Faculty of Engineering

ONE- DIMENSIONAL CONSOLIDATION OF MODIFIED PEAT SOIL

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ABSTRACT

Peat soil has been known to be the major group of problem soil in Malaysia. In Sarawak alone, peat covers 13% of the total land area. The main problem in peat is the excessive and differential settlement which results difficult design and construction condition. Furthermore, peat is difficult to sample and test using conventional method. One important characteristic that is important for analysis is the consolidation characteristic. This is because the consolidation behavior is related to the organic content of the soil. Therefore, the aim of this study is to investigate the consolidation behaviors of peat, in particular the consolidation parameters with respect to the organic content and relationships. The Oedometer consolidation test equipment will be used to obtain the results and effects of organic content on the coefficient of consolidation (C_v), coefficient of compression index (C_c) and coefficient of volume compressibility (m_v). From the experiments conducted, the value of C_v was found to be in the range of 0.094 to 0.848 cm^2/min. Where as the value of m_v was found to be decreasing as the organic content decreased. The value of C_c was also found to be decreasing as organic content decreased.

ABSTRAK

Tanah gambut telah dikenal pasti sebagai kumpulan tanah yang bermasalah di Malaysia. Di Sarawak sahaja, tanah gambut merangkumi 13% daripada jumlah tanah yang ada. Masalah bagi tanah gambut ialah pemendapan berlebihan dan berubah – ubah yang menyebabkan kesukaran kerja merekabentuk dan pembinaan. Tambahan pula, tanah gambut susah untuk disampel dan diuji menggunakan cara-cara konvensional. Salah satu ciri – ciri yang penting untuk dianalisa bagi tanah gambut ialah ciri – ciri pemendapannya. Ini adalah kerana sifat – sifat pemendapannya adalah bergantung kepada kandungan organiknya. Oleh itu, matlamat kajian ini ialah untuk menyiasat sifat – sifat tanah gambut, terutamanya parameter pemendapan dan hubungannya dengan kandungan organik. Ujian pengukuhan digunakan untuk memperolehi keputusan dan juga kesan kandungan organik terhadap parameter pemalar pemendapan (C_v), pemalar kebolehmampatan isipadu (m_v) dan pemalar index kebolehmampatan, (C_c). Daripada eksperimen yang dijalankan, didapati nilai C_v adalah dalam lingkungan 0.094 hingga 0848 cm^2/min. Manakala nilai m_v didapati semakin berkurangan selaras dengan pengurangan kandungan organik. Nilai C_c juga didapati berkurangan bila kandungan organik dikurangkan.

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1 INTRODUCTION AND SCOPE OF STUDY

1.1 Introduction

The aim of this study is to investigate the consolidation behavior of peat before and after being modified with an increasing percentage of sand. A series of tests are carried out to determine the properties of peat and its relationship with respect to the organic content after different percentage of sand increment. The following test are carried out in this study:

i) Moisture content

ii) Degree of humification

iii) Ignition loss

iv) Hydrometer analysis

v) Specific gravity

vi) Atterberg limits

vii) Compaction and

viii) Consolidation

1.2 Background

Organic soils especially peat or sometimes also known as peat swamps covers a total of 2.7 million hectares in Malaysia which is an overall 8% of the land. In Sarawak alone, peat covers 13% of the total state land area which is approximately 1.7 million hectares. Besides being part of the natural landscape of our country, peat has been identified as one of the major problem soils in Malaysia and other countries. Peat is generally defined as soil having high organic content. The organic content are mainly decomposed plant remains whose accumulation rate is faster than the rate of decay*. These are then intermixed with sand, silt and clay. According to Coduto (1999), peat has dark brown to black color, a spongy consistency, and an organic odor. Soil scientist defines peat as soil with organic content higher than 35%.

In terms of geotechnical engineering, the Public Works Department, Malaysia defines soils with organic content more than 20% as organic soils where as peat is an organic soil with organic content more than 75%. Peat is sometimes classified as soft soils because of its instability and long term consolidation. The bulk density, porosity, wood content, degree of humification, hydrology and its water holding properties are mainly the factors that determine their physical properties (Sunday Tribune, 2003). Almost 90% of peat in Sarawak have depths more than 1.5m, i.e. which is classified as deep peat. Their depths increases from the coast towards the inlands.

Tropical peat in Sarawak are in general non-homogenous. The overall hydrological characteristic depends on the rainfall and the surface topography. Peatland is sometimes known as wetland because of the high depth of water table which is sometimes even higher than the peat surface. Peat has very high moisture content and capacity to hold water, making it very buoyant and high in pore volume. These characteristic are the main cause of peat to have low bearing capacity and bulk density. Due to this, peat is only capable of carrying little weight.

In order to develop peatlands for infrastructure or agriculture, the excess water has to be drained. But unfortunately drainage may cost bigger problems to

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*Cited from Sunday Tribune, 2003, www

peatlands. According to the Sunday Tribune (2003), a study by Melling and HAtano has shown that draining out water may cause severe greenhouse effect. Other problems are oxidation, consolidation or subsidence of the land, flood occurrence, forest fire, pest infestation etc. Consolidation or subsidence also poses a great threat to peatland as it may cause flooding and damage of structures particularly roads. Years of study in the engineering field has come up with a few methods of improving peat. They are the excavation and replacement, vertical drains, piled supports, surface reinforcement (geotextile and geogrids) and the latest alternative which is the lightweight fill.

Even though faced with many problems, liming and fertilization of peat has been widely used in agriculture and has been successful especially for oil palm, sago and pineapple. Other application are such as fuel in many area of the world due high to organic content which makes peat a combustible material. Previous studies have also shown the suitability of peat as a filter medium in biofilters for wastewater treatment, (Shibchurn, 2001).

1.3 Scope of Present Study

The present study is mainly concerned on the settlement of peat. This is because the settlement of soil plays an important role in designing a civil engineering structures. When a structure is build, there is a compression of soil layers due to deformation of soil particles, relocation of soil particles and the expulsion of water or air from the void spaces (Das, 1998). The apparatus used in conducting the consolidation test is the Oedometer. From the test, 3 main phases that needs to be analyzed are;

Stage 1 : Initial Compression, mostly caused by preloading

Stage 2 : Primary Consolidation, during which excess pore water is gradually transferred into effective stress due to the expulsion of pore water.

Stage 3 : Secondary Consolidation, which occurs after dissipation of pore water pressure, when soil deforms due to plastic readjustment of soil fabric.

Since peat is considered as soft soils, it is important to analyze the consolidation properties before commencing on the actual work. The dependency of peat on its organic content makes it even harder to analyze and classify as results vary depending on the amount of organic content. Therefore, the aim of this is to analyze the consolidation of several modified peat soil samples. The reason is to compare the samples for future improvement of peat soils. The results of this modification will be used as guidelines in improving the peat soil condition is Sarawak.

The objectives of the project are as follows:

I. To determine the physical properties of modified peat soil and to compare with natural peat soil.
II. To find out the primary and secondary consolidation of the modified peat.
III. To compare the results and conclude the suitability of the modification.
IV. To study the consolidation parameters of the modified samples.

The outline of the project report are as follows:

Section 1 presents the introduction, background, scope and the objectives of the study.

Section 2 presents a review of the characteristic and properties of peat soil and its behavior with respect to different experiments.

Section 3 is conceerned with the experimental investigation study of the soil used and the procedures of performing the test.

Section 4 presents the results and discussion of the experimental investigation outlined in Chapter 3. This chapter also presents the relationship and outcomes of the different range of modification.

Section 5 Contains an outline of the conclusions drawn in the project and the recommendations for further development of the present work for future research.

1.4 Limitations

Eventhough the Oedometer can be used to study the consolidation of peat soil to a certain extent. Still it does have certain limitations. Moreover, the number of equipment available was also insufficient. To perform the consolidation test on peat, ample time is needed and because of the time needed for each test, it was impossible to repeat the test to confirm results. More equipment should be made available so that test can be done simultaneously. Also to be taken note that the test is very sensitive to any movement and vibration. Therefore, the consolidation test should be performed in a separate room free from any disturbance. Finally, to make sure all test are done according to schedule, it is recommended that the test be conducted as early as possible to make allowance for any long compression period or any repeating of test.

2 LITERATURE REVIEW

2.1 General

The main objective of this research is to study the effects on the consolidation parameters of peat soils which have been modified. To investigate this effect, all parameters related to this research are described below.

2.2 Basic Properties of Peat

In general, peat is classified in various different ways depending on the purpose for which they are being described. Different emphasis is given according to nature of study and research. The most relevant characteristic in research is the moisture relationship, acidity, bulk density, porosity, and the swelling and shrinking.

Information on the moisture relationship in peat is important especially when comes to the design of drainage. Various methods have been done to determine the water content of different organic soils. The results however vary from the other. The best method preferred hy soil scientists is by using pressure plate and pressure membrane apparatus. The results (Table 2.1) shows great difference in water release characteristics between different organic materials (Andriesse,1988). Studies by Driessen and Rochimah (1977) : quoted from Andriesse (1988) on lowland Borneo peat has shown 79-91 percent by volume at suction of 0.01 bar, 75-89 percent by volume at 0.1 bar and 71-85 percent by volume at 0.33 bar (Andriesse,1998,). It is also shown that fibric peats lose their retained water at low suction.

Bulk density is the most characteristic as most properties are related to it. The value of bulk density is dependant on the amount of compaction, degree of decomposition, botanical composition, and the mineral and moisture content. Bulk density for organic soil is defined as the weight of a given volume of soil usually expressed on a dry weight basis in g/cm^3. Values range from 0.05 g/cm^3 in very fibric, undecomposed materials to 0.5 g/cm^3 in decomposed materials. According to Andriesse (1974), the mean bulk densities for Sarawak (Malaysia) peat is reported to be 0.12 and 0.09 g/cm^3. While Tie and Kueh (1979) reported that the bulk densities is 0.15 and 0.13 g/cm^3 in Sarawak. As for specific density (particle density), Driessen and Rochimah (1976) quoted that, for peats in general to be ranging from 1.26 g/cm^3 to 1.80 g/cm^3 (Andriesse,1988).

The porosity of peat is dependant on the bulk density. It also determines the water retention in soils. Table 2.2 shows the calculated total pore space for tropical lowland peats in Indonesia.

The texture and ignition loss of peat is important as the estimation of amount and distribution of mineral matter can predict the drainage behavior in the soil. Skaven-Haug (1972) stated that for tropical peat consisting of pure organic materials, a presumed ash percentage of one percent seems reasonable (Andriesse,1988).

Shrinkage is the percentage of the original volume. In general, organic soils shrinks when dried and swells when re-wetted. The shrinkage at range from 90 percent for aquatic peat to 40 percent for fibric peat. Similar to the Canadian peat, low land coastal peat usually show the greatest shrinkage (Andriesse,1988).

Although the chemical compound in peat is seldom taken into account in geotechnical engineering, it is still an important characteristic in the classification of the soil. The degree of composition, parent vegetation and the original chemical environment is the main influence in the chemical composition of peat. The main organic constituents can be grouped into five fractions (Andriesse,1988.):

a) Water soluble compounds

b) Ether and alcohol soluble materials

c) Cellulose and hemicellulose

d) Lignin and lignin-derived substance

e) Nitrogeneous materials or crude proteins

The acidity or pH of organic soils depends on the organic content itself, iron sulphide and the exchangeable hydrogen and aluminium. For tropical peat of ombrogeneous and oligotrophic nature, the pH range in water is from 3 to 4.5. Furthermore, the thickest peat in lowland Borneo has an average of pH 3.3 whereas shallow peat with pH 4.3 (Andriesse,1988).

2.3 Moisture Content

In general, all soils contains water. For highly fibrous organic soils, such as peat, are generally characterized by relatively high moisture content, sometimes over 100 percent and an increase in organic content as little as 1 to 2 percent can result to a decrease of the maximum dry density and an increase in the optimum moisture content (Geotechnical News Quarterly, 2001). According to MARDI, field moisture content of peat ranges from about 100% to 1300%, on a dry weight basis. According to Vazirani and Chandola (1994), moisture content is the ratio of the weight of water present in the soil to the dry weight of soil which have been kept in the oven for 24 hours at a temperature of 105 to 110°C.

2.4 Particle Size Distribution

The particle distribution is an analysis which involves the determination of the percentage of weight within different ranges of size. According to Vazirani and Chandola (1994), in the field method of particle size distribution analysis, the rate of sedimentation is determined from the rate of decrease of density of the upper part of the liquid as larger particles settle out. The density is measured by hydrometer or sieve analysis. The actual dimensions are usually in terms of equivalent diameter and size fractions are specified as lying between certain limits of particle diameters. Vazirani and Chandola (1994) also stated the limits of equivalent diameter:

Gravel	60 - 2.0mm
Sand	2.0 – 0.06mm
Silt	0.06 – 0.002mm
Clay	Below 0.002mm

The results of particle size distribution are widely used in studies related with soil classifications. A soil is considered well-graded when it has good representation of particles of all sizes where as a soil is considered to be poorly graded if it has an excess of certain particles and deficiency of others.

2.5 Organic Content and Ignition Loss

Peat is a soil with high organic content (more than 75%) mainly consisting of decomposed or not fully decomposed plant remains. Geotechnical earthwork specifications generally require that selected fill be free of organic matter. According to Geotechnical News Quarterly (2001), fill materials containing more than 2.0 percent by weight of organic matter are generally not used in suitable for engineering purposes. To assess fill materials, three randomly selected samples from each soil stratum or fill stockpile are tested. If any of these individual test results exceeds 3.0 percent, the stratum or stockpile is rejected.

According to Adel, Huat and Munzir (2003) , the American Society for Testing and Materials (ASTM) has classified peat and organic soil which are shown below:

I. OC 6 – 20% :Effects properties but behavior is still like mineral soils, organic silts and clays.

II. OC 21 – 74% :Organic matter govern properties ; traditional soil mechanics applicable.

III. OC>75% :Displays behavior distinct from traditional soil mechanics especially at low stresses i.e. peat.

BS 1377:Part 3 (1990) has stated the method of determining the organic content using the Walkley and Black method where as the mass loss on ignition is related to the organic content of the soil. Edil (2003) has stated the determination of organic content by ignition of the soil at high temperature of 440°C to 550°C to achieve destruction of organic matter. For Geotechnical purposes, the American Society for Testing and Materials (ASTM) has specified 440°C as percentage of oven dried mass at 105°C. According to Adel, et. al. (2003) and Skempton and Petley (1970) found the following relationship between ignition loss (N) and organic content (H)

$$H = 1 - 1.04\,(1 - N) \qquad (2.1)$$

Where both H and N are expressed as ratio and the difference between both is negligible for organic content greater than 25%.

2.6 Specific Gravity

Specific gravity is defined as the ratio of the weight of a given volume of material to the weight of an equal volume of water. According to Edil (2003), the specific gravity of solids in peat and organic soils is greater than 1 and increases with increasing mineral content and could be slightly higher for some organic soils with low organic content. In determination of the specific gravity, several methods can be used such as kerosene displacement instead of water. However, an easier alternative method is by using ash or organic content (Ignition Loss). Equation 2.2 shows the average specific gravity of soil solids which can be written as,

$$G_S = 2.7\,(1 - OC) + 1.5\,OC \qquad (2.2)$$

Where GS = Specific Gravity

OC = the organic content or ignition loss. This assumption may lead to error as high as 18% (Edil, 2003 from Doyle, 1963)

Edil (2003) also stated that for a given organic deposit, correlations between specific gravity and Ignition Loss or Organic Content can be developed experimentally by using the relationship equation shown:

$$1/G_S = OC/1.365 + (1 - OC)/2.695 \qquad (2.3)$$

where OC = Organic content

GS = Specific Gravity

2.7 Degree of Humification (Decomposition)

The process where the vegetative material in peat swamps decomposes by microbial activity is termed humification. The Von Post Degree of humification (Table 2.3) has classified peat to 10 categories according to its structure. According to Harwant and Huat (2003), the Department of Agriculture (USDA) based on the Government of Sarawak (1990) classification based on fibre content has also subdivided peat into three subgroups such as Fibric, Hemic and Sapric as shown in Table 2.4. The degree of humification, (H_n) is generally used to correlate the bulk density, liquid limit and natural water content i.e. bulk density increases with H_n, while liquid limit and natural water content decreases with H_n.

2.8 Atterberg Limits

According to Das (1998), Atterberg limit describes the consistency of fine-grained soils with varying moisture content (Figure 2.1). The concept of Atterberg limits for a soil is related to the amount of water that is attracted to the surface of the particles. The behavior of the soils can be divided into 4 basic states: solid, semisolid, plastic and liquid. In addition to this, the soil and water may flow like liquid if the moisture content is high.

The method stated in the BS 1377 for determining the liquid limit is the cone penetrometer method. According to Adel, Huat and Munzir (2003), it is impossible to perform this test if the material is too fibrous. Skempton and Petley (1970), however found a rather good correlation between liquid limit and ignition loss,

$$W_L = 0.50 + 5.0N \tag{2.4}$$

Where W_L = Liquid Limit

N = Ignition loss

Moreover, the correlation between the organic content and liquid limit proposed by Skempton and Petley (1970), Miyakawa (1960) and Farrell (1997) including samples taken from other areas according to Adel, Huat and Munzir (2003) is shown in Figure 2.2

2.9 Compaction of Soils

In general, compaction is the densification of soil by removal of air from void spaces between particles using mechanical energy. According to Cheng and Evett (1990), the effect of compression increases soil density and therefore produces three changes in soil:

1. Increase in shear strength
2. Decrease in future settlement
3. Decrease in permeability

These changes are beneficial for most construction as soil is used as an engineering material and in some cases the structure itself eg. Earth dams and highway embankments. In other words, compaction is a rather cheap and effective way to improve soil properties.

During the process of compaction, air and water is reduced in volume by the momentary application of loads. The amount of compaction is quantified in terms of dry unit weight of the soil. The process of increasing the density of soil will gradually cause a reduction in the volume of air. Being one of the most widely used and the oldest technique of soil improvement, compaction improves the engineering properties of the soil mass. Results from compaction test produces the optimum moisture content and maximum dry density. By using the results, the moisture needed to get the highest dry density is known. According to Das (1998), for organic soils, the increase in organic content increases the optimum moisture content for a given compactive effort.

2.10 Compression Behavior of Peat Soils

Structures built on soil are subjected to settlement. Some settlement is tolerable but some is not. In the case of peat, it is very important to know the cause of settlement and the means of predicting settlement. Civil engineers have the responsibility to make sure that there is no excessive settlement of the structure load of any civil engineering structure design. According to Das (1998), the soil settlement caused by loads may be divided into three broad categories :

I. Immediate settlement, which is caused by elastic deformation of dry soil and of moist and saturated soils without any change in the moisture content.

II. Primary consolidation settlement, which is the result of a volume change in saturated cohesive soils because of expulsion of the water that occupies the void spaces.

III. Secondary consolidation settlement, which is observed in saturated cohesive soils and is the results of the plastic adjustment of soil fabrics. It is an additional form of compression that occurs at a constant effective stress.

Consolidation is the process of expulsion of pore water due to loading resulting in the volume changes in soil with time. In granular soils, the settlement is instantaneous because the granular soils are freely drained. This is called immediate settlement. For fine grained soils i.e. clay, the water is squeezed out of the clay over a long period of time due to low permeability of the clay. This resulting settlement is called consolidation settlement.

2.10.1 Primary Compression

Primary consolidation is a very slow process and may continue over a long period of time. It is a process of expulsion of water from voids in fine grained soils as a result of increased loading. This results in the volume of soil changes with time.

2.10.2 Secondary Compression

Secondary consolidation starts when primary consolidation ends (after complete dissipation of excess pore water pressure). During this period of time, some settlement may occur because of the plastic adjustment of soil fabrics. In peat soils, secondary consolidation is more important than primary consolidation because of the presence of organic matter which influences greatly the fabric adjustment of soils. The results may vary for different organic matter content.

