standard.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Results obtained from the analysis will be discussed based on the two conducted tests: Standard Proctor Test and Unconfined Compressive Strength (UCS) Test in this chapter. The two tests have been conducted on specimens with different proportions of stabiliser (lime and press mud) or alkaline solution with different temperatures and three designated curing periods. A total of 120 soil samples were prepared and labelled accordingly for the determination of the effects of different percentages of mixed proportions of stabiliser on the compaction properties such as optimum moisture content and maximum dry density, unconfined compressive strength of peat soil and the influence of different activation temperature on the unconfined compressive strength of peat soil.

4.2 Mixed Proportion of Soil Specimen

Table 3.1, 3.2 and 3.3 show the combination of mixing in percentages based on the dry weight of the soil sample prepared. The percentage of lime was set at 3% and 5.5% while the percentage of press mud (PM) was set at 0.0%, 0.25%, 0.50%, 1.0% and 2.0% for the Standard Proctor test. The stabilisers for the UCS test were various percentages of press mud (0.0%, 0.25%, 0.50%, 1.0% and 2.0%) and cold and warm activators where the temperature of activators is at room temperature (26°C) and 50°C respectively. All the soil specimens with 0.0% PM were set as a controlled set and were used to compare and compute the strength improvement with soil specimen containing PM based on respective curing period.

4.3 Standard Proctor Test

The Standard proctor test was conducted to identify the effects of lime and press mud on the moisture content and dry density of peat soil. The Standard proctor test has a theoretical objective to determine the relationship between the unit weight of soil and the degree of compaction and moisture content. In this section, the optimum moisture content and maximum dry density will be discussed.

4.3.1 Optimum Moisture Content and Maximum Dry Density of 3% Lime and 5 Different Press Mud Percentages Stabilised Peat Soil Specimens

The optimum moisture content and maximum density of 3% lime and 0.0%, 0.25%, 0.50%, 1.0% and 2.0% PM stabilised are tabulated in Table 4.1 and shown in Figure 4.1. Figure 4.1 showed the movement of optimum moisture content and maximum dry density where optimum moisture content moves upwards and maximum dry density moves downwards as the PM percentages increased.

Table 4.1: Results of Optimum Moisture Content and Maximum Dry Density for 3% Lime and 5 Different Percentages of PM Stabilised Peat Soil Specimens.

Press Mud (%)	0.0	0.25	0.50	1.0	2.0
Optimum Moisture Content (%)	27.29	27.84	27.98	30.10	32.39
Maximum Dry Density (Mg/m^3)	0.59	0.57	0.56	0.49	0.42

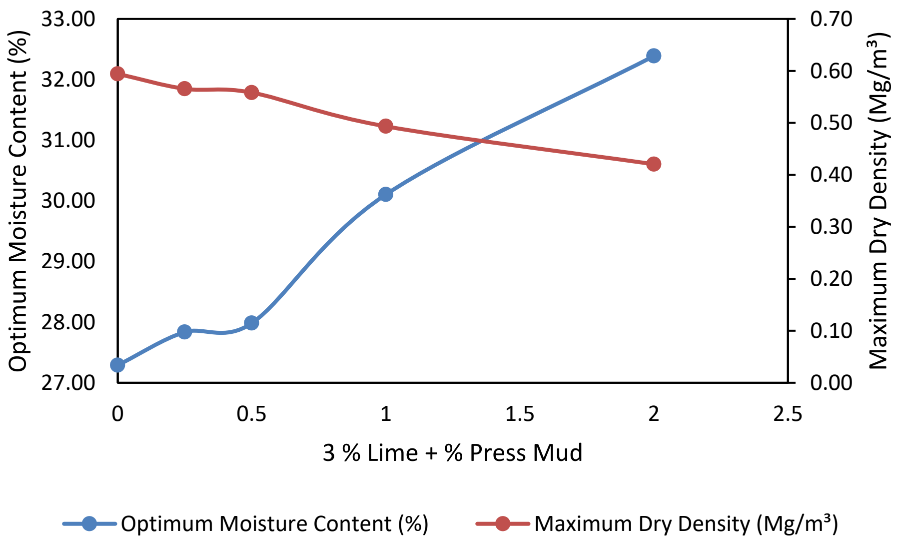

Figure 4.1: Results of Optimum Moisture Content and Maximum Dry Density for 3% Lime and 5 Different Percentages of PM Stabilised Peat Soil Specimens.

4.3.2 Optimum Moisture Content and Maximum Dry Density of 5.5% Lime and 5 Different Press Mud Percentages Stabilised Peat Soil Specimens

The optimum moisture content and maximum density of 5.5% lime and 0.0, 0.12, 0.50, 1.0 and 2.0% PM stabilised are organised in Table 4.2 and shown in Figure 4.2. Figure 4.2 showed the direction of optimum moisture content and maximum dry density. The optimum moisture content escalates and maximum dry density decreases as the PM percentages increase.

Table 4.2: Results of Optimum Moisture Content and Maximum Dry Density for 5.5% Lime and 5 Different Percentages of PM Stabilised Peat Soil Specimens.

