APPLICATION OF PALM OIL FUEL ASH (POFA) AS A STABILIZER IN

TROPICAL PEAT SOIL

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TROPICAL PEAT SOIL

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Thesis submitted in fulfilment of the requirements for the award of the degree of Bachelor of
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SUPERVISOR'S DECLARATION

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Dedicated to my beloved father and mother, and family
and dear friends

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ABSTRACT

Among the different types of soft soil, peat is considered to be the poorest foundation materials due to its natural properties of high water content, high compressibility and low bearing capacity. Moreover, peat soil is susceptible to instability such as slip failure and localized sinking. Peat soil causes cracking, settlements and break-up of pavements, railways, highways, embankments, roadways, building foundations, reservoir linings and sewer line. These entire problems can be solved by improving the engineering properties of peat to make them suitable for construction. Therefore, palm oil fuel ash (POFA) was introduced as a soil stabilizer to improve the peat. POFA is one of the agricultural waste from the palm oil production mills. POFA in both cost-effective and environmentally friendly ways has potential applications in soft soil stabilization. The main focus of the research was to investigate the effect of POFA on the compressibility of peat soil. In this research, the disturbed peat soil extracted from the Pekan, Pahang, Malaysia was mixed with the ultrafine POFA to prepare samples with different dosages range from 5% – 20% of the wet mass of peat soil. All the samples were water cured for 7 and 28 days respectively. After curing, consolidation of treated samples was investigated by standard oedometer consolidation test. The size of all samples was 50mm in diameter, and 20mm in height. Compression index, coefficient of consolidation, and coefficient of volume compressibility were obtained by standard oedometer consolidation test. The method used for sample preparation was aimed at simulating the field condition of the mass stabilization technique. Prior to the oedometer test, the engineering characteristics of Pekan peat were determined. These are the fundamental tests which are important to give a clear full description of Pekan peat. Based on the results obtained, it shows that the increase in POFA ratio led to considerable decreases in compression indices of the stabilized Pekan peat.

ABSTRAK

Antara tanah lembut yang berlainan jenis, tanah gambut dianggap sebagai tanah yang paling kurang kualitinya untuk menampung pembinaan, disebabkan sifat-sifatnya yang tinggi kandungan air dan juga mampatan, serta tekanan galas yang rendah. Lebih-lebih lagi, tanah gambut adalah mudah terdedah kepada ketidakstabilan seperti kegagalan geliciran dan ketenggelaman setempat. Tanah gambut menyebabkan keretakan dan kepecahan di laluan pejalan kaki, landasan kereta api, lebuh raya, benteng, jalan raya dan dan infrastruktur yang lain. Masalah-masalah ini dapat diselesaikan dengan menambahbaikan sifat kejuruteraan tanah gambut supaya menjadikan lebih sesuai untuk tujuan pembinaan. Oleh itu, abu bahan api kelapa sawit (POFA) telah diperkenalkan sebagai penstabil tanah untuk menambahbaikan tanak gambut. POFA adalah salah satu bahan buangan dari kilang pegeluaran minyak sawit. POFA sebagai bahan yang berkos efektif dan mesra alam mempunyai potensi untuk digunakan dalam penstabilan tanah. Fokus utama kajian ini adalah untuk mengkaji kesan POFA pada kebolehmampatan tanah gambut. Dalam kajian ini, tanah gambut terganggu yang diekstrak dari Pekan, Pahang, Malaysia telah bercampur dengan POFA halus untuk menyediakan sampel dengan dos yang berbeza bermula dari 5% – 20% daripada jisim kering tanah gambut. Semua sampel direndam dalam air selama 7 dan 28 hari masing-masing. Selepas itu, pengukuhan sampel dirawat dijalankan dengan oedometer, dengan saiz tanah ujiannya 50mm diameternya, dan 20mm tingginya. Indeks mampatan, pekali pengukuhan, dan pekali kebolehmampatan isipadu diperolehi dengan manjalankan ujian pengukuhan oedometer. Kaedah yang digunakan untuk penyediaan sampel bertujuan untuk mensimulasikan keadaan padang semasa teknik penstabilan massa dijalankan. Sebelum menjalankan ujian pengukuhan oedometer, ujian-ujian sifat kejuruteraan telah dijalankan untuk memberi huraian yang jelas tentang tanah gambut Pekan. Berdasarkan keputusan yang diperolehi, ia menunjukkan bahawa peningkatan dalam nisbah POFA membawa kepada penurunan yang besar dalam indeks mampatan tanah gambut Pekan.

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LIST OF SYMBOLS

%	Percent
σ	Consolidation pressure
log σ	Logarithmic of consolidation pressure
g	Gram
kg	Kilogram
m	Metre
mm	Millimetre
kPa	Kilo pascal
deg.C	Degree Celsius
C_c	Compression index
C_v	Coefficient of consolidation
m_v	Coefficient of volume compressibility
m^2/yr	Square metre per year
Mg/m^3	Megagram per cubic metre
m^2/MN	Square metre per meganewton

CHAPTER 1

INTRODUCTION

1.1   Background

In Malaysia, peatlands are the most widespread type of wetlands, occurring in more than six of the 13 states and covering an area of approximately 8% of the total land area, which is about 3 million (Hashim and Islam, 2008). Peat is a non-homogeneous soil, which is brownish-black in colour. It is formed by partial decomposition and disintegration of organic matters and vegetation under condition of high water content and incomplete aeration. Peat soil has typical characteristics of high natural moisture content, high compressibility and low load bearing capacity. In addition, peat is difficult to sample (Von Post, 1922; MacFarlane, 1969; Terzaghi et al., 1996; Denhaan, 1997; Huat, 2004; Mesri and Ajlouni, 2007).

The organic matter in peat soil leads to continuous decomposition over time and cause uneven settlement in peatland. Peat soil can settle easily, even when subjected to a light load (Jarrett, 1995). Hence, it is challenging for infrastructure development on peatland due to its poor engineering properties. As the demand for construction land rises with the gradual increase of world population, construction on peat land is unavoidable. Therefore, alternative ways to construct on a peatland for future development is important.

Various approaches are used to enhance the engineering properties of peat soil. The common way for peat soil improvement is by using displacement and replacement

method. In this context, peat soil is being excavated and then replaced back with good granular soil, but this method is not encouraged as it is uneconomical. Moreover, if heavily loaded infrastructures are to be constructed on peatland, pile foundation will be the option as pilling can transfer the whole structure load to the hard rock layer. On the other hand, for light load infrastructures, or a road is to be constructed, it is not recommended to construct the structures using pile foundation due to its high expenditure. The method of pre-consolidation by preloading is the most widely used method by the geotechnical engineers to improve the soil, but this method requires a long period of time. Nevertheless, all these practices have drawback from its constrained by technical feasibility, construction cost, space and time limitations, and preferences. Therefore, it is more economical if we could improve the engineering properties of the soil so that the structures can be built directly on the soft soil.

In this research, mass stabilization method was used. The fundamental feature of this method is to add binder materials into the soil and hence further stabilize the soil. The stabilizer will interact chemically with the peat soil, and improves the engineering properties of the unstabilized peat soil. There are researchers have done researches on the stabilization of peat soil using binders like cement, kaolin, lime, and blast furnace slag. However, only few studies discussed on the peat soil stabilization by using palm oil fuel ash. The use of POFA as a stabilizer is not only improve the engineering properties of peat soil, but also reduce the landfill area for industrial solid waste disposal. Thus, POFA is used in this research. The objective of this paper is to demonstrate the feasibility of POFA as an admixture in stabilizing peat soil and to evaluate the response of stabilized peat towards settlement.

1.2   Problem Statement

Among the different types of soft soil, peat is considered to be the poorest foundation materials as it is susceptible to instability such as long-term consolidation settlements and slip failure. Thus, peat land is unfavourable for construction in its natural state. Various construction techniques have been carried out to support embankments and other structures over peat deposits without risking bearing failures but settlements of these

embankments remains excessively large and continues for many years (Huat, 2004). With the rising demand of land for construction, it becomes important to develop the peat land. Therefore, it is necessary to improve the peatland for future construction project. In this study, the researcher is mainly focused on the settlement problem of Pekan peat.

1.3   Objectives

The objective of this research is to investigate the effect of POFA as an additive in stabilization of tropical peat soil. Therefore, researcher interested to achieve the following objectives:

1. To determine compressibility parameters of unstabilized Pekan peat soil.
2. To determine compressibility parameters of peat soil stabilized with POFA.

1.4   Scope of Study

The scope of this research focuses on the laboratory test to determine the compressibility parameters of stabilized peat soil using POFA. The peat soil used in this research was obtained from a site in Pekan, Pahang, Malaysia. While the POFA was collected from Kilang Sawit LCSB Lepar, Gambang, Pahang. The standard oedometer consolidation test was conducted to determine the effectiveness of POFA in reducing settlement of stabilized peat soil. Only three compressibility parameters: compression index, coefficient of consolidation and coefficient of volume compressibility are measured using standard oedometer consolidation test.

The test was conducted by applying a sequence of four vertical loadings and two unloading to a laterally confined specimen which is 20mm thick and 50mm in diameter. The vertical compression under each loading was observed over a period of time. Only three compressibility parameters will be determined, which are compression index (C_c), coefficient of consolidation (C_v), and coefficient of volume compressibility (m_v).

Consolidation settlement is defined as the vertical displacement of the soil surface in corresponding to the change in volume at any consolidation stage. Stabilized peat soil specimen will be tested by conducting standard oedometer consolidation test after water curing for 7 and 28 days.

1.5   Significance of Study

Peat soil stabilization using POFA instead of conventional materials is much more economical. The reuse of waste material is attractive because it is relatively cheaper, compared with conventional cement, as well as promoting sustainable construction. Utilization of waste material for soil improvement not only reduce landfill space limitation, but also provide a new alternative for ground improvement techniques. The use of POFA as binder in mass stabilization can reduce the usage of cement and at the same time alleviate the solid waste disposal issue. Research and development on POFA as soil stabilizer will provide more options for geotechnical engineers to select the most suitable material for mass stabilization. In addition, the use of POFA in peat soil stabilization is less popular in Malaysian construction industry. Hence, research will be able to enhance the understanding towards the suitability of POFA as chemical stabilizer in tropical peat soil improvement.

Below are some major contributions of this research towards the construction industry:

1. Reduce settlements in pavements, embankments and building foundations due to high compressibility of peat.
2. Reduce maintenance cost of repairing cracks and settlements due to long-term consolidation caused by peat.

1.6   Thesis Structure

The thesis is composed of five chapters. Chapter 1 presents general idea regarding background, problem statement, objectives, scope, significance of study, and thesis structure. Chapter 2 is Literature Review. It provides the background of previous studies on different topics related to the research. This chapter introduce the general characteristics of peat soil, the theory of consolidation, standard oedometer consolidation test method and the theories developed by researchers for the study of peat soil compressibility.

Chapter 3 presents the overall experimental program and flow. The methods of conducting this research including laboratory test and data analysis are roughly stated here. The experimental program includes sampling of peat and laboratory soil tests in order to classify the soil and determination of its basic properties. Meanwhile, this chapter also discuss the detail set up and procedures on standard oedometer consolidation test and data analysis.

Chapter 4 is Results and Analysis. This chapter presents general characteristics of peat soil derived from the preliminary test results. These include soil identification, soil classification, and compressibility data obtained from the standard oedometer consolidation test. Chapter 5 is Conclusions and Recommendations. In this chapter, summary is made according to the objectives listed previously, and provide some recommendations to improve the project.

CHAPTER 2

LITERATURE REVIEW

2.1   Definition of Peat and Organic Soil

From technical perspective, any material which contains carbon is considered 'organic'. However, when application this term to soil, engineers and geologist have their own definition. An organic soil contains a significant amount of organic matter which derived recently from plant remains (Huat, 2004). Meaning the soil is still in the decomposition process, and thus retains a distinctive texture, colour and odour. Hence, in this context, some soils are not considered as organic soil although they contain carbon, because the carbon content are not recently derived from plant residues. While in the perspective of geotechnical engineering, soils with organic content greater than 20% are categorised as organic soil. Whereas 'peat' is an organic soil with organic content of more than 75% (Huat, 2004). Table 2.1 shows the ASTM (D4427) classification of peat samples by laboratory testing.

Table 2.1: Organic content ranges

Basic soil type	Description	Organic content (%)
Clay or silt or sand	Slightly organic	2–20
Organic soil		25–75
Peat		>75

Source: ASTM (2013)

Peats comprised mainly of decomposing plant materials with a much smaller amount of mineral deposits. Approximately 95% percent of peat deposits are formed from vegetation decomposing under condition of sufficient oxygen. The decomposition rate is several thousand times faster under aerobic as opposed to anaerobic conditions, which are characterized by cold climate and excess water. Oxygen sufficiency is important to the growth and decomposition, whereas oxygen insufficiency will pause surface growth and slow down sub-surface decomposition.

Peat is composed of liquid, gaseous, and solid state matter under natural conditions (Figure 2.1). The solid component of peat comprises of organic matter and mineral matter. Organic matter is the principal component of solid phase of peat, which include incompletely decomposed humus and plant debris. Plant debris comprises the main part of organic matter in peat, including plants' root, stems, leaves, fruits, seeds, spores, and pollen. Humus, accounting for 20% to 70% of the organic matter of peat, is an organic chemical complex with a complicated structure which arose during peat-forming process. On the other hand, the mineral matter in peat may be of two types: material that was carried into peat by running water and wind during the accumulation process, or material that was formed by the decomposition of plant debris. The former is called secondary ash, while the latter is called original ash, which sum up to be the total content of mineral matter in peat.

These situations lead to complicated growth and decomposition patterns of moss and fibrous sedge plants. Sedge plants are much more resistant to decomposition than moss, which leads to natural reinforcement of the weaker moss plants. This reinforcement effect is even more pronounced and the soil variability is much more significant if trees

and shrubs grow in the area (Landva and Pheeney, 1980). Although this description of peat formation is simplified, it does provide a basic conceptual building block for the understanding of peats and organic soils.

Identification of organic soil is important for geotechnical engineers as they have much weaker shear strength and higher compressibility compared to inorganic (mineral) soil. Hence, organic soil is geotechnical problematic to most engineering projects.
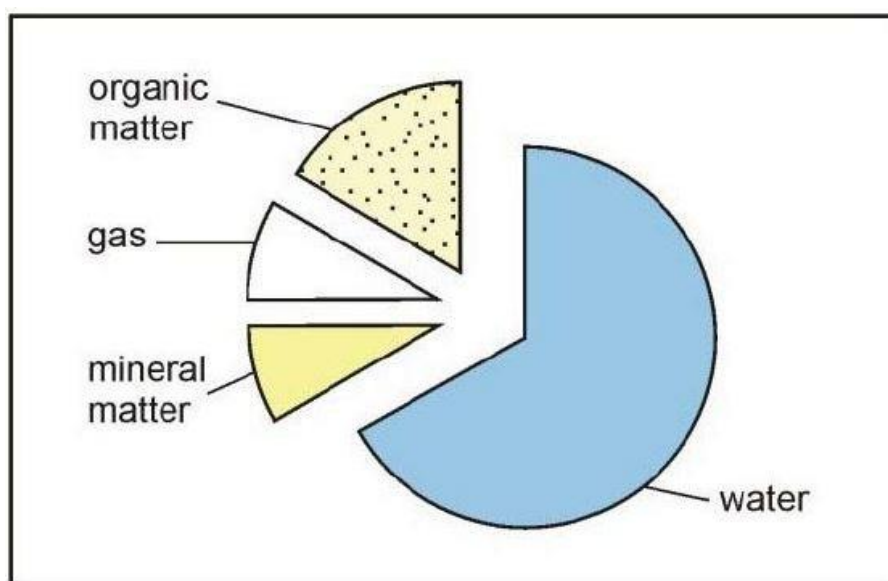
Figure 2.1: Matter composition of peat

Fibrous peat has an open structure with interstices filled with a secondary structural arrangement of nonwoody and fine fibrous material (Dhowian and Edil, 1980). Hence, physical properties of fibrous peat differ markedly from those of mineral soils. Kogure *et al.* (1993) presented the idea of multi-phase system of fibrous peat which made up of organic bodies and organic space. The organic body comprises of organic matter and water in inner voids, while the organic space comprises of soil particles and water in outer voids.

The cross section of deposition and schematic diagram of the multi-phase system of fibrous peat are shown in Figure 2.2 (a) and 2.2 (b). It can be seen from Figure 2.2 (a),

the organic particles consist of solid organic matter and inner voids. The solid organic matter is flexible due to the water in the inner voids, where the water can be drained under consolidation pressure. In addition, the spaces between the organic bodies, called outer voids are also filled with solid particles and water.

	Organic matters (Solids)
Organic bodies	Water (Inner voids)
Organic spaces	Water (Outer voids)
	Soil particles (Solids)

(a)   (b)
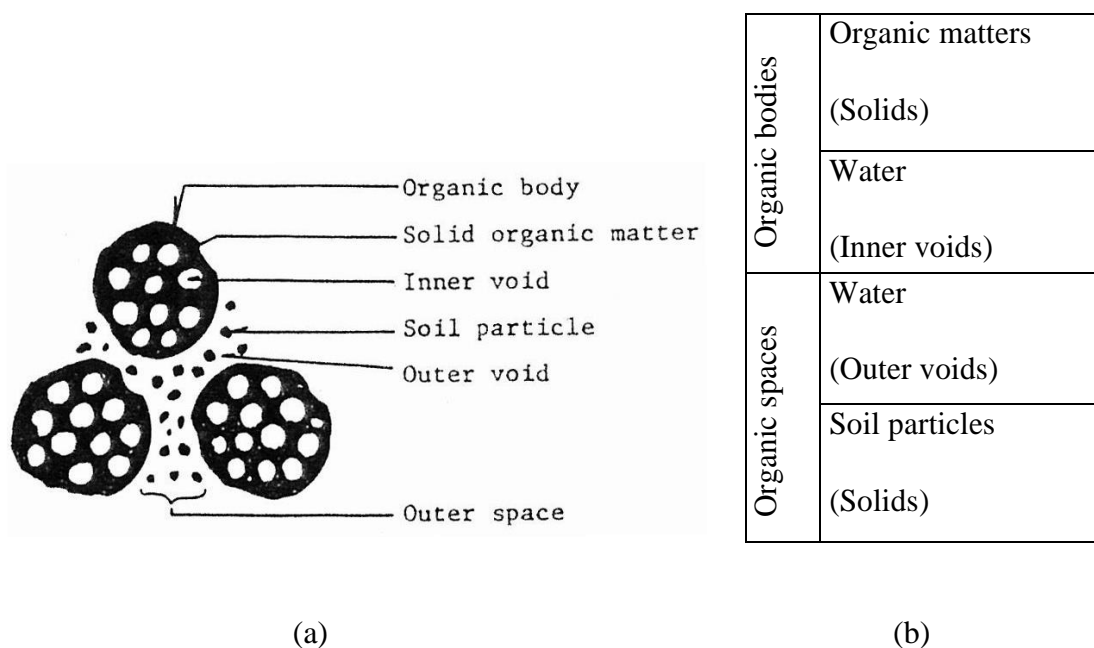
Figure 2.2: (a) Schematic diagram of deposition and **(b)** multi-phase system of fibrous peat (Kogure *et al.*, 1993)

2.2   Distribution of Peat

Peat is found in all part of the world except in deserts and the arctic regions. The most extensive areas are located in the northern hemisphere. It is estimated that there are about 1 billion acres of peatland in the world or about 4.5% of total land areas. In United State, peat is found in 42 states with a total area of 30 million hectares. While Canada and Russia are two countries with the largest area of peat, which is 170 and 150 million hectares respectively. In Japan, peat is widely distributed throughout Hokkaido, the northernmost island of Japan, with an area of approximately 200 thousand hectares, which

cover about 6% of the flat area of the island. The total area of tropical peat swamp forest or tropical peatland in the world amounts to about 30 million hectares (Deboucha et al., 2008). Table 2.2 shows the distribution of peat deposits throughout the world.

