Effectiveness of Sugarcane Bagasse Ash(SCBA) Utilization in Peat Stabilization

モハマド, ハイデイル ビン アブ タリブ

https://doi.org/10.15017/1654849

出版情報：九州大学, 2015, 博士（工学）, 課程博士
バージョン：

Effectiveness of Sugarcane Bagasse Ash (SCBA) Utilization in Peat Stabilization

Mohd Khaidir Bin Abu Talib

March, 2016

Effectiveness of Sugarcane Bagasse Ash (SCBA) Utilization in Peat Stabilization

A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Engineering

By

Mohd Khaidir Bin Abu Talib

To the:

DEPARTMENT OF CIVIL ENGINEERING

GRADUATE SCHOOL OF ENGINEERING

KYUSHU UNIVERSITY

Fukuoka, Japan

March, 2016

DEPARTMENT OF CIVIL AND STRUCTURAL ENGINEERING
GRADUATE SCHOOL OF ENGINEERING
KYUSHU UNIVERSITY
Fukuoka, Japan

CERTIFICATE

The undersigned hereby certify that they have read and recommended to the Graduate School of Engineering for the acceptance of this thesis entitled, “***Effectiveness of Sugarcane Bagasse Ash (SCBA) Utilization in Peat Stabilization***” by **Mohd Khaidir Bin Abu Talib** in partial fulfillment of the requirements for the degree of **Doctor of Engineering**.

Dated: March, 2016

Thesis Supervisor:

Prof. Noriyuki Yasufuku, Dr. Eng.

Examining Committee:

Prof. Hideki Shimada, Dr. Eng.

Assoc. Prof. Kiyonobu Kasama, Dr. Eng.

Prof. Noriyuki Yasufuku, Dr. Eng.

ABSTRACT

Peat distribution is extensive and can be found in many countries throughout the world. These soils are problematic as they are very highly compressible and low shear strength. Conventionally, the normal practice is to avoid these soils area, soil replacement or driven pile. However due to dearth of suitable land for development, avoidance of construction on peat is no relevance anymore. Replacement method will make large scale disposal of peat in unacceptable amount in future. Structures on peat that suspended on piles normally give deposition effect to surrounding ground. In Malaysia, there is approximately 26000 km^2 of peat. Johor is 3rd largest of peat total area in Peninsular Malaysia but recorded the largest oil palm and other crops plantation area on peat. Malaysia once becomes the main contributor of oil palm in the world but after 2006 Malaysia turn into second place after Indonesia. According to Malaysia Palm Oil Board (MPOB), transportation problem on peat identified as one reason of oil palm production shortage.

In scope of effective, economic and rapid improvement method, mass stabilization technique by using cement perceived a good option for peat stabilization on oil palm planting area. Nevertheless, cement productions contributes roughly 5% of carbon oxide (CO_2) all over the world. Until 2012, cement volumes are approximately 3.7 billion ton and forecast to reach 4.4 billion ton by 2050. Average emissions are approximately 900 kg CO_2/ton cement. The prices of cement are also expected increases year by year. For these reasons, utilization of biological plant waste materials is seen to be a good measure in creating a new sustainable method for peat stabilization. Sugarcane production is presently world No. 1 commodities. About 32% of bagasse is produced from every ton of sugar cane that been processed. The total plantation area of sugarcane bagasse in Malaysia is nearly 150 km^2. About 82000 ton of sugarcane is produced in 2012; hence bagasse also can be easily obtained in Malaysia. Normally, bagasse burned to produce energy and steam for power in factory and finally leave the ash as the waste. Increasing concern of disposal of bagasse ash residual creates interest to explore the potential application of this material. Main objectives of this study are to demonstrate the effectiveness of Sugarcane Bagasse Ash (SCBA) as pozzolanic materials that possibly can be used

for partial cement replacement in peat mass stabilization. This dissertation consists of seven chapters. The specific content of each chapter are described as follows:

Chapter 1 presents an introduction of this research. Current problem and motivation to conduct this research are to be presented in this chapter. Objectives and structure of the thesis are also described.

Chapter 2 deliberates an overview of peat concerning to geotechnical characteristics that highlight the physical, chemical and mechanical properties. The collected results of studied peat from Hokkaido then compared to Malaysia peat in order to investigate the similarity potential. It is observed that studied peat has similar properties with the Johor peat located in southern part of peninsular Malaysia. Therefore, it is expected the research finding could be also applied on Johor peat in future.

Chapter 3 presents the approach method to clarify the effectiveness of three types SCBA utilization on peat strength. The Unconfined Compressive Strength (UCS) tests were conducted at all samples with the aim to elucidate the stabilized peat strength improvement. The new simple method for preloading during curing was executed by using controlled air pressure instead of iron rod in conventional method. The main target of this chapter is to determine the optimum SCBA inclusion as partial replacement of cement. Next, the optimum mixtures from each SCBA were used in further UCS test that stresses on various effect factors in peat stabilization. It was found that optimum Peat-Cement-Bagasse (PCB) mixtures attain the maximum UCS and discovered greater than Peat-Cement (PC) specimen. Moreover, the proposed calculation to predict deformation modulus of PCB mixtures based on two-phase mixtures model was introduced and developed. The main benefit of this proposed model is the ability to determine the optimum PCB mixture which depends on the physical and chemical effects of SCBA. It was observed that the proposed model outcomes demonstrate a well agreement with the experimental results. At the optimal mix design, the UCS of the stabilized peat specimens increased with increasing of curing time, Ordinary Portland Cement (OPC) dosage, silica sand dosage and preloading. At final stage, the preloading rates during curing and ideal mixture proportions are recommendable for the peat stabilization to be effective.

Chapter 4 discusses the strength improvement mechanism of stabilized peat by focusing on the microstructure and chemical composition enhancement. The main objective in this chapter is to verify the results obtained from previous chapter. It can be stated that the stabilized soil is characterized by a well cemented soil medium with tiny pore spaces within it as a result of the pozzolanic activity of SCBA. The oxide compound percentages from Energy-dispersive X-ray spectroscopy (EDX) results clearly depict that lower CO_2 and higher calcium oxide (CaO_2) portions contribute the better results of strength. Additionally, the essential pozzolanic oxide compounds [Silica (SiO_2) and Alumina, (Al_2O_3)] display the high proportions for stabilized peat which proves the formation of cementation products namely Calcium Silicate Hydrates (CSH) and Calcium Alumina Silicate Hydrates (CASH).

Chapter 5 considers the evaluation of SCBA quality on pozzolanic effect in stabilized peat. Pozzolanic effect of SCBA was determined from the outcomes of UCS with different curing duration by setting the strength of PC mixture as a reference. Previously, it was detected that the main different between SCBA characteristics are their particle sizes and chemical compositions. Hence, mean grain size (D_{50}) and CaO_2:SiO_2 ratio of SCBA were adopted in statistical multiple regression model analysis in order to predict the mixtures strength that consider many other factors of peat stabilization. Considering the suggestion of the preloading rates and best mixture proportions in chapter 3, the estimation equations were simplified to easy form that emphasizes the SCBA quality and quantity only. Finally, the quality of SCBA characteristics (D_{50} and CaO_2:SiO_2) that can be utilized in hemic peat stabilization were suggested.

Chapter 6 illustrates the effectiveness of optimum PCB mixtures on peat deformation behavior. Afterward, the outcomes were compared to PC mixture and untreated peat compressibility test results. There was a significant reduction of void ratio (e) for optimum PCB mixtures as compared to the untreated one. The essential effect of treatment on the compression behavior is the increase in the preconsolidation pressure, σ'_c with curing period which means the compression curve of the stabilized soil is shifted to higher effective stress. It is found that the ratio of the secondary compression index, C_α to compression index, C_c or C_α/C_c of untreated peat obviously decrease after stabilized with optimum PCB mixtures. As the C_α/C_c ratio declines, the soils engineering behaviors is shift from organic soils to inorganic soils and finally reach to a granular material after a month of curing age on the best optimum PCB mixtures. As a result, stabilized peat with high quality SCBA inclusions was found to be a good foundation material by the geotechnical engineers.

Chapter 7 concludes all the research works together with study limitation and future works.

ACKNOWLEDGEMENTS

First of all, I am very grateful to Allah the Almighty for His grace I managed to complete my PhD successfully. In preparing and completing the research and PhD thesis, I have received invaluable help from many people. As a token of gratitude to them, I would like to present some of individual who have contributed to my success.

To begin with, I really would like to express my sincere gratitude to my supervisor, Prof. Dr. Noriyuki Yasufuku for the continuous support of my PhD study, for his patience, tolerance, motivation and good guidance. I am very fortunate to have a supervisor who is very kind and knowledgeable as he was. He always gives me a freedom in conducting research but will be reprimanded if something went wrong and then give a valuable recommendation. Besides my advisor, I would like to express my gratefulness to members of examining committee, Prof. Dr. Hideki Shimada and Assoc. Prof. Dr. Kiyonobu Kasama for their treasured time, attentive evaluation and valuable comments on my works.

I would also like to thank Prof. Dr. Hemanta Hazarika and Dr. Ryohei Ishikura who sometimes share some useful knowledge during my PhD research. Not to forget also great appreciation to Mrs. Aki Ito in student affairs and Mr. Michio Nakashima who helps a lot in the success of the experimental work in the laboratory. I owe a debt of gratitude to all my comrades from Geotechnical Engineering Laboratory on their good assistance throughout my study and live in Japan. They are Dr. Mahmoud Hassan Fawzy, Dr. Jiang Zhenbo, Mr. Shintaro Miyamoto, Dr. He Yi, Dr. Teng Teng, Dr. Miao Jiali, Dr. Luky Handoko, Dr. Zentaro Furukawa as well as many other students in our research group for their decent cooperation. I am also indebted to Dr. Midori Watanabe from Centre of Advanced Instrumental Analysis with whom I have interacted during the SEM and EDX test. I would like to extend my great acknowledgement to my employer in Malaysia, Universiti Tun Hussein Onn Malaysia (UTHM) in providing me the scholarship to further my PhD study at Kyushu University.

Finally, I am indebted to my most lovable parents and siblings for their indirect encouragement from homeland. Special thanks to my beloved wife and my little daughter who are always supports and show unconditional love to me.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE AND ABBREVIATIONS

ASTM	American Society for Material Testing
USCS	United Soil Classification System
MSCS	Malaysian Soil Classification Systems
SCBA	Sugarcane Bagasse Ash
OPC	Ordinary Portland Cement
$CaCl_2$	Calcium Chloride
K7	Silica sand
w	Natural water content, %
A.C	Ash content, %
O.C	Organic content, %
F.C	Fiber content, %
γ	Bulk unit weight, kN/m^3
G_s	Specific gravity
L_L	Liquid Limit, %
pH	Acidity
q_u	Unconfined Compressive strength, kPa
S_u	Undrained shear strength, kPa
E_{50}	Secant Young’s modulus at 50% of the q_u, MPa
ε_f	Strain at failure, %
P	Untreated peat samples
PC	Peat-cement mixtures
PCB	Peat-cement-bagasse mixtures
CSH	Calcium Silicate Hydrate
CASH	Calcium Aluminate Silicate Hydrate
CH	Calcium Hydroxide
UCS	Unconfined Compressive Strength, kPa
SAI	Strength Activity Index, %
SEM	Scanning Electron Microscopy
EDX	Energy-dispersive X-ray
CO_2	Carbon Oxide

C	Carbon
Ca	Calcium
Si	Silica
Al	Alimina
Fe	Feric
Ca/Si	Ratio of calcium to silica
D_{50}	Average/ mean particle sizes, µm
ANOVA	Analysis of the variance
e	Void ratio
e_o	Initial void ratio
$\sigma_{v'}$	Vertical stress, kPa
m_v	Coefficient of volume compressibility, 1/kPa
C_v	Coefficient of consolidation, m^2/s
k	coefficient of permeability, m^2/s
C_c	Compressive index
C_α	Secondary compressive index
C_c / $1+e_o$	Compression index ratio
C_α / $1+e_o$	Secondary compression index ratio
C_α / C_c	Ratio of compression to secondary compression index ratio

CHAPTER 1

INTRODUCTION

1.1 Research background and problem statements

1.1.1 General problem of peat

Consequence of population and economic growth, land use activities perceived increased intensely. As a result, suitable land for infrastructure development has decreased and become a problem in the future. Therefore, it is inevitable to construct on less favorable soils, like peat. Peat distribution is extensive and can be found in many countries throughout the world when the conditions are favorable for their accumulation and formation [1-3]. The vastness of peat land coverage and its occurrence close to or within population centres and existing cropped areas means some form of infrastructure development has to be carried out in these areas. To stimulate agriculture development for instance, basic civil engineering structures such as roads are required [4].

The identification of peat is very important because they are much weaker than mineral (inorganic) soils. As such they do not provide suitable supports for most engineering works. Peat and organic soil represent the extreme form of soft soil and subject to instability and enormous primary as well as long-term settlement even when subjected to moderate load [5]. These materials can also change chemically and biologically over time. For instance, humidification of organic matter that continues may change the mechanical properties of soil such as compressibility, shear strength and hydraulic conductivity. Dropping of ground water may cause shrinking and oxidation of peat leading to humidification with consequent increase in permeability and compressibility. Besides, these soils are problematic as they are very highly compressible and are of very low shear strength [6].

Numerous construction techniques have been carried out to support embankments over peat without risking bearing failures but settlement of these embankments remains extremely large and continues for many years. In addition, stability problems during construction such as localized bearing failures and slip failures need to be considered [2]. Access to these superficial deposits is usually very difficult as the water table will be at near or above the ground surface. Undoubtedly, this is a consequence of the tendency to avoid either the construction and building on this land, or when this is not possible, to just remove, replace or supersede those in certain circumstances can lead to possibly uneconomical design and construction alternative [7]. Peat bearing capacity is very low and seems to be influenced by the water table and the presence of wood chips under the ground [8; 9].

To sum up, peat is considered as unsuitable soils for supporting foundations or any construction works in its natural state.

1.1.2 Oil palm plantation in Johor, Malaysia

During the Tenth Plan period (2011-2015), Malaysia will focus its economic growth efforts on National Key Economic Areas (NKEA)as shown in Figure 1.1. An NKEA is defined as a driver of economic activity that has the potential to directly and materially contribute a quantifiable amount of economic growth to the Malaysian economy. One of the listed NKEA is palm oil. Palm oil production is vital for the economy of Malaysia, which is the world's second- largest producer of the commodity. Oil palm is the most efficient oil crop in the world. A hectare of oil palm can produce up to 10 times more oil than other leading oil crops [10].

There are 281,652 ha of peat under cultivation in Peninsular Malaysia, of which 203,455 ha or 72% are under oil palm plantations (Table 1.1). Johor has the greatest area of peat under agriculture (crops/husbandry) like shown in Figure 1.2. One third of all oil palm plantations on peat in Peninsular Malaysia are found in Johor.

Figure 1.1: Malaysia National Key Economic Areas (NKEA); Sources: [11]

Oil palm plantations comprise a large proportion of the total area of peatlands in Johor utilised for agriculture. Conversion of peat swamp forest in Johor began in early 1974, when 95,000 ha of West Johor peatlands were converted for agricultural purposes. According to a survey carried out in 1997, a subsidence rate of 1.2 m was recorded in the district of Pontian [12].

Oil palm plantation transportation challenge on peat ground

The oil palm industry is still very much dependent on manual labour to carry out most of the operations, particularly in harvesting. To remain competitive, the industry is constantly searching and using new machines to increase outputs and to cut production costs. Field transportation and mechanical harvesting (Figure 1.3) of oil palm fresh fruit bunches (FFB) remains an important issue that needs to be solved.

The harvested FFB must be quickly evacuated to the mill with as little damage to the FFB as possible. Oil palm plantations cover a wide variety of topography and ground conditions and hence requiring various systems to address specific needs. Conventional methods, including the wheelbarrow and animal drawn carts (Figure 1.3), are still being practiced in areas where heavy machines are not accessible. One of the challenging tasks when it comes to crop evacuation is when the palms are planted on peat. This is due to the 'very loose' and 'very soft' nature of peat where the machines do not have sufficient traction and ability to float, thereby restricting smooth movement of the machine. [10].

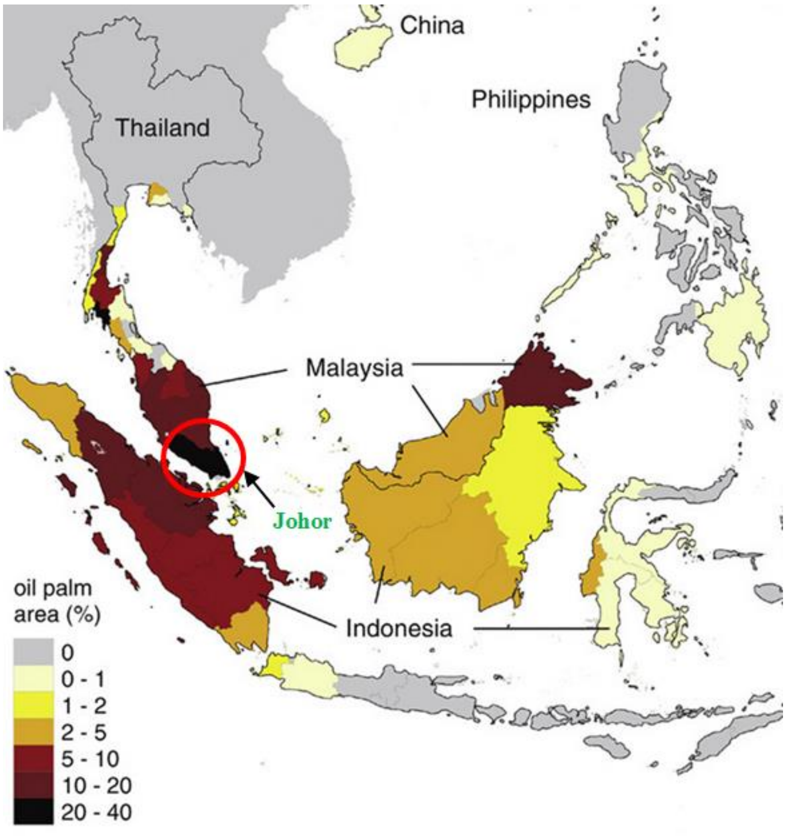
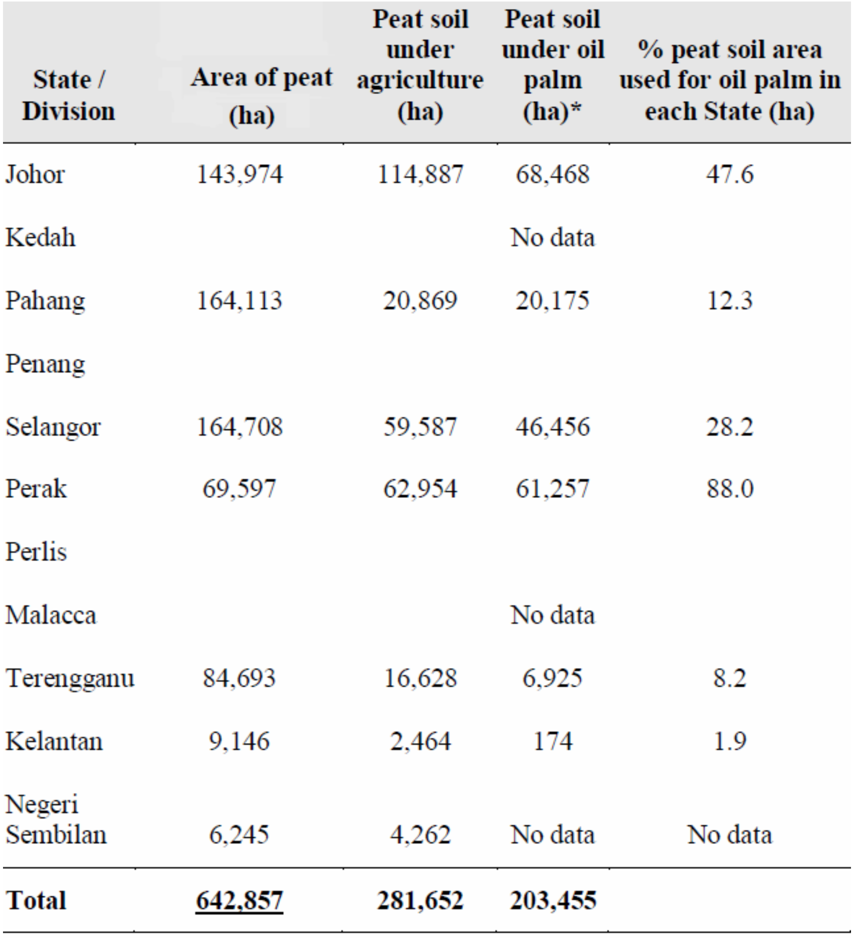


Figure 1.2: Oil palm distribution area in Southeast Asia; sources: [13]

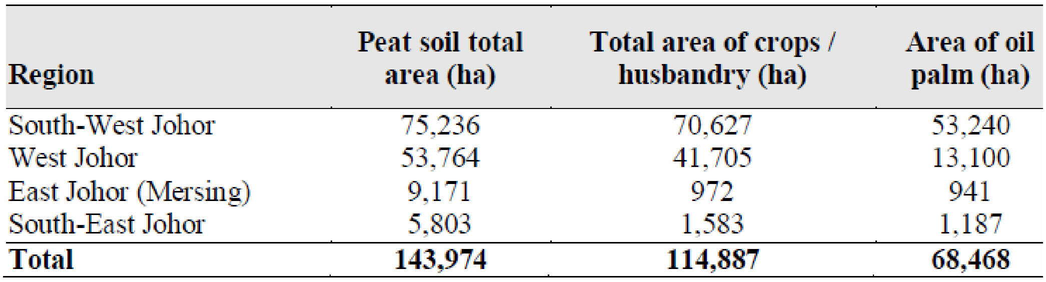
Frequently, palm oil and other crop plantations include production areas requiring supporting infrastructure such as light buildings and roads. When there is a better management of the roads in the estates, better quantity and quality crops yield will be sent to mill and processed. Road transport has a fundamental meaning for the sustainable agriculture. Poor quality (Figure 1.4) and inadequate coverage of roads will continue to hinder economic development in the future plantation. It is well-known that long term settlements of road embankment and pavement deformations are widespread on peat. These have resulted to unsafe, poor riding quality and high road maintenance costs [14].

Table 1.1: Area of peat under agriculture and oil palm in peninsular Malaysia; Sources: [12]



State / Division	Area of peat (ha)	Peat soil under agriculture (ha)	Peat soil under oil palm (ha)*	% peat soil area used for oil palm in each State (ha)
Johor	143,974	114,887	68,468	47.6
Kedah			No data	
Pahang	164,113	20,869	20,175	12.3
Penang				
Selangor	164,708	59,587	46,456	28.2
Perak	69,597	62,954	61,257	88.0
Perlis				
Malacca			No data	
Terengganu	84,693	16,628	6,925	8.2
Kelantan	9,146	2,464	174	1.9
Negeri Sembilan	6,245	4,262	No data	No data
Total	**642,857**	**281,652**	**203,455**	

Table 1.2: Area of peat under agriculture and oil palm in Johor; Sources: [12]



Region	Peat soil total area (ha)	Total area of crops / husbandry (ha)	Area of oil palm (ha)
South-West Johor	75,236	70,627	53,240
West Johor	53,764	41,705	13,100
East Johor (Mersing)	9,171	972	941
South-East Johor	5,803	1,583	1,187
Total	**143,974**	**114,887**	**68,468**

Figure 1.3: Field transportation and mechanical harvester on normal ground (above) and on peat ground (below); Sources: [10]

Figure 1.4: Example of poor quality of road for oil palm transportation

1.1.3 Cement consumption in peat stabilization

The use of cement and its capability in inorganic soil stabilization is very popular since long time ago. However, the use of cement is not given much attention in the stabilization of organic soils because evasion is often become the first choice rather than build up any infrastructure on these problem land. However, over the past few years, there are researchers who began to observe the ability of the cement in the stabilization of organic soil [6; 15-20].

It is well recognized that organic soils can retard or prevent the proper hydration of binders such as cement in binder-soil mixtures [17]. The combination of humic acid with calcium ions produced in cement hydration makes it difficult for the calcium crystallization, which is responsible for the increase of peat-cement mixture strength to take place [18]. The acids may also cause the soil pH to drop and this negatively affects the reaction rate of the binder, resulting in a slower strength gain in peat [16].

Due to high organic content and less solid particles in peat, cement alone is insufficient as a chemical admixture for peat stabilization. Compared with clay and silt, peat has a considerably lower content of clay particles that can enter into secondary pozzolanic reactions [21]. That means unless a large quantity of cement is mixed with the soil to neutralize the acids, the process of the soil stabilization remains retarded. However, adding a large quantity of cement into the peat is definitely an unfriendly and uneconomical solution to deep peat ground improvement considering the fact that the peat ground is covers a wide area, and the rising cost of cement and its transportation to the site [22]. Cement is responsible for about 5%–8% of global CO_2 emissions and expected to grow 0.8 to 1.2% per year until may reach 4.4 billion tonnes of productions in 2050 [23].

1.1.4 Sugarcane bagasse ash (SCBA)

A pozzolana is a material occurring either naturally or artificially, and which contains silica, iron and aluminum ions that can generate a pozzolanic reaction [24]. Small amount of pozzolans can be added to cement stabilized peat to enhance the secondary pozzolanic reaction in the stabilized soil [22] . One of pozzolan materials sources are getting from agricultural waste ash such as rice husk ash, straw ash and sugarcane bagasse ash. Production of large quantity of agricultural wastes all over the world faces serious problems of handling and disposal. The disposal of agricultural wastes creates a potential negative impact on the environment causing air pollution, water pollution finally affecting the local ecosystems. Hence safe disposal of agricultural wastes becomes challenging task for engineers [25].

Sugarcane production is world number one commodities with amount approximately 1.8 billion tonnes in 2012. Bagasse is the residue left after the crushing of sugarcane for juice extraction and on average, about 32% of bagasse is produced from every tonne of sugarcane been processed. The total plantation area of sugarcane bagasse in Malaysia is nearly 37000 acre. About 800000 ton of sugarcane is produced in 2012; hence bagasse also can be easily obtained in Malaysia. Furthermore, Federal Agriculture Marketing Authority (FAMA) Malaysia has also built a Sugarcane Collection Center or *Pusat Pengumpulan Tebu* (PPT) with cost RM4.5 million in Batu Pahat, Johor for export marketing to Singapore. Increasing concern of disposal of bagasse residual creates interest to explore the potential application of this material [26]. The sugarcane industry is still seeking solutions to dispose of the wastes generated by the sugar and alcohol production processes. This ash is used as fertilizer in the plantations, but it does not have adequate mineral nutrients for this purpose. SCBA has also been studied as a promising pozzolanic material and can be used in civil construction especially in concrete study [27-33]. Nowadays, despite the increasing interest in the potential use of SCBA as a pozzolan in concrete technology, there is no evidence in the current literature of its use as a soil stabilizer especially for organic soil.

1.2 Research objectives

By taking into the account the increasing demand and consumption of cement together with the backdrop of SCBA waste problems, it could be something very beneficial to develop alternate binders that are environment friendly and contribute towards sustainable management. Hence, the utilization of SCBA in the stabilization of peat can be a compelling idea and seems to be promising alternative when considering issues of energy consumption and pollution.

The objective of this research works is to evaluate and clarify the effectiveness factors of SCBA in peat stabilization. It is expected that the obtained optimum mix design can be applied to stabilized peat layer in order to support the infrastructure construction within estate area which could lead towards a more sustainable agriculture plantation in the future.

1.3 Research scopes

In this research works, the soil that had been used is Hokkaido peat. In order to focus for achieving the study target or objectives, experimental works plans were divided by two stages that comprise three main parts from each stage. The stages mentioned are untreated and stabilized Hokkaido peat while the main parts are physical, chemical and mechanical properties for both said stages (Figure 1.5). Briefly, this study scopes were concentrated to strength and deformation of stabilized peat by utilizing sugarcane bagasse ash (SCBA) as partial cement replacement. To evaluate the degree of improvement, the established parameters of this peat-cement-bagasse (PCB) mixture must be compared to those of untreated peat and cemented peat.

1.4 Research motivation

There are several important factors that encourage this research works. Among these are:

a. Trying to meet the recommendations of the Ministry of Public Works, Malaysia, Datuk Seri Fadillah Yusof that stating more research is still needs to be done on peat in Malaysia since the soil conditions complicate efforts to implement infrastructure projects. He also noted the focus needs to be done to develop the better technology and construction materials for the peat as it will significantly reduce the cost of construction of roads, buildings, utilities and other and maintenance thereafter.

b. The facilities of research centers operating under UTHM (Research Center of Soft Soil, RECESS and Peat Test Research Station, PTRs) that allows the study of structures / infrastructures on the peat ground can be done on an ongoing basis in the years to come and thus contribute new technologies or green materials in implementing development on peat.

c. An effort to improve the transportation of oil palm plantation over the peat ground particularly in Johor and thus improve the quality/ production of agricultural revenue of the country.

1.5 Dissertation overview

This research work contains seven chapters that can be described as follows:

Chapter 1 presents an introduction of this research. Current problem and motivation to conduct this research are to be presented in this chapter. Objectives and structure of the thesis are also described.

Chapter 2 deliberates an overview of peat concerning to geotechnical characteristics that highlight the physical, chemical and mechanical properties. The collected results of studied peat (Hokkaido peat) then compared to Malaysia peat in order to investigate the similarity potential.

Chapter 3 presents the approach method to clarifying effectiveness the three types of sugarcane bagasse ash (SCBA) utilization on peat strength. The unconfined compressive strength (UCS) tests were conducted at all samples with the aim to elucidate the stabilized peat strength improvement. The main target of this chapter is to determine the optimum SCBA inclusion as partial replacement of cement. The best mixtures from each SCBA then chosen and use in further UCS test which is stresses on various effect factor in peat stabilization.

Chapter 4 discusses about the strength improvement mechanism of stabilized peat by focusing on the microstructure and chemical composition enhancement. The main objective in this chapter is to verify the results obtained from previous chapter. It can be stated that the stabilized soil is characterized by a well cemented soil medium with tiny pore spaces within it as a result of the pozzolanic activity of SCBA.

Chapter 5 consider about the evaluation of sugarcane bagasse ash (SCBA) quality characteristics on pozzolanic effect in stabilized peat. Pozzolanic effect of SCBA was determined from the UCS of curing effect results by making a peat-cement (PC) mixture as a reference. It was detected that the main different between SCBA's characteristics is their particle sizes (physical effect) and chemical compositions (chemical effect). Hence, mean grain size (D_{50}) and CaO:SiO_2 ratio of SCBA were adopted in regression model analysis in order to predict the strength and minimum cement consumption that consider many other factor of peat stabilization.

Chapter 6 illustrates the effectiveness of optimum peat-cement-bagasse ash (PCB) mixtures on peat deformation behavior. Afterward, the outcomes were compared to peat-cement (PC) mixture and untreated peat in order to analyze the contribution of SCBA inclusion in stabilized peat.

Chapter 7 concludes all the research works together with study limitation and future works.

1.6 Research contributions

There are several contributions in this research work. The first one is the new developed alternate binders that are economy and environment friendly by utilization of the sugarcane bagasse ash (SCBA) as supplementary cement materials in peat stabilization which can reach 20% of cement replacement with good quality of SCBA. This mixture is expected suitable for supporting the infrastructure construction within estate area especially at the palm oil plantation area which vastly planted on peat ground with regularly not exceeds 3m depth in Malaysia [34]. The better supporting infrastructure such as rural-urban connection highway including road networks for agricultural activity will lead towards a more sustainable agriculture plantation in the future. Consequently, increase the production tremendously and simultaneously may raise the country revenue.

The second contribution is a suggested method of preloading during curing by air pressure in the laboratory rather than solid iron rod (conventional method from literature) as a simulation of initial loading at site. This technique is easier to apply on many samples with various size and pressure at once. As a result, it will lead to time and cost savings in conducting test. The third one is suggestion of minimum amount of cement, silica sand and preloading for the peat stabilization to be effective and achieve the minimum strength target (345kPa). Furthermore, the proposed calculation to predict deformation modulus of Peat-Cement-Bagasse (PCB) mixtures based on two-phase mixtures model was introduced and developed. The proposed modified model was demonstrates a well agreement with the experimental results.

The final one is the statistical regression model to predict the strength gained for the PCB mixtures that consider many other factor of peat stabilization. Considering the suggestion of admixtures minimum amount above, the estimation equations were simplified to easy form that emphasizes the SCBA quality and quantity only. The percentage of SCBA inclusion depends on the quality of SCBA which in this study were focusing in average particle size, D_{50} (physical effect) and ratio of calcium to silica, Ca/Si (chemical effect). After that, the minimum quality of raw SCBA that can be utilizing in peat stabilization without any special process to harmonize this ash was recommended. This mean that the SCBA that fulfill the suggested requirement can be chosen from mills and directly consumed in peat improvement (specifically on hemic peat type such as Hokkaido and Johor peat). Therefore, it saves the budget (avoid additional process), environment and time.

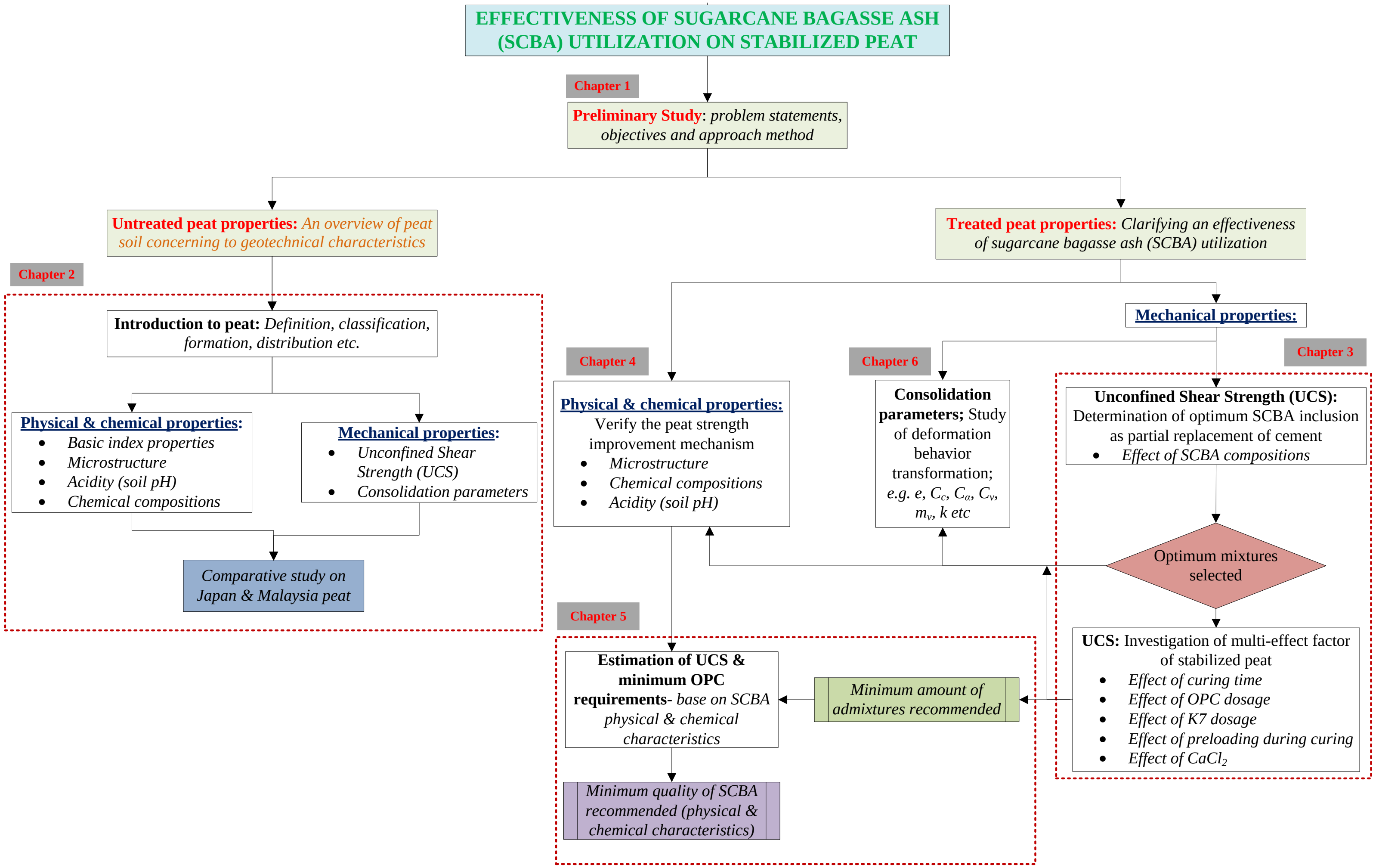


Figure 1.5: Flowcharts of research works

1.7 References

[1] Asadi, A., Huat, B.B.K., Hanafi, M.M., Mohamed, T.A. and Shariatmadari, N., 2009. Role of organic matter on electroosmotic properties and ionic modification of organic soils. Geosciences Journal, 13(2): 175-181.

[2] Duraisamy, Y., Huat, B.K., Muniandy, R. and Aziz, A.A., 2008. Compressibility Behavior of Fibrous Peat Reinforced with Cement Columns. ICCBT- E-(09)–pp93-110.

[3] Montanarella, L., Jones, R.J.A. and Hiederer, 2006. The distribution of peatland in Europe. Mires and Peat, 1 (2006), Article 01, 1-10.

[4] Huat, B.K., Sew, G.S. and Ali, F.H., 2004. Organic and Peat Soils Engineering. Serdang, University Putra Malaysia, Press, ISBN Number: 983-2871-08-5.

[5] Jarrett, P.M., 1995. Site investigation for organic soils and peat. Geoguide 6. JKR Document 20709- 0341-95. Public Works Department Malaysia. Malaysia.

[6] Huat, B.K., Maail, S. and Mohamed, T.A., 2005. Effect of Chemical Admixtures on the Engineering Properties of Tropical Peat Soils. American Journal of Applied Sciences, 2(7): 1113-1120.

[7] Huat, B.K., 2006. Deformation and Shear Strength Characteristics of Some Tropical Peat and Organic Soils. Pertanika J. Sci. & Techno., 14(1&2): 61-74.

[8] Islam, M.S. and Hashim, R., 2008. Use of Mackintosh Probe Test for Field Investigation in Peat Soil. Proc. of Int. Conf. on Highway and Geotechnical Engineering, 26th - 27th May 2008, Best Western Premier Seri Pacific Kuala Lumpur, Malaysia, pp. 27.

[9] Andriesse, J.P., 1988. Nature and Management of Tropical Peat Soils. FAO Soils Bulletin 59 Rome, ISBN Number: 9251026572, Edition Number: 291894.

[10] MPOB, 2014. International Competition on Oil Palm Mechanisation. http://www.mpob.gov.my/ICOPM/ICOPM%20brochure%20web.pdf.

[11] http://business.malaysia.my/en/articles/why-malaysia/initiatives/national-key-economic-area-n-k-e-a,

[12] International, W., 2010. A quick scan of peatlands in Malaysia, Wetlands International- Malaysia: Petaling Jaya, Malaysia. 74 pp.

[13] UNEP, 2011. Oil palm plantations: threats and opportunities for tropical ecosystems. http://www.na.unep.net/geas/getUNEPPageWithArticleIDScript.php?article_id=73, United Nations Environment Programme (UNEP).

[14] Vincent, T.C.K., 2010. Road Construction on Soft Soils in Sibu: A Practical Perspective. Workshop on Ground Improvement Techniques on Peat in Sarawak.

[15] EuroSoilStab, 2002. Development of design and construction methods to stabilize soft organic soils. Design guide soft soil stabilization. CT97-0351. Project No. BE 96-3177, Industrial & Materials TechnologiesProgramme (Brite- EuRam III), European Commission.

[16] Axelsson, K., Johansson, S.E. and Anderson, R., 2002. Stabilization of Organic Soils by Cement and Puzzolanic Reactions- Feasibility Study, Swedish deep stabilization Research Centre, Report 3, English translation.

[17] Hebib, S. and Farrell, E.R., 2003. Some experiences on the stabilization of Irish peats. Canadian Geotechnical Journal, 40(1): 107-120.

[18] Chen, H. and Wang, Q., 2006. The behaviour of organic matter in the process of soft soil stabilization using cement. Bulletin of Engineering Geology and the Environment, 65(4): 445-448.

[19] Sobhan, K., Reddy , D.V. and Ramirez, J.C., 2012. Cement Stabilization of Organic Subgrades for Pavement Preservation. In: LACCEI (Editor), Megaprojects: Building Infrastructure by fostering engineering collaboration, efficient and effective integration and innovative planning Panama City, Panama.

[20] Ahnberg, H., 2006. Strength of stabilised soils– A laboratory study on clays and organic soils stabilised with different types of binder, Swedish deep stabilization Research Centre, Report 16, English translation.

[21] Janz, M. and Johansson, S.E., 2002. The function of different binding agents in deep stabilization, Swedish Deep Stabilization Research Center, Linkoping: SGI. 9.

[22] Wong, L.S., Hashim, R. and Ali, F.H., 2009. A Review on Experimental Investigations of Peat Stabilization. Australian Journal of Basic and Applied Sciences, 3(4): 3537-3552, 2009. ISSN 1991-8178.

[23] WBCSD, 2009. Cement Technology Roadmap 2009, World Business Council for Sustainable Development, W.B.C.S.D. Internationa Energy Agency, I.E.A.

[24] Velosa, A.L. and Cachim, P.B., 2009. Hydraulic-lime based concrete: Strength development using a pozzolanic addition and different curing conditions. Construction and Building Materials, 23(5): 2107-2111.

[25] Chittaranjan, M., Vijay, M. and Keerthi, D., 2011. Agricultural wastes as soil stabilizers International Journal of Earth Sciences and Engineering, ISSN 0974-5904, Volume 04, No 06 SPL, October 2011, pp 50-51

[26] Lee, S.C. and Mariatti, M., 2008. The effect of bagasse fibers obtained (from rind and pith component) on the properties of unsaturated polyester composites. Materials Letters, 62(16): 2253-2256.

[27] Cordeiro, G.C., Toledo Filho, R.D., Tavares, L.M. and Fairbairn, E.M.R., 2009. Ultrafine grinding of sugar cane bagasse ash for application as pozzolanic admixture in concrete. Cement and Concrete Research 39, 110-115.

[28] Paya, J., Monzo, J., Borrachero, M.V., Diaz-Pinzon, L. and Ordonez, L.M., 2002. Sugar-cane bagasse ash (SCBA): studies on its properties for reusing in concrete production. Journal of Chemical Technology and Biotechnology, 77(3): 321-325.

[29] Ganesan, K., Rajagopal, K. and Thangavel, K., 2007. Evaluation of bagasse ash as supplementary cementitious material. Cement & Concrete Composites, 29(6): 515-524.

[30] Cordeiro, G.C., Toledo, R.D., Tavares, L.M. and Fairbairn, E.M.R., 2008. Pozzolanic activity and filler effect of sugar cane bagasse ash in Portland cement and lime mortars. Cement & Concrete Composites, 30(5): 410-418.

[31] Fairbairn, E.M.R. et al., 2010. Cement replacement by sugarcane bagasse ash: CO2 emissions reduction and potential for carbon credits. J Environ Manage; 91:1864-71.

[32] Sales, A. and Lima, S.A., 2010. Use of Brazilian sugarcane bagasse ash in concrete as sand replacement. Waste Management, 30(6): 1114-1122.

[33] Frias, M., Villar, E. and Savastano, H., 2011. Brazilian sugar cane bagasse ashes from the cogeneration industry as active pozzolans for cement manufacture. Cement & Concrete Composites, 33(4): 490-496.

[34] RISDA, Garis Panduan Pengurusan Dan Penanaman Sawit Di Kawasan Tanah Gambut. www.mpn.gov.my/c/document_library/get_file?uuid=363518fc-f66b-4c80-b942-d9bc33adb8ed&groupId=82677.

CHAPTER 2

AN OVERVIEW OF PEAT CONCERNING TO GEOTECHNICAL CHARACTERISTICS

2.1 Introduction

This chapter deliberates an overview of peat concerning to geotechnical characteristics that highlight the physical, chemical and mechanical properties. The collected results of studied peat (Hokkaido peat) then compared to Malaysia peat in order to investigate the similarity potential.

2.1.1 Definition and classification

Peat definitions and classifications are different between countries. Some such names are bogs, moors, muskeg, mire, tropical swamp forests and fens. These names help characterize the peat by its differences resulting from the effect of climate and type of plant materials that constitute the peat. Geotechnically, peat described as soil that having an organic content greater than 75%. In Japan, peat generally includes soil with more than 20% organic contents because of their engineering properties [1]. Most of these soils are controlled by its organic matter quantity, quality and physical properties. However, the definition and description of peat between soil scientists and geotechnical engineers are different. Scientists have described as peat with organic matter content greater than 25%. Figure 2.1 shows the variety of peat definition based on multi-discipline background.

Current classification systems for peat and organic soils were used organic and ash content as the sole parameter in classification [2-5] but it has resulted in a wide variation in the definition of peat which is compared in Figure 2.2. Loughlin and Lehane [6] observed that a classification system based on organic content and ash content was not sufficient; other factors such as natural water content, structure, degree of humidification, nature of organic material and also specific gravity also need to be considered. United Soil Classification System (USCS), adopted by the American Society for Material Testing (ASTM) defines organic soils as a separate soil class in the standard classification of soils for engineering.

In Malaysia, classification of peat and organic soils is based on the British Standard 5930:1981. Nevertheless, this classification has been upgraded by Public Work Malaysia & Jarret [7] to make this system more clear and suitable to the Malaysia situation. The Malaysian Soil Classification Systems (MSCS) introduced the degree of humidification by Von Post scale as the second important parameter to be considered after organic content [3].

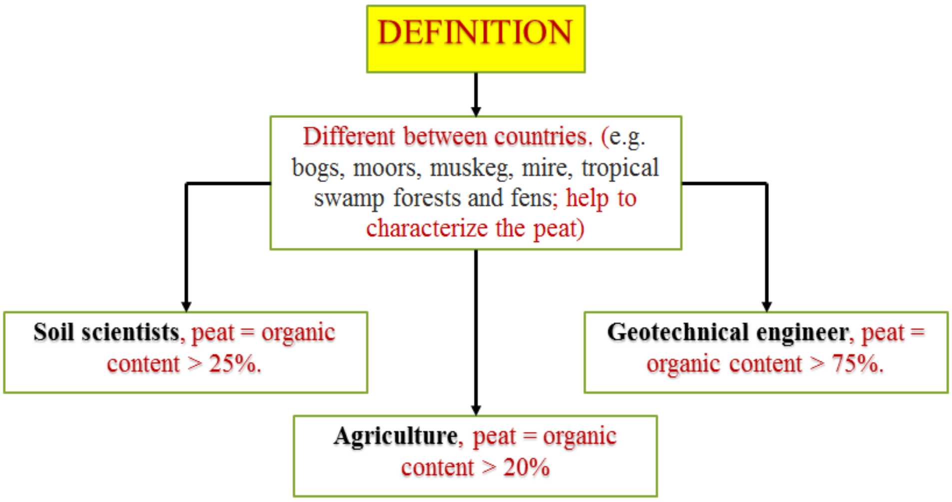
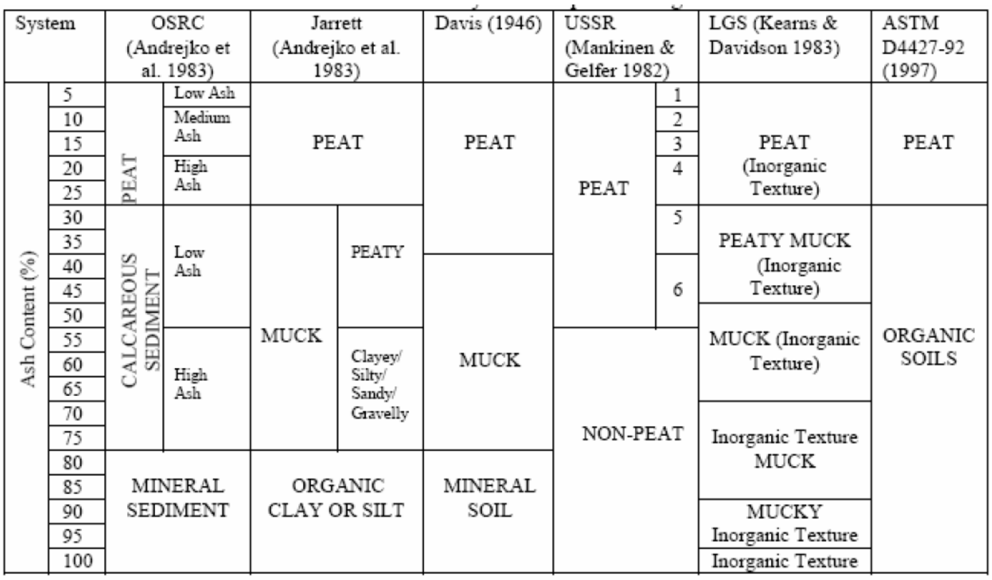


Figure 2.1: Peat definitions

In technical term of geotechnology edited by Japanese Society of Soil Mechanics and Foundation Engineering, soil with more than 5% organic contents classified as organic soils and with more 50% as highly organic soils and generally called peat in Japanese soil science particularly by Hokkaido Agriculture Experiment Station. They classify the soil with 20-50% of organic contents as sub-peat. Between the range 5% to 50% organic contents, the soils has classified as low organic soils such as Kuroboku soil [1]. Studies conducted by Noto [1] on engineering characteristic of Hokkaido peat, the organic content of peat are between 20 and 98%. These roughly show that Hokkaido peat is similar to Malaysian peat with very high content of loss of ignition value. Another useful method to classify peat or organic soil is by referring its degree of humification or decomposition that also known as the Von Post scale system (Figure 2.3).



System	OSRC (Andrejko et al. 1983)		Jarrett (Andrejko et al. 1983)		Davis (1946)	USSR (Mankinen & Gelfer 1982)		LGS (Kearns & Davidson 1983)	ASTM D4427-92 (1997)
Ash Content (%)									
5	PEAT	Low Ash	PEAT		PEAT	PEAT	1	PEAT (Inorganic Texture)	PEAT
10		Medium Ash					2		
15							3		
20		High Ash					4		
25									
30	CALCAREOUS SEDIMENT	Low Ash	MUCK	PEATY			5	PEATY MUCK (Inorganic Texture)	ORGANIC SOILS
35									
40					MUCK		6		
45									
50								MUCK (Inorganic Texture)	
55		High Ash		Clayey/ Silty/ Sandy/ Gravelly		NON-PEAT			
60									
65									
70								Inorganic Texture MUCK	
75									
80	MINERAL SEDIMENT		ORGANIC CLAY OR SILT		MINERAL SOIL				
85									
90								MUCKY Inorganic Texture	
95									
100								Inorganic Texture	

Figure 2.2: Comparison of classification systems used for peat and organic soils [8]

Degree of humification	Decomposition	Plant structure	Content of amorphous material	Material extruded on squeezing (passing between fingers)	Nature of residue
H_1	None	Easily identified	None	Clear, colorless water	
H_2	Insignificant	Easily identified	None	Yellowish water	
H_3	Very slight	Still identifiable	Slight	Brown, muddy water; no peat	Not pasty
H_4	Slight	Not easily identified	Some	Dark brown, muddy water; no peat	Somewhat pasty
H_5	Moderate	Recognizable but vague	Considerable	Muddy water and some peat	Strongly pasty
H_6	Moderately strong	Indistinct (More distinct after squeezing)	Considerable	About one third of peat squeezed out; water dark brown	
H_7	Strong	Faintly recognizable	High	About one half of peat squeezed out; any water very dark brown	
H_8	Very strong	Very indistinct	High	About two thirds of peat squeezed out; also some pasty water	Plant tissue capable of resisting decomposition (roots, fibers)
H_9	Nearly complete	Almost not recognizable		Nearly all the peat squeezed out as a fairly uniform paste	
H_{10}	Complete	Not discernible		All the peat passes between the fingers; no free water visible	

Figure 2.3: Degree of humification (Von Post scale system) [5]

2.1.2 Formation and distribution

Jarret [9] described peat as naturally occurring, highly organic substance derived primarily from plant materials. Peat is formed when the rate of accumulation of organic matter is greater than the rate of decay. Peat actually represents an accumulation of the disintegrated plant remains, which have been preserved under condition of incomplete aeration and high water content as shown in Figure 2.4.

Peat formed in very wet conditions accumulates considerably faster and is less decomposed than peat accumulating in drier places [10]. It accumulation wherever the conditions are suitable, that is, in areas with excess rainfall and the ground are poorly drained, irrespective of latitude or altitude. Nonetheless, peat tend to be more common in those regions with comparatively cool wet climate. Physico-chemical and biochemical process cause this organic material to remain in a state of preservation over a long period of time. In other words, waterlogged poorly drained condition, not only favor the growth of a particular type of vegetation but also help preserve the plant remains [11].

Peat in Japan, in many cases is basin peat, formed when lakes and marshes become filled with dead plants growing around them and then turn into land. This type of peat is characterized by the spongy formation of plant fiber. In the peatland of Hokkaido, peat commonly accumulates to a thickness of three to five meters on the ground surface, while the soft clay layer underlying is the peat is often over 20 meters thick. In some areas, a sand layer exists between the peat and the clay layers. The rate of deposition of peat depends on humidity and weather conditions [1; 12].

Huat [12] observed the depths for peat in Malaysia were varying from 1m to 20m. The color of peat in Malaysia is generally dark reddish brown to black. It consists of loose partly decomposed leaves, branches, twigs and tree trunks with a low mineral content [2]. The ground water table in these areas is always high and occurs at or near the surface [13]. According to Jamil [14] where soil with peat depth of <1.0 m, 1.0 – 1.5 m, 1.5 – 3.0 m, and >3.0 m is classified as shallow, moderate, deep and very deep peat. In its drained state, the peat will transform to a compact soil mass consisting of partially large wood fragments and tree trunks embedded in it.

Drainage influences the degree of decomposition, shrinkage and consolidation behavior of the soil [2].

The peat land consists of nearly 5 to 8% of the earth land surface and nearly 60% of the wetland of the world is peat [1] (Figure 2.5). While the areas occupied by the tropical peat land is about 30 million hectares and two third of that are in South East Asia. These soils are found in many countries throughout the world. In the US, peat is found in 42 states, with a total acreage of 30 million hectares. Canada and Russia are the two countries with a large area of peat, 170 and 150 million hectares respectively. In term of country land area, Finland recorded the highest percentage with 33.5% while Malaysia was ranked 10th in the world with 8% and Japan ranked 26th with 0.5% [16].