Press Mud (%)	0.0	0.25	0.50	1.0	2.0
Optimum Moisture Content (%)	55.30	55.70	55.73	56.94	63.44
Maximum Dry Density (Mg/m³)	0.67	0.67	0.66	0.66	0.65

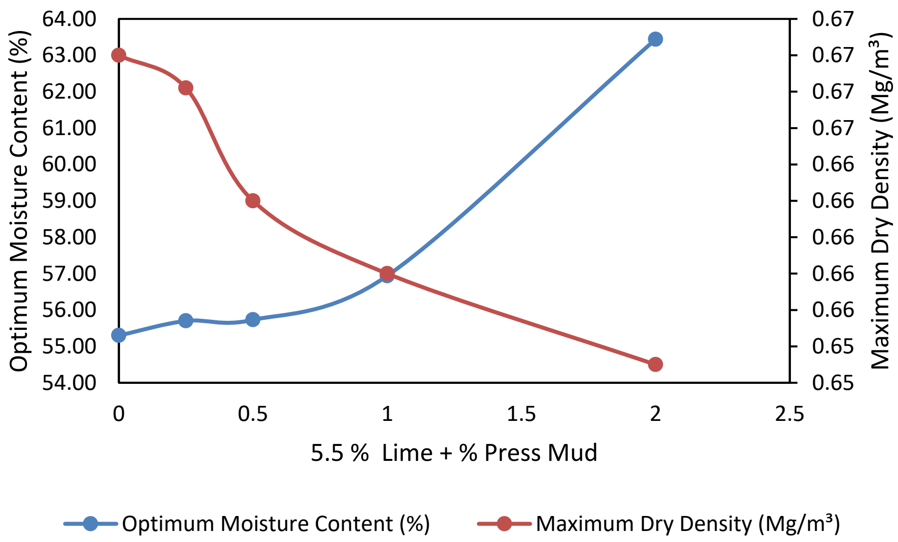

Figure 4.2: Results of Optimum Moisture Content and Maximum Dry Density for 5.5% Lime and 5 Different Percentages of PM Stabilised Peat Soil Specimens.

4.3.3 Effects of Stabilising Peat Soil with Lime and Press Mud on The Optimum Moisture Content and Maximum Dry Density

Results in Figure 4.1 and 4.2 showed that increases in optimum moisture content results in decreases in maximum dry density. The value of optimum moisture content of 3% and 5.5% lime stabilised peat is 32.39% and 63.44% respectively and both moisture content is achieved at 2.0% PM. The maximum dry density of both 3% and 5.5% lime stabilised soil is shown at 0.0% PM and the value is 0.59 and 0.67 respectively.

This scenario is affected by the nature of peat soil and PM. Both peat soil and PM have good water holding capacity which tends to absorb water. This makes the water content in the soil sample increase and eventually increases the optimum moisture content.

The existence of PM has made the peat soil more capable for water absorption. In order to reduce the optimum moisture content of soil samples, lime is added to the soil samples. However, the amount of lime (3% and 5.5%) added to the soil samples showed less effect on reducing optimum moisture content and increasing maximum dry density. This is due to the reason the lime content is not adequate to lower the water content and improve the workability and load bearing capacity of peat soil, so, the optimum moisture content in soil samples increases and the maximum dry density in soil samples decreases.

4.4 Unconfined Compressive Strength Test

The Unconfined compressive strength test was carried out to determine the unconfined compressive strength of the soil sample. The theoretical purpose of conducting this experimental test is to quickly determine the unconfined compressive strength of fine-grained soils and rocks that is cohesive enough to be tested in an open environment. The results of unconfined compressive strength were computed into the unit of kilonewton/square meter. In this section, the unconfined compressive strength of peat soil stabilised with different proportions of lime and press mud will be discussed.

4.4.1 UCS Gained by 3% Lime and 5 Different Press Mud Percentages Stabilised Peat Soil Specimens

Results of 3% lime and 5 different percentages of PM: 0.0%, 0.25%, 0.50%, 1.0% and 2.0% to the UCS of peat soil specimens are shown in Figure 4.3. The UCS of 3% lime stabilised peat soil specimens experienced a significant drop when 0.25% PM is added into the soil sample at the 7, 14 and 28 curing periods. For the other 4 percentages of PM, the UCS of soil specimens are increased at curing periods 7, 14 and 28 days, but the increments are not significant.

The UCS of soil specimens showed negative results in terms of strength improvement except for results at curing period 0 day. These results are similar to the results obtained by James and Pandian in 2016. This situation indicates the addition of 5 different percentages of PM into 3% lime stabilised peat soil has no obvious effect on the UCS development of peat soil. James and Pandian (2016) claimed the results obtained has close result to the UCS development of pure lime stabilised peat soil.

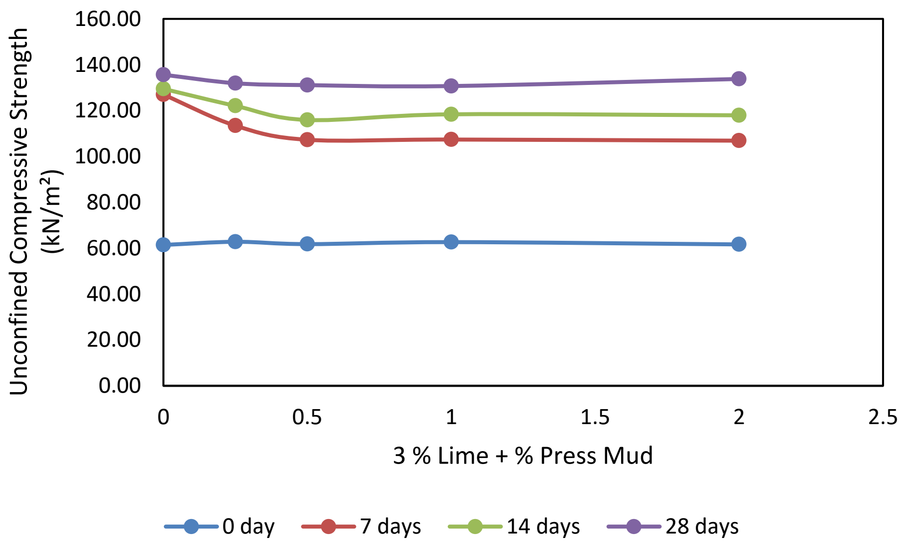

Figure 4.3: Results of 3 % Lime and 5 Different Percentages of PM to UCS of Peat Soil Specimens.