In Malaysia, approximately 3 million hectares or 8% of the country land area is covered with peat (Table 2.3). Peat can be found in both the east and west coasts of Peninsular Malaysia (Huat, 2004). Generally, the peat is shallower near the coast and increases along the land inwards, locally exceeding more than 20 metres. Due to environmental factors, peat soil can vary from muddy to fibrous. The deposit is shallow in most of the cases, but in worst situation, it can extend to several metres below the surface level (Pousette et al., 1999; Cortellazzo and Cola, 1999; Ahnberg and Holm, 1999). In general, the peat land along the coastal area is well elevated above adjacent river courses (Huat, 2004). Moreover, the peat soil particles in this area is usually elongated and irregular in shape, instead of having the ideal round bog shape, this is due to alluvial and coastal geomorphology.

Table 2.2: Percentage of national area covered by peat in different countries in rank order

Rank	Country	Peat land area (Million hectares)	Peat area order (%)
1	Finland	10.4	33.5
2	Canada	170	18.4
3	Republic of Ireland	1.2	17.2
4	Sweden	7.6	17.1
5	Indonesia	26	13.7
6	Northern Ireland	0.2	12.7
7	Scotland	0.8	10.4
8	Iceland	1.0	9.7
9	Norway	3.0	9.4
10	Malaysia	3.0	8.0
11	Wales	0.2	7.7
12	The Netherlands	0.3	7.4
13	Russia	150	6.7
14	Germany	1.7	4.8
15	Poland	1.4	4.4
16	Cuba	0.5	3.9
17	USA (including Alaska)	30	3.3
18	England	0.4	2.8

19	Austria		2.8
20	Denmark	0.1	2.8
21	Switzerland	0.1	1.3
22	Hungary	0.1	1.1
23	New Zealand	0.2	0.6
24	Belgium		0.6
25	Uruguay	0.1	0.5
26	Japan	0.2	0.5
27	Yugoslavia	0.1	0.4
28	China	3.5	0.4
29	Italy	0.1	0.4
30	France	0.1	0.2
31	Argentina		0.016
32	Spain		0.012
33	Australia		0.002
34	Bulgaria		0.001

Source: Hartlen and Wolski (1996)

Table 2.3: The area (ha) of peat soil in Peninsula Malaysia, Sarawak and Sabah

Region	Area (ha)	Percentage (%)
Sarawak	1,697,847	69.08
Peninsular Malaysia	642,918	26.16
Sabah	116,965	4.76
Total	2,457,730	

Source: Wetlands International (2010)

2.3   Index Properties of Peat

Peat owns a wide range of physical properties such as texture, colour, water content, density, and specific gravity. The texture of fibrous peat is coarse when compared to clay. This has an implication on the geotechnical properties of peat related to the particle size and compressibility behaviour of peat. Soil fabric characterized by organic coarse particles hold a considerable amount of water because they are generally very loose,

and the organic particle itself is hollow and largely full of water. It comprises of high percentage of organic and natural water content up to more than 75% and 400% respectively (Huat, 2004). High water content results in high buoyancy and high pore volume leading to low bulk density and low bearing capacity. Unit weight of peat is typically lower compared to inorganic soils. The average unit weight of fibrous peat is about equal to or slightly higher than the unit weight of water. A range of 8.3–11.5 kN/m^3 is common for unit weight of fibrous peat in West Malaysia (Huat, 2004).

According to H.S. Ooi (1982) and Andriesse (1988), peat soil has very low load bearing capacity and influenced by the sub-surface woody debris and the ground water table. This fact is supported by Islam and Hashim, whereby they mentioned that water table and woody debris are affecting the bearing capacity of peat soil (M. S. Islam and R. Hashim, 2008). The underground solid woody debris could reach up to 15% of the soil volume (A. Mohammad and A.B. Ismail, 2005).

Specific gravity of fibrous peat soil ranges from 1.3 to 1.8 with an average of 1.5 (Ajlouni, 2000). The low specific gravity is due to low mineral content of the soil. Natural void ratio of peat is generally higher than that of inorganic soils indicating their higher capacity for compression. Natural void ratio of 5-15 is common and a value as high as 25 have been reported for fibrous peat (Hanharan, 1954). Peat will shrink extensively when dried. The shrinkage could reach 50% of the initial volume, but the dried peat will not swell up upon re-saturation because dried peat cannot absorb water as much as initial condition; only 33% to 55% of the water can be reabsorbed (Mokhtar, 1998).

Generally, peat soils are very acidic with low pH values, often lies between 4 and 7 (Lea, 1956). Peat existing in Peninsular Malaysia is known to have very low pH values ranging from 3.0 to 4.5, and the acidity tends to decrease with depth (Muttalib et.al., 1991). The submerged organic component of peat is not entirely inert but undergoes very slow decomposition, accompanied by the production of methane and less amount of nitrogen and carbon dioxide and hydrogen sulfide. Gas content affects all physical properties measured and field performance that relates to compression and water flow. A gas content of 5 to 10% of the total volume of the soil is reported for peat and organic soils (Muskeg Engineering Handbook, 1969).

2.3.1 Moisture Content

Moisture content is required as a guide to classify natural soils and as a control criterion in re-compacted soils. Water is present in most naturally occurring soils and play a significant effect on soil behaviour. The moisture content of soil is assumed to be the amount of water within the pore space between the soil grains which is removable by oven-drying and can be expressed as a proportion by mass of the dry solid particles. According to Duraisamy et al. (2007), the moisture content of peat from west coast of Peninsular Malaysia ranged from 140 – 350 %. Table 2.4 shows typical values of natural water content of various soil deposits.

The moisture content of the soil sample is determined using the procedures as detailed in BS1377: Part 2: 1990: 3.2, which involves drying a soil sample in an oven at 105°C for 24 hours. This method is also named as oven-drying method. The oven-drying method is the definitive procedure used in standard laboratory practice. The moisture content, w is calculated using the formula:

$$w = \frac{m_2 - m_3}{m_3 - m_1} x\ 100\% \qquad (2.1)$$

where,

w = moisture content

m_1 = mass of container + lid

m_2 = mass of container + lid + wet soil

m_3 = mass of the container + lid + dry soil

There is a general worry that standard drying of the soil at 105°C for 24 hours will lead to charring of the organic component in peat, thus resulting a huge figure for water content. Therefore, some studies propose a lower temperature, which is between 50°C

and 95°C. Skempton and Petley (1970) and Kabai and Farkas (1988) investigated the effect, and found that the loss of organic matter at 105°C is insignificant, while in fact drying at lower temperature is unable to remove all the moisture. Zainorabidin and Bakar (2003) investigated the drying temperature effect for hemic peat soil and suggest that for a temperature range from 100°C to 200°C, and drying period is between 24 hours to 60 hours.

Table 2.4: Natural water content of various soil deposits

Soil deposits	Natural water content (%)
Malaysia west coast clay	70 - 140
Malaysia east coast clay	36 - 73
Quebec fibrous peat	370 - 450
Antoniny fibrous peat, Poland	865 - 1400
Co. Offaly fibrous peat, Ireland	450
Cork amorphous peat, Ireland	759 - 946
Cranberry bog peat, Massachusetts	200 - 800
Austria peat	334 - 1320
Japan peat	200 - 300
Italy peat	115 - 1150
America peat	200 - 700
Canada peat	223 - 1040
Hokkaido peat	115 - 1150
West Malaysia peat	200 - 700
East Malaysia peat	200 - 2207
Central Kalimantan peat	467 - 1224

Source: Huat (2004)

2.3.2 Organic Content

Organic content is an important parameter for peat soil, which differentiate it from mineral soil (silts and clay). According to ASTM D2974, the organic content is determined from the loss on ignition test as a percentage of oven-dried mass. This is a method for quantitative determination of the organic content in a soil sample by ignition

of a dry test sample. This method is suitable for fine-grained soils with relatively high organic content, but containing little chalky material. The moist sample is first fried in an oven at a temperature of 105°C for 24 hours. A crucible is then placed in the muffle furnace at a temperature of 450°C for 1 hour, and weighed to obtain its mass, M_1. The dried soil from the oven is then weighed together with the crucible giving M_2. The soil sample together with the crucible is then heated again in the furnace at 450°C for 5 hours until no further change of mass occurs, the final constant mass is recorded as M_3 after cooled in desiccator at room temperature. Loss on ignition, N is calculated as:

$$N = \frac{M_2 - M_3}{M_2 - M_1} \tag{2.2}$$

Organic content, H is calculated according to an equation proposed by Skempton and Petly (1970) as follows:

$$H\% = 100 - C(100 - N) \tag{2.3}$$

Where C is the correction factor. For a temperature of 450°C, C = 1.0 (Arman, 1971). In Europe, a higher temperature of 550°C is used for combination of peat, and C=1.04 is then used as correction. However, the difference is usually small, hence it is insignificant for practical considerations (Edil, 2003). The organic content of west Malaysia peat ranged from 70 – 88% (Duraisamy et al., 2007). Table 2.5 shows the organic content of various peat deposits found throughout the world.

Table 2.5: Organic content of various peat deposits

Peat deposits	Organic content (%)
Antoniny fibrous peat, Poland	65 – 85
Co. Offaly fibrous peat, Ireland	98 – 99
Cork amorphous peat, Ireland	80
Cranberry bog peat, Massachusetts	60 – 77
Italy peat	70 – 80
Japan peat	20 – 98
Canada peat	17 – 80
Hokkaido peat	20 – 98
West Malaysia peat	65 – 97
East Malaysia peat	76 – 98
Central Kalimantan peat	41 – 99

Source: Huat (2004)

2.3.3   Atterberg Limits

The Atterberg limits were determined in accordance with BS 1377: part 2: 1990. The peat sample was sieved through 424μm. Material retained on the sieve was rejected for this test. The soil was then oven-dried for 24 hours, where moisture content reduced between 150 % and 200 % prior to the test. Table 2.6 shows the Atterberg limits of various soil deposits.

2.3.3.1 Liquid Limit

The liquid limit is the empirically established moisture content at which a soil passes from the liquid state to the plastic state. The liquid limit provides a means of identifying and classifying fine-grained cohesive soils especially when also the plastic limit is known. Variations in the moisture content in soil may have significant effect on its shear strength, especially on fine-grained soils.

The cone penetrometer method is the preferred method to the Casagrande test as it is essentially a static test depending on soil shear strength. This method covers the determination of the liquid limit of a sample in its natural state, or a sample from which material retained on a 425mm test sieve has been removed. It is based on the measurement of penetration into the soil of a standardised cone. The liquid limit for west Malaysia peat was within the range of 240 – 398 % (Duraisamy et al., 2007).

2.3.3.2 Plastic Limit

The plastic limit is the empirically established moisture content at which a soil becomes too dry to be plastic. It is used together with the liquid limit to determine the plasticity index which when plotted against the liquid limit on the plasticity chart provides a means of classifying cohesive soils. The plasticity index is the difference between the liquid limit and the plastic limit. The plasticity index is the range of moisture content in which a soil in plastic, the finer the soil, the greater the plasticity index. This method covers the determination of the liquid limit of a sample in its natural state, or a sample from which material retained on 425um test sieve has been removed.

The plasticity index (I_p) is defined as the difference between the liquid limit (w_L) and the plastic limit (w_P), and is calculated from the equation:

$$I_P = w_L - w_P \qquad\qquad (2.4)$$

Table 2.6: Atterberg limit of various soil deposits

Soil deposits	Liquid limit (%)	Plastic limit (%)
Malaysia west coast clay	56 – 90	35 – 30
Fen peat	200 – 600	–
Bog peat	800 – 1500	–
Antoniny fibrous peat, Poland	305 – 310	–
Cork amorphous peat, Ireland	690	561
Cranberry bog peat, Massachusetts	580 – 600	375 – 400
West Malaysia peat	190 - 360	100 – 200
Samarahan (hemic) peat	210 – 550	125 – 297

Source: Huat (2004)

2.3.4 Fibre Content

Botanical terms used in describing peat especially for horticultural purposes but such terms also have relevance to engineering because of the texture they imply. Sphagnum peat designates a material with predominantly sphagnum moss (>60 to 75%). Sedge peat has one or more species of sedge (plants that are glasslike in appearance). Woody peat is another term that designates dominance of woody pieces. Other terms include taxodium peat, reed peat and combinations of botanical terms. Of course, for highly decomposed peat with low fibre content (<33%), it would be difficult to identify the botanical origin. According to Duraisamy et al., the fibre content of west coast peat ranged from 31 – 77%.

The structure of peat and organic soils in an arrangement of primary and secondary elements that make up the soil. On a qualitative basis, however, organic ground can be described in terms of its fibre content and type. Fibre content is determined typically from dry weight of fibres retained on #100 sieve (>0.15mm opening size) as a percentage of oven-dried mass (ASTM Standard D 1997). Fibres may be fine (woody or nonwoody) or coarse (woody). Organic matter that does not have an identifiable fibre shape is finer in size than 0.15mm and designated as amorphous-granular matter. It is also referred to as peat humus.

2.3.5 Specific Gravity

The specific gravity of any material is the ratio of its density to that of water. In the case of soil, it is computed for the solid phase only,

$$G_s = \frac{M_S}{V_s \rho_w}$$

(2.5)

where $\rho_w = density\ of\ water$

The specific gravity of soil solids can be tested in the laboratory using the specific gravity bottle method or the gas jar method (ASTM D854, BS 1377: 1900). For most mineral soils (sand, silt and clay), the specific gravity ranges from 2.60 – 2.80. The specific gravity for organic soils however is affected by the organic constituents, and cannot be simply set to somewhere near the mineral soils. Cellulose has a specific gravity of approximately 1.58, while for lignin it is approximately 1.40. These low values reduce the compounded specific gravity of organic soils. The specific gravity of west Malaysia peat ranged from 1.42 – 1.56 (Duraisamy et al, 2007). Table 2.7 shows the typical specific gravity of various soils.

Table 2.7: Typical specific gravity of various soils and minerals

Soil type/mineral	Specific gravity
Non-clay	
Quartz	2.65
Mica	2.76 - 3.20
Gypsum	2.32
Clay minerals	
Kaolinite	2.62 – 2.66
Montmorillonite	2.75 – 2.78
Illite	2.60 – 2.96
Peat	
Bog peat	1.40 – 1.60
Fen peat	1.80
West Malaysia peat	1.38 – 1.70
Samarahan peat	1.07 – 1.63
Central Kalimantan peat	1.50 – 1.77

Source: Huat (2004)

2.3.6   Classification of Peat

Peat soils have been classified to 10 degrees of humification (H1–H10) by Von post (1922) based on degree of humification, botanical composition, water content and content of fine and coarse fibres (Appendix A). The Von Post system utilizes visual-manual identification methods. This method is used particularly for evaluating the degree of decomposition. The degree of decomposition, also known as the degree of humification, is the most significant contribution of the Von Post system. This simple field classification test consists of taking a sample of peat and squeezing it in the hand. The material that is extruded between the fingers is examined, and the soil is classified as belonging to one of ten (H1–H10) humification or decomposition categories (Andriesse 1974; Engineering Geology Working Group 2007; Alaska Department of Transportation and Public Facilities 2007).

In modern classification, peat can be narrowed into 3 classes according to their level of decomposition, which are fibric or fibrous (least decomposed), hemic or semi-fibrous and Sapric or amorphous (most decomposed) (Magan, 1980). According to Duraisamy *et al.* (2007), when a load is applied over a period of time, the tropical fibric peat settle the most, following by hemic and sapric peat. ASTM standards have stated, the hemic peat has fibre content which is in the range of 33% to 67% and the fibric peat has more than 67% of fibres while the sapric peat has the lowest, which is less than 33% of fibres.

2.4   Compressibility of Peat

High organic matters indicate that the soil is highly compressible and swell (Mesri and Ajlouni, 2007; Anand J. et al., 2007; Kazemian et al., 2009). The main factors which alter the compressibility of peat include the fibre content, natural moisture content, void ratio, initial permeability, nature and arrangement of soil particles, and interparticle chemical bonding in some of the soils (Mesri and Ajlouni, 2007). Standard oedometer consolidation test is usually used to determination of compressibility of fibrous peat, where a soil specimen is restrained laterally and loaded axially through the application of a static force. Measurements of the elapsed time, and the deformation of the specimen constitute the primary data from the test. The data from this test can be used to estimate both the magnitude and the rate of settlement that can be expected in a field condition, and is thus a crucial piece of information for almost any geotechnical application (ASTM D2435). Fibrous peat undergoes large settlements in comparison to clays when subjected to loading. The in situ void ratio of fibrous peats is very high because of the fact that very compressible and bendable hollow cellular fibres form an open entangled network of particles and the high initial water content.

Generally, the compressibility of soil comprises of three phases, namely initial compression, primary consolidation, and secondary compression. Initial compression occurs instantly after loading was applied, whereas primary and secondary compressions are both time dependent. The initial compression happens mainly due to the compression of gas within the pore spaces and the elastic compression of soil grains. Primary

consolidation occurs after the increase in effective vertical stress which cause dissipation of excess pore water pressure. Although the rate of primary consolidation of fibrous peat is very high, it decreases with the application of consolidation pressure. Due to its high to moderate initial permeability, peat have relatively short duration of primary consolidation and large secondary compression, even tertiary compression of peat can be observed. The initial permeability of peat is between 100 to 1000 times that of soft clays and silts and its coefficient of consolidation is between 10 to 100 times greater (Colleselli et al., 2000). According to Lea and Brawner (1963), there will be a significant decrease in the rate of coefficient of consolidation (C_v) during application of pressure from 10 to 100 kPa. The significant reduction factor of 5−100 is attributed to the reduction of permeability due to the appreciation of pressure.

Next, secondary compression would take place once the dissipation of excess pore water pressure has completed at constant effective vertical stress. But according to Leonards and Girault (1961), there is a possibility that secondary compression starts before the dissipation of excess pore water pressure is completed. During both primary and secondary compression, water is expelled simultaneously from within and among the peat particles (Mesri and Ajlouni, 2007). Therefore, the e-log p' curves show a steep slope indicating a high value of the compression index (C_c). The compression index of peat soil ranges from 2 to 15. Under the data collection by Hussien (1997), a summary of the values of compression index are shown in Table 2.8.

Secondary compression is generally found as the more significant part of compression because the time rate is much slower than the primary consolidation (Yulindasari, 2006). The secondary compression of peat might due to further decomposition of fibre which assumed to occur at a slower rate after the completion of primary consolidation (Mesri et al., 1997).

In this research, only three main compressibility parameters will be determined in order to find out the effect of POFA in reducing the compressibility of peat soil, namely compression index (C_c), coefficient of consolidation (C_v), and coefficient of volume compressibility (m_v).

Table 2.8: Summary of compressibility parameters of Peninsular Malaysia

soft soil deposits from various researchers

West Coast	C_c
Abdullah & Chandra (1987)	0.4 – 1.38
MHA (1989)	0.5 – 2.35
Kobayashi et al (1990)	0.35 – 1.8
Aziz (1993)	1 – 2
Mohammad et al (1994)	0.4 – 3.2
Hussein (1995)	0.6 – 2.2
Hussein (1997)	0.1 – 2.4
East Coast	
Abdullah & Chandra (1987)	0.02 – 0.08
Kobayashi et al (1990)	0.9 – 1.2
Hussein (1997)	0.1 – 1.13

2.5   Mass Stabilization

Mass stabilization is the process of utilizing chemical admixtures and stabilizing agents to improve the strength and settlement characteristics of soft soils. Effectiveness of different binders are varying (Huat, 2004). This is a relatively new soil improvement method for soft soil layers. This method can be achieved by situ stabilization or ex-situ stabilization. Its purpose is to minimize structure settlement during construction and operation period, thereby improving structural stability and reducing the risk of collapse. Stabilisation is done by wet mixing or dry mixing of binder throughout the volume of the treated soil layer. The application of mass stabilization techniques improves the technical engineering and environmental properties of soft soil in such a way that it is possible to construct directly on top of the stabilized soil or to utilize it as a filling or construction material. The stabilized soil has a higher strength, lower permeability and lower compressibility than the untreated soil (Keller brochure 32-01E).