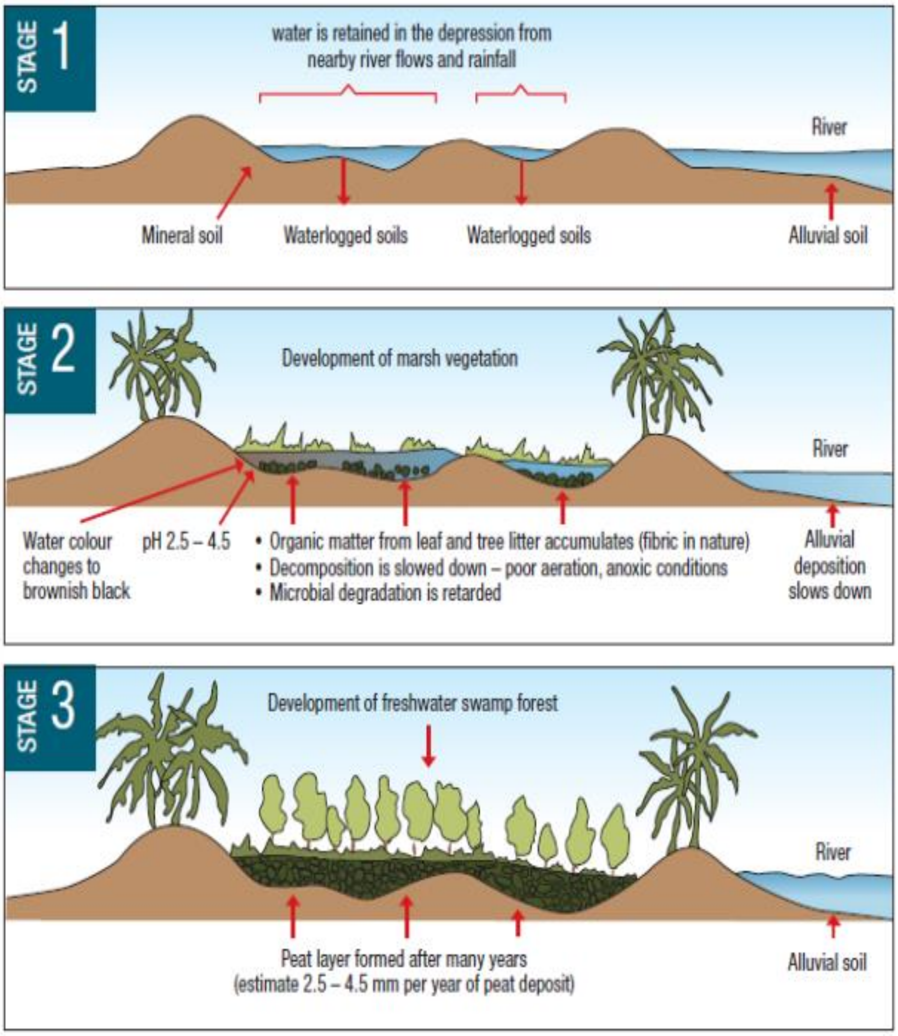
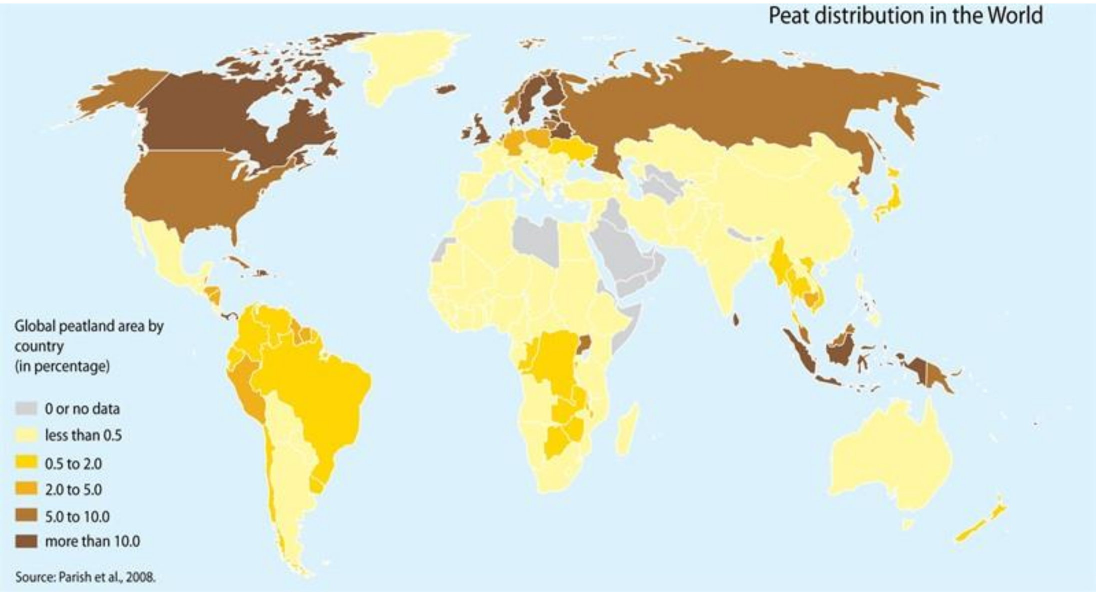


Figure 2.4: Formation of peat ground [10]

In Malaysia, there is approximately 26,000 km^2 of peat that accounting for about 8% of the country's land area (Figure 2.6) [16; 17]. Among these lands, 6,300 hectares of the peat lands are found in Pontian, Batu Pahat and Muar in West Johore [18]. Peat forests, once found extensively in the district of Pontian, have been converted to agriculture for oil palm, pineapple and other food crops [8]. The state that covers the largest area of peat land in Malaysia is Sarawak which is about 13% of the state area or 1.66 million hectares with 89% of these areas are more than 1m in depth [19]. In Japan, peat is widely distributed through Hokkaido especially along the lower reaches of the Ishikari, Kushiro and Tashio Rivers with approximately 2,000 km^2 which equals to 6% of the flat area of the island (Figure 2.7) [1].



Source: Parish et al., 2008.

Figure 2.5: Peat distribution in the world [20]

2.2 Geotechnical characteristic review on Japan and Malaysia peat

The physical study of peat on geotechnical characteristics has been done by several researchers especially geotechnical engineers and academician to ensure that any construction on peat are safe. As mentioned earlier, this chapter presents some review of peat from Japan and Malaysia pertaining to geotechnical properties. The parameters studied were the moisture content, loss on ignition, unit weight, specific gravity, fiber contents, acidity, liquid limit, plastic limit, plastic index and shear strength as shown in Table 2.1.

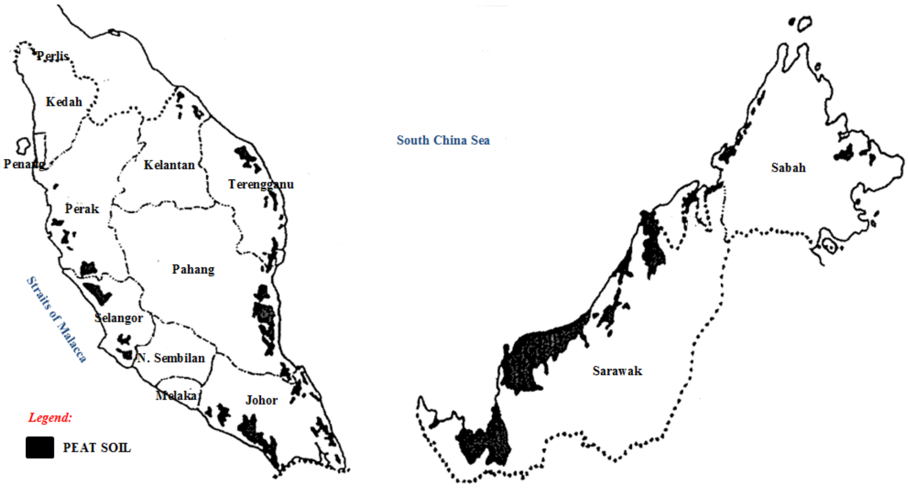


Figure 2.6: Peat land distribution in West (left) and East Malaysia (right)

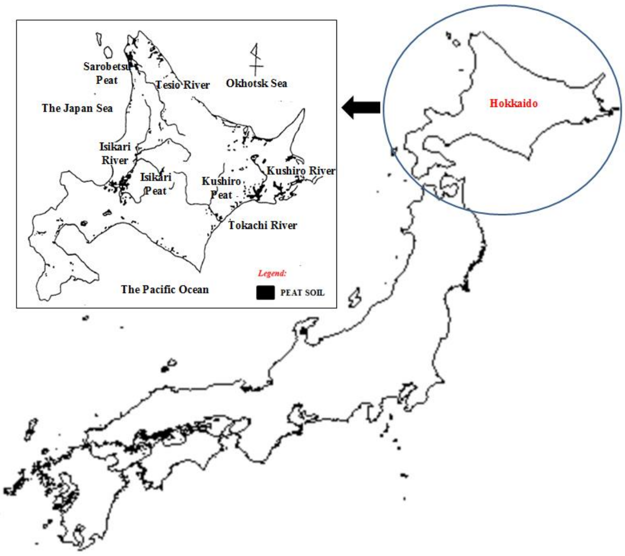


Figure 2.7: Distribution of peat land in Hokkaido, Japan

2.2.1 Physical properties

Methodology

In this study, peat from Hokkaido, Japan had been used in order to compare with Malaysia peat. The depth of excavated samples is about 1m from ground surface. The test of physical, mechanical and chemical properties of these peats had been conducted like shown in Figure 2.8 and Figure 2.9 while the entire laboratory test regulation and standards that had been implemented was shown in Table 2.2.

Table 2.1: Geotechnical engineering characteristic of peat land in Malaysia and Japan

	Japan		**Malaysia**		
Properties	**Hokkaido**		**West**	**East**	**Johore**
Natural water content, %	580	115-1570	200-700	200-2207	230-659
Ash content, %	16.79	2-80	3-35	5-50	1.5-20
Organic content , %	83.21	20-98	65-97	50-95	80-98.5
Bulk unit weight (kN/m^3)	10.57	7.1-19.7	8.3-11.5	8-12	7-12.3
Specific gravity, G_s	1.67	1.04-2.63	1.38-1.7	1.07-1.63	1.44-1.8
Fiber content, %	43	42-86.9	31-77	-	49
Acidity ,pH	5.46	-	-	3-7.2	3.63
Liquid Limit	375	-	190-360	210-550	220-380
Compression Index, C_c	4.89	0.3-14	1.0-2.6	0.5-2.5	0.9-1.5
Undrained shear strength, *kPa*	6.80	5-40	8-17	8-10	7-11
References	Authors	[1; 21; 22]	[12; 23-25]	[12; 23-25]	[3; 24; 26]

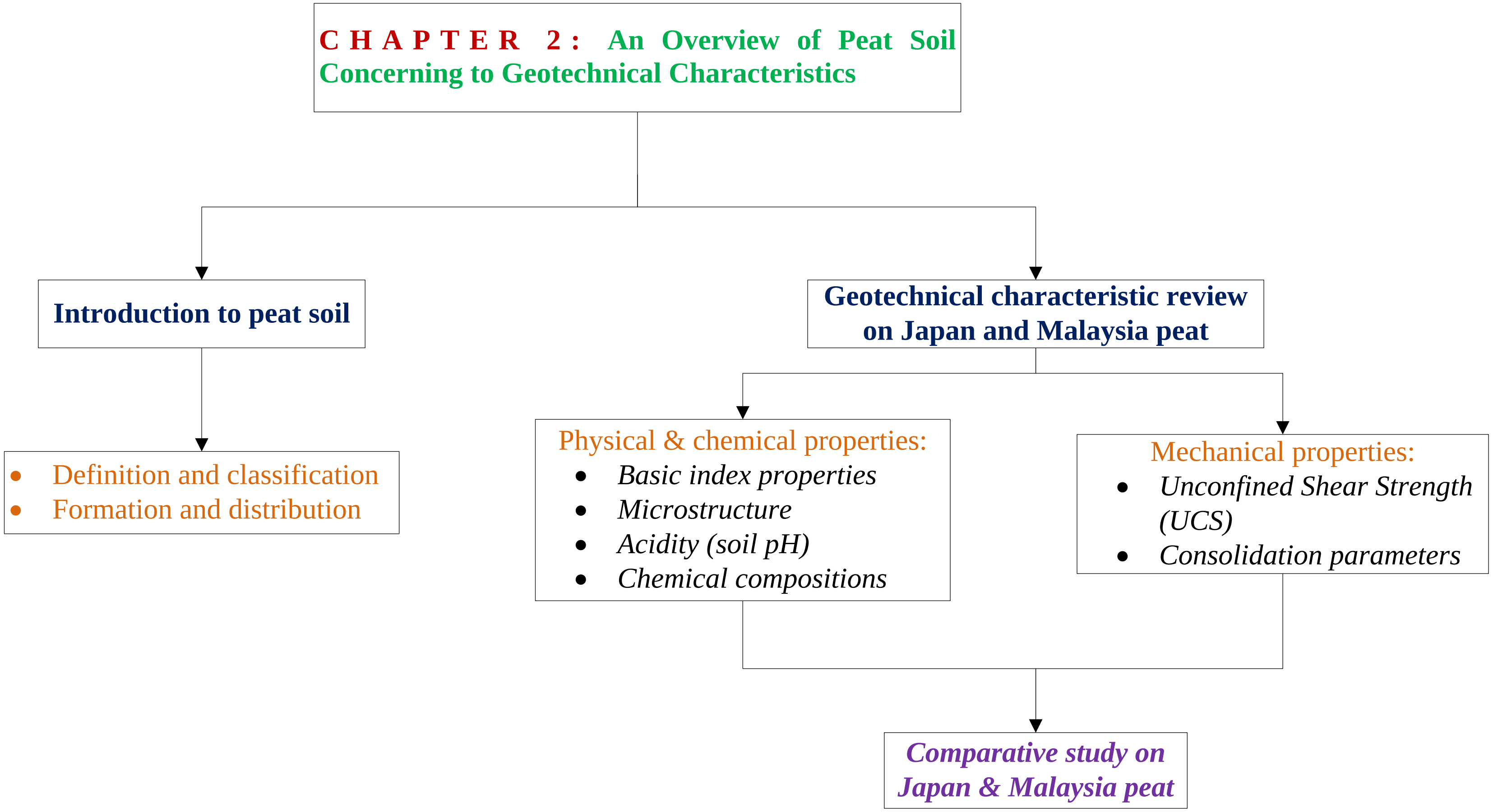


Figure 2.8: Research flowcharts of chapter 2

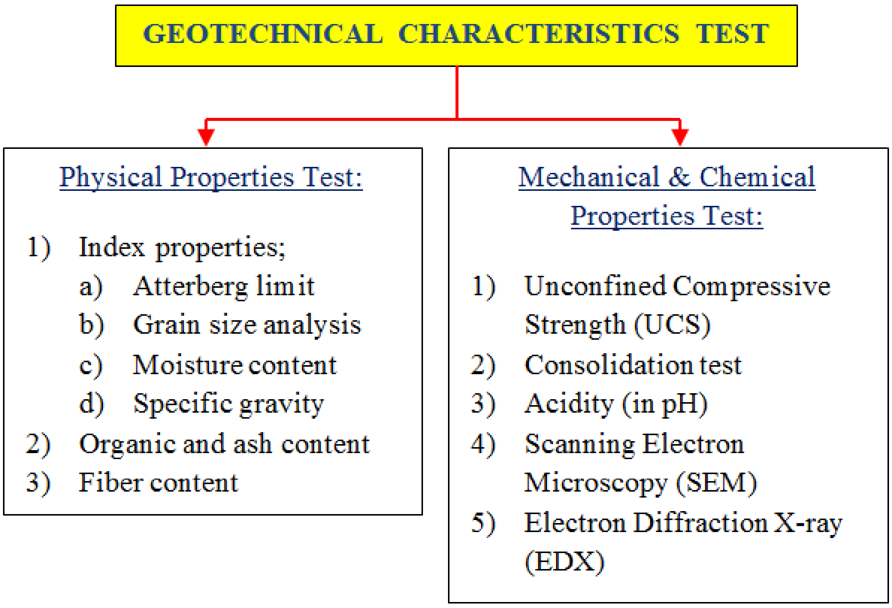


Figure 2.9: Geotechnical characteristic laboratory test

Table 2.2: Adopted standards for test method

Testing Names	**Standards**
Atterberg Limit	JGS 0141-2009
Moisture Content	ASTM- D 2974
Particle Size Distribution	ASTM- D 422
Specific Gravity	ASTM- D 854
Organic (ash) Content	ASTM- D 2974
Fiber Content	ASTM- D 1997
Acidity (pH Test)	ASTM- D 2976
Consolidation test	ASTM- D 2435
Unconfined Compression Strength	ASTM- D 2166

Moisture contents, organic and ash contents

One of the significant and most variable properties of peat is its water or moisture content. The value of water content depends on the origin, degree of decomposition and the chemical composition of peat. Naturally, peat has very high natural water content due to its natural water-holding capacity. The high natural water holding capacity is because of the soil structure characterized by organic coarse particles (fibers) which can hold a considerable amount of water since the soil fibers are very loose and hollow. The high water content is also because peat has low bulk density and low bearing capacity as results of high buoyancy and high pore volume [27].

Ajlouni [28] emphasized that the water content of peat may range from 200 to 2000% which is quite different from that for clay and silt deposits which rarely exceed 200%. The results in Table 2.1 revealed that Malaysia and Japan peat varies from different geographical locations when natural water content is consent. This is due to the influence of different agricultural background of the area and rainfall intensity [3]. Natural water contents and organic contents for tested peat sample from Hokkaido were determined by authors by drying a peat or organic soil sample at 105° for 24 hours. Ash content was determined by igniting the oven-dried sample in a muffle furnace at 440°C about 5 hours (until no change in mass) as shown in Figure 2.10. The ash content is expressed as a percentage of the mass of the oven-dried sample.

Figure 2.10: Oven and muffle furnace for moisture and ash contents test

Organic matter is determined by subtracting percent ash content from one hundred. The results for water and organic contents as calculated were 580% and 83.21% respectively. These values are consistent with studies conducted by Noto [1] and Hamamoto [21] which revealed that Hokkaido peat have range of water content 110% to 1600% while organic content range 20% to 98%. In Malaysia, these parameters are higher than Japan peat with water contents accounted to 200% and can reach to 2200% whereas organic content range 50% to 98%. With 16.79% of ash contents, studied peat is classified in high ash group. Compared with fibrous peat, sapric peat are likely to exist at lower void ratios and display lower permeability, lower compressibility, a lower friction angle and a higher coefficient of earth pressure at rest. Hemic peat have properties intermediate between fibrous and sapric peats [27].

The correlation between organic content to water content for Malaysia and Japan peat was revealed in Figure 2.11. The results from Malaysia were studied by Kazemian et al. [24] for tropical hemic of West Malaysia. After several laboratories test for organic and water contents of untreated Hokkaido peat, authors were plotted and gain the fitted line (dotted red line) like shown in this figure. Clearly, present study outcomes illustrate the similarity results to Kazemian et al. [24] finding since the obtained line was slightly less than average line of Malaysia peat. It is also shows that the current study results are in the range of upper and lower bound of Malaysia peat and have significant match to Seri Medan and Parit Sulung peat which located in Johor.

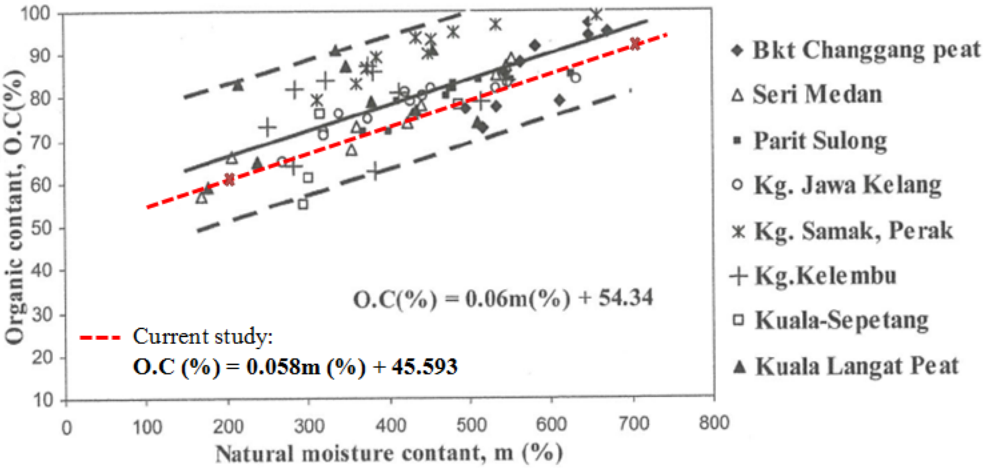


Figure 2.11: Organic content versus natural moisture content [12]

Atterberg limits

For liquid limit and plastic limit test, cone penetrometer method had been used. The values of this parameter on Malaysia peat varies from 190% to 550% and 100% to 300% respectively while the studied peat gave the results 375% for liquid limit. Figure 2.12 and Figure 2.13 shows the Atterberg limit test execution and the graph of Hokkaido peat analysis for liquid limit determination respectively. Figure 2.14 shows the comparison of organic contents, OC% versus liquid limit, L_L% for studied peat to tropical peat of West Malaysia [24] and temperate peat by Skempton [29]. The results revealed that Hokkaido peat was more near to tropical peat line rather than temperate peat line which indicate the similarities with Malaysia peat.

Figure 2.12: Atterberg limit test execution

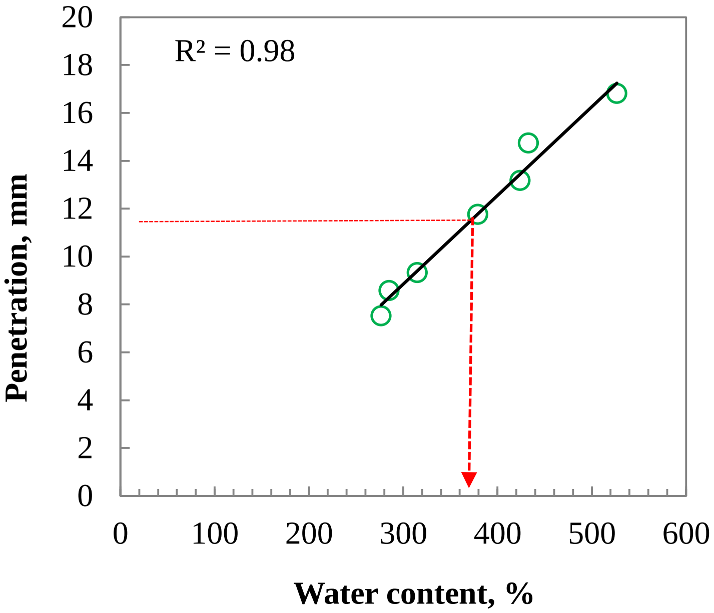


Figure 2.13: Graph of liquid limit analysis

Japanese Geotechnical Society (JGS 0142-2000) describes the determination of liquid limit using the fall- cone method. JGS method suggests be careful roll soil samples into threads until it become thinner and eventually break at about 3 mm diameter. Authors face the problem in order to get the plastic limit of tested peat by this method. Peat can be moulded to this shape but failure occurred due to peat not behaving as a plastic material [30]. Bei-Lin Tang [30] also proved hemic peat in her study gave almost zero plastic limit by adopting Feng method. Zainorabidin and Ismail [31] have previously encountered problems when attempting to determine the plastic limit of Malaysian hemic peat. The presence of the fibres in peat makes the process of determining the Atterberg limits difficult and less accurate. According to Hobbs [32], it was impossible to carry out plastic limits tests on pure bog peat. On the other hand, even if the peat is highly humidified there was little point in performing plastic limit testing on peat since the deduced plasticity index gives little indication of their character.

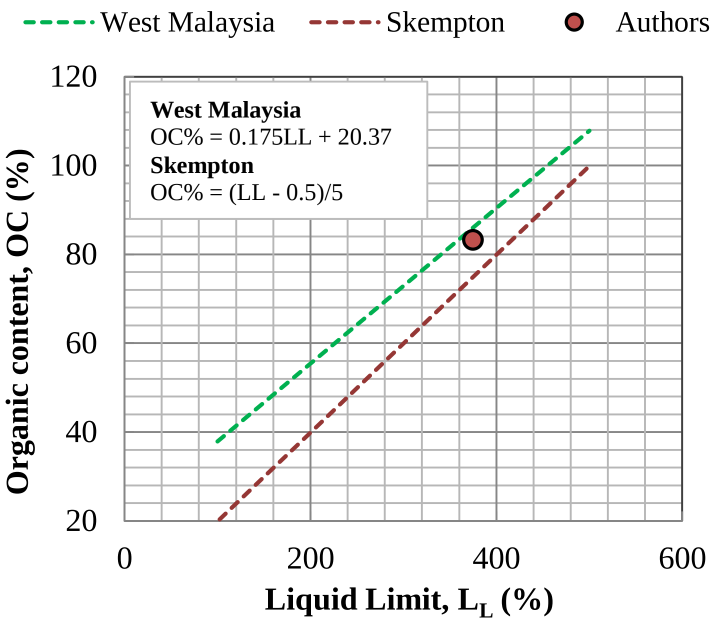


Figure 2.14: Comparison of organic contents, OC% versus liquid limit, L_L%

Fiber contents and degree of humification

Fiber content is determined typically from dry weight of fibres retained on a sieve size of 100 (less than 0.15mm opening size). A known mass of undried peat is soaked in a dispersing agent (5 % sodium hexametaphosphate) for approximately 15 h. The material is then washed through a 100-mesh (150 μm) sieve by application of a gentle flow of tap water. The fibrous material left on the sieve is oven-dried (at 105°C) until a constant mass is achieved. The mass of fiber is expressed as a percentage of the oven-dried mass of the original sample. In fiber content test, calculated fiber content is 41% which is categorized as hemic peat according to classification of peat by ASTM.

Through visual observation on the studied peat, the soil was brown in color. When the soil was extruded on squeezing (passing between fingers), it could be observed that the soil was somewhat pasty with dark brown water squeezed out, and the plant structure was unclear. Based on this observation, the soil can be classified as H6 according to von Post System (Figure 2.3) based on its degree of humification.

Specific gravity and bulk unit weight

Specific gravity of peat is greatly affected by its composition and percentage of inorganic component. It is related to the degree of decomposition and mineral content of peat. Higher specific gravity indicates a higher degree of decomposition and higher mineral content. For peat with an organic content of 75% and greater, the specific gravity is in the range from 1.3 to 1.8 with an average of 1.5 [28; 33]. Specific gravity for tested peat was recorded 1.67 which is mean this soil have fairly high degree of decomposition and mineral content. In fact, above 600% water content, both the specific gravity and water content do not greatly influence bulk density. On the other hand, low influence is attributed to higher degree of saturation or gas content [32; 34]. Peats frequently are not saturated and may be buoyant under water due to the presence of gas. Except at low water contents (less than 500%) with high mineral contents, the average bulk density of peat often is slightly lower than that of water.

The bulk density (unit weight) of peat is low and variable compared to mineral soils. The average bulk density of fibrous peat is around the unit weight of water (9.81kN/m^3). Range of 8 to 12 kN/m^3 is common for unit weight of peat in Malaysia [12]. In Japan, range of unit weight is between 7 and 20kN/m^3. Unit weight of the peat will be affected by the water content of peat; as the water content increase, the unit weight will show a sharp reduction. When water content about 500%, the unit weight ranges from 10 to 13kN/m^3 [7; 35]. This fact proved by author when obtaining the unit weight of Hokkaido peat with 12.5kN/m^3 at 580% water contents. Similar with the specific gravity, the bulk density of peat depends on the structure and degree of decomposition. Bulk density of peat is usually smaller than the mineral soils due to the lower specific gravity of the solids found and the higher water holding capacity in peat and the presence of gas [36]. Figure 2.15 portrays the comparison of specific gravity, G_s versus organic contents, OC% for studied peat to various type of peat over the world. The outcomes discovered that Hokkaido peat almost on the line of general peat on earth and clearly close to Parit Sulong peat in Johor, Malaysia.

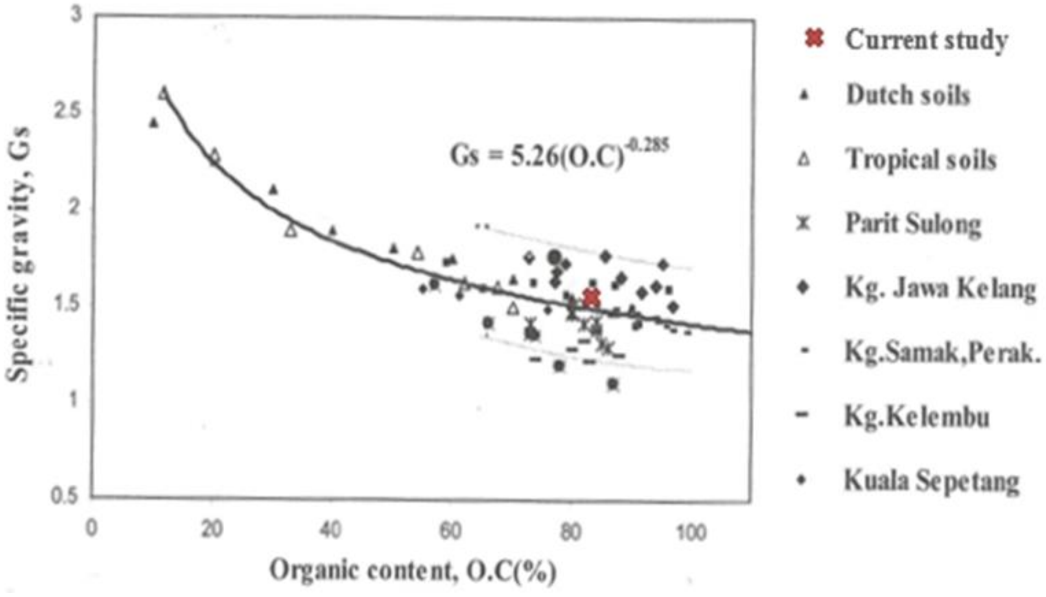


Figure 2.15: Comparison of specific gravity, G_s versus organic contents, OC%

Particles size distribution

The peat tested in this study often produce clods. The particle size distribution curves for the studied soils were obtained by standard dry sieve analysis and laser diffraction particle size analyzer (Figure 2.16). In addition to this standard sieve test method, the soil fraction finer than 75µm was analyzed using a diffraction laser method (SALD-3103 and SALD-MS30 model by Shimadzu, Japan) which is interpreted as one graph in Figure 2.17. As can be seen, Hokkaido peat consists broadly of sand to fine size base on Unified Soil Classification System (USCS) gradation and on average, 90% of the soil is finer than 4.75mm, and 2% is finer than 75µm. The coefficient of uniformity, C_u is 9.3, and the average coefficient of gradation C_g is 1.71. Pattern of Hokkaido peat particle size distribution is quite similar with Malaysia peat conducted by Kalantari [37].

Figure 2.16: Standard sieve and diffraction laser apparatus

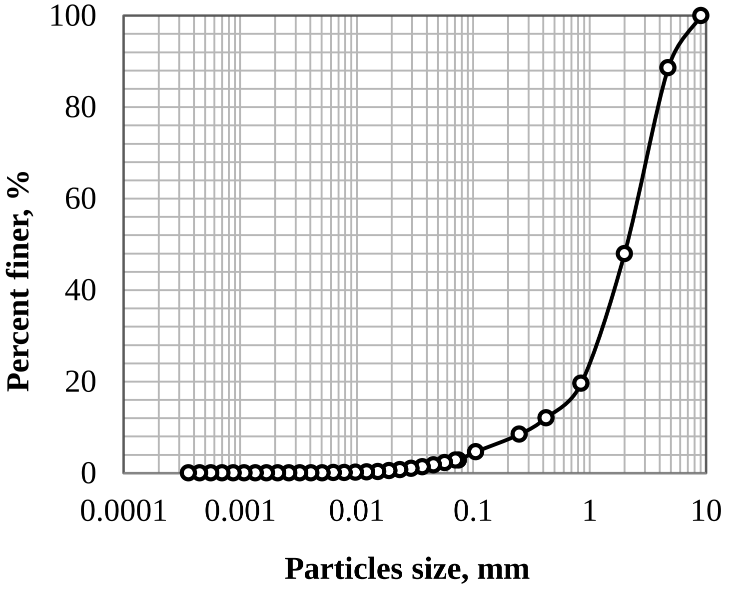


Figure 2.17: Graph of particle size between 4.75 mm and 75µm

2.2.2 Mechanical and chemical properties

Unconfined shear strength (UCS)

Since strength of stabilized peat is often evaluated by measuring its unconfined compressive strength due to the soil low permeability and high stiffness, unconfined compression tests (Figure 2.18) often provide relatively fast and cheap means of determining the soil strength [38].

The unconfined compressive strength (q_u) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test [39]. In this study, the unconfined compressive strength is taken as the maximum load attained per unit area or the load per unit area at 15% axial strain, whichever occurs first during the performance of a test. For untreated peat, the specimen was prepared in the mould size of 50 mm diameter and 100 mm length in three layers. Each layer was subjected 10 full thumb pressures at about 10 seconds [40]. The sample then trimmed and tested under vertical axial load at constant rate of strain of 1 mm min^{-1}. The detail calculations to compute UCS are shown in Appendix A. The result shows the peak was not obtained until 20% of axial strains. Hence, the max value of UCS was taken at 15% of strain which is equal to 13.6 kPa (Figure 2.19). From this result, undrained shear strength, ($S_u = q_u/2$) was equal to 6.8kPa. These values indicate that Hokkaido peat is very soft.

Figure 2.18: Laboratory unconfined compression tests

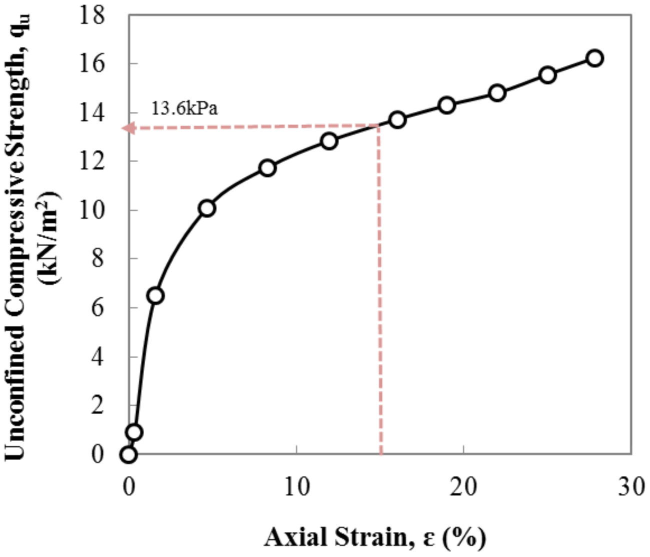


Figure 2.19: Unconfined Compression Strength (UCS) of Hokkaido peat

Consolidation

Consolidation tests were carried out in the standard 1D Oedometer apparatus (Figure 2.20) on the Hokkaido peat. The sizes of specimens were 60 mm in diameter and 30 mm in height. The Oedometer tests comprised seven incremental-load stages and each load stage lasted 24 hours. An initial stress of 10 kPa was applied and the stress was increased in steps at the end of each load stage using a load increment ratio of unity until a final stress of 640 kPa had been applied.

Figure 2.20: Laboratory standard 1D Oedometer apparatus

It revealed from the Figure 2.21 that untreated Hokkaido peat demonstrated the high void ratio, e and consequently contribute high coefficient of compression, $C_c = \Delta e / (\Delta \log \sigma_{v'})$ with about 9 and 4.9 respectively. This is because of plant matters that constitute peat particles are light and hold a considerable amount of water. Peat grains, plates, fibers, or elements are light because the specific gravity of organic matter is relatively small and the particles are porous. As a consequence of high in e, peat display high values of C_c [41].

Compare to Malaysia peat, studied peat shows the higher numbers in C_c but this results almost in range of C_c mentioned by Huat et al. [12] which C_c can be as high as 5 to 10 for tropical peat .However in Malaysia, typical C_c was detected in range of 0.5 and 2.6 (Table 2.1). By using Casagrande method (Figure 2.21), the pre-consolidation pressure, $\sigma_{c'}$ estimation of untreated Hokkaido peat was given approximately 25 kPa.

Scanning Electron Microscope (SEM), Energy-Dispersive X-Ray Spectroscopy (EDX) and pH test

Scanning Electron Microscope, SEM apparatus was used to examine microstructure of untreated peat. The detail of experiment apparatus and procedure had been describing in Chapter 4. Figure 2.22 (a) depicts the results of SEM test on untreated peat samples. It has been observed that the untreated peat contains coarse organic particles and fibers in a loose condition. They were organized arbitrarily without significant microstructural orientation. The organic coarse particles were typically hollow and spongy. Due to spongy nature of organic coarse particles, untreated peat is highly compressible and has a high water holding capacity when fully saturated [42].

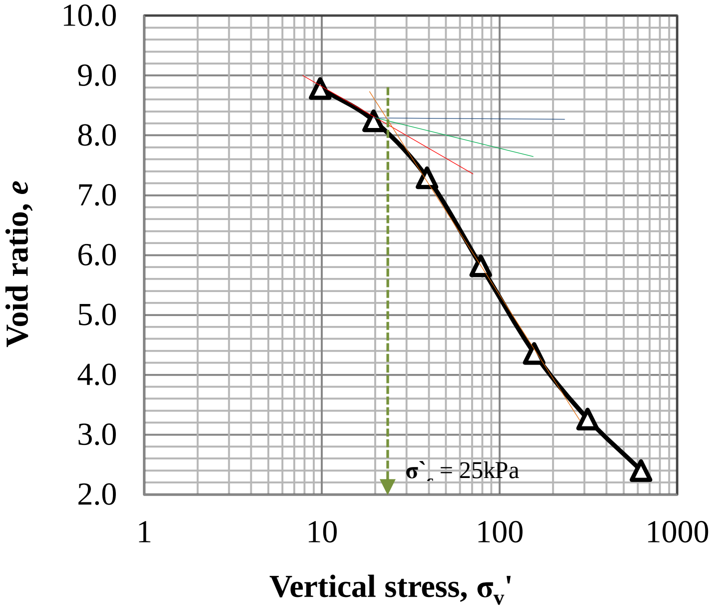


Figure 2.21: Void ratio (e) versus effective vertical stress (σ'_v) for Hokkaido peat

Dry samples of test specimens of untreated Hokkaido peats was scanned in energy dispersive X-ray (EDX) and the chemical composition percentages outcomes are displayed in Figure 2.22 (b). It can be detected from this figure that the untreated peat is predominantly characterized by carbon (C) and oxide (O) which are two main components of organic matter. It is obvious that the peat has also a very low content of pozzolanic minerals with 4.6% SiO_2, 3.1% Al_2O_3 and 2.1% Fe_2O_3 together with low calcium at about only 1%.

It is known one of crucial parameter of peat is their acidity (pH). The electrometric measurement of the pH of peat in suspensions of water and calcium chloride solutions is made with a potentiometer using a glass-calomel electrode system calibrated with buffers of known pH (pH 4, 7, 9 and 12). The average result of peat pH in this study is about 5.4 which quite large compared to Malaysia peat with range of 3 to 7 (Table 2.1). This means Hokkaido peat are categorized as lightly acidic peat. It appears that organic acids mixed with soil and cement that produce a pH lower than 9 in the pore solution, prevent the development of the cementing products because the pH is too low to allow secondary mineral formation [43].

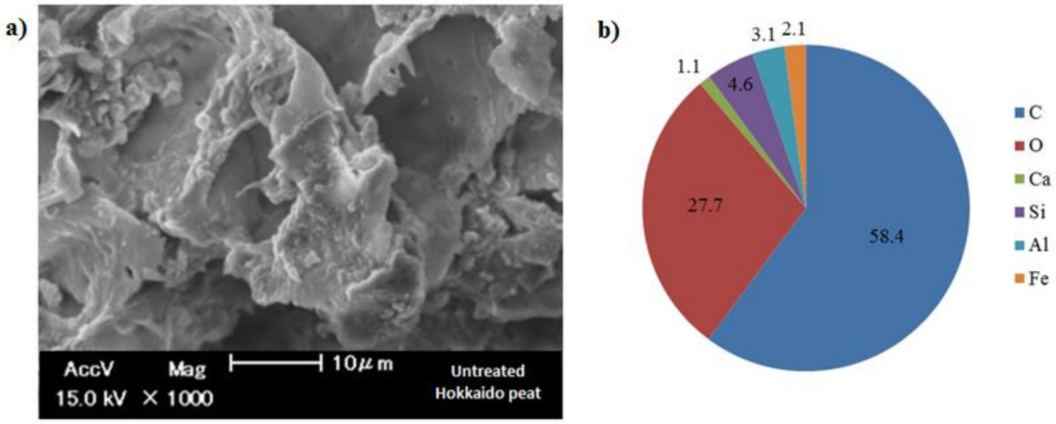


Figure 2.22: Result of; a) SEM, b) EDX on Hokkaido untreated peat

Classification of Hokkaido studied peat

United Soil Classification System (USCS), adopted by the American Society for Material Testing (ASTM) defines organic soils as a separate soil class in the standard classification of soils for engineering as shown in Table 2.3. In Malaysia, classification of peat and organic soils is based on the British Standard 5930:1981. Nevertheless, this classification has been upgraded by Public Work Malaysia & Jarret [7] to make this system more clear and suitable to the Malaysia situation. The Malaysian Soil Classification Systems (MSCS) showed in Table 2.4 introduced the degree of humidification by Von Post scale as the second important parameter to be considered after organic content [3].

In order to compare with Malaysia peat and classify the investigated peat, Figure 2.23 was created based on the collected results in Table 2.1 . This figure and

Figure 2.24 includes the typical of Hokkaido peat basic properties with the reasons to confirm and ensure the assessment results by authors are reliable. It can be seen that the peat has fiber content between 33% and 67%, ash content exceed 15%, and pH value between 4.5 and 5.5. Hence, this peat can be classified as hemic peat with high ash content and moderate acidic [44]. With the high water content, high liquid limit and low shear strength, the studied peat demonstrated the high compressibility and instability characteristics. Roughly, it can be said that studied peat are always in the range of typical Hokkaido and Malaysia peat.

Table 2.3: Classification of peat based on ASTM standards

Fiber content (ASTM D1997)	Fibric peat- fibers > 67% Hemic peat- 33% < fibers < 67% fibers Sapric peat- fibers < 33%
Ash content (ASTM D2974)	High ash peat- ash > 15% Medium ash peat- 5% < ash < 15% ash Low ash peat- ash < 5%
Acidity (ASTM D2976)	Highly acidic peat- pH < 4.5 Moderate acidic peat- 4.5 < pH < 5.5 Slightly acidic peat- 5.5 < pH < 7.0 Basic peat- pH ≥ 7.0

Table 2.4: Malaysian Soil Classification Systems (MSCS) for Organic and Peat [5]

Soil group	Organic content	Soil Symbol	Degree of Humidification	Subgroup name	Field Identification
Peat	> 75%	Pt	H1-H3	Fibric or Fibrous Peat	Dark brown to black in color. Material has low density so seems light. Majority of mass is organic so if fibrous the whole mass will be recognized plant remains. More likely to smell strongly if highly humidified
			H4-H6	Hemic or moderately decomposed peat	
			H7-H10	Sapric or amorphous peat	

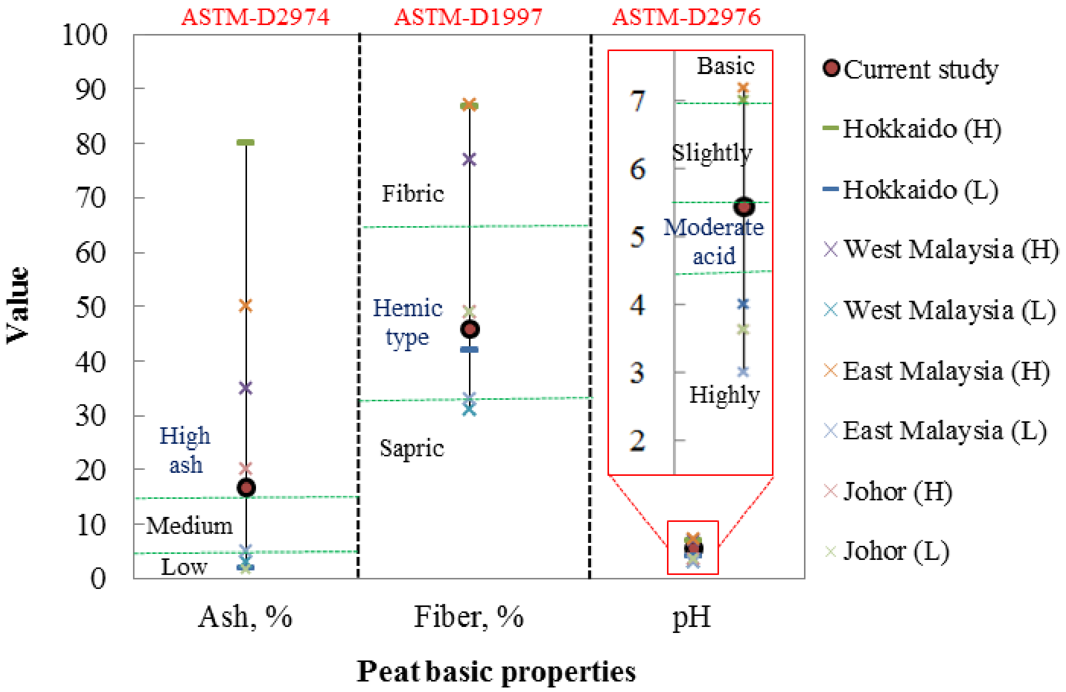


Figure 2.23: Illustration of comparative study between Malaysia and Japan peat

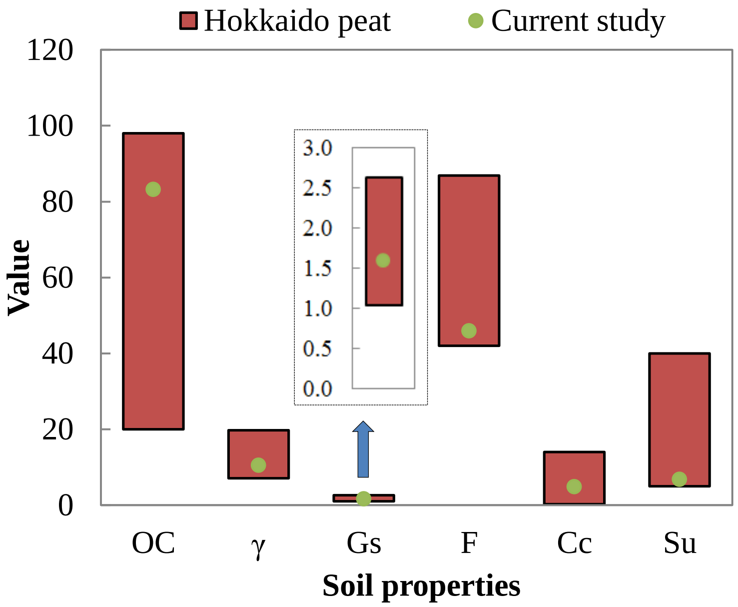


Figure 2.24: Typical of Hokkaido peat basic properties

2.3 Summary

As summary, this chapter briefly introduces the peat in general in order to develop an understanding about this ground. These include about peat definition, classification, formation and distribution in the world especially in Japan and Malaysia. Moreover, this chapter deliberates an overview of peat concerning to geotechnical characteristics that highlight the physical, chemical and mechanical properties. The collected results of studied peat (Hokkaido peat) then compared to Malaysia peat in order to investigate the similarity potential.

Overall, Hokkaido peat that had been studied has some similarities of peat properties with Malaysia peat especially in West region including Johor peat. Therefore, it is expected the research finding could be also applied on Johor peat in future. These similarities display in Table 2.1 and Figure 2.23 which is shows the whole comparison between Malaysia and Hokkaido peat. Studied peat can be categorized as hemic with high ash and lightly acidic peat. This chapter results also lead to a better understanding of the performance of Japan and Malaysia peat for better geotechnical design in future.

2.4 References

[1] Noto, S., 1991. Peat Engineering Handbook. Civil Engineering Research Institute, Hokkaido Development Agency, Prime Minister's Office,Japan.

[2] Zainorabidin, A. and Wijeyesekera, D.C., 2007. Geotechnical Challenges with Malaysian Peat. Proceedings of the AC&T, pp.252-261.

[3] Zainorabidin, A., Wijeyesekera, D.C. and Mohd Masirin, M.I., 2007. Comparative Study of British And Malaysian Peat Soils Pertaining To Geotechnical Characteristics. Sri lankan Geotechnical Society, University of Arizona (Tucson) and ISSMGE.

[4] Andrejko, M.J., Fience, F. and Cohen, A.D., 1983. Comparison of ashing techniques for determination of the inorganic content of peats. Testing of peats and organic soils, ASTM Special Technical Publication nr. 820, 5-20.

[5] Landva, A.O., Korpijaako, E.O. and Pheeney, P.E., 1983. Geotechnical classification of peats and organic soils. Testing of peat and organic soils, ASTM Special Technical Publication nr. 820, 37-51.

[6] Loughlin, C.D. and Lehane, B.M., 2003. A Study of the link between composition and compressibility of peat and organics soil. In Proceedings of 2nd International Conference on Advances in Soft Soil Engineering and Technology, ed. Huat et al, pp.135-152 Putra Jaya, Malaysia.

[7] Jarrett, P.M., 1995. Site investigation for organic soils and peat. Geoguide 6. JKR Document 20709- 0341-95. Public Works Department Malaysia. Malaysia.

[8] Leong, E.C. and Chin, C.Y., 2000. Geotechnical Characteristics of Peaty Soils in Southeast Asia. In Proceedings of GeoEngineering, Melbourne, Australia.

[9] Jarret, P.M., 1997. Recent development in design and construction on peat and organic soils. In Proceedings of Recent Advances in Soft Soil Engineering,ed. Huat and Bahia, pp.1-30.Sarawak.

[10] Leete, R., 2006. Malaysia peat swamp forest conservation and sustainable use. Publised by United Nations Development Programme Malaysia,. Ministry of Natural Resources and Environment, Malaysia.

[11] Huat, B.K., Maail, S. and Mohamed, T.A., 2005. Effect of Chemical Admixtures on the Engineering Properties of Tropical Peat Soils. American Journal of Applied Sciences, 2(7): 1113-1120.

[12] Huat, B.K., Sew, G.S. and Ali, F.H., 2004. Organic and Peat Soils Engineering. Serdang, University Putra Malaysia, Press, ISBN Number: 983-2871-08-5.

[13] Kamarudin, A. and Lulie, M., 1999. Management practices for sustainable cultivation of crop plants on tropical peatland. In Proceedings of the International Symposium on tropical peatlands, pp. 119-134, Bogor, Indonesia.

[14] Jamil, M.A., Chow, W.T., Chan, Y.K. and Yew, S.K., 1989. Land use of Peat in Peninsular Malaysia. Proc. of the Nat. Workshop on Peat Research and Development, MARDI, pp. 27- 39.

[15] Asadi, A., Huat, B.B.K., Hanafi, M.M., Mohamed, T.A. and Shariatmadari, N., 2009. Role of organic matter on electroosmotic properties and ionic modification of organic soils. Geosciences Journal, 13(2): 175-181.

[16] Hartlen, J. and Wolski, J., 1996. Embankments on organic soils. Elsevier.

[17] Mutalib, A.A., Lim, J.S., Wang, M.H. and Koonvai, L., 1991. Characterization, distribution and utilization of peat in Malaysia. In Proceeding of International Symposium on Tropical Peatland 6 - 10 May 1991, 7-8. Sarawak.

[18] Yulindasari, I., 2006. Compressibility characteristics of fibrous peat soil, Master Dissertation, Universiti Teknologi Malaysia, Malaysia.

[19] Said, J.M. and Taib, S.N.L., 2009. Peat stabilization with carbide lime. UNIMAS- E- J. Civil Eng., 1: 1.

[20] http://www.grida.no/graphicslib/detail/peat-distribution-in-the-world_8660,

[21] Hamamoto, S., Dissanayaka, S., Kawamoto, K. and Komatsu, T., 2010. Effects of Moisture Content and Shrinkage on Soil-Thermal Properties for Peat Soils in Japan. International Conference on Sustainable Built Environment (ICSBE), Kandy, Sri Lanka, pp. 53-57.

[22] Hayashi, H., Nishimoto, S. and Takahashi, M., 2011. Field Performance of PVD Combined With Reinforced Embankment on Peaty Ground. Soils and Foundation, Japanese Geotechnical Society, Vol. 51, No. 1, 191-201, Feb. 2011.

[23] Huat, B.K., Prasad, A., Asadi, A. and Kazemian, S., 2014. Geotechnics of Organic Soils and Peat. Technology & Engineering. CRC Press, London, UK, 250 pp.

[24] Kazemian, S., Asadi, A. and Huat, B.K., 2009. Laboratory study on geotechnical properties of tropical peat soils. Int. J. Geotechnics Environ., 1: 69-79.

[25] Al-Raziqi, A.A., Huat, B.K. and Munzir, H.A., 2003. Index Properties of Some Tropical Peat and Organic Soils. In Proceedings of 2nd International Conference on Advances in Soft Soil Engineering and Technology,2-4July 2003, ed. Huat et al, 183-190.Putra Jaya, Malaysia.

[26] Lin, T.B., 2011. Revitalization of Organic and Peat Soils, Universiti Tun Hussein Onn Malaysia, Malaysia.

[27] Huat, B.K., Kazemian, S., Prasad, A. and Barghchi, M., 2011. State of an art review of peat: General perspective. International Journal of the Physical Sciences Vol. 6(8), pp. 1988-1996, 18 April, 2011.

[28] Ajlouni, M.A., 2000. Geotechnical properties of peat and related engineering problems, PhD Dissertation, University of Illinois at Urbana-Champaign. 15-189.

[29] Skempton, A.W. and Petley, D.J., 1970. Ignition loss and other properties of peats and clays from Avonmouth, King’s Lynn and Cranberrry Moss. Geotechnique, 20 (4): . 343-356.

[30] Tang, B.L., Bakar, I. and Chan, C.M., 2011. Reutilization of Organic and Peat Soils by Deep Cement Mixing. International Journal of Environmental, Earth Science and Engineering, Vol:5 No:2.

[31] Zainorabidin, A. and Bakar, I., 2003. Engineering properties of in-situ and modified hemic peat soil in Western Johor. In Proceedings of 2nd International Conference on Advances in Soft Soil Engineering and Technology,2-4 July 2003, ed. Huat et al, 173-182.Putra Jaya, Malaysia.

[32] Hobbs, N.B., 1986. Mire morphology and the properties and behaviour of some British and foreign peats. Quart. J. of Eng. Geol., (19), 7-80.

[33] Davis, J.H., 1997. The peat deposits of florida: their occurrence, development and uses. Florida Geological Survey. Geol. Bull., 3.

[34] Bell, F.G., 2000. Engineering Properties of Soils and Rocks. Malden, MA, Blackwell Science. 1st ed., pp 1-496.

[35] Kazemian, S. and Huat, B.K., 2009. Compressibility characteristics of fibrous tropical peat reinforced with cement column. Electronic J. Geotech. Eng., 14E: 1-8.

[36] Boelter, D.H., 1968. Important physical properties of peat materials. Proceedings of the Third International Peat Congress. Quebec, Canada. 150-156.

[37] Kalantari, B., Prasad, A. and Huat, B.B.K., 2012. Use of cement, polypropylene fibers and optimum moisture content values to strengthen peat. International Journal of Physical Sciences, 7(8): 1276 - 1285.

[38] Wong, L.S., Hashim, R. and Ali, F., 2011. Unconfined compressive strength characteristics of stabilized peat. Scientific Research and Essays, 6(9): 1915-1921.

[39] ASTM-D2166, 2005. Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. American Society for Testing and Materials Standards, Pennsylvania, USA, Volume 04.08.

[40] Axelsson, K., Johansson, S.E. and Anderson, R., 2002. Stabilization of Organic Soils by Cement and Puzzolanic Reactions- Feasibility Study, Swedish deep stabilization Research Centre, Report 3, English translation.