2.10.3 Tertiary Compression

Tertiary compression in one-dimensional laterally-confined compression can be defined as decrease of slope m in a plot of log strain rate versus log time, after a relatively constant stretch at m<1(den Haan (1994) quoted from Edil, 2003). Therefore tertiary compression simply means the decreasing strain rate however changing at an increasing rate (Edil, 2003). Figure 2.3 shows the primary, secondary and tertiary phases in the Oedometer compression.

2.10.4 One – Dimensional Consolidation

Consolidation is the process of expulsion of pore water, induced due to imposed load. In order to calculate the consolidation of a soil at any time after load increment, Terzaghi has developed a theory of one-dimensional consolidation (only the expulsion of pore water from the soil). Compare to the three-dimensional consolidation which is complex and has limited use, one-dimensional consolidation is simplification for solving consolidation problems. According to Terzaghi's theory, several assumptions are made :

- The soil is fully saturated and homogenous.
- Darcy's law is valid.

- Soil grains and water are incompressible.
- The compression and flow is one-dimensional.
- Co-efficient of permeability, k and co-efficient of consolidation, C_V is constant.
- There is unique relationship between void ratio and effective stress
- Soil is laterally confined.

2.10.5 One – Dimensional Consolidation Test

In the Oedometer test, the two main parameters required are compressibility and time effect. The compressibility is the measured amount by which the soil will compress when load is applied and soil is allowed to consolidate. Time effects is the time period over which consolidation settlement takes place. In soils with low permeability, the rate of settlement can take a much longer time (months, years, decades). Therefore it is important to estimate the rate of settlement in foundation design. Identifying this problem, Terzaghi proposed a theoretical approach to the process of consolidation by designing the first consolidation apparatus which is now called 'Oedometer (from Greek oidima meaning swelling).

Coefficient of Compressibility (a_v)

Defined as decrease in void ratio per unit increase in pressure

$$a_v = \frac{\Delta e}{\Delta p} \tag{2.5}$$

where,

Δe is the difference in void ratio

Δp is the difference in pressure

Coefficient of Volume Compressibility (m_v)

Defined as the compression of a soil layer per unit of original thickness due to a given unit increase in pressure.

$$m_v = \frac{a_v}{1+e_o} \tag{2.6}$$

or

$$m_v = \frac{a_v}{1+e_o} \frac{\Delta e}{\Delta p} \tag{2.7}$$

where e_o is the void ratio at the start of pressure increment interval, and is different from the original void ratio at the start of testing

Coefficient of Consolidation (C_v)

In general, the value of the coefficient of consolidation decreases as the liquid limit of soil increases (Das,1998). The range variation of C_v for a given liquid limit of soil is wide. Coefficient of consolidation is the parameter which relates the change in excess pore water pressure with respect to time, to the amount of water draining out of the voids of a clay prism during the same time due to consolidation.

Organic content also affects the coefficient of consolidation. Figure 2.4 shows the different amounts of organic content and the significant decrease in the coefficient of consolidation when the effective stress is increased. Another correlation is shown in Figure 2.5 on how the increase in organic content of an undisturbed sample causes the coefficient of consolidation to gradually increase (Kueh,1999 from Farrell, O'Neill & Morris, 1994)

For a given load increment on a specimen, two graphic methods are commonly used for determining C_v from laboratory one-dimensional consolidation test. One is the logarithm-of-time method proposed by Casagrande and Fadum (1940) and the other method is the square-root-of-time method suggested by Taylor (1942)*

Logarithm-of-time method,

$$C_v = \frac{0.197 H^2_{dr}}{t_{50}} \tag{2.8}$$

Square-root-of-time method,

$$C_v = \frac{0.848 H^2_{dr}}{t_{90}} \tag{2.9}$$

Where H_{dr} is the average longest drainage path during consolidation.

An alternative method as illustrated in Figure 2.6 is used for peat. Definitions and terms used for peat in Figure 2.6 are as follows :

* Cited from Kueh L.L. (1999)

Primary Consolidation (Cp) : Total compression accompanied by the dissipation of excess pore water pressure which takes place during a loading stage from the end of the primary consolidation to the previous stage to the end of the primary phase of the stage considered.

Time (t_p) : The time elapsed from the start of the load increment to the end of the primary phase.

Initial Compression (C_i) : The amount of compression which occurs from the instant of loading (t = 0) to the arbitrarily selected time t = 15s (0.25 min), being the time at which the first sensible settlement reading can usually be observed (d_0).

Compression ΔHp : The cumulative compression of the specimen up to the time t_p, normally when ΔHp extends a horizontal line it will be the d_{100} where 100% consolidation occurs.

Coefficient of Secondary Compression (Cα) : The ratio of the change in height of the specimen over one cycle of log time during the secondary phase, to the original height of the specimen.

Coefficient of Secondary Consolidation (Cα)

During the end of primary consolidation (after complete dissipation of excess pore water pressure), some settlement is observed due to the plastic adjustment of soil fabrics. This stage is called secondary consolidation. During secondary consolidation, the plot of deformation against the log of time is practically linear (Figure 2.7).

The variation of the void ratio with time for a given load increment will be similar to that shown in Figure 2.7. This variation is shown in Figure 2.8. The coefficient of secondary consolidation can be defined from Figure 2.8 as

$$C\alpha = \frac{\Delta e}{Log\,t_2 - Log\,t_1} = \frac{\Delta e}{Log\left(t_2/t_1\right)} \tag{2.10}$$

where,

$C\alpha$ = Coefficient of secondary consolidation

Δe = Change of void ratio

t_1, t_2 = time

Secondary consolidation may not be obvious for inorganic soils but may be prominent in highly organic soils. Based on different relationship between $C\alpha$ and Cc, Bowles (1984) suggested the values of $C\alpha$ / Cc ≤ 0.005 for inorganic soils and the corresponding values for organic soils are in the range of 0.07 to 0.10. Typical values of $C\alpha$ for several soil are given in Table 2.5

Compression Index (Cc)

After the laboratory test results for void ratio and pressure have been obtained, the compression index for the calculation of field settlement caused by consolidation can be determined by graphic construction as shown in Figure 2.9.

Furthermore, the formula used in calculating the C_c is taken from Das (1998). The formula used is shown in equation 2.11.

$$C_c = \frac{e_1 - e_2}{Log(^{p_2}/_{p_1})} \qquad (2.11)$$

where,

e_1, e_2, P_1 and P_2 are illustrated in Figure 2.10

TABLES

Table 2.1 Water retention properties of three different organic soils (source Dyal 1960, as quoted by Farnham and Finney 1965).

	Kind of organic soil horizon		
	Fibric	Mesic	Sapric
Water retention 1/10 bar(%)	570	193	163
Water retention 1/3 bar (%)	378	150	144
Water retention 15 bar (%)	67	84	100

Table 2.2 Calculated total pore space (% vol.) for tropical lowland peats in Indonesia (Andriesse, 1998)

	Specific bulk density (g/cm^3)		
	1.30	1.40	1.50
Non-specific bulk density	%volume	%volume	%volume
0.10	92.3	92.9	93.3
0.15	88.5	89.3	90.0
0.20	84.6	85.7	86.7
0.25	80.8	82.1	83.3

Table 2.3 Von Post Degree of humification (Liang, 1998)

Degree of humification	Description
H1	Completely undecomposed peat which releases almost clear water. Plant remains easily identifiable. No amorphous material present
H2	Almost completely undecomposed peat, which releases clear or yellowish water. Plant remains still easily identifiable. No amorphous material present.
H3	Very slightly decomposed peat which releases muddy brown water, but for which no peat passes between the fingers. Plant remains still identifiable and no amorphous materials present.
H4	Slightly decomposed peat, which releases very muddy dark water. No peat is passed between fingers but the plant remains are slightly pasty and have lost some of tbe identifiable features.

H5	Moderately decomposed peat which releases very "muddy" water with also very small amount of amorphous granular peat escaping between the fingers. The structure of plant remains is quite indistinct, although it is still possible to recognize certain features. The residue is strongly pasty.
H6	Moderately strongly decomposed peat with very a indistinct plant structure. When squeezed, about one-third of the peat escapes between the fingers. The residue is strongly pasty but show the plant structure more distinctly than before squeezing.
H7	Strongly 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 strongly decomposed peat with a large quantity of amorphous material and very dry 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, almost all of the peat escapes between the fingers as a fairly uniform paste.
H10	Completely decomposed peat with no discernible plant structure. When squeezed, all the wet peat escapes between the fingers.

Table 2.4 USDA classification based on fibre content (Govt. of Sarawak, 1990) (Harwant and Huat, 2003)

Type of peat	Fibre content	Von Post class
Fibric peat	Over 66%	H4 or less
Hemic peat	33 to 66%	H5 or H6
Sapric peat	less than 33%	H7

Table 2.5 Typical values of Coefficient of Secondary Compression, $C\alpha$ (after Ladd, 1967)

Types of Soil	$C\alpha$
Normally consolidated clays	0.005 to 0.02
Very plastic soils, Organic soils	≥0.03
Precompressed clay with OCR > 2	< 0.001

FIGURES

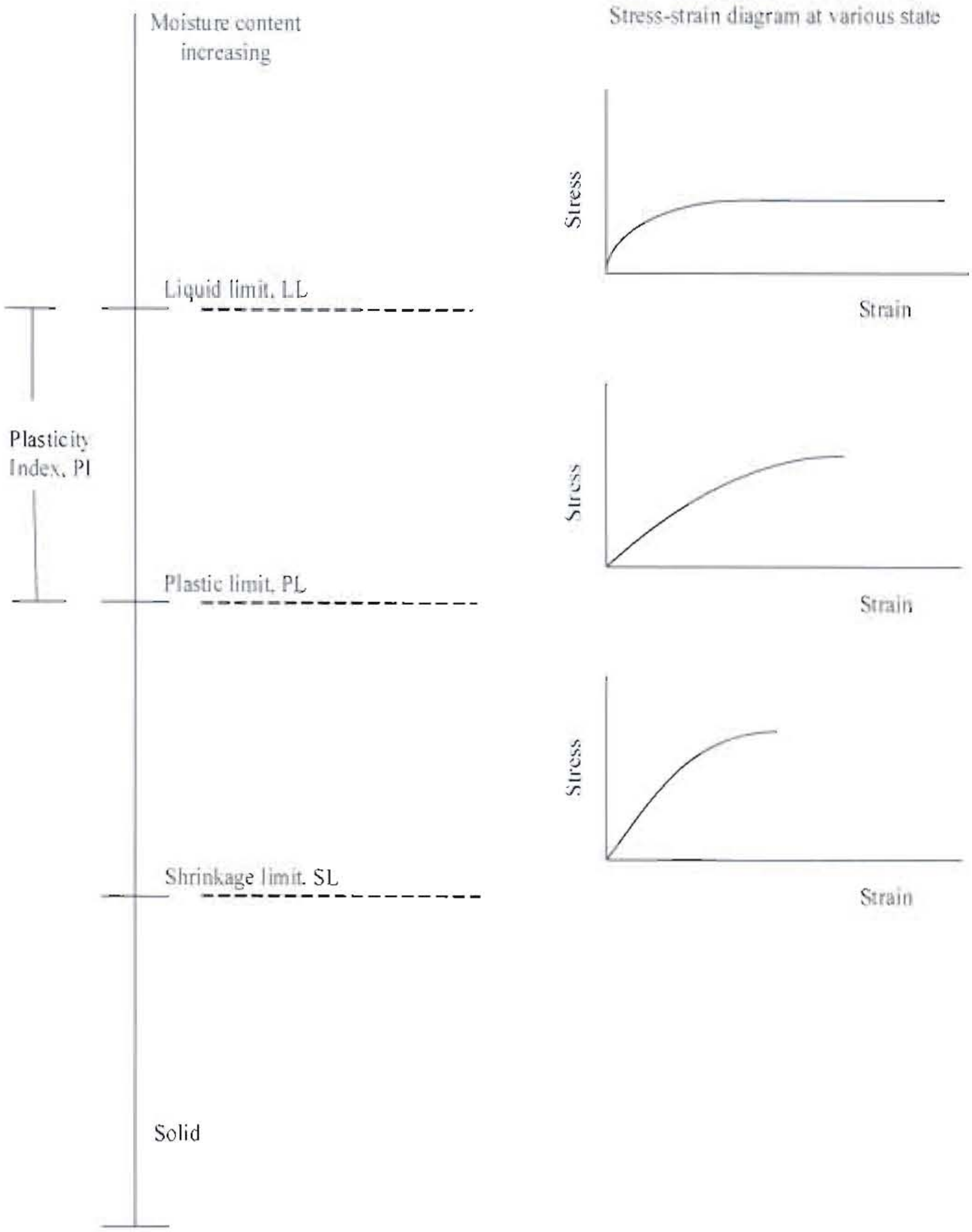


Figure 2.1 Atterberg limits (Das, 1998)

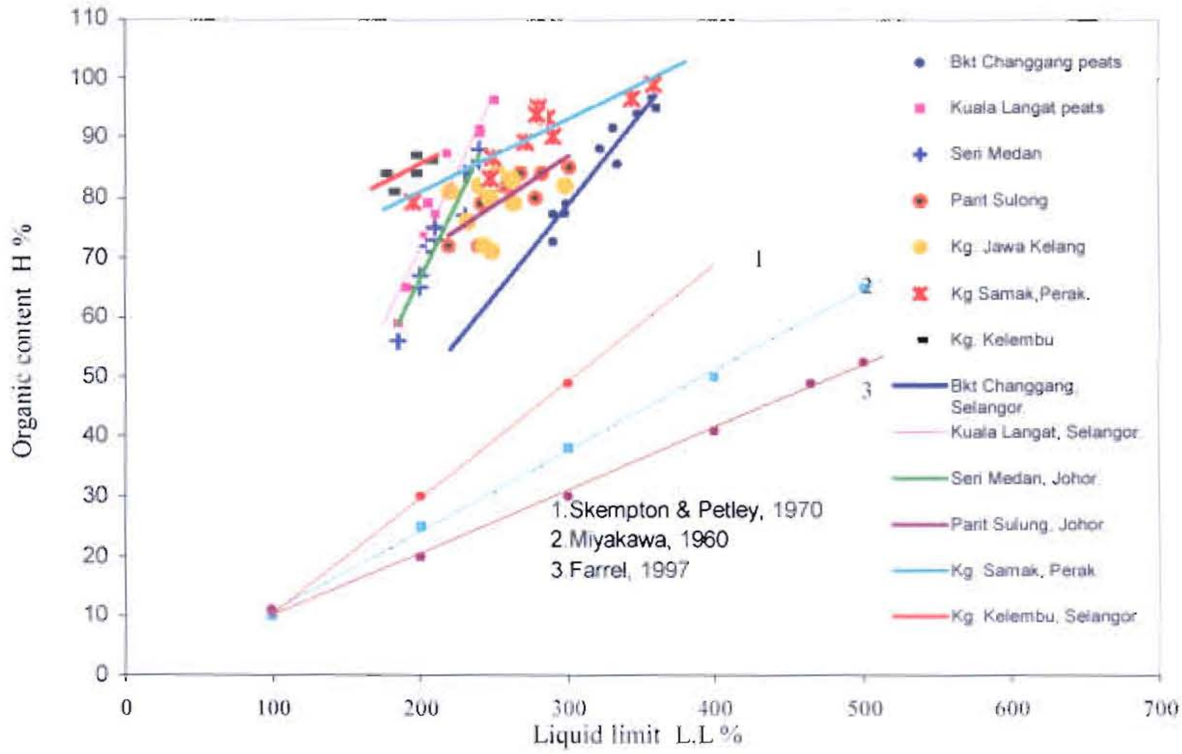


Figure 2.2 Correlation between organic content and liquid limit (Adel, Huat and Munzir ,2003)

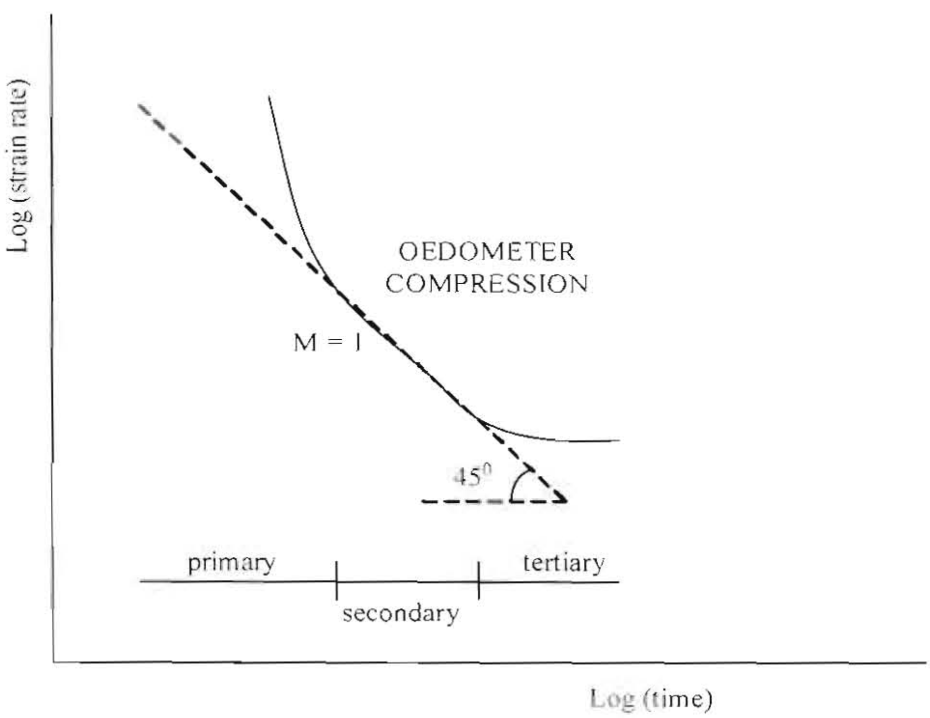


Figure 2.3 Primary, secondary, and tertiary phases in Oedometer compression (Kueh, 1999)

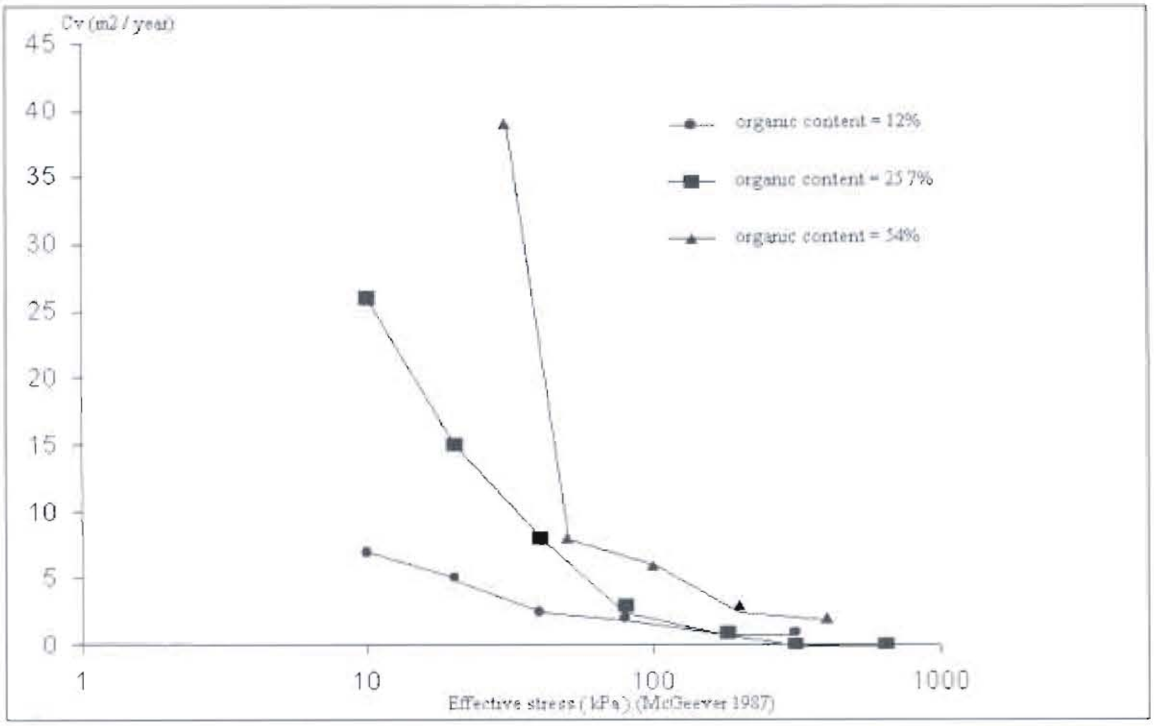


Figure. 2.4 Correlation between coefficient of consolidation and effective stress (Kueh, 1999)