The strengthening mechanism for organic soils depends on several properties. The most significant characteristics that determine the effectiveness of the treatment are the type of peat, size and abundance of fibres, type of binder, concentration of binder, curing

time after stabilization, and degree of decomposition (Huttunen and Kujala, 1996). Of particular relevance concerning the use of the binding agents with organic soils is the role of the degree of decomposition (Huttunen and Kujala, 1996).

Owing to the development of versatile binders, various kinds of soft soils can be stabilized in a cost-effective way. All mass stabilization projects utilize a binder, or chemical stabilizing agent which reacts with the soil mass to change its properties. New binders and binder mixtures using different industrial byproducts are being introduced to the market continuously. The most common binding materials used are: Portland cement, quicklime, gypsum, fly ash, coal slag, and other pozzolanic materials (Esrig, 1999). The use of various industrial byproducts as binders in mixtures with commercial binders enable cost-effective application of the mass stabilization method. These binding compounds all work in a manner to increase the pH of the soil environment above a value of 12.4, which allows the silica and alumina of the soil to become available for the pozzolanic reaction to take place (Esrig, 1999).

The strengthening is also contributed by the reduction of water content in the soil that takes place upon hydration of the binding agent. Ground investigation and laboratory testing programmes have to be done first in order to find out the optimum quantity and quality of the binders which can achieve the target properties with minimal investment. Although higher strength value may achieve through lab based experiment, but it will still help to assess the suitability of the binders. In addition, the laboratory test results will enhance the knowledge on the choice of binders and the optimum amounts (EuroSoilStab, 2002). However, the decision to technological usage depends on which soil properties have to be enhanced, can it be the volume stability, strength, compressibility, permeability and durability of soil (Ingles and Metcalf, 1972; Sherwood, 1993; EuroSoilStab, 2002).

The most commonly used binder in mass stabilization is cement but the use of lime is also possible in many cases (lime cement). Additionally, various reactive byproducts originating from industrial processes may be used alongside as a mixture component. These include such byproducts as slags, fly ash, and/or gypsum components. The use of industrial byproducts allows for achieving stabilized masses with a better technical and/or environmental quality, as well as it decreases the overall costs of the binder agents.

The main factors influencing the selection process are target strength, material price and its availability. Other issues to be considered include, among others, curing time, stress-strain properties, and in some cases also impacts on leaching and permeability features.

2.6   Palm Oil Fuel Ash

Palm oil production is one of the most important agricultural industry in Malaysia, Indonesia and Thailand. Palm oil is extracted from the fruit and copra of the palm oil tree. After the extraction process, waste products such as palm oil fibres, shells, and empty fruit brunches are burnt as biomass fuel at temperature about 800°C to 1000°C to boil water, which generates electricity for crude palm oil extraction process. After that, a significant amount of the resulting ashes known as palm oil fuel ash (POFA) was generated.

As one of the world's largest producers and exporters of palm oil, Malaysia has generated approximately 4 million tons of POFA each year. Whereas in Thailand, about 0.1 million tons of POFA were produced annually (Chindaprasirt *et al*., 2007; MPOB, 2013). This amount keeps rising every year as palm oil is one of the major raw materials for the production of biodiesel.

Nowadays, POFA are disposed as landfill material without any economic return (Awal and Nguong, 2011 and Borhan *et al.,* 2010). According to Abdul et al. (1997), million tons of POFA will be produced every year and the Malaysian Government need to allocate more dumping land to dispose the waste. Open disposal of these wastes without proper management will a cause potential environmental and health hazard which can lead to the bronchi and lung diseases (Tay and Show, 1995). As a result, solid waste management has become one of the major environmental concerns in the world.

However, POFA is one of the potential recycle materials from palm oil industry as it has been identified possess good pozzolanic properties that can be used to substitute cement in soil improvement. POFA has strong potential to treat physicochemical characteristics of soft soils due to its amorphous nature and high silica content (Pourakbar

et al., 2015). Several studies have also validated on different occasions the benefits of using POFA, instead of asphalt, as primary road material (Ndoke, 2006; Amu et al., 2008). Ismail and Keok (Ismail and Keok, 2010) also produced bricks with satisfactory strength using POFA and paper sludge. From the geotechnical and geoenvironmental perspectives, Brown et al. (2011) reported that clayey soils treated with POFA as landfill liner exhibit an increase in optimum moisture water content despite a decrease in maximum dry density. A review of the literature reveals that not much effort has been exerted in the past to evaluate the efficacy of POFA-stabilized soils, particularly soft soils that usually demand high quantities of stabilizer to reach satisfactory results.

According to Bamaga et al. (2013), three different palm oil fuel ashes were collected from three different palm oil mills in Malaysia and namely CAPOFA, KTPOFA and ALPOFA, each of their chemical compositions are shown in Table 2.9. Based on the chemical composition of POFA ashes and cement presented in Table 2.9, CAPOFA are rich in silica content and could be classified as class N pozzolana according to the standard (ASTM C618-03, 2004). ALPOFA has high content of silica and could be classified as class N pozzolana when LOI requirement is ignored. However, LOI effect has been proven not to be very effective (Al Amoudi et al., 1993). KTPOFA comply with the requirements of class F pozzolana according to the standard (ASTM C618-03, 2004).

Hypothetically, the large amount of amorphous silica in POFA potentially contributes to the pozzolanic reaction during hydration, which results in cementitious compounds called calcium aluminate hydrates (CAH) and calcium silicate hydrates (CSH). These compounds are responsible for improving the engineering characteristics of soils that increase over time as the pozzolanic reaction develops (Seco et al., 2012). The potential is further strengthened and driven by the insight that oil constitutes only 10% of the palm production, while the rest of 90% is the residue (Foo and Hameed, 2009). The use of supplementary cementing materials, like POFA in mass stabilization has attracted attention over the past decades because of its abundant accessibility and low profitable commercial value.

Table 2.9: Chemical composition of POFA and cement

Chemical Composition	Cement	CAPOFA	ALPOFA	KTPOFA
SiO_2	21.9	58.30	59.60	52.50
Al_2O_3	5.00	6.69	7.05	8.83
Fe_2O_3	2.60	9.77	8.77	5.73
CaO	65.10	6.72	8.06	11.30
MgO	3.10	3.69	3.09	3.55
SO_3	-	0.96	0.57	0.82
K_2O	0.50	8.40	7.64	10.20

Source: Bamaga et al. (2013)

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology of this research was summarized in the flowchart shown in Figure 3.1. This research started with the identification of problem statement. This topic is related to geotechnical engineering and has been narrowed to the identification of engineering properties of peat soil, which include moisture content, organic content, fibre content, Atterberg limits, and specific gravity. In addition, the determination of peat soil compressibility parameters also has been carried out. Next, literature study was made to understand rationale of the research and to gather sufficient information on the consolidation behaviour of tropical peat. Reference has also been done on primary and secondary resources as summarized in Chapter 2: Literature Review.

Laboratory testing was the dominant part of this research. In general, laboratory tests were done in order to obtain data for result analysis. It is performed according to ASTM standards and BS 1377 Methods of Test for Soils for Civil Engineering Purposes. BS 1377 recommends the terminology and criteria for the systematic description and classification of soils for engineering purposes. The details of the test are listed in Table 3.1.

```
┌─────────────────────────────────┐
│      Problem Identification      │
└─────────────────────────────────┘
                 │
                 ▼
┌─────────────────────────────────┐
│  Preliminary Research Assessment │
│            (Proposal)            │
├─────────────────────────────────┤
│  1. Introduction                 │
│  2. Objective                    │
│  3. Scope of work                │
│  4. Literature review            │
│  5. Methodology                  │
└─────────────────────────────────┘
                 │
                 ▼
┌─────────────────────────────────┐
│       Research Appraisal         │
└─────────────────────────────────┘
                 │
                 ▼
┌──────────────────────────────────────────────┐
│ Sampling and Preparation of Material & Equipment │
└──────────────────────────────────────────────┘
        │                               │
        ▼                               ▼
┌──────────────────────┐   ┌──────────────────────────┐
│ Characterization Testing │ │      Main Testing        │
├──────────────────────┤   ├──────────────────────────┤
│  • Moisture content  │   │ Compressibility Parameters│
│  • Organic content   │   │ Testing:                 │
│  • Fiber content     │   │                          │
│  • Atterberg limits  │   │  • Standard Oedometer    │
│  • Specific gravity  │   │    Consolidation Test    │
└──────────────────────┘   └──────────────────────────┘
        │                               │
        └───────────────┬───────────────┘
                        ▼
          ┌─────────────────────────┐
          │   Results and Discussion │
          └─────────────────────────┘
                        │
                        ▼
          ┌──────────────────────────────┐
          │ Conclusion and Recommendation │
          └──────────────────────────────┘
```

Figure 3.1: Flow chart of research methodology

Table 3.1: List of tests with different standard

| Number	Test	Standard
I	Natural Moisture Content	BS 1377: Part 2: 1990 section 3
II	Organic Content	BS 1377: Part 3: 1990 section 3
III	Atterberg Limits	BS 1377: Part 2: 1990 section 4
IV	Specific Gravity	BS 1377: Part 2: 1990 section 8.3
V	Fibre Content	ASTM D1997-91
VI	Classification	Von Post degree of humification

Tests on different proportion of POFA were carried out to obtain the optimum proportion of stabilizer that will reduce the settlement in tropical peat soil. Undisturbed peat sample also been tested in order to compare the improvement made on the peat soil samples after adding POFA.

After all the laboratory tests, all the data were analysed and presented in Chapter 4. Besides, there was an analysis on the consolidation on peat soil. The square root time plot of Taylor applied here.

Last but not least, there are some conclusions drawn out. In this section, the factors of affecting laboratory tests will be discussed. The results obtained from the curve of consolidation were led to some final conclusions based on the objectives made earlier. More details are displayed in Chapter 5.

3.2   Sampling Location

Peat sampling was carried out and collected from a site in Pekan, Pahang, Malaysia (Figure 3.2). The sampling location was just beside the Kuantan – Pekan highway, and near to the Taman Indera Sempurna (3.742153, 103.267816). The samples were excavated to a depth of 0.3m. The soil was excavated and collected randomly as disturbed peat samples to form reconstituted samples. The disturbed samples were placed and kept in plastic containers immediately with lid to preserve the natural moisture content.
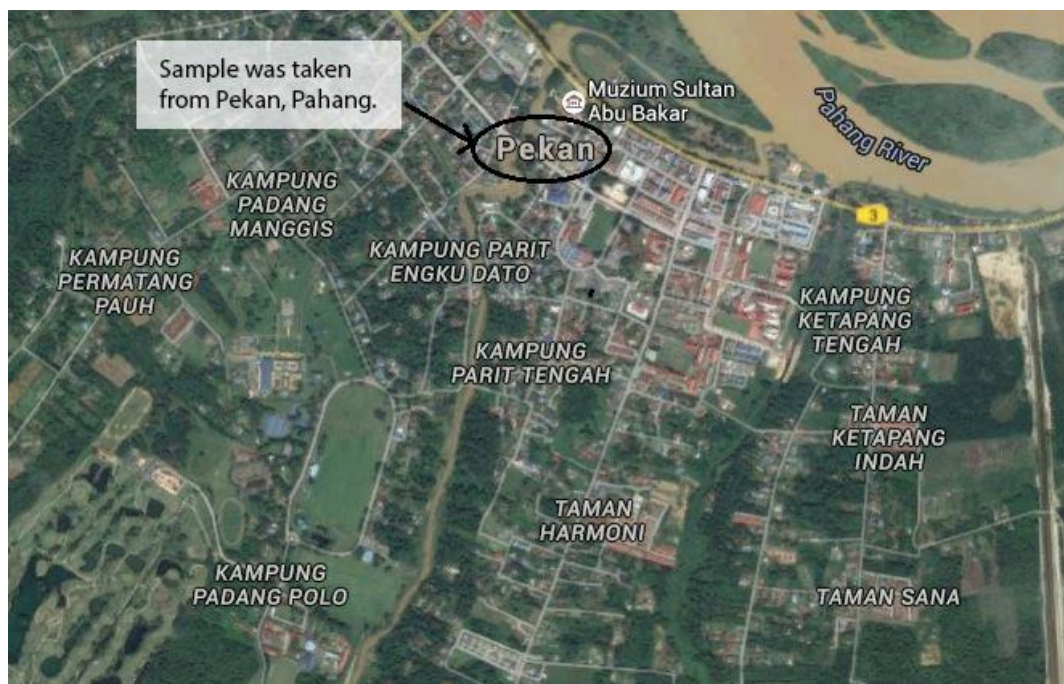
Figure 3.2: Map of Pekan, Pahang, Malaysia.

(Source: googlemaps.com)

3.3   Peat Soil Characterization Method

After the sampling process, the peat samples were subjected to soil characterization test. Test included moisture content, fibre content, organic content, Atterberg limits and specific gravity. These parameters were assessed and measured throughout the laboratory tests.

3.3.1   Moisture Content

Oven-drying method was used to determine the moisture contents of the samples. A small representative specimen obtained from large bulk samples were weighed, followed by oven drying at 105°C for 24 hours. The sample was then reweighed, and the difference in weight was assumed as the total weight of water driven off during the oven drying process. The weight difference was divided by the weight of dry soil, hence giving the moisture content on a dry weight basis. Please refer to equation 2.1.

3.3.2   Organic Content

The organic content of soil was determined by first oven drying a representative sample of each soil at 105°C for 24 hours. Then, the sample was transferred to a muffle furnace and heated to 440°C, reweighed the sample until a nearly constant mass was achieved. The ash content of the sample was recorded as the weight loss due to ignition divided by the initial weight of dry soil. The organic content (%) was then calculated as 100 minus the ash content. Equation 2.2 and 2.3 is referred.

3.3.3 Atterberg Limits

Soil sample was subjected to Atterberg limits testing to determine the liquid limit of peat. The soil was first dried for 24 hours, where moisture content reduced between 150% and 200% prior to the test. A cone penetrometer was used to determine the liquid limit of the soil sample using dry soil passing through a 475 µm (No. 40) sieve. Please refer to Chapter 2.3.3.

3.3.4 Specific Gravity

In this research, kerosene is used in specific gravity test instead of water as the soil solids will float in water. Values for specific gravity of the soil solids were determined by placing a known weight of oven-dried soil in a small pycnometer, then fill it with kerosene. During the de-airing process, the slurry was agitated often to make sure that small air bubbles could move up easily and the soil would not stick to the glass. The weight of displaced kerosene was then calculated by comparing the weight of the soil and kerosene in the pycnometer with the weight of pycnometer containing only kerosene. Next, calculate the specific gravity by dividing the weight of the dry soil by the weight of displaced kerosene. Equations 3.1 and 3.2 are used to determine the specific gravity of soil sample.

$$\text{Specific gravity, } G_S = \frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)} \tag{3.1}$$

$$\text{Specific gravity relative to water, } G_S = \frac{Density\ of\ Kerosene}{Density\ of\ Water} \ x\ Specific\ Gravity \tag{3.2}$$

where,

$W_1 = $ weight of bottle + stopper

$W_2 = $ weight of bottle + stopper + dry soil

$W_3 = $ weight of bottle + stopper + soil + water

$W_4 = $ weight of bottle + stopper + kerosene

Density of kerosene $= 810 \text{ kg/m}^3$

Density of water $= 1000 \text{ kg/m}^3$

3.3.5   Fibre Content

This test is used to measure the amount of plant materials that are larger than 0.15mm and smaller than 20mm. A known mass of undried sample was soaked in a dispersing agent (5% sodium hexametaphosphate) for 15 hours. The mixture was stirred and sieved with 150μm (No. 100) sieve. The soil sample was then rinsed with 2% of hydrochloric acid (HCl) in order to dissolve the carbonates that present on the soil surface. The soil sample was filtered using the filter funnel and filter paper and the mass is measured before it is oven-dried. The fibrous material left on the filter paper was oven-dried at 105 °C until reached a nearly constant mass. The mass of fiber is expressed as a percentage of the oven-dried of the original sample. Equation 3.3 is referred.

$$Fibre\ content, \% = \frac{M_f}{M_s} x100 \tag{3.3}$$

where,

$M_f = $ dry mass of specimen after washing

$M_s = $ initial dry mass of specimen, mg $= [M/ (w +100)] \times 100$

$M = $ initial total mass of specimen, mg

$W = $ water content as determined

3.3.6   Classification of Peat

The peat was classified based on the degree of humification known as Von Post scale and the organic and the fibre content in the soil sample (Appendix A). Sample of peat was tested by squeezing in hand (Figure 3.3). The colour and form of fluid that is extruded between the fingers is observed together with the pressed residue remaining in the hand after squeezing with reference to the ten points scale.

Figure 3.3: Peat condition when squeezed in hand

3.4   Methods for Preparing Samples

3.4.1   Reconstituted Sample

Prior to preparation of treated samples, peat samples were openly air dried under room temperature and any soil in larger form was broken down manually by hand. No sieving for soil sample in order to simulate the field condition of site. Larger plant remains also taken out manually to ease the moulding process.

On the other hand, raw POFA cannot be used due to its uncombusted palm fibres, unknown moisture content, large particle size and residual carbon. Thus, pre-treatment of POFA was undertaken before its use as soil stabilizer. The POFA were oven dried for 24 hours before cold down to room temperature and kept in sealed plastic bag. Then, the dried POFA were sieved through a 300μm in order to remove any foreign material and bigger size ash particles. Ashes which passed through 63μm sieve was collected (Figure 3.4). This process effectively increased specific surface and improved pozzolanic reaction between the peat soil and POFA. The higher the specific surface is, the faster the binder reacts.

This explanation is similar to that reported by Janz and Johansson (Janz and Johansson, 2002), in which the reactivity of a stabilizer is highly related by its fineness, which is generally expressed as the specific surface. Next, the treated samples were prepared by dry mixing between peat sample and different percentages of POFA ranged between 5% and 20% of wet weight of base soil (Figure 3.5). The soil sample is then placed inside a metal ring with a porous stone at the top of the sample and another at the bottom.

Figure 3.4: Palm oil fuel ash (POFA)

Figure 3.5: Dry mixing of peat sample and POFA

3.4.2   Dosage Rates

Dosage rates can be specified in many different ways, in this research, the dosage is based on the wet weight of the soil to be treated. Researcher's recommendations for POFA used in this research are given as a percentage of the wet weight of the untreated peat soil. Accordingly, the amount of POFA to be used was found from the equation 3.4.

$$\text{Amount of POFA to add (g)} = PS \times W_{TOT} \qquad (3.4)$$

where,

PS = Percent by wet weight of POFA to be used

W_{TOT} = Wet weight of batch prior to addition of POFA

For the POFA used, researcher's recommendations and historical data indicates that typical dosage rates commonly used for peat soil is 20 percent by wet weight of peat soil. Four proportions of mixtures studied were from 5:95 (POFA: peat), 10:90, 15:85 and 20:80.

3.4.3   Curing Time

All samples were cured at room temperature (approximately 27°C), as this research did not investigate the effect of variations of curing temperature. Moreover, the samples together with consolidation cell were submerged in water bath to provide a 100% relative humidity curing environment (Figure 3.6). In this research, only 7 and 28 days of curing period were used.