[41] Mesri, G., Stark, T.D., Ajlouni, M.A. and Chen, C.S., 1997. Secondary compression of peat with or without surcharging. J. Geotech. Geoeviron. Engr., 123(5):411-421.

[42] Wong, L.S., Hashim, R. and Ali, F., 2013. Improved strength and reduced permeability of stabilized peat: Focus on application of kaolin as a pozzolanic additive. Construction and Building Materials, 40: 783-792.

[43] Tremblay, H., Duchesne, J., Locat, J. and Leroueil, S., 2002. Influence of the nature of organic compounds on fine soil stabilization with cement. Canadian Geotechnical Journal, 39(3): 535-546.

[44] ASTM, 2005. American Society of Testing Materials, Annual Book of ASTM Standards, Soil and Rock (I): D 420 - D 5611, Vol. 04.08.

CHAPTER 3

CLARIFYING AN EFFECTIVENESS OF SUGARCANE BAGASSE ASH (SCBA) UTILIZATION ON THE STRENGTH OF STABILIZED PEAT

3.1 Introduction

Due to high organic content, presence of humic acid and less solid particles in peat, cement alone is inadequate as a chemical admixture for this ground stabilization except a large quantity of cement is mixed. Sugarcane production is world number one commodities and produced a lot of bagasse. Bagasse is burnt to generate power required for diverse activities in the factory and leave bagasse ash as a waste. Increasing concern of disposal of bagasse residual creates interest to explore the potential application of this material.

This chapter emphasis on laboratory investigation on the application of Sugarcane Bagasse Ash (SCBA) to maximize the filler and pozzolanic effects on the strength of stabilized peat. Other than SCBA, calcium chloride ($CaCl_2$), Ordinary Portland Cement (OPC) and silica sand (K7) were used as additives to stabilize the peat sampled from Hokkaido, Japan. To develop the optimal mix design, specimens of stabilized peat were tested in unconfined compression. In order to clarify an effectiveness of SCBA in peat stabilization, some factors that affect the pozzolanic reactivity of stabilized peat were considered. These factors are OPC-SCBA composition, duration of curing in water, OPC dosage, K7 dosage and preloading effects. The flowchart of this chapter implementation is displays in Figure 3.1.

3.2 Literature review

3.2.1 Introduction

Peat is considered as challenging soils in the view of design parameter and always associated to low bearing capacity, poor strength characteristics, large deformation, high compressibility, and high rates of creep [1-5]. Shear strength is considered as one of the most important fundamental property required in geotechnical design and analysis. Shear strength always plays a vital role when dealing with soil especially during pre and post-construction since it is used to evaluate the foundation and slope stability of soil [1; 6; 7].

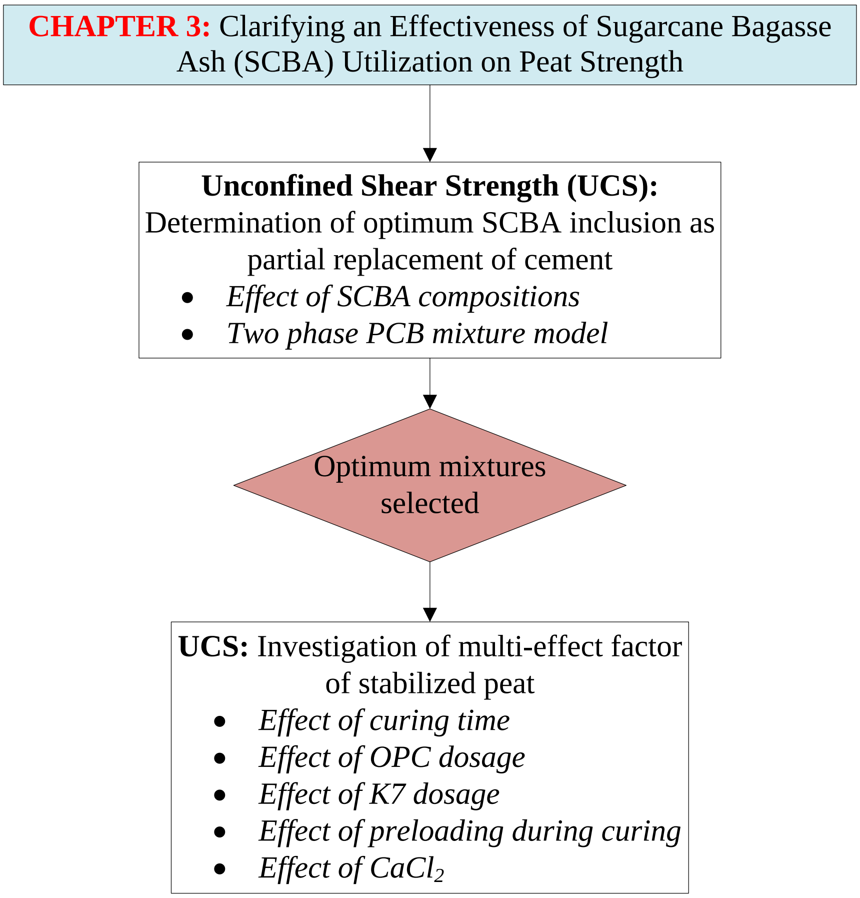


Figure 3.1: Execution planning of Chapter 3

The shear strength properties of soil are normally determined by unconfined compression tests, triaxial tests or the fall-cone test [8]. Due to the soil low permeability and high stiffness, unconfined compression tests often provide relatively fast and cheap means of determining the soil strength [9]. In recent years, unconfined compressive (UCS) test become popular in determine the strength of untreated and stabilized peat in the laboratory [8-15]. The other common laboratory test is direct shear test in determining the drained shear strength of fibrous peat. Triaxial test is frequently used for evaluation of shear strength of peat in the laboratory under consolidated-undrained (CU) conditions. This is due to the fact that the results of triaxial test on fibrous peats are difficult to interpret because fiber often act as horizontal reinforcement, so failure is seldom obtained in a drained test [1]. Generally, results from the simple shear tests give lesser strength than triaxial compression tests because of the fiber orientation (typically horizontal) relative to the shear plane. It is expected the deduction due to this effect could be as much as 25% [16]. Due to several advantages of UCS tests to stabilized peat as described above, this test were chosen and applied in this study.

The effective internal friction, ø' of peat is generally higher than inorganic soil. However, fibrous peat (normally at shallow depth) showed values of *c* and the angle of friction higher compared than other peat types (e.g. hemic and sapric). [7; 17-19]. The high friction angle of peat not actually reflects high shear strength as a result of the fact that the fibers are not always solid and may be filled with water and gas. The presence of fibers will modify the strength behavior of peat since the fibers can be considered as reinforcement and the fibers can provide effective stress where there is none and it induces anisotropy[1]. The fibers can influence the strength of peat in that the shear resistance continues to develop at high strain values without a significant peak behavior and will exhibit K_0 values decrement compared to that of clays [20].

3.2.2 Peat improvement methods

Conventionally, the normal practice is to avoid peat ground, or excavate (cut and fill or replacement method) or drive pile through them [17]. However due to dearth of suitable land for infrastructure development and agriculture, evasion of construction on poor lands such as organic and peat land is no longer option anymore. Replacement method (Figure 3.2) will make large scale disposal of peaty soils in unacceptable amount in future [21]. Excavation and replacement of the peat below the road line is the safest option for constructing, or improving, a road over peat other than by avoidance. In this method all of the weak materials under the road line are excavated out to a suitable firm layer and the embankment constructed on the exposed sound foundation, preferably with non-cohesive material locally won on site. However, the actual economic at a particular construction location will depend on the local parameters for example the type of peat, the depth of peat, the area of peat, the cost of the backfill material and availability of disposal areas [22]. Disposal of poor quality surplus material can be regarded as one of the most significant environmental problems in construction. The other disadvantages of this method are the difficulties in excavation and placing fill below water table. Normally demands high quality of fill material (low percentage of fines). Deep excavations may have effects on adjacent lands and structures. Unexcavated soft material below embankment may cause future settlements [22; 23]. Structures on peat that suspended on piles normally give deposition effect to surrounding ground [24] like shown in Figure 3.3. Currently, the utilization of peat land in Malaysia is quite low although construction on marginal land such as peat has become increasingly necessary for economic reasons. Engineers are reluctant to construct on peat because of difficulty to access the site and other problems related to unique characteristics of peat. Thus, not much research has been focused on the development of soil improvement method for construction on peat [25].

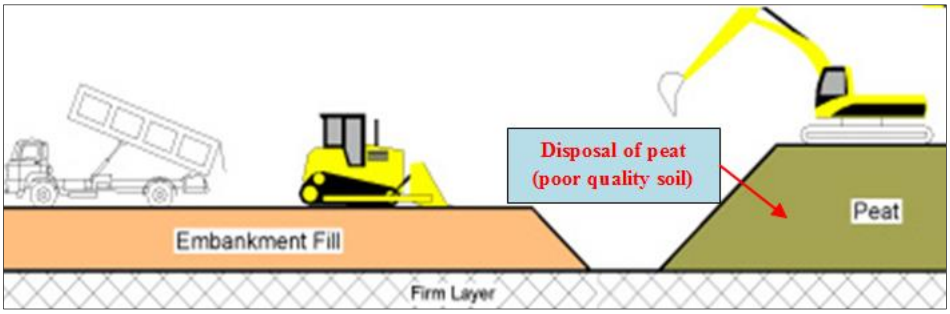


Figure 3.2: Replacement (cut and fill) method on the peaty ground [22]

There are a number of improvement options that can be applied to peat especially for road construction, namely: excavation-displacement or replacement; left in place such as strength improvement (e.g. preloading- Figure 3.4), load modification- Figure 3.5 (e.g. slope reduction, berms, lightweight fill), reinforcement- Figure 3.6 (e.g. geotextiles, geogrid, timber raft, and steel mesh), vertical drainage, piling, stabilization (e.g. in-situ chemical admixtures). These chemical admixtures can be applied either as deep in situ mixing method (cement columns), or as surface stabilizer (mass stabilization) and this method considered as economical and time saving option [20; 22; 26-28].

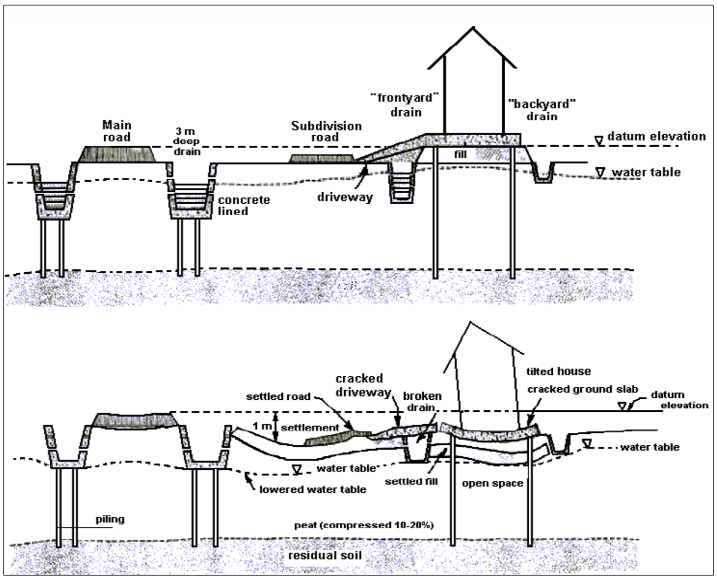


Figure 3.3: Usual section of construction on peat: Immediately after completion of structure (above) and after several years of construction completion (below)

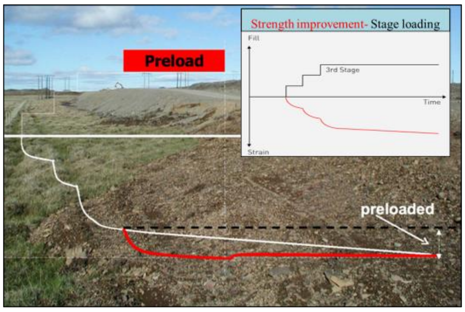


Figure 3.4: Peat improvement by preloading method [22]

Chemical admixture method in peat stabilization

Chemical admixtures or chemical stabilization always involves treatment of the soil with some kind of chemical compound, which when added to the soil, would result in a chemical reaction. This method has been extensively used in both shallow and deep stabilization in order to improve inherent properties of the soil such as strength and deformation behavior. Lime or cement has commonly been used as chemical admixtures for soil stabilization and mixing method to improve the properties of soils since olden times. However in the case of tropical peat, little is known about it responding to chemical admixtures such as cement and lime [24; 29; 30].

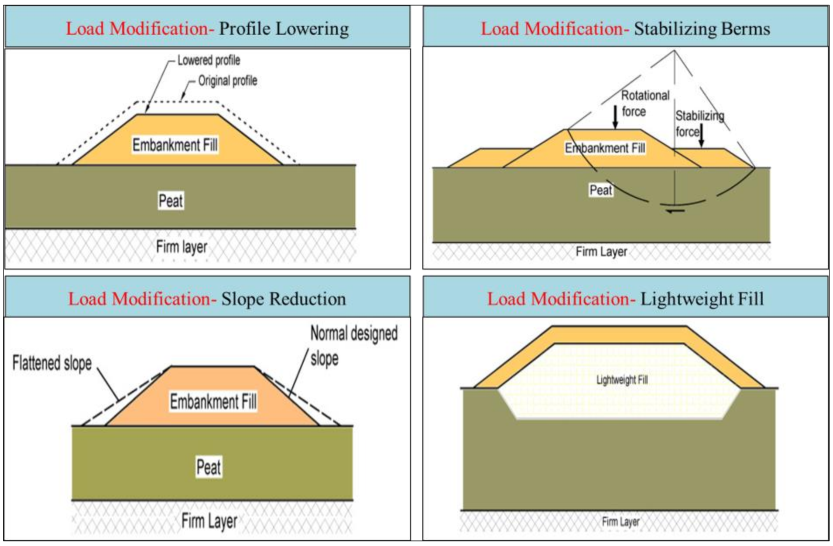


Figure 3.5: Peat improvement by load modification method [22]

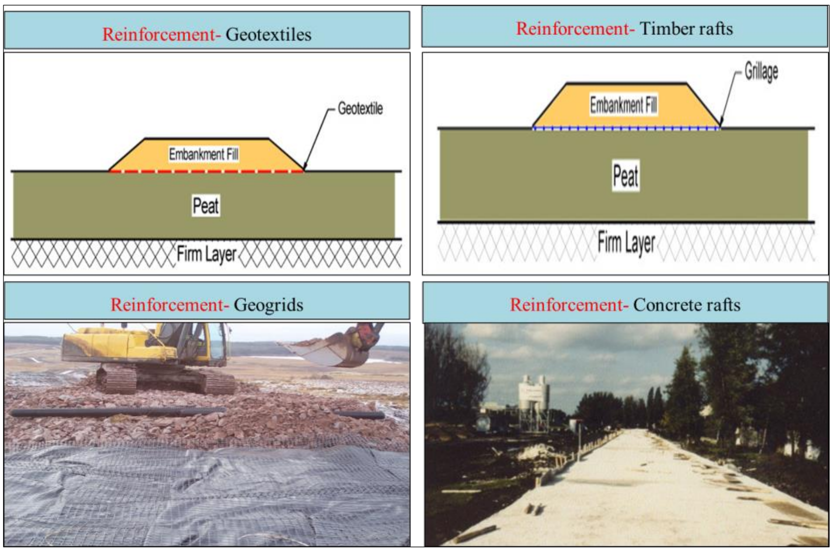
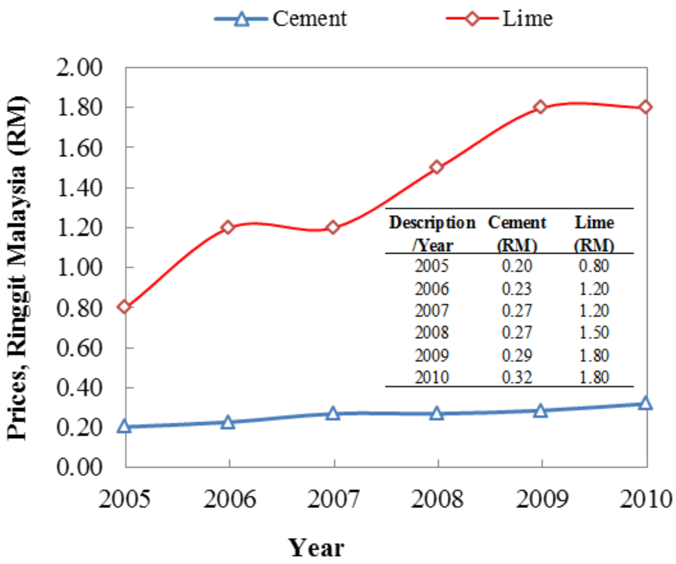


Figure 3.6: Peat improvement by reinforcement method [22]

The use of cement and its capability in inorganic soil stabilization is very popular since long time ago. Nevertheless, the use of cement is not given much attention in the stabilization of organic soils because evasion is often become the first choice rather than build up any infrastructure on these problem land. However, over the past few years, there are researchers who began to observe the ability of the cement in the stabilization of organic soil [8; 10; 11; 24; 31-35]. From the literature review on peat stabilization by chemical admixtures, cement mixtures usually gives the better results than lime [11; 24]. Other than it potential as stabilizer, cement is also considered as low cost admixtures compared to lime (Figure 3.7) and ease of storage in a hot and humid climate such as Malaysia [36].



Description /Year	Cement (RM)	Lime (RM)
2005	0.20	0.80
2006	0.23	1.20
2007	0.27	1.20
2008	0.27	1.50
2009	0.29	1.80
2010	0.32	1.80

Figure 3.7: Cement and lime prices comparison for Malaysia market [36]

Peat mass stabilization method

In recent years, one of the popular peat improvement techniques that get attention is mass stabilization by use cement as a main binder (Figure 3.8). One of the limitation of this stabilization practice is the depth of peat should not more than 5m. However this constraint may be able to be a great approach for peat stabilization in oil palm plantation since peat ground under oil palm estate is very suitable at peat depth that not more than 3 meter [37]. As stated by Allu [38], mass stabilization is very suitable for the shallow depth (under 5m) and wide area of peat ground improvement.

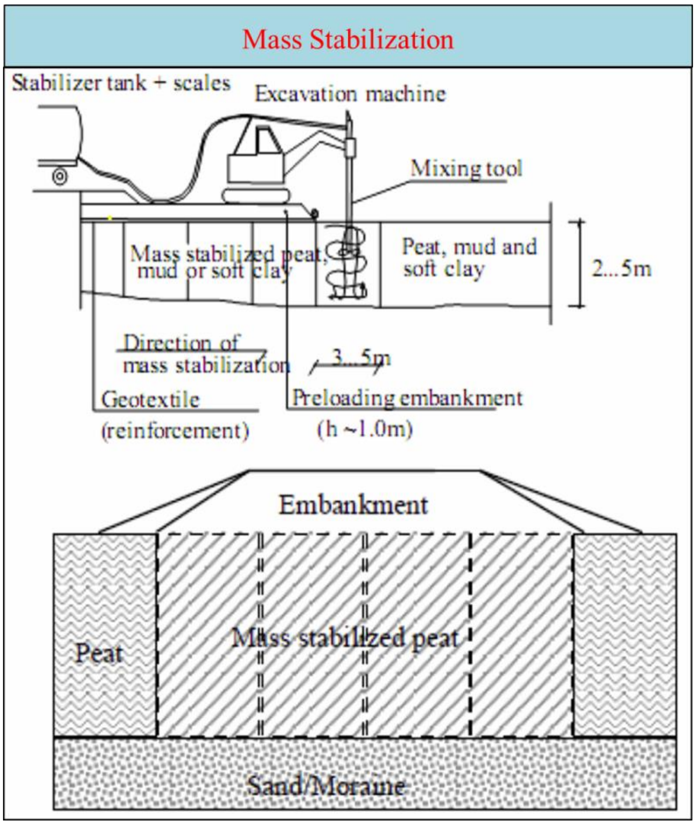


Figure 3.8: Peat improvement by mass stabilization method [22]

Mass stabilization is a relatively new soil reinforcement technique (especially for soft soil like peat, organic and mud) in which stabilizing agents are blended into the entire soil layer and applied with good results in a number of projects in Sweden and Finland. Unlike the deep mixing method, these results in a stabilized block that increases the stability of the soil. The method is to mix an appropriate amount of dry or wet binder throughout the volume of the soil layer. The mixing is carried out both horizontally and vertically to set depth. In Finnish projects using mass stabilization, shear strength has been increased by factors of up to 40 in mud and up to 20 in peat [11; 39]. According to Jelisic and Leppanen [23], the mass stabilisation method has many benefits, including:

a. It is a rapid ground improvement method, and can be adapted to varying soil conditions

b. It is in most cases economically efficient and saves materials and energy.
c. It improves the engineering properties of the soil and can be flexibly linked with other structures and with the surroundings (no harmful settlement differences)
d. Transfer of the natural soil elsewhere is not needed, so there is less transportation and traffic pollution and no need for disposal sites and offsite transport.

Mass stabilization method is suitable for reduction of settlement and for improvement of stability of soft ground and is applicable in infrastructure projects like roads and railways. It is also used for foundation of smaller buildings and bridges, and for stabilization of excavations, lagoons and natural slopes. In general, the method is found technically, economically and environmentally favorable compared to other alternatives [39]. In obtaining effectiveness of this method, some stabilizing factors should be taken into account and carefully observed. There are cement dosage (sometimes together with accelerator), pozzolana (e.g. fly ash to enhance the secondary pozzolanic reaction), filler (e.g. fine sand to increase solid particles in peat), temperature, curing duration and preloading during curing [11; 31; 40; 41].

3.3 Methodology

3.3.1 Description of materials

Figure 3.9 shows the materials that had been used in this study. There are peat, Ordinary Portland Cement (OPC), silica sand so called K7, calcium chloride ($CaCl_2$) and Sugarcane Bagasse Ash (SCBA). The site of the peat under study is located at Sapporo in the Hokkaido region, Japan. Peat was excavated approximately to a depth of 1 m below the ground surface in order to obtain samples for laboratory experimental. Two types of SCBA samples were obtained from Kagoshima prefecture in Kyushu, Japan. One type is expected to be a high quality pozzolan than other one. The 3rd type of SCBA was created by mixing both, high and low quality of collected SCBA's. Other than OPC as main binder and $CaCl_2$ as cement accelerator, well graded silica sand (K7) was prepared as a filler to increase the solid particles and enhance the filling effect of the stabilized peat.

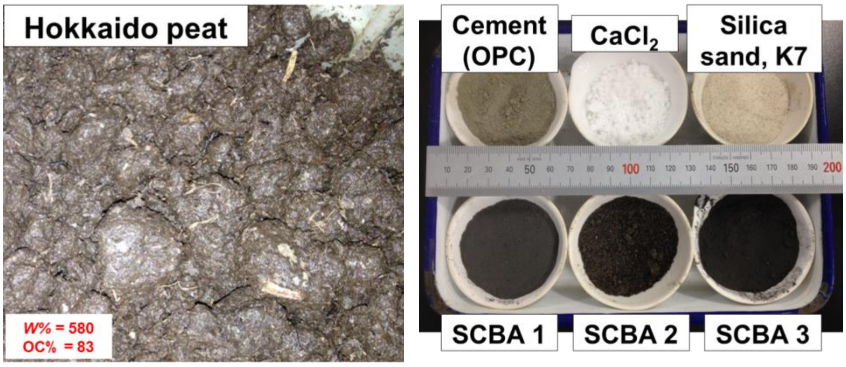


Figure 3.9: All study materials: Hokkaido peat, OPC, K7, $CaCl_2$, SCBA

3.3.2 Mixing designs of laboratory test

In order to ensure the safety and the quality of the final stabilized product, a number of stabilization tests must be carried out in the laboratory beforehand to establish the most suitable stabilizers, to optimize the quantity of stabilizer and to assess strength-deformation properties of the stabilized soil for the actual case. A new laboratory testing procedure has been introduced for peat so that the actual loading conditions in the field can be simulated in laboratory [23]. About 50-70 % of the total costs in stabilization project are caused by the binder. By careful laboratory work the suitable binder and its optimized quantity [in kg/m^3] is selected and thus considerable savings are reached [38].

In order to clarify an effectiveness of SCBA in peat stabilization, some factors that affect the pozzolanic reactivity of stabilized peat were considered. These factors are OPC-SCBA composition, duration of curing in water, OPC dosage, K7 dosage and preloading effect. The selection of these factors is based on the literature review [8; 10; 34; 38; 41]. The mix designs of stabilized peat for laboratory testing are shown in Table 3.1. These mix designs were implemented to all SCBA types. The basic mixtures were produce by include OPC and K7 dosage at 300 kg/m^3 and 500 kg/m^3 respectively. These mixtures then cured under 20 kPa of air pressure for 7 days. These admixtures amount would change depend on the purpose of investigation as described in Table 3.1.

Table 3.1: Laboratory mix design

No. of test	**Type of test**	**Description of test purpose**	**Curing durations (days)**	**Initial pressure (kPa)**	**OPC dosages (kg/m^3)**	**K7 dosages (kg/m^3)**	**$CaCl_2$ dosages (%)**	**Mixtures compositions**
1	UCS , pH, *w*	To investigate the effect of binder composition on the tested specimens	7	20	300	500	3	100% OPC @ PC 95%OPC:5%SCB @ PCB-5 90%OPC:10%SCB @ PCB-10 85%OPC:15%SCB @ PCB-15 80%OPC:20%SCB @ PCB-20 75%OPC:25%SCB @ PCB-25 70%OPC:20%SCB @ PCB-30 65%OPC:25%SCB @ PCB-35
2	UCS , pH, *w*	To investigate the effects curing duration on the tested specimens	7, 14, 21, 28, 60	20	300	500	3	The optimum binder composition from test (1)
3	UCS, pH, *w*	To investigate the effects of initial pressure on the tested specimens	7	0, 20, 40, 60, 80, 100	300	500	3	The optimum binder composition from test (1)
4	UCS , pH, *w*	To investigate the effect of binder dosage on the tested specimens	7	20	100, 150, 200, 250, 300	500	3	The optimum binder composition from test (1)
5	UCS , pH, *w*	To investigate the effect of silica sand (filler) dosages on the tested specimens	7	20	300	0, 100, 200, 300, 400, 500	3	The optimum binder composition from test (1)
6	UCS , pH, *w*	To investigate the effect of $CaCl_2$ dosages on the tested specimens	7	20	300	500	0, 1, 2, 3, 4	The optimum binder composition from test (1)

3.3.3 Laboratory sample preparation procedures

The mix designs of stabilized peat were formulated in term of binder composition and dosage as conducted by EuroSoilStab [15]. A total of 140 samples of stabilized peat were prepared for all three types of SCBA. Each admixture consists of 3 samples in order to keep results consistency and reliability. Each binder dosage was determined based on the bulk density of peat that remoulded at its average natural water content.

Initially, cylinder mould for the mixtures was prepared (Figure 3.10). Each cylinder mould has a size of 60 mm internal diameter and 300 mm height. One of the important factors of mould preparing is to calibrate the friction between mould cell inner wall and the piston block that occurred during curing under a certain subjected pressure. The calibration of these was conducted by comparing the magnitudes of the applied pressure and the corresponding pressure response at the bottom of the cell. The lubricant oil was applied at first to the wall and the side of piston block before the test implemented. In this study, air pressure had been used rather than iron rod in conventional method [8; 11; 23; 38] with the aim of the field preloading simulation. The air pressures with magnitudes of 20, 40, 80 and 100 kPa were subjected to the piston block in the mould cell consequently (Figure 3.10). This test had been conducted on three random mould cells in order to get an average response pressure. As shown in Figure 3.11, the response pressure shows the slight low reading compared to applied pressure which means the friction between cell wall and piston block exist. However, this friction can be neglected since the graph trendline results is approach to perfect line with R^2 is almost 1.

In producing each admixture, a mixer was used to intimately mix the peat with other materials for 10 minutes. At first 3 minutes, the admixtures were mixed without peat by using standard kitchen mixer. For another 7 minutes the all materials were mixed and by using hybrid mixer. The process of mixing was displayed in Figure 3.12. The main part of the special mixer is driller that combined with kitchen mixer blade. In order to maximize the homogenization of samples mixing, regulator has been used on this special mixer and set to the constant power. Preparation of each test specimen of stabilized peat for unconfined compression test will be done by filling and tamping the stabilized soil admixture in five equal layers in the cylinder mould as shown in Figure 3.13. Then the piston was lubricated and pushed gently to rest at the upper mixture surface. The remaining area between the cells caps then filled with the water for the safety purpose. After that, cell was screwed once again by the mould lid before it immersed in a water container for curing (Figure 3.13) at specified duration under an initial pressure by using air pressure to simulate the surcharge pressure on the stabilized soil at site.

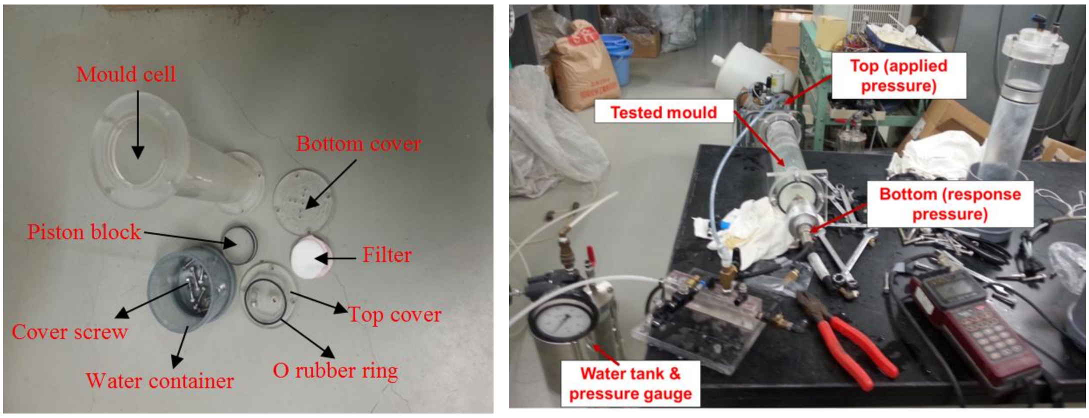


Figure 3.10: Mixtures mould cell parts (left) and the cell calibrations method (right)

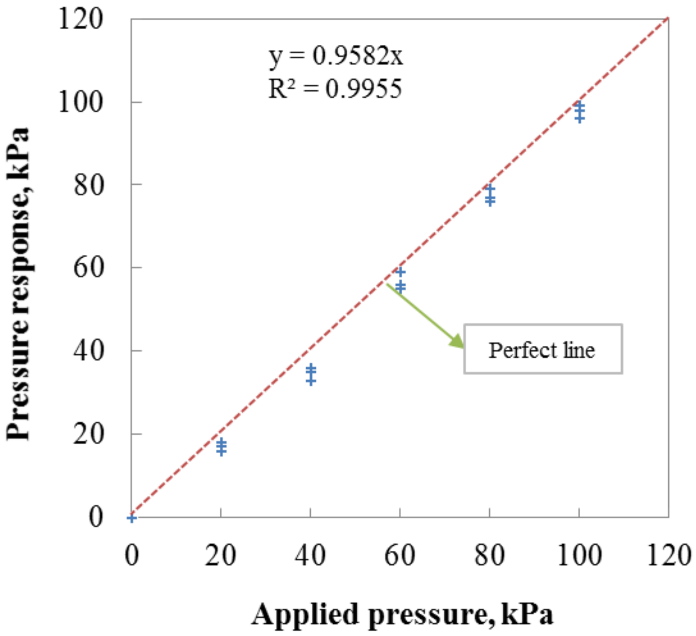


Figure 3.11: Sample mould cells friction test results

Figure 3.12: Mixing tools and method

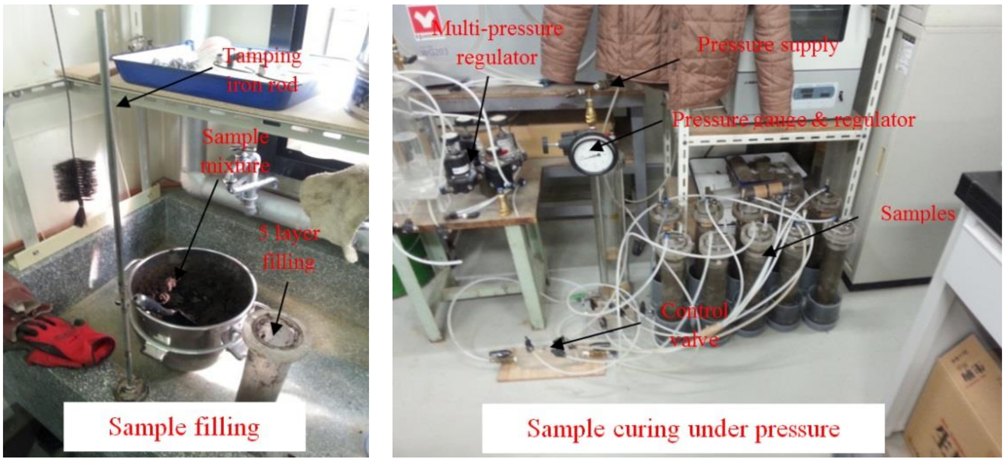


Figure 3.13: Samples filling and curing method

Figure 3.14 presents the schematic diagram that shows the detail arrangement of sample curing under air pressure. This method can be considered as a new technique for curing the sample under pressure since the conventional method (Figure 3.15) was using iron cylinder as a load pressure [8; 38]. Once the mixture cured, the cylinder tube is removed and the test specimen is trimmed to the required size for testing by using special sample extruder and cutter (Figure 3.16). To evaluate the degree of improvement, the established parameters of the stabilized soil must be compared to those of untreated peat.

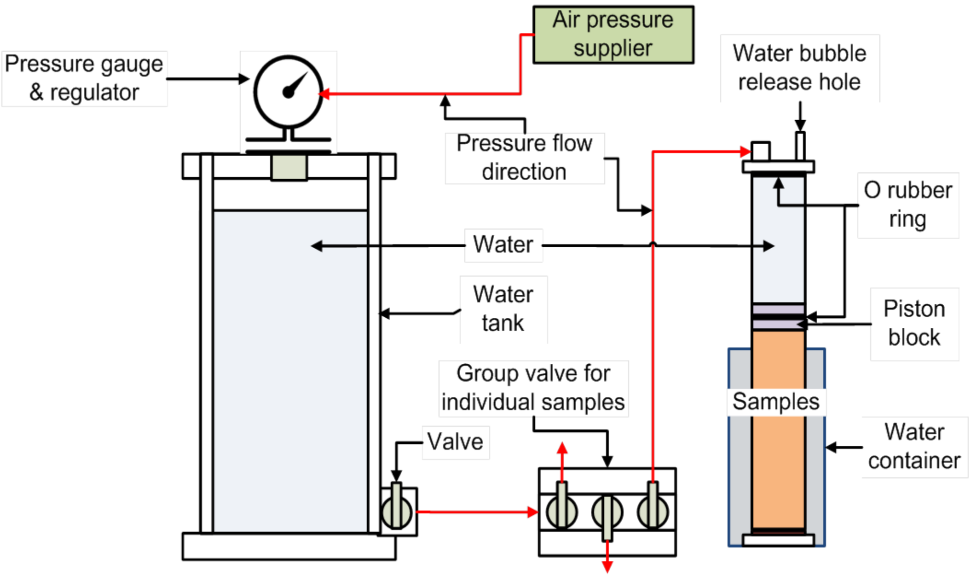


Figure 3.14: Schematic diagram of sample curing under air pressure

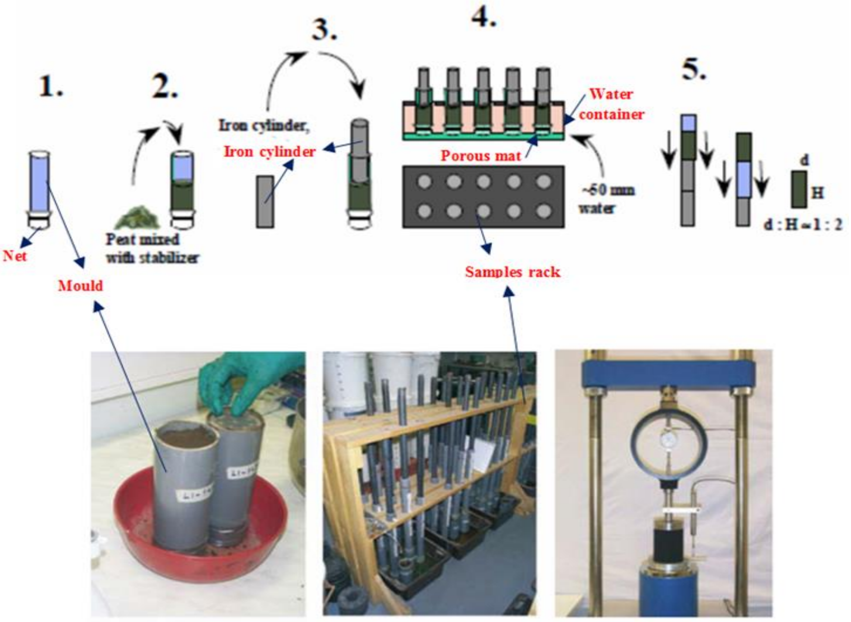


Figure 3.15: Conventional method in making, loading and testing of stabilized peat

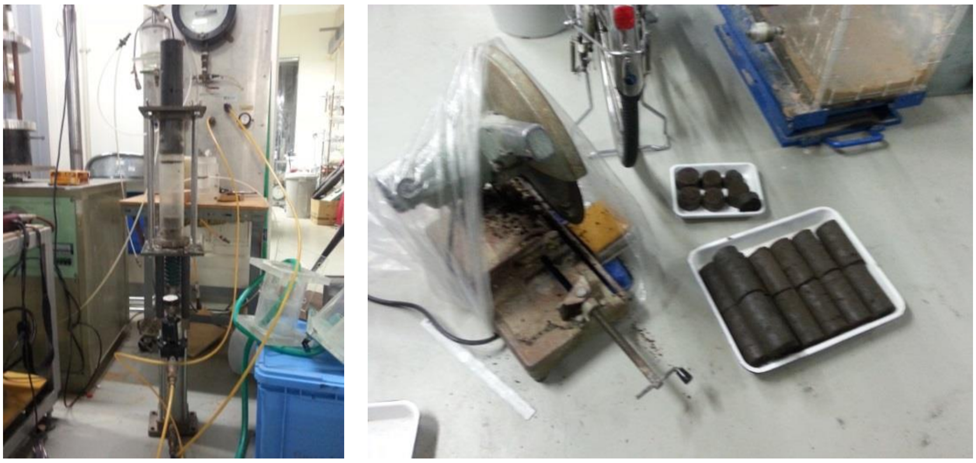


Figure 3.16: Sample extruder and cutter

3.4 Results and discussions

3.4.1 Materials properties

Table 3.2 demonstrates the percentages of oxide compounds of the materials and peat that used in this study. These results were obtained from EDX test. It is noticeable that the peat has very low contents of pozzolanic minerals as described in Chapter 2. The OPC is predominantly characterized by 65.4% CaO, 10.26% SiO_2, 6.6% Al_2O_3 and 5.57 Fe_2O_3. Based on a review, OPC is primarily characterized by quicklime (CaO), silica (SiO_2), alumina (Al_2O_3) and ferric oxide (Fe_2O_3) [42]. With content about 93% of SiO_2, it can be confirmed that quartz is the main mineral in the K7 silica sand. For SCBA 1 and SCBA 2, it was found that the summation of the crucial pozzolanic oxide compounds (SiO_2, Al_2O_3 and Fe_2O_3) is around 72% and 74% of the total oxide compounds. These results point out the suitability of used SCBA's as a pozzolan since the amount of such oxide compounds exceeds 70% as recommended by ASTM C618 Standard [43].

The particle size distribution of the peat and other materials are tabulated in Figure 3.17. The untreated peat particle size distribution curves result was briefly deliberated in Chapter 2. For materials grain size, most of K7 particles sizes are 0.05 to 0.3mm in range. The SCBA 1, SCBA 2 and SCBA 3 particles consist about 80%, 15% and 60% finer than 0.045mm (passing No. 325 sieve) respectively. This result also indicates that SCBA 1 is finer than SCBA 2 and SCBA 3 with average particle size are (D_{50}) around 18, 260 and 27 µm individually. Based on Figure 3.17, SCBA 3 particle size seems approach the SCBA 1 curves results especially in finer region. Although this SCBA is actually created by fair combination of SCBA 1 and SCBA 2, the finer results gained is probably because of mixing effect that contributes by mixer blade and duration. According to ASTM C 618 Standard [43], volume fraction of more than 66% of particles smaller than 45 µm is good for a pozzolanic material and this limit achieved only by SCBA 1 as proved in Table 3.3. Figure 3.18 had been created in order to simplify the results that obtained from Table 3.3. Clearly from this Figure 3.18 that only SCBA 1 passes the entire minimum requirement that assigned by ASTM [43] where the water contents, loss on ignition and sulfur oxide of pozzolan materials should not exceed 3, 6 and 5% respectively. Therefore, in this assessment, it can be understood that SCBA 1 has better quality than other SCBA in peat stabilization especially the contribution made by its fine particle size.

Table 3.2: Oxide compounds of peat and materials

Oxide Compound, %	**Untreated peat**	**OPC**	**Sand (K7)**	**SCBA 1**	**SCBA 2**	**SCBA 3**
CO_2	86.14	-	-	-	-	-
CaO_2	1.10	65.21	0.65	7.70	2.53	5.40
SiO_2	4.64	21.55	70.18	57.38	70.53	55.07
Al_2O_3	3.09	3.82	19.30	10.19	1.65	8.36
Fe_2O_3	2.07	1.28	0.17	4.07	2.24	4.32
Na_2O	0.76	1.51	0.00	1.71	0.51	0.73
MgO	0.95	1.97	0.42	1.23	1.22	2.02
P_2O_5	0.27	0.87	7.29	4.33	7.62	6.36
SO_3	0.54	1.68	0.67	1.47	0.15	2.42
K_2O	0.45	1.29	0.53	10.98	12.74	14.38
TiO_2	0.00	0.82	0.78	0.93	0.82	0.91
Total	100.0	100.0	100.0	100.0	100.0	100.0

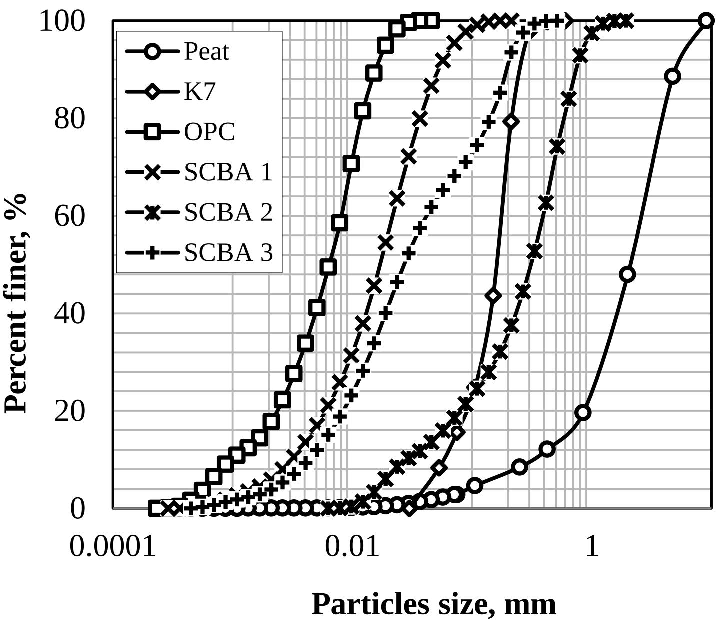


Figure 3.17: Particle size distribution of peat and materials

Table 3.3: Requirement of pozzolan materials results for all SCBA

Sources	Test results	Requirements	SCBA 1	SCBA 2	SCBA 3
Laboratory test	w, %	Less than 3%	2.89	35.67	16.27
	LOI, %	Less than 6%	3.91	9.93	6.91
	Passing 45μm, %	≥ 66%	85	15	62
	D_{50}, mm		0.018	0.260	0.027
SEM & EDX test	SO_3	Less than 5%	1.47	0.15	2.42
	CaO		7.70	2.53	5.40
	Al_2O_3		10.19	1.65	8.36
	SiO_2		57.38	70.53	55.07
	Fe_2O_3		4.07	2.24	4.32
	$SiO_2+Al_2O_3+Fe_2O_3$	≥ 70%	71.64	74.42	67.75
	CaO/SiO_2		0.134	0.036	0.098

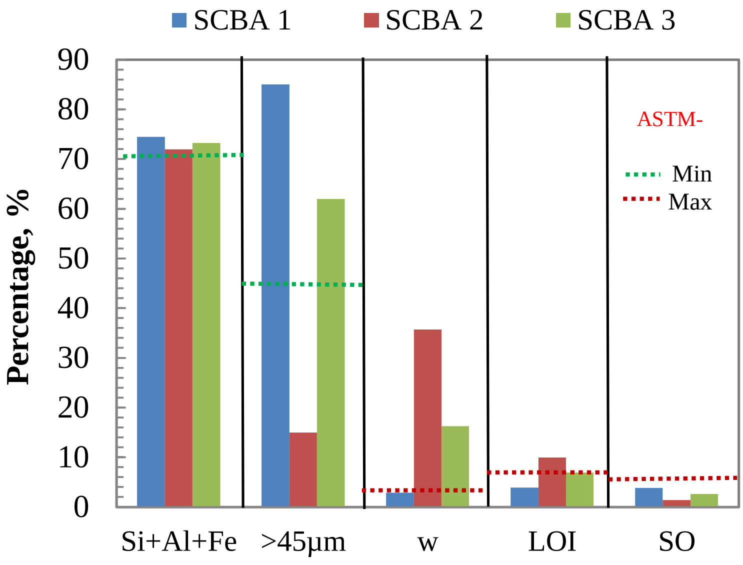


Figure 3.18: Comparison of all SCBA properties as pozzolan

3.4.2 Effect of partial replacement of Ordinary Portland Cement (OPC) with sugarcane bagasse ash (SCBA)

Figure 3.19 displays the experimental results of the effect of all types of SCBA percentage replacements on the UCS of the stabilized peat. The detail determination of UCS and its average reading were shown in Appendix B and Appendix D. An optimal UCS of the stabilized soil was evaluated based on the results of unconfined compression tests on the specimens of stabilized peat with partial replacement of the cement with SCBA that varies from 5% to 35% as shown in Table 3.1. However for SCBA 2 and SCBA 3, replacement percentage only done until the substitute amount achieved 25%. This is because the peak strength results shown for both SCBA are found at 5 and 10% replacement and continuously drop when the cement are reduces as much as 25%. It can be detected that the test specimen with 20% partial replacement of OPC with SCBA 1 (PCB1-20) has the highest UCS of 387 kPa and was discovered to be about 30 times better than untreated peat and approximately 1.2 times greater than UCS of PC specimen (Figure 3.19). On the other hand, SCBA 2 mixture achieves the optimum at only 5% of cement replacement (PCB2-5) and recorded slight increment compared to PC specimen. It seems SCBA 3 mixture recorded a little lower strength than SCBA 1 mixtures but it achieved an optimum at only 10% cement replacement (PCB3-10). This may cause by combination properties between two main SCBA's in SCBA 3 development especially influence by SCBA 1 grain characteristic as proved in Figure 3.17. As stated by ASTM D4609 [44], an increase in UCS of 345 kPa (adopted as minimum UCS target in this study) or more must be reached for a treatment to be considered effective.

The main reasons why PC mixture gave lesser strength than optimum mixture of SCBA 1, SCBA 2 and SCBA 3 are because peat consists of high organic content and less solid particles as showing in Table 3.2. Organic soils can retard or prevent the proper hydration of cement in soil mixtures and become insufficient to provide the required function for peat stabilization. Matched to clay and silt, peat has a considerably lower content of clay particles that can enter into secondary pozzolanic reactions [10; 40]. The combination of humic acid with calcium ions produced in cement hydration makes it difficult for the calcium crystallization, which is responsible for the increase of peat-cement mixture strength to take place [31].

$$\mathrm{C_3S + H = CSH + CH} \tag{3.1}$$

$$\mathrm{CH + Pozzolan + H = CSH\ or/and\ CASH} \tag{3.2}$$

Generally, chemical reactions between cement and pozzolan with water are denoted in Eqn. 3.1 and Eqn. 3.2. Calcium silicate hydrates (CSH) or also known as tobermorite gels together with calcium hydroxide (CH) are formed when cement reacts with water (H) in peat. The CSH act as adhesive that binds and grasp the soil particles together. Nevertheless, humic acid in peat reacts with calcium ion to form insoluble calcium humid acid. These conditions make the secondary pozzolanic reaction between CH and the peat is inhibited and this renders a low strength gain in the soil-cement mixture.

The fact that the test specimen of PCB1-20, PCB2-5and PCB3-10 has the better UCS may be explained by a condition whereby it has achieved an optimal effect of hydration reaction. By means of the inclusion of pozzolan such as SCBA in the soil-cement mixture, hydration of cement is accelerated when the pozzolan reacts with calcium hydroxide and water to form more secondary tobermorite gels along with calcium alumina silicate hydrates (CASH) as shown in Eqn. 3.2. This is probable because the pozzolan which contains extra silica and alumina that activated by cement is able to counterbalance the acid and create an alkaline atmosphere that boosts the secondary pozzolanic reaction within the cemented soil. Additional CSH and CASH densify the stabilized peat, thereby further enhancing its strength [45].

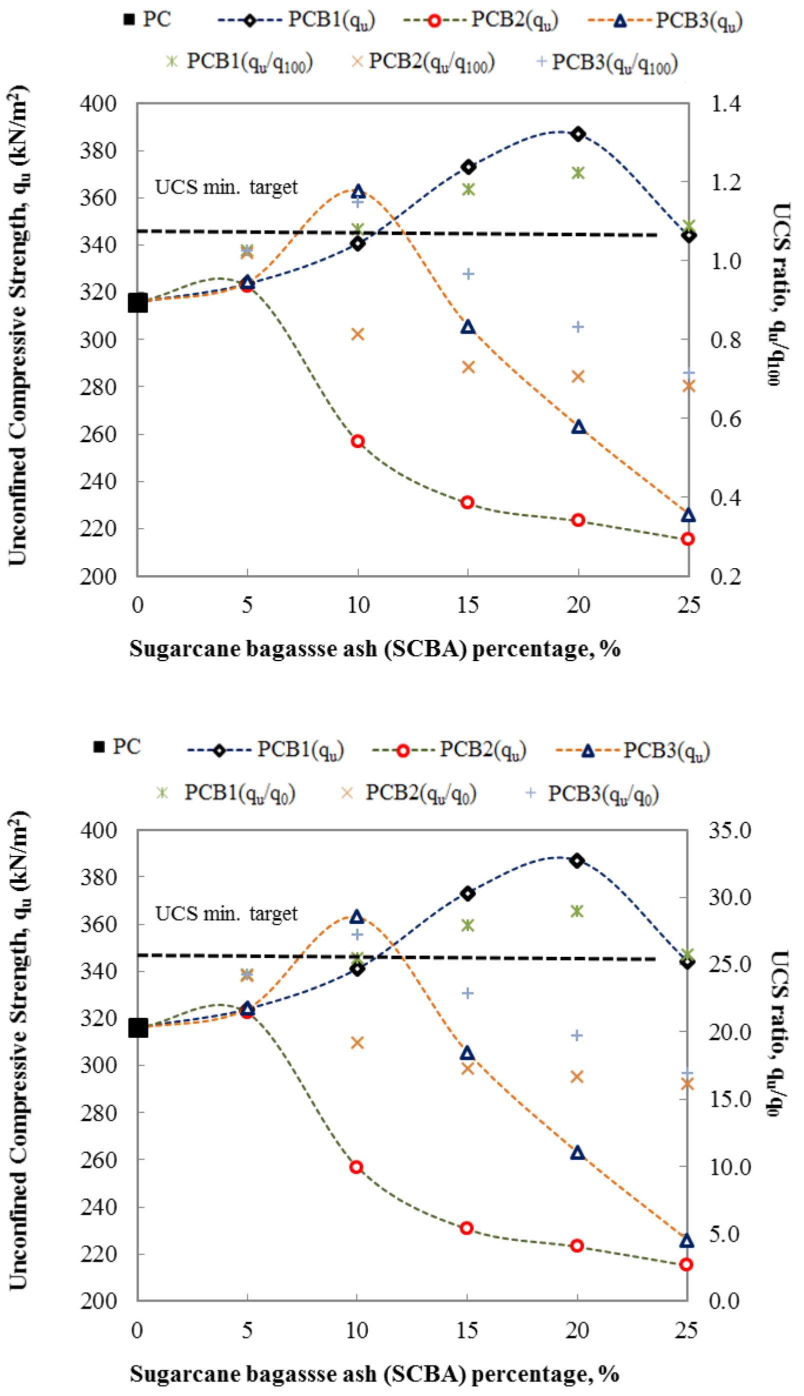


Figure 3.19: Unconfined compressive strength of PCB mixtures compared to PC mixture (top) and untreated peat (bottom)

Frequently, the pozzolanic effect depends not only on the pozzolanic reaction but also on the physical or filler effect of the smaller particles in the mixture [42]. The positive result indicates that the optimal mix design can be effectively applied to stabilize the peat in such a way that the fine particles of pozzolan fill up the pore spaces of the cemented soil, thus closely packing, reinforcing and strengthening its matrix as the hydration and pozzolanic products are formed during cement hydrolysis [41].

Figure 3.20 shows the results of pH and water contents for all PCB mixtures Generally, it can be seen that higher the pH seems gave better strength to specimens while water content looks like rely on rate of hydration by vary OPC composition. At peak point of all optimum PCB mixtures onwards, it seems clear decrease of the samples pH and consequently dropping its strength. It is observed this decrement pattern continuously occurred when the rate of cement content declined. In the other hand, water contents show the increment as SCBA percentage rose. In the other words, water consumption appears to increase as a percentage of cement is reduced. This is believed because of low hydration and pozzolanic reaction contributed both by SCBA inclusion and cement quantity. At 10% OPC replacement by SCBA, it was observed that UCS obtained for PCB 3 is higher than PCB 1. This phenomenon could be happened because of the SCBA reactivity amount and its grain size distribution. The SCBA particle in the PCB 3 that non-reactive normally will act as filler in mixtures which improve the stiffness (void filling) and strength of the mixing. This non-reactive particle is believed contributed by SCBA 2 (low quality SCBA). Since PCB 3 also comprise SCBA 1 particles, chemical effect was understood could be enhance its strength together with physical effect by finest grain of SCBA 1. It is well known that secondary pozzolanic reaction normally take place in later step and in long term hydration. The results in this figure were only revealed the UCS gained after 7 days curing. This is probably the reason why PCB 1 displays lower strength than PCB 3 at 10% OPC replacement.