4.4.2 UCS Gained by 5.5% Lime and 5 Different Press Mud Percentages Stabilised Peat Soil Specimens

Results of 5.5% lime and 5 different percentages of PM: 0.0%, 0.25%, 0.50%, 1.0% and 2.0% to the UCS of peat soil specimens are shown in Figure 4.4. According to Figure 4.4, the UCS of soil specimens increases drastically with 5.5% lime and 0.25% PM at 7, 14 and 28 days curing period. The rest percentage of PM also showed positive results in the strength gain at 7, 14 ad 28 days curing period but the results are not significant compared to 0.25% PM.

The UCS of soil specimens showed both positive and negative results in terms of strength improvement at 7, 14 and 28 days curing period. The negative results are shown at 5.5% lime with 2.0% PM at 7 days curing period and 5.5% lime with 1.0 and 2.0% PM at 28 days curing period.

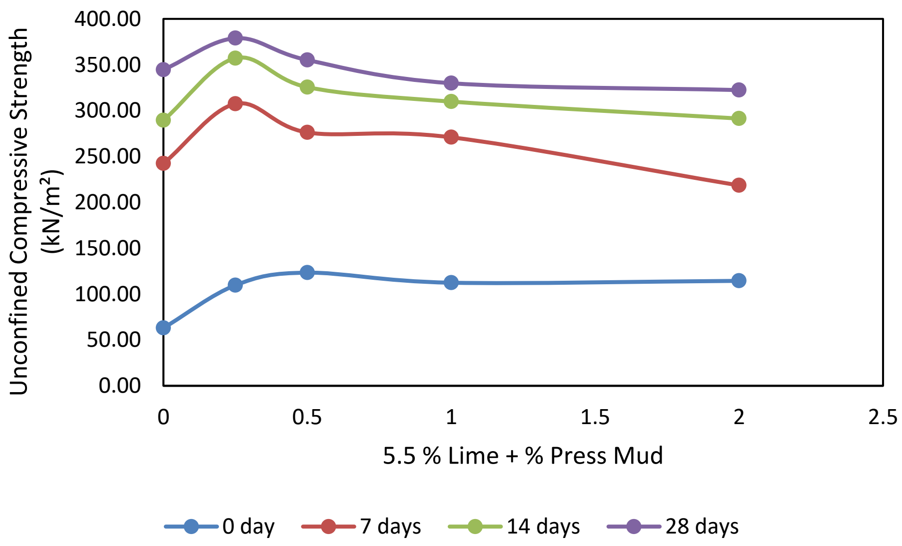

Figure 4.4: Results of 5.5% Lime and 5 Different Percentages of PM to UCS of Peat Soil Specimens.

4.4.3 Effects of Stabilising Peat Soil with Lime and Press Mud in Terms of UCS Strength Development

The addition of lime and PM showed good results in terms of unconfined compressive strength of peat soil specimens as shown in Figure 4.3 and 4.4. From the strength development perspective, only 5.5% lime with 5 different percentages of PM showed positive results. This circumstance can be explained by the properties of peat soil, lime and PM and the chemical reactions between them.

Peat soil has high water content and is acidic soil. Water consists of hydrogen ions, H^+ and oxide ions, O^{2-}, where the H^+ ions are cation which will bring acidity to a material. The acidity level of a material increases when the H^+ ions concentration increases, hence, the high water content of peat soil results in a high concentration of H^+ ions in peat soil and made peat soil a highly acidic soil.

Lime is an alkaline material which can be used to neutralise peat soil and improve the workability and load bearing capacity of soil while PM is an acidic material due to the high concentration of silicon dioxide, SiO_2 (25% of its composition). PM has the ability to accelerate early strength gain compared to that of pure lime stabilised soil, meanwhile, PM also produces humic acid which will weaken the soil and thus, reduced the strength gain availability of lime (James, 2020).

In the case of 3% lime with different percentages of PM, only specimens at 0 day curing period showed positive results for strength development. This is due to the reason that 3% lime is not enough to neutralise the soil sample and its availability for soil strengthening is affected. In the case of 5.5% lime with different percentages of PM, only 3 specimens gave negative value in strength development. This indicates that 5.5% lime is capable to neutralise the soil and enhance the soil workability and load bearing capacity. The 3 negative results are shown at 5.5% lime with 2.0% PM at 7 days curing period and with 1.0 and 2.0% PM at 28 days curing period. These 3 results can be explained by the availability of lime is weakened by humic acid (a by-product of PM), therefore, lime did not perform well in enhancing the strength development of soil specimens with a particular percentage of PM and at a particular curing period.

4.5 Effects of Activation Temperature on Unconfined Compressive Strength of Peat Soil

The effects of activation temperature on UCS of peat soil are determined with the UCS test. The alkaline solution, a mixture of sodium silicate and sodium hydroxide solution was used as activator in this finding. This test is conducted to determine the effects of temperature on the strength development of peat soil samples. The specimen is treated with cold and warm activators and 0.0%, 0.25%, 0.50%, 1.0% and 2.0% of PM. The cold activator is an alkaline activator stored at room temperature, 26°C while the warm activator is an activator stored at 50°C. The results of unconfined compressive strength were computed into the unit of kilonewton/square meter. In this section, the unconfined compressive strength of peat soil stabilised with warm and cold activator and different proportions of press mud will be discussed.

4.5.1 Analysis of Effects of Activation Temperature on Unconfined Compressive Strength of Peat Soil

The results of the effects of activation temperature on UCS of peat soil specimens are shown in Figure 4.5. In Figure 4.5, the UCS of peat soil specimens increases as the press mud percentage and curing period increase. The greatest strength gained is shown at 2.0% PM and soil specimens with the cold activator have better results in terms of strength development at all curing periods.