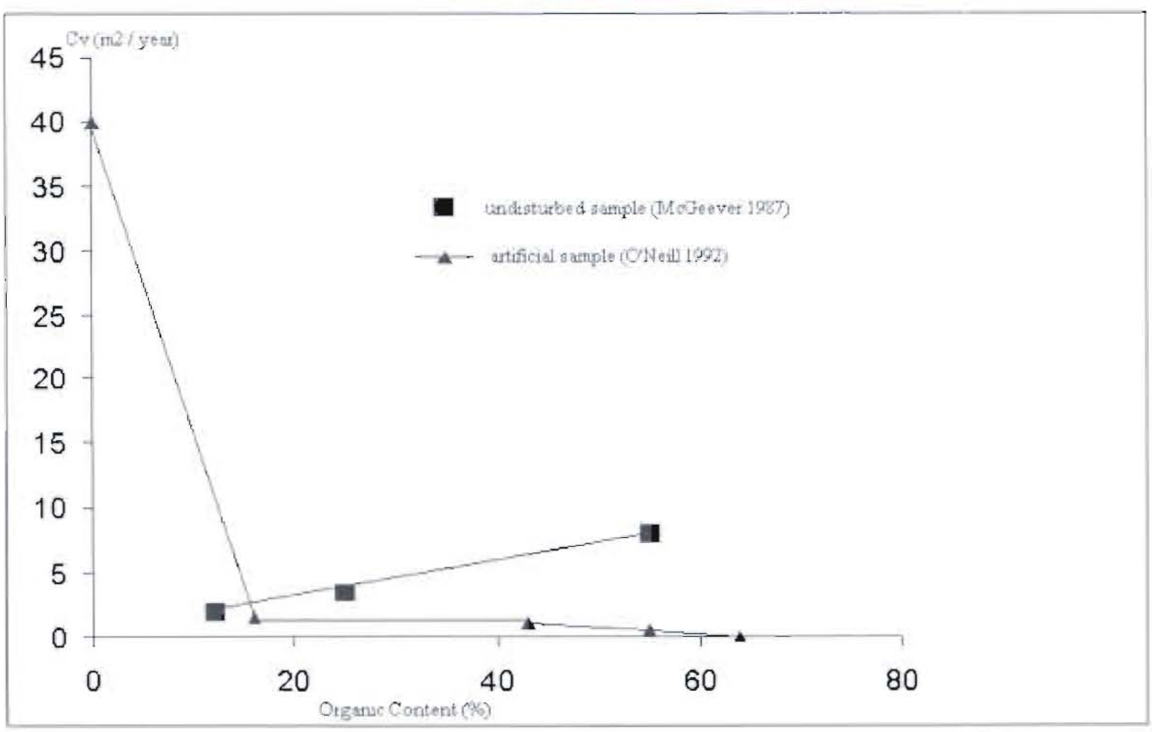


Figure 2.5 Correlation between coefficient of consolidation and organic content (Kueh, 1999)

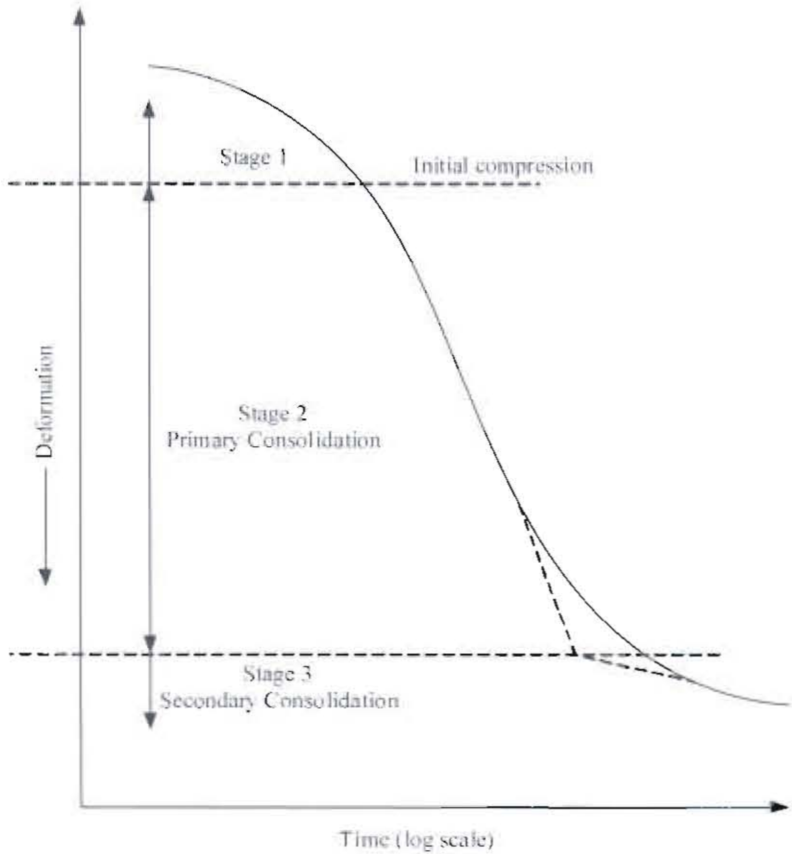


Figure 2.7 Time-deformation plot during consolidation for a given load increment (Das, 1998)

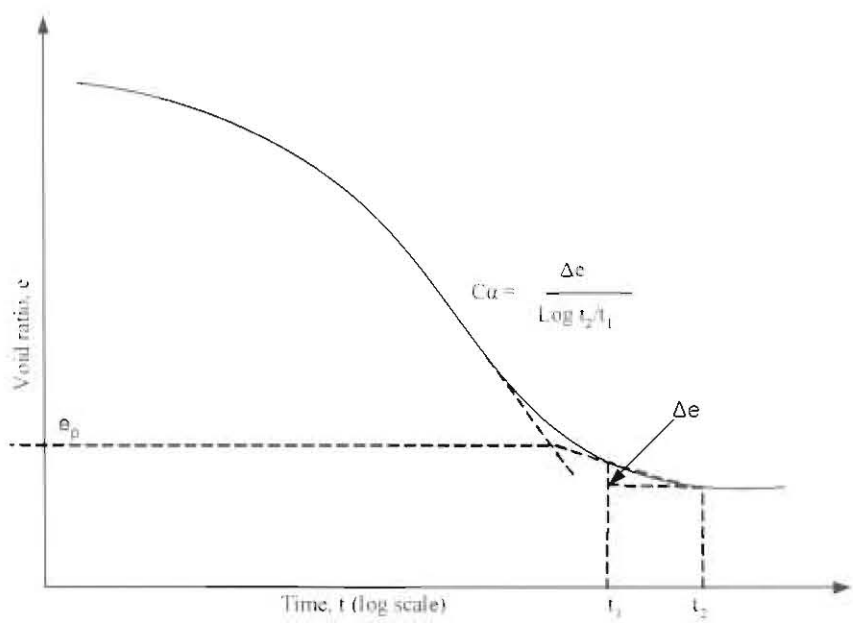


Figure 2.8 Variation of *e* with *log t* under a given load increment, and definition of secondary consolidation index (Das, 1998)

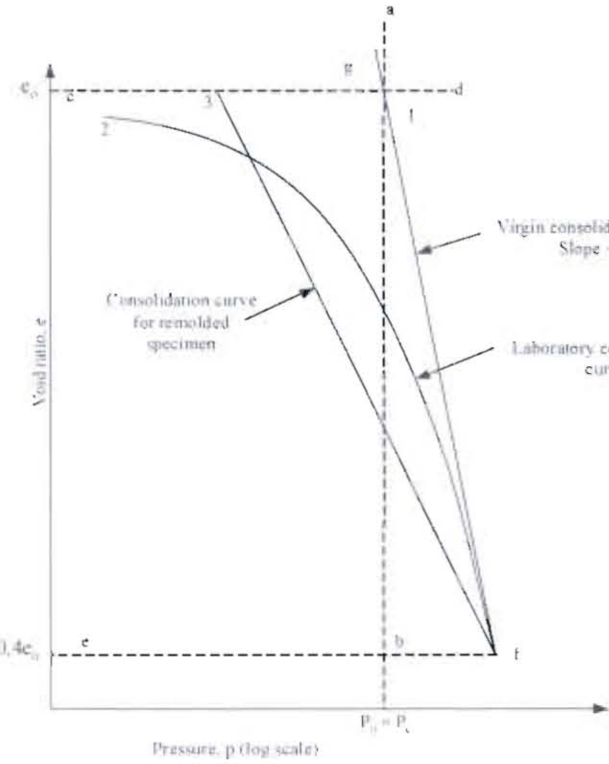


Figure 2.9 Consolidation characteristics of normally consolidated clay of low to medium sensitivity. (Das, 1998)

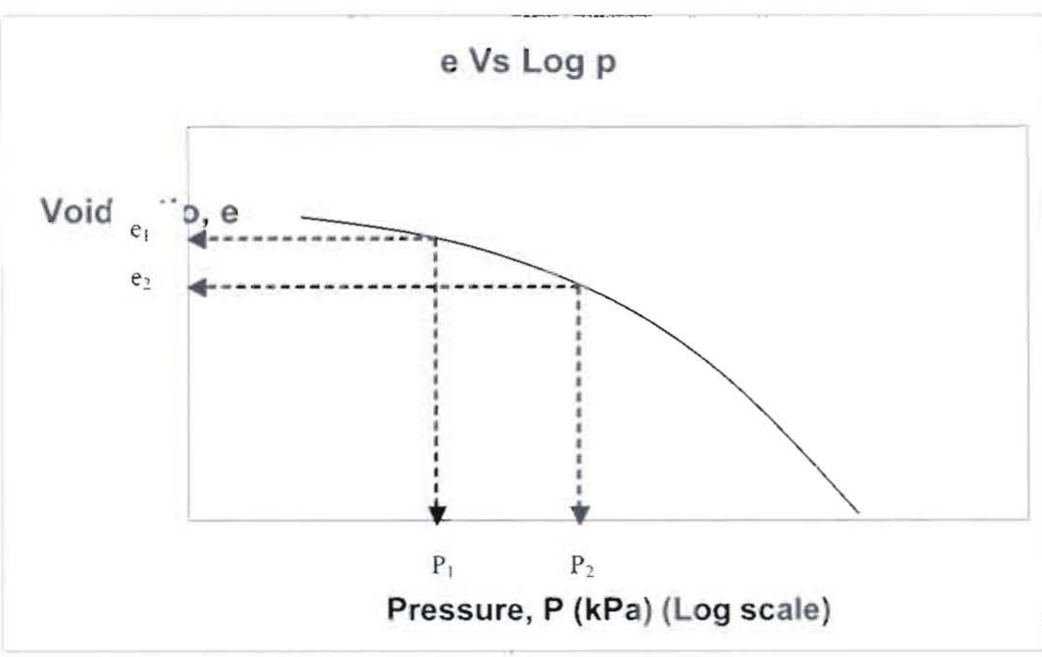


Figure 2.10 Graph of e log p curve (Das, 1998)

3 EXPERIMENTAL INVESTIGATION OF PEAT SOIL

3.1 General

The experimental investigation was mainly concerning the effects on compression behavior of peat which have been modified with sand. The reason for using sand as the modification properties are because sand is easily available, stable in properties, contains minimum organic content and also the conventional method for treating peat. The consolidation parameters consists of the coefficient of volume compressibility (m_v), coefficient of consolidation (Cv) and the compression index (C_c). Furthermore, the experimental work were carried out by using one sample of peat and later modifying it into five different samples according to the amount of sand added. This study consisted of the collection of samples, determination of moisture content, organic content, specific gravity, liquid limit and finally, the one – dimensional oedometer test. The procedures for conducting the experimental investigation was based on the British Standard BS 1377:1990 or otherwise stated. The following sections provide a brief description of the methods employed in the experimental investigation. The results obtained for peat soil and modified peat soil are presented separately in Section 4.

3.2 Collection of Samples

The collection of samples has been taken from a single site which is Matang. This is because there is sufficient supply of undisturbed peat in the rural areas in Matang. The sample was taken from a depth of approximately 0.5 – 1.0 m and placed in relevant containers according to their tests and packed accordingly during transportation to the laboratory.

3.3 Determination of Moisture Content (w)

Determination of moisture content is done by using the procedures detailed in BS 1377 : Part 2 : 1990. This method is also known as the oven-drying method. The method covers the determination of the moisture content of a specimen of soil as a percentage of its dry mass. The moisture content is calculated by using Equation 3.1 as shown below:

$$w = \frac{m_2 - m_3}{m_3 - m_1} \times 100\% \qquad (3.1)$$

where,

m_1 is the mass of container (in g)

m_2 is the mass of container and wet soil (in g)

m_3 is the mass of container and dry soil (in g)

The procedures include the cleaning and drying the container and weighing it to the nearest 0.01g (m_1). The soil sample which about 30 g is crumbled and placed loosely in the container and weighed to the nearest 0.01g (m_2). Then, soil sample is placed in the oven and dried at 105°C to 110°C. After 24 hours oven-dried, the container including the dry sample in weighed (m_3), and finally the moisture content of the soil is determined.

3.4 Particle Size Distribution

The hydrometer test is one of the methods that has been used in the measurement of the particle size distribution in the silt range (20 – 60 μm) for peat. (Figure 3.1) The test is done according to BS 1377 : Part 2 : 1990. By knowing the amount of soil in suspension and the time, the percentage of soil by weight finer than a given diameter is determined. Then, the equivalent particle diameter, D (in mm) is calculated by using the equation below

$$D = 0.005531\sqrt{\frac{\eta H_r}{(\rho_s - 1)t}} \tag{3.2}$$

where

η is the dynamic viscosity of water at the test temperature (in mPa)

H_r is the effective depth at which the density of the suspension is measured (in mm)

ρ_s is the particle density (in Mg/m^3)

t is the elapsed time (in min)

Finally, the percentage by mass, K of particles smaller than the corresponding equivalent particle diameter, D (Equation 3.1) is then calculated and was plotted against the corresponding particle diameter to obtain the percentage of peat fraction passing 2 μm.

$$K = \frac{100\rho_s}{m(\rho_s - 1)} \times R_d \tag{3.3}$$

where m is the mass of dry soil used (in g)

R_d is the modified hydrometer reading ($R_d = R_h' - R_o'$)

3.5 Determination of Ignition Loss and Organic Content

In order to determine the ignition loss, the organic content is calculated by applying Equation 2.1 in Section 2. This is because the equation shows the relationship between ignition loss (N) and organic content (H) (Adel, Huat and Munzir (2003), and Skempton and Petley (1970). The procedure for determining the ignition loss (N) is based on BS 1377 : Part 3 : 1990. A crucible is placed in the muffle furnace at a temperature of 440°C ± 25°C for 1 hour and then weighed as the mass of crucible (m_c). A soil sample which have been dried in the oven at 50°C ± 25°C for 24 hours is then weighed together with the crucible (m_3). Finally, to ignite the specimen, the soil sample together with the crucible is heated in the muffle furnace at 440°C ± 25°C for 4 hours and then weighed the sample to obtain the mass of crucible after ignition (m_4). From equation (3.4), the ignition loss (N) is obtained.

$$N = \frac{m_3 - m_4}{m_3 - m_c} \times 100\% \qquad (3.4)$$

where,

m_3 is the mass of crucible and oven-dry soil specimen (in g)

m_4 is the mass of crucible and specimen after ignition (in g)

m_c is the mass of crucible (in g)

N is the ignition loss

Finally, the organic content is calculated from Equation 2.1 as shown below.

$$H = 1 - 1.04(1 - N)$$

Where H is the Organic Content

N is the Ignition Loss

3.6 Determination of Specific Gravity

The specific gravity or particle density is determined using the small pyknometer method as described in BS 1377 : Part 2 : 1990. At least 2 specimens passing through the 425μm BS sieve, each between 5 g to 10 g of dry soils dried at 105°C to 110°C is used. Before the test, the bottle and stopper is cleaned and weighed to the nearest 0.001g giving the mass of density bottle (m_1). Then, the dried soil sample is weighed together with the bottle and stopper (m_2). Sufficient distilled water was then added to cover the soil in the bottle and left for 24 hours for the soil to settle. After that the air is removed gently by subjecting it to vacuum for about one hour until the air is dissolved. This is then weighed and recorded (m_3). The bottle is then cleaned and filled completely again with distilled water. The bottle is then weighed to obtain the mass of bottle when full of water (m_4). With all data taken, the specific gravity is calculated by using equation (3.5).

$$\rho_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \quad (3.5)$$

where,

m_1 is the mass of density bottle (in g)

m_2 is the mass of bottle and dry soil (in g)

m_3 is the mass of bottle, soil and water (in g)

m_4 is the mass of bottle when full of water only (in g)

3.7 Determination of Liquid Limit

There are two methods for determining the liquid limit of soils which are Cone Penetration method and the Casagrande method. In this study, the Cone Penetration method is chosen (Figure 3.2) because it has heen proved to be more consistent and less liable to experimental errors compared to those obtained by the Casagrande method (Sherwood and Ryley, 1968; quoted from Head, 1980). The test procedure is done according to BS 1377 : Part 2 : 1990. The sample passing the 425µm sieve weighing 200 g is taken. The soil is placed on flat glass and distilled water is added. The sample is mixed thoroughly with two palette knives until the mass becomes a thick homogeneous paste. The paste were then placed in an airtight container and left for 24 hours to allow uniform distribution of moisture without loss of water. After 24 hours, the sample is placed on a glass plate and mixed for 10 minutes. To allow first cone penetration reading to reach about 15 mm, more water is added. A portion of the sample were then pushed into a cup using a palette knife and excess soil is striked off. The penetration cone was then lowered until the tip touches soil surface, then locked in position. The dial gauge was lowered and the reading was recorded to the nearest 0.1 mm.

The cone was then released for a period of 5 ± 1 s and the readings recorded. The cone is lifted and cleaned. The moisture content of the sample is then determined. This process is repeated until the difference between the first and second penetration readings is less than 0.5mm. The average of the two penetration is recorded. The test is repeated five times by increasing the distilled water. The moisture content and cone penetration relationship is then plotted. The moisture content corresponding to a cone penetration of 20 mm is taken as the liquid limit.