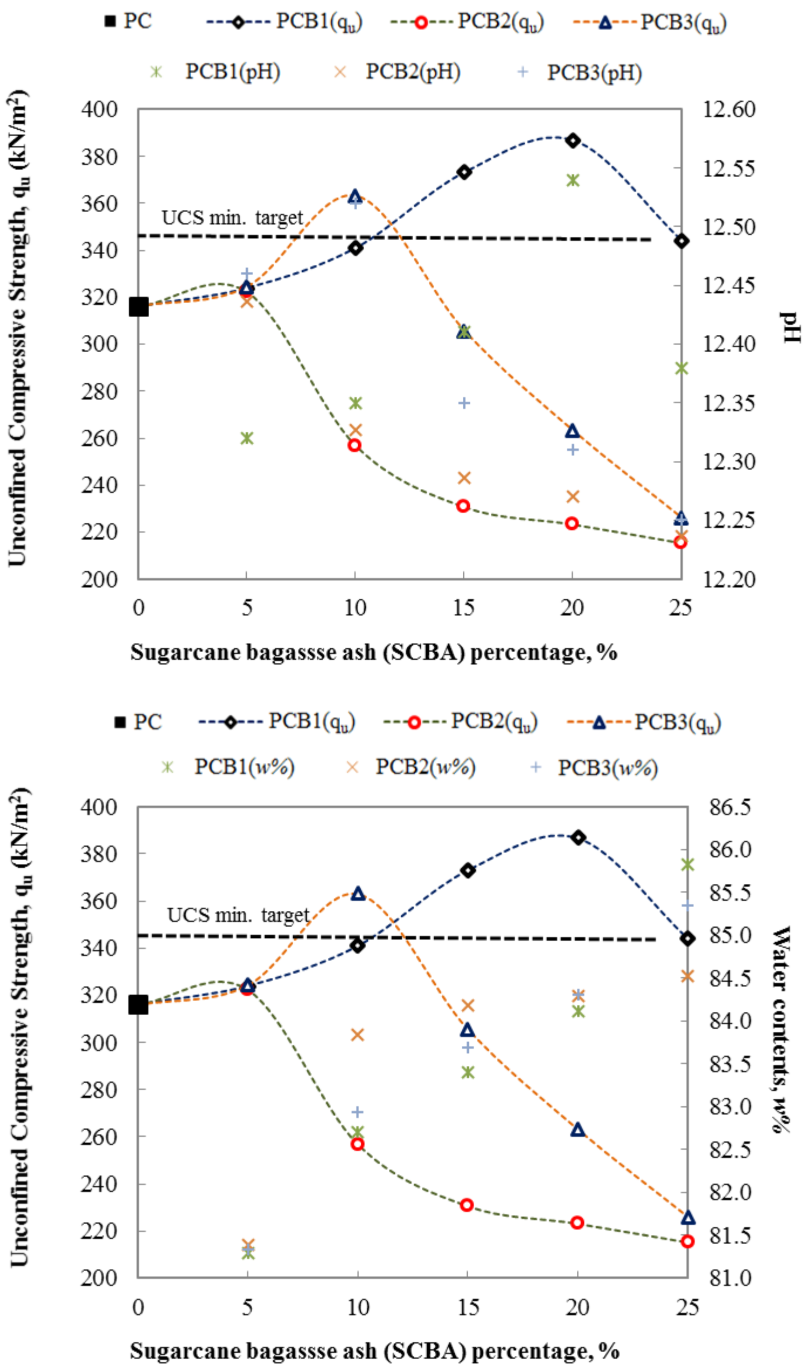


Figure 3.20: The results of pH (top) and water contents (bottom) for all PCB mixtures

For an organic soil stabilization to be effective, the pH value of the stabilized soil admixture must exceed 9. Tremblay et al. [46] stated that specimens with organic acids producing pH lower than 9 in the pore solution strongly affect the development of cementing products and also no strength gain was noted. However, they also mentioned that pore solution more than 9 not always indicate great strength gain. In the case of this study, for instance, although a pH value that exceeded the minimal required pH of 9 was achieved by stabilized peat admixture at all PCB mixtures, an unconfined compressive strength that exceeded the minimum target unconfined compressive strength of 345kPa was only reached at a minimum pH about 12.5 with maximum water contents about 85% (Figure 3.20). These occurrences happened because when insufficient cement is added, hydration and pozzolanic reaction become lower and effective neutralization of humid acids within the soil is not achieved. This is due to the limited formation of primary cementation products to bind the soil because the soil organic matter tends to retain the calcium ions produced from cement hydrolysis, resulting in a limited amount of calcium hydroxide that could react with silica and alumina of SCBA to yield secondary pozzolanic products during the pozzolanic reaction. The acids may also cause the soil pH to drop and this negatively affects the binder reaction rate, resulting in a slower strength gain in peat [11].

Secant values of Young's modulus of elasticity at 50% of the unconfined compressive strength, E_{50}, have been related to the unconfined compressive strength, q_u as shown in Figure 3.21. This relationship could be attained by dividing half of the peak strength ($q_u/2$) with the observed strain at the stress level in the UCS test. It was detected from this figure that a value of the ratio of E_{50} to q_u (E_{50}/q_u) for PCB 1 mixtures is greater than other mixtures and exceeds 50. From the literature review, values of E_{50}/q_u for the dry method of deep mixing have been stated in the range from 50 to 250 [47-49]. Figure 3.22 shows the relationship between strain at failure, ε_f and unconfined compressive strength, q_u for all optimum PCB mixtures. Obvious difference was detected between PCB 1 and PCB 2 mixtures which are represent high and low quality of SCBA respectively. This could be happened mainly because of percentage of SCBA in mixtures. When more SCBA was inserted in mixtures, ductile behavior was appeared. The different is PCB1 mixtures become ductile slowly compared to PCB2 with SCBA increment. This probably could be occurred because of the reactivity level of SCBA used in the mixtures. Higher reactivity pozzolan is tending to take part in hydration process and as a result the mixtures behavior is similar to the behavior of cement stabilized soil (generally shows the brittle behavior). On the contrary, non-reactive pozzolan like SCBA 2 will act as soil filler with limited hydration rate and finally make the mixtures more ductile.

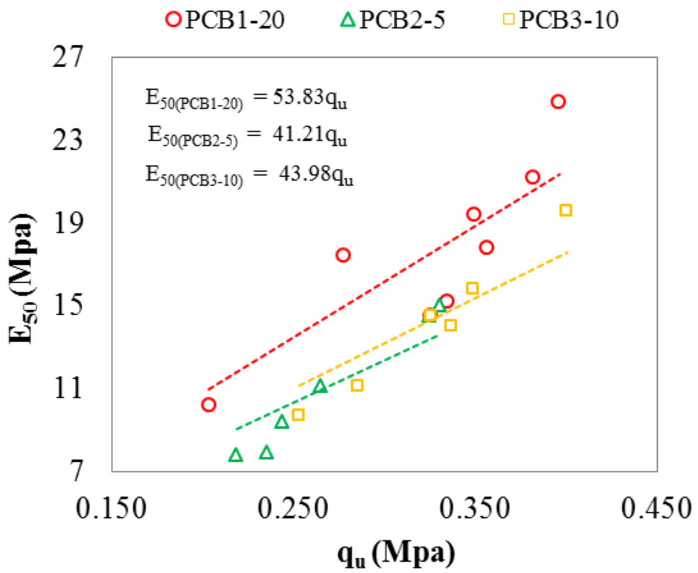


Figure 3.21: Relationship between secant modulus at E_{50} and unconfined compressive strength, q_u for all optimum PCB mixtures

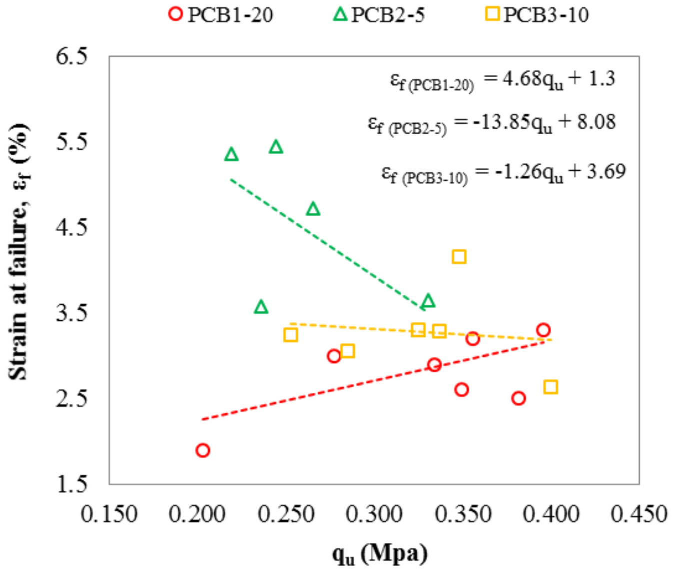


Figure 3.22: Relationship between strain at failure, ε_f and unconfined compressive strength, q_u for all optimum PCB mixtures

Based on the finding, the mixtures PC, PCB1-20, PCB2-5 and PCB3-10 corresponding to the optimal mix design was further applied to the remaining test specimens of stabilized peat in the experiment on various stabilization factor.

3.4.3 Two phase model for peat-cement-bagasse (PCB) mixtures

It is become something beneficial when PCB mixtures strength property at various percentage of SCBA inclusion could be estimated by knowing some important characteristics of raw SCBA. This idea possibly could be achieved through generalization of two phase mixtures model into studied PCB mixtures. Two phase mixtures can be defined as the mixtures that consist of a basic and a supplementary material which called a matrix and an inclusion. The concept in evaluate the deformation modulus of PCB mixture were shown in Figure 3.23. In this study, PC mixture that prepared in laboratory was considered as matrix while SCBA as an inclusion which its mechanical properties were known.

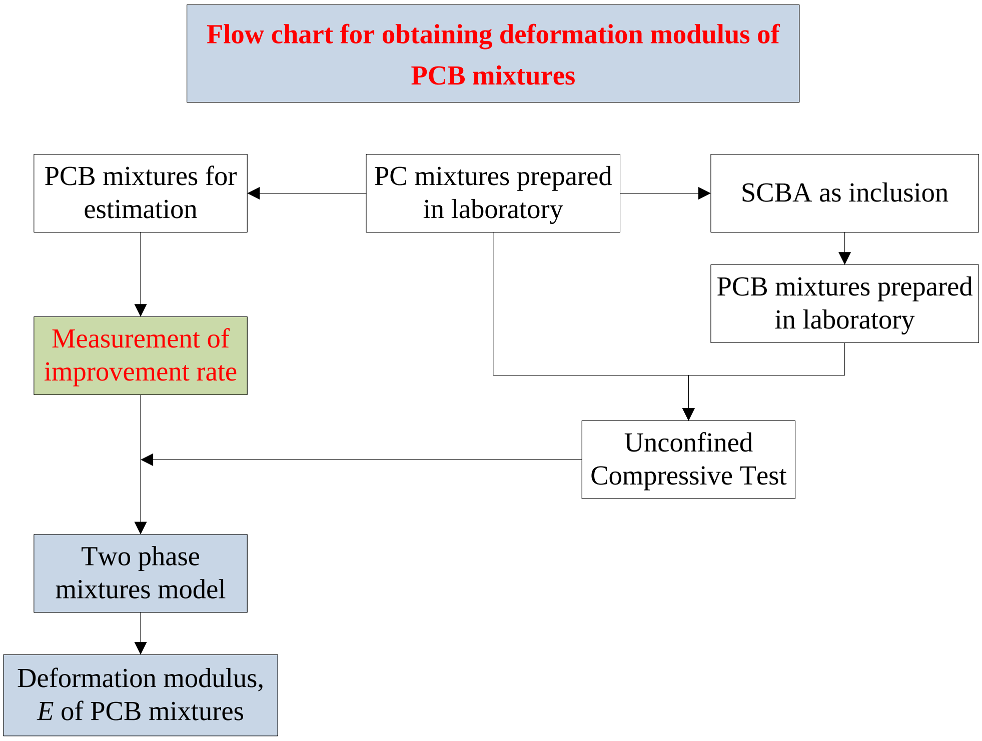


Figure 3.23: The concept in evaluate the deformation modulus of PCB mixture

Young modulus of two phase mixtures in 1-D stress condition from previous researcher [50-54] is represents by Eqn. 3.3 and Eqn. 3.4. For two phase model of peat- cement-bagasse (PCB) mixtures, b could be represents the estimation stress distribution while f_s denote the SCBA inclusion percentage. The parameter E_s and E^* indicate the deformation modulus of SCBA inclusion and PC mixture respectively. Deformation secant modulus, E_{50}, which is the compression stress-strain curve at a half of maximum compressive stress is usually used as parameter for representing unconfined compressive strength property. Therefore, the elastic moduli in Eqn. 3.3 correspond to the deformation moduli of the PCB mixtures as E= E_{50pcb}, E_s=E_{50s} and E^*=$E_{50}{}^*$.

$$E = \frac{(b-1) f_s + 1}{\frac{f_s b}{E_s} + \frac{(1-f_s)}{E^*}} \qquad (3.3)$$

where;

$$b = \left(\frac{E_s}{E^*} \right)^{1/2} \qquad (3.4)$$

The first step that had to be done with the intention of PCB mixtures deformation modulus, E_{50pcb} estimation is to determine the improvement rate of PC mixtures after SCBA inclusion. Therefore the vital parameters to evaluate first are E_s and E^*. As mentioned before, SCBA was considered as an inclusion and it deformation modulus, E_s will be assumed as constant (Eqn. 3.5). For E^*, it was expected that this values will increasing up to optimum PCB mixtures and gradually dropped afterwards. For that reason, the proposed equation for E^* is shown in Eqn. 3.6. By substituting Eqn.3.5 and Eqn. 3.6 into Eqn. 3.3 and Eqn. 3.4, Eqn. 3.7 and Eqn. 3.8 were derived for E_{50pcb} prediction.

$$E_s = \text{constant} \qquad (3.5)$$

$$E^* = E_0{}^*(1+\alpha\sqrt{f_s}) \qquad (3.6)$$

$$E = \frac{(b-1) f_s + 1}{\frac{f_s b}{E_s} + \frac{(1-f_s)}{E^*(1+\alpha\sqrt{f_s})}} \qquad (3.7)$$

where;

$$b = \left(\frac{E_s}{E^*(1+\alpha\sqrt{f_s})} \right)^{1/2} \qquad (3.8)$$

In Eqn. 3.6 to Eqn. 3.8, the main parameter is alpha (α). In this study, the α is suggested as indicator of quality characteristic of SCBA that could be enhance the filling (packing) and hydration effect of matrix until the optimum composition of PCB mixtures attained. After the optimum point reached, it is assumed that the more inclusion of SCBA will stop or decline the hydration effect in mixtures and consequently E_{50pcb} will decrease. As a result, α can be computed by Eqn. 3.9 and Eqn. 3.10. The Eqn. 3.9 is considered valid when $0 < f_s < f_{sopt}$ while the Eqn. 3.10 with the range $f_{sopt} < f_s < 1$. However there some limitation in Eqn. 3.10 which when f_s is larger than f_{sopt} and satisfy Eqn. 3.11, the α become zero.

$$\alpha = \alpha_0 f_{s_{opt}} \qquad \text{for} \qquad (0 < f_s < f_{sopt}) \qquad (3.9)$$

$$\alpha = \alpha_0 f_{s_{opt}} \left[1 - \left(\frac{f_s}{f_{s_{opt}}} - 1 \right)^{1/4} \right] \qquad \text{for} \qquad (f_{sopt} < f_s < 1) \qquad (3.10)$$

$$\alpha = 0 \qquad \text{when} \qquad \left(\frac{f_s}{f_{s_{opt}}} - 1 \right)^{1/4} > 1 \qquad (3.11)$$

In order to determine $\alpha_o f_{sopt}$, the graph α vs fs_{opt} (Figure 3.24) was developed by taking the optimum point for each SCBA from Figure 3.25 that created by using Eqn. 3.7. The α in Figure 3.25 were obtained by parametric study of this parameter in order to predict optimum point for all PCB mixtures. Next step is estimating the $\alpha_o f_{sopt}$ from the Figure 3.24 (equal to graph trend line gradient) which from this study the $\alpha_o f_{sopt} = 15 f_s$. This value then will be used in Eqn. 3.9 and Eqn. 3.10 before replace the α in Eqn. 3.7 for predicting all E_{50pcb}. With the intention of f_{sopt} (optimum percentage of SCBA inclusion) approximation, Figure 3.26 (f_{sopt} vs P_E/C_E) was developed and could be used. This graph was created base on the crucial characteristic that is able to distinguish between the good and low quality of all used SCBA. The characteristics were mainly focusing on physical effect, P_E (e.g. D_{50}) and chemical effect, C_E (e.g. CaO_2/SiO_2). Based on literature review [40; 42; 55; 56], these two vital characteristics are believed become the main contributor of filling and hydration effect in PCB mixtures.

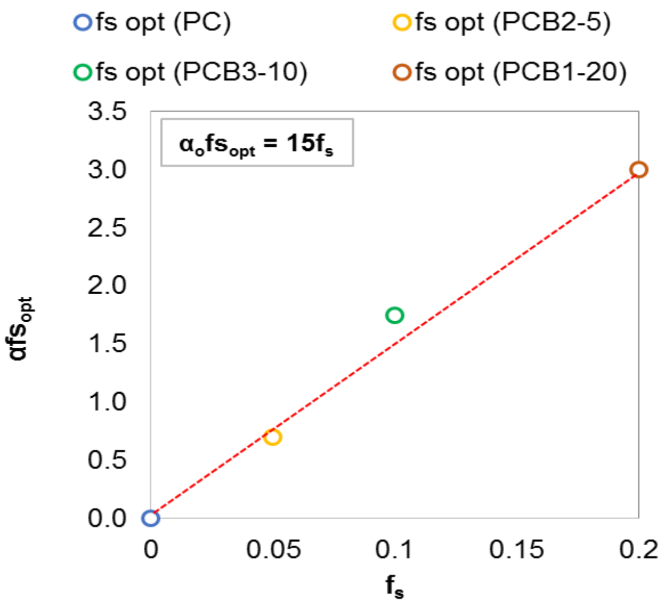


Figure 3.24: Relationship between alpha coefficient, α and optimum SCBA inclusion, f_{sopt}

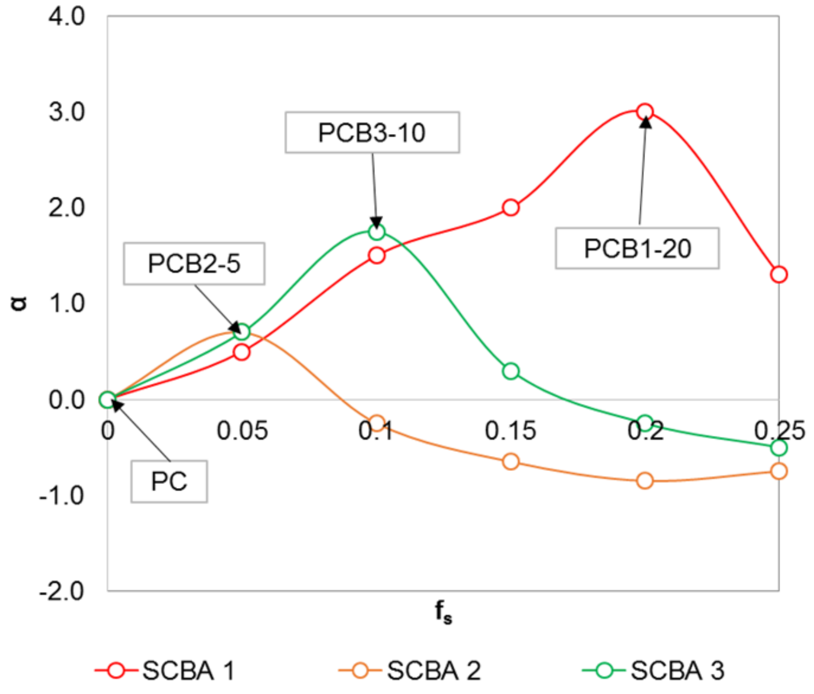


Figure 3.25: Relationship between alpha coefficient, α and SCBA inclusion, f_s

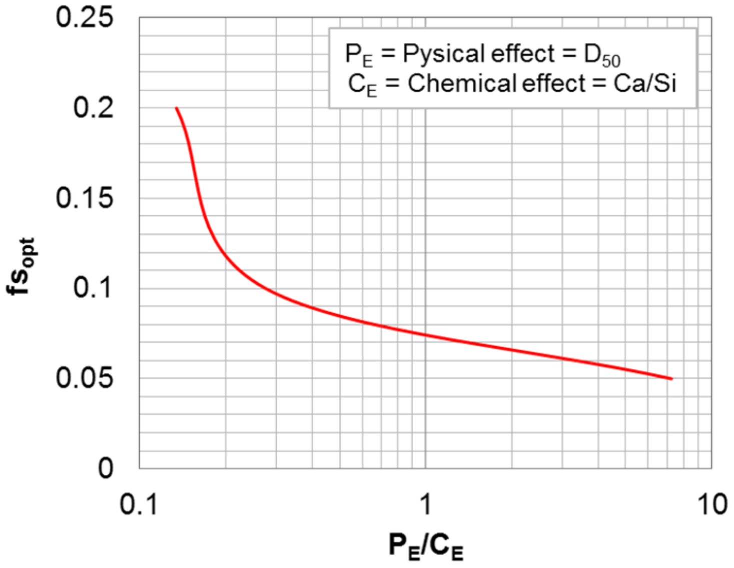


Figure 3.26: Relationship between physical effects: chemical effects ratio of SCBA, P_E/C_E and optimum SCBA inclusion, f_{sopt}

The data and results of calculation/estimation of E_{50pcb} versus experimental E_{50pcb} was summarized in Table 3.4 and Figure 3.27 for all PCB mixtures. Obviously, the proposed calculation results seem very effective by presenting the good agreement with the experimental PCB mixtures deformation modulus.

Table 3.4: The data of calculation/estimation of E_{50pcb} versus experimental E_{50pcb}

	Mixtures	**PCB5**	**PCB10**	**PCB15**	**PCB20**	**PCB25**
	f_s	0.05	0.1	0.15	0.2	0.25
PC mixtures	E_{50}^{*}	14.50				
SCBA 1	E_{50s}	7.60				
	$E_{50pcb\ (lab)}$	15.20	19.40	21.20	24.80	17.80
	$E_{50pcb\ (est)}$	16.25	19.21	22.25	24.84	17.05
SCBA 2	E_{50s}	2.08				
	$E_{50pcb\ (lab)}$	15.00	11.10	9.40	7.90	7.80
	$E_{50pcb\ (est)}$	15.13	11.68	10.55	9.56	8.69
SCBA 3	E_{50s}	4.10				
	$E_{50pcb\ (lab)}$	15.80	19.60	14.00	11.09	9.70
	$E_{50pcb\ (est)}$	15.83	18.22	13.35	11.17	10.49

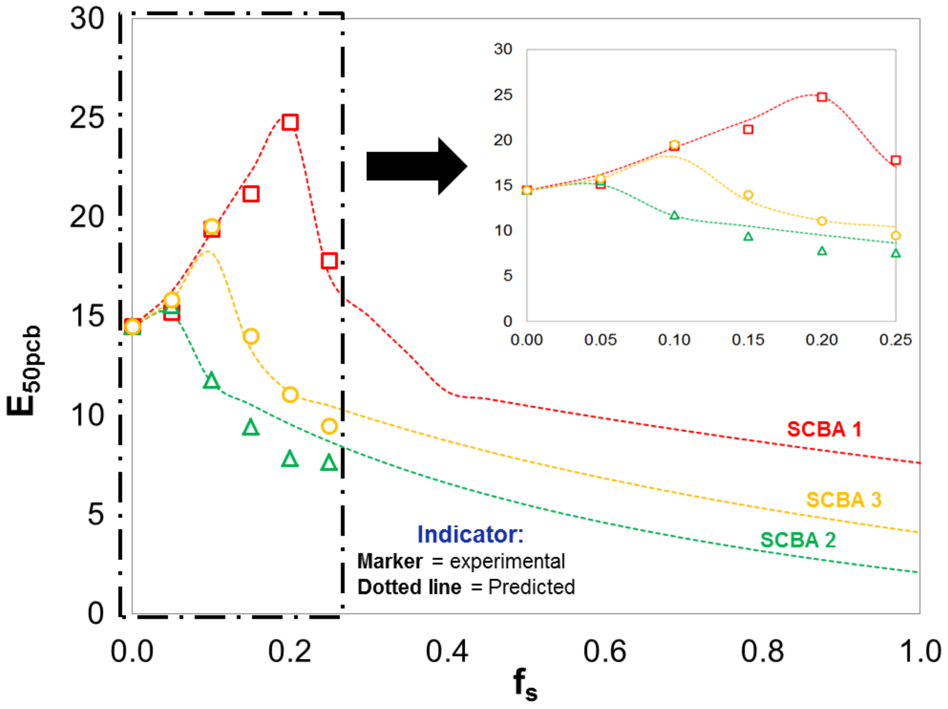


Figure 3.27: The results of calculation/estimation of E_{50pcb} versus experimental E_{50pcb}

3.4.4 Effects of duration of curing in water

It can be observed from Figure 3.28 that the UCS of all optimum PCB mixture specimens increased while increasing the duration of curing in water. When the surcharge of 20 kPa was applied, the UCS of test specimens increased progressively at the curing time in water of 7, 14, 21, 28 and 60 days for PC and PCB mixtures. It is evident from the findings that the duration of curing in water influenced the UCS of test specimens. All PCB mixtures show the slow increment compare to PC mixtures and overall PCB 1 mixtures shows the higher positive results. However, it is clear that after 7 to 14 days of curing, UCS of PCB2-5 and PCB3-10 mixtures become lesser than PC mixture and this trends looks continuously till 2 month of curing. This results shows the good agreement with the fact that cement hydration (PC mixtures) is normally rapid and effective at first month but almost stop or complete after that duration while pozzolan reaction can be occurred continuously until several month or even years [8; 38; 45]. Therefore it is plainly indicate that the quality of selected SCBA is very important and should be prudently examined in order to get long term strength gain.

The rate of the UCS development was very rapid within 7 days of curing duration, after which between 28 and 60 days of curing time, it reached a state of transition in which the UCS increase began to slow down. A drastic increase in the unconfined compressive strength at 7 days of curing was mainly attributed to a combination of cement accelerator ($CaCl_2$), filler effect of both silica sand and SCBA, hydration reaction of the cement, and pozzolanic activity of SCBA. Pozzolanic reactions depend on calcium hydroxide released by the hydration reactions of calcium silicates as exposed in Eqn. 3.2. Figure 3.29 represents the effect of curing duration for all peat-cement-bagasse ash (PCB) mixtures on the acidity, pH and water contents, *w%*. It was observed that pH increase with curing time and simultaneously reduces the *w*. The reason why this could be happened is perhaps because there are more hydration development occurred with elapsed time in alkaline condition and consequently enhance the mixture strength. As known, hydration process requires enough water in order to get proper cementation product and this progression is significant at first month of curing.

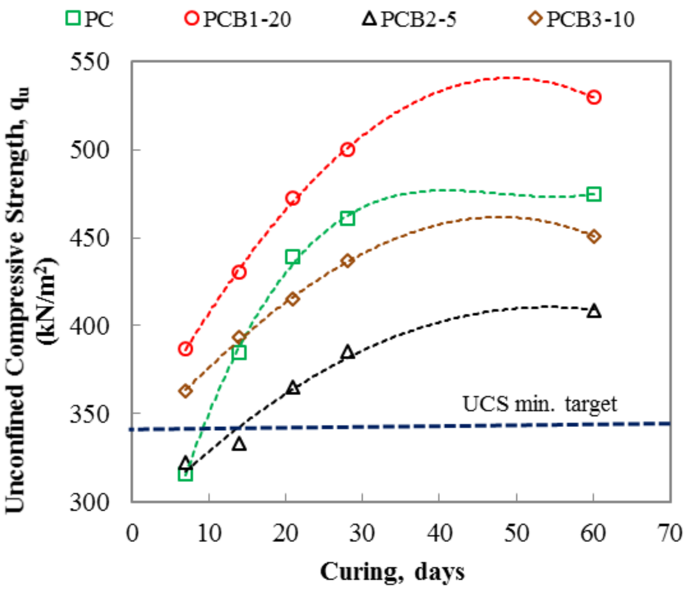


Figure 3.28: Effect of curing duration for all peat-cement-bagasse ash (PCB) mixtures on the unconfined compressive strength, q_u

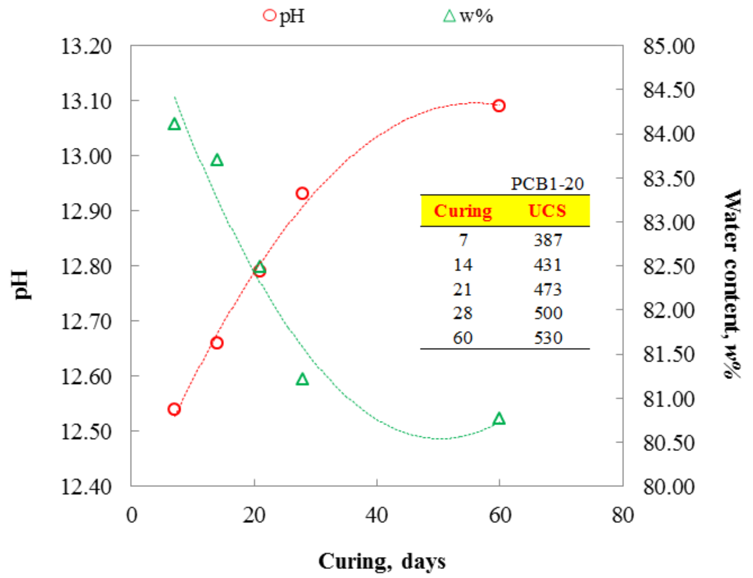


Figure 3.29: Effect of curing duration for PCB 1 mixtures on the acidity, pH and water contents, *w%*

3.4.5 Effect of preloading during curing

Figure 3.31 shows the results of preloading effect on stabilized peat by all PCB mixtures. The results indicate the positive and linear improvement when the initial loading rises for all PC and PCB mixtures. It observed that preloading gave the significant increment even only subjected the pressure as small as 20 kPa if compared to the specimen without pressure during curing. For PCB2-5, it is suggested to use at least 40 kPa (about 2 meter high of embankment in the field) preloading during to the aim of minimum strength. The strength of stabilized peat is pronouncedly affected by the application of initial load shortly after mixing with binder. Refer to Figure 3.31, PC mixtures strength was exceed PCB2-5 mixtures start from 60 kPa subjected initial loading and the different obvious at 100 kPa of preloading. This could be happened when more contact between material particles and cement, hydration progression could be formed easily and rapidly. Since PC mixtures consume 100% of OPC compositions, therefore more cement products able to produce while for PCB-5 mixtures was likely tend to fill the mixture voids caused by 5% of SCBA 2 replacement. For that reason it could be suggested that the replacement of cement by low quality of SCBA are not recommended for high embankment.

Particularly in stabilizing peat, an initial surcharge or preloading, in the field has been regarded necessary in order to create a more homogeneous stabilized mass of peat. Besides, preloading provides a trafficable bed for the continuous stabilization of adjacent areas, thereby considerably improve the strength of stabilized peat. Without preloading as a trafficable bed during peat stabilization, the situation that illustrated in Figure 3.30 may be occur. It is not the magnitude of the initial load itself that governs the increase in strength, but the amount of compression resulting from loading. The void spaces between the binder grains and the solid soil particles in peat would be reduced by the compression that occurs under preloading. With the increasing preloading, the compression increases resulting in the decrease of initial density of the stabilized soil and time lapse between mixing and loading [33]. Figure 3.32 indicates the effect of preloading for PCB 1 mixtures on the acidity, pH and water contents, w%. Overall, it can be seen from this graph that the water contents uniformly dropped by 5% between 0 kPa and 100 kPa of initial loading. On the contrary, pH results climbed rapidly at first 20 kPa of preloading and followed by gradual soared from that point. This finding shows the agreements with strength gained (from 218 kPa to 387 kPa) which is the preloading gave the significant increment when subjected the pressure of 20 kPa if compared to the sample without pressure during curing.

Figure 3.30: On site difficulty in peat stabilization

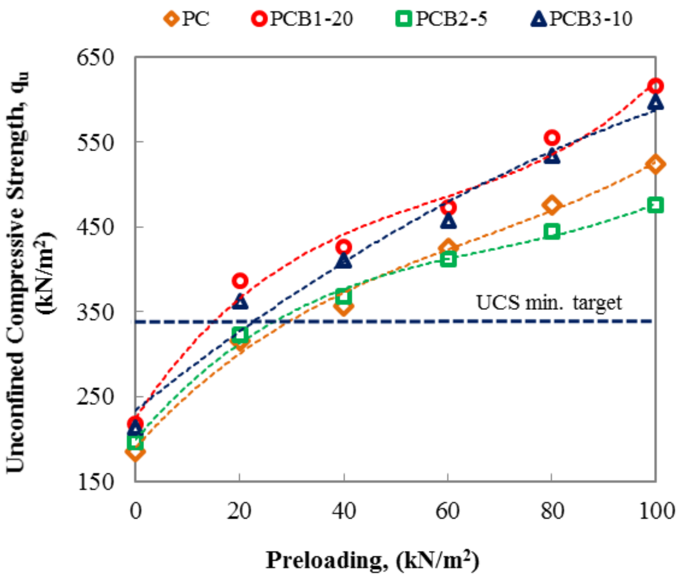
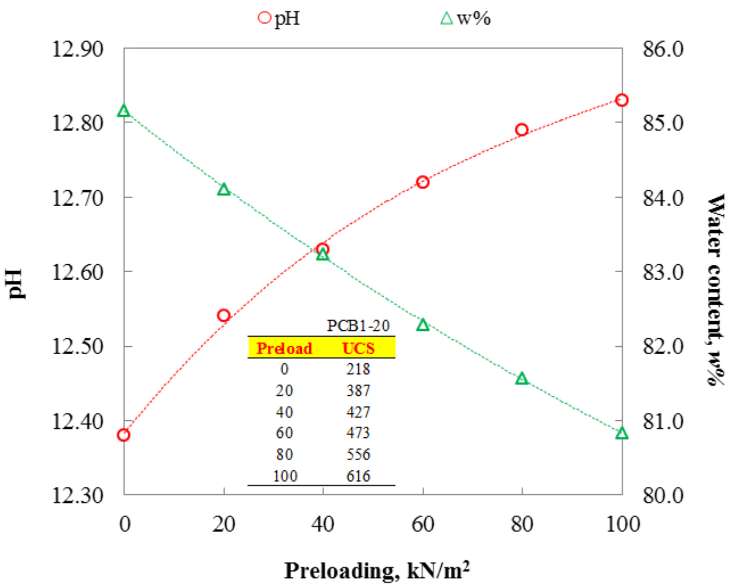


Figure 3.31: Effect of preloading for all peat-cement-bagasse ash (PCB) mixtures on the unconfined compressive strength, q_u



Preload	UCS
0	218
20	387
40	427
60	473
80	556
100	616

Figure 3.32: Effect of preloading for PCB 1 mixtures on the acidity, pH and water contents, *w%*

3.4.6 Effects of Ordinary Portland Cement (OPC) dosage

Figure 3.33 shows the results of the effect of the OPC dose to the unconfined compressive strength. In relation to the dosage of OPC, binder quantity must be adequate to achieve the threshold for effective stabilization of peat. It can be seen from Figure 3.33 that strength gain gradually increases with OPC dosage and it is more obvious especially after the amount exceed 250 kg/m^3. All PCB mixtures except PCB2-5 gave the good results that exceed the minimum UCS target in this study. It is revealed that at satisfactory OPC quantity, the acid in the peat could be neutralized. This also imply that below the threshold binder dosage, stabilization of the peat remains hindered due to insufficient binder to induce cement hydration and pozzolanic reactions in the test specimens. This is by reason of the limited formation of primary cementation products to bind the soil because the soil organic matter tends to retain the calcium ions produced from cement hydrolysis, resulting in a limited amount of CH that could react with silica (Si) and alumina (Al) of SCBA to yield secondary pozzolanic products during the pozzolanic reaction.

Figure 3.34 displays the effect of ordinary Portland cement (OPC) dosage for PCB 1 mixtures on the acidity, pH and water contents, w%. Similar to SCBA composition effect in Figure 3.20, the strength rose as the water contents decrease and the pH increased. Plainly, the water content declined sharply when the OPC contents larger. This situation can ensue due to high water consumption during the effective cement hydration that could only be achieved when the amount of cement reach optimum levels.

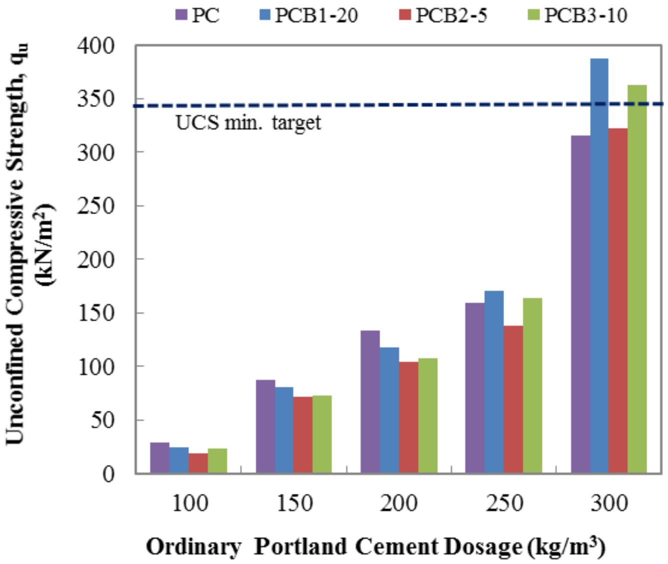


Figure 3.33: Effect of Ordinary Portland Cement (OPC) dosage for all peat-cement-bagasse ash (PCB) mixtures on the unconfined compressive strength, q_u

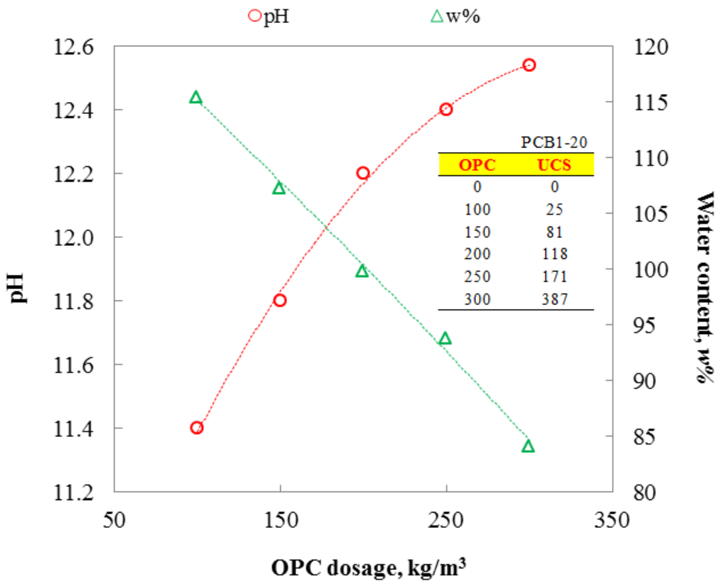


Figure 3.34: Effect of ordinary Portland cement (OPC) dosage for PCB 1 mixtures on the acidity, pH and water contents, *w%*

3.4.7 Effects of silica sand (K7) dosage

By the same optimum binder composition, test specimens were prepared at varying K7 silica sand dosages of 0, 100, 200, 300, 400 and 500 kg/m^3 for the purpose of evaluating its effect on the stabilized peat. The result in Figure 3.35 shows that there was a progressive increment of the UCS when the dosage of silica sand of the test specimens increases. This suggests that well graded silica sand had a positive effect on the development of the UCS in such a way that it increased the density and reduced the void of the test specimens. Because silica sand is chemically inert, it did not take part in the cement hydration process. However, it provided solid particles for the binder to bind and form a load bearing stabilized soil. The particle of the sand is strong and it shape almost spherical and uniform that make it almost no internal voids. For PCB1-20 and PCB3-10 mixture, inclusion of a minimum OPC dosage of 300 kg/m^3 and K7 dosage of 500 kg/m^3 along with curing under 20 kPa pressure is recommendable for the peat stabilization to be effective. However for PCB2-5 mixture, it suggested to use more OPC and K7 dosage or alternatively increase the preloading during curing to 40 kPa in order to achieve minimum strength target.

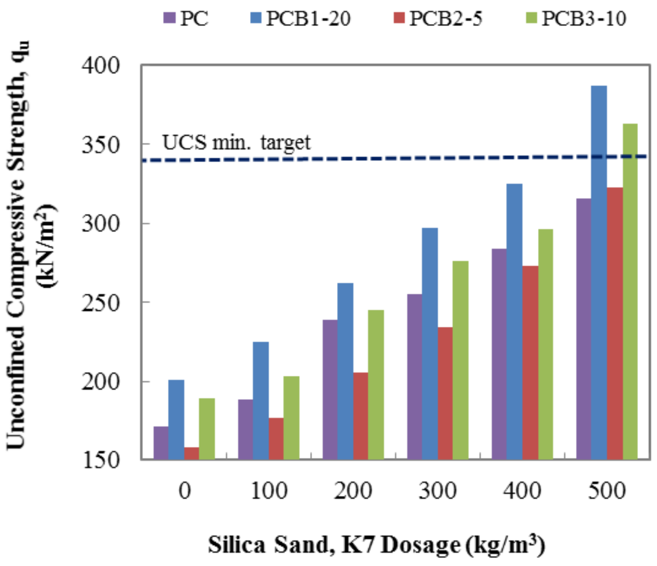


Figure 3.35: Effect of silica sand (K7) dosage for all peat-cement-bagasse ash (PCB) mixtures on the unconfined compressive strength, q_u

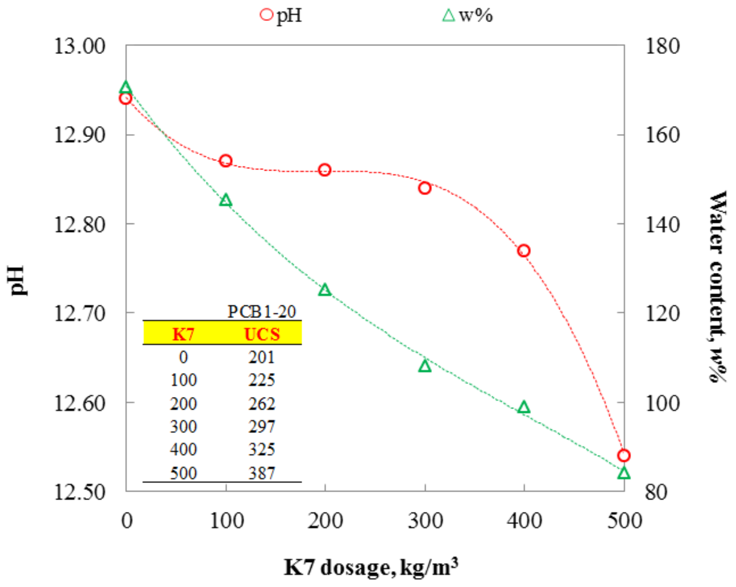


Figure 3.36: Effect of silica sand (K7) dosage for PCB 1 mixtures on the acidity, pH and water contents, *w%*

Figure 3.36 displays the effect of silica sand (K7) dosage for PCB 1 mixtures on the acidity, pH and water contents, w%. Visibly, the water contents percentage were observed fell rapidly from 170% to 84% between 0 and 500 kg/m^3 of K7. This sharp decline is due to the nature of the K7 which fulfill the void spaces between grains of soil, thus making the sample becomes more solid and strong. Contrary to previous findings, the pH results show the slight decrements as the strength augmented. This finding makes an agreement with Tremblay et al. [46] which mentioned that pore solution more than 9 not always indicate great strength gain. As explained before, since K7 is almost inert, this material is more likely contribute to the physical strength rather than chemical effect (not involve in hydration progression). This evidence is likely to became the causes why the pH decreased when K7 and strength of the sample increases.

3.4.8 Effect of calcium chloride ($CaCl_2$) as OPC accelerator

Calcium chloride is a common accelerator that used to quicken the period and the rate of strength gain especially in concrete technology. This material is well known as economical and effective accelerating admixtures. It should meet the requirements of ASTM D 98 [57]. Too much quantities of $CaCl_2$ in concrete mix may result in rapid stiffening, increase in drying shrinkage and corrosion of reinforcement. The normal range of $CaCl_2$ compositions are between 1 and 4% of cement amounts [58-61]. Figure 3.37 describes the effect of calcium chloride ($CaCl_2$) dosage for all peat-cement-bagasse ash (PCB) mixtures on the unconfined compressive strength, q_u. Strength improvement was perceived with $CaCl_2$ increases. However, the pattern of increments shows the non-uniform.

Noticeably for all PC and PCB mixtures, the strength gain significantly when the $CaCl_2$ rose from 1 to 3% and almost levelled off at 4%. According to Abrams [59], for concrete cured in a moist room, he found the optimum dosage to be 2% to 4%. In addition he concluded that no advantage was gained by using dosages higher than 3%. The study done by Price [62] prove that concrete with dosages up to 3% of $CaCl_2$ improved compressive strength at all ages up to a year. Besides, he also concluded that there was little advantage in using more than 3% $CaCl_2$ because the tests showed very little strength increase when the dosage was increased from 2% to 3%. These discoveries become the reasons why 3% of $CaCl_2$ was used in all samples for experimental laboratory works in this research study. Figure 3.38 illustrates the effect of calcium chloride (CaCl2) dosage for PCB 1 mixtures on the acidity, pH and water contents, w%. Undoubtedly, the strength shows the gradual improvement with increment of pH together with water contents reduction.

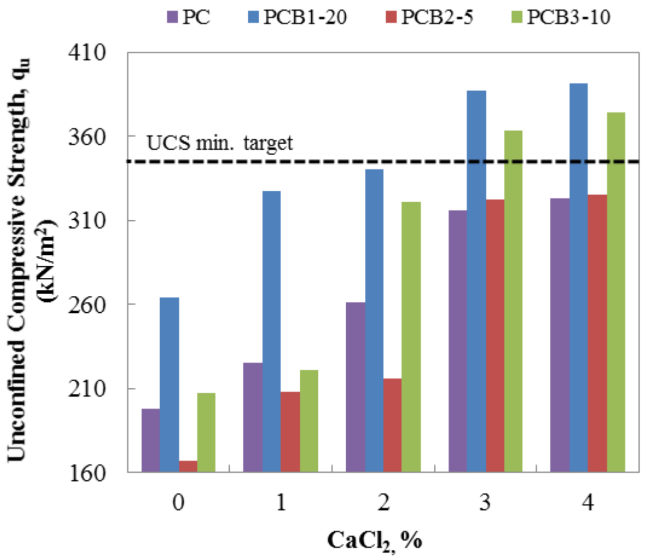
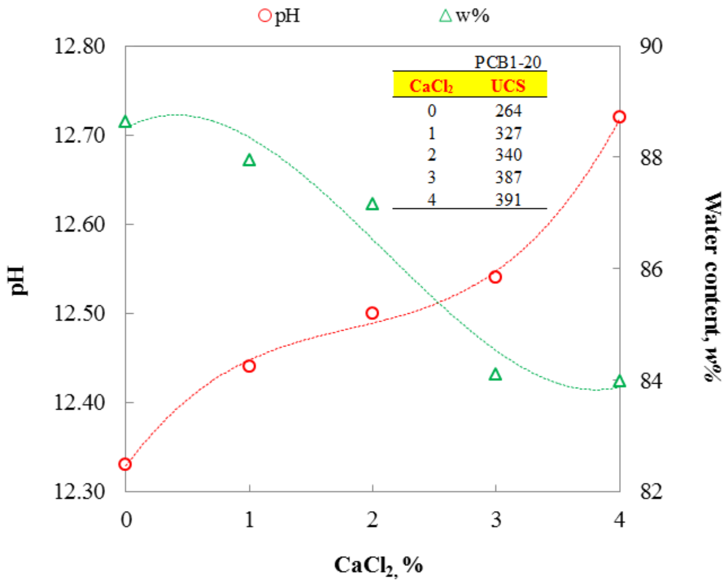


Figure 3.37: Effect of calcium chloride ($CaCl_2$) dosage for all peat-cement-bagasse ash (PCB) mixtures on the unconfined compressive strength, q_u



PCB1-20

$CaCl_2$	UCS
0	264
1	327
2	340
3	387
4	391

Figure 3.38: Effect of calcium chloride ($CaCl_2$) dosage for PCB 1 mixtures on the acidity, pH and water contents, *w%*

3.5 Summary

As summary, this chapter presents the approach method to clarifying effectiveness the three types of sugarcane bagasse ash (SCBA) utilization on peat strength. The unconfined compressive strength (UCS) tests were conducted at all samples with the aim to elucidate the stabilized peat strength improvement. The new simple method for preloading during curing was executed by using controlled air pressure instead of iron rod in conventional method. The main target of this chapter is to determine the optimum SCBA inclusion as partial replacement of cement. The best mixtures from eac h SCBA then chosen and use in further UCS test which is stresses on various effect factor in peat stabilization.

It was found that stabilized peat comprising 20%, 5% and 10% (PCB1-20, PCB2-5 and PCB3-10) partial replacement of OPC with SCBA 1, SCBA 2 and SCBA 3 attain the maximum unconfined compressive strength (UCS) and discovered greater than untreated soil (P) and peat-cement (PC) specimen. Generally, it observed that higher the pH seems gave better strength to specimens while water content looks like rely on rate of hydration by vary OPC composition. Moreover, the proposed calculation to predict deformation modulus of Peat-Cement-Bagasse (PCB) mixtures based on two-phase mixtures model was introduced and developed. The main benefit of this proposed model is the ability to determine the optimum PCB mixture which depends on the physical and chemical effects of SCBA. It was observed that the proposed model outcomes demonstrate a well agreement with the experimental results. At the optimal mix design, the UCS of the stabilized peat specimens increased with increasing of curing time, OPC dosage, K7 dosage and preloading. For PCB1-20 and PCB3-10 mixture, inclusion of a minimum OPC dosage of 300 kg/m^3 and K7 dosage of 500 kg/m^3 along with curing under 20 kPa pressure is recommendable for the peat stabilization to be effective. However for PCB2-5 mixture, it suggested to use more OPC and K7 dosage or alternatively increase the preloading during curing to 40 kPa in order to achieve minimum strength target.

3.6 References

[1] Kazemian, S., Huat, B.B.K., Prasad, A. and Barghchi, M., 2011. A state of art review of peat: Geotechnical engineering perspective. International Journal of the Physical Sciences, 6(8): 1974-1981.

[2] Haan, d.E.J. and Kruse, G.A.M., 2006. Characterisation and engineering properties of Dutch peats. In: D.W.H. K . K . Phoon , S . Leroueil , and T . S . Tan (Editor), Characterisation and Engineering Properties of Natural Soils. Taylor & Francis pp. 2101-2133.

[3] Islam, M.S. and Hashim, R., 2008. Use of Mackintosh Probe Test for Field Investigation in Peat Soil. Proc. of Int. Conf. on Highway and Geotechnical Engineering, 26th - 27th May 2008, Best Western Premier Seri Pacific Kuala Lumpur, Malaysia, pp. 27.

[4] Islam, S. and Hashim, R., 2008. Engineering properties of peat soils in peninsular Malaysia. J. Appl. Sci., 8(22).

[5] Andriesse, J.P., 1988. Nature and Management of Tropical Peat Soils. FAO Soils Bulletin 59 Rome, ISBN Number: 9251026572, Edition Number: 291894.

[6] Huat, B.K., 2006. Deformation and Shear Strength Characteristics of Some Tropical Peat and Organic Soils. Pertanika J. Sci. & Techno., 14(1&2): 61-74.

[7] Zainorabidin, A. and Wijeyesekera, D.C., 2008. Geotechnical Characteristics of Peat. Proceedings of the AC&T, pp.71 -78.

[8] EuroSoilStab, 2002. Development of design and construction methods to stabilize soft organic soils. Design guide soft soil stabilization. CT97-0351. Project No. BE 96-3177, Industrial & Materials TechnologiesProgramme (Brite- EuRam III), European Commission.

[9] Wong, L.S., Hashim, R. and Ali, F., 2011. Unconfined compressive strength characteristics of stabilized peat. Scientific Research and Essays, 6(9): 1915-1921.

[10] Hebib, S. and Farrell, E.R., 2003. Some experiences on the stabilization of Irish peats. Canadian Geotechnical Journal, 40(1): 107-120.

[11] Axelsson, K., Johansson, S.E. and Anderson, R., 2002. Stabilization of Organic Soils by Cement and Puzzolanic Reactions- Feasibility Study, Swedish deep stabilization Research Centre, Report 3, English translation.

[12] Hashim, R. and Islam, M.S., 2008. Properties of stabilized peat by soil-cement column method. EJGE. Electronic J. Geotechn. Eng., p.1-9.

[13] Islam, M.S. and Hashim, R., 2010. Stabilization of peat soil by soil-column technique and settlement of the group columns. International Journal of the Physical Sciences, 5(9): 1411-1418.

[14] Kazemian, S. and Huat, B.K., 2009. Compressibility characteristics of fibrous tropical peat reinforced with cement column. Electronic J. Geotech. Eng., 14E: 1-8.

[15] Moayedi, H., Kazemian, S. and Huat, B.B.K., 2013. Shear Strength Parameters of Improved Peat by Chemical stabilizer. Geotechnical and Geological Engineering, Volume 31, Issue 4, pp 1089-1106.

[16] Lechowicz, Z., 1994. An Evaluation of the Increase in Shear-Strength of Organic Soils. Advances in Understanding and Modelling the Mechanical Behaviour of Peat: 167-179.

[17] Huat, B.K., Sew, G.S. and Ali, F.H., 2004. Organic and Peat Soils Engineering. Serdang, University Putra Malaysia, Press, ISBN Number: 983-2871-08-5.

[18] Landva, A.O. and LaRochelle, P., 1983. Compressibility and shear characteristics of radforth peats. Testing Peat Organic Soils, ASTV STP, 820: 157-191.

[19] Culloch, F.M., 2006. Guidelines for the Risk Management of Peat Slips on the Construction of Low Volume/ Low Cost Road Over Peat. Scotland: For. Civ. Eng. For. Comm., pp. 1-46.

[20] Edil, T.B., 2003. Recent advances in Geotechnical characterization and construction over peat and organic soils. Proceedings 2nd International Conference on Advances in Soft Soil Engineering and Technology: 3-25.

[21] Leong, E.C. and Chin, C.Y., 2000. Geotechnical Characteristics of Peaty Soils in Southeast Asia. In Proceedings of GeoEngineering, Melbourne, Australia.

[22] Munro, R., 2004. Dealing with bearing capacity problems on low volume roads constructed on peat, The Highland Council, Environmental and Community Service, HQ, Glenurquhart Road, Scotland.

[23] Jelisic, N. and Leppanen, M., 1999. Mass stabilization of peat in road and railway construction. Dry Mix Methods for Deep Soil Stabilization: 59-64.

[24] Huat, B.K., Maail, S. and Mohamed, T.A., 2005. Effect of Chemical Admixtures on the Engineering Properties of Tropical Peat Soils. American Journal of Applied Sciences, 2(7): 1113-1120.

[25] Hashim, R. and Islam, M.S., 2008. A Model Study to Determine Engineering Properties of Peat Soil and Effect on Strength after Stabilisation. European Journal of Scientific Research, 22(2): 205-215.

[26] Kazemian, S. et al., 2011. Effect of aggressive pH media on peat treated by cement and sodium silicate grout. Journal of Central South University of Technology, 18(3): 840-847.

[27] Kazemian, S., Huat, B.K. and Prasad, A., 2011. Study of Peat Media on Stabilization of Peat by Traditional Binders. Int. J. Phys. Sci., 6(3): 476-481.

[28] Kazemian, S., Huat, B.K. and Barghchi, M., 2011. Effect of calcium chloride and kaolinite on shear strength and shrinkage of cement grout. Int. J. Phys. Sci., 6(4): 707-713.