Cristelo, Glendinning and Pinto (2011) said the increase in temperature helps in accelerating strength gain in the early stage but deteriorating peat soil structure in the long run. This fact is proved in this study as the strength improvement by percentage of warm activator stabilised soil decreases from time to time and has the least improvement at 28 days curing period. The soil samples stabilised with cold activator have smaller strength improvement compared to the soil samples stabilised by warm activator at 0 and 7 days curing period. This indicates that the increases in temperature can improve the strength development of peat soil at an early stage.

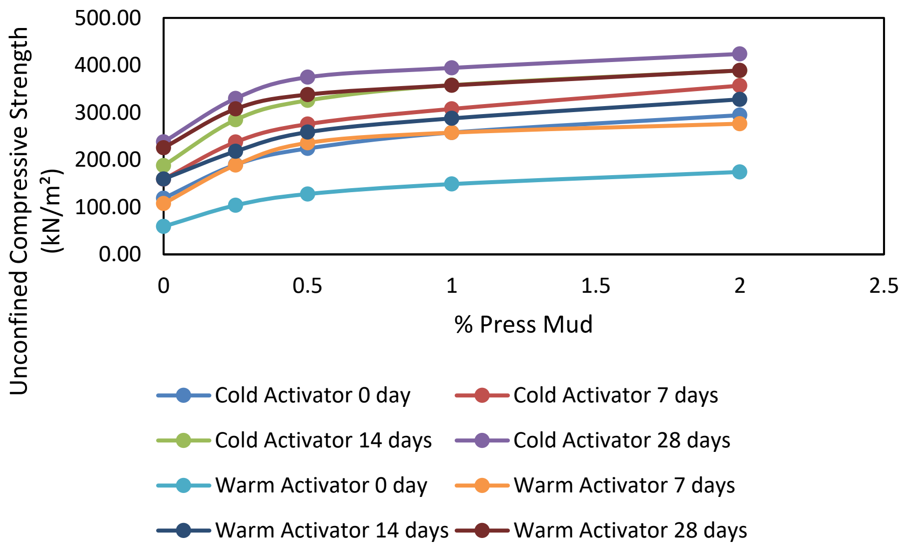

Figure 4.5: Effects of Activation Temperature on UCS of Peat Soil Specimens at 0, 7, 14 and 28 days.

4.6 Summary

This chapter has discussed the geotechnical properties of treated peat soil specimens with the stabilisers, lime and PM. The proportion of stabiliser of this study are 3% and 5.5% lime with 0.0%, 0.25%, 0.50%, 1.0% and 2.0% PM respectively. The cold and warm activators are used together with 0.0%, 0.25%, 0.50%, 1.0% and 2.0% PM to determine the effects of activation temperature on the UCS of peat soil. The soil specimens have been cured for 7, 14 and 28 days and performing UCS test was at each curing period to study the strength development of peat soil specimens. The optimum moisture content increases while the maximum dry density decreases when the PM percentages increase at both 3% and 5.5% lime stabilisation. The UCS of 3% lime stabilised peat soil showed negative results in strength development by percentage but positive results in terms of value at all curing periods. The worst result of 3% lime stabilised peat soil is at 7 days curing period and with 2.0% PM. The UCS of 3% lime and 2.0% PM stabilised peat soil specimen is 106.89 kN/m² while it has no strength improvement by percentage but a decrement in strength of 15.81%. The UCS of 5.5% lime stabilised peat soil showed positive results in terms of both value and strength improvement by percentage. The best result of 5.5% lime stabilised peat soil is when stabilised with 0.25% PM at 7 days curing period and the value is 307.35 kN/m² and the strength improvement by percentage is 26.82%. The activation temperature accelerates the early strength gain of peat soil specimens but affects the strength development negatively over a long period.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

Standard Proctor Test and Unconfined Compressive Strength (UCS) Test were conducted on the lime and press mud (PM) stabilised peat soil and alkaline activator stabilised peat soil. These 2 tests were conducted with the purpose to compare the effects of different percentages of mixed proportions of stabiliser on the optimum moisture content, maximum dry density, and unconfined compressive strength of peat soil and investigating the influence of different activation temperatures on the unconfined compressive strength of peat soil. The conclusions made based on the experimental results as listed:

1. The optimum moisture content increases continuously while the maximum dry density decreases continuously with the addition of lime and PM, and increases in PM percentages. The optimum moisture content and maximum dry density showed a significant change when 0.25% PM was added to the soil specimens for both 3% and 5.5% lime stabilisation. The optimum moisture content and maximum dry density for 3% lime and 0.25% PM stabilised peat soil specimen was 27.84% and 0.57 respectively. The optimum moisture content and maximum dry density for 5.5% lime and 0.25% PM stabilised peat soil specimen was 55.70% and 0.67 respectively. The addition of lime is to neutralise the peat soil and improve its load bearing capacity and PM was added to accelerate the reaction. In this case, both lime and PM did not show a significant effect.

2. The addition of 3% lime and 5 different percentages of PM showed the best results of strength development on the addition of 0.25% PM at all curing periods. The UCS of 3% lime and 0.25% PM stabilised peat soil are 62.80 kN/m², 113.45 kN/m², 122.08 kN/m² and 131.95 kN/m² at 0, 7, 14 and 28 days curing period respectively. The significant results are

shown at 5.5% lime and 0.25% PM stabilised peat soil. The UCS of 5.5% lime and 0.25% PM stabilised peat soil are 109.62 kN/m², 307.35 kN/m², 357.12 kN/m² and 378.92 kN/m² at 0, 7, 14 and 28 days curing period respectively. Lime improve the soil by improving its workability and load bearing capacity which are the important properties for flocculation while PM accelerate the strength development at the beginning stage.