Figure 3.6: Specimen undergoes water curing process

3.5   Methods for Testing Samples

Standard oedometer consolidation test in accordance to BS1377 Part 5:1990 was performed on both of unstabilized peat and stabilized peat cured after 7 and 28 days in order to evaluate the effect of POFA in reducing the compressibility of the Pekan peat. The testing was conducted in the Geotechnical Laboratory, University Malaysia Pahang. This experiment is mainly based on oedometer consolidation cell and DS7 software. The diameter and height of each soil specimen were 50mm and 20mm respectively.

Incremental loading was selected to simulate the effect of loading over time on the peat soil sample in real field condition. Loading of each soil specimen was done with a load increment ratio of 1. Stages of loading included the loading and unloading stage. The loadings for loading stage were 0.25 kg, 0.50 kg, 1.00 kg, and 2.00 kg, whereas for unloading stage, the loadings used were 0.50 kg and 0.125 kg. Load on the sample was applied through the lever arm and compression was measured by an electronic transducer. Each load was maintained for 24 hours and the data was recorded automatically by DS7

software into the computer. The oedometer consolidation cell was filled with water during the test. At the end of the test, the dry weight of the peat sample was determined. Figure 3.7 shows the exact picture of a typical oedometer.

Figure 3.7: A typical oedometer setup

Oedometer test has been used to run the one-dimensional consolidation test of peat soil. According to BS1377 Part 5:1990, the oedometer shall be in the fixed ring type. There are several components in an oedometer (Figure 3.8), which are:

    i.   A consolidation ring made of corrosion-resistant metal., which should completely and rigidly confine the peat soil specimen laterally.

    ii.   Corrosion-resistant porous plates, which are placed on the top and bottom of the peat soil specimen.

    iii.   A consolidation cell of suitable corrosion-resistant material within which to place the consolidation ring containing the soil sample.

    iv.   An electronic transducer, which is readable to 0.001 units and has a travel of 15cm.

    v.   A loading device which have a rigid bed to support the consolidation cell.

Figure 3.8: Typical oedometer consolidation cell

The following is a brief discussion and explanation of the procedure used for setting up and configuring DS7 software with the hardware before testing is done.

3.5.1 Initializing DS7 Software and Hardware

At this point, it is important that all the hardware was configured in the station configuration and setting of the communication devices was set up correctly before running a test. Upon clicking the DS7 browser on the desktop or in the program library of the computer, the following window will now be visible (Figure 3.9). Now click the New Test button and select a machine for the test (Figure 3.10).
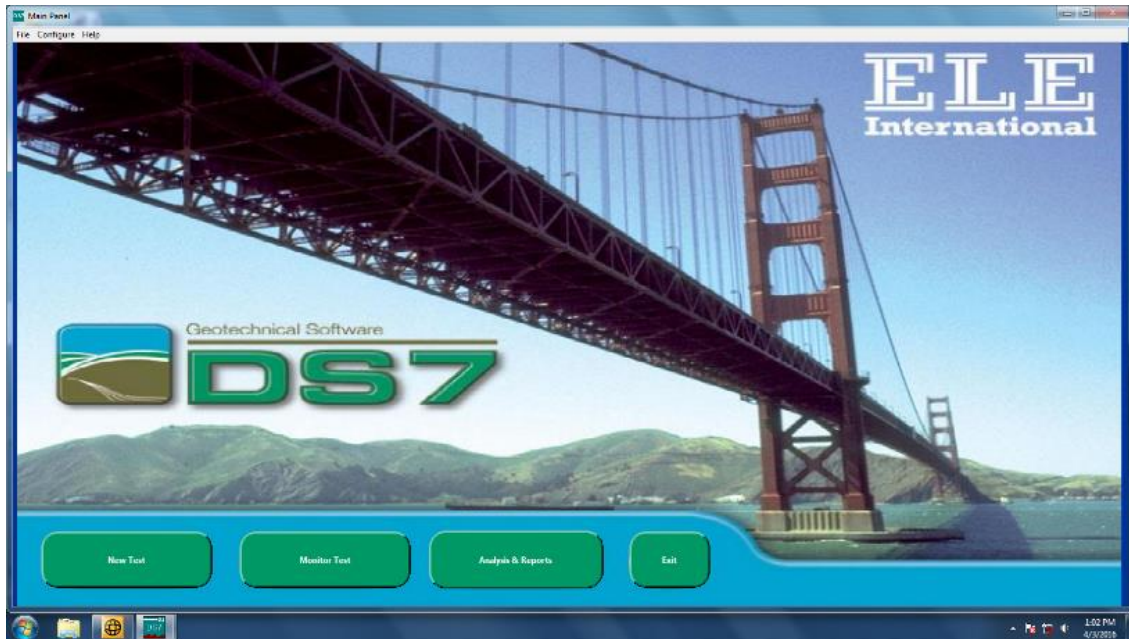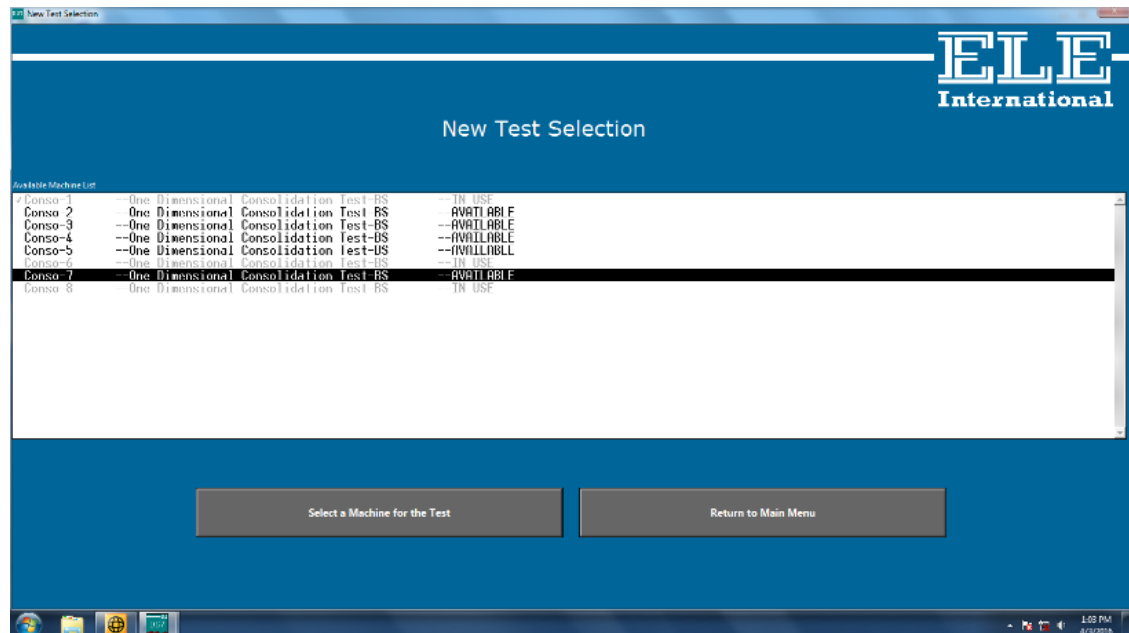
Figure 3.9: DS7 window view

Figure 3.10: New test selection

3.5.2 Entering Specimen Details

All the fields marked with (*) were filled up and clicked OK (Figure 3.11). Once the specimen details have been entered, the selected consolidation machine was configured and ready to start a test. Next, the machine was selected and clicked OK (Figure 3.12) to configure the first test stage.
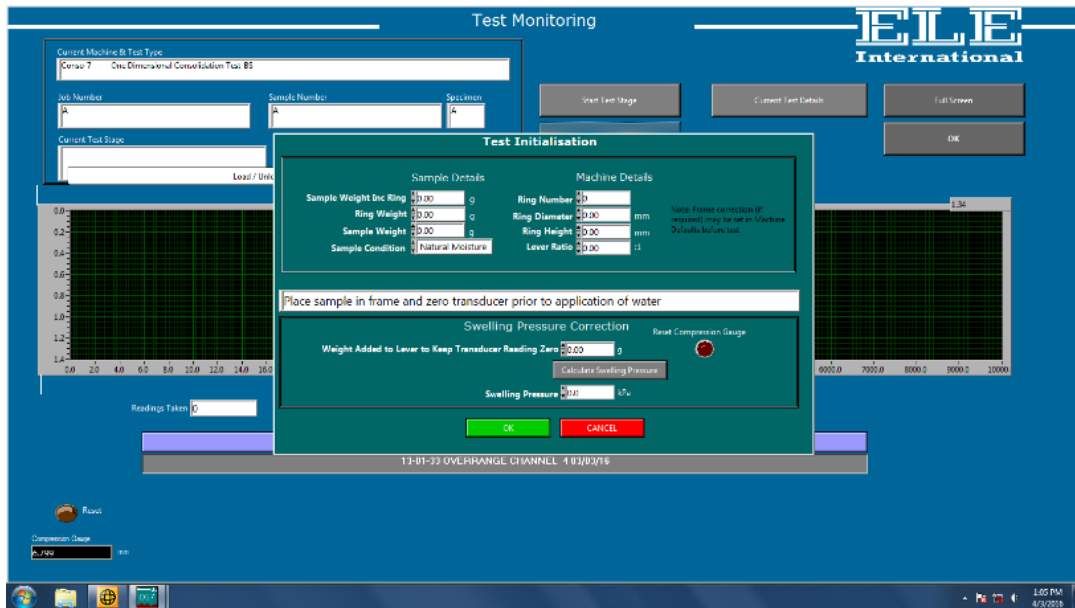

Figure 3.11: Entering specimen details
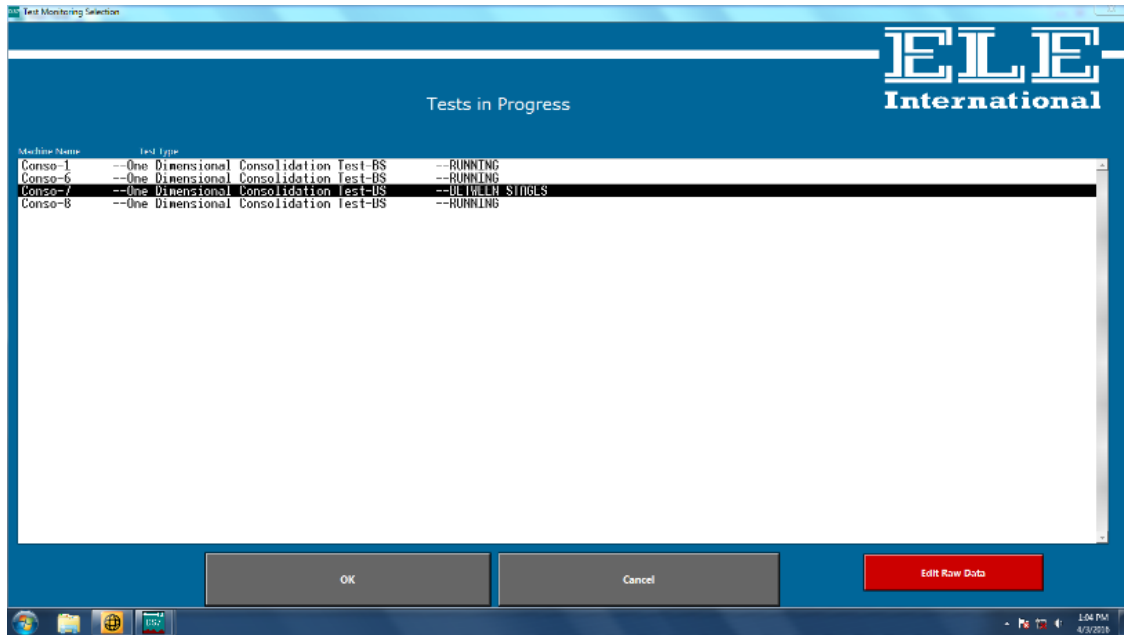
Figure 3.12: Selection of machine

3.5.3   Test Initialization

Clicking Start Test Stage button and select Test Initialization, then click OK. Next, enter the following specimen details: ring number, ring diameter, ring height and lever ratio (Figure 3.13). The lever ratio used was 10:1 as the load hanger was located at the middle of hangar pivots. Then, rest the compression gauge and click OK.

**Figure 3.13:** Entering specimen details

3.5.4   Loading Stage

Clicking Start Test Stage button and select Test Initialization, then click OK (Figure 3.14).
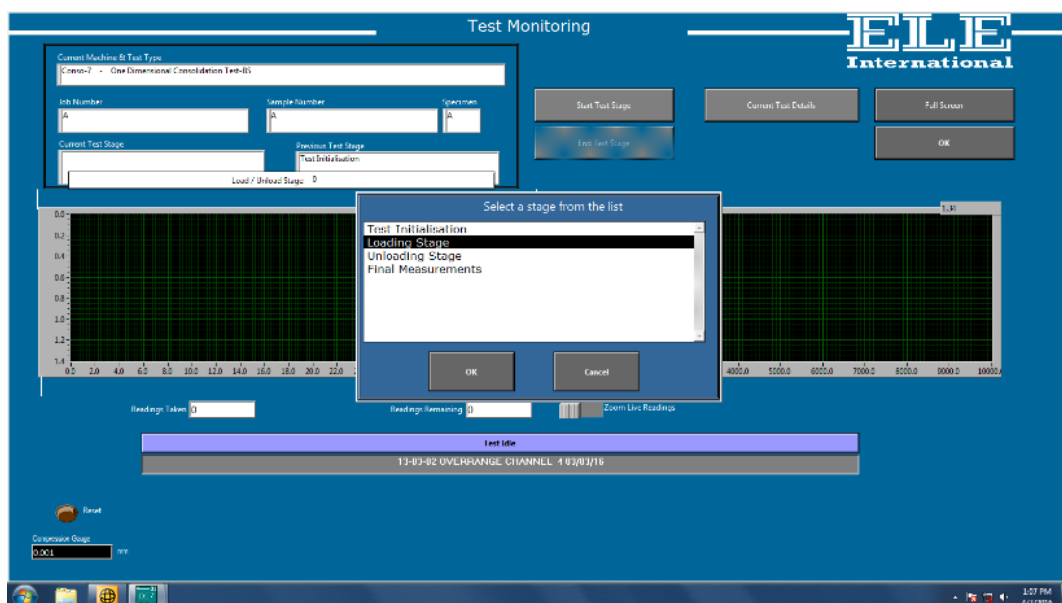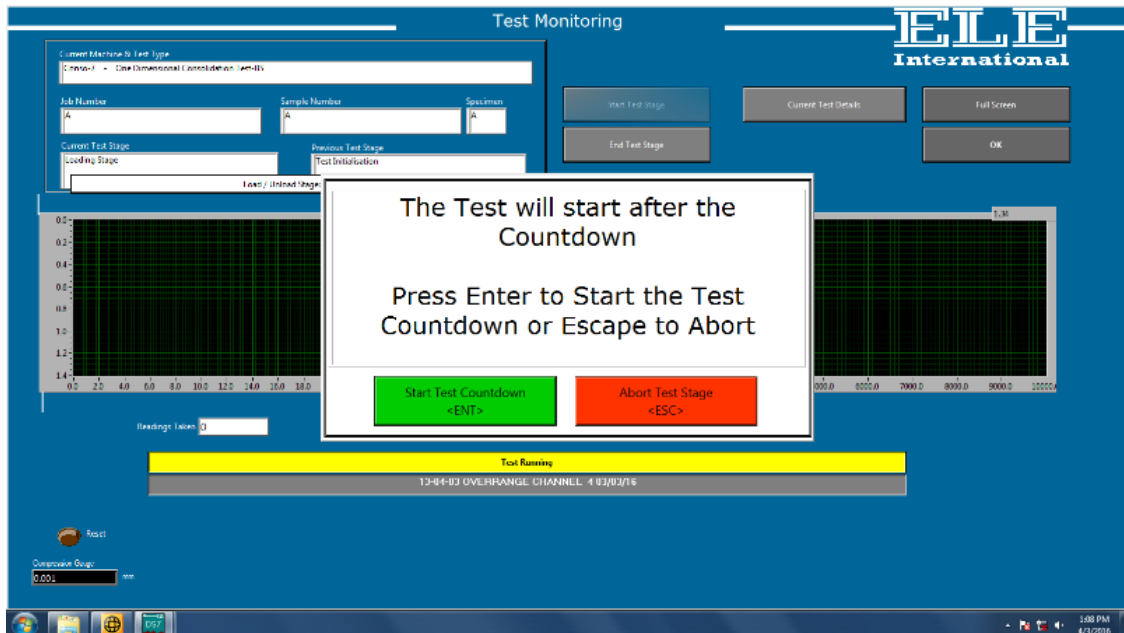

Figure 3.14: Loading stage

Next, enter required weight and stress (Figure 3.15). The slotted weight was placed on the load hanger and the lever arm was supported with jack. Then, click Continue and followed by Start Test Countdown (Figure 3.16). After beep for 5 seconds, quickly turned down the jack until it does not in touch with lever arm.
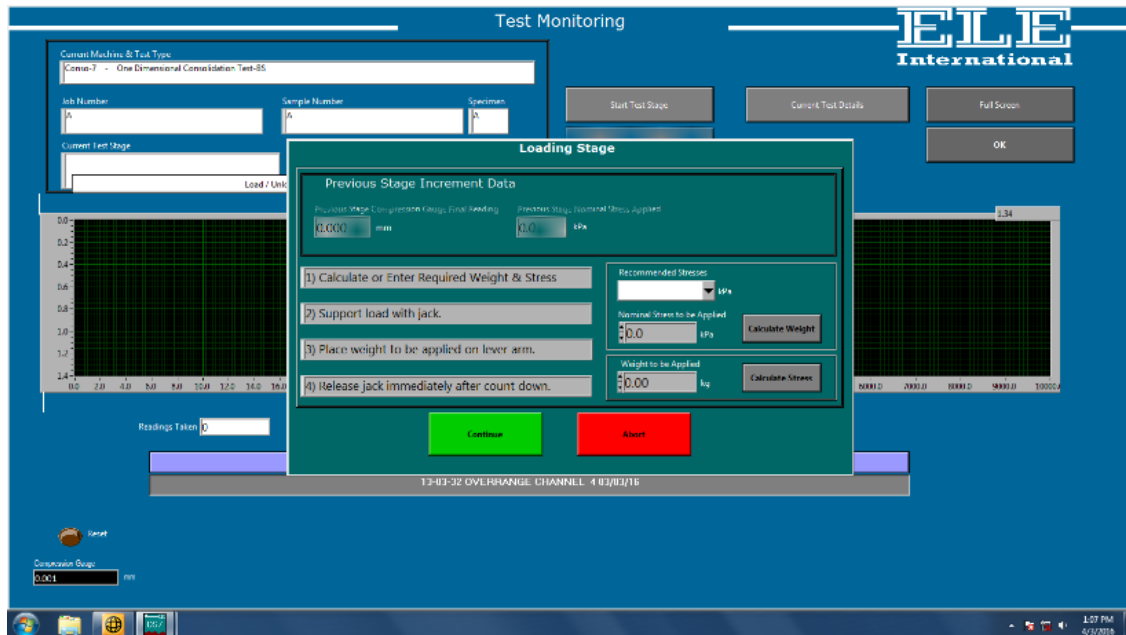
Figure 3.15: Entering loading details

Figure 3.16: Start test countdown

3.5.5 Adding Next Loading Stage

Clicking the End Test Stage icon to end the current loading stage, then the jack is raise to be in touch with the lever arm in order to prevent the sample form further settlement. Adding next slotted weight for new loading stage. Ensure that the load hanger do not swing when adding the slotted weight. Then, click the Start Test Stage (Figure 3.16) icon and choose Loading Stage. Next, key in the weight to be applied and click continue. Then click Start Test Countdown and after beep for 5 seconds, quickly turn down the jack until it does not in touch with lever arm. Repeat all the steps in Loading Stage mentioned above, until all loading stages completed.