3.8 Compaction Tests

Compaction of soil is done to obtain the relationship between compacted dry density and soil moisture content between peat soil and modified peat soil. The method of conducting the test is by using the standard proctor test as suggested by BS 1377 : Part 4 : 1990. To avoid the laborious hand compaction, an automatic compaction machine is used. In this project, the light compaction test in which a 2.5 kg rammer falling through a height of 300 mm is used to compact the soil in three layers into all compaction mould. In addition, an automatic blow pattern ensures optimum compaction for each layer of soil, since the plate in which the mould is placed rotates in equal steps on a base that is extremely stable. The number of blows per layer used is 25 times. This is because peat soil is fine-grained and easily compacted. The bulk density, ρ (in Mg/m^3) of each sample is calculated from the equation below.

$$\rho = \frac{m_2 - m_1}{v} \qquad (3.6)$$

where,

v is the internal volume of the mould (in cm^3)

m_1 is the mass of mould and baseplate (in g)

m_2 is the mass of mould, baseplate and compacted soil (in g)

And the dry density, ρ_d (in Mg/m^3) is calculated

$$\rho = \frac{100\rho}{100 + w} \qquad (3.7)$$

where w is the moisture content of the soil (in %)

From a series of trials, the value of dry densities and moisture content are plotted as ordinates. A curve is then plotted in order to obtain the maximum dry density and optimum moisture content of peat and modified peat soil.

3.9 One – Dimensional Consolidation Test

3.9.1 Preparation of Soil Samples

Several peat soil samples is taken from a single location and later modified into 4 different samples using different amount of sand. This is to investigate the effects of the modification towards the consolidation parameters of the sample. The consolidation apparatus (also known as the oedometer) is used to carry out the test.

All procedures of the test are done according to BS 1377 : Part 5 : 1990. The consolidation apparatus can referred to Figure 3.3. The samples are compacted at optimum moisture content by using the standard Proctor test. The amount of ratio for modification is stated below;

M1	:	Original peat
M2	:	Peat + 10% sand
M3	:	Peat + 20% sand
M4	:	Peat + 40% sand

3.9.2 Preparation of Test Specimen and Consolidation Cell

The sample of undisturbed soil is obtained using a sample tube. Short length of samples is then extruded in the lab. Before beginning the test, porous plates are check so that they are not clogged and the plates are highly permeable. The porous plates are then boiled in distilled water for at least 20 minutes. A consolidation ring (75 mm diameter and 20 mm height) which is to be used is also cleaned and weighed. This ring is then placed and pressed on top of the soil sample which was extruded earlier. The extra length of soil is then cut by using a fine piano wire. The sample plus ring is then weighed.

By using the procedures stated in the BS 1377, the porous plate is placed centrally in the consolidation cell. The specimen is then placed centrally on top of the porous plate. Another porous plate and a loading cap is later placed on top of the specimen. After the consolidation cell is positioned on the bed of the loading apparatus, the counterbalanced loading beam is adjusted so that when the load-transmitting members just make contact with the loading cap the beam is slightly above horizontal position. The compression gauge is then clamp securely into position to measure the relative movement between the loading cap and the base of the cell. When the test is started, the displacement in relative to time is recorded. The specimen is fully saturated by means the cell is filled with distilled water before starting and also filled all the time during the test.

In each stage, an increment of load is applied to increase the pressure on the soil specimens. The loading increments used in this study is in the following range : 5, 10, 20, and 40 (kg). Each load increment was done for 24 hours because the sample is considered as fully consolidated and saturated. After the final pressure applied is recorded, the load is removed from the test specimen. The ring and specimen is then weighed before taking out the specimen to oven dry for 24 hours to determine the final moisture content and dry weight of the soil. The following data is recorded after the test has been completed.

- The initial and final dimension of the sample;
- The initial and final moisture content;
- Plotting the graph for compression vs time (log time or square root time) for each load increment; and
- Values of m_v (in m^2/MN), C_v (cm^2/min), and C_c.

FIGURES

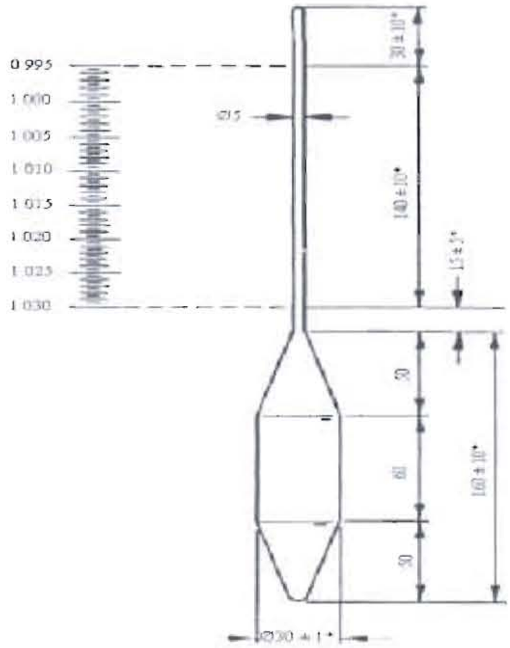
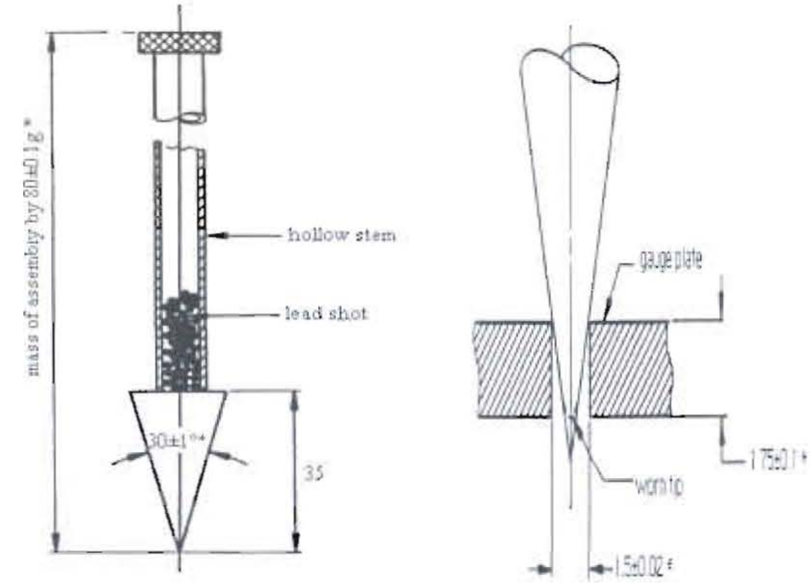


Figure 3.1 Hydrometer for determination of fine particle size (BS 1377:Part 2:1990)



a) **b)**

Figure 3.2 Cone Penetration Apparatus a) cone assembly, b) tip gauge (BS 1377:Part 2:1990)

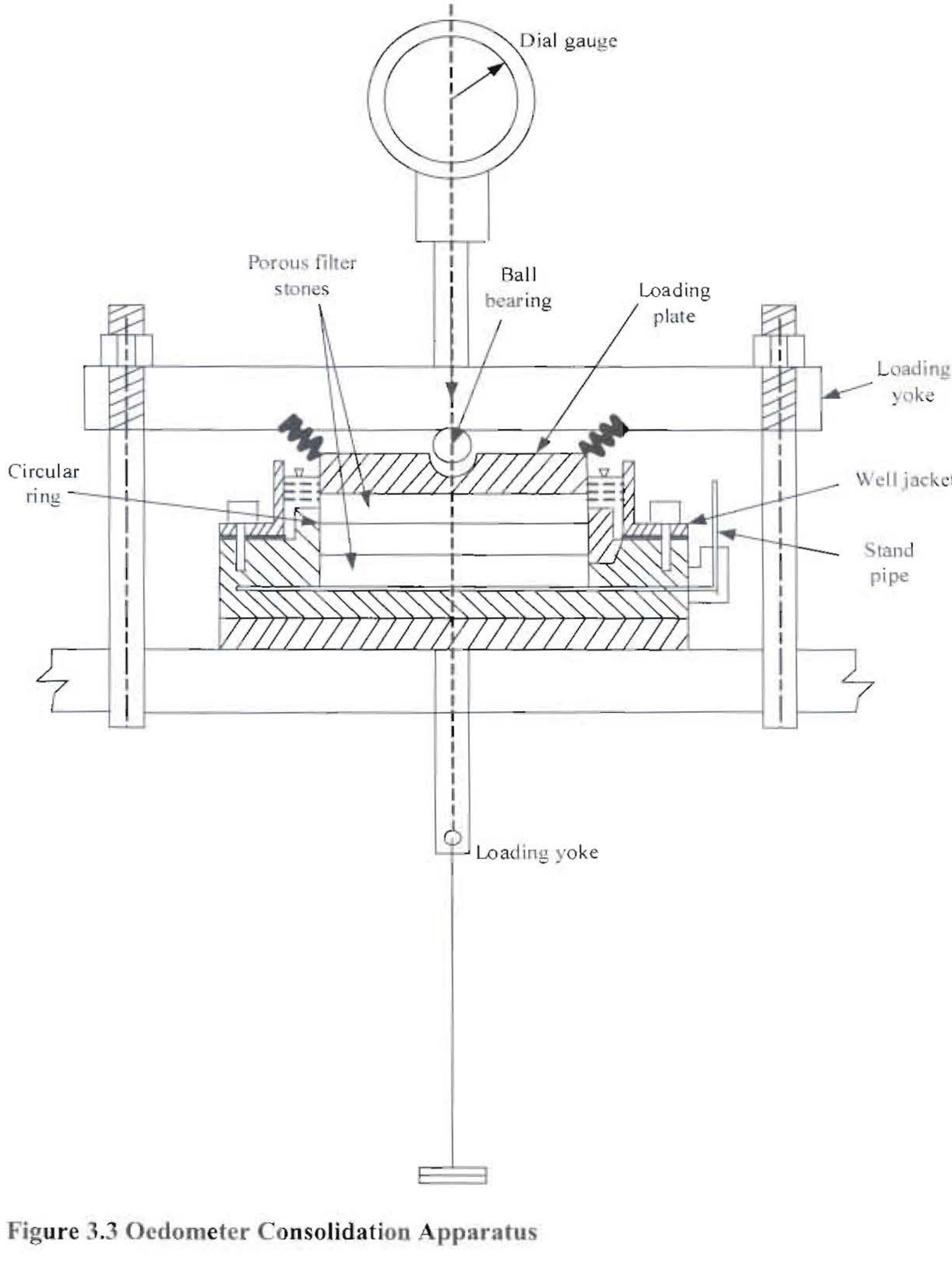


Figure 3.3 Oedometer Consolidation Apparatus

4 EXPERIMENTAL RESULTS AND DISCUSSION

4.1 General

There are three consolidation parameters to be determined in this study:

(i) Coefficient of consolidation (C_v),

(ii) Coefficient of volume compressibility (m_v), and

(iii) Coefficient of compression index (C_c).

The tests were carried out using soil samples taken from a single location and later modified into 4 different samples:

M1	:	Original peat
M2	:	Peat + 10% sand
M3	:	Peat + 20% sand
M4	:	Peat + 40% sand

In this section, the results of the experimental investigation are presented and discussed. Basically, the results obtained are from the soil classification test and one – dimensional consolidation test. Finally, the results from the experiments are discussed in the following sections.

4.2 Degree of Humification

During the process of sample collection, the sample was analyzed according to its structure and classified using the Von Post Degree of humification. From Table 2.3, the soil sample is classified as H5 which is moderately decomposed peat, that releases very "muddy" water with also very small amount of amorphous granular peat escaping between the fingers. The structure of plant remains is quite indistinct, although it is still possible to recognize certain features. The residue is strongly pasty.

4.3 Loss on Ignition and Organic Content of Soil Sample

Organic content of peat soil is determined from the Loss on Ignition test as stated in BS 1377 : Part 3 : 1990 together with equation (2.1) developed by Skempton and Petley (1970) as stated by Adel, Huat and Munzir (2003). The results of the loss on ignition and organic content are shown in Table 4.1. From Table 4.1, it shows that the organic content for original peat is 95.57 %. It is also seen that the organic content decreases for every increment of modification.

4.4 Moisture Content of Soil Sample

In general, the higher the organic content, the higher the moisture content of peat. However, it depends on the location whether the samples are taken from higher ground or waterlogged locations. The sample taken from Matang (Table 4.2) shows high in moisture content due to high in organic content and was taken from the waterlogged conditions area.

4.5 Particle Size Distribution

The method used to obtain the particle size distribution is the Hydrometer test. This is suitable for fine grained soil such as peat and however cannot be performed for samples which had been modified with sand. The test are performed in accordance to BS 1377 : Part 2 : 1990. Furthermore, from the hydrometer test the results show that the soil contains about 22 % passing 2 μm. The particle size distribution curve for sample M1 (original peat) are shown in Figure 4.1. Figure 4.2 shows the calibration of hydrometer readings to determine the equation of the calibration line by plotting the values obtained for effective depth (H_e) against true hydrometer reading (R_h). In Table 4.3 presents the hydrometer sedimentation test data, results and corresponding calculation.

4.6 Effects of Organic Content on Specific Gravity

The specific gravity test is done using the small pyknometer as stated in BS 1377 : Part 2 : 1990. According to Edil (2003), the specific gravity of solids in peat and organic soils is greater than 1 and increases with increasing mineral content. Using the data from the small pyknometer test, the specific gravity for each sample is calculated from Equation (3.5). The results for the four different samples are shown below in Table 4.4. Here, from Table 4.4, the value of specific gravity increases for every increment of modification. This is because for every increment of sand, the organic content of peat decreases. The experiment results indicated that the increasing in organic content caused the decreasing in the specific gravity of the soil (Figure 4.3).

4.7 Effects of Organic Content on Liquid Limit

Liquid limit (LL) is the moisture content corresponding to a penetration of 20 mm by using the Cone Penetration method. The penetration of the cone into the soil sample was measured at a variety of moisture content. Thus, the liquid limit obtained between peat soil and modified peat soil is tabulated in Table 4.5. Besides that, the determination of plastic limit (PL) and plasticity index (PI) are also shown in Table 4.5. Furthermore, the correlation between organic content and liquid limit of the four samples presented in Figure 4.4 clearly shows that the liquid limit increases as the organic content increased. Therefore, the results obtained from this investigation were found to be in general agreement with Adel, Huat and Munzir (2003) (Figure 2.2).

4.8 Effects of Organic Content on Compaction

The compaction test was carried out by using the standard Proctor test as suggested in BS 1377 : Part 4 : 1990. From a series of trials on each sample, the values of dry density and moisture content are plotted to form a curve where the maximum dry density and optimum moisture content is obtained. The results for the maximum dry density and optimum moisture content for each sample (M1, M2, M3 and M4) are summarized in Figure 4.5 and also tabulated in Table 4.6. Moreover, the results obtained from the experimental investigation have been found to be in agreement with the results reported by Das (1998) which indicated that the optimum moisture content for a sample increases as the organic content increases. Figure 4.6 shows the results which indicates the increase in optimum moisture content for every increasing organic content for all four samples.

4.9 Coefficient of Consolidation (C_v)

The coefficient of consolidation, C_v was determined by using the Square-root-of-time method as described in Chapter 2. The results of the coefficient of consolidation C_v is presented in Table 4.7. The experimental results for deformation versus square root of time for different load increment between peat and modified peat soil are presented in Figure 4.7, 4.8, 4.9 and 4.10 respectively. Furthermore, the relationship between the coefficient of consolidation, C_v at t_{90} and the load increment for each sample are summarized in Figure 4.11.

From all figures plotted, it was observed that all four samples have a similar trend. They indicate the high decrease in C_v at the beginning of the pressure increment. This is because most of the water was drained out of the voids during the initial pressure increment. Due to the limitations of time and equipment, it was impossible to determine further the reasons representing the behavior of these samples.

4.10 Coefficient of Compression Index (C_c)

The coefficient of compression index, C_c for each of the sample is calculated based on the e-log p curve graph presented in Figure 4.12, 4.13. 4.14 and 4.15. From the results obtained, it shows that the coefficient of compression index, C_c increases with an increase of moisture content (Table 4.8). In another words, the more the sample was modified, the less is the results of its C_c. This is because the void ratio decreases as the sample was further modified. Thus, the results obtained from the experiment were found to be in general agreement with Kueh (1999). Figure 4.16

shows the relationship between the organic content and the coefficient of compression index for each sample obtained.

4.11 Coefficient of Volume Compressibility (m_v)

The coefficient of volume compressibility, m_v is calculated by using equation (2.5) and (2.6) in Section 2. The results of m_v for each sample and load increment is shown in Table 4.9. The value of the volume of compressibility, m_v obtained from the experiment is plotted versus pressure which is presented in Figure 4.17.

From Table 4.10, it can be seen that the average m_v decreases when modification is increased. In correlation, the average m_v decreases as the organic content decreases.

TABLES

Table 4.1 Organic content of peat soil and modified peat soil

Sample	Loss on ignition, N (%)	Organic content, H (%)
M1	95.74	95.57
M2	88.03	87.55
M3	74.04	73.00
M4	50.17	48.18

Table 4.2 Moisture content of soil sample

Location	Moisture content (%)
Matang	698.45

Table 4.3 Hydrometer sedimentation test data, results and calculations

Elapsed time, t (min)	Temperature (°C)	Hydrometer reading, Rh	True reading, Rh'	Effective depth, He (mm)	Particle diameter, D (mm)	Corrected reading, R	% finer than D, K(%)
0							
0.25	25	11.50	21.5002	100.49	0.1745	9.50	97.84
0.5	25	11.50	21.5002	100.49	0.1234	9.50	97.84
1	25	11.50	21.5002	100.49	0.0872	9.50	97.84
2	25	11.30	21.7002	100.69	0.0617	9.30	95.78
4	25	11.00	22.0002	100.99	0.0437	9.00	92.69
9	25	10.00	23.0002	101.99	0.0293	8.00	82.39
15	25	8.00	25.0002	103.99	0.0229	6.00	61.79
30	25	7.00	26.0002	104.99	0.0163	5.00	51.49
60	25	6.10	26.9002	105.89	0.0116	4.10	42.22
120	25	5.10	27.9002	106.89	0.0082	3.10	31.93
1440	25	3.90	29.1002	108.09	0.0024	1.90	19.57

Table 4.4 Specific gravity for all four samples

Sample	M1	M2	M3	M4
Specific gravity, ρs	1.241	1.274	1.346	1.535

Table 4.5 Liquid limit for four samples

Sample	M1	M2	M3	M4
Liquid limit (%)	230	223	218	209
Plastic limit (%)	128.2	120.0	109.4	99.2
Plasticity Index (PI) (%)	101.6	103.0	108.6	109.8

Table 4.6 Maximum dry density and optimum moisture content for each sample

Sample	M1	M2	M3	M4
Maximum Dry Density (Mg/m^3)	0.524	0.617	0.703	0.845
Optimum Moisture Content (%)	104.1	77.5	58.8	38.0

Table 4.7 Results of Coefficient of consolidation for samples M1, M2, M3 and M4 for different load increments

Sample	C_v for 0 – 11.41 kPa (cm^2/min)	C_v for 11.41 – 22.82 kPa (cm^2/min)	C_v for 22.82 – 45.63 kPa (cm^2/min)	C_v for 45.63 – 91.26 kPa (cm^2/min)
M1	0.262	0.136	0.125	0.125
M2	0.235	0.141	0.125	0.094
M3	0.848	0.377	0.212	0.235
M4	0.136	0.160	0.331	0.175

Table 4.8 Coefficient of Compression Index for each sample

Sample	M1	M2	M3	M4
C_c	6.645×10^{-3}	4.153×10^{-3}	3.322×10^{-3}	2.990×10^{-3}

Table 4.9 Coefficient of volume compressibility for sample M1, M2, M3 and M4 for different load increments

Sample	m_v for 0 – 11.41 kPa (m^2/kN)	m_v for 11.41 – 22.82 kPa (m^2/kN)	m_v for 22.82 – 45.63 kPa (m^2/kN)	m_v for 45.63 – 91.26 kPa (m^2/kN)
M1	1.418×10^{-4}	1.758×10^{-4}	1.140×10^{-4}	7.048×10^{-5}
M2	6.30×10^{-5}	8.037×10^{-5}	5.738×10^{-5}	3.959×10^{-5}
M3	4.417×10^{-5}	6.137×10^{-5}	4.465×10^{-5}	3.523×10^{-5}
M4	3.617×10^{-5}	5.323×10^{-5}	3.981×10^{-5}	3.114×10^{-5}