3. The cold activator stabilised peat soil specimen showed better results compared to the warm activator stabilised peat soil. The development of UCS of peat soil specimens with 0.25% PM increases drastically for both cold and warm activators. However, the UCS of warm activator stabilised soil in terms of strength improvement by percentage decreases as the curing period increases. The use of a warm activator proved that activation temperature can improve the early strength gain of peat soil as the strength development by percentage of warm activator showed better results at 7 and 14 curing period compared to cold activator stabilised peat soil specimens at the same curing period.

5.2 Recommendations for future work

The lime and PM stabilised peat soil study is still new and limited in this field. Hence, recommendations shall be considered to improve future studies specifications:

1. Greater lime content such as 10%, 20% and 30% are suggested to determine the optimum moisture content and maximum dry density of lime and PM stabilised peat soil.

2. Including the Atterberg Limit Test and California Bearing Ratio Test to explore the effects of lime and PM on more geotechnical properties of peat soil such as pH value, liquid limit and shear strength.

3. Scanning Electron Microscopy Test is also suggested to study the peat soil, lime and PM structure for better understanding and evaluation.

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APPENDICES

APPENDIX A: Results of moisture content and dry density of peat soil specimens stabilised by 3% and 5.5% lime with 0.0%, 0.25%, 0.50%, 1.0% and 2.0% press mud.

Table A-1: Results of Moisture Content and Dry Density of 3% Lime and 0.0% PM Stabilised Peat Soil.

	10% Water			15% Water			20% Water			25% Water		
	Top	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**
Mass of mould, baseplate and peat soil (kg)		5384.64			5462.33			5460.89			5442.4	
Mass of can (g)	34.15	32.49	34.24	33.94	35.06	35.45	34.75	36.18	35.83	33.88	35.35	34.55
Mass of can + wet soil (g)	47.96	45.89	46.73	46.62	46.87	47.54	57.72	58.82	58.85	57.71	57.59	55.52
Mass of can + dry soil (g)	42.49	42.97	42.49	42.39	42.02	44.23	47.45	48.47	48.6	46.57	47.2	45.73
Mass of dry soil (g)	8.34	10.48	8.25	8.45	6.96	8.78	12.7	12.29	12.77	12.69	11.85	11.18
Mass of water (g)	5.47	2.92	4.24	4.23	4.85	3.31	10.27	10.35	10.25	11.14	10.39	9.79
Water content (%)	34.1055	14.4885	26.7248	26.0308	36.2356	19.6036	32.0504	33.7917	31.7384	37.3085	37.2532	37.1949
Average water content (%)		25.11			27.29			32.53			37.25	
Bulk Density (Mg/m³)		0.8879			0.9447			0.9436			0.9301	
Dry density (Mg/m³)	0.4121	0.5255	0.4506	0.5996	0.5434	0.6398	0.4946	0.4853	0.4963	0.4274	0.4277	0.4279
Average dry density (Mg/m³)		0.46			0.59			0.49			0.43	

Table A-2: Results of Moisture Content and Dry Density of 3% Lime and 0.25% PM Stabilised Peat Soil.

	10% Water			15% Water			20% Water			25% Water		
	Top	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**
Mass of mould, baseplate and peat soil (kg)		5456.19			5461.69			5427.69			5418.51	
Mass of can (g)	34.53	33.84	35.67	34.08	35.89	33.81	36.12	34.14	35.02	33.93	35.08	35.98
Mass of can + wet soil (g)	48.51	49.46	48.78	57.06	56.72	53.46	60.53	58.23	59.32	63.68	64.38	65.83
Mass of can + dry soil (g)	42.35	42.41	42.94	46.5	47.06	44.43	48.89	46.76	47.82	49	50.1	51.24
Mass of dry soil (g)	7.82	8.57	7.27	12.42	11.17	10.62	12.77	12.62	12.8	15.07	15.02	15.26
Mass of water (g)	6.16	7.05	5.84	10.56	9.66	9.03	11.64	11.47	11.5	14.68	14.28	14.59
Water content (%)	25.9616	27.7771	29.7717	39.2126	39.9705	39.2147	52.6651	52.5128	51.9097	50.6543	49.4381	49.7169
Average water content (%)		27.84			39.47			47.60			55.48	
Bulk Density (Mg/m³)		0.9402			0.9442			0.9193			0.9126	
Dry density (Mg/m³)	0.5764	0.5658	0.5545	0.5483	0.5446	0.5482	0.5722	0.5728	0.6052	0.5058	0.5107	0.5096
Average dry density (Mg/m³)		0.57			0.55			0.55			0.51	

Table A-3: Results of Moisture Content and Dry Density of 3% Lime and 0.50% PM Stabilised Peat Soil.

	10% Water			15% Water			20% Water			25% Water		
	Top	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**
Mass of mould, baseplate and peat soil (kg)		5436.5			5446.43			5457.87			5431.52	
Mass of can (g)	33.88	34.41	35.16	35.14	35.86	34.61	36.18	36.1	35.16	34.26	33.9	35.98
Mass of can + wet soil (g)	48.1	49.94	48.09	53.95	52.3	54.31	54.37	53.33	55.02	54.64	52.9	53.86
Mass of can + dry soil (g)	41.6	42.5	42.1	44.7	44.4	44.9	45.2	44.4	45.7	43.9	43.4	44.8
Mass of dry soil (g)	7.72	8.09	6.94	9.56	8.54	10.29	9.02	8.3	10.54	9.64	9.5	8.82
Mass of water (g)	6.5	7.44	5.99	9.25	7.9	9.41	9.17	8.93	9.32	10.74	9.5	9.06
Water content (%)	43.7824	47.8220	44.8818	38.7029	37.0023	36.5792	44.0540	46.6225	45.9810	57.9336	52.0000	53.4150
Average water content (%)		27.98			37.43			45.55			54.45	
Bulk Density (Mg/m³)		0.9258			0.9331			0.9414			0.9221	
Dry density (Mg/m³)	0.6439	0.6263	0.6390	0.6727	0.6810	0.6832	0.4635	0.4521	0.4549	0.4139	0.4367	0.4311
Average dry density (Mg/m³)		0.56			0.53			0.46			0.43	

Table A-4: Results of Moisture Content and Dry Density of 3% Lime and 1.0% PM Stabilised Peat Soil.