3.5.6　Unloading Stage

Clicking the End Test Stage icon to end the current stage, then raise the jack to be in touch with the lever arm. Click the Start Test Stage icon and choose Unloading Stage. Next, key in the weight to be applied (Figure 3.15) and click continue. Before taking out the slotted weight, hold lever arm to prevent it from overhanging freely. Then click Start Test (Figure 3.16) and after beep for 5 seconds, quickly release the lever arm. The same steps were repeated until all unloading stages completed.

3.5.7　Sample Identification System

Due to the large number of specimens, the testing procedures were separated into phases and sample identification system was developed to assign each specimen with identifying labels. Table 3.2 illustrates the sample identification system used, percentage of POFA, and curing periods.

Table 3.2: Sample name with respecting POFA percentage

SAMPLE NO.	POFA, %	CURING DAYS
A1	5	7
A2	10	7
A3	15	7
A4	20	7
B1	5	28
B2	10	28
B3	15	28
B4	20	28

3.6   Method of Analysing Data

Clicking the End Test Stage icon and end the test. Then, click the Start Test Stage button, choose Final Measurement and click OK. After that, the oedometer consolidation cell was disassembled and the wet sample together with ring were weighed. The sample was dried in oven for 24 hours. Next, enter the final specimen weight (wet) and specimen weight (dry), then click Confirm Data and Save in a folder. To generate the square root time plot of Taylor, click Analyse & Report button, and browse the specific file in the saved folder, then click Analyse Test (Figure 3.17). Re-enter the data required if there were changes, then Confirm Data and choose Root Time Method (Figure 3.18). At this phase, bring the red line to be in touch with the curve of the graph, and then plot the T90 point at the intersection of the graph and the white line (Figure 3.19). Lastly, click the Write Test Report button and Save, all the test data and graph will be automatically generated in Microsoft Word as shown in Appendix C.
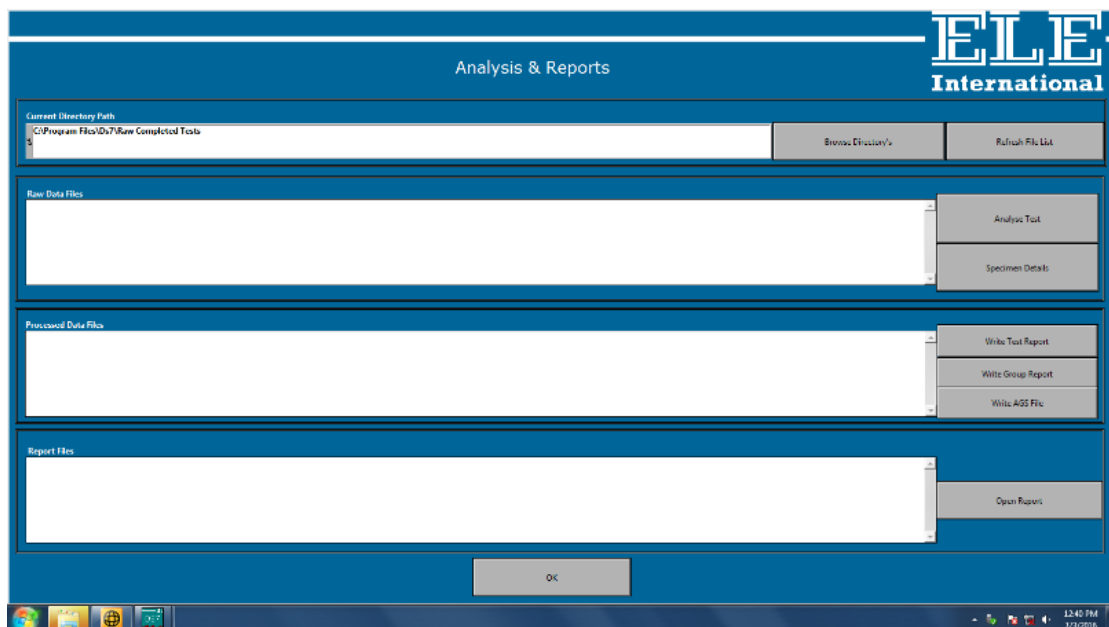
Figure 3.17: Browsing data file for analysing

Figure 3.18: Entering specimen details
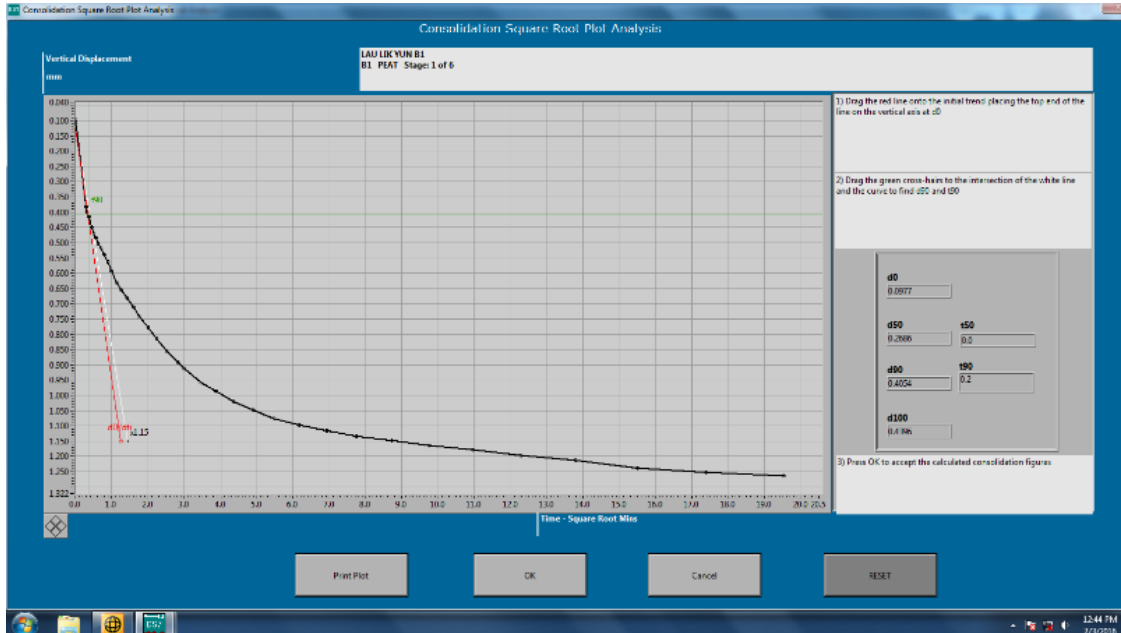
Figure 3.19: Graph plotting

CHAPTER 4

RESULTS AND DISCUSSION

4.1   Results of Laboratory Tests

In order to gain the parameters of the engineering characteristics of soil sample from Pekan, several classification tests and fundamental tests were carried out. The results of the tests are tabulated in Table 4.1.

Table 4.1: Basic properties of soil sample

Parameters	Results
Moisture content (%)	362.12
Organic content (%)	33.24
Liquid limit (%)	69.80
Plastic Limit (%)	56.72
Specific gravity	1.91
Fibre content (%)	30.54
Von Post Scale	H3

4.1.1   Moisture Content

According to the result obtained from moisture content test by oven-drying method, the natural moisture content was 362.12 %. This result is within the range of natural moisture content done by previous researchers for both east coast and west coast of Peninsular Malaysia. The natural moisture content for west Malaysia peat is within the range of 200 – 700 %, while for east Malaysia peat the range is within 200 – 2207 % as shown in Table 2.4 (Huat, 2004). According to Duraisamy et al. (2007), the moisture content of peat from west coast of Peninsular Malaysia ranged from 140 – 350 %. Hence, the result from this research fulfilled the above statement for east coast peat and also show similarity to peat from west Malaysia.

4.1.2   Organic Content

The organic content obtained from this research is 33.24 %. As mentioned in Chapter 2, soil with organic content greater than 20 % are generally termed organic soil. According to ASTM D4427, peat is an organic soil with organic content of more than 75 %. Hence, in this context, the soil sample of this research can only be categorised as organic soil. According to Huat (2004), the range for organic content of east Malaysia peat is 76 – 98 %. While Duraisamy et al. stated that organic content of west Malaysia peat ranged within 70 – 88 %. The less amount of organic content may due to the shallow depth of soil sampling of this research, which is only about 0.3m where most of them were young virgin peat with low decomposition rate.

4.1.3   Liquid Limit and Plastic Limit

In order to recognize a peat soil, liquid limit is needed. The liquid limit of the soil sample is 69.80 % as shown in Figure 4.1. The result is far below the range of 240 – 398 % conducted by Duraisamy et al. (2007). According to Huat (2004), the liquid limit for west

Malaysia peat is 190 – 360 %, which is also a lot higher compared to the result of this research. The huge difference in the result may due to the vaporization of moisture content during the sampling process, hence the liquid limit dropped. Different part of the country may also contribute to the gap of the liquid limit of peat. The plastic limit of this research is 56.72 %, which is also far lower than the one conducted by Huat (2004).
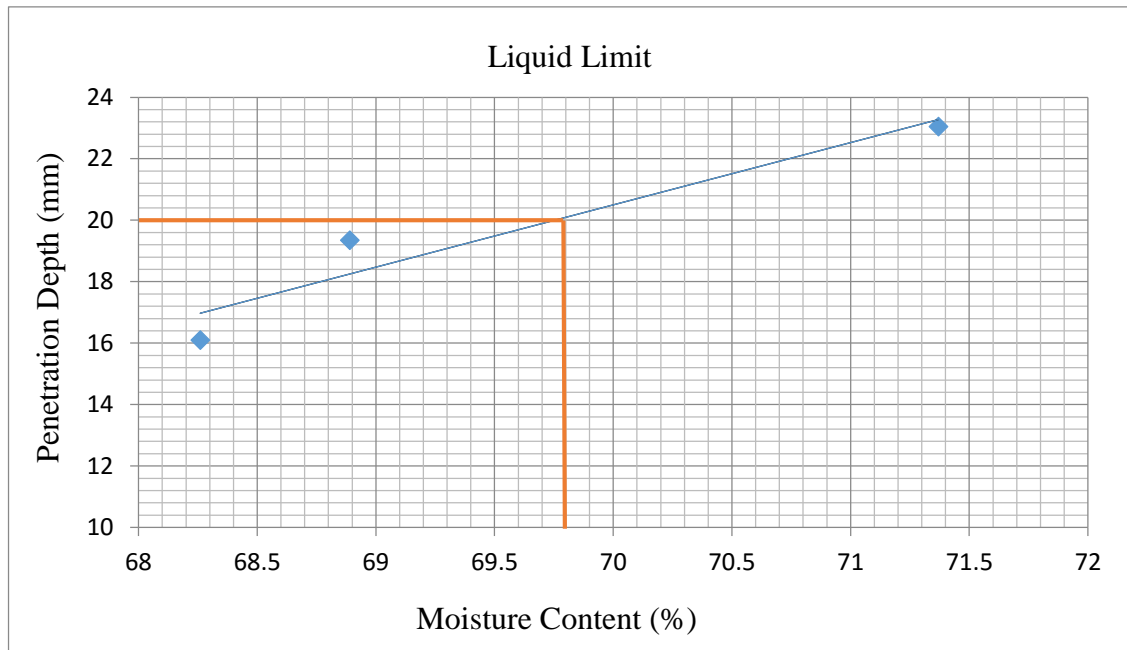
Figure 4.1: Plot of liquid limit

4.1.4 Specific Gravity

The value of specific gravity of soil solid, G_s obtained from pycnometer test is 1.91, which was low as compared to mineral soil. This result is higher than the range of 1.42 – 1.56 as proposed by Duraisamy et al. (2007) for west Malaysia peat. Same case happens when compared to previous result done by Huat (2004), which is within the range of 1.38 – 1.70 for west Malaysia peat. The difference of specific gravity between east Malaysia peat and west Malaysia peat may affected by the organic constituents.

4.1.5   Fibre Content

The fibre content gained from this research is 30.54 %, which according to ASTM 1997, the soil sample can be classified as Sapric peat. This result is slightly less than the result done by Duraisamy et al, (2007), where the fibre content for west coast peat was ranged from 31 % to 77 %. This shows that east coast peat and west coast peat has similarity in term of fibre content. However, there is a contradiction between the result from Von Post classification method and ASTM 1997, as H3 peat is very slightly decomposed, while Sapric peat is classified as most decomposed peat. Hence, further test should be conducted to get more accurate result.

4.1.6   Classification of Peat

In this research, peat was classified based on the Von Post scale. This Von Post classification system was conducted by taking a handful of peat and squeezes it in the palm of the hand. Meanwhile, the liquid or other material extruded between the fingers and the residue remaining in the hand should be examined. By comparing the description from Von Post scale (Appendix A), the degree of humification gained is H3, from the range of H1 – H10. It means, the soil sample is very slightly decomposed, when squeezed, releases muddy brown water. At the same time, no peat was passed between the fingers, and the plant remains were still identifiable and no amorphous material present. The colour of soil sample was dark brown. The degree of humification might due to the shallow depth of extraction of soil sample, which is only 0.3m and can be considered as surface peat. Hence, the soil sample was less decomposed and plant remains can be clearly identified.

4.1.7 Chemical composition of POFA

POFA obtained from Kilang Sawit LCSB Lepar in Pahang was used in this research. The specific gravity of POFA is 2.0. The chemical composition of POFA was tested at Central Laboratory, Universiti Malaysia Pahang and the results is given in Table 4.2. From the table, it shows that high percentage of Silica or Silicon Dioxide (SiO_2) in the POFA used in this research is very similar to those in literature review. This proved that the POFA used in this research is of suitable type. Large amount of amorphous silica in POFA can contributes to the pozzolanic reaction during hydration, which results in cementitious compounds called calcium aluminate hydrates (CAH) and calcium silicate hydrates (CSH). These compounds are responsible for improving the engineering characteristics of soils that increase over time as the pozzolanic reaction develops (Seco et al., 2012).

Table 4.2: Comparison of chemical composition of different POFA

| Oxide	CAPOFA (%)	ALPOFA (%)	KTPOFA (%)	This Research (%)
SiO_2	58.30	59.60	52.50	42.21
Al_2O_3	6.69	7.05	8.83	3.74
Fe_2O_3	9.77	8.77	5.73	4.88
CaO	6.72	8.06	11.30	9.60
MgO	3.69	3.09	3.55	3.67
SO_3	0.96	0.57	0.82	1.69
K_2O	8.40	7.64	10.20	7.59

Source: Bamaga et al. (2013)

4.2   Compressibility Parameters

4.2.1   Compression index (C_c)

Compression index (C_c) is defined by the slope of the final part of the void ratio versus logarithmic of consolidation pressure (*log σ*) curve. According to Li and Lee (2006), compressibility parameters of soil are to some extent stress dependent. Since developing peat ground often involves massive changes in the state of stress, as well as pressure and saturation changes, it is important to understand the stress dependent behaviour of compressibility parameters and incorporate it in the peat stabilization plan. All the compression index, C_c calculated from standard oedometer consolidation test were clearly plotted in graph. Based on Figure 4.2, C_c for the unstabilized peat was 0.805. For sample A1, A2, A3 and A4, the C_c values were 0.804, 0.725, 0.615 and 0.645 respectively. While for sample B1, B2, B3 and B4, the C_c values were 0.844, 0.689, 0.578, and 0.458 respectively. From the results, it proved that by increasing the percentage of POFA, the compression index will gradually decrease. Based on Figure 4.2, it shows that 28 days of curing period performed better in term of reducing compression index of soil sample, but the decrement was less significant. By comparison, the soil sample can be categorized as soft soil according to Hussein (1997), as C_c of the unstabilized sample is 0.805, and is fit into the range of 0.1 – 1.13 for east coast peat.
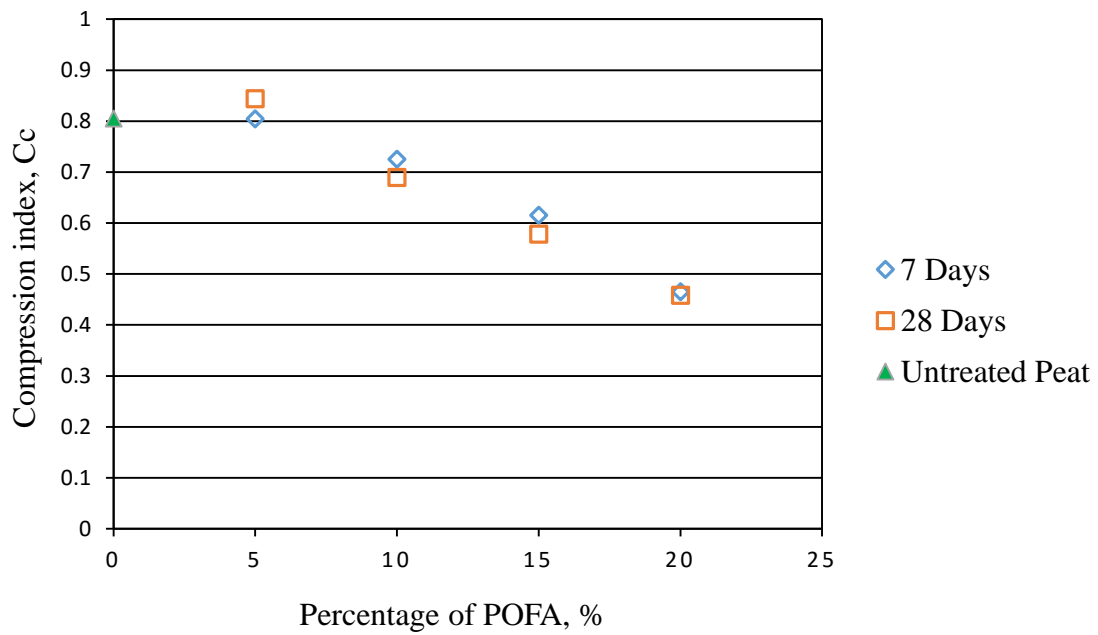
Figure 4.2: Compression index versus percentage of POFA

4..2.2   Coefficient of consolidation (C_v)