[29] Bergado, D.T., Anderson, L.R., Miura, N. and Balasubramaniam, A.S., 1996. Soft Ground Improvement. New York: ASCE Press.

[30] Mohidin, M.N. et al., 2007. Some Index Properties on Rengit Peat Soil Stabilize with Cement-Lime. Prosiding Kebangsaan Awam '07, Langkawi, Kedah.

[31] Chen, H. and Wang, Q., 2006. The behaviour of organic matter in the process of soft soil stabilization using cement. Bulletin of Engineering Geology and the Environment, 65(4): 445-448.

[32] Sobhan, K., Reddy , D.V. and Ramirez, J.C., 2012. Cement Stabilization of Organic Subgrades for Pavement Preservation. In: LACCEI (Editor), Megaprojects: Building Infrastructure by fostering engineering collaboration, efficient and effective integration and innovative planning Panama City, Panama.

[33] Ahnberg, H., 2006. Strength of stabilised soils– A laboratory study on clays and organic soils stabilised with different types of binder, Swedish deep stabilization Research Centre, Report 16, English translation.

[34] Wong, L.S., Roslan, H. and Ali, F.H., 2008. Engineering Behaviour of Stabilized Peat Soil. European Journal of Scientific Research, 21(4): 581-591.

[35] Wong, L.S., Hashim, R. and Ali, F., 2013. Improved strength and reduced permeability of stabilized peat: Focus on application of kaolin as a pozzolanic additive. Construction and Building Materials, 40: 783-792.

[36] Lin, T.B., 2011. Revitalization of Organic and Peat Soils, Universiti Tun Hussein Onn Malaysia, Malaysia.

[37] RISDA, Garis Panduan Pengurusan Dan Penanaman Sawit Di Kawasan Tanah Gambut. www.mpn.gov.my/c/document_library/get_file?uuid=363518fc-f66b-4c80-b942-d9bc33adb8ed&groupId=82677.

[38] Allu, F.O., 2005. Mass stabilization Manual.

[39] Maijala, A. et al., 2009. Cement stabilization and solidification- review of techniques and methods. Rap001-Id01.

[40] Janz, M. and Johansson, S.E., 2002. The function of different binding agents in deep stabilization, Swedish Deep Stabilization Research Center, Linkoping: SGI. 9.

[41] Wong, L.S., Hashim, R. and Ali, F., 2013. Utilization of sodium bentonite to maximize the filler and pozzolanic effects of stabilized peat. Engineering Geology, 152(1): 56-66.

[42] Isaia, G.C., Gastaldini, A.L.G. and Moraes, R., 2003. Physical and pozzolanic action of mineral additions on the mechanical strength of high-performance concrete. Cement & Concrete Composites, 25(1): 69-76.

[43] ASTM-C618, 2005. Standard Specification for Fly Ash and Raw or Calcium Natural Pozzolanas for Use in Concrete. American Society for Testing and Materials Standards, Pennsylvania, USA, Volume 04.02.

[44] ASTM, 2005. American Society of Testing Materials, Annual Book of ASTM Standards, Soil and Rock (I): D 420 - D 5611, Vol. 04.08.

[45] Wong, L.S., Hashim, R. and Ali, F.H., 2009. A Review on Experimental Investigations of Peat Stabilization. Australian Journal of Basic and Applied Sciences, 3(4): 3537-3552, 2009. ISSN 1991-8178.

[46] Tremblay, H., Duchesne, J., Locat, J. and Leroueil, S., 2002. Influence of the nature of organic compounds on fine soil stabilization with cement. Canadian Geotechnical Journal, 39(3): 535-546.

[47] Broms, B.B., 2003. Deep Soil Stabilization: Design and Construction of Lime and Lime/Cement Columns. Royal Institute of Technology, Stockholm, Sweden.

[48] Baker, S., 2000. Deformation Behaviour of Lime/Cement Column Stabilized Clay. Swedish Deep Stabilization Research Centre, Rapport 7, Chalmers University of Technology.

[49] Jacobson, J.R., Filz, G.M. and Mitchell, J.K., 2005. Factors Affecting Strength of Lime-Cement Columns Based on a Laboratory Study of Three Organic Soils. Deep Mixing '05:International conference on deep mixing best practice and recent advances.

[50] Omine, K., Ochiai, H. and Yasufuku, N., 1996. Evaluation of Strength-Deformation Properties of Light-Weight Soils Based on Two-Phase. Proc. of the 12 th Southeast Asian Geotechnical Conference on Tropical Soil, pp. 101-106, May 1996, Kuala Lumpur, Malaysia.

[51] Omine, K., Ochiai, H. and Bolton, M., 1998. Generalized Two-Phase Mixture Model and Its Application to Composite Ground. Memoirs of the Faculty of Engineering, Kyushu University, Vol.58, No.2, June 1998.

[52] Omine, K., Ochiai, H. and Yoshida, N., 1998. Estimation of In-Situ Strength of Cement-Treated Soils based on Two-Phase Mixture Model. Soils and Foundation, Vol. 38, No. 4, 17-29, Dec. 1998, Japanese Geotechnical Society.

[53] Yasufuku, N., Springman, S.M., Omine, K. and Ochiai, H., 2001. Stress-strain relationship of frozen sand as a composite geomaterial. Soils and Foundations, 41(3): 17-30.

[54] Yasufuku, N., Ochiai, H., Omine, K. and Iwamoto, N., 2001. Strength and Deformation Characteristics of Artificially Cemented Clay with Dispersion. Advanced Laboratory Sress-strain Testing of Geomaterials, Tatsuoka, Shibuya & Kuwano (eds), 2001 Swets & Zeitlinger Publishers Lisse, ISBN 90 2651 843 9.

[55] Cordeiro, G.C., Toledo, R.D., Tavares, L.M. and Fairbairn, E.M.R., 2008. Pozzolanic activity and filler effect of sugar cane bagasse ash in Portland cement and lime mortars. Cement & Concrete Composites, 30(5): 410-418.

[56] Cordeiro, G.C., Toledo Filho, R.D., Tavares, L.M. and Fairbairn, E.M.R., 2009. Ultrafine grinding of sugar cane bagasse ash for application as pozzolanic admixture in concrete. Cement and Concrete Research 39, 110-115.

[57] ASTM-D98, 1998. Standard Specification for Calcium Chloride. American Society for Testing and Materials Standards, Pennsylvania, USA, Volume 04.03.

[58] Clemmer, H.F. and Burggraf, F., 1923. An Investigation of the Use of Calcium Chloride As a Curing Agent and Accelerator of Concrete. ASTM Proceedings, Part II, ASTM, p. 314.

[59] Abrams, D.A., 1924. Calcium Chloride As an Admixture in Concrete. ASTM Proceedings, Part II, pp. 781–834.

[60] Yates, J.C., 1941. Effect of Calcium Chloride on the Strength Development of Concrete Stored at Low Temperatures. Proceedings, Highway Research Board, pp. 288–293.

[61] Shideler, J.J., 1952. Calcium Chloride in Concrete. Jourrnal of the American Concrete Institute, pp. 537–559 .

[62] Price, W.H., 1951. Factors Influencing Concrete Strength. Jourrnal of the American Concrete Institute, American Concrete Institute, Farrmington Hills, Mich., pp. 423–424.

CHAPTER 4

VERIFICATION OF PEAT STRENGTH IMPROVEMENT VIA MICROSTRUCTURE AND CHEMICAL COMPOSITION ASSESSMENT

4.1 Introduction

This chapter discusses the strength improvement mechanism of stabilized peat by focusing on the microstructure and chemical composition enhancement. The main objective in this chapter is to verify the results obtained from previous chapter. The flowcharts of this chapter implementation can be illustrated in Figure 4.1.

A scanning electron microscope (SEM) is a type of electron microscope that creates images of a sample by scanning it with a focused beam of electrons. The electrons act together with atoms in the sample, generating many signals that can be detected and that contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image [1].

Energy-dispersive X-ray spectroscopy (EDX) is an analytical technique used for the elemental analysis or chemical characterization of a sample. It relies on an interaction of some source of X-ray excitation and a sample. Its characterization capabilities are due in large part to the fundamental principle that each element has a unique atomic structure allowing unique set of peaks on its X-ray emission spectrum [2].

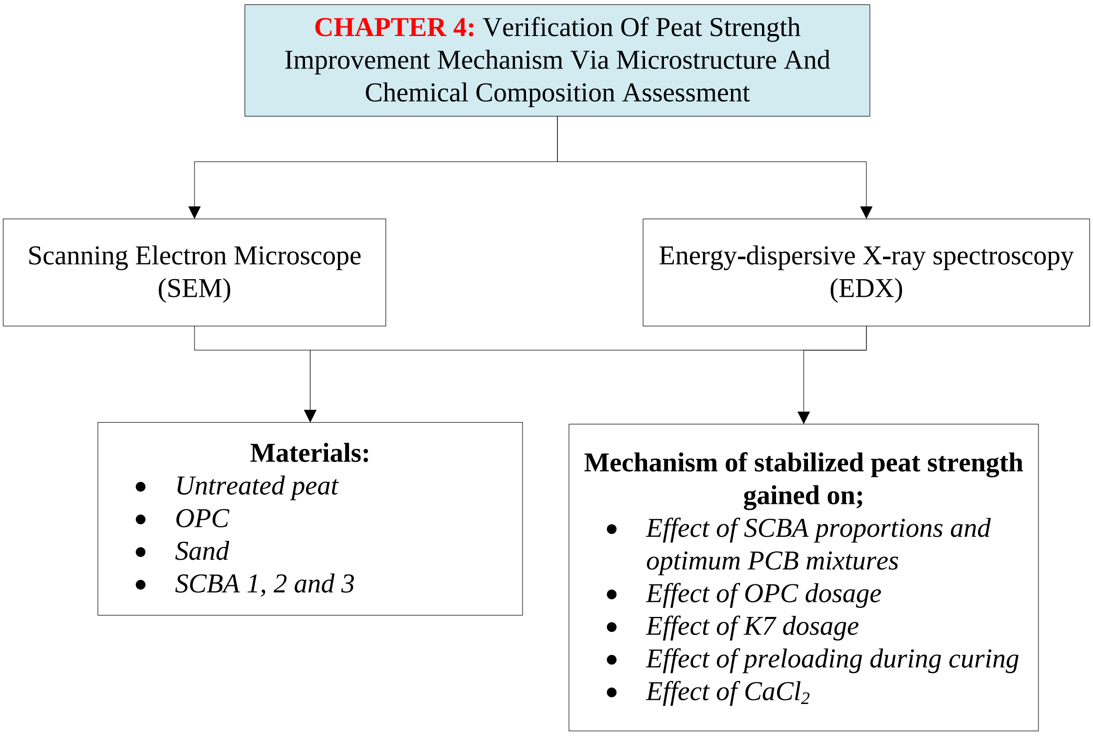


Figure 4.1: Execution planning of Chapter 4

4.2 Methodology

In this study, the SEM test was conducted by using the instruments brands of Shimadzu, Japan (Model: SS-550) as displayed in Figure 4.2. The main specifications of this device were listed in the Table 4.1. This apparatus not only can produce an image but chemical compositions as well. The SS-550 was attached together with Energy-dispersive X-ray (EDX) system namely Genesis2000 that able to generate chemical elements analysis of studied sample.

Figure 4.2: SEM superscan (SS-550) apparatus

Table 4.1: Main specification of SEM550 apparatus

Main specification of SEM-SS550	
Resolution	3.5 nm
Magnification	x 20 ~ x 300,000
Accelerating voltage	0.5 ~ 30 kV 10 V step
Maximum specimen size	125 mmf

Firstly, an air dried broken sample that cured for 7 days in the water were prepared and placed on the double sided tape that affixed over the aluminum stub as shown in Figure 4.3. After that, samples were positioned in coater apparatus (JFC-1600 manufactured by JEOL Corporation) for platinum coating that providing conductivity between the samples and SS-550 apparatus. The coating time was set to auto with a specific electric current. Next, sample was placed in the specimen chamber and then SEM and EDX analysis conducted (Figure 4.4). Micrograph of SEM analysis was taken at a magnificent of 1000 for all samples for the purpose of uniformity. Afterwards the EDX test analyses were performed with the intention of obtaining the chemical elements amounts in each sample. The EDX outputs were measured as the average of three measurements of the same area. Other than that, EDX test results also able to provide a plot of X-ray counts (intensity) versus Energy (Ke-V). This plot is important to show the spectrum of chemical compositions in the tested samples and revealed the improvement evidence of all sample mixtures if compared to untreated samples. The changes were studied to further validate the results obtained from the tests discussed in the previous chapter.

Figure 4.3: Examples of prepared sample for SEM and EDX test

Figure 4.4: Coating apparatus and specimen chamber of SS-550

4.3 Results and discussions

4.3.1 Materials

Scanning Electron Microscopy (SEM)

Figure 4.5 portrays the results of SEM test on untreated peat and materials used in this study. It has been observed that the untreated peat (Figure 4.5a) consists of coarse organic particles and fibers in a loose condition. They were organized arbitrarily without significant microstructural orientation. The organic coarse particles were typically hollow and spongy. Due to spongy nature of organic coarse particles, untreated peat is highly compressible and has a high water holding capacity when fully saturated [3]. The OPC image was observed exposes the box and stone-shaped particles in Figure 4.5b. Most particles of OPC will be composed of some calcium rich phases which generally extremely fine grained and often occur without distinct grain boundaries. Figure 4.5c shows the silica sand (K7) microscopy results. Since the main component of silica sand is quartz, the surface of this material looks very hard and flat with very little cleavage.

When seen by SEM on the SCBA samples (Figure 4.5d, e and f), the presence of coarse and porous particles are detected and these are typical materials present in SCBA. Generally, prismatic, angular, spherical and fibrous particles are shown on the SCBA morphologies. The size of these particles differs noticeably between the types of ashes. The particle sizes increase in the following order: SCBA 1 < SCBA 3

< SCBA 2. The SCBA 2 shows the morphology with large voids and high coarse particles content; while SCBA 1 demonstrate the finest particles together with small pores. The SCBA 2 also comprises a large quantity of long cylindrical porous plates of sugarcane bagasse that not burnt. Since SCBA 3 is combination of SCBA 1 and SCBA 2 materials, therefore its produce the intermediate particle size between the used ashes. These images finding are similar to previous researcher that focus on SCBA materials [4-9].

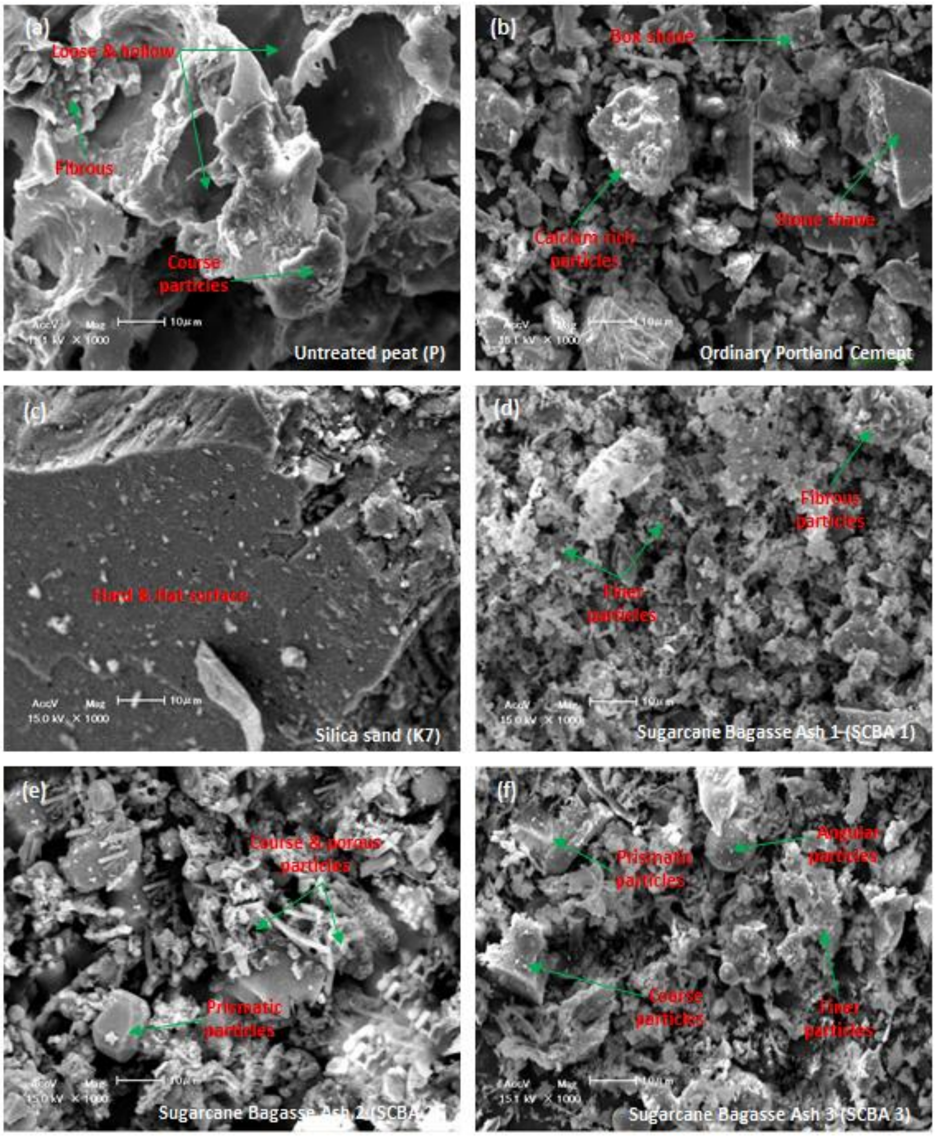


Figure 4.5: Scanning Electron Microscopy (SEM) results on materials used: a) Untreated peat, b) Silica sand, c) Ordinary Portland Cement, d) Sugarcane Bagasse Ash 1, e) Sugarcane Bagasse Ash 2, f) Sugarcane Bagasse Ash 3

Energy-dispersive X-ray spectroscopy (EDX)

Table 4.2 demonstrates the average percentages of oxide compounds of the materials and peat. It is obvious that the peat has a very low content of pozzolanic minerals with 4.64% SiO_2, 3.09% Al_2O_3 and 2.07% Fe_2O_3. In this study, OPC is predominantly characterized by 65.21% CaO, 21.55% SiO_2, 3.82% Al_2O_3 and 1.28 Fe_2O_3. Based on a review, OPC is primarily characterized by quicklime (CaO), silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3) [10]. These findings agree with the typical constituents of Portland cement released by Cement Chemists Notation (CCN) [11]. With a content of 70.18% SiO_2 and 19.3% Al_2O_3, it can be affirmed that quartz and alumina are the major mineral in the K7 silica sand. For SCBA 1, SCBA 2 and SCBA 3, it was found that the summation of the crucial pozzolanic oxide compounds (SiO_2, Al_2O_3 and Fe_2O_3) is 71.64%, 74.42% and 67.75% of the total oxide compounds respectively. These results indicate the potential of SCBA as a pozzolan since the amount of such oxide compounds approximately 70% as recommended by ASTM C 618 Standard.

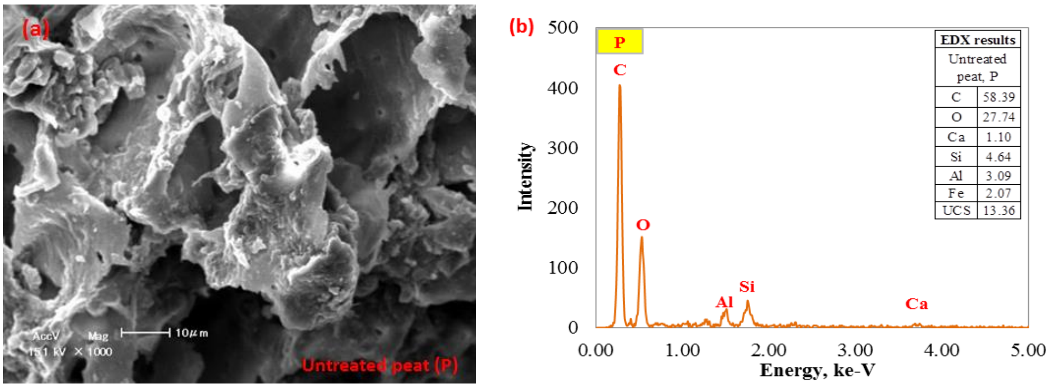
Table 4.2: Energy Dispersive X-ray (EDX) test results of untreated peat and materials

Oxide Compound, %	**Untreated peat**	**OPC**	**Sand (K7)**	**SCBA 1**	**SCBA 2**	**SCBA 3**
CO_2	86.14	-	-	-	-	-
CaO_2	1.10	65.21	0.65	7.70	2.53	5.40
SiO_2	4.64	21.55	70.18	57.38	70.53	55.07
Al_2O_3	3.09	3.82	19.30	10.19	1.65	8.36
Fe_2O_3	2.07	1.28	0.17	4.07	2.24	4.32
Na_2O	0.76	1.51	0.00	1.71	0.51	0.73
MgO	0.95	1.97	0.42	1.23	1.22	2.02
P_2O_5	0.27	0.87	7.29	4.33	7.62	6.36
SO_3	0.54	1.68	0.67	1.47	0.15	2.42
K_2O	0.45	1.29	0.53	10.98	12.74	14.38
TiO_2	0.00	0.82	0.78	0.93	0.82	0.91
Total	100.0	100.0	100.0	100.0	100.0	100.0

4.3.2 Untreated peat versus stabilized peat

Scanning Electron Microscopy (SEM) and Energy-dispersive X-ray spectroscopy (EDX)

Figure 4.6 depicts the results of SEM and EDX test on untreated Hokkaido peat samples in this study. For SEM results of untreated peat in Figure 4.6a, it was given detail explanation in subchapter 4.3.1 (Figure 4.5a). Figure 4.6b illustrates the outcomes of EDX test in term of chemical elements intensity (scatter plot) and percentages (small tables). The strength (UCS) of sample that obtained from Chapter 3 was also included in this table for comparison purpose. The chemical elements percentages were attains by taking an average EDX outcomes of chemical compound proportions readings as shown in Table 4.3. These results take into account only the essential elements i.e. carbon (C), calcium (Ca), silica (Si), alumina (Si) and iron (Fe). It is clear that untreated peat mainly comprises a high peak of carbon (C) and oxide (O) that given an evident of the presence of two primary elements of organic matter. It is about 86% of untreated peat are contain these two chemical compounds. This figure also discovered that the peat has a very low content of pozzolanic minerals (SiO_2+ Al_2O_3 +Fe_2O_3) with 9.8% in total. This results can become the reason why cement stabilized peat had a low potential to generate secondary hydration that mainly contributed by mentioned pozzolanic minerals.



EDX results	
Untreated peat, P	
C	58.39
O	27.74
Ca	1.10
Si	4.64
Al	3.09
Fe	2.07
UCS	13.36

Figure 4.6: Test results of untreated peat, P on SEM (a) and EDX (b)

Table 4.3: Summary of EDX test results of untreated and stabilized peat on the percentage of crucial chemical elements

Sample	Point	C	O	Ca	Si	Al	Fe
P (Untreated peat)	1	56.59	31.81	1.17	4.08	2.59	1.34
	2	59.15	26.41	1.15	4.94	2.91	2.39
	3	59.44	25.01	0.97	4.89	3.77	2.48
	Avg	**58.39**	**27.74**	**1.10**	**4.64**	**3.09**	**2.07**
	Std. dev.	1.28	2.93	0.09	0.39	0.50	0.52
	Std. err.	0.91	2.07	0.06	0.28	0.35	0.37
PC (C100)	1	11.70	33.65	24.98	17.07	4.52	1.97
	2	10.40	33.72	33.77	11.39	3.19	3.35
	3	11.06	30.98	34.07	10.36	3.95	3.05
	Avg	**11.05**	**32.78**	**30.94**	**12.94**	**3.89**	**2.79**
	Std. dev.	0.53	1.28	4.22	2.95	0.54	0.59
	Std. err.	0.31	0.74	2.43	1.70	0.31	0.34
SCBA 1 PCB1-20 (C80B20)-optimum	1	5.97	29.17	35.98	10.43	3.92	3.40
	2	7.90	29.63	34.26	9.54	3.55	4.64
	3	6.44	30.86	34.86	10.16	3.73	2.73
	Avg	**6.77**	**29.89**	**35.03**	**10.04**	**3.73**	**3.59**
	Std. dev.	0.82	0.71	0.71	0.37	0.15	0.79
	Std. err.	0.47	0.41	0.41	0.22	0.09	0.46
SCBA 1 PCB1-30 (C70B30)	1	25.26	29.92	18.45	12.44	2.21	2.90
	2	25.38	34.10	20.20	11.84	1.97	0.00
	3	27.15	30.13	19.33	11.70	1.81	1.86
	Avg	**25.93**	**31.38**	**19.33**	**11.99**	**2.00**	**1.59**
	Std. dev.	0.86	1.92	0.71	0.32	0.16	1.20
	Std. err.	0.50	1.11	0.41	0.19	0.09	0.69
SCBA 2 PCB2-5 (C95B5)-optimum	1	10.08	28.64	31.99	14.09	4.01	3.94
	2	11.13	30.03	30.93	13.78	3.61	2.62
	3	10.90	28.90	32.94	13.78	3.95	2.56
	Avg	**10.70**	**29.19**	**31.95**	**13.88**	**3.86**	**3.04**
	Std. dev.	0.45	0.60	0.82	0.15	0.18	0.64
	Std. err.	0.26	0.35	0.47	0.08	0.10	0.37
SCBA 3 PCB3-10 (C90B10)-optimum	1	8.47	27.74	34.83	13.99	3.16	2.77
	2	7.49	27.25	34.75	14.16	3.62	2.78
	3	5.36	26.47	35.93	15.46	3.84	1.52
	Avg	**7.11**	**27.15**	**35.17**	**14.54**	**3.54**	**2.36**
	Std. dev.	1.30	0.52	0.54	0.66	0.28	0.59
	Std. err.	0.75	0.30	0.31	0.38	0.16	0.34

Figure 4.7 illustrates the assessment outcomes of stabilized peat of peat-cement (PC) and peat-cement-bagasse ash 1 mixture (PCB1) on the SEM and EDX test. Obvious change had apparent and occurred when comparing the SEM results of PC, PCB 1-20 and PCB 1-30 (Figure 4.7a, b, c) with the untreated peat (Figure 4.6a). Minor void spaces can be detected in the micrographs of all stabilized peats mixtures. However, compared to PC and PCB1-30 mixtures, a PCB1-20 mixture gave the significant pore improvement that can be perceived in the photomicrograph of the stabilized peat. Figure 4.7a (PC mixture), is clearly shows the noticeable gel plume

of hydrated cement-soil by means of results from the reaction of cement and water as described in chapter 3. When SCBA was included as much as 30% replacement of OPC (Figure 4.7c @ PCB1-30), SEM images shows the worst packing structures among other stabilized mixtures. It can be witnessed that the gel clots was reduced (cement-soil hydration decrease) while coarse particles that probably contribute by abandoned SCBA inclusion is greatly observed. As conclusion, it can be stated that the stabilized soil is characterized by a well cemented soil medium with very small pore spaces within it as a result of the pozzolanic activity of SCBA.

By comparing to EDX outcomes from untreated peat in Figure 4.6b, it is discovered that lower carbon (C) and higher calcium (Ca) chemical elements fractions shows the better results of strength for all stabilized peat (Figure 4.7d, e, f). The essential pozzolanic oxide compounds (silica-Si, alumina-Al and iron-Fe) display the high values for all stabilized peat are almost certainly because of SCBA and K7 presence in the mixtures. For EDX findings of optimum mixtures (PCB1-20 @ Figure 4.7e), it was clearly shown the highest intensity (peak) of the elements of Ca, Si, Al and O if compared to other stabilized peat. It is important to note that the four elements are essential for the formation of CSH and CASH crystals, which are the main cementation products of the stabilized soil [12; 13]. Obvious decrement of carbon elements percentage was observed after Hokkaido peat was stabilized. For instance, by comparing P mixtures with optimum mixtures (PCB1-20), the carbon elements fell dramatically from 58% to 7%. This finding proves that neutralization of organic matter in peat by peat-cement-bagasse ash combinations are going very well. Based on same comparison above, calcium constituent proportion shows significant increment from 1% to 35%. The high Ca concentration in the stabilized peat specimens confirms that a large number of calcium ions were produced from the rapid cement hydration process. This promoted alkaline condition, in which more silica and alumina became soluble in the soil–cement admixture. This enabled secondary pozzolanic reaction to take place, of which additional cementation bonds of mainly secondary calcium silicate hydrates were developed [3]. At mix binder PCB1-30 (Figure 4.7f), carbon and main pozzolanic minerals (silica and alumina) demonstrates the increment intensity while the calcium was declining. This finding becomes evidence why the SEM of PCB1-30 shows the large void images and more coarse particles were detected. This is due to the limited formation of primary cementation products to bind the soil because the soil organic matter tends to retain the calcium ions produced from cement hydrolysis, resulting in a limited amount of calcium hydroxide (CH) that could react with silica and alumina of SCBA to yield secondary pozzolanic products during the pozzolanic reaction.

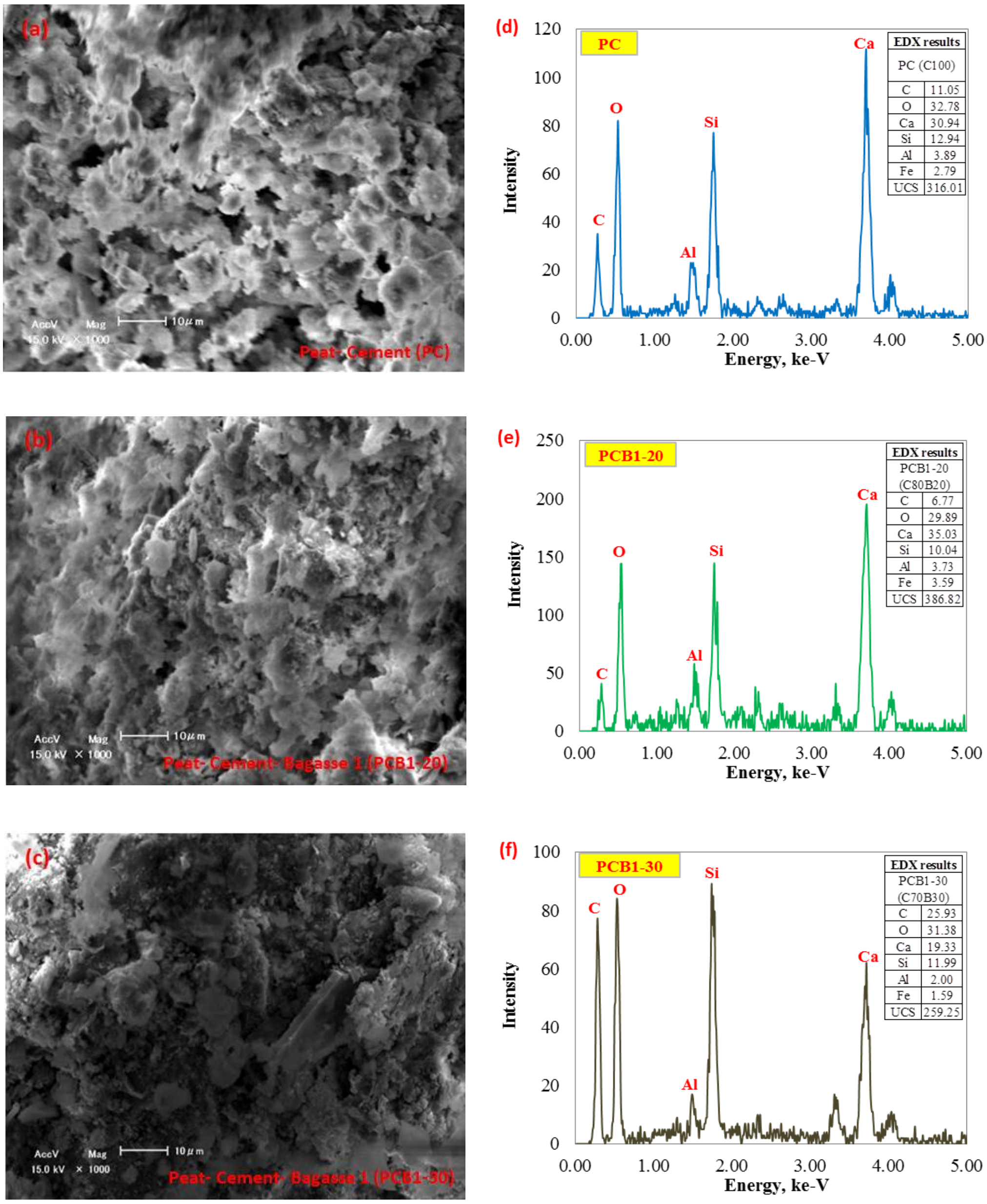
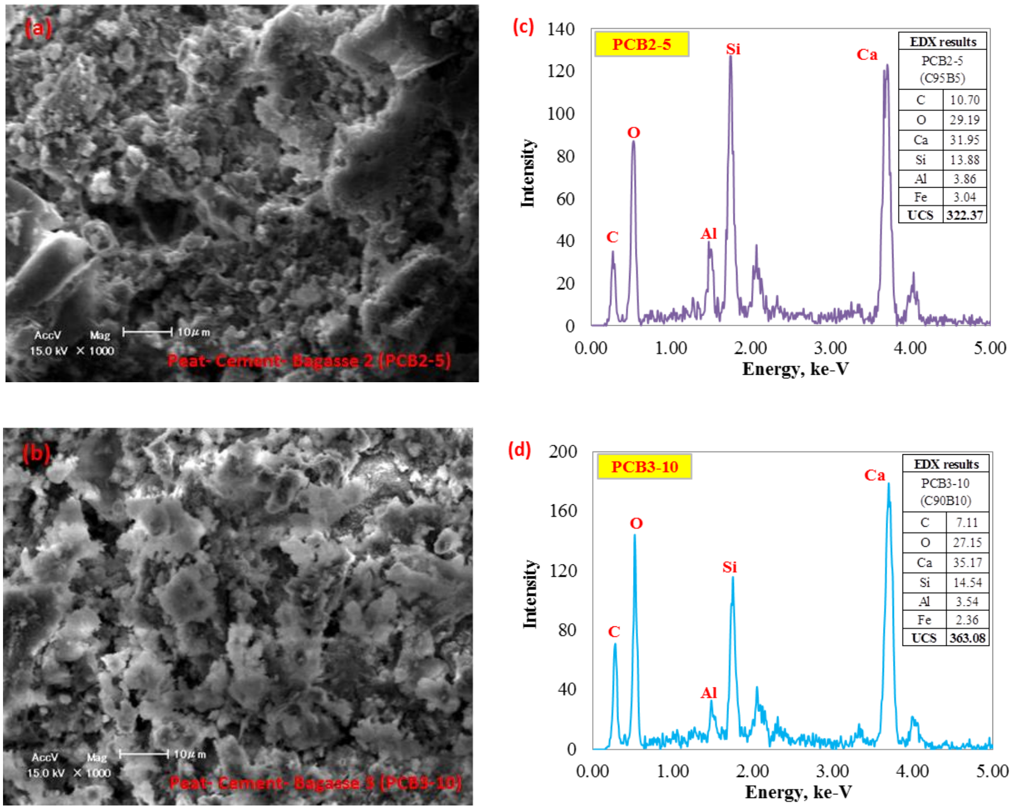


Figure 4.7: Test results of stabilized peat of PC and PCB1 mixtures on SEM (left side @ a to c) and EDX (right side @ d to f)

Figure 4.8 represents the assessment products of stabilized peat of PCB2-5 and PCB3-10 mixtures on the SEM and EDX test. Overall, it was noticed that the results are having some similarity to the results shown in Figure 4.7. For example, Figure 4.8a shows that PCB2-5 mixtures have some similar pattern of the stabilized parts area with PC mixture where coagulated hydrated gel could be seen. It may happen is because of cement content is replaced only at 5% by SCBA 2 in order to obtain the optimum mixture. That is means that the OPC is still the main admixtures in this blend and almost retain its micrograph behavior. It can be said that this mixture was generated mostly by primary cement hydration process like mentioned in Chapter 3 (Eqn. 3.1 under Subtopic 3.4.2) and followed by the little pozzolanic reaction of SCBA 2. However, PCB2-5 shows the slight denser arrangement with fewer voids compared to PC mixture that may be attributed by SCBA 2 existence. It also seen the clumps were developed by combination of SCBA particles and cement gel products. This clump conversely is different with SEM results of PCB1-20 mixtures where PCB2-5 seems shows there are more coarse SCBA particles that covered by cement products. The reactive and finer particles of SCBA 1 become the strong reason why this could be happen. The densification in PCB3-10 (Figure 4.8b) displays the almost same stabilized structure with PCB1-20 mixtures that perhaps because of SCBA 1 inclusion effect. However, PCB3-10 shows more heterogeneity arrangement together with some of coarse SCBA particles that probably contributed by SCBA 2 in this mixtures.

It was apparent the similar amount of C, Ca, Si and Al elements between PCB1-20 and PCB3-10. Percentage of Si and Al compounds in PCB1-20 is detected slightly lower than PCB3-10 probably because of there are more pozzolanic reaction occurred which involves these elements. In this reaction, Si and Al are the most vital elements to generate additional CSH and CASH. When organic matter smoothly counteracted from the peat, cement hydrolysis able to release more CH from primary hydration and consequently more pozzolanic reaction is likely happened to produce more secondary pozzolanic products. This is also become the reason why the UCS results of these two mixture gave comparable results with 386kPa and 363kPa respectively. However, EDX plot proves that PCB1-20 portrays higher intensity rate of Ca, Si and Al components than PCB3-10 like shown in Figure 4.9.



EDX results	
PCB2-5 (C95B5)	
C	10.70
O	29.19
Ca	31.95
Si	13.88
Al	3.86
Fe	3.04
UCS	**322.37**

EDX results	
PCB3-10 (C90B10)	
C	7.11
O	27.15
Ca	35.17
Si	14.54
Al	3.54
Fe	2.36
UCS	**363.08**

Figure 4.8: Test results of stabilized peat of PCB2-5 and PCB3-10 mixtures on SEM (left side @ a and b) and EDX (right side @ c and d)

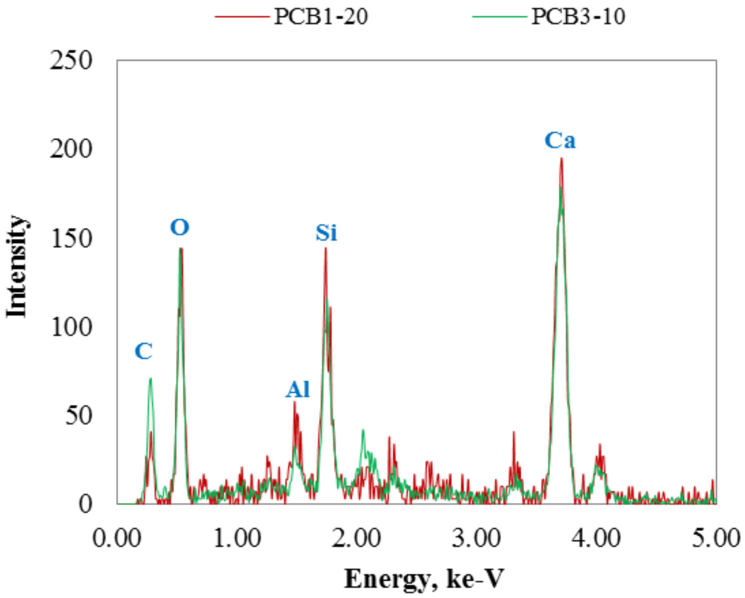


Figure 4.9: EDX plot results of PCB1-20 and PCB3-10

Other possible reasons of slight difference of obtained UCS for PCB1-20 and PCB3-10 are an effect of $CaCl_2$ and the change of particle size during mixing. Figure 4.10 portrays the effect of $CaCl_2$ on the strength activity index (SAI) for all PCB at 7 days of curing. Obviously seen that when inclusion 3% of $CaCl_2$ into PCB3, the SAI go up almost reach to similar SAI of PCB1. In contrast, SAI of PCB1 mixture was lower at 3% of $CaCl_2$ inclusion compare to without $CaCl_2$. This state happened because the $CaCl_2$ amount is highly related to cement content in produce higher strength. With higher dosage of cement, there are more hydration occurred especially at early stage. As known, PCB3-10 mixture consists of 90% of OPC while PCB1-20 is made of 80% of OPC and as a result, the obtained UCS between PCB1-20 and PCB3-10 is comparable. Figure 4.11 displays the particle size distribution of all SCBA. As mentioned in previous chapter, SCBA 3 was prepared by mixing both SCBA 1 and SCBA 2 equally. Logically, particle size results should show the intermediate distribution. However, clearly that particle size of SCBA 3 becomes similar to PCB1 especially after 10µm. These results possibly due to mixer blade effect and finally affect the results of UCS of PCB mixtures.

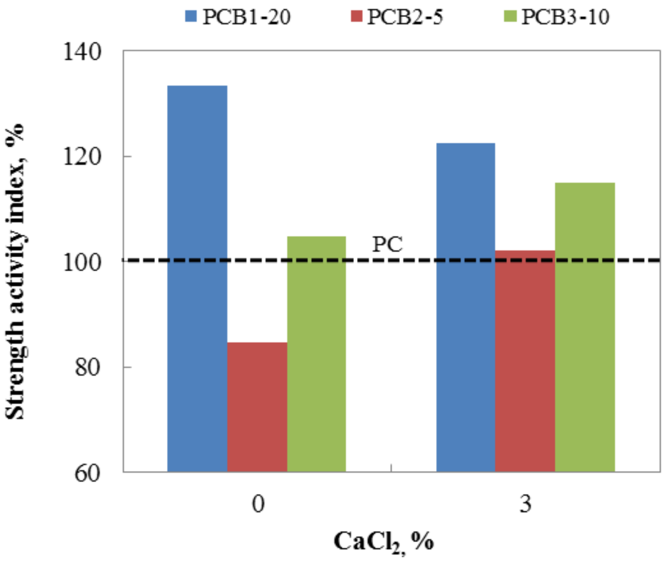


Figure 4.10: Effect of calcium chloride, $CaCl_2$ on the strength activity index

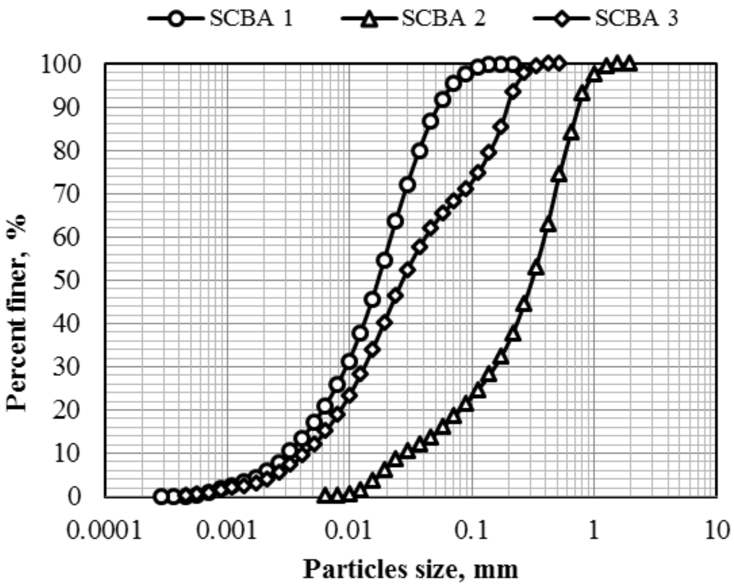


Figure 4.11: Particle size distribution of all SCBA

Table 4.4 represents the summary of EDX test results of various stabilization factors on the PCB1-20 mixtures. As described previously in Chapter 3, among the factors that included in this study are cement effect, preloading effect, silica sand effect and calcium chloride effect. The optimum mixture (PCB1-20) was used as references for the purpose of comparison valuation. For cement effect, the inclusion of 100kg/m^3 or PCB1-20-C1 (Point 2) was chosen for comparison purpose to the optimum one (Point 1). This OPC amount is the minimum dosage used in the cement effect investigation. The UCS and EDX results of the OPC dosage effect of PCB1-20 mixtures were displayed in Figure 4.12. Perceptibly, calcium compounds dropped when the OPC quantity was reduced from 300 kg/m^3 in the optimum mixture to 100 kg/m^3 in PCB1-20-C1 mixtures. In the same time, carbon and oxide elements were increased which connotes there are still a lot of organic matter that not counteracted. Moreover, the percentages of silica and alumina (contributed by K7 and SCBA) also higher indicate that no or very little pozzolanic reaction involve in this mixture. These occurrences happened because when insufficient cement is added, hydration and pozzolanic reaction become lower and effective neutralization of humid acids within the soil is not achieved. Consequently, the strength becomes smaller. As can be seen in Figure 4.12, UCS of PCB1-20-C1 mixture shows the decrement as much as 15 times compared to optimum mixtures and slightly higher than untreated peat.

Table 4.4: Summary of EDX test results of various stabilization factors on the PCB1-20 mixtures

	Sample	**Point**	**C**	**O**	**Ca**	**Si**	**Al**	**Fe**
PCB1-20	**Opt.**	1	5.97	29.17	35.98	10.43	3.92	3.40
		2	7.90	29.63	34.26	9.54	3.55	4.64
		3	6.44	30.86	34.86	10.16	3.73	2.73
		Avg	**6.77**	**29.89**	**35.03**	**10.04**	**3.73**	**3.59**
		Std. dev.	0.82	0.71	0.71	0.37	0.15	0.79
		Std. err.	0.47	0.41	0.41	0.22	0.09	0.46
	C1	1	14.03	40.15	4.89	22.40	8.19	0.98
		2	12.49	39.61	4.22	23.63	9.01	1.31
		3	12.87	40.57	4.51	23.37	8.71	0.94
		Avg	**13.13**	**40.11**	**4.54**	**23.13**	**8.64**	**1.08**
		Std. dev.	0.66	0.39	0.27	0.53	0.34	0.17
		Std. err.	0.38	0.23	0.16	0.31	0.20	0.10
	L0	1	18.53	44.23	12.28	18.17	2.93	0.86
		2	14.70	41.23	12.50	24.12	3.57	0.91
		3	14.26	41.28	12.61	23.62	4.21	0.36
		Avg	**15.83**	**42.25**	**12.46**	**21.97**	**3.57**	**0.71**
		Std. dev.	1.92	1.40	0.14	2.69	0.52	0.25
		Std. err.	1.11	0.81	0.08	1.56	0.30	0.14
	K0	1	21.30	43.22	13.66	9.12	3.30	0.98
		2	20.79	42.64	13.87	9.95	3.49	1.53
		3	21.63	41.74	13.29	9.98	3.62	2.20
		Avg	**21.24**	**42.53**	**13.61**	**9.68**	**3.47**	**1.57**
		Std. dev.	0.35	0.61	0.24	0.40	0.13	0.50
		Std. err.	0.20	0.35	0.14	0.23	0.08	0.29
	CC0	1	18.29	36.04	19.79	10.38	3.62	2.20
		2	16.42	34.75	22.10	11.38	3.99	1.95
		3	14.05	38.82	21.86	11.26	3.79	1.88
		Avg	**16.25**	**36.54**	**21.25**	**11.01**	**3.80**	**2.01**
		Std. dev.	1.73	1.70	1.04	0.45	0.15	0.14
		Std. err.	1.00	0.98	0.60	0.26	0.09	0.08

Figure 4.13 to Figure 4.15 shows the UCS and EDX of preloading rate, K7 dosage and $CaCl_2$ composition effect on PCB1-20 mixtures (Point 1). All the outcomes displays almost the same pattern which is the higher calcium together with lower carbon mixtures will gain the greater UCS. It clearly sees in the Figure 4.13, the calcium reduce while silica percentage rose if there is no preloading (PCB1-20-L0) subjected to samples. These results prove that when preloading throughout curing process will increase the surface contact between soil particles and admixtures during hydration course. When there is more interaction of the soil material with the binder, there are easier and more CSH and CASH could be produced. Moreover, Figure 4.13 revealed that preloading effect contributes the significant stabilization

enhancement of peat and among the most important factor apart from the effect of cement dosage.

Figure 4.14 exposed that K7 presence is crucial in order to increase the solid particles in the original peat. In addition, K7 could be act as filler to peat that very hollow or in the other words too much voids. This is proved by the low percentage of silica in the mixtures without K7 (PCB1-20-K0). This lower silica content is believed mainly contributed by SCBA elements solely. As a result, contact point between binder, density and void of sample decrease and consequently dropped the strength. Since calcium chloride was used as a cement accelerator, it seems EDX results in Figure 4.15 just affected on the calcium amount while silica and alumina shows the equivalency to the optimum mixtures. Figure 4.16 shows the ratio of calcium to silica, Ca/Si for all mixtures including original peat. The graph exposed that higher Ca/Si ratio will attain better UCS and implicitly display dense matrices in SEM results. It should be noted that the higher Ca/Si ratio indicating the greater CSH gels were produced. It is understandable that by increasing the Ca/Si ratio, the confections density increases and this agrees well with the EDX results [14].

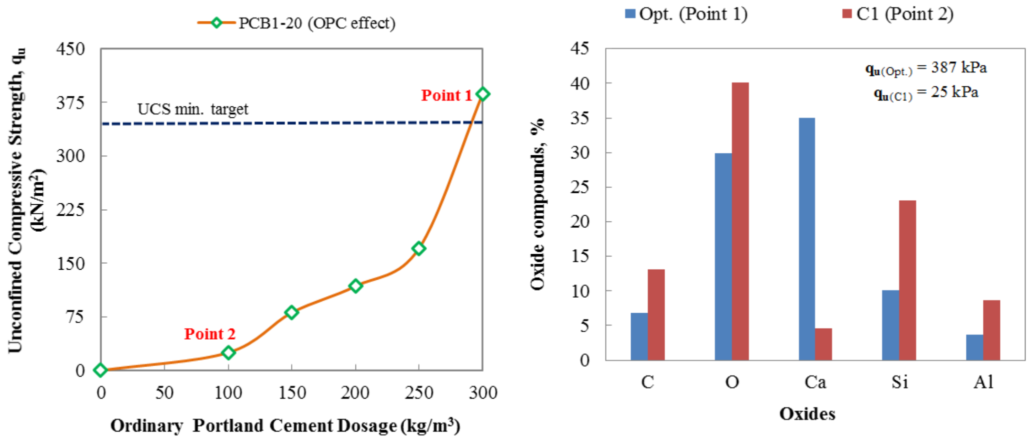


Figure 4.12: The UCS and EDX results of OPC dosage effect on PCB1-20 mixtures

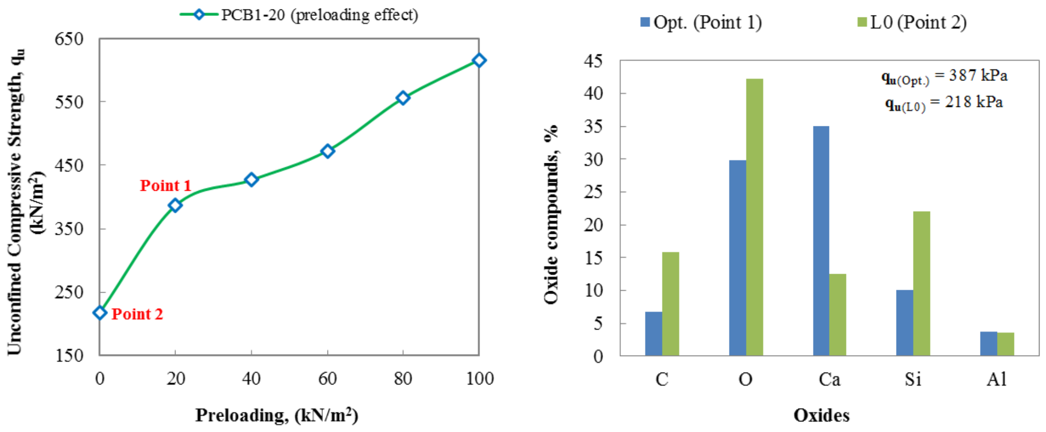


Figure 4.13: The UCS and EDX results of preloading effect on PCB1-20 mixtures

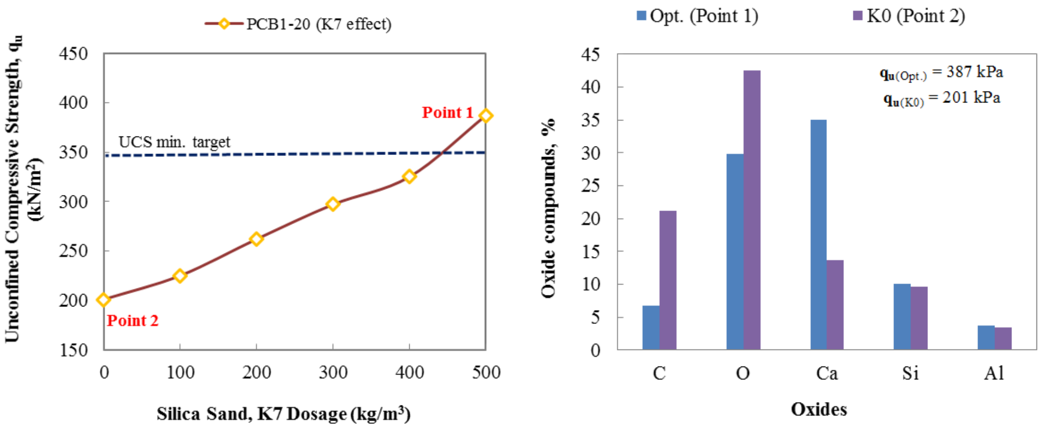


Figure 4.14: The UCS and EDX results of K7 effect on PCB1-20 mixtures

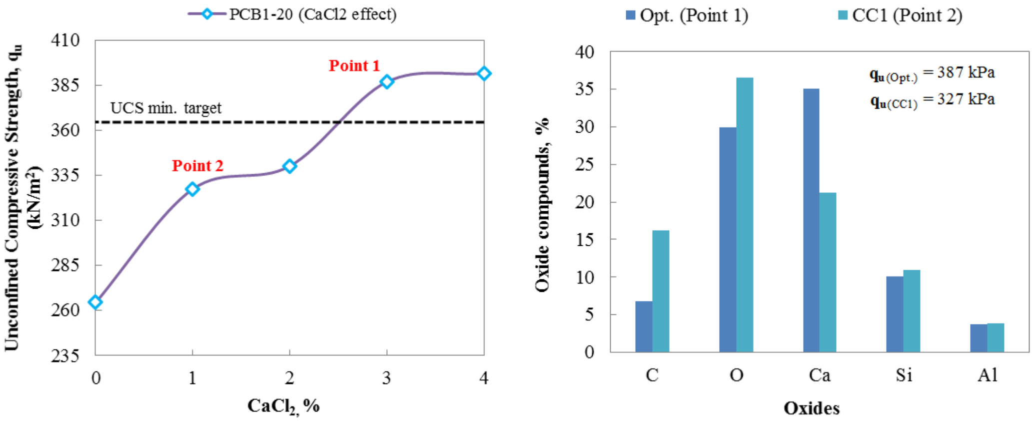


Figure 4.15: The UCS and EDX results of $CaCl_2$ effect on PCB1-20 mixtures

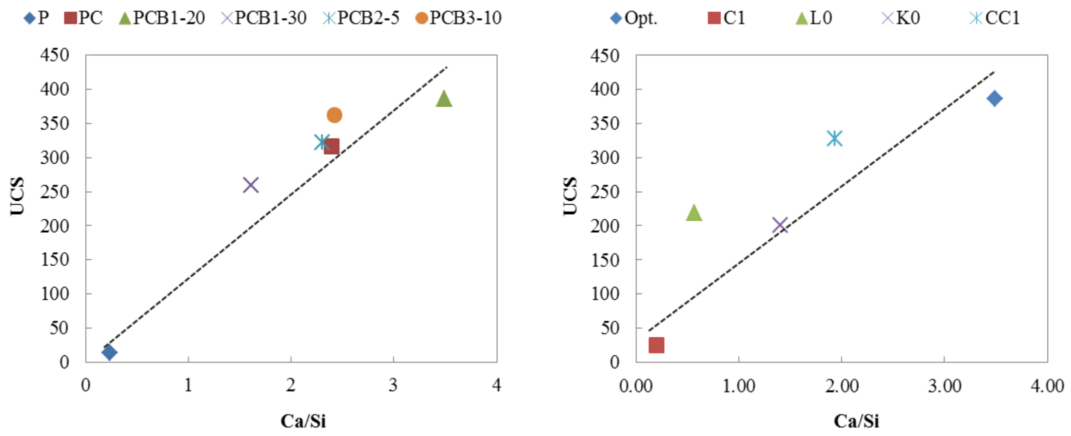


Figure 4.16: Ratio of calcium to silica for all mixtures

4.4 Summary

As summary, objectives of Chapter 4 were achieved. Verification of the strength results gained in Chapter 3 was accomplished. The strength improvement mechanisms of stabilized peat were observed by focusing on the microstructure and chemical composition enhancement. The summary of the UCS and EDX results for all mixtures were depicts in Figure 4.17 and Figure 4.18.