	10% Water			**15% Water**			**20% Water**			**25% Water**		
	Top	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**
Mass of mould, baseplate and peat soil (kg)		5402.41			5393.11			5399.17			5372.08	
Mass of can (g)	34.11	34.05	34.27	33.88	35.05	35.46	34.8	33.81	35.84	33.84	35.3	34.7
Mass of can + wet soil (g)	57.53	56.46	55.04	60.42	60.18	58.1	58.37	55.3	56.56	58.04	58.71	58.84
Mass of can + dry soil (g)	45.8	46.59	45	46.88	47.42	46.72	45.9	44.39	45.74	45.14	46.61	45.83
Mass of dry soil (g)	11.69	12.54	10.73	13	12.37	11.26	11.1	10.58	9.9	11.3	11.31	11.13
Mass of water (g)	11.73	9.87	10.04	13.54	12.76	11.38	12.47	10.91	10.82	12.9	12.1	13.01
Water content (%)	35.0279	23.7782	31.5061	38.1600	37.6395	36.5542	43.4180	38.6219	41.8323	46.3628	42.6322	47.7835
Average water content (%)		30.10			37.45			41.29			45.59	
Bulk Density (Mg/m³)		0.9009			0.8941			0.8985			0.8787	
Dry density (Mg/m³)	0.4672	0.5278	0.4850	0.4471	0.4496	0.4547	0.3865	0.4082	0.3935	0.4203	0.4360	0.4146
Average dry density (Mg/m³)		0.49			0.45			0.40			0.42	

Table A-5: Results of Moisture Content and Dry Density of 3% Lime and 2.0% PM Stabilised Peat Soil.

	10% Water			**15% Water**			**20% Water**			**25% Water**		
	Top	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**
Mass of mould, baseplate and peat soil (kg)		5402.41			5393.11			5399.17			5372.08	
Mass of can (g)	34.11	34.05	34.27	33.88	35.05	35.46	34.8	33.81	35.84	33.84	35.3	34.7
Mass of can + wet soil (g)	57.53	56.46	55.04	60.42	60.18	58.1	58.37	55.3	56.56	58.04	58.71	58.84
Mass of can + dry soil (g)	45.8	46.59	45	46.88	47.42	46.72	45.9	44.39	45.74	45.14	46.61	45.83
Mass of dry soil (g)	11.69	12.54	10.73	13	12.37	11.26	11.1	10.58	9.9	11.3	11.31	11.13
Mass of water (g)	11.73	9.87	10.04	13.54	12.76	11.38	12.47	10.91	10.82	12.9	12.1	13.01
Water content (%)	31.6779	31.3282	34.1561	38.1600	37.6395	36.5542	46.4180	41.6219	44.8323	49.3628	45.6322	50.7835
Average water content (%)		32.39			37.45			44.29			48.59	
Bulk Density (Mg/m³)		0.9009			0.8941			0.8985			0.8787	
Dry density (Mg/m³)	0.4241	0.4260	0.4115	0.3971	0.3996	0.4047	0.3336	0.3544	0.3404	0.2983	0.3134	0.2927
Average dry density (Mg/m³)		0.42			0.40			0.34			0.30	

Table A-6: Results of Moisture Content and Dry Density of 5.5% Lime and 0.0% PM Stabilised Peat Soil.

	10% Water			15% Water			20% Water			25% Water		
	Top	Bottom	Middle	Top	Bottom	Middle	Top	Bottom	Middle	Top	Bottom	Middle
Mass of mould, baseplate and peat soil (kg)		5384.64			5462.33			5460.89			5442.4	
Mass of can (g)	34.15	33.89	34.24	33.94	35.06	35.45	34.75	36.18	35.83	33.88	35.35	34.55
Mass of can + wet soil (g)	49.35	50.68	50.9	52.15	54.91	50.82	57.72	58.82	58.85	57.71	57.59	55.52
Mass of can + dry soil (g)	43.3	43.99	44.11	44.39	46.37	44.3	47.45	48.47	48.6	46.57	47.2	45.73
Mass of dry soil (g)	9.15	10.1	9.87	10.45	11.31	8.85	12.7	12.29	12.77	12.69	11.85	11.18
Mass of water (g)	6.05	6.69	6.79	7.76	8.54	6.52	10.27	10.35	10.25	11.14	10.39	9.79
Water content (%)	54.8125	54.8736	56.2030	63.6144	64.2644	63.3096	70.0504	71.7917	69.7384	75.6485	75.5932	75.5349
Average water content (%)		55.30			63.73			70.53			75.59	
Bulk Density (Mg/m³)		0.8879			0.9447			0.9436			0.9301	
Dry density (Mg/m³)	0.6735	0.6733	0.6684	0.6274	0.6251	0.6285	0.6149	0.6093	0.6159	0.5695	0.5697	0.5699
Average dry density (Mg/m³)		0.67			0.63			0.61			0.57	

Table A-7: Results of Moisture Content and Dry Density of 5.5% Lime and 0.25% PM Stabilised Peat Soil.