Table 4.10 Value of average m_v

Sample	M1	M2	M3	M4
Average m_v	1.255×10^{-4}	6.009×10^{-5}	4.636×10^{-5}	4.009×10^{-5}

FIGURES

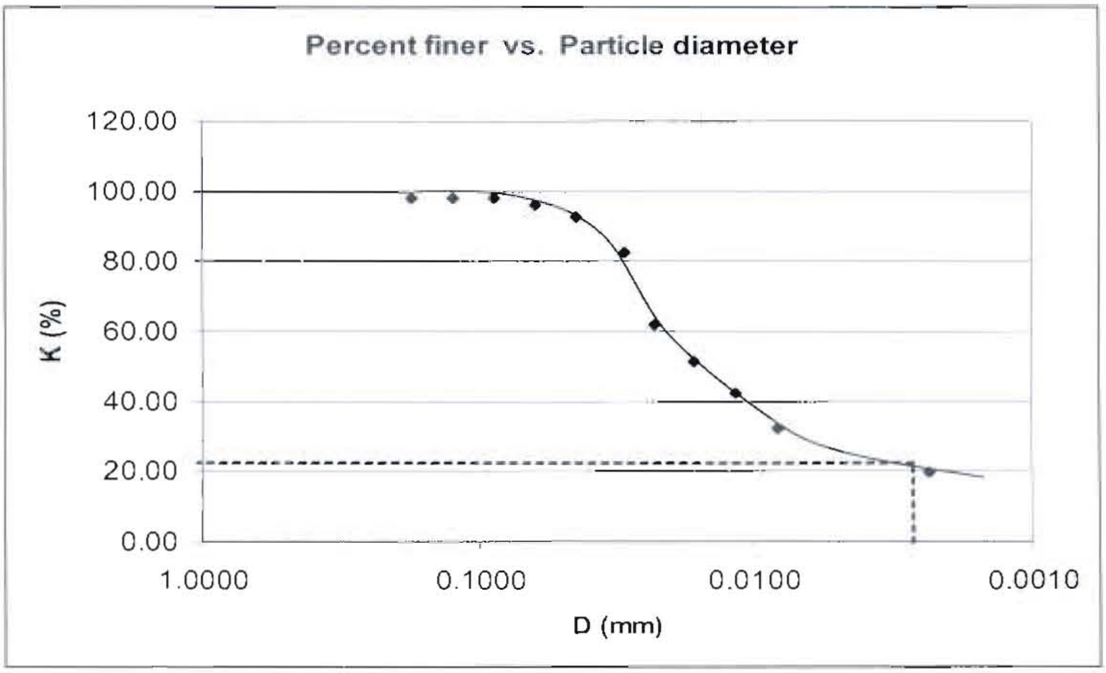


Figure 4.1 Particle size distribution curve

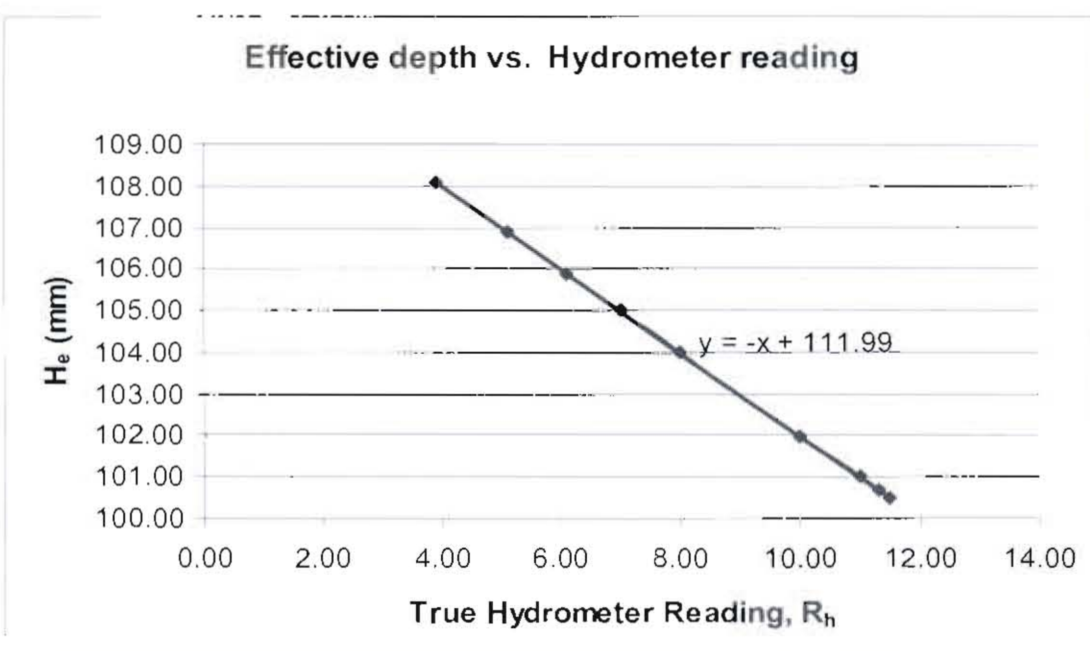


Figure 4.2 Hydrometer calibration curve

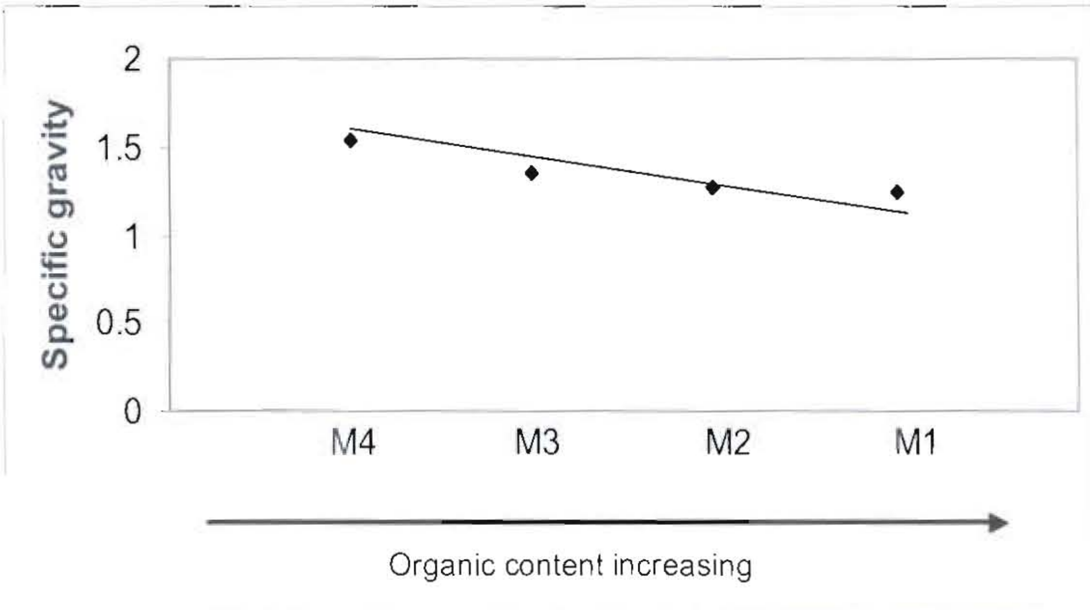


Figure 4.3 Relationship between organic content and specific gravity

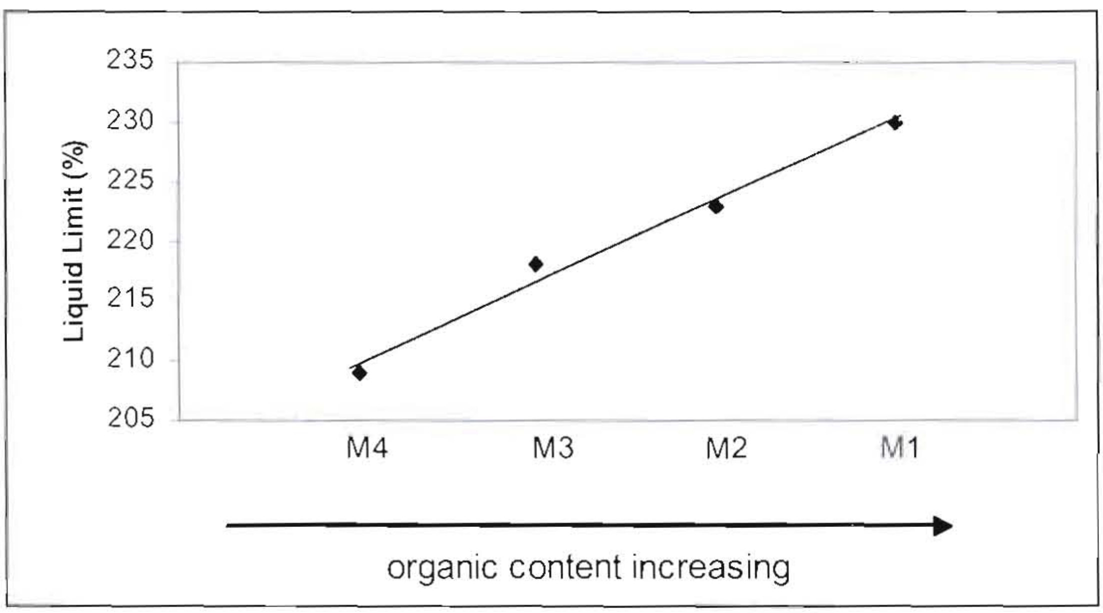


Figure 4.4 Relationship between organic content and liquid limit

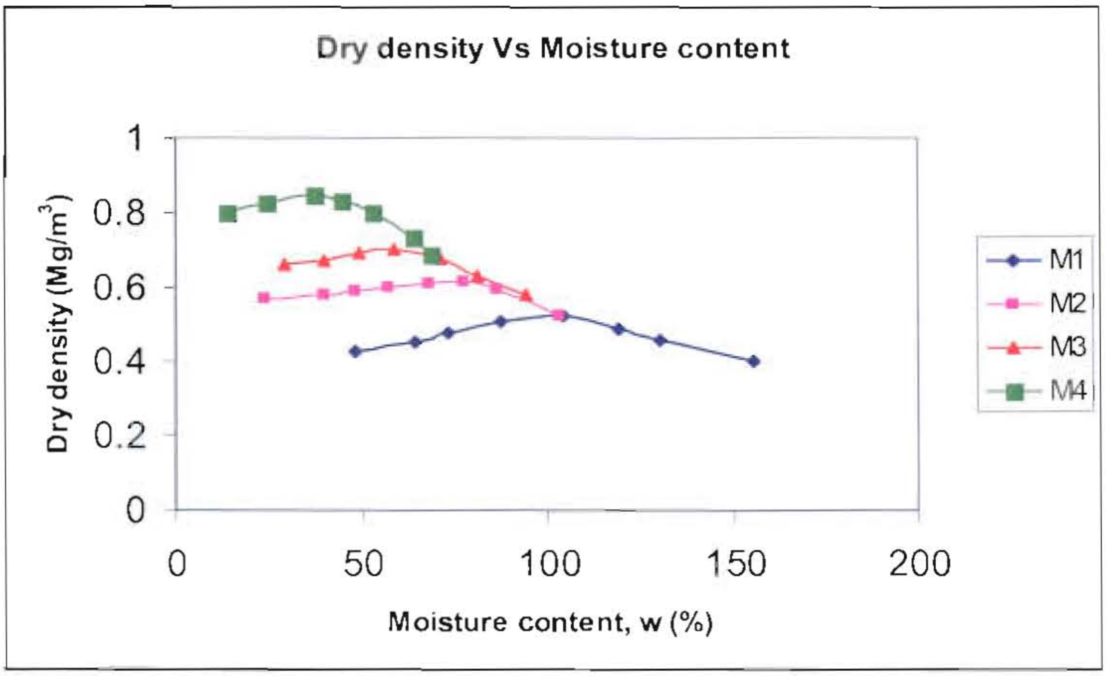


Figure 4.5 Summary of compaction test results obtained for M1, M2, M3 and M4

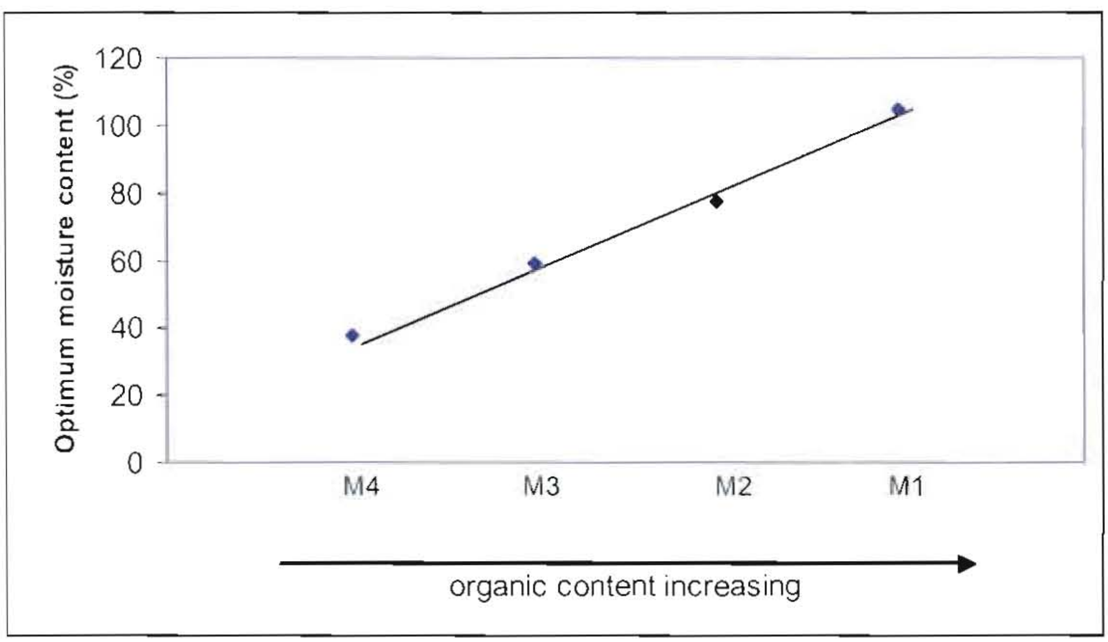


Figure 4.6 Relationship between organic content and optimum moisture content

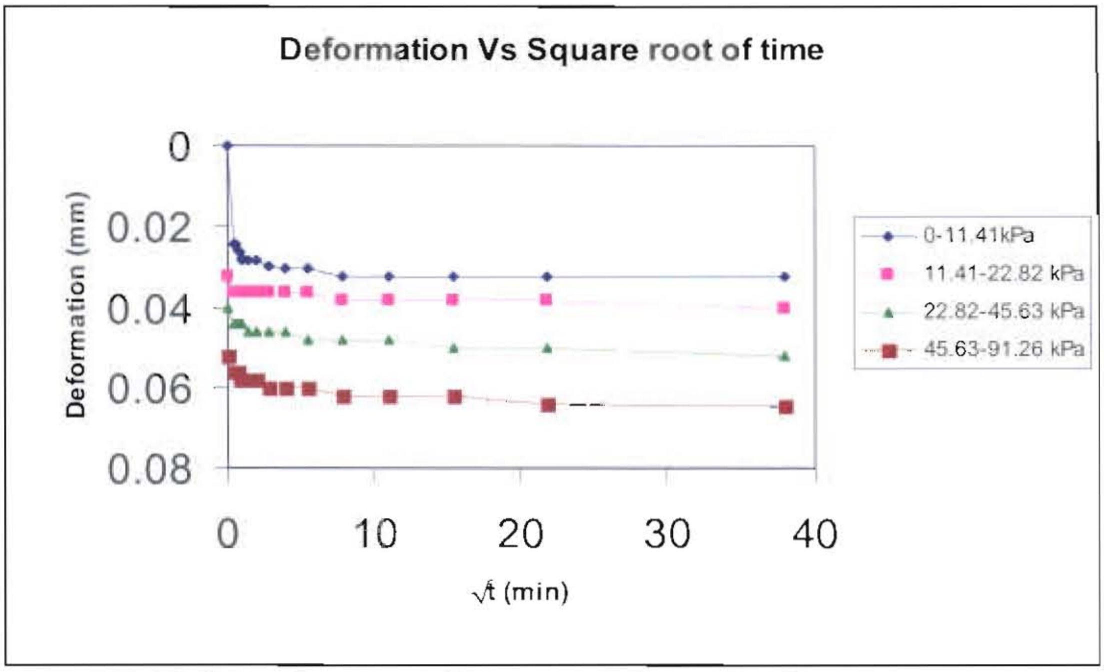


Figure 4.7 Deformation versus Square root of time for M1

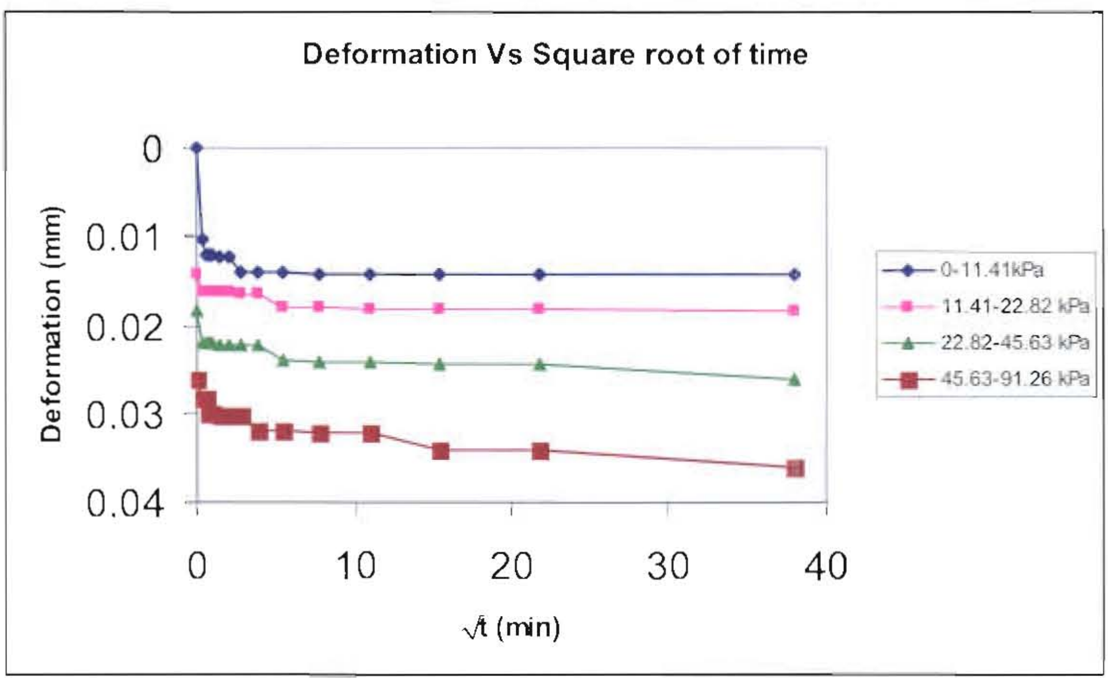