Overall, it can be stated that the stabilized soil is characterized by a well cemented soil medium with tiny pore spaces within it as a result of the pozzolanic activity of SCBA and other admixtures. The reactive and finer particles of SCBA can be said as one of the strong reason why this could be happen. The oxide compound percentages from EDX results clearly depict that lower carbon (C) and higher calcium (Ca) oxide fractions shows the better results of stabilized peat strength (UCS). The essential pozzolanic oxide compounds (SiO_2 and Al_2O_3) display the high values for stabilized peat mainly because of SCBA and K7 presence. In secondary pozzolanic reaction, Si and Al are the most vital elements to generate additional CSH and CASH. When organic matter smoothly counteracted from the peat, cement hydrolysis able to release more CH from primary hydration and consequently more pozzolanic reaction is likely happened to produce more secondary pozzolanic products.

An optimum mixture (PCB1-20) shows the highest intensity (peak) of the elements of Ca, Si, Al and O if compared to other stabilized peat. It is important to note that the four elements are essential for the formation of CSH and CASH crystals. The high Ca concentration in the stabilized peat specimens proves that a great quantity of calcium ions were produced from the rapid cement hydration process and eventually promoted alkaline condition. In this condition, more silica and alumina able to involved in secondary pozzolanic reaction. This process then leads to higher strength obtained in the mixtures. When insufficient cement is added, hydration and pozzolanic reaction become lower and effective neutralization of humid acids within the soil is not achieved. As results, amount of calcium hydroxide (CH) that could react with silica and alumina of SCBA to yield secondary pozzolanic products during the pozzolanic reaction become inadequate. Consequently, the strength becomes smaller.

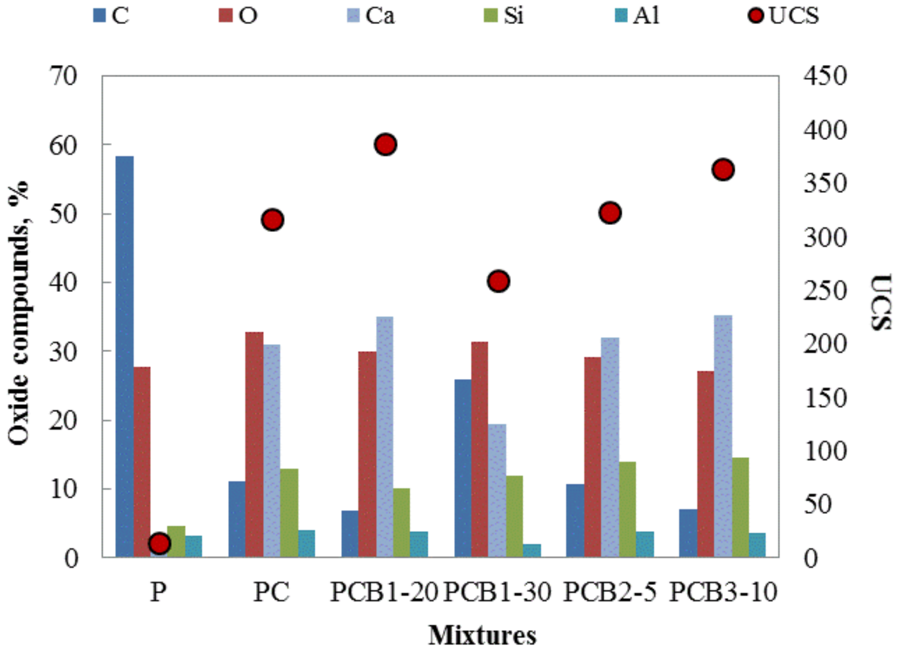


Figure 4.17: Summary of the UCS and EDX results of P, PC and PCB mixtures

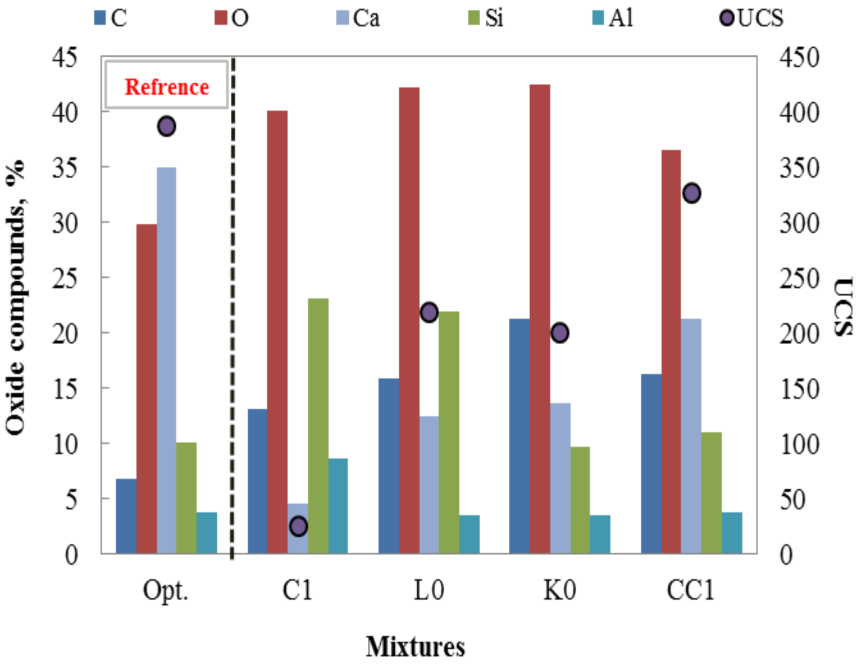


Figure 4.18: Summary of the UCS and EDX results of various effect of admixtures on PCB1-20 mixtures

4.5 References

[1] Wikipedia, 2015. Scanning electron microscope. 18 June. Wikipedia, the free encyclopedia. https://en.wikipedia.org/?title=Scanning_electron_microscope.

[2] Wikipedia, 2015. Energy-dispersive X-ray spectroscopy. 18 June. Wikipedia, the free encyclopedia. https://en.wikipedia.org/wiki/Energy-dispersive_X-ray_spectroscopy#cite_note-2.

[3] Wong, L.S., Hashim, R. and Ali, F., 2013. Improved strength and reduced permeability of stabilized peat: Focus on application of kaolin as a pozzolanic additive. Construction and Building Materials, 40: 783-792.

[4] Faria, K.C.P., Gurgel, R.F. and Holanda, J.N.F., 2012. Recycling of sugarcane bagasse ash waste in the production of clay bricks. Journal of Environmental Management, 101: 7-12.

[5] Frias, M., Villar, E. and Savastano, H., 2011. Brazilian sugar cane bagasse ashes from the cogeneration industry as active pozzolans for cement manufacture. Cement & Concrete Composites, 33(4): 490-496.

[6] Cordeiro, G.C., Toledo Filho, R.D., Tavares, L.M. and Fairbairn, E.M.R., 2009. Ultrafine grinding of sugar cane bagasse ash for application as pozzolanic admixture in concrete. Cement and Concrete Research 39, 110-115.

[7] Sales, A. and Lima, S.A., 2010. Use of Brazilian sugarcane bagasse ash in concrete as sand replacement. Waste Management, 30(6): 1114-1122.

[8] Paya, J., Monzo, J., Borrachero, M.V., Diaz-Pinzon, L. and Ordonez, L.M., 2002. Sugar-cane bagasse ash (SCBA): studies on its properties for reusing in concrete production. Journal of Chemical Technology and Biotechnology, 77(3): 321-325.

[9] Alavez-Ramirez, R., Montes-Garcia, P., Martinez-Reyes, J., Altamirano-Juarez, D.C. and Gochi-Ponce, Y., 2012. The use of sugarcane bagasse ash and lime to improve the durability and mechanical properties of compacted soil blocks. Construction and Building Materials, 34: 296-305.

[10] Isaia, G.C., Gastaldini, A.L.G. and Moraes, R., 2003. Physical and pozzolanic action of mineral additions on the mechanical strength of high-performance concrete. Cement & Concrete Composites, 25(1): 69-76.

[11] Wikipedia, 2015. Portland cement. 24 June. Wikipedia, the free encyclopedia. https://en.wikipedia.org/?title=Portland_cement.

[12] Wong, L.S., Hashim, R. and Ali, F., 2013. Utilization of sodium bentonite to maximize the filler and pozzolanic effects of stabilized peat. Engineering Geology, 152(1): 56-66.

[13] Lav, A.H. and Lav, M.A., 2000. Microstructural development of stabilized fly ash as pavement base material. Journal of Materials in Civil Engineering, 12(2): 157-163.

[14] Kazemian, S., Prasad, A., Huat, B.B.K., Mohammad, T.A. and Aziz, F.N.A.A., 2013. Stabilization of tropical peat by chemical grout. Journal of the Chinese Institute of Engineers, 36(1): 114-128.

CHAPTER 5

EVALUATION OF SUGARCANE BAGASSE ASH (SCBA) QUALITY CHARACTERISTICS ON POZZOLANIC EFFECT IN STABILIZED PEAT

5.1 Introduction

This chapter considered about the evaluation of sugarcane bagasse ash (SCBA) quality characteristics on pozzolanic effect in stabilized peat. Pozzolans play an important role when added to Portland cement because they usually increase the mechanical strength and durability of concrete structures depending on its reactivity. Higher reactivity of pozzolan has more cementitious strength value and consequently the amount of cement reduction will be greater. The most important effects in the cementitious paste microstructure are chemical effect and physical or filler effect [1; 2].

In recent science, regression analysis is an essential part of virtually almost any data reduction process. Popular spreadsheet programs such as Microsoft Excel provide comprehensive statistical program packages, which include a regression tool among many others. Regression models analysis can be classified as the relationship of regression function, between one dependent variable, y and several others independent variables, x_i. Regression function also includes a set of unknown parameters, b_i. If a regression function is linear in the parameters (but not necessarily in the independent variables) we term it a linear regression model. Otherwise, the model is called non-linear. Linear regression models with more than one independent variable are referred to as multiple linear models, as opposed to simple linear models with one independent variable [3]. Multiple linear models can be expressed by mathematical formula as shown below;

$$y = b_0 + b_1x_1 + b_2x_2 + \dots b_ix_i \qquad (5.1)$$

Where;

y = dependent variable (predicted by a regression model)
i = number of independent variables (number of coefficients)
x_i = i^{th} independent variable
b_i = i^{th} coefficient corresponding to x_i
b_0 = intercept (or constant)

The main aim of multiple linear regression analysis is to determine the best set of parameters; b_i such that the model predicts experimental values of the dependent variable as accurately as possible (i.e. calculated values ought to be close to experimental values). Furthermore, the model itself must be evaluated whether it is adequate to fit the observed experimental data and required to check whether all terms in model are significant.

5.2 Methodology

Pozzolanic effect of SCBA was determined from the UCS of curing effect results by making a peat-cement (PC) mixture as a reference. As stated in Chapter 3 and Chapter 4, the main different between SCBA 1 and 2 characteristics are their particle sizes and chemical composition. The SCBA 1 was recorded the finer particles and higher ratio of calcium to silica (Ca/Si) composition if compared to SCBA 2. Janz and Johansson [4] point out that the Ca/Si ratio, which stands for relative abundance of CaO and SiO_2, is the sign of the potential for pozzolanic reactions and those binders with larger Ca/Si ratios are likely to be more effective stabilizers. This important characteristic also had been studied by Tastan et al. [5] on organic soil stabilization by using fly ash. Therefore, it is important to estimate the effect of these characteristics on the strength of- stabilized peat by using SCBA.

In order to achieve this goal, all the average unconfined strength, q_u results were collected for carrying out a statistical analysis. Important factors that include in this analysis are SCBA replacement percentage, SCBA average particle sizes (D_{50}), curing durations (D), cement dosage (C), silica sand dosage (S) and preloading during curing (P). Each of these variables was included in a multiple linear regression analysis to find an equation that can be used to predict the q_u of peat-cement-bagasse ash (PCB) mixtures. For the final results, the simple formula and graphs were developed with the aim of strength prediction. This prediction model will emphasize the chemical and physical characteristic of SCBA for achieving the minimum target of strength. The flowcharts of this chapter implementation can be illustrated in Figure 5.1.

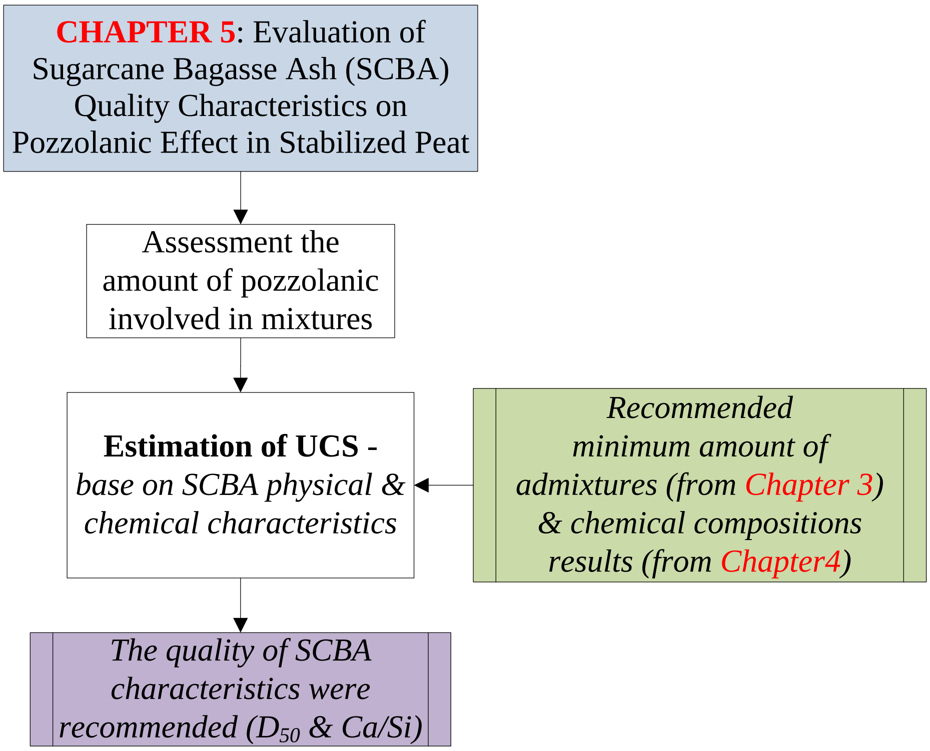


Figure 5.1: Execution planning of Chapter 5

5.3 Results and discussions

5.3.1 Performance/amount of pozzolanic effect (physical and chemical effect) on stabilized peat

Figure 5.2 indicates the effect of curing durations on the strength activity index (SAI) of the samples. This graph illustrates the amount of pozzolanic effect on all optimum PCB. The strength activity index was calculated by follow the procedures that provided in ASTM-C311 [6]. The dotted line with PC sign is the references line (PC control mixtures) which used to compare the strength activity index among the tested specimens. At 7 days curing time, it was visibly shows the highest strength activity index and all optimum PCB mixtures were observed exceed the PC line. One of the probable reasons this condition could be happened is because the strength activity index of optimum PCB mixtures due to filler effect is higher than due to pozzolanic reaction at early curing days. This findings was coincides to the obtained results of Tangpagasit et al. [7] that concludes that the packing effect of fly ash mortar is higher than the pozzolanic reaction at initial ages. Similarly, Isaia et al. [1] state that physical or filler effect increased more than the pozolanic reaction when the results for the same strength values are compared. Micro-filler effect is at least equally important or even more significant than the pozzolanic effect [8; 9].

Pozzolanic reactions are highly related to released calcium hydroxide ($CaOH_2$) or lime that depends on the amount of cement hydration. At early ages only a small amount of cement has hydrated and thus the amount of released $CaOH_2$ becomes low and limited. Consequent to this situation, pozzolanic reaction also is small at early curing times and the pozzolan particles that are not completely reacted may fill the voids and increase mixtures density [2; 10]. At this moment, filler or packing effect of SCBA take part as the significant contributor of samples compressive strength. Filler effect is an appropriate arrangement of small particles which block the voids and contribute to the increment of compressive strength without any chemical reaction [1; 7; 9]. However, it also become possible that the higher strength gained at early age is because the great combination of SCBA physical and chemical effect. Inclusion of $CaCl_2$ is well known could create high cement hydration at early time. Therefore, along with filler effect that mentioned above, the strength of the sample that curing under 20 kPa pressure at 7 days recorded the greatest value.

Conversely, between 7 and 28 days of curing periods, the highest strength activity index demonstrates the slight declination and levelled off. Just after 28 days of curing durations onwards, these strength activity index back to increase minimally. This could be occurred by the reason of the fact that cement hydration (PC mixtures) is normally rapid and effective at first month but almost stop or complete after that duration while pozzolan reaction can be occurred continuously until several month or even years [11-13]. The overall results of Figure 5.2 were also exposed that the finer SCBA (SCBA 1) particles provide higher compressive strength if compared to coarse SCBA (SCBA 2 and SCBA 3). The physical action of the pozzolans provides a denser, more homogeneous and uniform paste that may reduce the wall effect in the transition zone between the paste and the soil particles. This weaker zone is strengthened due to the higher bond between these two phases, improving the PCB mixtures microstructures and properties [8; 9; 14; 15].

In Figure 5.3, the comparative study analysis between an effect of silica sand, K7 and the strength activity index was illustrated. This comparison comprises of all optimum mixture of PCB (with 500kg/m^3 K7) and the mixtures that without any K7. The main purpose of this figure is to determine an effect of pozzolan reaction produced by SCBA. Since the K7 or silica sand is almost inert (non-reactive materials) which not involve in any chemical reactions, hence the pozzolanic reaction amount might be attain by calculating the differences of strength activity index between the mixtures with and without K7. Obviously from the mixtures without K7 for PCB1-20, the pozzolanic reaction of SCBA seems gave the significant improvement (contribute about 18% of strength activity index) while on the other hand K7 effect only contribute approximately 5% of strength activity index for the same SCBA. The amount of these reactions were evaluate by subtract the strength activity index of mixtures without K7 to PC mixtures and the optimum mixtures. A PCB3-10 mixture similarly shows that pozzolanic effect of SCBA is better than K7 influence. In contrast, PCB2-5 demonstrates that SCBA 2 (low quality

SCBA) pozzolanic effect was insufficient and not recommended to use in the PCB mixtures considering its strength activity index is lesser than PC mixtures. Inclusion of K7 shows the better improvement of strength for PCB2-5.

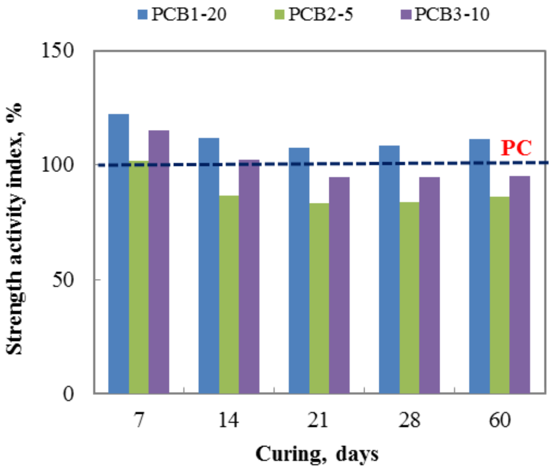


Figure 5.2: Effect of curing durations on the strength activity index of all optimum PCB

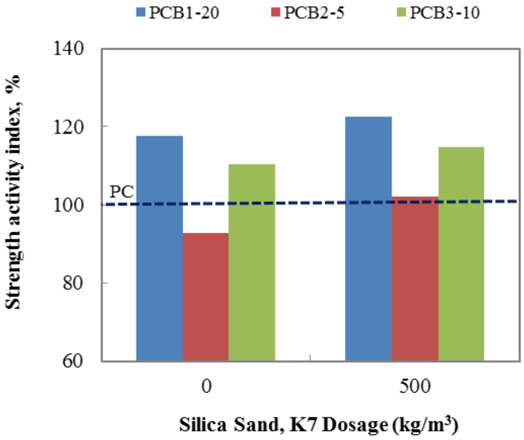


Figure 5.3: Effect of silica sand, K7 on the strength activity index

5.3.2 Estimation of the strength (q_u) that focusing on the physical and chemical effect of SCBA

Table 5.1 represents the collected results for multiple regression analysis of peat stabilization by SCBA focusing on median particle size and Ca/Si ratio effects. Each UCS average results were obtained from 3 or at least 2 tested samples. The data comprises all the compressive strength of various factors for the PC, PCB1 and PCB2 mixtures. The PCB 1 and PCB 2 blends were represents the good and low quality of SCBA respectively. This analysis will be emphasis on the physical and chemical effect of SCBA. For the physical effect, median particle size D_{50} was chosen as the indicator parameter. On the other hand, Ca/Si ratio had been used in order to determine the SCBA quality in term of chemical effect.

The important factors of peat stabilization that include in this statistical analysis were SCBA replacement percentage (B), SCBA average particle sizes (D_{50}), curing durations (D), cement dosage (C), silica sand dosage (S) and preloading during curing (P). Each of these variables was included in a linear regression analysis to find an equation that can be used to predict the compressive strength, q_u of PCB mixtures. The median particle size of SCBA 1 and SCBA 2 are 0.018mm and 0.26mm respectively while their Ca/Si ratios are 0.134 and 0.036. The results of peat stabilization effect factors were taken and accumulate from the Chapter 3.

Table 5.2 displays the correlation coefficients between UCS and various factor of peat stabilization by SCBA focusing on median particle size and Ca/Si ratio effects. Basically, correlation can express something about the relationship between variables. It is used to understand whether the relationship is positive or negative and the strength of relationship. Correlation is a powerful tool that provides these vital pieces of information. Statistical correlation is measured by what is called coefficient of correlation (r). Its numerical value ranges from +1.0 to -1.0. It gives us an indication of the strength of relationship. In general, $r > 0$ indicates positive relationship, $r < 0$ indicates negative relationship while $r = 0$ indicates no relationship (or that the variables are independent and not related). Here $r = +1.0$ describes a perfect positive correlation and $r = -1.0$ describes a perfect negative correlation. Closer the coefficients are to +1.0 and -1.0, greater is the strength of the relationship between the variables. As a rule of thumb, the statistical correlation guidelines on strength of relationship in Table 5.3 are often useful [16].

Table 5.1: Collected results for multiple regression analysis of peat stabilization by SCBA focusing on median particle size and Ca/Si ratio effects

	Unit	*kPa*	*%*	*mm*		*Days*	*kg/m*^{3}	*kg/m*^{3}	*kN/m*^{2}
	Symbol	q_u	B	D_{50}	CaO_2/SiO_2	D	C	S	P
		UCS$_{avg}$	**SCBA**	**D$_{50}$**	**Ca/Si**	**Curing**	**OPC dosage**	**K7 dosage**	**Preloading**
	PC	316	0	0	0	7	300	500	20
SCBA 1	B effect	324	5	0.018	0.134	7	285	500	20
		341	10	0.018	0.134	7	270	500	20
		373	15	0.018	0.134	7	255	500	20
		387	20	0.018	0.134	7	240	500	20
	D effect	387	20	0.018	0.134	7	240	500	20
		431	20	0.018	0.134	14	240	500	20
		473	20	0.018	0.134	21	240	500	20
		500	20	0.018	0.134	28	240	500	20
		530	20	0.018	0.134	60	240	500	20
	C effect	25	20	0.018	0.134	7	80	500	20
		81	20	0.018	0.134	7	120	500	20
		118	20	0.018	0.134	7	160	500	20
		171	20	0.018	0.134	7	200	500	20
		387	20	0.018	0.134	7	240	500	20
	S effect	201	20	0.018	0.134	7	240	0	20
		225	20	0.018	0.134	7	240	100	20
		262	20	0.018	0.134	7	240	200	20
		297	20	0.018	0.134	7	240	300	20
		325	20	0.018	0.134	7	240	400	20
		387	20	0.018	0.134	7	240	500	20
	P effect	218	20	0.018	0.134	7	240	500	0
		387	20	0.018	0.134	7	240	500	20
		427	20	0.018	0.134	7	240	500	40
		473	20	0.018	0.134	7	240	500	60
		556	20	0.018	0.134	7	240	500	80
		616	20	0.018	0.134	7	240	500	100
SCBA 2	B effect	322	5	0.260	0.036	7	285	500	20
		257	10	0.260	0.036	7	270	500	20
		231	15	0.260	0.036	7	255	500	20
		223	20	0.260	0.036	7	240	500	20
	D effect	322	5	0.260	0.036	7	285	500	20
		333	5	0.260	0.036	14	285	500	20
		365	5	0.260	0.036	21	285	500	20
		386	5	0.260	0.036	28	285	500	20
		409	5	0.260	0.036	60	285	500	20
	C effect	19	5	0.260	0.036	7	80	500	20
		72	5	0.260	0.036	7	120	500	20
		104	5	0.260	0.036	7	160	500	20
		138	5	0.260	0.036	7	200	500	20
		322	5	0.260	0.036	7	240	500	20
	S effect	158	5	0.260	0.036	7	285	0	20
		177	5	0.260	0.036	7	285	100	20
		206	5	0.260	0.036	7	285	200	20
		234	5	0.260	0.036	7	285	300	20
		273	5	0.260	0.036	7	285	400	20
		322	5	0.260	0.036	7	285	500	20
	P effect	197	5	0.260	0.036	7	285	500	0
		322	5	0.260	0.036	7	285	500	20
		368	5	0.260	0.036	7	285	500	40
		412	5	0.260	0.036	7	285	500	60
		445	5	0.260	0.036	7	285	500	80
		476	5	0.260	0.036	7	285	500	100

Table 5.2: Correlation between UCS and various factor of peat stabilization by SCBA focusing on median particle size and Ca/Si ratio effects

	UCS_{avg}	SCBA	D_{50}	Ca/Si	Curing	OPC dosage	K7 dosage	Preloading
UCS_{avg}	1.00							
SCBA	0.20	1.00						
D_{50}	-0.25	-0.81	1.00					
Ca/Si	0.25	0.88	-0.93	1.00				
Curing	0.35	0.01	0.01	0.01	1.00			
OPC dosage	0.55	-0.36	0.26	-0.31	0.12	1.00		
K7 dosage	0.29	-0.01	-0.01	-0.01	0.14	-0.16	1.00	
Preloading	0.54	0.01	0.01	0.01	-0.11	0.12	0.14	1.00

Referring to Table 5.3, an effect of OPC dosage and preloading shows the strong relationship to UCS gained which both of this effect factors are more than 0.5. With 0.35, curing effect can be grouped as moderate relationship to UCS expanded. Replacement of SCBA percentage into peat-cement mixtures shows the lowest reading of relationship with only 0.2 and categorized as weak correlations. Although this value is small, it is still should be included in this analysis since the replacement of SCBA percentage inextricably linked with cement dosage which mentioned previously had very high correlation to better PCB mixture strength. Nonetheless, SCBA crucial characteristics shows the better potential in UCS increments which mean particle sizes, D_{50} and Ca/Si ratio share the same values of 0.25. Negative signs in D_{50} anticipate that finer particles of SCBA could improve mixtures strength. The table also revealed that SCBA is highly depending to these two vital characteristics at approximately 80% to 90% of correlations (3rd column). Nevertheless, coefficient of correlation or ‘r’ should not be used to say anything about cause and effect relationship. Put differently, by examining the value of 'r', we could conclude that variables x and y are related. However the same value of 'r' does not tell us if x influences y or the other way round. Statistical correlation should not be the primary tool used to study causation, because of the problem with third variables [16].

Table 5.3: Statistical correlation guidelines on strength of relationship

Sources: [16]

Value of r	**Strength of relationship**
-1.0 to -0.5 or 1.0 to 0.5	Strong
-0.5 to -0.3 or 0.3 to 0.5	Moderate
-0.3 to -0.1 or 0.1 to 0.3	Weak
-0.1 to 0.1	None or very weak

In order to verify the model accuracy, two main criteria must be calculated and checked in this analysis. The first one is regression statistic and the second, an analysis of the variance (ANOVA). Table 5.4 shows the regression statistics of median particle size, D_{50} (physical effect) and Ca/Si ratio on pozzolanic physical effects analysis. The multiple correlations coefficient, R is around 0.95. This indicates that the correlation among the independent and dependent variables is positive. This statistic, which ranges from -1 to +1, does not indicate statistical significance of this correlation. The coefficient of determination, R^2 and adjusted R square value indicates the wellness of the independent variable estimation. The closer R^2 is to one, the better the model describes the data [3; 17]. In the case of a perfect fit R^2=1. In this case, it point out about 90% of the observed UCS can be predicted using this model for both vital characteristics of SCBA. The adjusted R^2 is preferable value that is commonly used in simple linear regression. It adjusts the R^2 value to consider both the sample size and the number of predictors [17]. Strictly speaking adjusted R^2 should be used as an indicator of an adequacy of the model, since it takes in to account not only deviations, but also numbers of degrees of freedom. Standard error is an estimate of the deviation of experimental values of the dependent variable *y* with respect to those predicted by the regression model. It is used in statistics for different purposes [3]. There were 53 observations for both regression statistics.

Table 5.4: Regression statistics of median particle size, D_{50} (left) and Ca/Si ratio (right) on pozzolanic effects analysis

Regression Statistics	
Multiple R	0.94
R Square	0.89
Adjusted R Square	0.88
Standard Error	47.68
Observations	53

Regression Statistics	
Multiple R	0.95
R Square	0.89
Adjusted R Square	0.88
Standard Error	46.80
Observations	53

Table 5.5 and Table 5.6 represents the ANOVA of median particle size, D_{50} and Ca/Si ratio on pozzolanic physical effects analysis respectively. The signs *df, SS, MS, F* and *significance F* (P_R)denotes the degrees of freedom, sum of squares, mean square (variance), test of significance and F-numbers. In study case, P_R= 1.91E-20 and 8.19E-20, the approximate corresponding level of confidence 1 - P_R = 0.999. Therefore with the confidence near to 100%, it can be said that at least one of coefficients b_1 and b_2 is significant for the model illustrated in Eqn. 5.1.This proved there was a significant relationship among independent variables and the dependent variable. A coefficient in ANOVA output represents the b_i coefficients from the Eqn. 5.1. The t-Stat is the ratio of the predictors’ coefficient to the standard error. The P value is the probability that the null hypothesis is correct. If the corresponding P value for each independent variable is less than an arbitrary value of 0.05, the null hypothesis is rejected. In this series of analyses, the null hypothesis was defined as the absence of a significant relationship between the independent variable and dependent variable [17]. In this analysis, all the predictors had a P value of <0.05; hence, prove that all of the predictors could affected the response.

Table 5.5: Analysis of variance (ANOVA) on pozzolanic physical effects analysis

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	851079.54	141846.59	62.39	1.91E-20
Residual	46	104586.27	2273.61		
Total	52	955665.81			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-371.43	58.32	-6.37	8.10E-08	-488.83	-254.03
SCBA	4.32	1.58	2.74	8.67E-03	1.15	7.49
D50	-257.64	91.77	-2.81	7.30E-03	-442.37	-72.92
Curing days	3.42	0.62	5.48	1.71E-06	2.16	4.67
OPC dosage	1.70	0.14	11.83	1.48E-15	1.41	1.99
K7 dosage	0.30	0.05	5.69	8.39E-07	0.19	0.40
Preloading	2.97	0.33	8.98	1.11E-11	2.31	3.64

Table 5.6: Analysis of variance (ANOVA) on pozzolanic chemical effects analysis

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	854907.38	142484.56	65.05	8.19E-21
Residual	46	100758.43	2190.40		
Total	52	955665.81			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-466.30	48.39	-9.64	1.30E-12	-563.70	-368.89
SCBA	2.64	1.90	1.39	1.71E-02	-1.18	6.46
Ca/Si	863.36	274.00	3.15	2.86E-03	311.83	1414.89
Curing days	3.33	0.61	5.44	1.95E-06	2.10	4.56
OPC dosage	1.73	0.14	12.29	3.94E-16	1.44	2.01
K7 dosage	0.30	0.05	5.99	3.02E-07	0.20	0.41
Preloading	2.93	0.32	9.01	9.97E-12	2.27	3.58

The following regression model for predict the q_u of peat-cement-bagasse ash (PCB) mixtures was developed from the analysis:

$$q_{u\,(}\text{stabilized}_{)} = 4.32B - 0.26D_{50} + 3.42D + 1.7C + 0.3S + 2.97P - 371.43 \qquad (5.2)$$

$$q_{u\,(}\text{stabilized}_{)} = 2.64B - 863Ca/Si + 3.33D + 1.73C + 0.3S + 2.93P - 466.3 \qquad (5.3)$$

where B= SCBA % of OPC replacement; D= D_{50} of SCBA in µm; C= OPC dosage in kg/m^3; S= K7 dosage in kg/m^3; P= Preloading during curing in kN/m^2. Eqn. 5.2 represents the regression model for physical effects, D_{50} while Eqn. 5.3 for chemical effects, Ca/Si ratio. A comparison of the predicted versus experimental unconfined compressive strength of median particle size, D_{50} and Ca/Si ratio on pozzolanic physical effects analysis is shown Figure 5.4. It shows that the regression model represents the q_u data is reasonably fit, with $R^2 = 0.89$ for both SCBA characteristics.

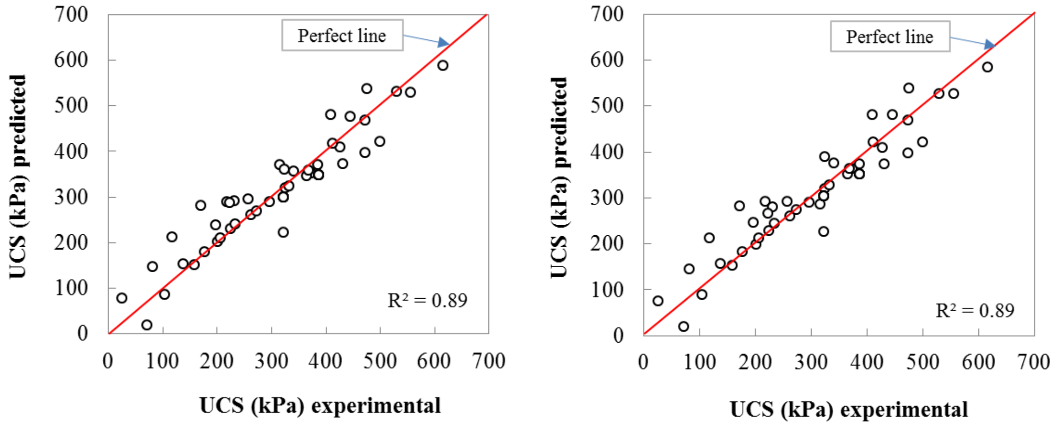


Figure 5.4: Predicted versus experimental UCS of median particle size, D_{50} (left) and Ca/Si ratio (right) on pozzolanic effects analysis

Generally, Eqn. 5.2 and 5.3 can be used at any values of multi-factor of studied peat stabilization. However, from previous multi-factor in peat stabilization results in Chapter 3, it was suggested the mixture that able to achieve minimum q_u target of 345kPa could be obtained at; Curing= 7days; OPC= 300kg/m^3; K7= 500kg/m^3; and P=20kPa (about 1m embankment). Therefore, the Eqn. 5.2 and Eqn. 5.3 can be simplified to;

$$q_{u\ (stabilized)} = 0.78B - 0.26D_{50} + 369.55 \tag{5.4}$$

$$q_{u\ (stabilized)} = -2.54B + 863Ca/Si + 285.79 \tag{5.5}$$

for physical effects and chemical effects respectively. From the Eqn. 5.4 and 5.5, the correlation chart between predicted q_u to D_{50} and Ca/Si ratio had been made like shown in Figure 5.5. However, the developed charts were limited to apply on Hokkaido peat or hemic peat stabilization with constant dosage/amount of cement, silica sand and initial loading. According to Figure 5.5, the following inferences can be made: (1) q_u gained has a close relationship to D_{50} and Ca/Si ratio; (2) increase in the SCBA percentage decreases the q_u of the PCB mixture but depends on SCBA particles size and its chemical characteristics; and (3) smaller size of D_{50} and larger Ca/Si ratio indicates greater q_u of the PCB mixture and simultaneously can decrease -

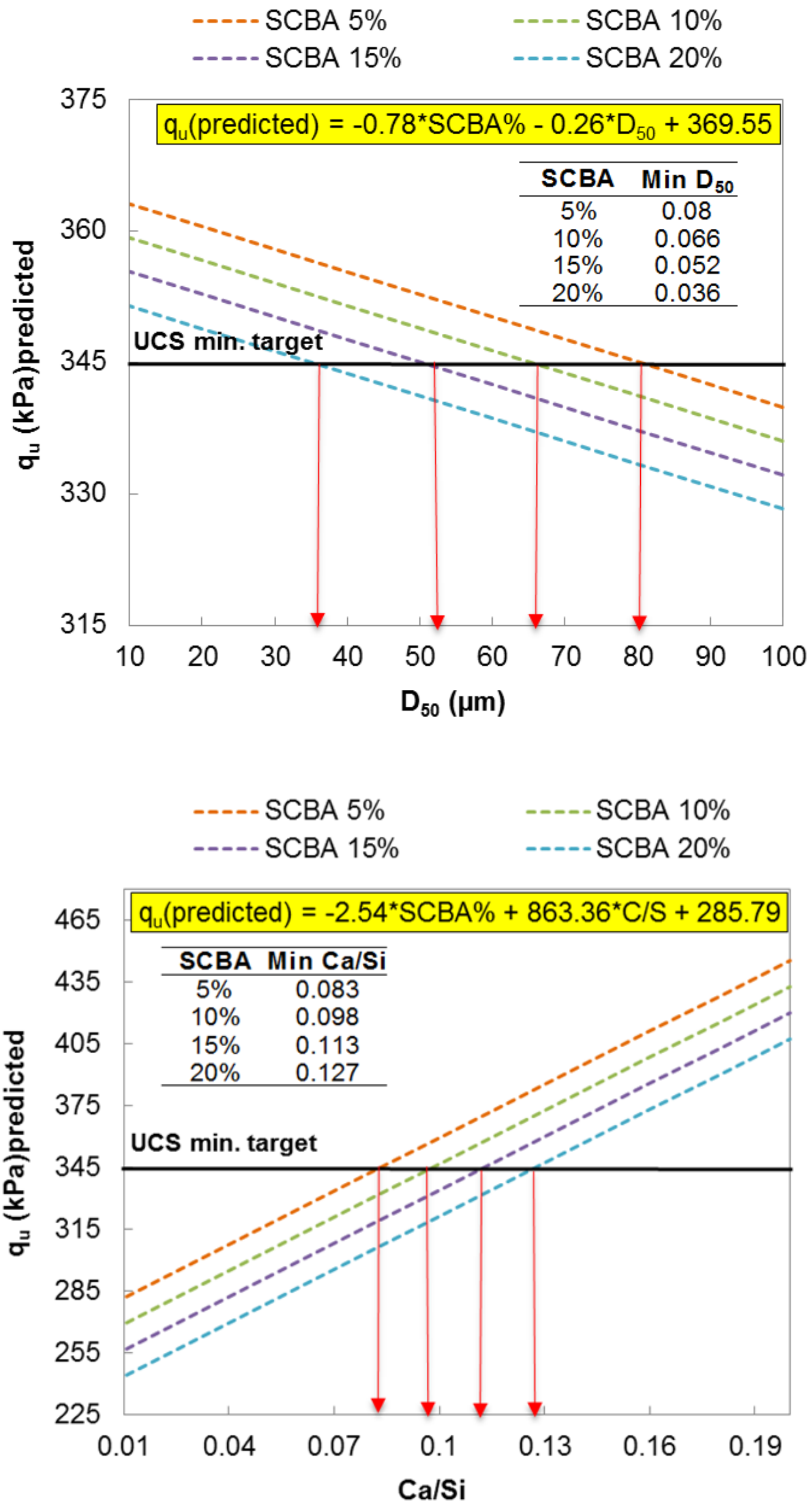
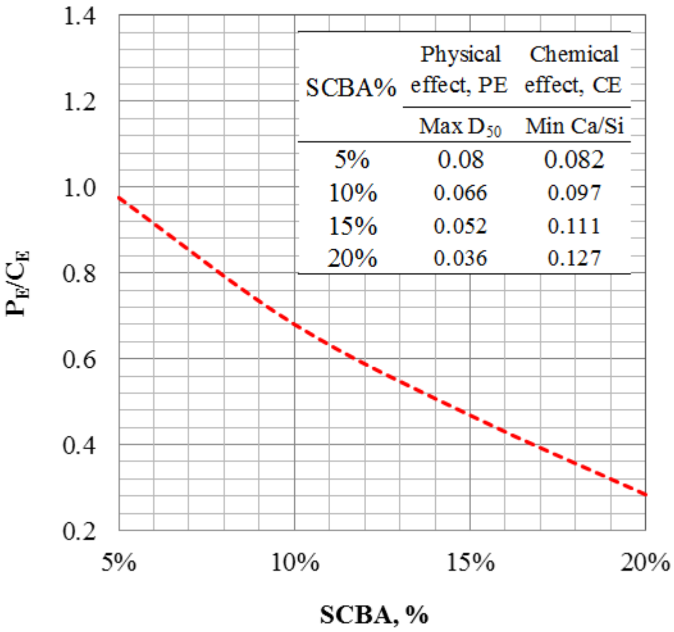


Figure 5.5: Effect of median particle size (top) and Ca/Si ratio (bottom) of SCBA on UCS

the OPC inclusion percentages. In this investigation, in order to achieve minimum UCS target, it is suggested the maximum D_{50} is should not exceed 80µm and Ca/Si compositions should more than 0.083 for at least 5% SCBA replacement of OPC content. So as to reach 20% SCBA replacement of OPC, D_{50} must finer than 36µm while Ca/Si proportion ought to larger than 0.127. From this obtained results, Figure 5.6 had been construct for simplify the requirement of physical-chemical effect ratio of SCBA in order achieved 345kPa (minimum strength target).



SCBA%	Physical effect, PE	Chemical effect, CE
	Max D_{50}	Min Ca/Si
5%	0.08	0.082
10%	0.066	0.097
15%	0.052	0.111
20%	0.036	0.127

Figure 5.6: Ratio of physical-chemical ratio of SCBA versus SCBA percentage inclusion

5.4 Summary

As summary, evaluation of SCBA quality characteristics on pozzolanic effect in stabilized peat has been examined in this chapter. It can be summarized from the experimental results that SCBA characteristics have made a significant influence on the mechanical properties of the stabilized peat. Based on the outcome of the this chapter analysis, the following concluding comments are made.

i. Curing duration of samples at 7 days was visibly shows the highest strength activity index and all optimum PCB mixtures were observed exceed the PC line. The probable reasons this condition could be happened is because;
   a. the strength activity index of optimum PCB mixtures due to filler effect is higher than due to pozzolanic reaction at early curing days.
   b. the great combination of SCBA physical and chemical effect. Inclusion of $CaCl_2$ is well known could create high cement hydration at early time.

ii. Pozzolanic reaction still occurred after a month of curing. This could be happened by the reason of the fact that cement hydration (PC mixtures) is normally rapid and effective at first month but almost stop or complete after that duration while pozzolan reaction can be occurred continuously until several month.

iii. Effect of SCBA pozzolan was observed has more significance influence on the strength activity index if compare to silica sand, K7 inclusion.

iv. Regression statistical analysis was successfully verified and completed. The outcomes are;
   a. q_u gained has a close relationship to D_{50} and Ca/Si ratio of SCBA.
   b. increase in the SCBA percentage decreases the q_u of the PCB mixture but depends on SCBA particles size and its chemical characteristics.
   c. finer size of D_{50} and larger Ca/Si ratio indicates greater q_u of the PCB mixture and simultaneously can increase the SCBA percentage replacement or on the other hand decrease the OPC inclusion percentages.
   d. in this study, in order to achieve minimum UCS target , it is suggested the maximum D_{50} is should not exceed 80µm and Ca/Si compositions should more than 0.083 for at least 5% SCBA replacement of OPC content. So as to reach 20% SCBA replacement of OPC, D_{50} must finer than 36µm while Ca/Si proportion ought to larger than 0.127.

5.5 References

[1] Isaia, G.C., Gastaldini, A.L.G. and Moraes, R., 2003. Physical and pozzolanic action of mineral additions on the mechanical strength of high-performance concrete. Cement & Concrete Composites, 25(1): 69-76.

[2] Edwin, R.D., 2011. How Does Pozzolanic Reaction Make Concrete “Green”?, World of Coal Ash (WOCA), Denver, CO, USA.

[3] Orlov, M.L., 1996. Multiple Linear Regression Analysis Using Microsoft Excel. Chemistry Department, Oregon State University, http://chemistry.oregonstate.edu/courses/ch361-464/ch464/RegrssnFnl.pdf.

[4] Janz, M. and Johansson, S.E., 2002. The function of different binding agents in deep stabilization, Swedish Deep Stabilization Research Center, Linkoping: SGI. 9.

[5] Tastan, E.O., Edil, T.B., Benson, C.H. and Aydilek, A.H., 2011. Stabilization of Organic Soils with Fly Ash. Journal of Geotechnical and Geoenvironmental Engineering, 137(9): 819-833.

[6] ASTM-C311, 2005. Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete. American Society for Testing and Materials Standards, Pennsylvania, USA, Volume 04.02.

[7] Tangpagasit, J., Cheerarot, R., Jaturapitakkul, C. and Kiattikomol, K., 2005. Packing effect and pozzolanic reaction of fly ash in mortar. Cement and Concrete Research, 35(6): 1145-1151.

[8] Goldman, A. and Bentur, A., 1993. Effects of pozzolanic and non-reactive fillers on the transition zone of high strength concrete. Maso JC, editor. RILEM International Symposium on Interfaces in cementitious composites Toulouse, 1992, Proceedings. London: E&FN SPON; p. 53–62(RILEM Proceedings 18).

[9] Goldman, A. and Bentur, A., 1993. The influence of micro-fillers on enhancement of concrete strength. Cem Concr Res;23:962–72.

[10] Berry, E.E., Hemmings, R.T., Zhang, M.H., Cornelius, B.J. and Golden, D.M., 1994. Hydration in High-Volume Fly-Ash Concrete Binders. Aci Materials Journal, 91(4): 382-389.

[11] EuroSoilStab, 2002. Development of design and construction methods to stabilize soft organic soils. Design guide soft soil stabilization. CT97-0351.

Project No. BE 96-3177, Industrial & Materials TechnologiesProgramme (Brite- EuRam III), European Commission.

[12] Wong, L.S., Hashim, R. and Ali, F.H., 2009. A Review on Experimental Investigations of Peat Stabilization. Australian Journal of Basic and Applied Sciences, 3(4): 3537-3552, 2009. ISSN 1991-8178.

[13] Allu, F.O., 2005. Mass stabilization Manual.

[14] Mehta, P.K. and Aitcin, P.C., 1990. Principles underlying production of highperformance concrete. Cem Concr Aggregate;12(2):70–8.

[15] Roy, D.M., 1992. Advanced cement systems including CBC, DSP, MDF. International Congress on the Chemistry of Cement, 9th, New Delhi, , Proceedings, vol. 4. New Delhi: National Council for Cement and Building Materials; 1992. p. 357–80.

[16] Explorable.com, 2009. Statistical Correlation. Retrieved Aug 26, 2015 from Explorable.com: https://explorable.com/statistical-correlation

[17] Motamedi, S., Song, K.I. and Hashim, R., 2015. Prediction of unconfined compressive strength of pulverized fuel ash-cement-sand mixture. Materials and Structures, 48(4): 1061-1073.

CHAPTER 6

EFFECTIVENESS OF OPTIMUM PEAT-CEMENT-BAGASSE ASH (PCB) MIXTURES ON PEAT DEFORMATION BEHAVIOUR

6.1 Introduction

This chapter illustrates the effectiveness of optimum peat-cement-bagasse ash (PCB) mixtures on peat deformation behavior. Afterward, the outcomes were compared to peat-cement (PC) mixture and untreated peat in order to analyze the contribution of SCBA inclusion in stabilized peat.

The compressibility of soil commonly comprises three phases namely initial compression, primary consolidation, and secondary compression. Initial compression occurs instantaneously after the load is applied whereas primary and secondary compressions depend upon the length of time the load is applied. The initial compression occurs mainly due to the compression of gas within the pore spaces and also due to the elastic compression of soil grains [1]. Primary consolidation observed during the increase in effective vertical stress caused the dissipation of excess pore water pressure. After the completion of dissipation of excess pore water pressure, the secondary compression would take place at constant effective vertical stress.

The compression behavior of peat varies from the compression behavior of other types of soils in two ways. First, the compression of peat is much larger than that of other soils. Secondly, the creep portion of settlement plays a more significant role in determining the total settlement of peat than of other soil types. The dominant factors controlling the compressibility characteristics of peat include the fiber content, natural water content, void ratio, initial permeability, nature and arrangement of soil particles, and inter-particle chemical bonding in some of the soils. Determination of compressibility of fibrous peat is usually based on the standard consolidation test [2; 3]. For more temperate regions, this subsidence rate was high for Malaysia as shown in the Figure 6.1 [4; 5].

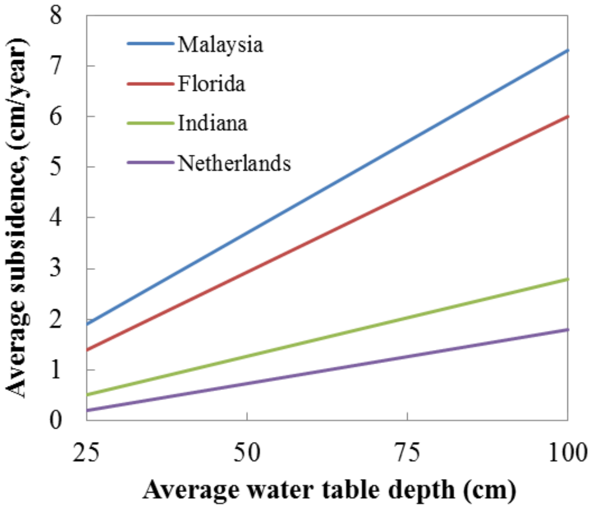


Figure 6.1: Subsidence rate versus groundwater level relationships for different areas in the world [4]

The calculation of the settlement requires evaluation of soil parameters from the compression curves which are usually obtained from laboratory Oedometer tests. The results of incremental loading Oedometer tests are usually presented as the relationship between void ratio, e, and effective vertical stress, σ_v'. The σ_v' may be plotted on a linear scale to determine the coefficient of volume change, m_v or on logarithmic scale to determine the compression index, C_c. As with mineral soils (silt and clay), the settlement parameters of peat (i.e. consolidation settlement) may also be determined from standard incremental Oedometer (one dimensional compression) tests [6; 7]. The parameters are interpreted from traditional e log σ_v' plots. There may be differences in the magnitudes of various quantities measured but the general shape of the consolidation curves appear reasonably similar and the formulation developed for clay compression can be used to predict the magnitude and rate of settlement [7].

6.2 Methodology

Consolidation tests were carried out in the standard Oedometer apparatus on the untreated (P) and stabilized peat (PC, PCB1-20 and PCB2-5) mixtures samples that obtained from UCS test in Chapter 3. The flowchart that related to this chapter had been shown in Figure 6.2. The sizes of specimens were 60 mm in diameter and 30 mm in height. The standard Oedometer tests comprised seven incremental load stages and each load stage lasted 24 hours. An initial stress of 10 kPa was applied and the stress was increased in steps at the end of each load stage using a load increment ratio of unity until a final stress of 640 kPa had been applied.The detail computations for this compressibility were shown in Appendix F.

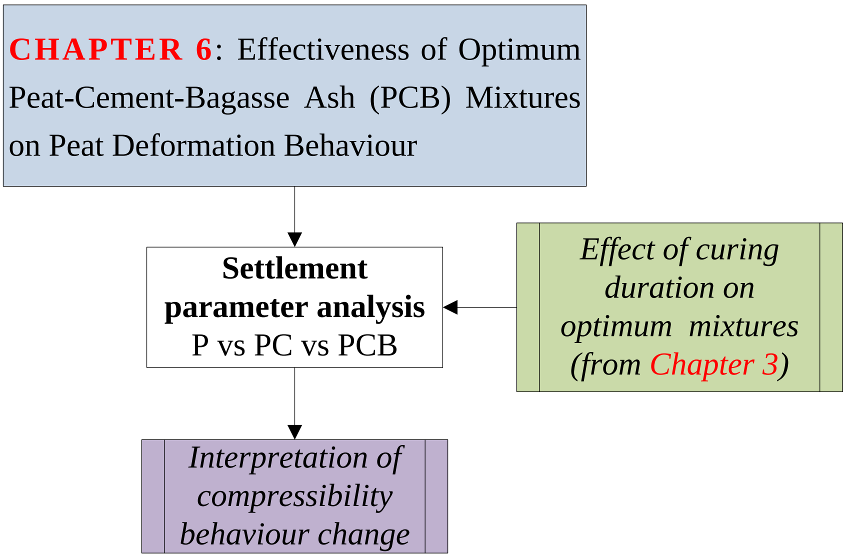


Figure 6.2: Flowchart of Chapter 6 experimental planning

6.3 Results and discussions

6.3.1 Void ratio (e), coefficient of permeability (*k*) and pre-consolidation pressure (σ_c')

The void ratio, e versus effective vertical stress, σ_v' for untreated is shown in Figure 6.3. The results reveal that untreated Hokkaido peat demonstrated the high e and as a result contribute high coefficient of compression, $C_c = \Delta e / (\Delta \log \sigma_v')$ with about 9 and 4.9 respectively. The average value of the specific gravity, G_s of studied

Hokkaido peat (G_s= 1.67) was used in phase relationship to determine the initial void ratio of the soil specimen employed in the experimental program. The high void ratio is believed predominantly contributed by high water contents and liquid limit in peat. This matter has also been discovered by Huat [7] and Den Haan [131]. However, the void ratio was seen reduced with σ_v' increment and consequently drop the *k* significantly.