From Figure 4.5, there was a significant drop in the C_v when with 5 % of POFA was added into the soil sample at the same consolidation load applied. The results implied that the coefficient of consolidation was significantly reduced with addition of POFA. According to Farrell et al. (1994), this decrease is more marked in the samples, which had higher organic contents. For curing period of 7 days, the coefficient of consolidation was decreased around 35%, by increasing the POFA percentage from 10% to 20%. Based on Figure 4.4 and Figure 4.5, the value of C_v for 10 % POFA reduced slightly from 4.8 to 4.4 when the curing period is 28 days. Meaning the effect of curing period was less significant in reducing the coefficient of consolidation. For fibrous peat, the results indicate that the coefficient of consolidation decreased by increasing POFA ratio.
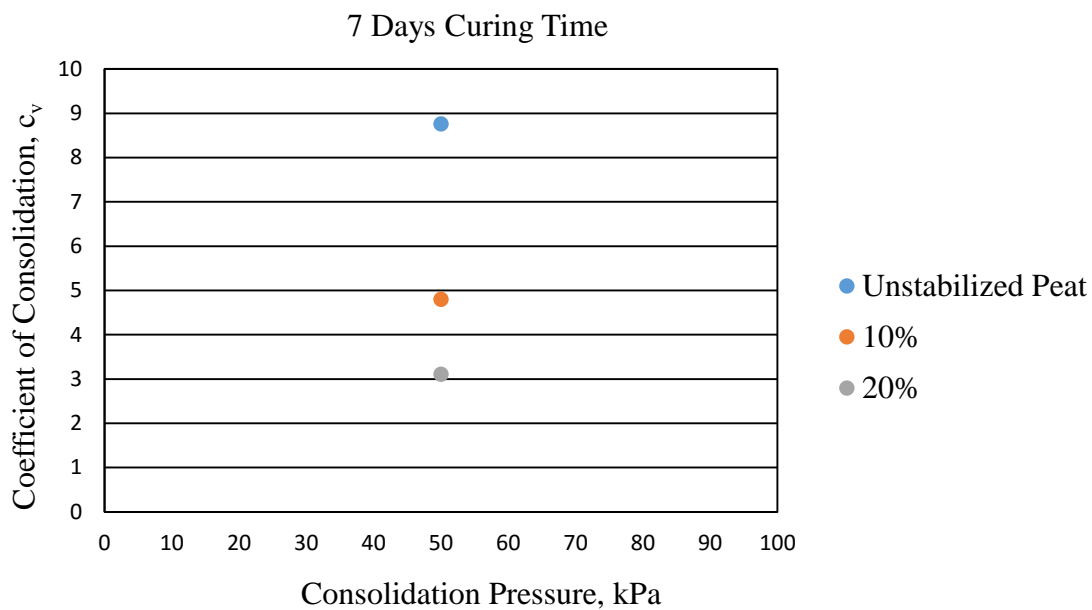
Figure 4.3: Coefficient of consolidation versus consolidation pressure at 7 days
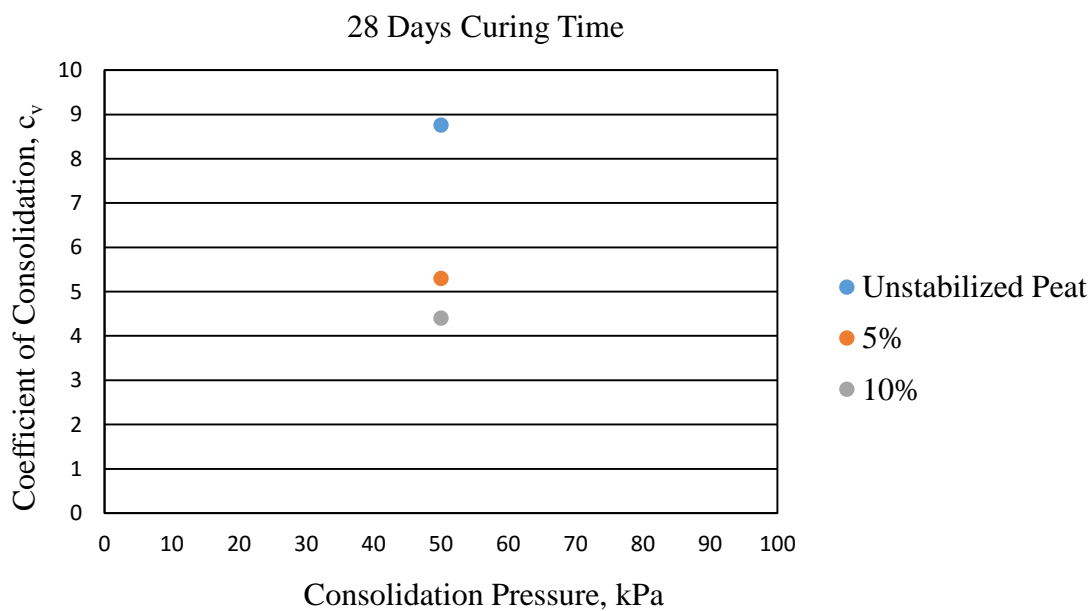
Figure 4.4: Coefficient of consolidation versus consolidation pressure at 28 days

4.2.3   Coefficient of Volume Compressibility (m_v)

From Figure 4.5, it is observed that that m_v gradually decreases upon increase in POFA percentage. It was observed that m_v declined from 1.23 m^2/MN for unstabilized peat soil to 1.02 m^2/MN for peat soil added with 20 % POFA at σ of 100 kPa for 7 days curing period. Whereas for 28 days curing period, m_v declined from 1.23 m^2/MN for unstabilized peat soil to 0.99 m^2/MN for peat soil added with 20 % POFA at σ of 100 kPa. The low decrement in coefficient of volume compressibility for 28 days under same consolidation pressure shows that the curing period is less significant in compressibility of organic soil.
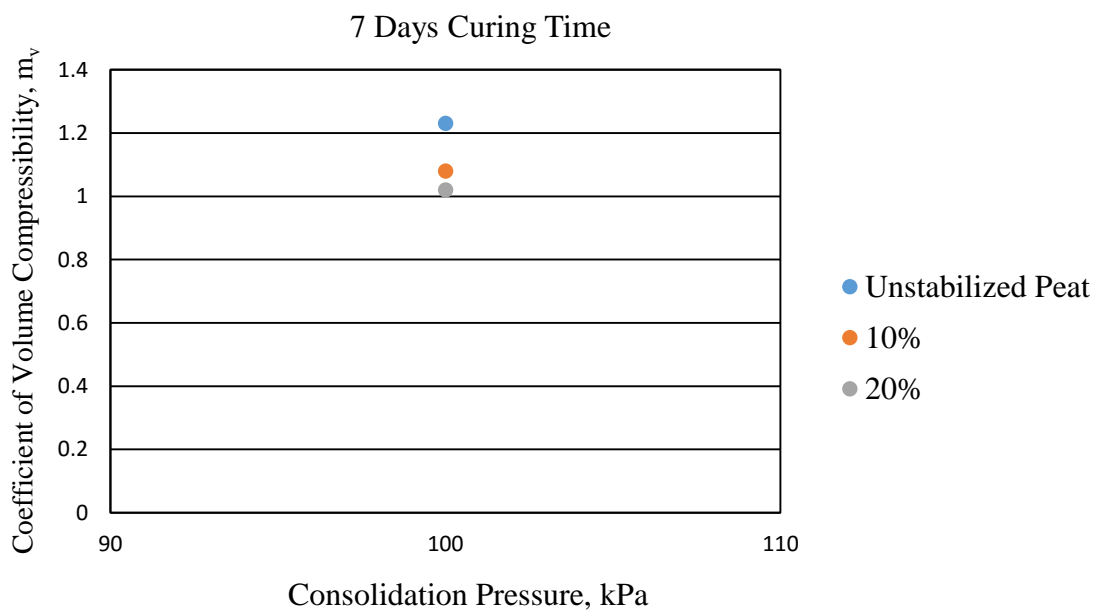
Figure 4.5: Coefficient of volume compressibility versus consolidation pressure at 7 days
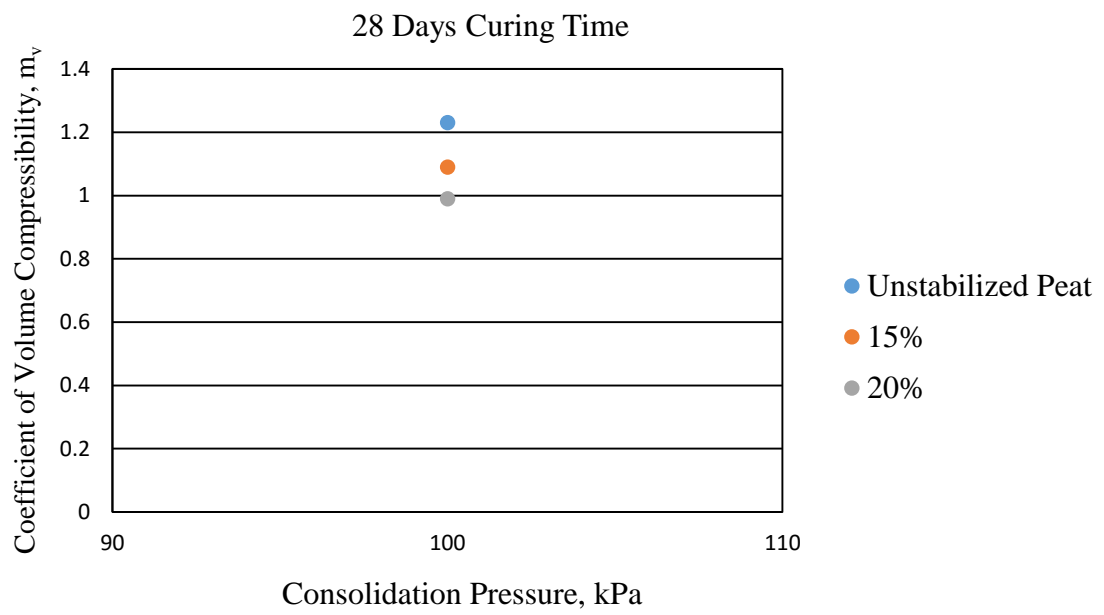
Figure 4.6: Coefficient of volume compressibility versus consolidation pressure at 28 days

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

In view of the importance of achieving the status of green environmental policy and cleaner technology approach, the innovation of using POFA in peat soil stabilization was investigated. The positive findings of this research work proved the feasibility of ultrafine POFA in Pekan peat stabilization. These findings can help attacking two aspects: First, under adequate technical and environmental conditions, massive amounts of this residue would be partially reduced, converted to useful, value-added adsorbents, and second, can result in more economic projects. Although the use of POFA in ground improvement applications is still in its infancy stage, the widespread and significant progress in the application of this environment-friendly stabilizer in organic soil stabilization can be expected in the future. The laboratory results obtained from this research lead to the following conclusions:

1. Based on the results obtained, the soil sample used in this research is classified as organic soil or young virgin peat, as the organic content is more than 20 % but less than 75 %.

2. The C_c values from standard oedometer consolidation test for the unstabilized soil and sample A1, A2, A3, A4 were 0.805, 0.804, 0.725, 0.615 and 0.645 respectively. While for sample B1, B2, B3 and B4, the C_c values were 0.844, 0.689, 0.578, and 0.458 respectively. It implies that by increasing the POFA ratio, the C_c value is decreasing gradually up to 43%.

3. Given the same consolidation pressure applied, the C_v and m_v of the unstabilized organic soil gradually decreases upon increase in POFA percentage.

4. Compression index, coefficient of consolidation, and coefficient of volume compressibility decreases considerably after stabilisation. This result indicates that compressibility of peat soil can be improved by stabilisation with mass stabilization method by using POFA as stabilizer.

5. Based on the results, the effect of curing period in the compressibility of organic soil stabilized using POFA is less significant, as 28 days of curing period only shows a minor decrease in compressibility parameters than 7 days.

5.2   Recommendations

Nowadays, although more advanced consolidation tests are now available, oedometer consolidation test is still recognized as the standard test for determining the consolidation characteristics of soil. Conventional oedometer test using normal size of specimen may not be suitable for peats, unless there are modified procedures used. Oedometer cell can accommodate 50 mm diameter and 20 mm thick samples. Due to the relatively small specimen thickness, testing time is not excessively long and the test can be extended to a long-term test if secondary characteristics are required. The rate of settlement is always underestimated, where the total settlement is reached in a shorter time than that predicted from the test data. This is largely due to the size of sample which does not represent soil fabric and its profound effect on drainage conditions. Other than the natural condition of the peat sample, sampling disturbance also contribute effect on

the results of the test done on small samples. In addition, the boundary effect from the ring increases the friction of the sample. Friction reduces the stress acted on the soil during loading and reduces swelling during unloading.

For standard oedometer test, the samples were subjected to consolidation pressures with load increment ratio of one. The load is applied through a mechanical lever arm system, hence, transducer reading can be easily affected by sudden shock or external vibration. Excessive disturbance affects the e-log p' plot and tends to obscure the effect of stress history, and gives high coefficient of volume compressibility at low stresses. Excessive disturbance also reduces the effect of secondary compression which is a very important characteristic of fibrous peat. The other limitation of oedometer test is that there is no means of measuring excess pore-water pressures, the dissipation of which control the consolidation process. Therefore, the estimation of compressibility is based solely on the change of height of the specimen.

Instead of oedometer, Rowe consolidation cell is preferable for the consolidation test of peat soil. The advantages of Rowe consolidation cell come from the hydraulic loading system itself, where there are control facilities available, and ability to measure pore water pressure. Besides, Rowe consolidation cell is capable of testing samples of large diameter, as large-diameter specimen will provide more reliable data for settlement analysis. Another main reason of oedometer is not suitable for consolidation of peat soil is because large amount of secondary compression in peat soil following each primary consolidation phase can affect the primary phase of the subsequent loading stage. In addition, oedometer cannot control the degree of saturation and calculate pore pressure of the peat sample, where these factors can affect the results.

In order to increase the accuracy of each laboratory test, every single error should be avoided. For instance, the general error, which is caused by lack of experience while conducting the laboratory tests, wrong way of reading data, wrong way of recording data, and calculation errors. These can be avoided by learning, practices, and take several times of data. Besides, there are systematically errors caused by nonlinearity and improper symbols. These can be avoided by using the correct symbols, and the utilization of proper standards.

In addition, the laboratory tests might also influence by conformance error, which is due to the wrong way of equipment setting up. Thus, a thorough understanding of every equipment is needed before running the relevant tests. Last but not least, the random error, which is caused by friction, surrounding condition and shaking. Hence, one should be very careful to avoid any possible disturbance on the equipment throughout the testing progress.

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APPENDIX A

Table A: Von Post degree of humification

Symbol	Description
H1	Completely undecomposed peat which, when squeezed, releases almost clear water. Plant remains easily identifiable. No amorphous material
H2	Almost entirely undecomposed peat which, when squeezed, releases clear or yellowish water. Plant remains still easily identifiable. No amorphous material present.
H3	Very slightly decomposed peat which, when squeezed, releases muddy brown water, but from which no peat passes between the fingers. Plant remains still identifiable, and no amorphous material present.
H4	Slightly decomposed peat which, when squeezed, releases very muddy dark water. No peat is passed between the fingers but the plant remains are slightly pasty and have lost some of their identifiable features.
H5	Moderately decomposed peat which, when squeezed, releases very "muddy" water with a very small amount of amorphous granular peat escaping between the fingers. The structure of the plant remains is quite indistinct although it is still possible to recognize certain features. The residue is very pasty.
H6	Moderately highly decomposed peat with a very indistinct plant structure. When squeezed, about one-third of the peat escapes between the fingers. The residue is very pasty but shows the plant structure more distinctly than before squeezing.
H7	Highly decomposed peat. Contains a lot of amorphous material with very faintly recognizable plant structure. When squeezed, about one-half of the peat escapes between the fingers. The water, if any is released, is very dark and almost pasty.
H8	Very highly decomposed peat with a large quantity of amorphous material and very indistinct plant structure. When squeezed, about two-thirds of the peat escapes between the fingers. A small quantity of pasty water may be released. The plant material remaining in the hand consists of residues such as roots and fibres that resist decomposition.
H9	Practically fully decomposed peat in which there is hardly any recognizable plant structure. When squeezed it is a fairly uniform paste.
H10	Completely decomposed peat with no discernible plant structure. When squeezed, all the wet peat escapes between the fingers.

Source: Andriesse (1988)

APPENDIX B

BASIC PROPERTIES OF SOIL SAMPLE

Table B1: Moisture Content

Location Pekan	Job ref.			
	Borehole/ Pit no.			
Soil description Peat	Sample no.			A1
	Depth:			0.3 m
Test method BS 1377 : Part 2 : 1990 : 3.2	Date:			25/1/2016
Related test				
Specimen ref.				
Container no.	1	2	3	4
Mass of wet soil + container (m_2)	35.83	50.32	32.68	45.45
Mass of dry soil + container (m_3)	15.37	24.79	16.48	21.85
Mass of container (m_1)	9.72	10.12	9.65	10.13
Mass of moisture ($m_2 - m_3$)	20.46	25.53	16.2	23.6
Mass of dry soil ($m_3 - m_1$)	5.65	10.48	6.83	11.72
Moisture content w $= \frac{m_2 - m_3}{m_3 - m_1} x 100\%$	362.12	280.06	237.19	201.37

Table B2: Organic content

Sample	Mass of crucible (g)	Mass of crucible + dried sample (g)	Mass of crucible + ignition sample (g)	Loss on ignition (%)
1	69.43	80.71	76.96	33.24
2	86.13	100.11	95.64	31.97
3	71.26	87.17	82.25	30.92
4	71.45	83.17	79.41	32.08

Table B3: Liquid Limit

Liquid Limit	Test no.	1		2		3	
Cone Penetration	mm	16.2	16.0	19.0	19.7	22.7	23.4
Average Penetration	mm	16.10		19.35		23.05	
Container no.		A		B		C	
Mass of Wet Soil + Container	g	20.08		24.44		23.95	
Mass of Dry Soil + Container	g	16.08		18.78		18.39	
Mass of Container	g	10.22		10.49		10.60	
Mass of Wet Soil, W_w	g	9.86		13.95		13.35	
Mass of Dry Soil, W_d	g	5.86		8.26		7.79	
Moisture Loss, $W_w - W_d$	g	4		5.69		5.56	
Moisture Content	%	68.26		68.89		71.37	

$$\text{Moisture content} = \frac{W_w - W_d}{W_d} \times 100\%$$

Table B4: Plastic Limit

Plastic Limit	Test No.	1	2	3	4
Container No.		A	B	C	D
Mass of Wet Soil + Container	g	16.37	13.23	18.17	17.6
Mass of Dry Soil + Container	g	14.17	12.03	15.37	15.00
Mass of Container	g	10.35	9.91	10.33	10.45
Mass of Wet Soil	g	6.02	3.32	7.84	7.15
Mass of Dry Soil	g	3.82	2.12	5.04	4.55
Moisture Loss	g	2.20	1.20	2.80	2.60
Moisture Content	%	57.59	56.60	55.56	57.14
Average	%		56.72		

Table B5: Specific Gravity

Location: Geotechnical Laboratory		Job ref.	
		Bore hole/ Pit no.	
Soil Description: Peat		Sample no.	1
		Depth	0.3 m
Test method ASTM D854-92 / BS 1377: Part 2: 1990: 8.3/8.4		Date	25/1/16
Method of preparation: Pycnometer method			
Small/Large pycnometer			
Density bottle No.		X	Y	Z
Weight of density bottle	g	26.80	26.90	27.58
Weight of bottle + Stopper (W_1)	g	31.92	32.17	32.66
Weight of bottle + Stopper +Dry soil (W_2)	g	38.00	38.23	38.74
Weight of bottle +Stopper + Soil +Water (W_3)	g	115.10	115.30	115.53
Weight of bottle + Stopper + Kerosene (W_4)	g	111.60	111.85	111.99
Weight of dry soil ($W_2 - W_1$)	g	6.08	6.06	6.08
Weight of kerosene ($W_4 - W_1$)	g	79.68	79.68	79.33
Weight of soil + Kerosene ($W_3 - W_2$)	g	77.10	77.07	76.79
Specific gravity, G_s		2.36	2.32	2.39
Specific gravity relative to water, G_s		1.91	1.88	1.94
Average specific gravity		1.91		

Specific gravity, $G_s = \dfrac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)}$

Specific gravity relative to water, $G_s = \dfrac{Density\ of\ Kerosene}{Density\ of\ Water} \times Specific\ Gravity$

Density of Kerosene = 810 kg/m^3

Density of Water = 1000 kg/m^3

Table B6: Fibre content

Sample No.	Mass of Plate + Filter + Paper + Dry Specimen (g)	Mass of Filter Paper (g)	Mass of Plate (g)	Dry Mass of Specimen (g)
1	34.93	1.70	25.05	8.21
2	25.48	1.50	13.39	10.59
3	36.21	1.56	23.98	10.67
Total dry mass of specimen (g)			29.47	
Initial mass of specimen (g)			100.00	
Moisture content (%)			362.00	
Initial dry mass of specimen, M_s			96.51	
Fibre content (g)			30.54	