	10% Water			15% Water			20% Water			25% Water		
	Top	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**
Mass of mould, baseplate and peat soil (kg)		5456.33			5483.75			5489.97			5474.9	
Mass of can (g)	34.34	35.46	34.85	34.05	34.19	35.44	36.25	33.98	33.95	36.02	36.1	23
Mass of can + wet soil (g)	50.83	51.48	51.39	52.92	53.44	53.9	58.83	58.05	58.58	61	60.07	48.52
Mass of can + dry soil (g)	43.6	44.38	44.28	44.08	44.33	45.3	47.93	46.58	46.63	48.56	48.12	36
Mass of dry soil (g)	9.26	8.92	9.43	10.03	10.14	9.86	11.68	12.6	12.68	12.54	12.02	13
Mass of water (g)	7.23	7.1	7.11	8.84	9.11	8.6	10.9	11.47	11.95	12.44	11.95	12.52
Water content (%)	55.9004	56.6901	54.5068	60.8305	61.7179	60.3550	63.5274	62.3365	64.0063	69.5853	69.6972	68.0800
Average water content (%)		55.70			60.97			63.29			69.12	
Bulk Density (Mg/m^3)		0.9403			0.9604			0.9649			0.9539	
Dry density (Mg/m^3)	0.6731	0.6701	0.6786	0.6271	0.6238	0.6289	0.5901	0.5944	0.5883	0.5625	0.5621	0.5675
Average dry density (Mg/m^3)		0.67			0.63			0.59			0.56	

Table A-8: Results of Moisture Content and Dry Density of 5.5% Lime and 0.50% PM Stabilised Peat Soil.

	10% Water			15% Water			20% Water			25% Water		
	Top	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**
Mass of mould, baseplate and peat soil (kg)		5421.02			5480.58			5496.27			5475.12	
Mass of can (g)	34.59	35.37	34.97	34.28	34.45	34.3	34.65	35.08	34.89	20.08	19.82	19.95
Mass of can + wet soil (g)	50.23	51.75	52.74	52.7	53.7	53.5	56.85	57.73	58.1	49.9	47.87	48.78
Mass of can + dry soil (g)	43.59	44.48	45.19	44.44	44.83	44.84	46.48	47.03	47.39	35.47	34.4	34.81
Mass of dry soil (g)	9	9.11	10.22	10.16	10.38	10.54	11.83	11.95	12.5	15.39	14.58	14.86
Mass of water (g)	6.64	7.27	7.55	8.26	8.87	8.66	10.37	10.7	10.71	14.43	13.47	13.97
Water content (%)	54.6644	57.7973	54.7149	59.2756	61.4355	59.7249	68.5824	69.5607	67.5536	72.7563	72.0412	72.8856
Average water content (%)		55.73			60.15			68.57			72.56	
Bulk Density (Mg/m³)		0.9145			0.9580			0.9695			0.9540	
Dry density (Mg/m³)	0.6613	0.6495	0.6611	0.6315	0.6234	0.6298	0.5751	0.5718	0.5786	0.5522	0.5545	0.5518
Average dry density (Mg/m³)		0.66			0.63			0.58			0.55	

Table A-9: Results of Moisture Content and Dry Density of 5.5% Lime and 1.0% PM Stabilised Peat Soil.

	10% Water			15% Water			20% Water			25% Water		
	Top	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**
Mass of mould, baseplate and peat soil (kg)		5456.22			5488.58			5479.87			5457.82	
Mass of can (g)	22.94	23.23	23.37	22.52	23.41	27.81	17.95	18.45	17.83	17.82	17.92	17.8
Mass of can + wet soil (g)	42	42.2	42.97	45.54	46.08	44.32	45.78	47.69	46.33	47.64	47.57	47.41
Mass of can + dry soil (g)	33.59	33.77	34.51	35.17	35.51	36.93	32.38	33.87	33.08	32.88	32.8	32.98
Mass of dry soil (g)	10.65	10.54	11.14	12.65	12.1	9.12	14.43	15.42	15.25	15.06	14.88	15.18
Mass of water (g)	8.41	8.43	8.46	10.37	10.57	7.39	13.4	13.82	13.25	14.76	14.77	14.43
Water content (%)	57.2929	57.8201	55.7201	61.6277	64.4248	61.1360	71.2883	69.6044	68.1803	71.9641	72.6156	70.4308
Average water content (%)		56.94			62.40			69.69			71.67	
Bulk Density (Mg/m³)		0.9402			0.9639			0.9575			0.9414	
Dry density (Mg/m³)	0.6577	0.6558	0.6638	0.6264	0.6162	0.6282	0.5590	0.5646	0.5693	0.5474	0.5454	0.5524
Average dry density (Mg/m³)		0.66			0.62			0.56			0.55	

Table A-10: Results of Moisture Content and Dry Density of 5.5% Lime and 2.0% PM Stabilised Peat Soil.

	10% Water			**15% Water**			**20% Water**			**25% Water**		
	Top	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**	**Top**	**Bottom**	**Middle**
Mass of mould, baseplate and peat soil (kg)		5456.22			5488.58			5479.87			5457.82	
Mass of can (g)	22.94	23.23	23.37	22.52	23.41	27.81	17.95	18.45	17.83	17.82	17.92	17.8
Mass of can + wet soil (g)	42	42.2	42.97	45.54	46.08	44.32	45.78	47.69	46.33	47.64	47.57	47.41
Mass of can + dry soil (g)	33.59	33.77	34.51	35.17	35.51	36.93	32.38	33.87	33.08	32.88	32.8	32.98
Mass of dry soil (g)	10.65	10.54	11.14	12.65	12.1	9.12	14.43	15.42	15.25	15.06	14.88	15.18
Mass of water (g)	8.41	8.43	8.46	10.37	10.57	7.39	13.4	13.82	13.25	14.76	14.77	14.43
Water content (%)	63.7929	64.3201	62.2201	70.6277	73.4248	70.1360	76.2883	74.6044	73.1803	78.9641	79.6156	77.4308
Average water content (%)		63.44			71.40			74.69			78.67	
Bulk Density (Mg/m^3)		0.9402			0.9639			0.9575			0.9414	
Dry density (Mg/m^3)	0.6440	0.6422	0.6496	0.6149	0.6058	0.6165	0.5532	0.5584	0.5629	0.5260	0.5241	0.5306
Average dry density (Mg/m^3)		0.65			0.61			0.56			0.53	

APPENDIX B: Results of unconfined compressive strength for 3% and 5.5% lime with 5 different percentages of PM stabilised peat soil specimens at 0, 7, 14 and 28 days sequentially.