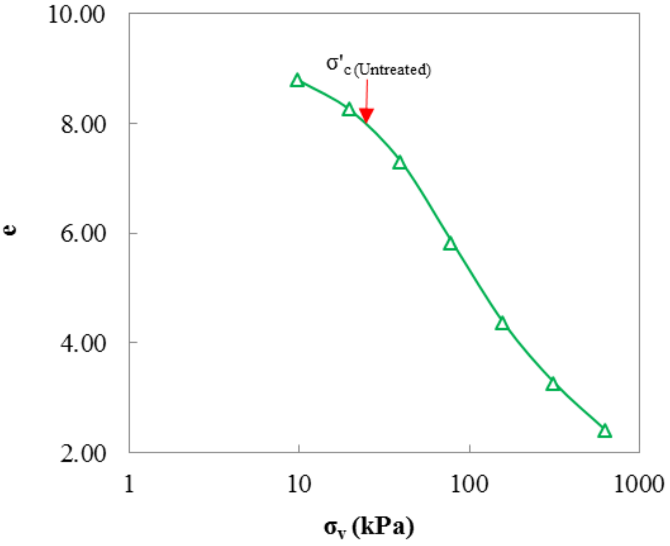


Figure 6.3: Void ratio, e versus effective vertical stress, σ_v' for untreated peat

The relationship between e, k and σ_v' for untreated Hokkaido peat was shown in Figure 6.4. The *k* noticeably decreases once after the small load was subjected as shown in Figure 6.4a. This is because peat represent the extreme form of soft soil and subject large settlement even when subjected to moderate load [9]. The change in permeability as a result of compression is drastic for peats (as compression proceeds and void ratio decreases rapidly, permeability is greatly reduced as shown in Figure 6.4b). The application of consolidation pressure may induce a rearrangement of fiber orientation and drastically reduces the void, causing a significant reduction in the vertical permeability [10; 11]. In this study, e of untreated peat reduces from 9.6 to 2.4 while *k* decreases from $2.7E^{-08}$ to $3.2E^{-11}$ m/s which is mean as compression proceeds and void ratio decreases rapidly. Permeability is greatly reduced roughly 1000-fold to a value comparable to that of clay. In general, the initial permeability of peats is 100 -1000 times that of soft clays and silts [12] and Edil [13] stated that the rate of decrease of *k* with decreasing e is usually higher than that in clays. A range of the peat *k* between E^{-05} and E^{-08} m/s was obtained from previous studies [10; 14]. With $2.7E^{-08}$ for studied peat, it shows that hemic peat has lower permeability if compared to typical fibrous type in literature review.

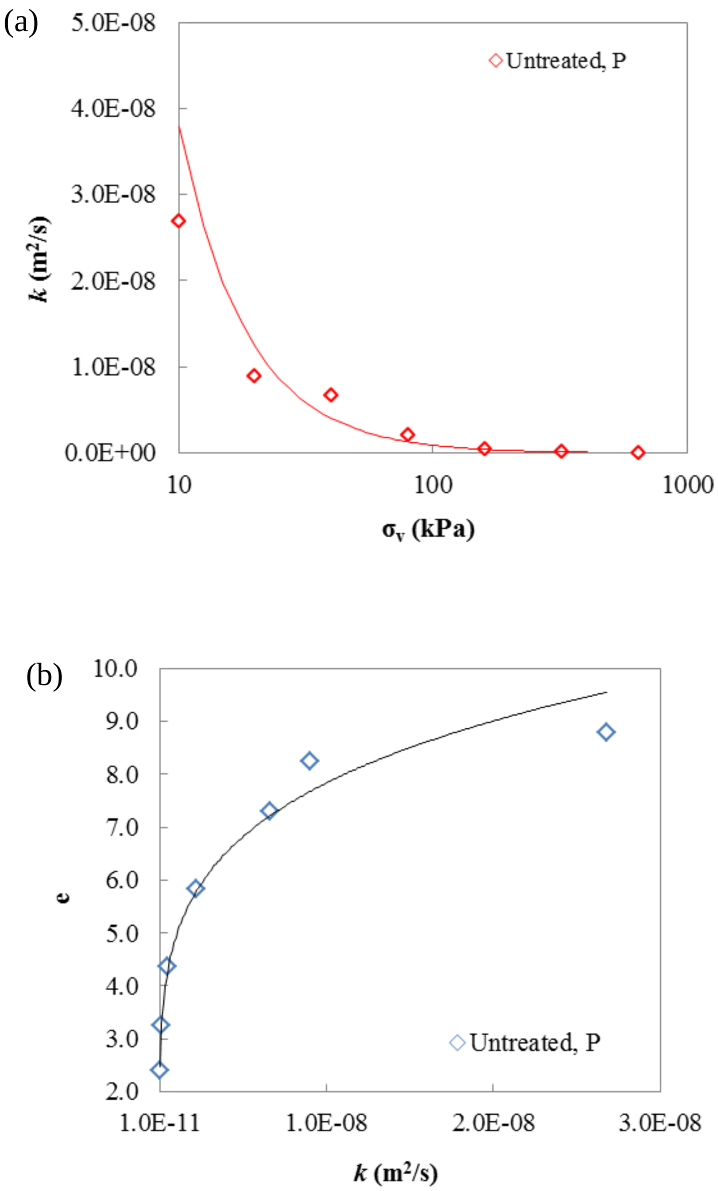


Figure 6.4: Relationship of coefficient of compressibility, *k*, effective vertical stress, σ_V' and void ratio, e of untreated peat

Another important characteristic of soil compressibility is the pre-consolidation pressure, $\sigma_{c'}$. The two most commonly used methods for determining the end of primary consolidation, namely the Taylor and Casagrande graphical constructions from a void ratio or axial strain, ε versus time curve [10; 15]. The $\sigma_{c'}$ estimation of untreated Hokkaido peat was given approximately 25 kPa by using Casagrande method [16] as shown in Figure 6.5. The obtained $\sigma_{c'}$ value has little in common with peat from the USA, UK and Malaysia. Mesri et al. [2], the researchers from the USA found the $\sigma_{c'}$ of his studied fibrous peat were lying between 30-34 kPa. One of active peat researcher in UK, O' Kelly [17; 18] was observed on six kind of UK peat which record the range of $\sigma_{c'}$ between 20 to 50 kPa. While in Malaysia, a study by Ali et al. [19] revealed that their studied fibrous peat $\sigma_{c'}$ is about 25.5kPa.

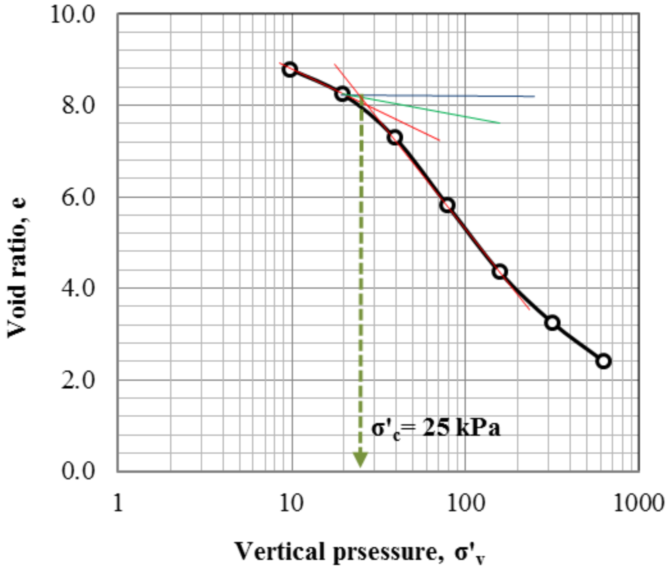


Figure 6.5: Determination of preconsolidation pressure, σ'_c by Casagrande's method for untreated peat

In the Figure 6.6a, there was a significant reduction of e in the stabilized peats (all optimum PCB and PC mixture at 7 days of curing) as compared to that of the untreated one (Figure 6.3a). Initially, the e for PCB1-20 represents the lowest and then followed by PCB2-5 and PC mixtures. Likewise to the results in Figure 6.6b, the e for 60 days curing of PCB1-20 represents the lowest and then followed by 28 and 7 days curing of same mixtures at the beginning, yet it is turn to inverse way at the final load (640kPa). This proves that the mixture of PCB1-20 is harder, denser and stronger with time and better than other mixtures in term of compressibility. However, the e of stabilized peat seems shows the slow lessening with curing age.

One of the reasons this could be occurred because the duration of stabilization generally does not affect its permeability to a large extent [20].

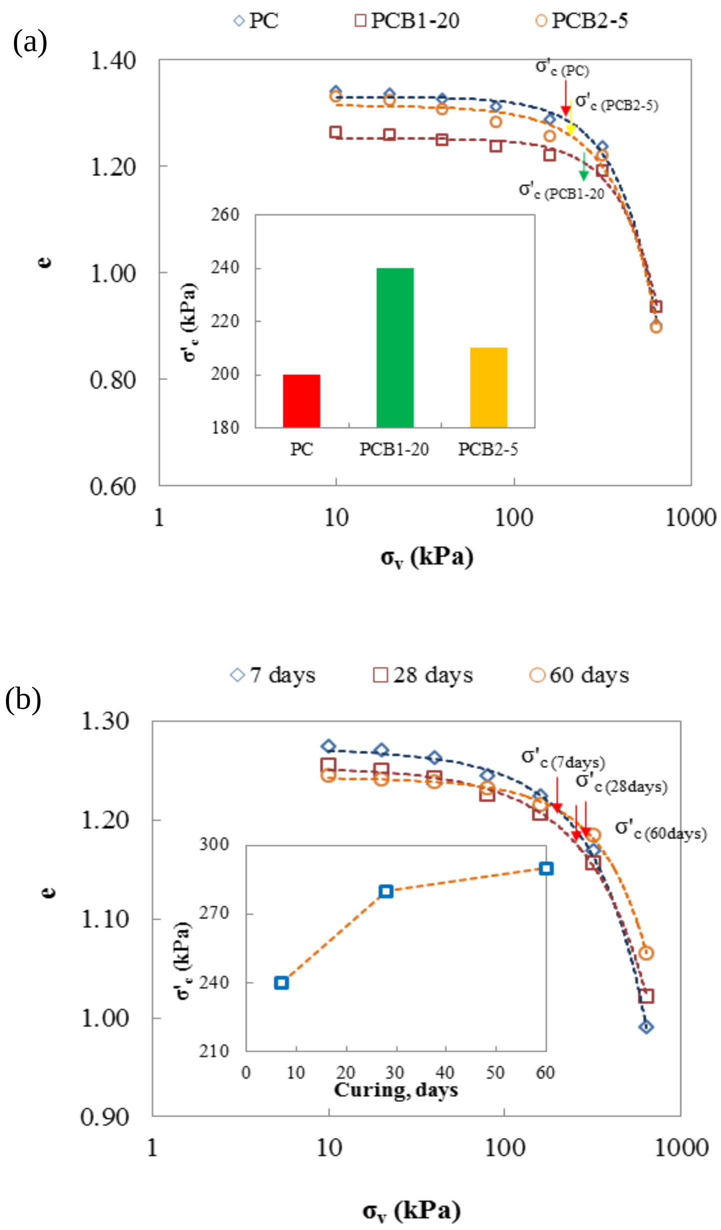


Figure 6.6: Void ratio, e versus effective vertical stress, σ_V' for; (a) all optimum PCB and PC mixture at 7 days of curing, (b) optimum PCB1-20 mixture at 7, 28 and 60 days of curing

The relationship between e, k and σ_V' for stabilized Hokkaido peat was shown in Figure 6.7 and Figure 6.8. In the same way with untreated peat, as compression proceeds and void ratio decreases, permeability is reduced but not as rapid and great as untreated peat. This is because the structure of stabilized peat is stiffer and solid compared to untreated. However, it was revealed that the initial *k* between stabilized and untreated almost same or small change.

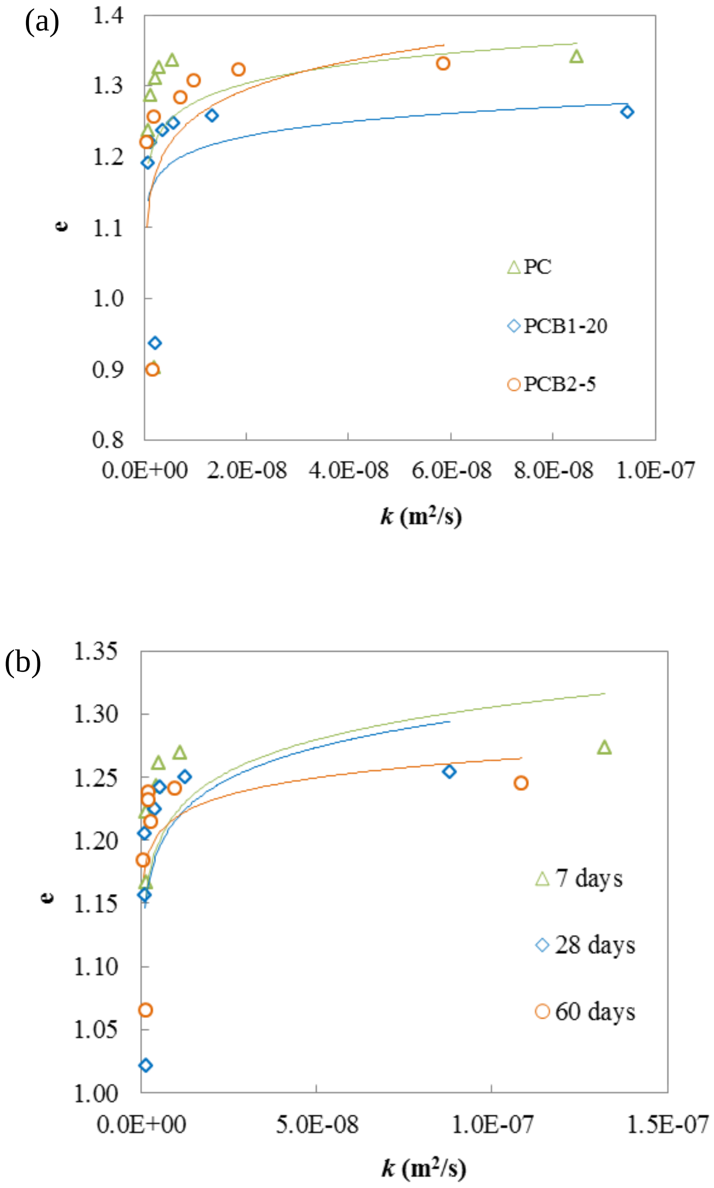


Figure 6.7: Void ratio, e versus coefficient of permeability, *k* for; (a) all optimum PCB and PC mixture at 7 days of curing, (b) optimum PCB1-20 mixture at 7, 28 and 60 days of curing

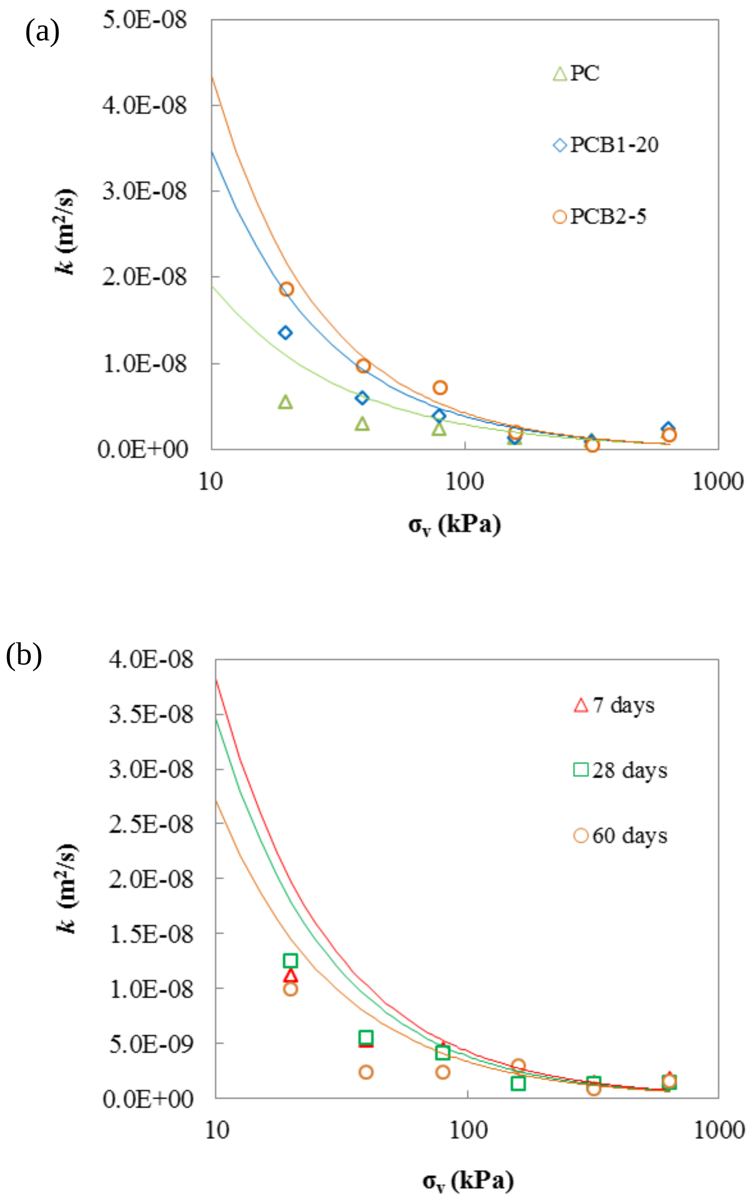


Figure 6.8: Coefficient of permeability, *k* versus effective vertical stress, σ_v' for; (a) all optimum PCB and PC mixture at 7 days of curing, (b) optimum PCB1-20 mixture at 7, 28 and 60 days of curing

The permeability of the cement-stabilized peat was of the same order or lower than the original peat depending on the stress state acting during curing [21]. It was found that the *k* for all mixtures encounter a very slight change between each other. The PC mixture shows the lowest *k* then other PCB mixtures. This is maybe because of SCBA presence in the other two mixtures which the particles are coarser than OPC and consequently change the soil fibric and increase the macropores. For curing effects, two month curing samples shows the less *k* and become prove it has higher strength and more compact. EuroSoilStab [22] reported that permeability tests on peat with different binders showed that the permeability of stabilized peat was between E^{-09} to E^{-08} m/s after 28 and 180 days respectively. Similar to study results, the *k* of stabilized peat was between E^{-09} to E^{-08} m/s in range of 7 to 60 days curing.

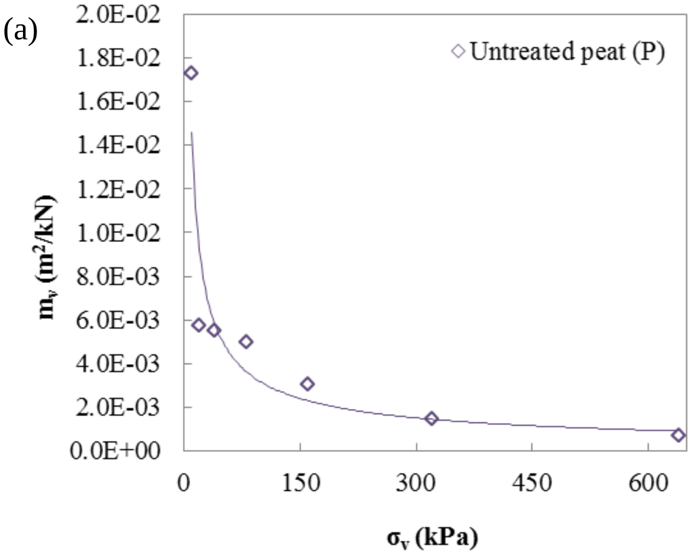
In addition, Figure 6.6 also point out that the important effect of treatment on the compression behavior is the increase in the pre-consolidation pressure, $\sigma_{c'}$ with different PCB mixture and curing period. In the consolidation tests the most evident effect of treatment with PC was the increase in the $\sigma_{c'}$. The development of this $\sigma_{c'}$ is the mechanism responsible for the reduction in deformations associated with any increase in effective stresses [15]. In contrast to e result, the $\sigma_{c'}$ shows the increment pattern. The $\sigma_{c'}$ increased from 25 kPa (untreated peat) to about 200 kPa, 210 kPa and 240 kPa for PC, PCB2-5 and PCB1-20 respectively. Similarly, Figure 6.6b shows the increment of the $\sigma_{c'}$ for optimum PCB1-20 mixture at 7, 28 and 60 days of curing with 240 kPa, 280 kPa and 290 kPa respectively. This increase in $\sigma_{c'}$ is in agreement with the increase in strength with time recorded from the UCS results in Chapter 3. These findings has an similarity with the observed results in Hebib and Farrell [21] study. As a result of the development of this $\sigma_{c'}$, the compression curve of the stabilized soil is shifted to higher effective stress. Moreover, the compressibility of the stabilized peat measured in the overconsolidated area also shows a decrease with increasing curing duration especially between 7 and 60 days. These two effects are an indication of the effectiveness of the treatment in reducing settlements [23]. As a result, the stabilized soil can sustain higher effective stress than the Hokkaido untreated peat at the same void ratio [15].

6.3.2 Coefficient of volume compressibility, m_v and coefficient of consolidation, C_v

Figure 6.9 displays the coefficient of volume compressibility, $m_v = [(\Delta H/H_{avg})\% \text{ x } \Delta P]$ versus effective vertical stress, σ_v' for untreated peat, all optimum PCB mixture at 7 days of curing and optimum PCB1-20 mixture at various days of curing. The results indicate that the addition of consolidation pressure has the effect of decreasing the coefficient of permeability of untreated and stabilized

Hokkaido peat. The m_v decreases drastically at the lower range of pressure but the effect become less at large compression. This trend is in agreement with the consolidation theory [10; 24].

According to Kazemian and Huat [25], this parameter is very useful to estimate the primary consolidation settlement. For the untreated peat, the m_v exhibits significant decrement if compared to stabilized specimens. The compressibility characters of soils are improved because of the hardened skeleton matrix formed by bagasse-cement particles bonding with soil particles. The optimum mixtures of PCB1-20 that cured for 60 days shows the lowest m_v if matched to other stabilized mixtures. Therefore, it can be said that the longer curing time with the high quality of SCBA inclusion in peat stabilization could be beneficial to reduce the m_v which indirectly reduce the soil settlement potential.



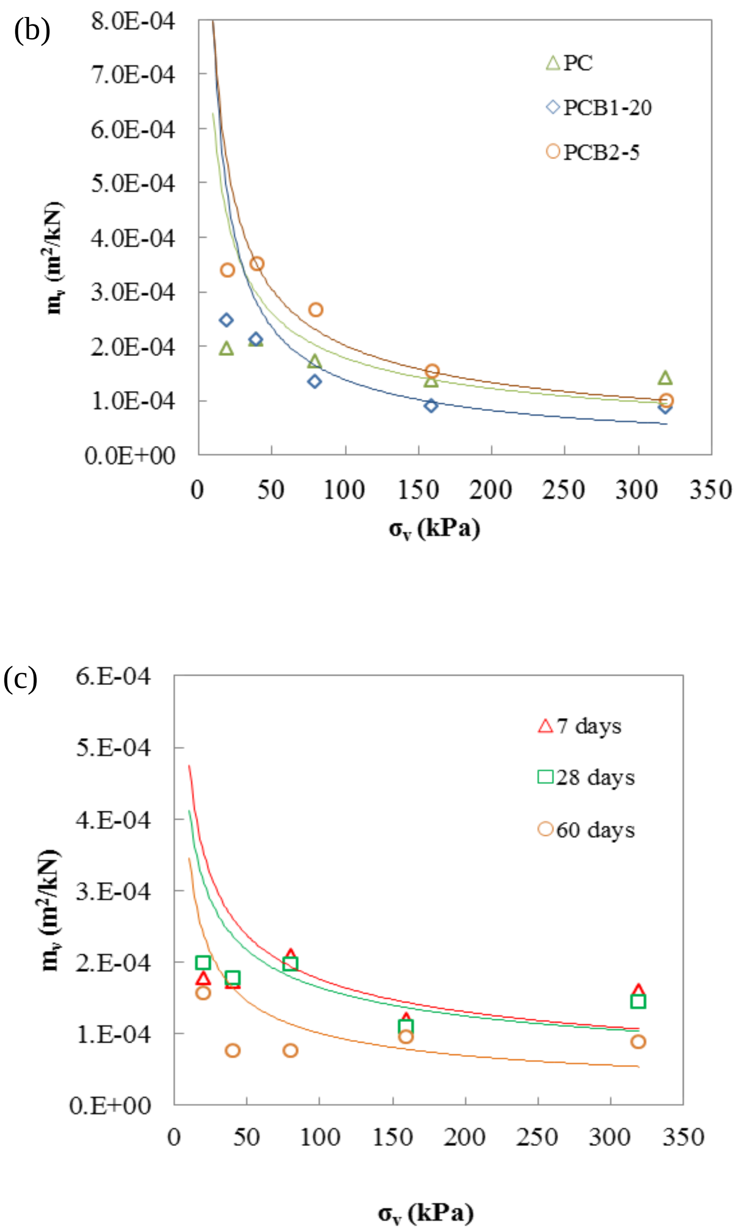


Figure 6.9: Coefficient of volume compressibility, m_v versus effective vertical stress, σ_v' for; (a) untreated peat, (b) all optimum PCB mixture at 7 days of curing, (c) optimum PCB1-20 mixture at 7, 28 and 60 days of curing

There are two practical methods available to determine the coefficient of consolidation rate, C_v from laboratory consolidation test; log t method and square root t, √t method. In this study √t method was adopted to define the C_v as this method was believed has better accuracy [19]. Figure 6.11 displays the coefficient of consolidation rate, $C_v = [0.848/t_{90} \text{ x } (H_{avg}/2)^2]$ versus effective vertical stress, σ_v' for untreated peat, all optimum PCB mixture at 7 days of curing and optimum PCB1-20 mixture at various days of curing. The values of t_{90} were obtained from the settlement vs $\sqrt{t}$ curve as shown in Figure 6.10 as example. Similar pattern were observed between untreated and stabilized peat where the C_v reduce as vertical consolidation pressure increase. Ajlouni [26] pointed out a pronounced decrease in C_v with load during consolidation due to large reduction in permeability. It was revealed that the C_v of stabilized peat potrays the higher values than untreated one where the C_v for PCB1-20 mixtures that cured for two month gave the higher values among the stabilized mixtures. As mentioned previously, it is because of the effect of SCBA inclusions in the mixtures that could replace organic matter in the soil. Study by Hassan et al. [27] shows that increasing percentage of sand content in peat stabilization may replace the organic content and finally increase the C_v. As stated by Farrell et al. [28], lower C_v is more evidence in specimen with higher organic contents. Therefore, it can be concluded that PCB1-20 mixtures represents the lowest organic content by the effect of primary and secondary hydration. It was also can be proved from the chemical results in Chapter 4 where this mixture has the lowest carbon contents which can be considered as lower organic contents.

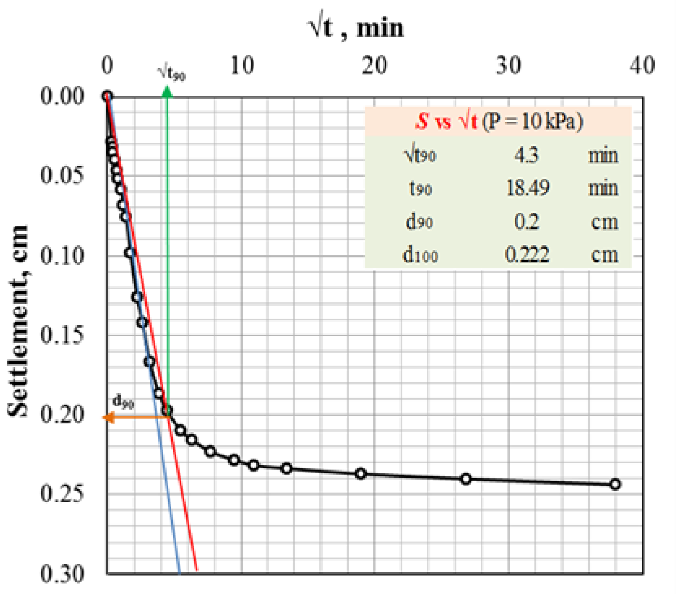
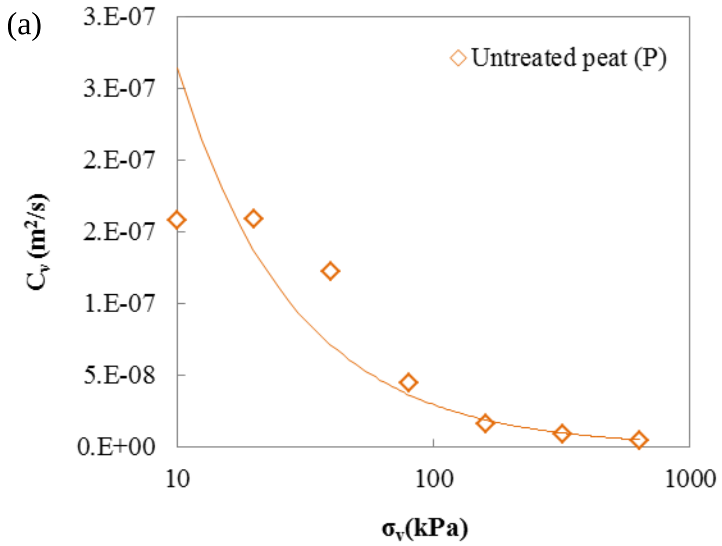
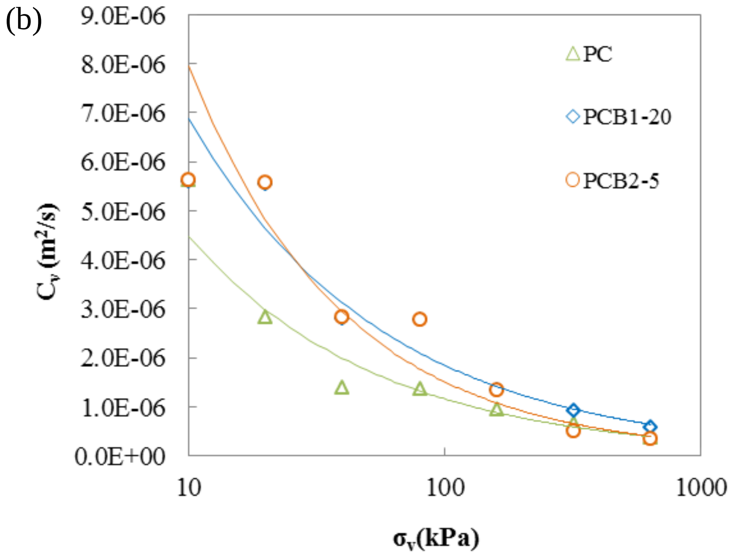


Figure 6.10: Settlement vs square root time curve; example for determination of coefficient of consolidation rate, C_v in laboratory consolidation test


(a)
3.E-07
3.E-07
2.E-07
2.E-07
1.E-07
5.E-08
0.E+00
C_v (m^2/s)
Untreated peat (P)
10
100
1000
σ_v(kPa)


(b)
9.0E-06
8.0E-06
7.0E-06
6.0E-06
5.0E-06
4.0E-06
3.0E-06
2.0E-06
1.0E-06
0.0E+00
C_v (m^2/s)
PC
PCB1-20
PCB2-5
10
100
1000
σ_v(kPa)

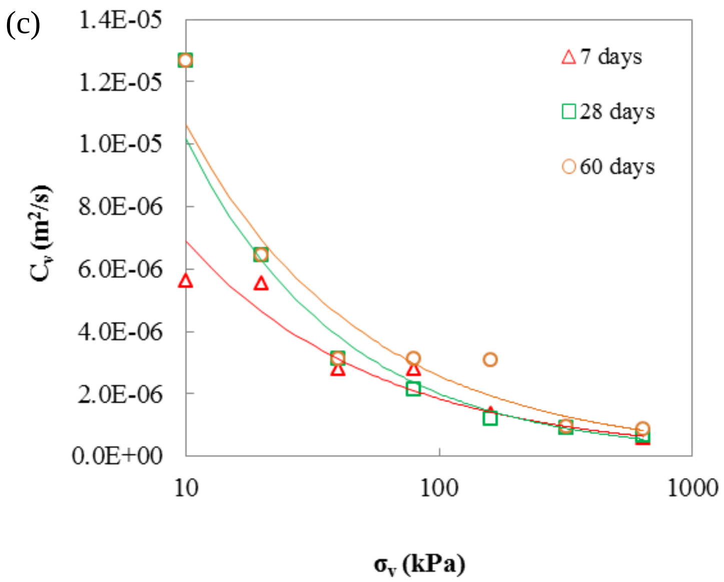
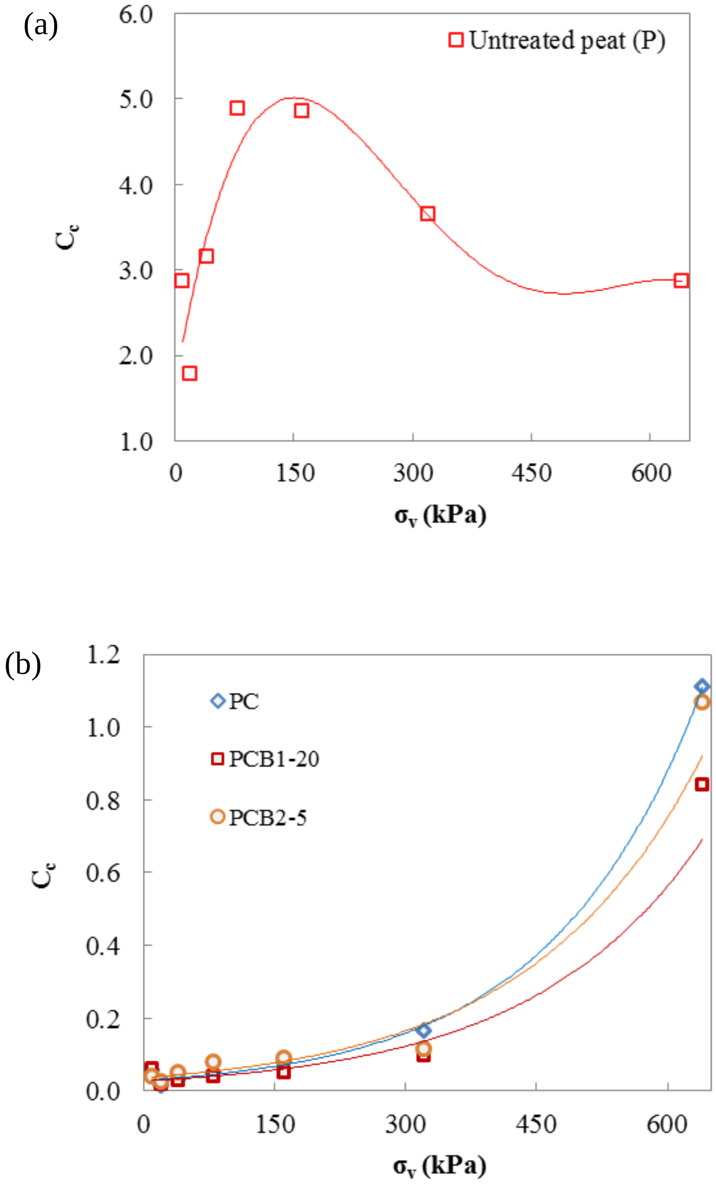


Figure 6.11: Coefficient of consolidation rate, C_v versus effective vertical stress, σ_v' for; (a) untreated peat, (b) all optimum PCB mixture at 7 days of curing, (c) optimum PCB1-20 mixture at 7, 28 and 60 days of curing

6.3.3 Compression index, C_c and secondary compression index, C_α

Figure 6.12 and Figure 6.13 displays the primary and secondary compression index, (C_c and C_α) versus effective vertical stress, σ_v' for untreated peat, all optimum PCB mixture at 7 days of curing and optimum PCB1-20 mixture at various days of curing. For the purpose of $C_\alpha = \Delta e / (\Delta \log t)$ determination, the slope of the *e* – log t curves were used. It was easy to compute C_α for untreated Hokkaido peat since the curve shows the typical S-curve like exposed in Figure 6.14. However, considering the standard oedometer apparatus that had been used in this study cannot determine the dissipation of water during consolidation, it assumes that secondary compression started 4 hours (240 minutes) after loading for stabilized peat. This assumption approach adopted from previous research conducted by Hebib and Farrel [21] and Duraisamy [29]. Therefore, C_α was determined from the slope of the *e* – log t curves 4–24 hour after a load increment was applied (Figure 6.15).

In the case of untreated peat, it was discovered that C_c and C_α significantly increase with the increase of σ_v' near the preconsolidation pressure, σ_c. At values of σ_v' past about $3\sigma_c$, C_c gradually decreases with the increase in σ_v'. Consequently, according to the C_α/C_c concept of compressibility, C_α is expected to gradually decrease with time. Similar to the study by Mesri et al. [2], they found that the lowest values of C_α were encountered in the recompression range where C_c is small, and the highest values of C_α were observed at effective vertical stresses just past the preconsolidation pressure where C_c maximizes.



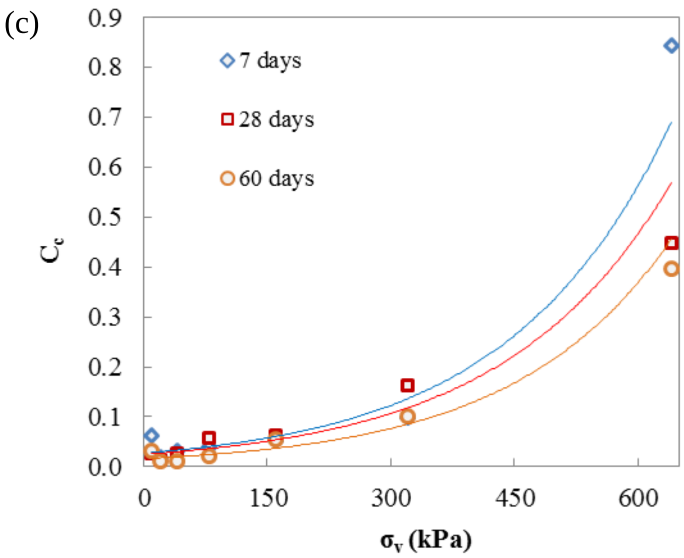
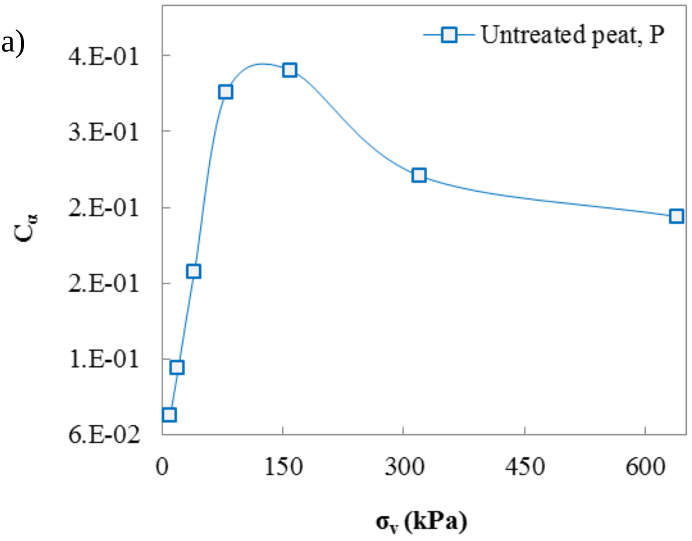


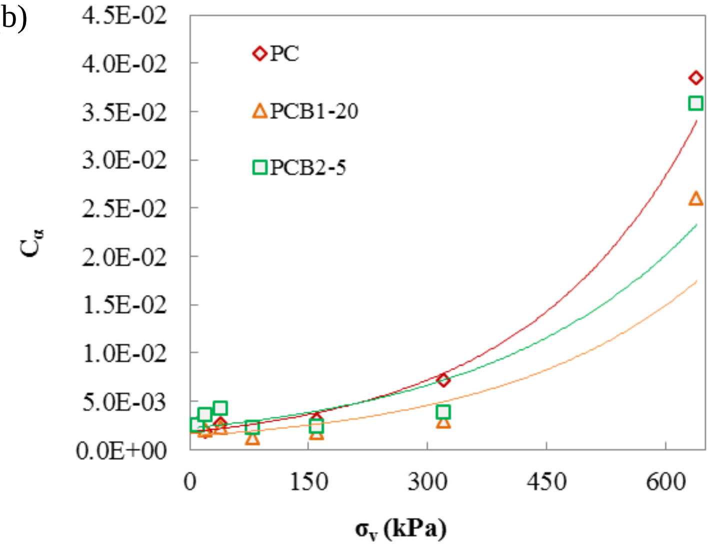
Figure 6.12: Compression index, C_c versus effective vertical stress, σ_v' for; (a) untreated peat, (b) all optimum PCB mixture at 7 days of curing, (c) optimum PCB1-20 mixture at 7, 28 and 60 days of curing

Contrary to the untreated peat, the C_c and C_α for stabilized peat continuously increase with the increase of σ_v' even beyond the preconsolidation pressure, σ_c. These increments seem obvious just after the σ_v' exceed the UCS of mixtures that obtained from Chapter 3. For instance after 320 kPa of σ_v' was subjected on PCB1-20 mixtures, the curves shows the drastic raises of these two important parameter especially when the load reach and past about 380 kPa (UCS of PCB1-20 mixtures). It also shown the value of C_c and C_α was relatively low at low effective stresses, however it increased as preconsolidation pressure was approached and continuous to rise after beyond these pressure. Significant increase in C_c and C_α occurs after σ_v' for the cement-stabilized peat discovered that creep could be associated with a structural breakdown [21].

(a)


Untreated peat, P
4.E-01
3.E-01
2.E-01
2.E-01
1.E-01
6.E-02
C_α
0
150
300
450
600
σ_v (kPa)

(b)


PC
PCB1-20
PCB2-5
4.5E-02
4.0E-02
3.5E-02
3.0E-02
2.5E-02
2.0E-02
1.5E-02
1.0E-02
5.0E-03
0.0E+00
C_α
0
150
300
450
600
σ_v (kPa)

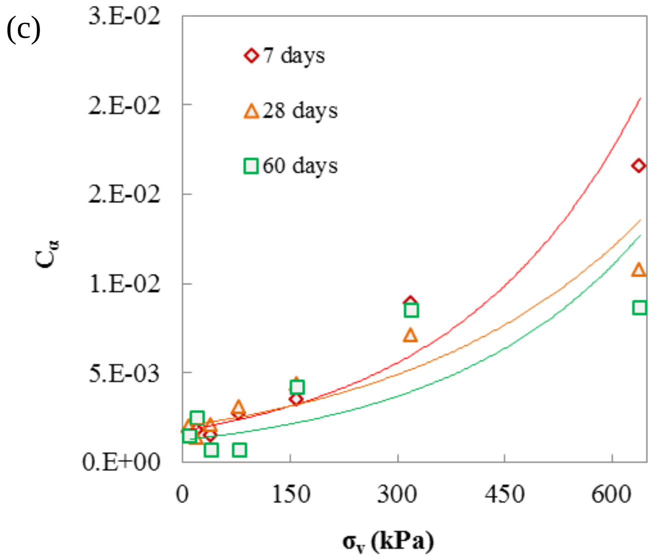


Figure 6.13: Secondary compression index, C_α versus effective vertical stress, σ_v' for; (a) untreated peat, (b) all optimum PCB mixture at 7 days of curing, (c) optimum PCB1-20 mixture at 7, 28 and 60 days of curing

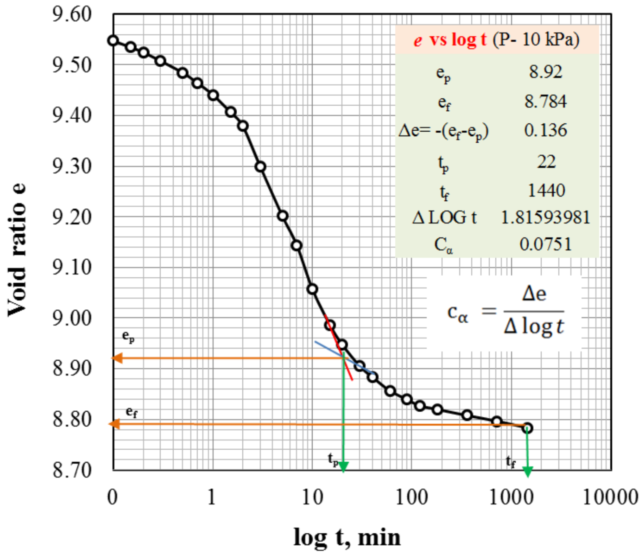


Figure 6.14: Void ratio, e vs log time curve, example for determination of secondary compression index, C_α in untreated peat (P) compressibility analysis

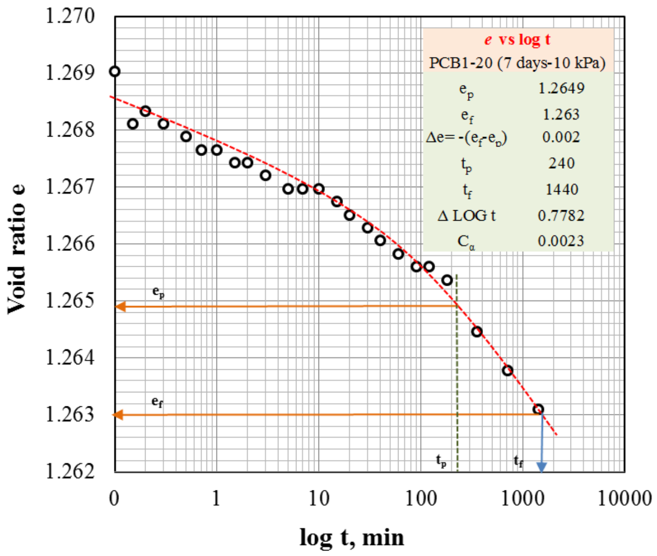
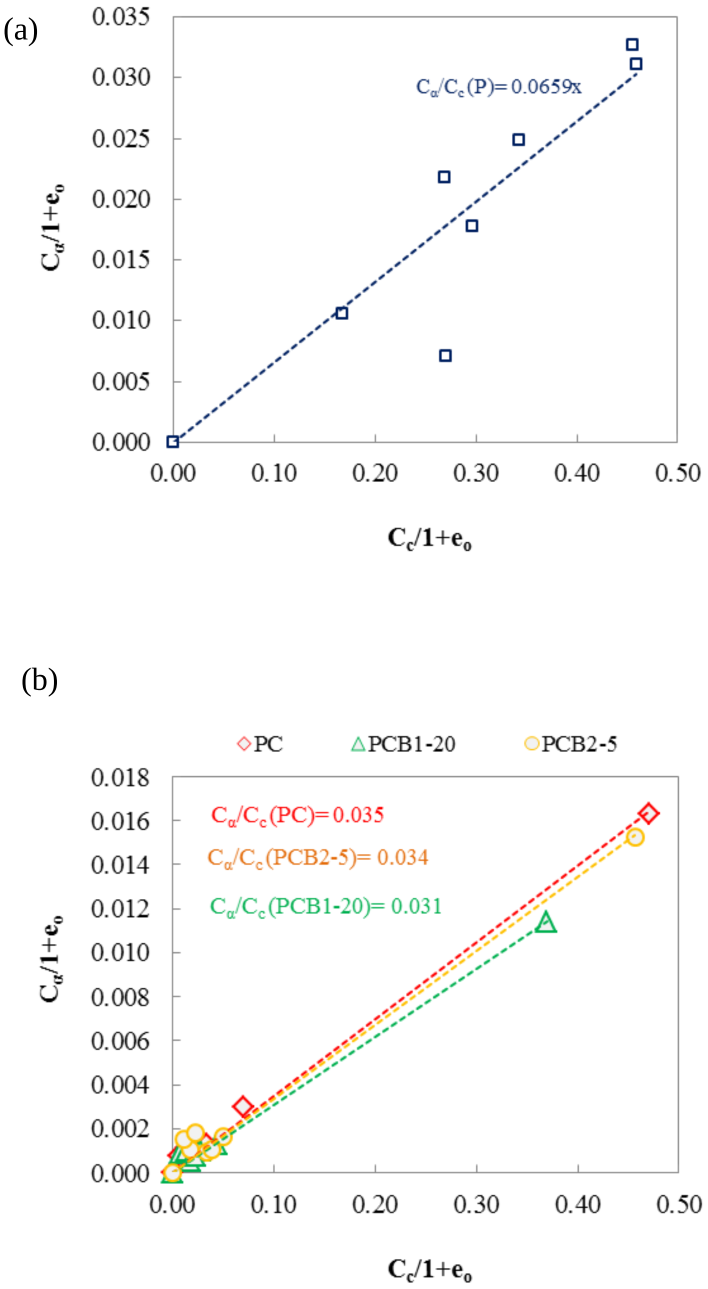


Figure 6.15: Void ratio, e vs log time curve; example for determination of secondary compression index, C_α in stabilized peat (PCB1-20 mixtures at 7 days curing) compressibility analysis

Figure 6.16 shows the compression index ratio, $C_c/1+e_o$ against secondary compression ratio, $C_\alpha/1+e_o$ for untreated peat, all optimum PCB mixture at 7 days of curing and optimum PCB1-20 mixture at 7, 28 and 60 days of curing. With C_α/C_c about 0.066, untreated Hokkaido peat listed in the typical range of peat compression ratio. The most detailed measurements and existing reliable data suggest a range of C_α/C_c = 0.06 ± 0.01 for natural peat [2]. Lower ratio of C_α/C_c indicates the lesser compressibility of soils. Compared to untreated Hokkaido peat, stabilized peat demonstrates the good enhancement of C_α/C_c ratio. Figure 6.16b portrays that PCB1-20 is the best improvement of settlement and followed by PCB2-5 and PC mixtures. Therefore these best mixtures then were examined on the effect of curing time at 7, 28 and 2 month and the outcomes shown in Figure 6.16c. The result indicates the significant improvement of C_α/C_c ratio with 0.031, 0.028 and 0.027 individually. For that reason, it can be said that less creep settlements develop when the peat is stabilized with optimum PCB mixtures. The ratio C_α/C_c was perceived slightly higher at 7 and 28 days and still improved at 60 days curing. This could be explained by the fact that the soil is still experiencing chemical reaction between this duration of curing. In other words, the longer duration of curing of the stabilized peat in water, the lesser was its ratio of C_α/C_c which is indicating that it was less compressible.



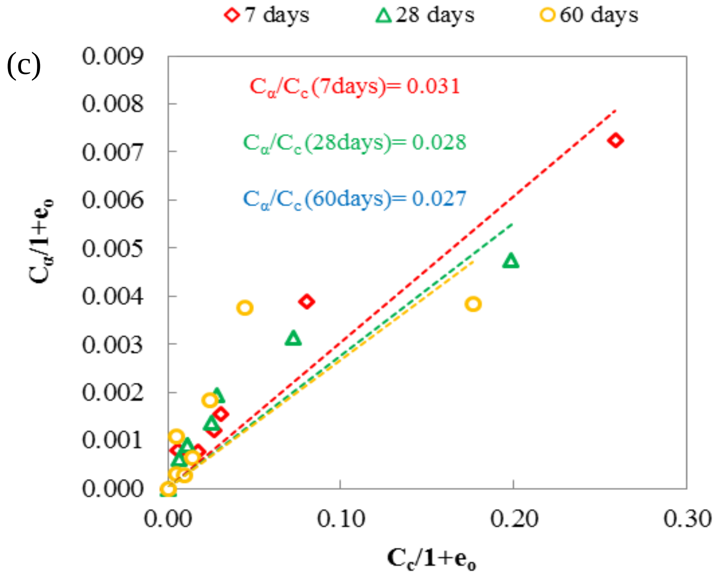
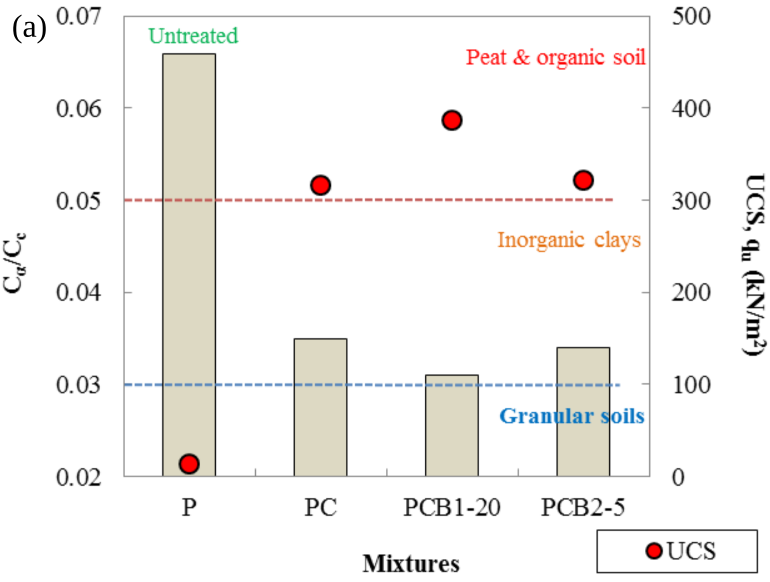


Figure 6.16: Compression ratio, $C_c/1+e_o$ versus secondary compression ratio, $C_\alpha/1+e_o$ for; (a) untreated peat, (b) all optimum PCB mixture at 7 days of curing, (c) optimum PCB1-20 mixture at 7, 28 and 60 days of curing

Similarly, Figure 6.17 shows the compression index ratio, C_c/C_α for all mixture at 7 days of curing and optimum PCB1-20 mixture at 7, 28 and 60 days of curing. As the C_α/C_c ratio decreases, the soil engineering behavior is known to shift from that of peaty or organic soils to inorganic soils and finally to a granular material [15; 23; 30; 31]. It is found that the stabilized peat C_α/C_c ratios reached to granular soil materials at a curing age of 1 month and above. With curing duration from 28 days to 60 days, small noticeable improvements were observed and the pattern was similar to gained UCS results. These results are encouraging, since the compression behavior of organic soils appears to be fundamentally changed to that of granular soil, which is considered to be an excellent foundation material by the geotechnical and pavement engineers [31].