Figure 4.8 Deformation versus Square root of time for M2

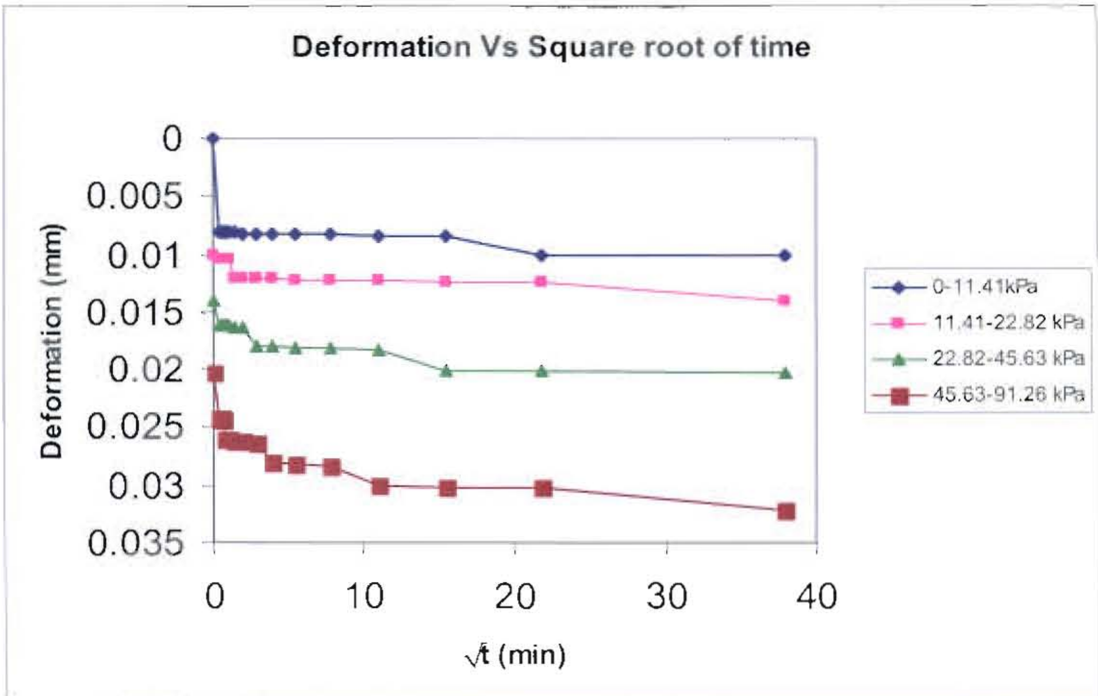


Figure 4.9 Deformation versus Square root of time for M3

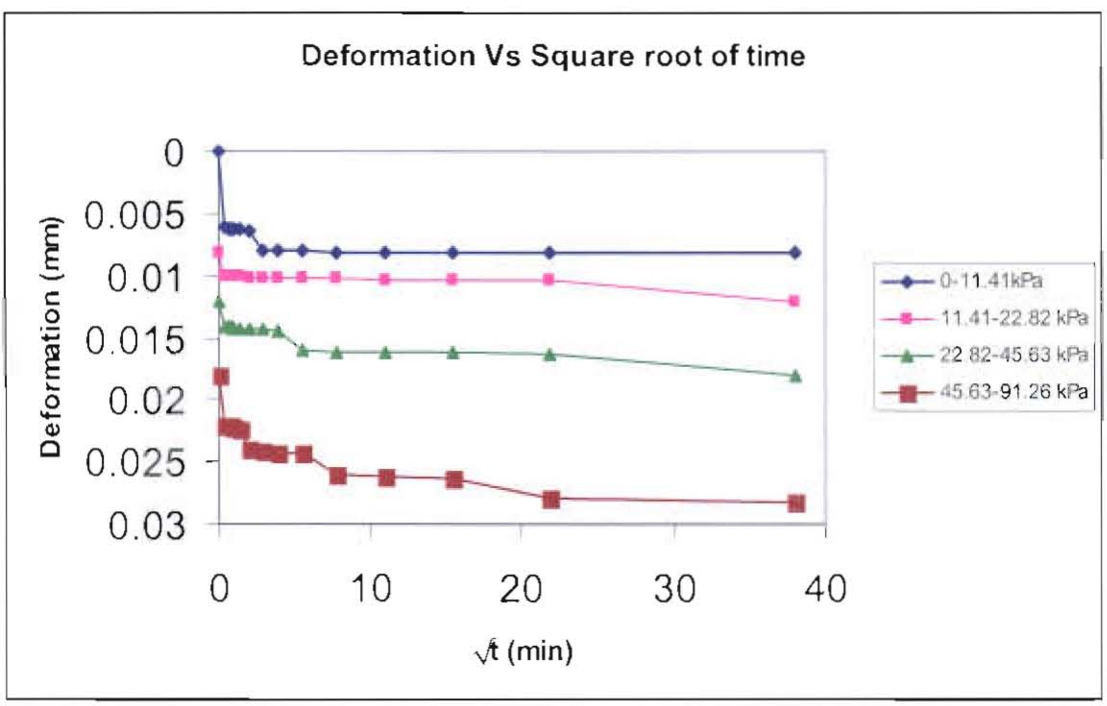


Figure 4.10 Deformation versus Square root of time for M4

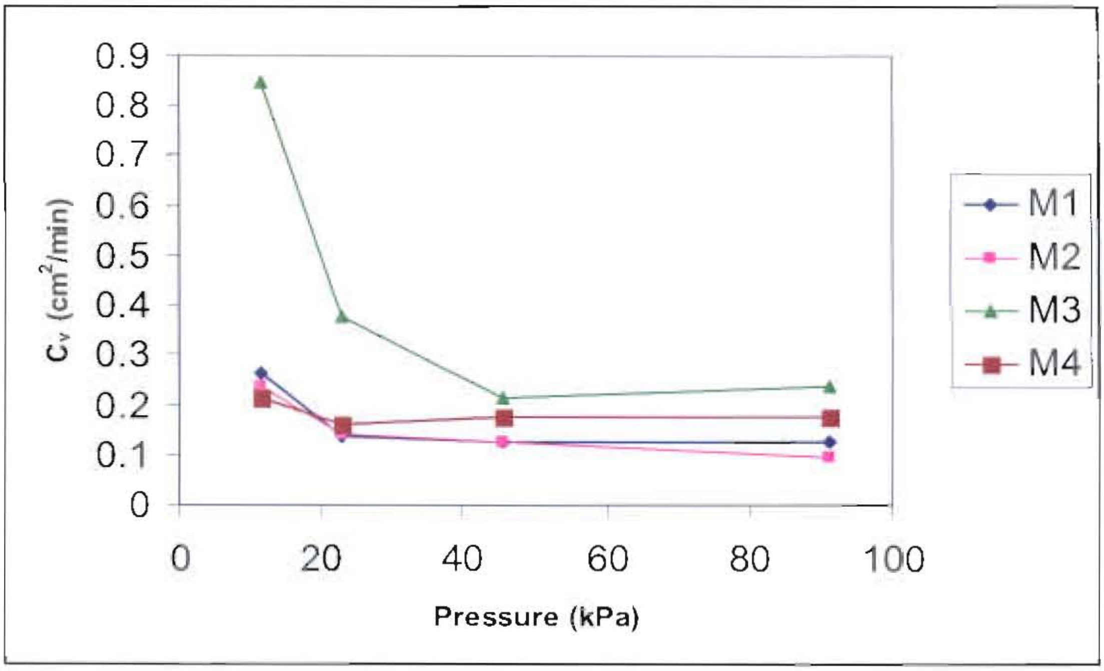


Figure 4.11 Relationship between coefficient of consolidation, C_v and pressure for sample M1, M2, M3 and M4

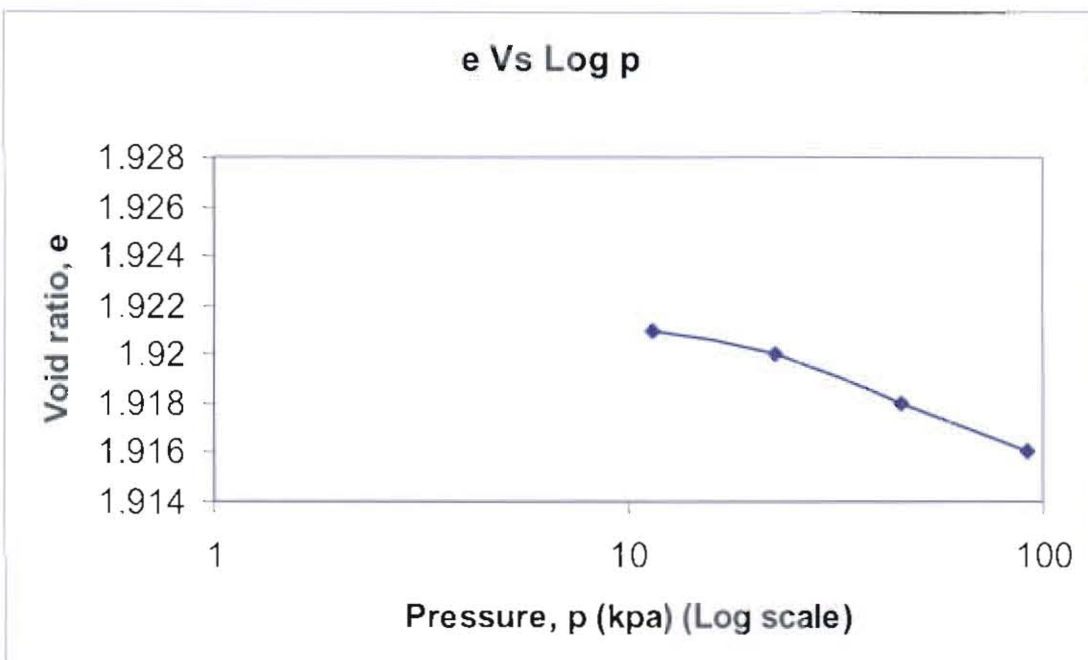


Figure 4.12 Graph e log p for sample M1

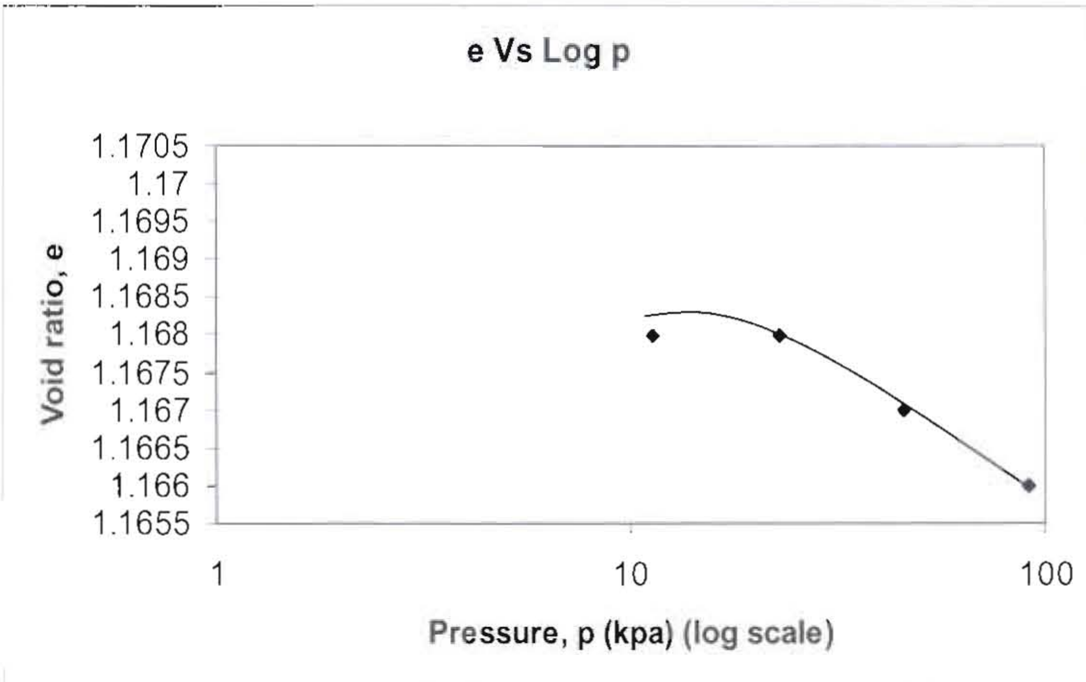


Figure 4.13 Graph e log p for sample M2

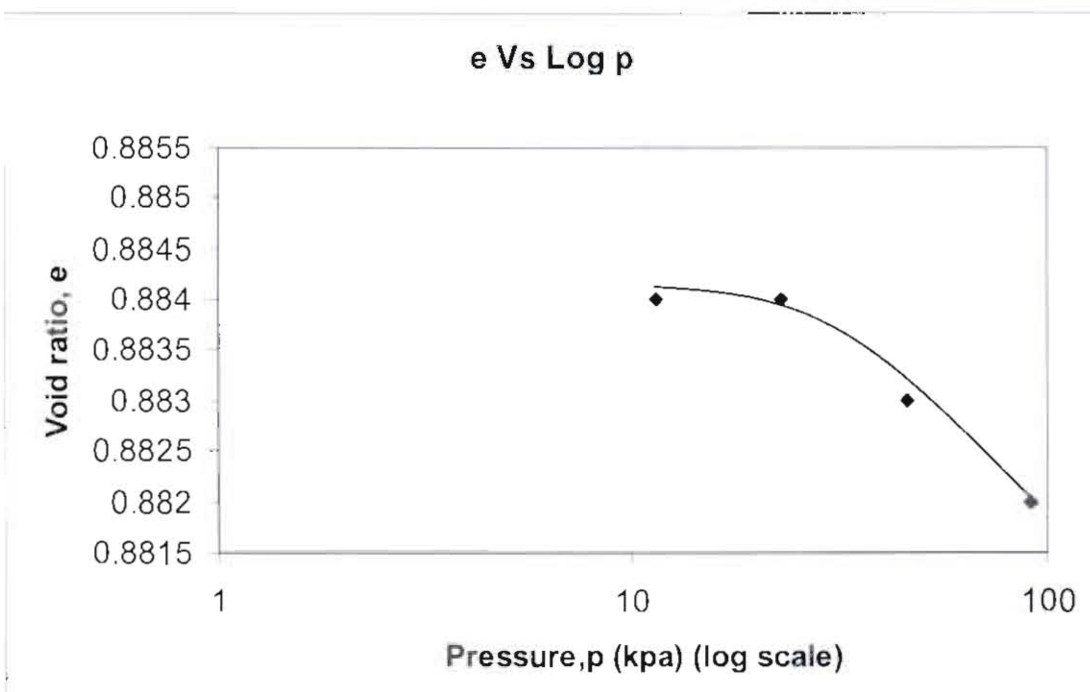


Figure 4.14 Graph e log p for sample M3

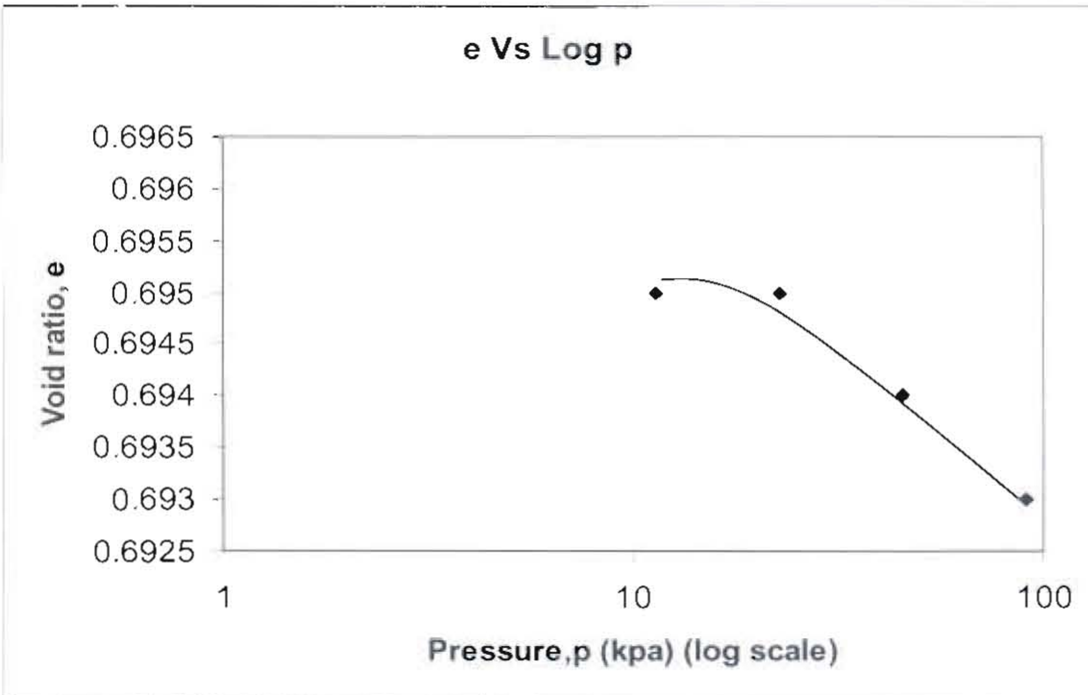


Figure 4.15 Graph e log p for sample M4

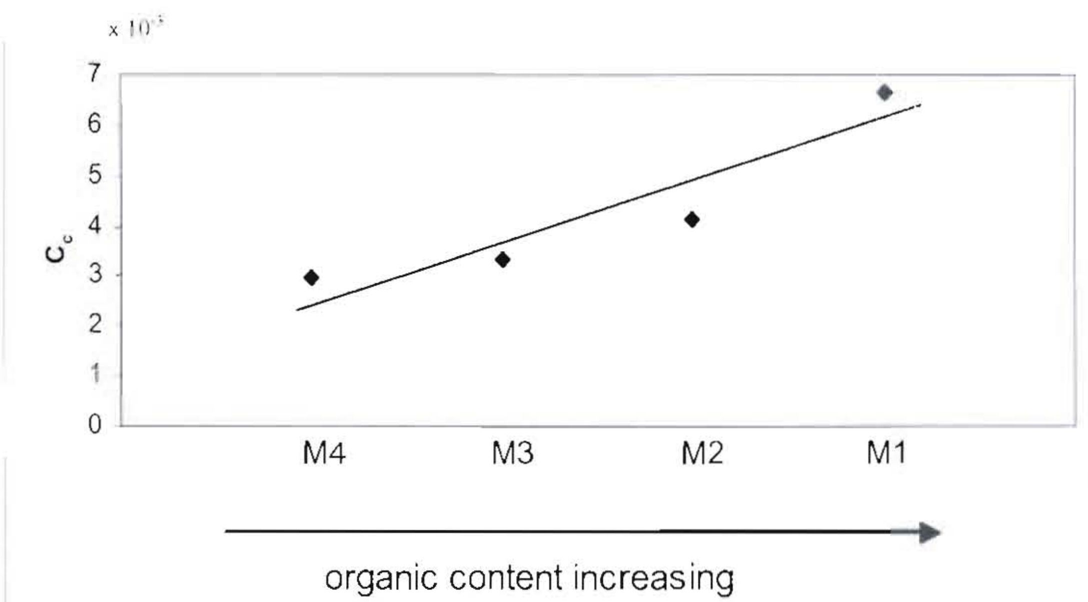


Figure 4.16 Relationship between organic content and coefficient of compression index.