Table B-1: UCS of 3% Lime and 5 Different Percentages of PM Stabilised Peat Soil Specimens.

3 % Lime					
Specimens	**Dry density (Mg/m^3)**	**Press Mud (%)**	**UCS (kN/m^2)**	**Strength Improvement by Percentage (%)**	**Curing Period (days)**
U0	0.59	0.0	61.42	-	
U1	0.60	0.25	62.8	2.25	
U2	0.56	0.50	61.79	0.60	0
U3	0.49	1.0	62.65	2.00	
U4	0.42	2.0	61.66	0.39	
U5	0.59	0.0	126.97	-	
U6	0.60	0.25	113.45	-10.65	
U7	0.56	0.50	107.29	-15.50	7
U8	0.49	1.0	107.38	-15.43	
U9	0.42	2.0	106.89	-15.81	
U10	0.59	0.0	129.48	-	
U11	0.60	0.25	122.08	-5.71	
U12	0.56	0.50	115.92	-10.48	14
U13	0.49	1.0	118.38	-8.57	
U14	0.42	2.0	117.96	-8.90	
U15	0.59	0.0	135.65	-	
U16	0.60	0.25	131.95	-2.73	
U17	0.56	0.50	131.12	-3.34	28
U18	0.49	1.0	130.72	-3.64	
U19	0.42	2.0	133.80	-1.36	

Table B-2: UCS of 5.5% Lime and 5 Different Percentages of PM Stabilised Peat Soil Specimens.

5.5 % Lime					
Specimens	**Dry density (Mg/m^3)**	**Press Mud (%)**	**UCS (kN/m^2)**	**Strength Improvement by Percentage (%)**	**Curing Period (days)**
U20	0.67	0.0	63.00	-	
U21	0.67	0.25	109.62	74.00	
U22	0.66	0.50	123.32	95.74	0
U23	0.66	1.0	112.38	78.38	
U24	0.65	2.0	114.42	81.62	
U25	0.67	0.0	242.35	-	
U26	0.67	0.25	307.35	26.82	
U27	0.66	0.50	276.23	13.98	7
U28	0.66	1.0	270.90	11.78	
U29	0.65	2.0	218.45	-9.86	
U30	0.67	0.0	289.42	-	
U31	0.67	0.25	357.12	23.39	
U32	0.66	0.50	325.55	12.49	14
U33	0.66	1.0	309.83	7.05	
U34	0.65	2.0	291.34	0.66	
U35	0.67	0.0	344.56	-	
U36	0.67	0.25	378.92	9.97	
U37	0.66	0.50	355.15	3.07	28
U38	0.66	1.0	329.85	-4.27	
U39	0.65	2.0	322.38	-6.44	

APPENDIX C: Results of unconfined compressive strength for peat soil specimens stabilised by cold and warm activators with 5 different percentages of PM at 0, 7, 14 and 28 days sequentially.

Table C-1: UCS of Cold Activator and 5 Different Percentages of PM Stabilised Peat Soil Specimens.

Cold Activator					
Specimens	**Dry density (Mg/m^3)**	**Press Mud (%)**	**UCS (kPa)**	**Strength Improvement by Percentage (%)**	**Curing Period (days)**
A0	0.59	0	118.73		
A1	0.57	0.25	189.79	59.85	
A2	0.56	0.5	223.94	88.61	0
A3	0.49	1	257.63	116.99	
A4	0.42	2	294.39	147.95	
A5	0.59	0	158.94		
A6	0.57	0.25	237.59	49.48	
A7	0.56	0.5	275.43	73.29	7
A8	0.49	1	307.59	93.53	
A9	0.42	2	356.79	124.48	
A10	0.59	0	187.78		
A11	0.57	0.25	284.57	51.54	
A12	0.56	0.5	325.59	73.39	14
A13	0.49	1	357.89	90.59	
A14	0.42	2	388.74	107.02	
A15	0.59	0	237.89		
A16	0.57	0.25	329.83	38.65	
A17	0.56	0.5	374.58	57.46	28
A18	0.49	1	394.36	65.77	
A19	0.42	2	423.85	78.17	

Remarks: Activator is a mixture of Sodium Silicate and Sodium Hydroxide Solution.

Cold Activator is stored at room temperature (26°C).

Table C-2: UCS of Warm Activator and 5 Different Percentages of PM Stabilised Peat Soil Specimens.

Warm Activator					
Specimens	**Dry density (Mg/m^3)**	**Press Mud (%)**	**UCS (kPa)**	**Strength Improvement by Percentage (%)**	**Curing Period (days)**
A20	0.67	0	59.00		
A21	0.67	0.25	103.87	76.05	
A22	0.66	0.5	127.68	116.41	0
A23	0.66	1	148.73	152.08	
A24	0.65	2	174.33	195.47	
A25	0.67	0	107.45		
A26	0.67	0.25	188.94	75.84	
A27	0.66	0.5	235.79	119.44	7
A28	0.66	1	257.48	139.63	
A29	0.65	2	276.33	157.17	
A30	0.67	0	159.46		
A31	0.67	0.25	217.94	36.67	
A32	0.66	0.5	258.49	62.10	14
A33	0.66	1	287.58	80.35	
A34	0.65	2	327.79	105.56	
A35	0.67	0	225.49		
A36	0.67	0.25	307.57	36.40	
A37	0.66	0.5	337.94	49.87	28
A38	0.66	1	357.48	58.53	
A39	0.65	2	388.94	72.49	

Remarks: Activator is a mixture of Sodium Silicate and Sodium Hydroxide Solution.

Warm Activator is keeping warm at 50°C.