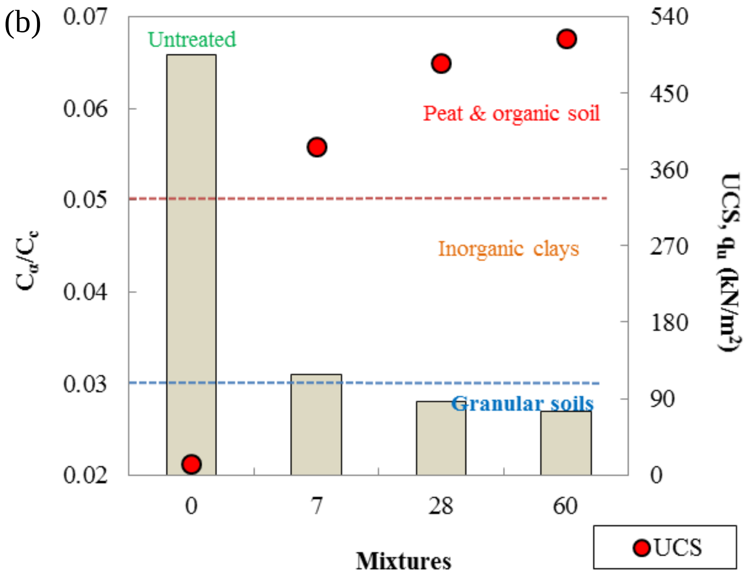


Figure 6.17: Compression index ratio, C_c/C_α for; (a) all mixture at 7 days of curing, (b) optimum PCB1-20 mixture at 7, 28 and 60 days of curing

In Figure 6.18, the compression ratio, $C_c/1+e_o$ for all mixture at 7 days of curing and optimum PCB1-20 mixture at 7, 28 and 60 days of curing were shown. According to Loughlin and Lehane [32], compressibility level could be classified by referring compression index ratio, $C_c/1+e_o$ of tested peat as shown in Table 6.1. Figure 6.18a was revealed that stabilized peat significantly change the compressibility behavior of original peat from very compressible to slightly compressible. It was exposed that PCB1-20 shows the less compressibility compare to other stabilized peat with $C_c/1+e_o$= 0.079 and dropped as much 77% from untreated peat ($C_c/1+e_o$= 0.345). On the same direction, Figure 6.18b discover that curing duration on best optimum mixtures (PCB1-20) contribute better improvement which change the compressibility behavior from slightly to very slightly compressibility after two month curing duration.

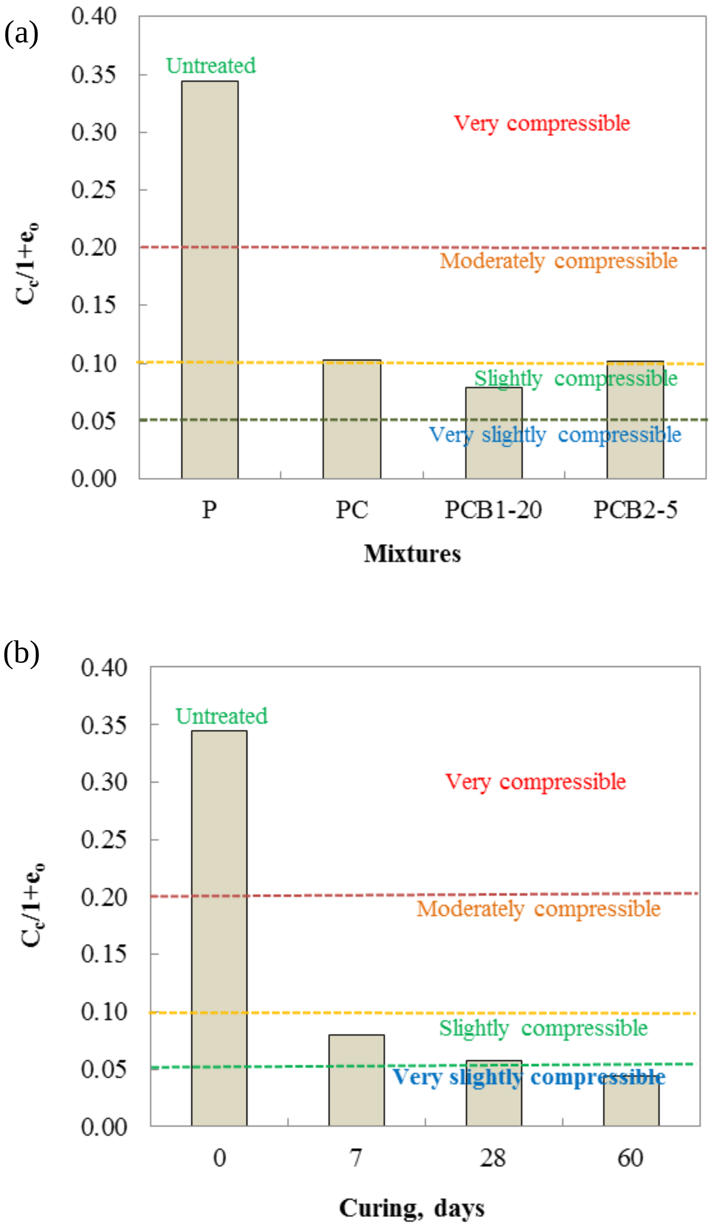


Figure 6.18: Compression ratio, $C_c/1+e_o$ for; (a) all mixture at 7 days of curing, (b) optimum PCB1-20 mixture at 7, 28 and 60 days of curing

Table 6.1 Classification of compression ratio [30]

Compression ratio ($C_c/1+e$)	Classification
0 – 0.05	Very slightly Compressible
0.05 – 0.10	Slightly Compressible
0.10 – 0.20	Moderately Compressible
>0.20	Very Compressible

6.4 Summary

As summary, this chapter proves the effectiveness of optimum peat-cement-bagasse ash (PCB) mixtures on peat deformation behavior. There was a significant reduction of void ratio, e for stabilized peat mixtures as compared to that of the untreated one. Consequently, the permeability coefficient, *k* noticeably decreases. However, the e of this stabilized peat seems shows the slow decreasing with curing age. It was found that the *k* for all mixtures encounter a very slight change between each other. The PC mixture shows the lowest *k* then other PCB mixtures. This is maybe because of SCBA presence in the other two mixtures which the particles are coarser than OPC and consequently change the soil fibric and increase the macropores. The *k* of stabilized peat was between E^{-09} to E^{-08} m/s in range of 7 to 60 days curing.

The important effect of treatment on the compression behavior is the increase in the pre-consolidation pressure, $\sigma_{c'}$ with different PCB mixture and curing period. This $\sigma_{c'}$ increment is in agreement with the increase in strength with time recorded from the UCS results. As a result of the development of this $\sigma_{c'}$, the compression curve of the stabilized soil is shifted to higher effective stress. The m_v decreases drastically at the lower range of pressure but the effect become less at large compression. The C_v reduce as vertical consolidation pressure increase due to large reduction in permeability.

In the case of untreated peat, it was discovered that C_c and C_α significantly increase with the increase of σ_v’ near the preconsolidation pressure, σ_c. At values of σ_v’ past about $3\sigma_c$, C_c gradually decreases with the increase in σ_v’. Contrary to the untreated peat, the C_c and C_α for stabilized peat continuously increase with the increase of σ_v' even beyond the preconsolidation pressure, σ_c. Significant increase in C_α occurs after σ_v' for the cement-stabilized peat discovered that creep could be associated with a structural breakdown. Compared to untreated Hokkaido peat, stabilized peat demonstrates the good enhancement of C_α/C_c ratio. The less creep settlements develop when the peat is stabilized with optimum PCB mixtures at the longer duration of curing of the stabilized peat in water.

As the C_α/C_c ratio decreases, the soil engineering behavior is known to shift from that of peaty or organic soils to inorganic soils and finally to a granular material. As a result, stabilized peat considered to be an excellent foundation material by the geotechnical and pavement engineers. The compression ratio, $C_c/1+e_o$ results revealed that stabilized peat significantly change the compressibility behavior of original peat from very compressible to slightly compressible and finally to very slightly compressible after cured for 2 month.

6.5 Reference

[1] Kazemian, S., Huat, B.B.K., Prasad, A. and Barghchi, M., 2011. A state of art review of peat: Geotechnical engineering perspective. International Journal of the Physical Sciences, 6(8): 1974-1981.

[2] Mesri, G., Stark, T.D., Ajlouni, M.A. and Chen, C.S., 1997. Secondary compression of peat with or without surcharging. J. Geotech. Geoeviron. Engr., 123(5):411-421.

[3] Mesri, G. and Ajlouni, M., 2007. Engineering properties of fibrous Peats. Journal of Geotechnical and Geoenvironmental Engineering, 133(7): 850-866.

[4] Wosten, J.H.M., Ismail, A.B. and vanWijk, A.L.M., 1997. Peat subsidence and its practical implications: A case study in Malaysia. Geoderma, 78(1-2): 25-36.

[5] Haider, A.A., Erwin, O. and Gary, C., 2013. Engineering properties of peat in estuarine environment. Foundation and Soft Ground Engineering Conference Thu Dau Mot UniversityICTDMU-1, Binh Duong.

[6] Huat, B.K., 2006. Deformation and Shear Strength Characteristics of Some Tropical Peat and Organic Soils. Pertanika J. Sci. & Techno., 14(1&2): 61-74.

[7] Edil, T.B., 1997. Construction over peats and organic soils. In Proceedings of Recent Advances in Soft Soil Engineering, ed. Huat and Bahia, pp.85-108.Sarawak.

[8] Den Haan, E.J., 1997. An overview of the mechanical behaviour of peats and organic soils and some appropriate construction techniques. In Proceedings of Conference on Recent Advances in Soft Soil Engineering, ed. Huat and Bahia, p. 17-45. Kuching, Sarawak, Malaysia.

[9] Jarrett, P.M., 1995. Site investigation for organic soils and peat. Geoguide 6. JKR Document 20709- 0341-95. Public Works Department Malaysia. Malaysia.

[10] Gofar, N., 2006. Determination of coefficient of rate of horizontal consolidation of peat soil, Master Dissertation, Universiti Teknologi Malaysia, Malaysia. 36-172.

[11] Dhowian, A.W. and Edil, T.B., 1980. Consolidation behavior of peats. Geotech. Testing J., 3(3): 105-114.

[12] Colleselli, F., Cortellazzo, G. and Cola, S., 2000. Laboratory Testing of Italian Peat Soils. Geotechnics of High Water Content Materials, ASTM STP 1374, Edil, T.B., and Fox, P.J. (Eds.), American Society for Testing and Materials, West Conshohocken, PA.

[13] Edil, T.B., 2003. Recent advances in Geotechnical characterization and construction over peat and organic soils. Proceedings 2nd International Conference on Advances in Soft Soil Engineering and Technology: 3-25.

[14] Miyakawa, J., 1960. Soils engineering research on peats alluvia, Reports 1-3. Civil Engineering Research Institute, Hokkaido Development Bureau Bulletin No. 20.

[15] Hwang, J., Humphrey, A., Bobet, A. and Santagata, M.C., 2005. Stabilization and Improvement of Organic Soils. Publication FHWA/IN/JTRP-2004/38. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana.

[16] Casagrande, A., 1936. The determination of the pre-consolidation load and its practical significance. Proceedings of the First International Conference on Soil Mechanics and Foundation Engineering.

[17] O'Kelly, B.C., 2005. Compressibility of some peats and organic soils. Proceedings of International Conference on Problematic Soils, Cyprus, Vol. 3, pp. 1193-1202.

[18] O'Kelly, B.C., 2007. Compressibility and permeability anisotropy of some peaty soils. Proceedings of the 60th Canadian Geotechnical Conference, Ottawa, Ontario.

[19] Ali, F.H., Sing, W.L. and Hashim, R., 2010. Engineering properties of improved fibrous peat. Scientific Research and Essays, 5(2): 154-169.

[20] Wong, L.S., Hashim, R. and Ali, F.H., 2009. A Review on Experimental Investigations of Peat Stabilization. Australian Journal of Basic and Applied Sciences, 3(4): 3537-3552, 2009. ISSN 1991-8178.

[21] Hebib, S. and Farrell, E.R., 2003. Some experiences on the stabilization of Irish peats. Canadian Geotechnical Journal, 40(1): 107-120.

[22] EuroSoilStab, 2002. Development of design and construction methods to stabilize soft organic soils. Design guide soft soil stabilization. CT97-0351.

Project No. BE 96-3177, Industrial & Materials TechnologiesProgramme (Brite- EuRam III), European Commission.

[23] Bobet, A., Hwang, J.H., Johnston, C.T. and Santagata, M., 2011. One-dimensional consolidation behavior of cement-treated organic soil. Canadian Geotechnical Journal, 48(7): 1100-1115.

[24] Yulindasari, I., 2006. Compressibility characteristics of fibrous peat soil, Master Dissertation, Universiti Teknologi Malaysia, Malaysia.

[25] Kazemian, S. and Huat, B.K., 2009. Compressibility characteristics of fibrous tropical peat reinforced with cement column. Electronic J. Geotech. Eng., 14E: 1-8.

[26] Ajlouni, M.A., 2000. Geotechnical properties of peat and related engineering problems, PhD Dissertation, University of Illinois at Urbana-Champaign. 15-189.

[27] Hassan, Z.A., Daud, M.N.M., Yahya, M.A. and Shaharuddin, M.S., 2013. Effect of Granular Material on the Rate of Consolidation of Peat Soil. Electronic Journal of Geotechnical Engineering, Vol. 13, Bund. F, 6113-6123.

[28] Farrell, E.R., O'Neill, C. and Morris, A., 1994. Changes in the Mechanical Properties of Soils with Variation in Organic Content. In Advances in Understanding and Modeling the Mechanical of Peat, Balkema Rotterdam, 19-25.

[29] Duraisamy, Y., Huat, B.K., Muniandy, R. and Aziz, A.A., 2008. Compressibility Behavior of Fibrous Peat Reinforced with Cement Columns. ICCBT- E- (09)–pp93-110.

[30] Mesri, G., Stark, T.D. and Chen, C.S., 1994. Cc/Cα concept applied to compression of peat. discussion. J. Geotech. Geoenv. Eng., 120: 764-766.

[31] Sobhan, K., Reddy , D.V. and Ramirez, J.C., 2012. Cement Stabilization of Organic Subgrades for Pavement Preservation. In: LACCEI (Editor), Megaprojects: Building Infrastructure by fostering engineering collaboration, efficient and effective integration and innovative planning Panama City, Panama.

[32] Loughlin, C.D. and Lehane, B.M., 2003. A Study of the link between composition and compressibility of peat and organics soil. In Proceedings of

2nd International Conference on Advances in Soft Soil Engineering and Technology, ed. Huat et al, pp.135-152 Putra Jaya, Malaysia.

CHAPTER 7

CONCLUSIONS AND FUTURE WORKS

7.1 Conclusions

As conclusions, the main objective of this research works was achieved where the effectiveness of SCBA in stabilized peat successfully evaluated and clarified. The first important step in this study is the comparative study between Hokkaido and Malaysia peat. The main purpose is to check the similarity potential of peat geotechnical characteristics so that the research finding possible to apply on Malaysia peat in future. As stated in Chapter 1, the research scopes were concentrates to the strength and compressibility of stabilized peat that will be compare to untreated peat. Therefore, the conclusions regarding the enhancement of the strength and compressibility of stabilized peat by utilizing SCBA are presented;

1. The stabilized peat comprising 20%, 5% and 10% (PCB1-20, PCB2-5 and PCB3-10) partial replacement of OPC with SCBA 1 (good quality), SCBA 2 (low quality) and SCBA 3 (intermediate quality) attain the maximum UCS and discovered greater than P and PC specimen.
2. The proposed calculation to predict deformation modulus of Peat-Cement-Bagasse (PCB) mixtures based on two-phase mixtures model was introduced and developed. The main benefit of this proposed model is the ability to determine the optimum PCB mixture which depends on the physical and chemical effects of SCBA. The proposed modified model was exhibits a good agreement with the experimental results.

3. At each optimal mix of PCB mixtures, the UCS increased with increasing of curing time, OPC dosage, K7 dosage and preloading. For PCB1-20 and PCB3-10 mixture, inclusion of a minimum OPC dosage of 300 kg/m^3 and K7 dosage of 500 kg/m^3 along with curing under 20 kPa pressure is recommendable for the peat stabilization to be effective. However PCB2-5 mixture is not recommended to use in stabilized peat unless more OPC and K7 dosage should be consumed in order to achieve minimum strength target.
4. Pozzolanic reaction still occurred after a month of curing for PCB1-20 because of the fact that cement hydration (PC mixtures) is normally rapid and effective at first month but almost stop or complete after that duration while pozzolan reaction may be occurred continuously until several month.
5. From multiple regressions statistical model, the q_u gained has a close relationship to D_{50} and Ca/Si ratio of SCBA. Finer size of D_{50} and larger Ca/Si ratio indicates greater q_u of the PCB mixture and simultaneously can increase the SCBA percentage replacement or on the other hand decrease the OPC inclusion percentages.
6. There was a significant reduction of void ratio, e for stabilized peat mixtures as compared to that of the untreated one. Consequently, the permeability coefficient, k noticeably decreases.
7. The $\sigma_{c'}$ shows the increment with different PCB mixture and curing period. This $\sigma_{c'}$ increment is in agreement with the increase in strength with time recorded from the UCS results. Consequently to the development of $\sigma_{c'}$, the compression curve of the stabilized soil is shifted to higher effective stress.
8. The m_v decreases drastically at the lower range of pressure but the effect become less at large compression while the C_v reduce as vertical consolidation pressure increase due to large reduction in permeability.
9. For untreated peat, C_c and C_α significantly increase with the increase of σ_v' near the σ_c. At values of σ_v' past about $3\sigma_c$, C_c gradually decreases with the increase in σ_v'. The C_c and C_α for stabilized peat continuously increase with the increase of σ_v' even beyond the σ_c. Significant increase in C_α occurs after σ_v' for the cement-stabilized peat discovered that creep could be associated with a structural breakdown.

10. Compared to untreated Hokkaido peat, stabilized peat demonstrates the good enhancement of C_α/C_c ratio. The less creep settlements develop when the peat is stabilized with optimum PCB mixtures at the longer duration of curing of the stabilized peat in water. As the C_α/C_c ratio decreases, the soil engineering behavior is known to shift from that of peaty or organic soils to inorganic soils and finally to a granular material. As a result, stabilized peat considered to be an excellent foundation material by the geotechnical and pavement engineers. The compression ratio, $C_c/1+e_o$ results revealed that stabilized peat significantly change the compressibility behavior of original peat from very compressible to slightly compressible and finally to very slightly compressible after cured for 2 month.

7.2 Future works

Overall, this study main objective was positively accomplished where the effectiveness of SCBA utilization in stabilized peat was revealing the good outcomes. However, there are still many improvement and further study on this new material. Currently, the improvement and future works that planned to be focus are listed below and shown in;

1. Study on effectiveness of SCBA on other type of peat (fibric and sapric) so that this material can be utilized and generalized in peat stabilization.
2. Material safety identification by leaching tes such as Toxicity Characteristic Leaching Procedure (TCLP).
3. Make additional test for road construction purpose such as resilient modulus and California Bearing test (CBR) which important to evaluate the mechanical strength of road subgrades.
4. Improve the compressibility study on PCB mixtures on long term duration with proper apparatus such as Rowe cell that can accurately compute the dissipation of water during compression.
5. Deeply study on the SCBA characteristics reaction with the aim of quantifies how much reactive rate of SCBA during hydration process. Therefore, possibility

to understand how much non-reactive SCBA becomes filler and how much reactive SCBA that enhances the chemical reaction become clearer.

6. Field test trial and make comparative study with laboratory experimental results.

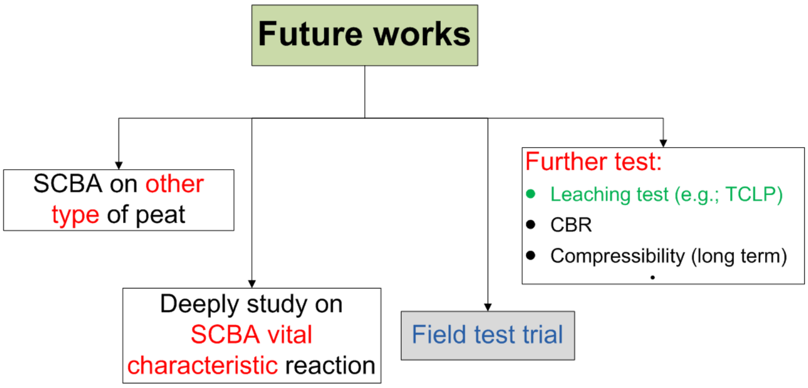


Figure 7.1 Future works

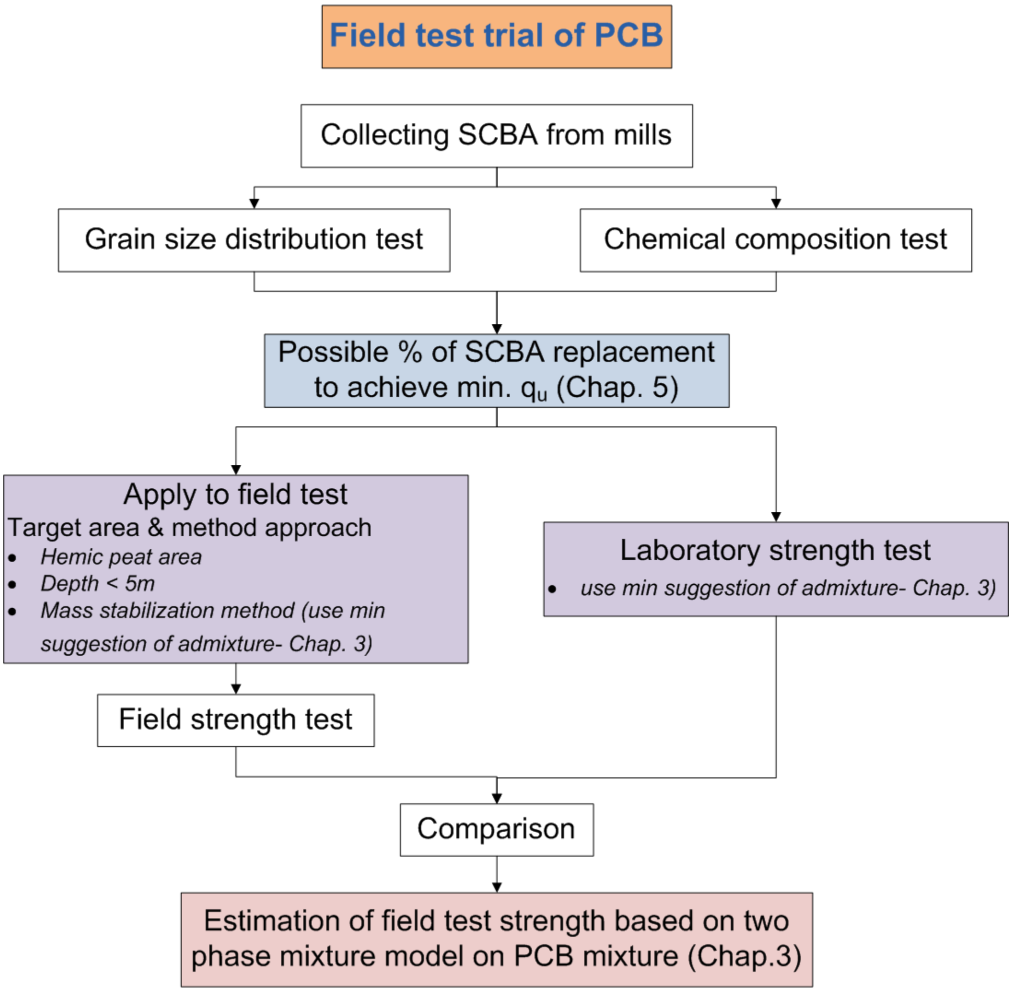


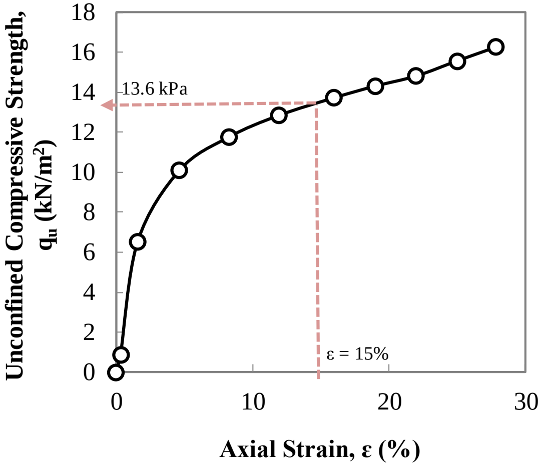
Figure 7.2 Planning idea for field test trial of PCB mixtures

APPENDIX

Appendix A: Determination of Unconfined Compressive Strength (UCS) of untreated peat specimens (P)

Sample height, H (cm)	12
Sample diameter, D (cm)	6
Area, A_o (m^2)	0.00283
Dial gauge, D_g (mm)	0.001
Load dial, K (kN)	0.00125

	Lab data		*Column 1*	*Column 2*	*Column 3*	*Column 4*	*Column 5*
No.	**Δh**	**P_{lab}**	**ΔH (mm)**	**ε, %**	**A_c (m^2)**	**P, *kN***	**σ, kN/m^2**
1	0	0	0.00	0.00	0.0000	0.0000	0.00
2	40	2	0.04	0.33	0.0028	0.0025	0.88
3	190	15	0.19	1.58	0.0029	0.0187	6.52
4	560	24	0.56	4.67	0.0030	0.0300	10.11
5	990	29	0.99	8.25	0.0031	0.0362	11.76
6	1430	33	1.43	11.92	0.0032	0.0412	12.84
7	1920	37	1.92	16.00	0.0034	0.0462	13.73
8	2280	40	2.28	19.00	0.0035	0.0500	14.31
9	2640	43	2.64	22.00	0.0036	0.0537	14.82
10	3000	47	3.00	25.00	0.0038	0.0587	15.57
11	3340	51	3.34	27.83	0.0039	0.0637	16.26



Column 1: $$\Delta H = \frac{\Delta h}{D_g}$$

Column 2: $$\varepsilon = \frac{\Delta H}{H} \text{ x } 100$$

Column 3: $$A_c = \frac{A_o}{1-\varepsilon}$$

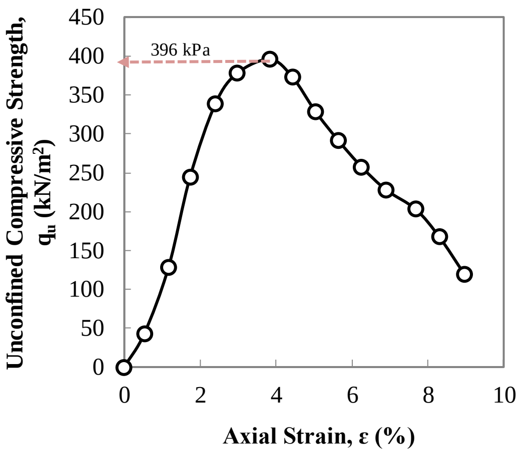
Column 4: $$\mathrm{P} = P_{lab} \text{ x } K$$

Column 5: $$\sigma = \frac{P}{A_c}$$

Appendix B: Determination of Unconfined Compressive Strength (UCS) of stabilized peat specimens (Example: PC mixtures- Sample 3)

Sample height, H (cm)	12
Sample diameter, D (cm)	6
Area, A_o (m^2)	0.00283
Dial gauge, D_g (mm)	0.001
Load dial, K (kN)	0.00125

	Lab data		*Column 1*	*Column 2*	*Column 3*	*Column 4*	*Column 5*
No.	**Δh**	**P_{lab}**	**ΔH (mm)**	**ε, %**	**A_c (m^2)**	**P, *kN***	**σ, kN/m^2**
1	0	0	0.00	0.00	0.00000	0.0000	0.00
2	64	98	0.06	0.53	0.00284	0.1224	43.07
3	141	295	0.14	1.18	0.00286	0.3685	128.80
4	209	564	0.21	1.74	0.00288	0.7044	244.84
5	289	786	0.29	2.41	0.00290	0.9817	338.90
6	359	883	0.36	2.99	0.00291	1.1029	378.45
7	462	932	0.46	3.85	0.00294	1.1641	395.91
8	533	883	0.53	4.44	0.00296	1.1029	372.79
9	605	784	0.61	5.04	0.00298	0.9792	328.92
10	677	700	0.68	5.64	0.00300	0.8743	291.82
11	751	622	0.75	6.26	0.00302	0.7769	257.61
12	829	554	0.83	6.91	0.00304	0.6919	227.85
13	922	498	0.92	7.68	0.00306	0.6220	203.12
14	997	413	1.00	8.31	0.00308	0.5158	167.31
15	1076	297	1.08	8.97	0.00311	0.3710	119.45



Column 1: $\Delta H = \frac{\Delta h}{D_g}$

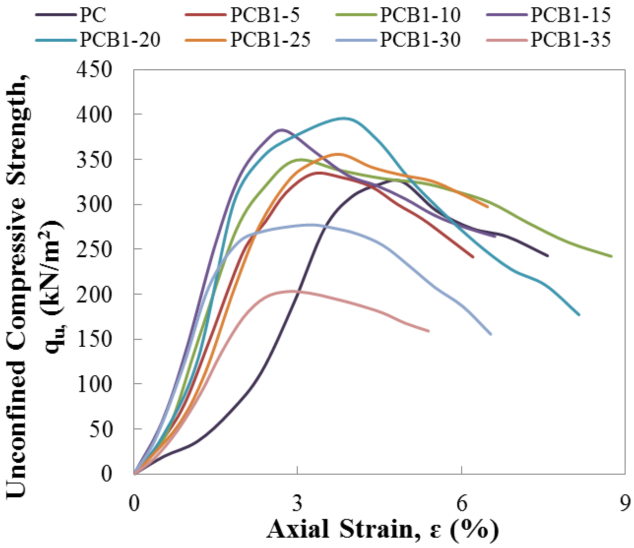
Column 2: $\varepsilon = \frac{\Delta H}{H}$ x 100

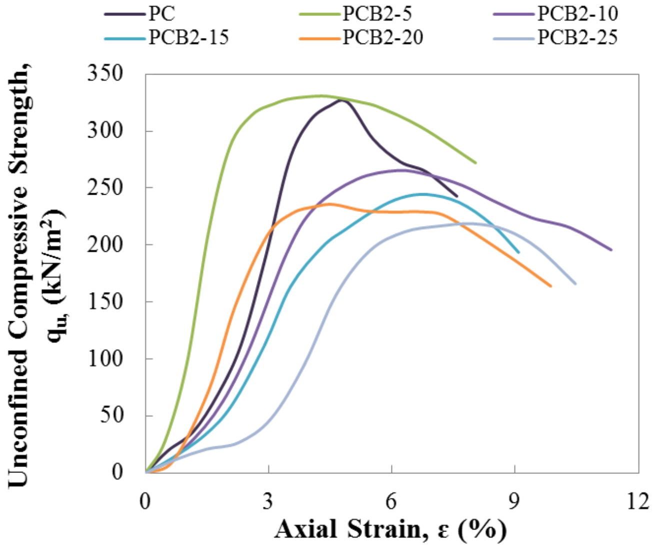
Column 3: $A_c = \frac{A_o}{1-\varepsilon}$

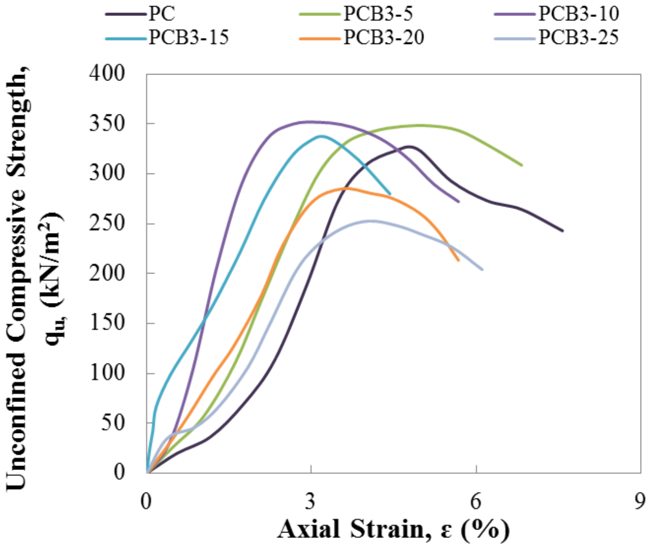
Column 4: $P = P_{lab}$ x K

Column 5: $\sigma = \frac{P}{A_c}$

Appendix C: Stress- strain for all PC and PC mixtures







Appendix D: Determination of average Unconfined Compressive Strength (UCS): Example of PC and PCB1 mixtures

Sample height, H (cm)	12
Sample diameter, D (cm)	6
Area, A_o (m^2)	0.002827
Dial gauge, D_g (mm)	0.001
Load dial, K (kN)	0.00125

		Lab data		*Column 1*	*Column 2*	*Column 3*	*Column 4*	*Column 5*	
	Sample	**Δh**	**$P_{lab\ (max)}$**	**ΔH**	**ε, %**	**A_c (m^2)**	**P, *kN***	**σ, kN/m^2**	**Average**
PC	1	656	754	0.656	5.4667	0.00299	0.9417	314.91	**316**
	2	546	731	0.546	4.5500	0.00296	0.9130	308.27	
	3	591	774	0.591	4.9250	0.00297	0.9667	325.12	
PCB1-5	1	393	782	0.393	3.2750	0.00292	0.9767	334.18	**324**
	2	349	745	0.349	2.9083	0.00291	0.9305	319.58	
	3	375	743	0.375	3.1250	0.00292	0.9280	318.01	
PCB1-10	1	274	807	0.274	2.2833	0.00289	1.0079	348.40	**341**
	2	497	768	0.497	4.1417	0.00295	0.9592	325.26	
	3	357	815	0.357	2.9750	0.00291	1.0179	349.36	
PCB1-15	1	315	877	0.315	2.6250	0.00290	1.0954	377.30	**373**
	2	335	889	0.335	2.7917	0.00291	1.1104	381.81	
	3	324	839	0.324	2.7000	0.00291	1.0479	360.67	
PCB1-20	1	350	866	0.35	2.9167	0.00291	1.0816	371.45	**387**
	2	423	923	0.423	3.5250	0.00293	1.1528	393.42	
	3	462	932	0.462	3.8500	0.00294	1.1641	395.91	
PCB1-25	1	320	767	0.32	2.6667	0.00290	0.9580	329.83	**344**
	2	452	837	0.452	3.7667	0.00294	1.0454	355.87	
	3	385	811	0.385	3.2083	0.00292	1.0129	346.81	
PCB1-30	1	326	544	0.326	2.7167	0.00291	0.6795	233.82	**259**
	2	379	648	0.379	3.1583	0.00292	0.8094	277.25	
	3	364	623	0.364	3.0333	0.00292	0.7781	266.90	
PCB1-35	1	510	466	0.51	4.2500	0.00295	0.5820	197.13	**198**
	2	336	473	0.336	2.8000	0.00291	0.5908	203.13	
	3	531	459	0.531	4.4250	0.00296	0.5733	193.82	

Column 1: $\Delta H = \frac{\Delta h}{D_g}$

Column 2: $\varepsilon = \frac{\Delta H}{H} \text{ x } 100$

Column 3: $A_c = \frac{A_o}{1-\varepsilon}$

Column 4: $P = P_{lab} \text{ x } K$

Column 5: $\sigma = \frac{P}{A_c}$

Appendix E: All collected results of Unconfined Compressive Strength (UCS) at various factor in peat stabilization

				UCS (kPa)				pH				*w* (%)			
Test Purpose	**Mixtures**	**Samples**		**1**	**2**	**3**	**Avg**	**1**	**2**	**3**	**Avg**	**1**	**2**	**3**	**Avg**
		Original	**0**	12.80	13.97	13.31	13	5.35	5.49	5.54	5.46	603.24	564.17	572.59	580.00
	PC	C100	0	314.83	308.18	325.03	316	12.38	12.48	12.01	12.29	75.87	78.94	77.81	77.54
Effect of OPC-SCBA compositions	**SCBA 1**	C95B5	5	334.09	319.49	317.92	324	12.11	12.35	12.50	12.32	83.12	79.13	81.65	81.30
		C90B10	10	348.30	325.17	349.26	341	12.39	12.19	12.47	12.35	80.84	83.55	83.71	82.70
		C85B15	15	377.19	381.70	360.57	373	12.25	12.37	12.61	12.41	81.67	85.08	83.45	83.40
		C80B20	20	371.34	393.31	395.80	387	12.39	12.61	12.62	12.54	83.17	85.13	84.03	84.11
		C75B25	25	329.74	355.77	346.71	344	12.31	12.43	12.40	12.38	87.34	84.11	86.04	85.83
		C70B30	30	233.75	277.17	266.82	259	12.27	12.13	12.17	12.19	86.09	88.82	87.38	87.43
		C65B35	35	197.08	203.07	193.76	198	11.83	12.02	11.91	11.92	90.13	87.53	91.02	89.56
	SCBA 2	C100	0	314.83	308.18	325.03	316	12.38	12.48	12.01	12.29	75.87	78.94	77.81	77.54
		C95B5	5	330.72	310.81	325.56	322	12.42	12.51	12.38	12.44	80.18	82.47	81.50	81.38
		C90B10	10	246.92	265.37	258.52	257	12.30	12.36	12.32	12.33	82.91	84.45	84.18	83.85
		C85B15	15	213.85	244.39	234.12	231	12.26	12.29	12.31	12.29	83.45	85.24	83.87	84.19
		C80B20	20	235.61	211.32	223.05	223	12.24	12.21	12.36	12.27	83.62	85.73	83.53	84.29
		C75B25	25	217.00	218.72	210.41	215	12.31	12.22	12.18	12.24	83.17	85.13	85.28	84.53
	SCBA 3	C100	0	314.83	308.18	325.03	316	12.38	12.48	12.01	12.29	75.87	78.94	77.81	77.54
		C95B5	5	306.62	348.11	318.17	324	12.38	12.48	12.52	12.46	82.46	78.94	82.59	81.33
		C90B10	10	337.45	400.02	351.75	363	12.53	12.35	12.68	12.52	83.12	80.13	85.57	82.94
		C85B15	15	296.85	283.53	336.62	306	12.39	12.27	12.39	12.35	84.23	83.55	83.29	83.69
		C80B20	20	243.39	261.11	284.97	263	12.25	12.37	12.31	12.31	83.55	85.08	84.27	84.30
		C75B25	25	222.17	203.23	252.61	226	12.39	12.18	12.18	12.25	86.34	85.13	84.56	85.34

				UCS (kPa)				pH				*w* (%)			
Test Purpose	**Mixtures**	**Samples**		**1**	**2**	**3**	**Avg**	**1**	**2**	**3**	**Avg**	**1**	**2**	**3**	**Avg**
		Original	**0**	12.80	13.97	13.31	13	5.35	5.49	5.54	5.46	603.24	564.17	572.59	580.00
Effect of optimum PCB mixtures on curing duration	PC	D1	7	314.83	308.18	325.03	316								
		D2	14	335.80	426.99	393.42	385								
		D3	21	417.00	444.35	455.87	439								
		D4	28	440.37	483.00	458.87	461								
		D5	60	460.01	495.94	470.42	475								
	PCB1-20	D1	7	371.34	393.31	395.80	387	12.39	12.61	12.62	12.54	83.17	85.13	84.03	84.11
		D2	14	433.15	428.30	-	431	12.51	12.75	12.72	12.66	81.56	84.77	84.77	83.70
		D3	21	476.12	469.21	-	473	12.64	12.76	12.97	12.79	81.49	84.05	81.93	82.49
		D4	28	501.29	498.86	-	500	12.77	13.02	13.00	12.93	79.48	83.65	80.50	81.21
		D5	60	517.93	541.38	-	530	12.49	13.17	13.61	13.09	79.79	81.07	81.45	80.77
	PCB2-5	D1	7	330.72	310.81	325.56	322								
		D2	14	346.48	319.39	-	333								
		D3	21	401.56	328.30	-	365								
		D4	28	425.41	346.00	-	386								
		D5	60	452.87	364.50	-	409								
	PCB3-10	D1	7	337.45	400.02	351.75	363								
		D2	14	403.00	383.33	-	393								
		D3	21	445.30	384.91	-	415								
		D4	28	444.38	429.16	-	437								
		D5	60	468.95	433.02	-	451								

Appendix E: All collected results of Unconfined Compressive Strength (UCS) at various factor in peat stabilization: Continued

				UCS (kPa)				pH				*w* (%)			
Test Purpose	**Mixtures**	**Samples**		**1**	**2**	**3**	**Avg**	**1**	**2**	**3**	**Avg**	**1**	**2**	**3**	**Avg**
		Original	**0**	12.80	13.97	13.31	13	5.35	5.49	5.54	5.46	603.24	564.17	572.59	580.00
Effect of optimum PCB mixtures on initial loading variation	PC	L0	0	174.86	196.71	-	186								
		L1	20	314.83	308.18	325.03	316								
		L2	40	354.04	360.19	-	357								
		L3	60	422.05	428.43	-	425								
		L4	80	483.40	468.36	-	476								
		L5	100	512.31	535.42	-	524								
	PCB1-20	L0	0	200.86	235.49	-	218	12.51	12.12	12.51	12.38	84.23	86.11	85.14	85.16
		L1	20	371.34	393.31	395.80	387	12.39	12.61	12.62	12.54	83.47	85.77	83.09	84.11
		L2	40	409.22	444.72	-	427	12.57	12.67	12.65	12.63	81.98	84.21	83.53	83.24
		L3	60	452.70	493.00	-	473	12.82	12.73	12.61	12.72	81.46	84.01	81.40	82.29
		L4	80	530.26	581.19	-	556	12.67	12.88	12.82	12.79	80.03	84.37	80.31	81.57
		L5	100	599.29	632.79	-	616	12.69	12.87	12.93	12.83	79.87	81.55	81.07	80.83
	PCB2-5	L0	0	204.38	189.03	-	197								
		L1	20	330.72	310.81	325.56	322								
		L2	40	372.80	362.57	-	368								
		L3	60	415.62	407.71	-	412								
		L4	80	482.15	407.23	-	445								
		L5	100	537.03	414.32	-	476								
	PCB3-10	L0	0	218.85	209.18	-	214								
		L1	20	337.45	400.02	351.75	363								
		L2	40	413.30	407.88	-	411								
		L3	60	483.44	431.81	-	458								
		L4	80	563.85	504.23	-	534								
		L5	100	641.42	553.53	-	597								

				UCS (kPa)				pH				*w* (%)			
Test Purpose	**Mixtures**	**Samples**		**1**	**2**	**3**	**Avg**	**1**	**2**	**3**	**Avg**	**1**	**2**	**3**	**Avg**
		Original	**0**	12.80	13.97	13.31	13	5.35	5.49	5.54	5.46	603.24	564.17	572.59	580.00
Effect of optimum PCB mixtures on OPC dosage	PC	C1	100	27.63	29.38	-	29								
		C2	150	89.84	83.19	-	87								
		C3	200	135.76	132.35	-	134								
		C4	250	167.30	150.29	-	159								
		C5	300	314.83	308.18	325.03	316								
	PCB1-20	C1	100	24.29	25.22	-	25	11.11	11.67	11.42	11.40	114.73	116.21	115.44	115.46
		C2	150	81.72	80.99	-	81	11.59	11.71	12.10	11.80	108.34	106.54	106.94	107.27
		C3	200	119.84	117.11	-	118	12.13	12.19	12.28	12.20	100.82	98.99	99.71	99.84
		C4	250	178.07	164.86	-	171	12.97	13.29	10.94	12.40	95.21	92.87	93.37	93.82
		C5	300	371.34	393.31	395.80	387	12.39	12.61	12.62	12.54	83.17	85.13	84.03	84.11
	PCB2-5	C1	100	21.15	17.54	-	19								
		C2	150	70.42	73.45	-	72								
		C3	200	97.39	110.23	-	104								
		C4	250	133.83	141.97	-	138								
		C5	300	330.72	310.81	325.56	322								
	PCB3-10	C1	100	22.77	23.82	-	23								
		C2	150	76.37	70.29	-	73								
		C3	200	106.14	108.55	-	107								
		C4	250	166.27	161.27	-	164								
		C5	300	337.45	400.02	351.75	363								

Appendix E: All collected results of Unconfined Compressive Strength (UCS) at various factor in peat stabilization: Continued

				UCS (kPa)				pH				*w* (%)			
Test Purpose	**Mixtures**	**Samples**		**1**	**2**	**3**	**Avg**	**1**	**2**	**3**	**Avg**	**1**	**2**	**3**	**Avg**
		Original	**0**	12.80	13.97	13.31	13	5.35	5.49	5.54	5.46	603.24	564.17	572.59	580.00
Effect of optimum PCB mixtures on K7 dosage	PC	S0	0	167.43	174.96	-	171								
		S1	100	174.50	201.27	-	188								
		S2	200	223.03	255.18	-	239								
		S3	300	276.69	234.25	-	255								
		S4	400	299.02	269.17	-	284								
		S5	500	314.83	308.18	325.03	316								
	PCB1-20	S0	0	169.52	231.87	-	201	12.78	13.04	13.00	12.94	167.98	171.35	172.20	170.51
		S1	100	216.60	233.29	-	225	12.73	12.91	12.97	12.87	144.35	147.46	144.18	145.33
		S2	200	258.53	265.89	-	262	12.82	12.76	13.00	12.86	123.31	126.76	125.86	125.31
		S3	300	295.85	298.40	-	297	12.71	12.93	12.88	12.84	107.59	109.73	107.38	108.23
		S4	400	344.33	305.95	-	325	12.67	12.88	12.76	12.77	100.25	98.03	98.26	98.85
		S5	500	371.34	393.31	395.80	387	12.39	12.61	12.62	12.54	83.17	85.13	84.03	84.11
	PCB2-5	S0	0	166.77	150.06	-	158								
		S1	100	173.98	179.34	-	177								
		S2	200	218.75	192.83	-	206								
		S3	300	214.64	253.38	-	234								
		S4	400	274.23	271.97	-	273								
		S5	500	330.72	310.81	325.56	322								
	PCB3-10	S0	0	166.92	210.57	-	189								
		S1	100	197.56	209.13	-	203								
		S2	200	236.62	252.90	-	245								
		S3	300	264.36	287.86	-	276								
		S4	400	291.60	300.41	-	296								
		S5	500	337.45	400.02	351.75	363								

				UCS (kPa)				pH				*w* (%)			
Test Purpose	**Mixtures**	**Samples**		**1**	**2**	**3**	**Avg**	**1**	**2**	**3**	**Avg**	**1**	**2**	**3**	**Avg**
		Original	**0**	12.80	13.97	13.31	13	5.35	5.49	5.54	5.46	603.24	564.17	572.59	580.00
Effect of optimum PCB mixtures on $CaCl_2$ dosage	PC	CC0	0	208.57	187.27	-	198								
		CC1	1	225.91	224.50	-	225								
		CC2	2	242.07	279.94	-	261								
		CC3	3	314.83	308.18	325.03	316								
		CC4	4	338.60	307.33	-	323								
	PCB1-20	CC0	0	279.67	249.13	-	264	12.19	12.44	12.36	12.33	89.54	88.05	88.31	88.63
		CC1	1	319.52	335.12	-	327	12.55	12.38	12.39	12.44	89.46	86.94	87.41	87.94
		CC2	2	320.79	359.37	-	340	12.63	12.47	12.40	12.50	87.13	88.46	85.86	87.15
		CC3	3	371.34	393.31	395.80	387	12.39	12.61	12.62	12.54	83.17	85.13	84.03	84.11
		CC4	4	417.36	365.63	-	391	12.59	12.77	12.80	12.72	85.23	82.87	83.83	83.98
	PCB2-5	CC0	0	161.63	173.18	-	167								
		CC1	1	177.91	238.3	-	208								
		CC2	2	185.75	245.99	-	216								
		CC3	3	330.72	310.81	325.56	322								
		CC4	4	298.13	351.93	-	325								
	PCB3-10	CC0	0	181.43	233.1	-	207								
		CC1	1	194.25	248.15	-	221								
		CC2	2	289.39	352.92	-	321								
		CC3	3	337.45	400.02	351.75	363								
		CC4	4	382.04	366.06	-	374								

Appendix F: Calculation for compressibility test by Oedometer

STEP 1: Laboratory data analysis: Example of untreated peat, P at σ'_v = 10kPa

Initial height, H_o (cm)	Diameter, D (cm)	Area, A (cm^2)	Specific gravity, G_s	Water density, ρ_w (g/cm^3)	Dry mass of sampel, M_s (g)	Mass of sampel, M (g)	*w*	Mass of sampel+mould, M_2 (g)	Mass of mould, M_3 (g)
3	6	28.27	1.670	1.000	13.30	90.44	5.8	332.76	242.32

Hence;

Solid height, H_s	0.282
Dial gauge, D_g	0.002

$$M = M_2 - M_3$$

$$A = \frac{\pi D^2}{4}$$

$$M_s = \frac{M}{1+w}$$

$$H_s = \frac{M_s}{A G_s \rho_w}$$ *(Assumption: G_s is constant)*

Time(sec)	**Settlement$_{lab}$, Δh_{lab}(mm)**	**Settlement, Δh(mm)**	**Settlement, Δh(cm)**	**Final height, H (cm)**	**Void height, H_v (cm)**	**Void ratio, *e***	**Time, t (min)**	**$\sqrt{t}$ (min)**
0	0	0.000	0.000	3.000	2.718	9.649	0.00	0.000
6	143	0.286	0.029	2.971	2.690	9.548	0.10	0.316
9	161	0.322	0.032	2.968	2.686	9.535	0.15	0.387
12	175	0.350	0.035	2.965	2.683	9.525	0.20	0.447
18	199	0.398	0.040	2.960	2.678	9.508	0.30	0.548
30	232	0.464	0.046	2.954	2.672	9.484	0.50	0.707
42	260	0.520	0.052	2.948	2.666	9.464	0.70	0.837
60	293	0.586	0.059	2.941	2.660	9.441	1.00	1.000
90	341	0.682	0.068	2.932	2.650	9.407	1.50	1.225
120	380	0.760	0.076	2.924	2.642	9.379	2.00	1.414
180	493	0.986	0.099	2.901	2.620	9.299	3.00	1.732
300	630	1.260	0.126	2.874	2.592	9.202	5.00	2.236
420	712	1.424	0.142	2.858	2.576	9.144	7.00	2.646
600	833	1.666	0.167	2.833	2.552	9.058	10.00	3.162
900	933	1.866	0.187	2.813	2.532	8.987	15.00	3.873
1200	988	1.976	0.198	2.802	2.521	8.948	20.00	4.472
1800	1048	2.096	0.210	2.790	2.509	8.905	30.00	5.477
2400	1078	2.156	0.216	2.784	2.503	8.884	40.00	6.325
3600	1116	2.232	0.223	2.777	2.495	8.857	60.00	7.746
5400	1141	2.282	0.228	2.772	2.490	8.839	90.00	9.487
7200	1158	2.316	0.232	2.768	2.487	8.827	120.00	10.954
10800	1168	2.336	0.234	2.766	2.485	8.820	180.00	13.416
21600	1185	2.370	0.237	2.763	2.481	8.808	360.00	18.974
43200	1201	2.402	0.240	2.760	2.478	8.796	720.00	26.833
86400	1219	2.438	**0.244**	2.756	2.474	8.784	1440.00	37.947

$$\Delta h(\mathrm{mm}) = \frac{\Delta h_{lab}}{D_g}$$

$$H(\mathrm{cm}) = H - \Delta h$$

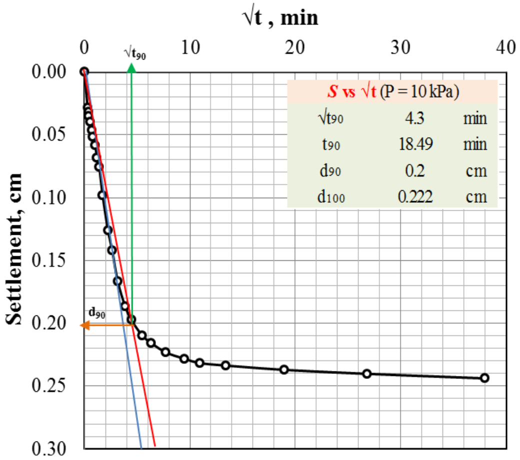
$$e = \frac{H_v}{H_s}$$

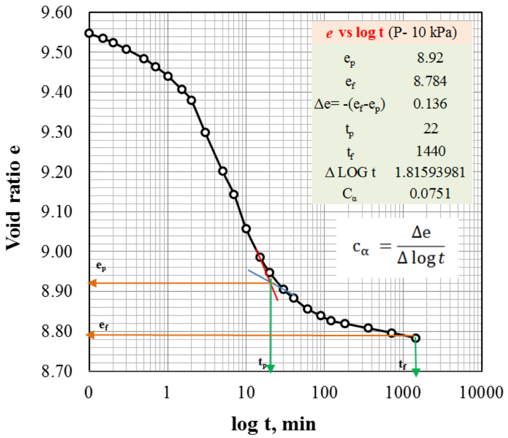
$$\Delta h(\mathrm{cm}) = \frac{\Delta h(\mathrm{mm})}{10}$$

$$H_v(\mathrm{cm}) = H - H_s$$

$$t(\mathrm{min}) = \frac{t(\mathrm{sec})}{60}$$

STEP 2: Determination of t_{90} and secondary compression index, C_α by develop the graph Δh vs √t and *e* vs log *t*.





STEP 3: Determination of compression index, C_c, coefficient of compressibility, m_v, coefficient of consolidation, C_v and coefficient of permeability, *k*.

Pressure, *P* (kPa)	**Total settlement, ΔH (cm)**	**Final height, H (cm)**	**Void height, H_v (cm)**	**Void ratio, *e***	**Specimen average height, H_{avg} (cm)**	**Δε (%)**	**Δp (kN/m²)**	**C_c**	**m_v (m²/kN)**	**t_{90} (min)**	**C_v (m²/s)**	**k (m²/s)**		**C_α**	**C_c/ 1+e_o**	**C_α/ 1+e_o**
0	0.000	3.000	2.718	9.649	0.000	0.000	0	0.000	0.000	0.00	0.000	0.000		0.000	0.000	0.0000
10	0.244	2.756	2.474	8.784	2.878	8.471	10	2.875	8.471E-03	18.49	1.58E-07	1.315E-08		0.075	0.270	0.0071
20	0.152	2.604	2.323	8.245	2.680	5.664	10	1.790	5.779E-03	16.00	1.59E-07	8.994E-09		0.113	0.168	0.0106
40	0.268	2.336	2.055	7.293	2.470	10.848	20	3.160	5.424E-03	17.64	1.22E-07	6.505E-09		0.189	0.297	0.0178
80	0.415	1.922	1.640	5.821	2.129	19.483	40	4.891	4.871E-03	36.00	4.45E-08	2.126E-09		0.331	0.459	0.0311
160	0.412	1.510	1.228	4.359	1.716	24.002	80	4.856	3.000E-03	64.00	1.63E-08	4.783E-10		0.348	0.456	0.0327
320	0.309	1.200	0.919	3.261	1.355	22.832	160	3.648	1.427E-03	73.96	8.77E-09	1.228E-10		0.265	0.343	0.0249
640	0.243	0.958	0.676	2.400	1.079	22.482	320	2.861	7.026E-04	90.25	4.56E-09	3.142E-11		0.233	0.269	0.0218
														Average	0.3647	

$$\Delta H\ (\text{cm}) = \textit{Final settlement from Step 1 (example)}$$

$$H_{avg}\ (\text{cm}) = \frac{H + H'}{2} \qquad m_v\ (\text{kPa}^{-1}) = \frac{\Delta\varepsilon/100}{\Delta p}$$

$$\Delta\varepsilon\ (\%) = \frac{\Delta H}{H_{avg}} \text{ x } 100 \qquad c_v\left(\frac{m^2}{s}\right) = 0.848 \text{ x } \left(\frac{H_{avg}}{2}\right)^2 \text{ x } \frac{1.67E^{-6}}{t_{90}}$$

$$c_c = \frac{\Delta e}{\Delta \log \sigma'_v}$$

Notes: An average of $C_c/1+e_o$ (between 40kPa to 640kPa) was used to compare the compressibility level.

STEP 4: Determination of preconsolidation pressure, σ'_c, compression index ratio, C_α/C_c and compression ratio, $C_c/1+e_o$ by develop the graph *e* vs σ'_v *and* $C_\alpha/1+e_o$ vs $C_c/1+e_o$.