APPENDIX C

STANDARD OEDOMETER RESULT SHEETS

Sheet C1: Oedometer result for sample A0

Test Details			
Standard	BS 1377: Part 5:1990: Clause 3	Particle Density	1.91 Mg/m3
Sample Type	Core sample	Lab Temperature	0.0 deg.C
Sample Depth	0.00 m		
Sample Description			
Variations from Procedure	None		

Specimen Details			
Specimen Reference	A0	Description	
Depth within Sample	0.00mm	Orientation within Sample	
Specimen Mass	56.55 g	Condition	Natural Moisture
Specimen Height	20.00 mm	Preparation	
Comments			

Test Apparatus			
Ring Number	1	Ring Diameter	50.00 mm
Ring Height	20.00 mm	Ring Weight	68.34 g
Lever Ratio	10.00 : 1		

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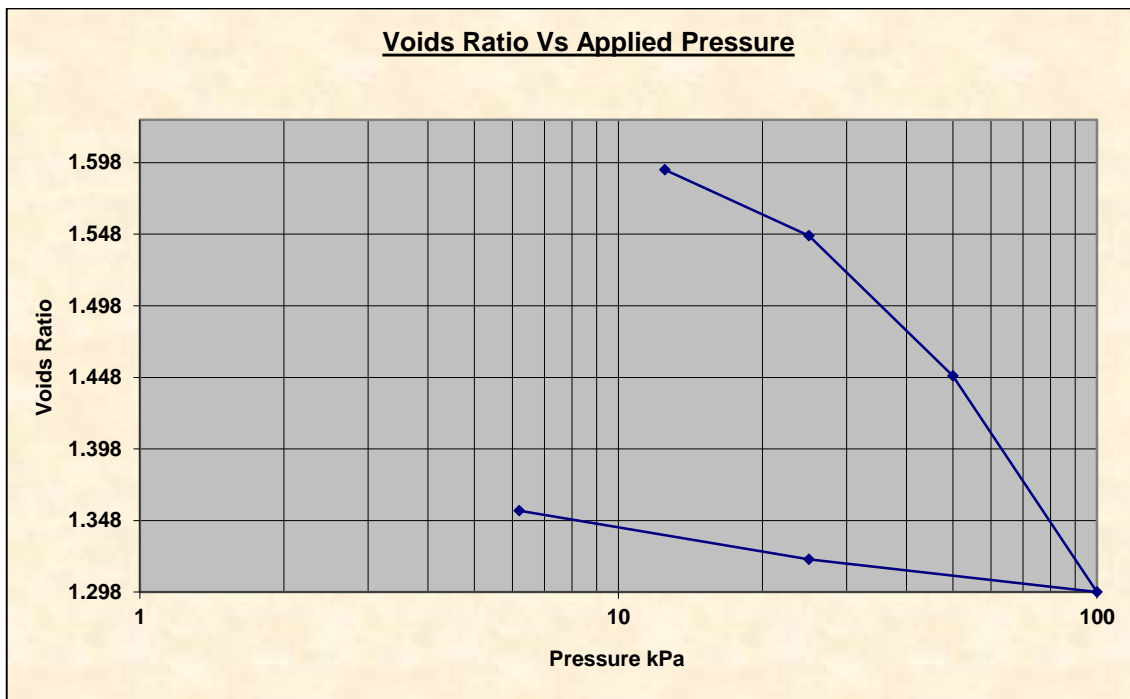
Height of Solid Particles	7.61 mm	Swelling Pressure	0.0 kPa
Initial Moisture Content*	98.1 %	Final Moisture Content	135.9 %
Initial Bulk Density	1.44 Mg/m3	Final Bulk Density	1.91 Mg/m3
Initial Dry Density	0.73 Mg/m3	Final Dry Density	0.81 Mg/m3
Initial Void Ratio	1.6281	Final Void Ratio	1.3548
Initial Degree of Saturation	115.14%	Final Degree of Saturation	191.57 %

- Calculated from initial and dry weights of whole specimen

Pressure (Loading Stages)	Coefficient of Volume Compressibility (m_v)	Coefficient of Consolidation (c_v)
0.00		
12.5 kPa	1.07 m2/MN	10.67 m2/yr
25.0 kPa	1.41 m2/MN	13.55 m2/yr
50.0 kPa	1.54 m2/MN	8.76 m2/yr
99.9 kPa	1.23 m2/MN	8.16 m2/yr
25.0 kPa	0.13 m2/MN	---------
6.2 kPa	0.78 m2/MN	---------

Method of Time Fitting Used	Square Root Time

Sheet C2: Oedometer result for sample A1

Test Details			
Standard	BS 1377: Part 5: 1990: Clause 3	Particle Density	1.96 Mg/m3
Sample Type	Core sample	Lab Temperature	0.0 deg.C
Sample Depth	0.00 m		
Sample Description			
Variations from Procedure	None		

Specimen Details			
Specimen Reference	A1	Description	
Depth within Sample	0.00mm	Orientation within Sample	
Specimen Mass	49.37 g	Condition	Natural Moisture
Specimen Height	20.00 mm	Preparation	
Comments			

Test Apparatus			
Ring Number	1	Ring Diameter	50.00 mm
Ring Height	20.00 mm	Ring Weight	0.00 g
Lever Ratio	10.00 : 1		

Voids Ratio Vs Applied Pressure
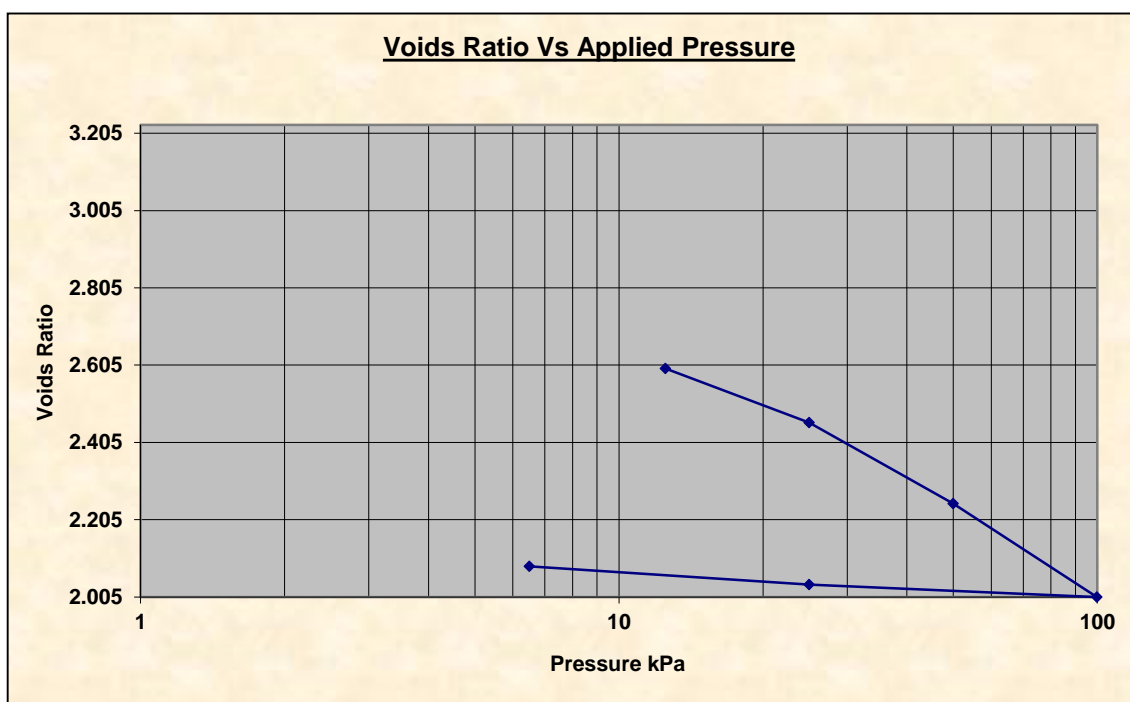
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Height of Solid Particles	4.73 mm	Swelling Pressure	0.0 kPa
Initial Moisture Content*	171.1 %	Final Moisture Content	113.6 %
Initial Bulk Density	1.26 Mg/m3	Final Bulk Density	1.36 Mg/m3
Initial Dry Density	0.46 Mg/m3	Final Dry Density	0.64 Mg/m3
Initial Void Ratio	3.2267	Final Void Ratio	2.0843
Initial Degree of Saturation	103.94%	Final Degree of Saturation	106.79 %

- Calculated from initial and dry weights of whole specimen

Pressure (Loading Stages)	Coefficient of Volume Compressibility (m_v)	Coefficient of Consolidation (c_v)
0.00		
12.5 kPa	11.95 m2/MN	1.56 m2/yr
25.0 kPa	3.13 m2/MN	2.22 m2/yr
50.0 kPa	2.41 m2/MN	2.47 m2/yr
99.9 kPa	1.49 m2/MN	1.85 m2/yr
25.0 kPa	0.14 m2/MN	---------
6.5 kPa	0.84 m2/MN	---------

Method of Time Fitting Used	Square Root Time

Sheet C3: Oedometer result for sample A2

Test Details			
Standard	BS 1377: Part 5: 1990: Clause 3	Particle Density	1.96 Mg/m3
Sample Type	Core sample	Lab Temperature	0.0 deg.C
Sample Depth	0.00 m		
Sample Description			
Variations from Procedure	None		

Specimen Details			
Specimen Reference	A2	Description	
Depth within Sample	0.00mm	Orientation within Sample	
Specimen Mass	51.77 g	Condition	Natural Moisture
Specimen Height	20.00 mm	Preparation	
Comments			

Test Apparatus			
Ring Number	1	Ring Diameter	50.00 mm
Ring Height	20.00 mm	Ring Weight	0.00 g
Lever Ratio	10.00 : 1		

Voids Ratio Vs Applied Pressure
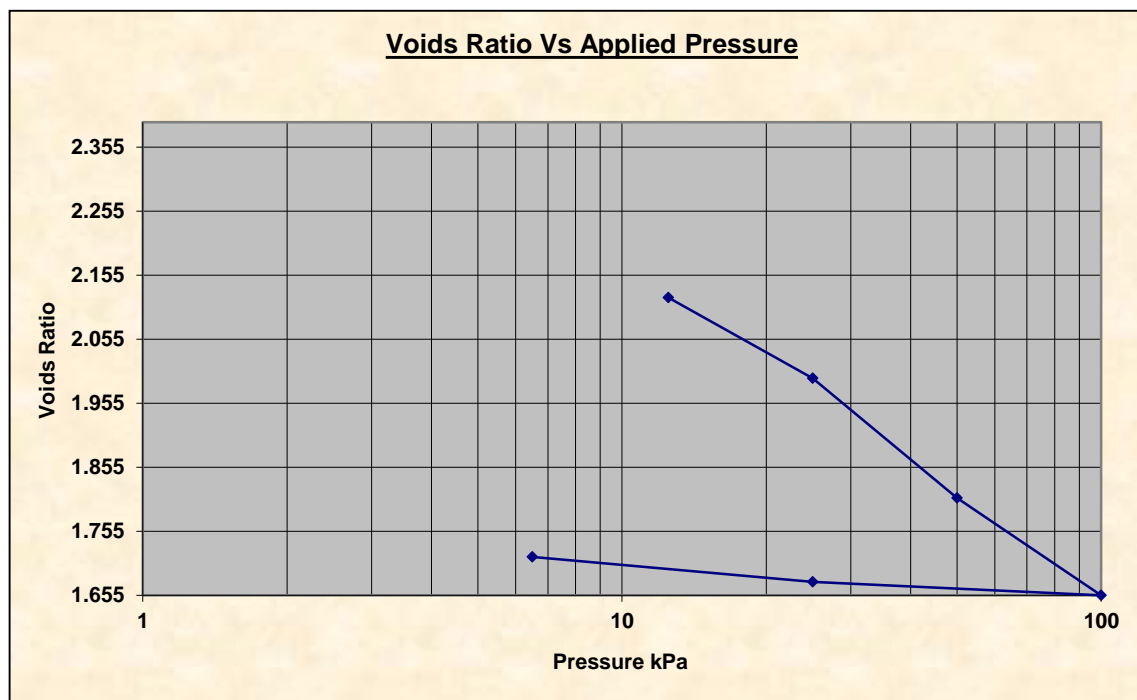
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Height of Solid Particles	5.89 mm	Swelling Pressure	0.0 kPa
Initial Moisture Content*	128.3 %	Final Moisture Content	92.2 %
Initial Bulk Density	1.32 Mg/m3	Final Bulk Density	1.39 Mg/m3
Initial Dry Density	0.58 Mg/m3	Final Dry Density	0.72 Mg/m3
Initial Void Ratio	2.3937	Final Void Ratio	1.7146
Initial Degree of Saturation	105.02%	Final Degree of Saturation	105.39 %

- Calculated from initial and dry weights of whole specimen

Pressure (Loading Stages)	Coefficient of Volume Compressibility (m_v)	Coefficient of Consolidation (c_v)
0.00		
12.5 kPa	6.45 m2/MN	9.44 m2/yr
25.0 kPa	3.23 m2/MN	7.33 m2/yr
50.0 kPa	2.51 m2/MN	4.80 m2/yr
99.9 kPa	1.08 m2/MN	4.38 m2/yr
25.0 kPa	0.10 m2/MN	---------
6.5 kPa	0.78 m2/MN	---------

Method of Time Fitting Used	Square Root Time

Sheet C4: Oedometer result for sample A3

Test Details			
Standard	BS 1377: Part 5: 1990: Clause 3	Particle Density	1.96 Mg/m3
Sample Type	Core sample	Lab Temperature	0.0 deg.C
Sample Depth	0.00 m		
Sample Description			
Variations from Procedure	None		

Specimen Details			
Specimen Reference	A3	Description	
Depth within Sample	0.00mm	Orientation within Sample	
Specimen Mass	51.24 g	Condition	Natural Moisture
Specimen Height	20.00 mm	Preparation	
Comments			

Test Apparatus			
Ring Number	1	Ring Diameter	50.00 mm
Ring Height	20.00 mm	Ring Weight	0.00 g
Lever Ratio	10.00 : 1		
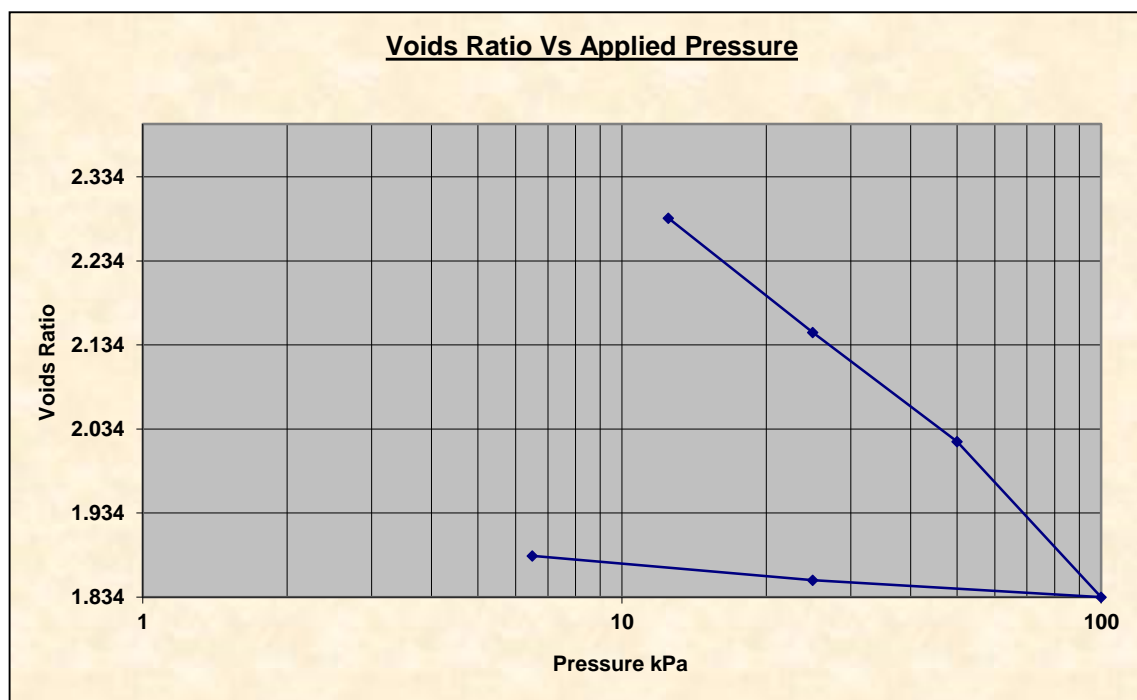
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Height of Solid Particles	5.89 mm	Swelling Pressure	0.0 kPa
Initial Moisture Content*	126.1 %	Final Moisture Content	98.3 %
Initial Bulk Density	1.30 Mg/m3	Final Bulk Density	1.35 Mg/m3
Initial Dry Density	0.58 Mg/m3	Final Dry Density	0.68 Mg/m3
Initial Void Ratio	2.3967	Final Void Ratio	1.8829
Initial Degree of Saturation	103.14%	Final Degree of Saturation	102.35 %

- Calculated from initial and dry weights of whole specimen

Pressure (Loading Stages)	Coefficient of Volume Compressibility (m_v)	Coefficient of Consolidation (c_v)
0.00		
12.5 kPa	2.63 m2/MN	10.94 m2/yr
25.0 kPa	3.32 m2/MN	15.87 m2/yr
50.0 kPa	1.66 m2/MN	11.64 m2/yr
99.9 kPa	1.23 m2/MN	14.42 m2/yr
25.0 kPa	0.09 m2/MN	---------
6.5 kPa	0.56 m2/MN	---------

Method of Time Fitting Used	Square Root Time

Sheet C5: Oedometer result for sample A4

Test Details			
Standard	BS 1377: Part 5: 199: Clause 3	Particle Density	1.96 Mg/m3
Sample Type	Core sample	Lab Temperature	0.0 deg.C
Sample Depth	0.00 m		
Sample Description			
Variations from Procedure	None		

Specimen Details			
Specimen Reference	A4	Description	
Depth within Sample	0.00mm	Orientation within Sample	
Specimen Mass	54.31 g	Condition	Natural Moisture
Specimen Height	20.00 mm	Preparation	
Comments			

Test Apparatus			
Ring Number	1	Ring Diameter	50.00 mm
Ring Height	20.00 mm	Ring Weight	0.00 g
Lever Ratio	10.00 : 1		
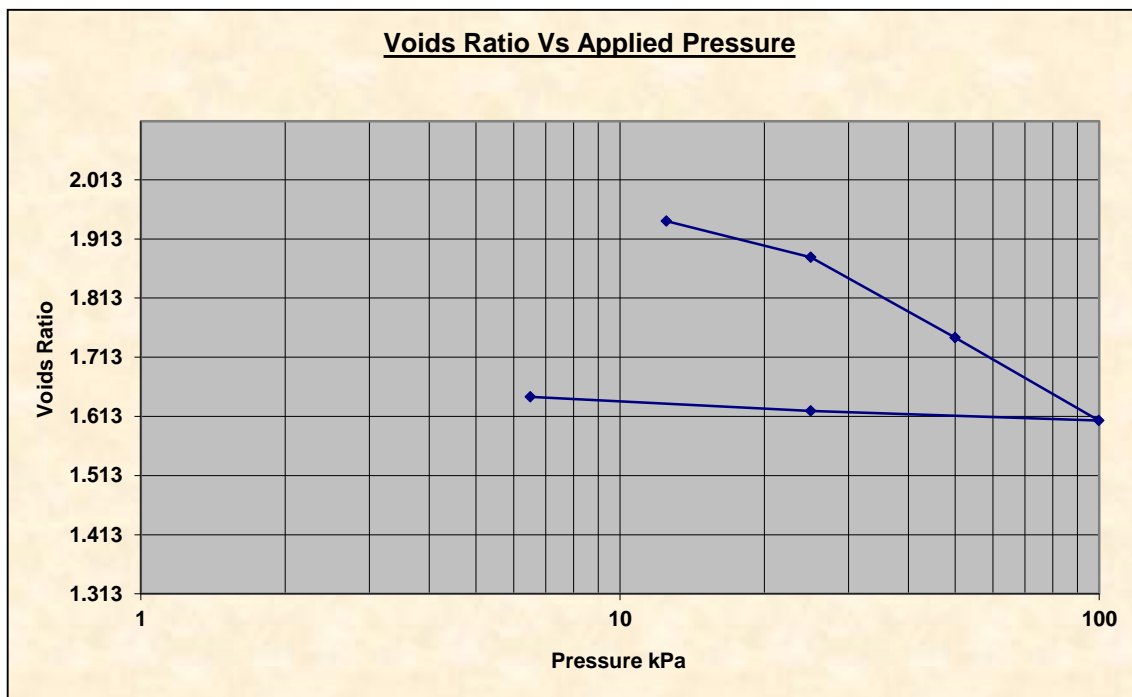
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Height of Solid Particles	6.43 mm	Swelling Pressure	0.0 kPa
Initial Moisture Content*	119.6 %	Final Moisture Content	92.7 %
Initial Bulk Density	1.38 Mg/m3	Final Bulk Density	1.43 Mg/m3
Initial Dry Density	0.63 Mg/m3	Final Dry Density	0.74 Mg/m3
Initial Void Ratio	2.1124	Final Void Ratio	1.6462
Initial Degree of Saturation	110.98%	Final Degree of Saturation	110.35 %