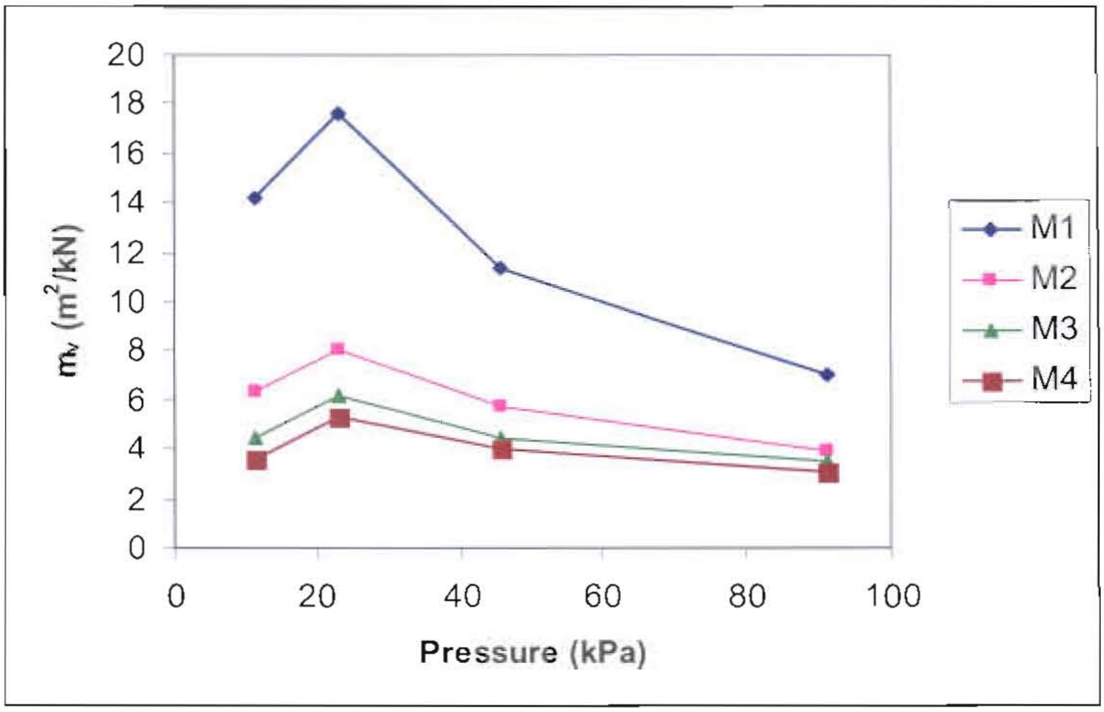


Figure 4.17 Relationship between coefficient of volume compressibility, m_v and pressure for sample M1, M2, M3 and M4.

5 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDY

5.1 Conclusions

The study was concerned with the comparison of the consolidation properties for peat and modified peat. The test was carried out on four different samples form one particular location where three of samples were modified so that each sample has a different organic content.

The results show that the peat sample taken contained high organic content. The specific gravity obtained from the small pyknometer method shows that increase in organic content decreases the value of specific gravity. However, results of the liquid limit test indicate that the liquid limit increases as the organic content increased. The compaction test showed a similar trend where the optimum moisture content for the samples increased as the organic content increased.

The consolidation test was performed using the one – dimensional consolidation test apparatus. From the test it was shown that all four samples show a similar trend. However it was very difficult to determine the relationship between the organic content and the coefficient of consolidation. More tests should be carried out to fully understand these relationship.

From the results, it was unable to obtain the coefficient of secondary compression. This is because the deformation of peat with respect to time kept on increasing in a similar rate even after the maximum loading was placed and even after the last loading was placed, the primary consolidation still takes place. This is because of the fibre content which is present in peat which makes the rate of primary consolidation longer.

The experimental results also shows that as the organic content increases, the coefficient of compression index C_c also increased. The similar trend is obtained for the coefficient of volume compressibility, m_v where the average m_v decreases as the organic content decreases. The reason for this behavior is because peat contains high organic and fibre content. This criteria determines the characteristic of the soil. Consequently, the results obtained for peat samples taken from different location may vary.

5.2 Recommendations

As the study was carried out, several recommendations are to be made for problem solving and future studies. They are as follows:

i) More samples from different places should be taken and studied so that variety of analysis can be done for peat soil

ii) Compacted peat was investigated under one – dimensional oedometer test without consideration permeability and suction in the samples. Thus, further development and research on this subject should be considered since peat has a very high capillary potential that allows it to retain water in its structure.

iii) More time is needed especially when studying the consolidation behavior of peat soil since it is time consuming.

iv) All laboratory equipment should be calibrated and in good working condition before performing any tests.

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APPENDIX

B

Loss on Ignition Determination

Location : Matang

Depth : 1 meter

Tested by : Arasavindiran. M

Crucible No	M1	M2	M3	M4
Mass of crucible, m_c (g)	21.42	21.47	21.42	20.64
Mass of crucible + dry soil, m_3 (g)	22.36	22.89	23.50	23.63
Mass of crucible + sample (after ignition), m_4 (g)	21.46	21.64	21.96	22.12
Loss on Ignition, N(%) $N = (m_3\text{-}m_4/m_3\text{-}m_c) \times 100\%$	95.74	88.03	74.04	50.17
Organic content, H(%) $H = 1 - 1.04\,(1 - N)$	95.57	87.55	73.00	48.18

C

Specific Gravity Determination

Location : Matang

Depth : 1 meter

Tested by : Arasavindiran. M

Sample	M1			M2		
Bottle No	1A	1B	1C	2A	2B	2C
Mass of bottle, m_1 (g)	17.21	18.87	17.94	18.35	18.96	17.68
Mass of bottle + dry soil, m_2 (g)	18.64	20.78	19.30	19.77	20.55	19.51
Mass of bottle + soil + water, m_3 (g)	42.35	44.20	43.28	43.29	43.90	43.06
Mass of bottle full of water, m_4 (g)	42.19	43.63	43.08	42.99	43.54	42.68
Specific Gravity, p_s $p_s = m_2-m_1/[(m_4-m_1)-(m_3-m_2)]$	1.126	1.425	1.172	1.268	1.293	1.262
Average	1.241			1.274		

Sample	M1			M2		
Bottle No	3A	3B	3C	4A	4B	4C
Mass of bottle, m_1 (g)	17.53	18.39	17.25	17.71	18.07	18.69
Mass of bottle + dry soil, m_2 (g)	18.51	19.50	18.49	20.09	20.62	21.34
Mass of bottle + soil + water, m_3 (g)	42.83	43.52	42.54	43.65	43.73	44.25
Mass of bottle full of water, m_4 (g)	42.59	43.24	42.20	42.76	42.93	43.31
Specific Gravity, p_s $p_s = m_2-m_1/[(m_4-m_1)-(m_3-m_2)]$	1.324	1.337	1.378	1.597	1.457	1.550
Average	1.346			1.535		

D1
Liquid Limit Determination

Sample No : M1

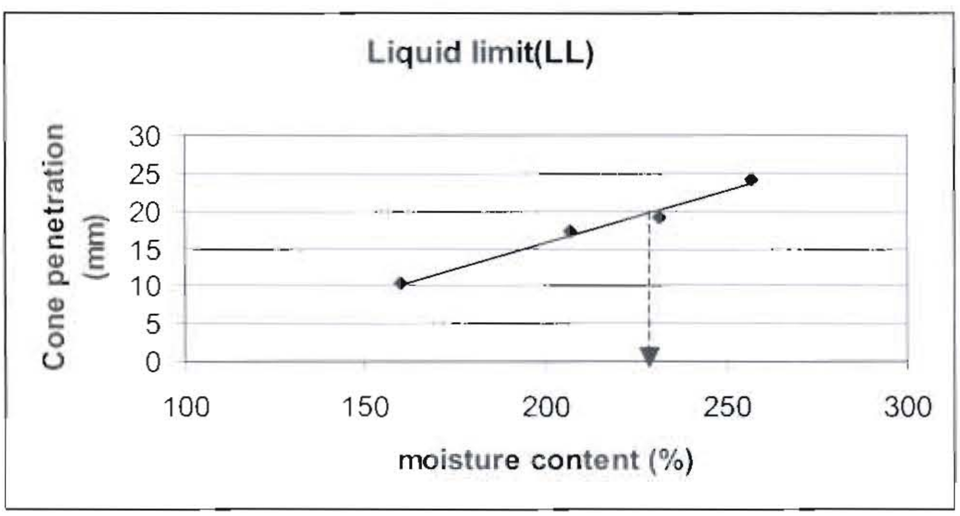
Location : Matang

Depth : 1 meter

Description : Peat soil

Tested by : Arasavindiran. M

Can No.	Weight of can (g)	Weight of can + wet sample (g)	Weight of can + dry sample (g)	Moisture content, w (%)	Penetration (mm)	Average moisture content, w (%)	Average penetration (mm)
A1 A2	9.68 9.79	10.79 11.07	10.10 10.29	164.3 156.0	11.00 9.50	160.2	10.25
B1 B2	10.22 9.83	11.16 11.07	10.53 10.23	203.2 211.0	16.50 18.00	207.1	17.25
C1 C2	9.84 9.65	11.25 12.23	10.27 10.42	227.9 235.1	18.50 19.50	231.5	19.00
D1 D2	9.95 9.71	13.14 12.62	10.84 10.53	258.4 254.9	24.50 24.00	256.7	24.25



Remarks:

Liquid limit = 230 %

D2
Liquid Limit Determination

Sample No : M2

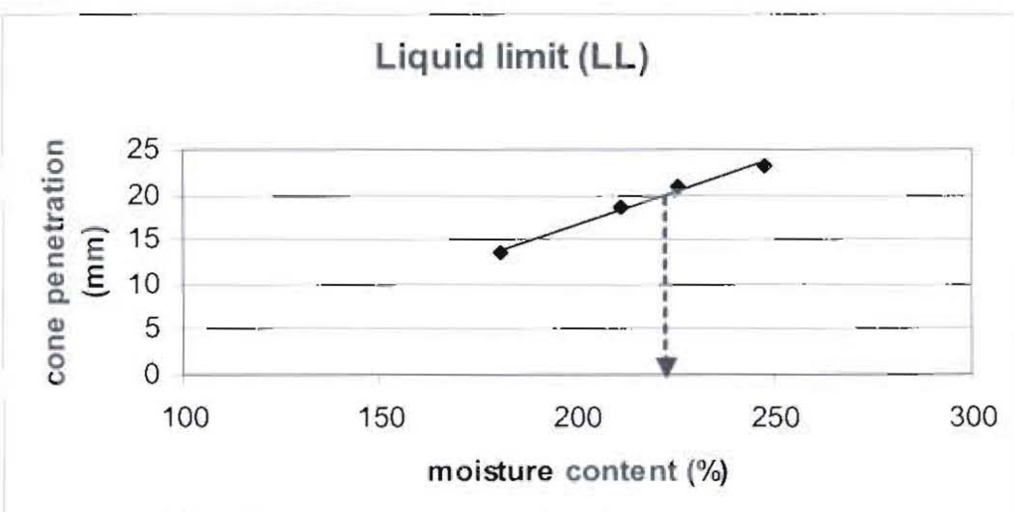
Location : Matang

Depth : 1 meter

Description : Peat soil + 10% sand

Tested by : Arasavindiran. M

Can No.	Weight of can (g)	Weight of can + wet sample (g)	Weight of can + dry sample (g)	Moisture content, w (%)	Penetration (mm)	Average moisture content, w (%)	Average penetration (mm)
A1 A2	9.57 9.57	12.56 12.62	10.62 10.67	184.8 177.3	13.00 14.00	181.1	13.50
B1 B2	9.66 9.74	14.06 14.36	11.07 11.23	212.8 210.1	19.50 18.00	211.5	18.75
C1 C2	9.86 9.71	14.03 14.46	11.16 11.15	220.8 229.9	21.50 20.50	225.4	21.00
D1 D2	9.87 10.19	13.83 14.92	11.00 11.56	250.4 245.3	23.50 23.00	247.9	23.25



Remarks:

Liquid limit = 223 %

D3
Liquid Limit Determination

Sample No : M3

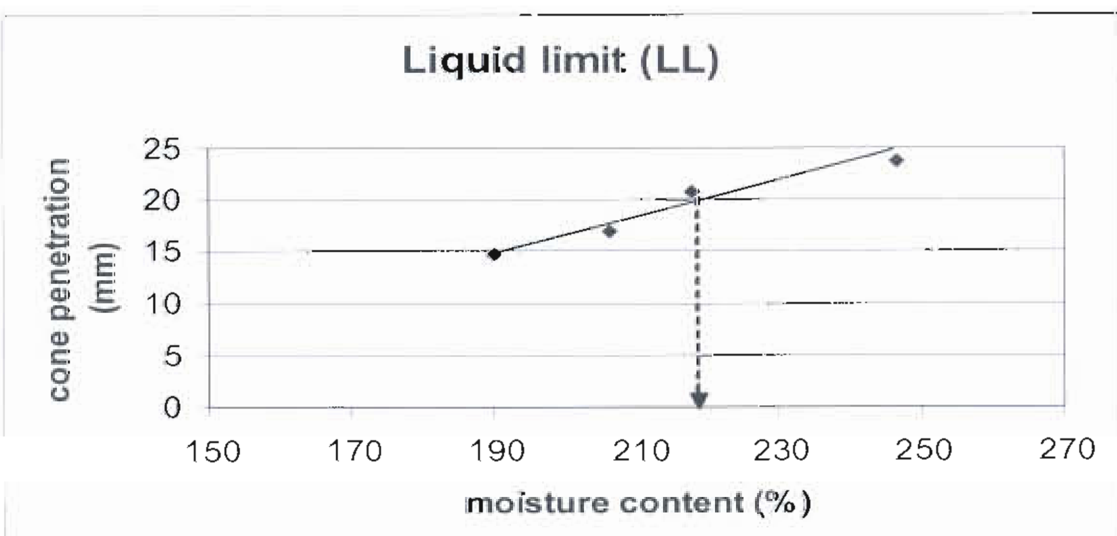
Location : Matang

Depth : 1 meter

Description : Peat soil + 20% sand

Tested by : Arasavindiran. M

Can No.	Weight of can (g)	Weight of can + wet sample (g)	Weight of can + dry sample (g)	Moisture content, w (%)	Penetration (mm)	Average moisture content, w (%)	Average penetration (mm)
A1 A2	9.56 9.58	14.66 16.32	11.36 11.85	183.3 196.9	15.00 14.50	190.1	14.75
B1 B2	9.67 9.74	16.59 15.09	11.90 11.51	210.3 202.3	16.50 17.50	206.3	17.00
C1 C2	9.87 9.72	16.37 15.02	11.88 11.42	223.4 211.8	21.00 20.50	217.6	20.75
D1 D2	9.87 10.19	17.14 16.32	11.89 12.03	259.9 233.2	23.00 24.50	246.6	23.75



Remarks:

Liquid limit = 218 %

D4
Liquid Limit Determination

Sample No : M4

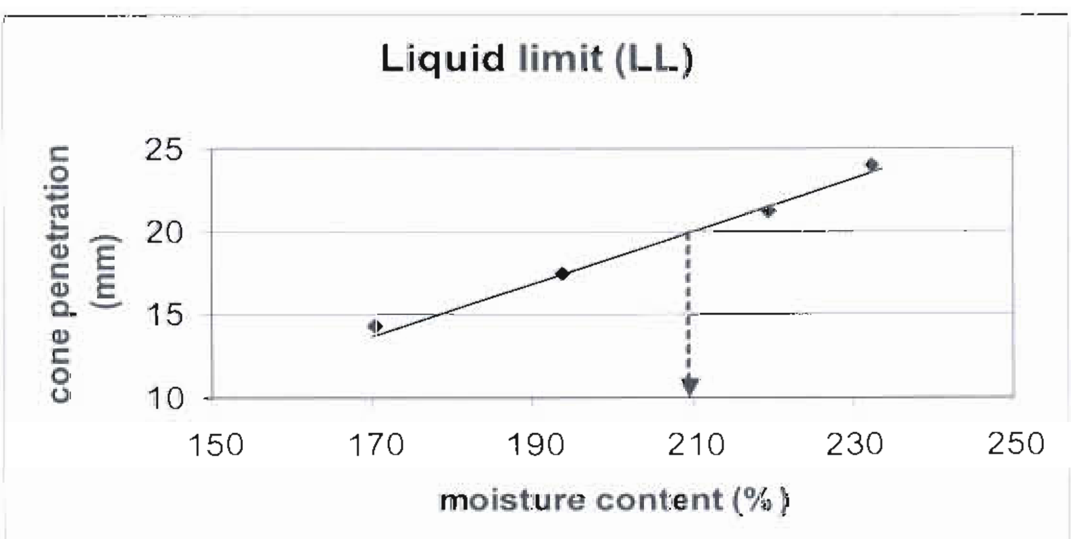
Location : Matang

Depth : 1 meter

Description : Peat soil + 40% sand

Tested by : Arasavindiran. M

Can No.	Weight of can (g)	Weight of can + wet sample (g)	Weight of can + dry sample (g)	Moisture content, w (%)	Penetration (mm)	Average moisture content, w (%)	Average penetration (mm)
A1 A2	9.58 9.58	13.46 15.34	11.01 11.72	171.3 169.2	14.00 14.50	170.3	14.25
B1 B2	9.69 9.75	16.17 14.72	11.93 11.42	189.3 197.6	17.50 17.50	193.5	17.50
C1 C2	9.88 9.73	17.00 16.70	12.09 11.93	222.2 216.8	21.50 21.00	219.5	21.25
D1 D2	9.88 10.19	14.36 16.39	11.24 12.04	229.4 235.1	23.50 24.50	232.3	24.00



Remarks:

Liquid limit = 209 %

E
Plastic Limit Determination

Location : Matang

Depth : 1 meter

Tested by : Arasavindiran. M

Can No.		Weight of can (g)	Weight of can + wet soil (g)	Weight of can + dry soil (g)	Moisture content, w (%)	Average Moisture content, w (%)
M1	A1	9.74	9.84	9.79	100.0	128.4
	A2	6.87	7.07	6.95	150.0	
	A3	6.63	7.03	6.80	135.3	

Can No.		Weight of can (g)	Weight of can + wet soil (g)	Weight of can + dry soil (g)	Moisture content, w (%)	Average Moisture content, w (%)
M2	A1	10.00	10.17	10.08	112.5	120.0
	A2	9.94	10.08	10.00	133.3	
	A3	9.81	9.96	9.88	114.3	

Can No.		Weight of can (g)	Weight of can + wet soil (g)	Weight of can + dry soil (g)	Moisture content, w (%)	Average Moisture content, w (%)
M3	A1	9.99	10.28	10.12	123.1	109.4
	A2	9.94	10.24	10.08	114.3	
	A3	9.82	10.03	9.93	90.9	

Can No.		Weight of can (g)	Weight of can + wet soil (g)	Weight of can + dry soil (g)	Moisture content, w (%)	Average Moisture content, w (%)
M4	A1	10.00	10.22	10.12	83.3	99.2
	A2	9.94	10.24	10.08	114.3	
	A3	9.86	10.04	9.95	100.0	

F1-1

Compaction Test

Method used	:	Standard Proctor Test
No. of blows	:	25
Diameter of mould	:	10.5cm
Height of mould	:	11.9cm
Internal volume of mould, v	:	1030cm^3

Sample No.	:	M1
Depth	:	1 meter
Location	:	Matang
Description	:	Peat soil
Tested by	:	Arasavindiran. M

Determination of Bulk density

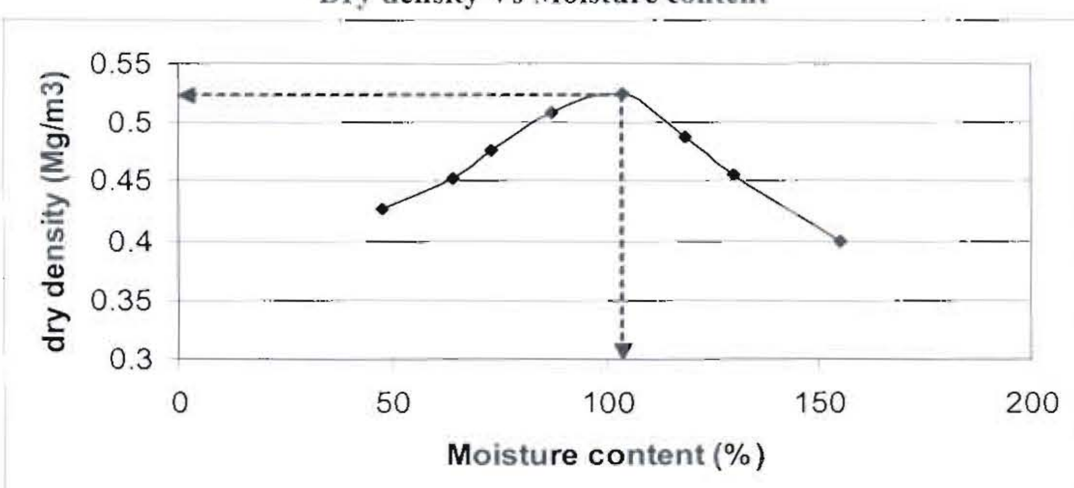
Trial No.	Amount of water (ml)	Weight of		Weight of compacted soil (g)	Bulk density, ρ (Mg/m^3)
		Compacted soil + mold + base, $m_{2\,(g)}$	Mold + base, m_1 (g)		
1	400	5050.2	4400	650.2	0.631
2	800	5164.4	4400	764.4	0.742
3	1200	5250.8	4400	850.8	0.826
4	1600	5380.1	4400	980.1	0.952
5	2000	5500.9	4400	1100.9	1.069
6	2400	5500.4	4400	1100.4	1.068
7	2800	5450.2	4400	1050.2	1.020
8	3200	5481.5	4400	1081.5	1.050