- Calculated from initial and dry weights of whole specimen

Pressure (Loading Stages)	Coefficient of Volume Compressibility (m_v)	Coefficient of Consolidation (c_v)
0.00		
12.5 kPa	4.35 m2/MN	8.66 m2/yr
25.0 kPa	1.67 m2/MN	8.16 m2/yr
50.0 kPa	1.89 m2/MN	3.11 m2/yr
99.9 kPa	1.02 m2/MN	9.28 m2/yr
25.0 kPa	0.08 m2/MN	---------
6.5 kPa	-6.39 m2/MN	---------
6.5 kPa	-Inf m2/MN	---------

Method of Time Fitting Used	Square Root Time

Sheet C6: Oedometer result for sample B1

Test Details			
Standard	BS 1377: Part 5: 1990: Clause 3	Particle Density	1.96 Mg/m3
Sample Type	Core sample	Lab Temperature	0.0 deg.C
Sample Depth	0.00 m		
Sample Description			
Variations from Procedure	None		

Specimen Details			
Specimen Reference	B1	Description	
Depth within Sample	0.00mm	Orientation within Sample	
Specimen Mass	48.80 g	Condition	Natural Moisture
Specimen Height	20.00 mm	Preparation	
Comments			

Test Apparatus			
Ring Number	1	Ring Diameter	50.00 mm
Ring Height	20.00 mm	Ring Weight	68.35 g
Lever Ratio	10.00 : 1		

Voids Ratio Vs Applied Pressure
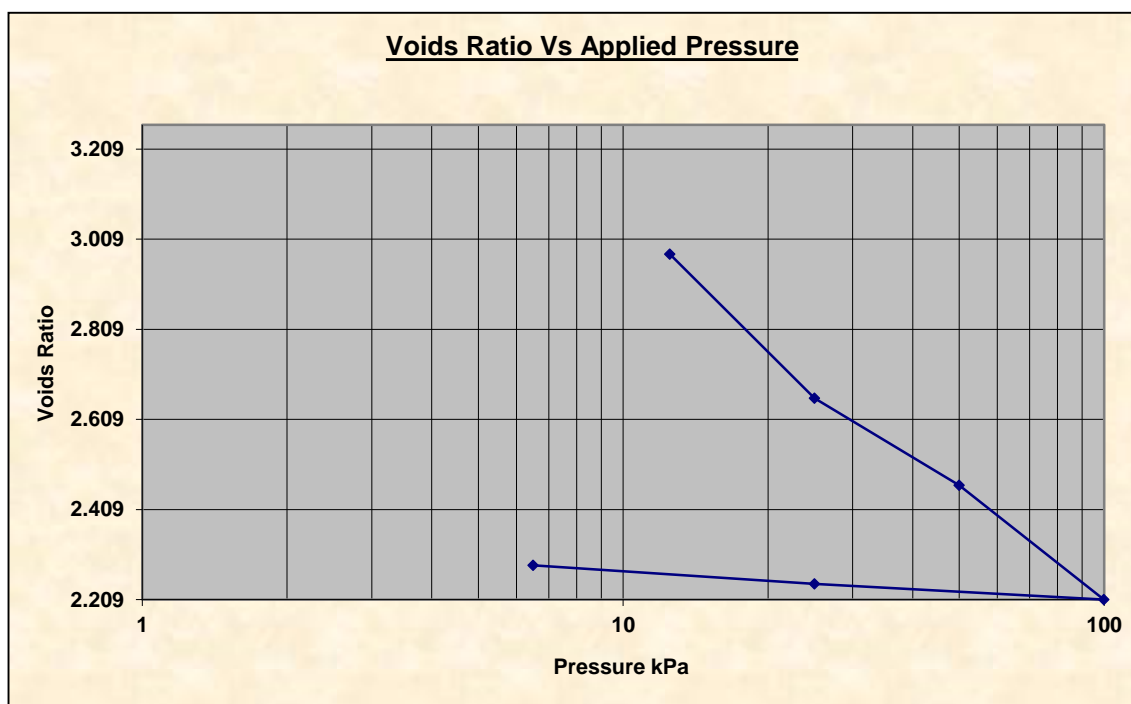
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Height of Solid Particles	4.69 mm	Swelling Pressure	0.0 kPa
Initial Moisture Content*	170.8 %	Final Moisture Content	112.4 %
Initial Bulk Density	1.24 Mg/m3	Final Bulk Density	1.26 Mg/m3
Initial Dry Density	0.46 Mg/m3	Final Dry Density	0.60 Mg/m3
Initial Void Ratio	3.2626	Final Void Ratio	2.2850
Initial Degree of Saturation	102.40%	Final Degree of Saturation	96.20 %

- Calculated from initial and dry weights of whole specimen

Pressure (Loading Stages)	Coefficient of Volume Compressibility (m_v)	Coefficient of Consolidation (c_v)
0.00		
12.5 kPa	5.39 m2/MN	8.50 m2/yr
25.0 kPa	6.43 m2/MN	4.80 m2/yr
50.0 kPa	2.12 m2/MN	5.30 m2/yr
99.9 kPa	1.47 m2/MN	11.27 m2/yr
25.0 kPa	0.15 m2/MN	---------
6.5 kPa	0.69 m2/MN	---------

Method of Time Fitting Used	Square Root Time

Sheet C7: Oedometer result for sample B2

Test Details			
Standard	BS 1377: Part 5: 1990: Clause 3	Particle Density	1.96 Mg/m3
Sample Type	Core sample	Lab Temperature	0.0 deg.C
Sample Depth	0.00 m		
Sample Description			
Variations from Procedure	None		

Specimen Details			
Specimen Reference	B2	Description	
Depth within Sample	0.00mm	Orientation within Sample	
Specimen Mass	50.28 g	Condition	Natural Moisture
Specimen Height	20.00 mm	Preparation	
Comments			

Test Apparatus			
Ring Number	1	Ring Diameter	50.00 mm
Ring Height	20.00 mm	Ring Weight	0.00 g
Lever Ratio	10.00 : 1		

Voids Ratio Vs Applied Pressure
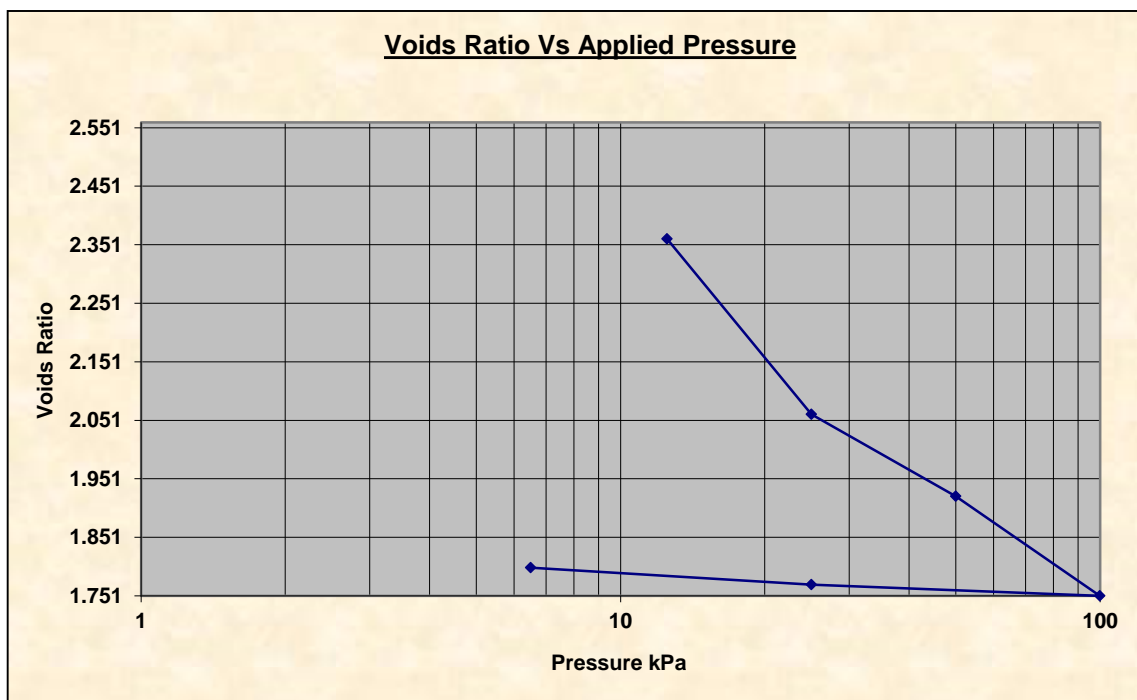
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Height of Solid Particles	5.62 mm	Swelling Pressure	0.0 kPa
Initial Moisture Content*	132.6 %	Final Moisture Content	99.2 %
Initial Bulk Density	1.28 Mg/m3	Final Bulk Density	1.40 Mg/m3
Initial Dry Density	0.55 Mg/m3	Final Dry Density	0.70 Mg/m3
Initial Void Ratio	2.5601	Final Void Ratio	1.7986
Initial Degree of Saturation	101.49%	Final Degree of Saturation	108.12 %

- Calculated from initial and dry weights of whole specimen

Pressure (Loading Stages)	Coefficient of Volume Compressibility (m_v)	Coefficient of Consolidation (c_v)
0.00		
12.5 kPa	4.49 m2/MN	2.09 m2/yr
25.0 kPa	7.13 m2/MN	2.37 m2/yr
50.0 kPa	1.83 m2/MN	4.40 m2/yr
99.9 kPa	1.17 m2/MN	4.05 m2/yr
25.0 kPa	0.09 m2/MN	---------
6.5 kPa	0.55 m2/MN	---------

Method of Time Fitting Used	Square Root Time

Sheet C8: Oedometer result for sample B3

Test Details			
Standard	BS 1377: Part 5: 1990: Clause 3	Particle Density	1.96 Mg/m3
Sample Type	Core sample	Lab Temperature	0.0 deg.C
Sample Depth	0.00 m		
Sample Description			
Variations from Procedure	None		

Specimen Details			
Specimen Reference	B3	Description	
Depth within Sample	0.00mm	Orientation within Sample	
Specimen Mass	49.74 g	Condition	Natural Moisture
Specimen Height	20.00 mm	Preparation	
Comments			

Test Apparatus			
Ring Number	1	Ring Diameter	50.00 mm
Ring Height	20.00 mm	Ring Weight	0.00 g
Lever Ratio	10.00 : 1		

Voids Ratio Vs Applied Pressure
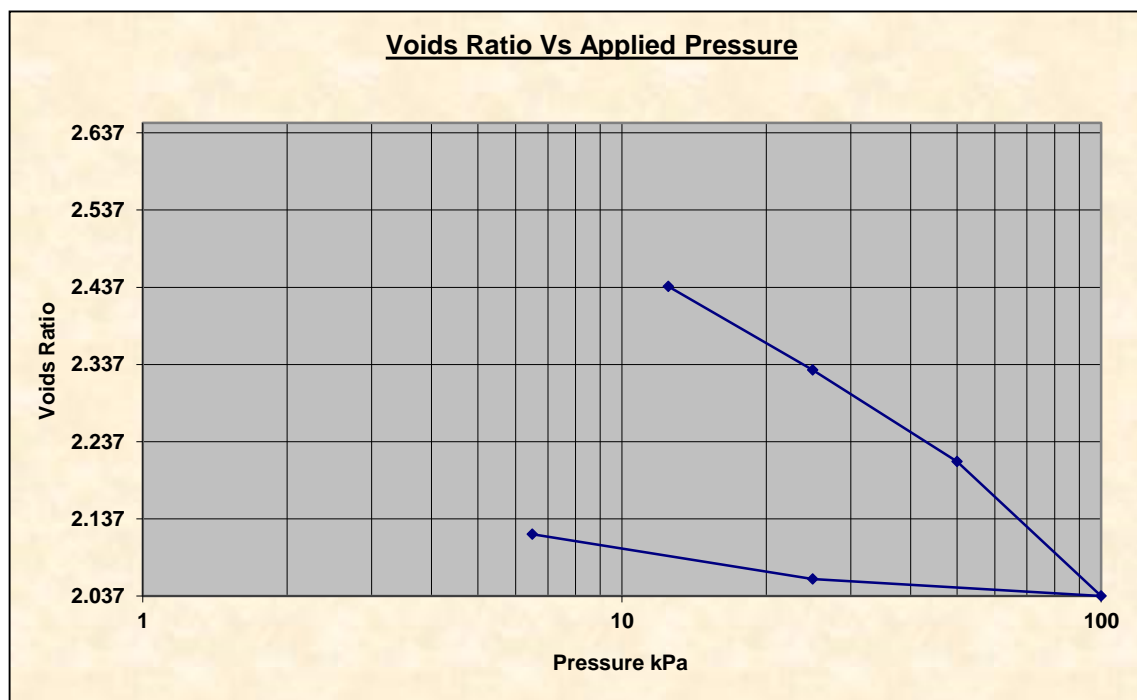
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Height of Solid Particles	5.48 mm	Swelling Pressure	0.0 kPa
Initial Moisture Content*	135.8 %	Final Moisture Content	104.7 %
Initial Bulk Density	1.27 Mg/m3	Final Bulk Density	1.29 Mg/m3
Initial Dry Density	0.54 Mg/m3	Final Dry Density	0.63 Mg/m3
Initial Void Ratio	2.6496	Final Void Ratio	2.1172
Initial Degree of Saturation	100.49%	Final Degree of Saturation	96.92 %

- Calculated from initial and dry weights of whole specimen

Pressure (Loading Stages)	Coefficient of Volume Compressibility (m_v)	Coefficient of Consolidation (c_v)
0.00		
12.5 kPa	4.64 m2/MN	8.87 m2/yr
25.0 kPa	2.52 m2/MN	6.36 m2/yr
50.0 kPa	1.43 m2/MN	12.28 m2/yr
99.9 kPa	1.09 m2/MN	15.22 m2/yr
25.0 kPa	0.10 m2/MN	---------
6.5 kPa	1.03 m2/MN	---------

Method of Time Fitting Used	Square Root Time

Sheet C9: Oedometer result for sample B4

Test Details			
Standard	BS 1377: Part 5: 1990: Clause 3	Particle Density	1.96 Mg/m3
Sample Type	Core sample	Lab Temperature	0.0 deg.C
Sample Depth	0.00 m		
Sample Description			
Variations from Procedure	None		

Specimen Details			
Specimen Reference	B4	Description	
Depth within Sample	0.00mm	Orientation within Sample	
Specimen Mass	53.21 g	Condition	Natural Moisture
Specimen Height	20.00 mm	Preparation	
Comments			

Test Apparatus			
Ring Number	1	Ring Diameter	50.00 mm
Ring Height	20.00 mm	Ring Weight	0.00 g
Lever Ratio	10.00 : 1		
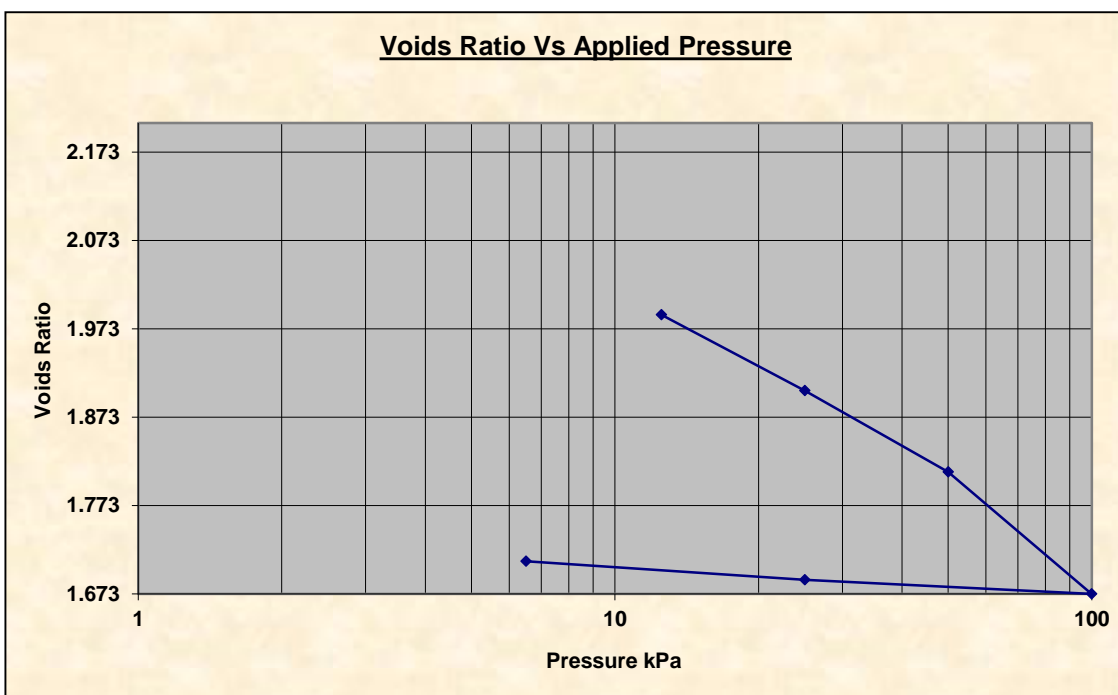
Continued

Height of Solid Particles	6.24 mm	Swelling Pressure	0.0 kPa
Initial Moisture Content*	121.6 %	Final Moisture Content	93.0 %
Initial Bulk Density	1.35 Mg/m3	Final Bulk Density	1.40 Mg/m3
Initial Dry Density	0.61 Mg/m3	Final Dry Density	0.72 Mg/m3
Initial Void Ratio	2.2057	Final Void Ratio	1.7096
Initial Degree of Saturation	108.07%	Final Degree of Saturation	106.58 %

- Calculated from initial and dry weights of whole specimen

Pressure (Loading Stages)	Coefficient of Volume Compressibility (m_v)	Coefficient of Consolidation (c_v)
0.00		
12.5 kPa	5.40 m2/MN	10.34 m2/yr
25.0 kPa	2.31 m2/MN	10.61 m2/yr
50.0 kPa	1.27 m2/MN	17.48 m2/yr
99.9 kPa	0.99 m2/MN	12.53 m2/yr
25.0 kPa	0.08 m2/MN	---------
6.5 kPa	0.42 m2/MN	---------

Method of Time Fitting Used	Square Root Time