Compaction Test

Determination of Moisture content and Dry density

Trial No.	Bulk density, ρ (Mg/m³)	Can No.	Weight of Can, m_1 (g)	Weight of Wet soil + can, m_2 (g)	Weight of Dry soil + can, m_3 (g)	Moisture content, (%)	Average moisture content, w(%)	Dry Density, ρd (Mg/m³)
1	0.631	A1	9.82	11.56	10.98	50.0	47.7	0.427
		A2	9.70	11.29	10.79	45.9		
		A3	10.00	12.31	11.57	47.1		
2	0.742	B1	9.58	10.79	10.31	65.8	64.3	0.452
		B2	9.85	12.00	11.19	60.4		
		B3	9.63	12.23	11.19	66.7		
3	0.826	C1	9.75	12.54	11.38	71.2	73.0	0.477
		C2	16.78	19.00	18.05	74.8		
		C3	10.10	19.27	15.40	73.0		
4	0.952	D1	9.87	14.16	12.19	84.9	.87.5	0.508
		D2	9.99	12.65	11.39	90.0		
		D3	10.05	13.30	11.78	87.8		
5	1.069	E1	16.97	20.20	18.57	101.9	104.1	0.524
		E2	9.58	11.84	10.67	107.3		
		E3	10.22	13.53	11.85	103.1		
6	1.068	F1	9.77	11.61	10.62	116.5	119.0	0.488
		F2	16.68	19.95	18.13	125.5		
		F3	9.80	14.72	12.09	114.9		
7	1.020	G1	31.10	36.64	33.54	127.1	130.2	0.456
		G2	9.65	13.60	11.39	127.0		
		G3	9.70	13.61	11.10	136.4		
8	1.050	H1	6.50	11.85	8.72	141.0	155.5	0.399
		H2	6.85	13.06	9.20	164.3		
		H3	6.58	13.06	9.06	161.3		

Dry density Vs Moisture content



Remarks:
Maximum Dry density = 0.524 Mg/m³
Optimum Moisture content = 104.1 %

F2-1

Compaction Test

Method used : Standard Proctor Test

No. of blows : 25

Diameter of mould : 10.5cm

Height of mould : 11.9cm

Internal volume of mould, v : 1030cm^3

Sample No. : M2

Depth : 1 meter

Location : Matang

Description : Peat soil + 10% sand

Tested by : Arasavindiran. M

Determination of Bulk density

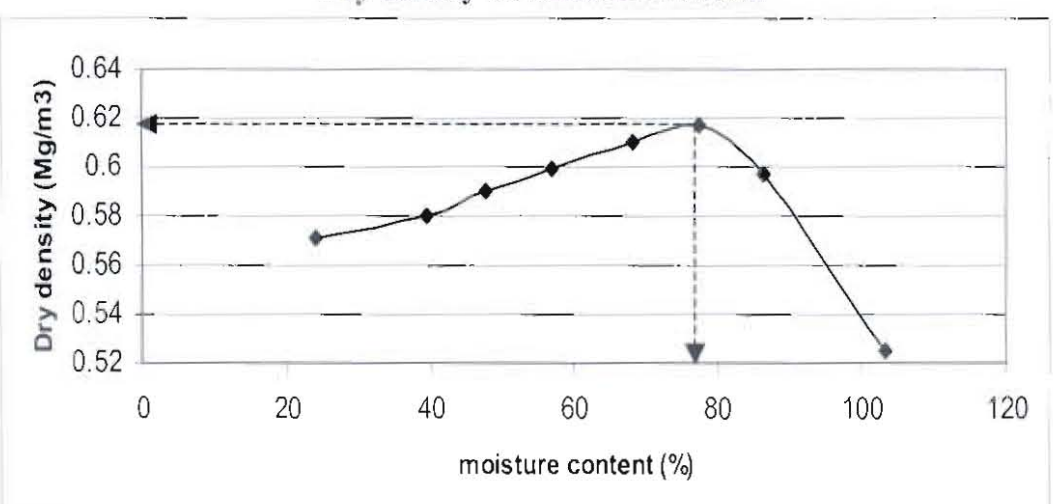
Trial No.	Amount of water (ml)	Weight of		Weight of compacted soil (g)	Bulk density, ρ (Mg/m^3)
		Compacted soil + mold + base, m_2 (g)	Mold + base, m_1 (g)		
1	200	5127.8	4400	727.8	0.707
2	400	5231.8	4400	831.8	0.808
3	600	5297.2	4400	897.2	0.871
4	800	5368.2	4400	968.2	0.940
5	1000	5456.1	4400	1056.1	1.025
6	1200	5527.4	4400	1127.4	1.095
7	1400	5546.3	4400	1146.3	1.113
8	1600	5500.0	4400	1100.0	1.068

Compaction Test

Determination of Moisture content and Dry density

Trial No.	Bulk density, ρ (Mg/m^3)	Can No.	Weight of			Moisture content, (%)	Average moisture content, w(%)	Dry Density, ρd (Mg/m^3)
			Can, m_1 (g)	Wet soil + can, m_2 (g)	Dry soil + can, m_3 (g)			
1	0.707	A1	9.68	11.42	11.10	22.54	23.87	0.571
		A2	9.78	10.95	10.72	24.47		
		A3	9.59	11.16	10.85	24.60		
2	0.808	B1	10.14	14.17	13.18	32.57	39.39	0.580
		B2	9.81	13.03	12.05	43.75		
		B3	6.90	9.95	9.05	41.86		
3	0.871	C1	9.84	13.00	11.99	46.98	47.74	0.590
		C2	9.63	13.31	12.12	47.79		
		C3	10.62	12.55	11.92	48.46		
4	0.940	D1	9.93	13.36	12.16	53.81	56.92	0.599
		D2	9.71	13.71	12.23	58.73		
		D3	6.95	10.51	9.20	58.22		
5	1.025	E1	9.69	13.41	11.95	64.60	68.11	0.610
		E2	9.78	14.18	12.37	69.88		
		E3	9.58	12.79	11.47	69.84		
6	1.095	F1	9.64	18.33	14.51	78.44	77.52	0.617
		F2	9.81	13.97	12.18	75.53		
		F3	7.05	11.14	9.34	78.60		
7	1.113	G1	9.71	19.16	14.72	88.62	86.42	0.597
		G2	.6.91	14.72	11.14	84.63		
		G3	16.98	21.32	19.32	85.47		
8	1.068	H1	6.48	17.38	11.81	104.50	103.30	0.525
		H2	9.72	15.14	12.41	101.49		
		H3	9.59	19.99	14.69	103.92		

Dry density Vs Moisture content



Remarks:
Maximum Dry density = 0.617 Mg/m^3
Optimum Moisture content = 77.5 %

Compaction Test

Method used	:	Standard Proctor Test
No. of blows	:	25
Diameter of mould	:	10.5cm
Height of mould	:	11.9cm
Internal volume of mould, v	:	$1030cm^3$

Sample No.	:	M3
Depth	:	1 meter
Location	:	Matang
Description	:	Peat soil + 20% sand
Tested by	:	Arasavindiran. M

Determination of Bulk density

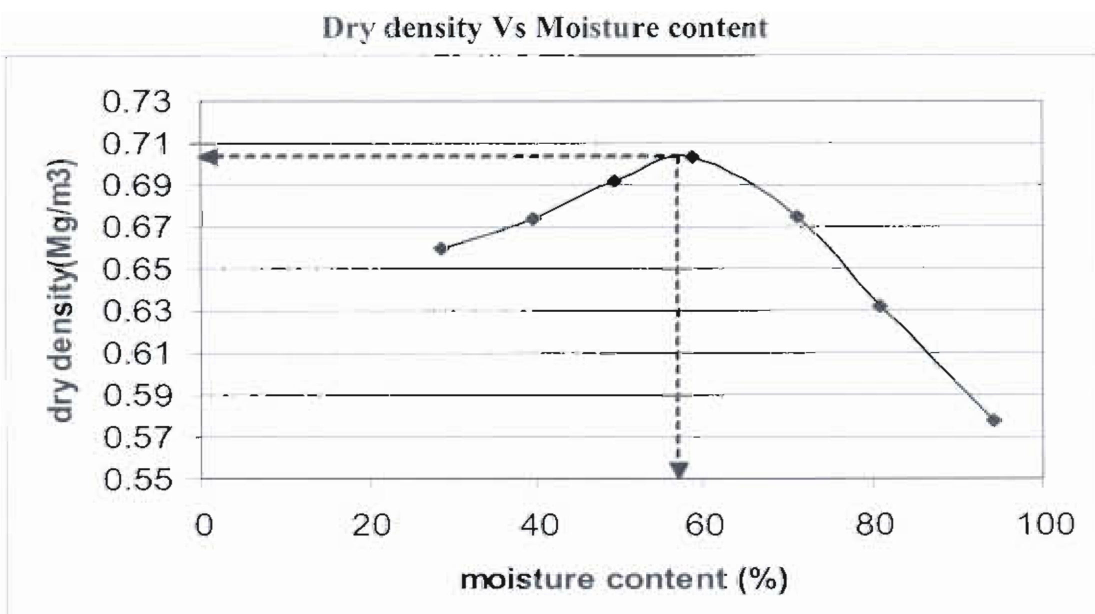
Trial No.	Amount of water (ml)	Weight of		Weight of compacted soil (g)	Bulk density, ρ (Mg/m^3)
		Compacted soil + mold + base, $m_{2\,(g)}$	Mold + base, m_1 (g)		
1	200	5275.3	4400	875.3	0.850
2	400	5370.6	4400	970.6	0.942
3	600	5437.2	4400	1037.2	1.032
4	800	5548.2	4400	1148.2	1.115
5	1000	5597.2	4400	1197.2	1.155
6	1200	5577.4	4400	1177.4	1.143
7	1400	5555.2	4400	1155.2	1.122

F3-2

Compaction Test

Determination of Moisture content and Dry density

Trial No.	Bulk density, ρ (Mg/m^3)	Can No.	Weight of			Moisture content, (%)	Average moisture content, w(%)	Dry Density, ρd (Mg/m^3)
			Can, m_1 (g)	Wet soil + can, m_2 (g)	Dry soil + can, m_3 (g)			
1	0.850	A1 A2 A3	9.82 7.30 6.87	13.30 10.52 9.82	12.55 9.80 9.14	27.47 28.80 29.96	28.74	0.660
2	0.942	B1 B2 B3	6.58 10.01 6.88	10.87 13.82 10.66	9.69 12.72 9.59	37.94 41.67 39.48	39.70	0.674
3	1.032	C1 C2 C3	6.78 7.12 6.49	11.30 11.16 10.18	9.80 9.82 8.98	49.67 49.63 48.19	49.16	0.692
4	1.115	D1 D2 D3	6.59 6.70 7.13	10.98 12.80 11.97	9.37 10.50 10.21	57.91 60.53 57.14	58.53	0.703
5	1.155	E1 E2 E3	6.77 7.31 6.65	13.10 12.79 13.17	10.38 10.52 10.55	75.35 70.72 67.18	71.08	0.675
6	1.143	F1 F2 F3	9.58 7.18 9.70	21.29 17.90 21.14	15.96 13.12 16.11	83.54 80.47 78.47	80.83	0.632
7	1.122	G1 G2 G3	7.02 6.87 6.51	17.33 13.30 15.25	12.28 10.22 11.00	96.01 91.94 94.65	84.20	0.578



Remarks:
Maximum Dry density = 0.703 Mg/m^3
Optimum Moisture content = 58.80 %

F4-1

Compaction Test

Method used	:	Standard Proctor Test
No. of blows	:	25
Diameter of mould	:	10.5cm
Height of mould	:	11.9cm
Internal volume of mould, v	:	$1030cm^3$

Sample No.	:	M4
Depth	:	1 meter
Location	:	Matang
Description	:	Peat soil + 40% sand
Tested by	:	Arasavindiran. M

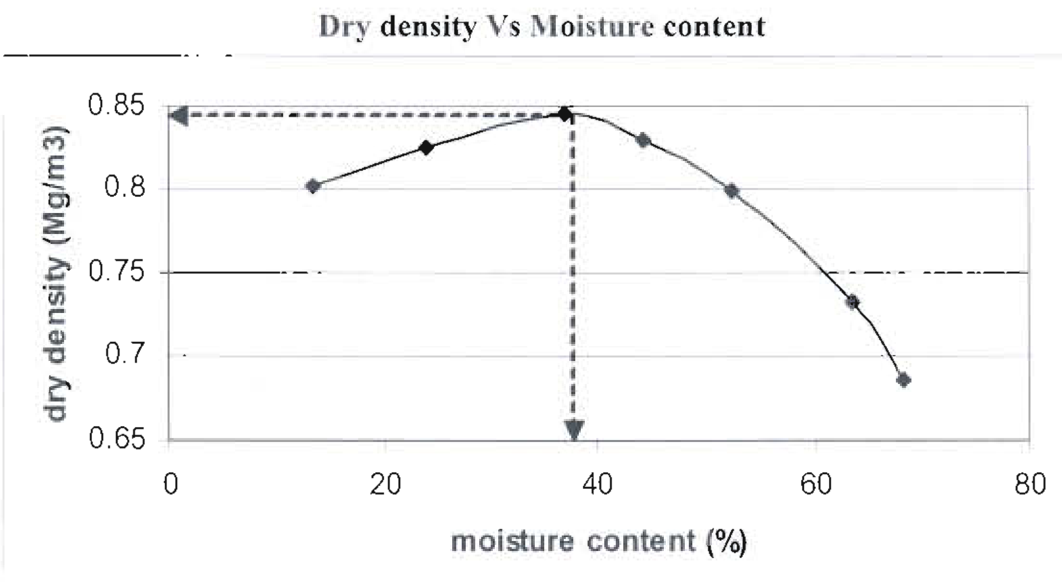
Determination of Bulk density

Trial No.	Amount of water (ml)	Weight of		Weight of compacted soil (g)	Bulk density, ρ (Mg/m^3)
		Compacted soil + mold + base, $m_{2\,(g)}$	Mold + base, m_1 (g)		
1	200	5337.3	4400	937.3	0.910
2	400	5453.7	4400	1053.7	1.023
3	600	5592.8	4400	1192.8	1.158
4	800	5632.9	4400	1232.9	1.197
5	1000	5652.0	4400	1252.0	1.216
6	1200	5635.3	4400	1235.3	1.199
7	1400	5589.4	4400	1189.4	1.155

Compaction Test

Determination of Moisture content and Dry density

Trial No.	Bulk density, ρ (Mg/m^3)	Can No.	Weight of Can, m_1 (g)	Weight of Wet soil + can, m_2 (g)	Weight of Dry soil + can, m_3 (g)	Moisture content, (%)	Average moisture content, w(%)	Dry Density, ρd (Mg/m^3)
1	0.910	A1	10.03	16.32	15.60	12.93	13.51	0.802
		A2	9.85	13.94	13.46	13.30		
		A3	9.75	15.34	14.64	14.31		
2	1.023	B1	9.85	15.91	14.75	23.67	23.96	0.825
		B2	9.69	16.60	15.26	24.06		
		B3	10.05	16.68	15.39	24.16		
3	1.158	C1	9.56	16.62	14.55	41.48	37.07	0.845
		C2	9.63	20.65	17.87	33.74		
		C3	9.92	17.59	15.56	35.99		
4	1.197	D1	9.66	18.69	15.59	52.28	44.27	0.830
		D2	9.57	22.31	18.57	41.56		
		D3	9.73	17.86	15.58	38.97		
5	1.216	E1	9.70	23.93	18.53	61.16	52.26	0.799
		E2	9.69	23.44	18.96	48.33		
		E3	10.00	18.47	15.75	47.30		
6	1.199	F1	9.78	25.82	19.16	71.00	63.49	0.733
		F2	9.61	27.72	20.82	61.55		
		F3	6.65	17.61	13.59	57.93		
7	1.155	G1	7.02	18.18	13.67	67.82	68.33	0.686
		G2	6.65	16.11	12.27	68.33		
		G3	6.86	18.73	13.89	68.85		



Remarks:
Maximum Dry density = 0.845 Mg/m^3
Optimum Moisture content = 38.0 %

G1

Consolidation Test

Sample No	:M1	Description	:Peat soil
Location	:Matang	Tested by	:Arasavindiran. M
Depth	:1 meter		

a. Specimen data

Beginning of test

Type of specimen = Compacted to optimum moisture content

Diameter of specimen = 7.47 cm

Area of specimen, A = 43.83 cm^2

Initial height of specimen, H_o = 2 cm

Initial volume of specimen = 87.65 cm^3

Weight of specimen ring + specimen = 188.41 g

Weight of specimen ring = 114.53 g

Initial wet weight of specimen = 73.88 g

Initial wet unit weight = 0.84 g/cm^3

Initial moisture content = 104.1% (optimum moisture content)

Initial dry weight of specimen = 36.2 g

Specific gravity of soil = 1.241

Volume of solid in soil specimen = 29.17 cm^3

Volume of void in soil specimen = 58.48 cm^3

Volume of water in soil specimen = 37.68 cm^3

(Note : unit weight of water = 1 g/cm^3)

Initial degree of saturation = 64.43 %

End of test

Weight of can = 9.76 g

Weight of can + wet specimen = 84.89 g

Weight of can + dry specimen = 46.96 g

Final dry weight of specimen = 37.2 g

Final moisture content = 101.96 %

Final degree of saturation = 100 %

Initial void ratio

Volume of solid in specimen = 29.96 cm^3

Initial volume of specimen = 87.65 cm^3

Initial volume of void in specimen = 57.69 cm^3

Initial void ratio, e_o = 1.926

b. Time versus Deformation data

Loading

Date	2/9/2004	3/9/2004	4/9/2004	5/9/2004
time/Load	Deformation for 11.41 kpa (mm)	Deformation for 22.82 kpa (mm)	Deformation for 45.63 kpa (mm)	Deformation for 91.26 kpa (mm)
0s	0.000000	0.032380	0.040164	0.052036
10s	0.024128	0.036044	0.044124	0.056168
20s	0.024244	0.036080	0.044288	0.056308
30s	0.026000	0.036100	0.044308	0.056372
40s	0.026208	0.036116	0.044352	0.058024
50s	0.028000	0.036128	0.044368	0.058044
1min	0.028140	0.036144	0.044396	0.058080
2min	0.028232	0.036184	0.046084	0.058200
4min	0.028360	0.036236	0.046176	0.058316
8min	0.030048	0.036288	0.046276	0.060044
15min	0.030144	0.036352	0.046372	0.060164
30min	0.030236	0.036352	0.048084	0.060284
1hr	0.032052	0.038024	0.048204	0.062028
2hrs	0.032128	0.038112	0.048340	0.062156
4hrs	0.032224	0.038208	0.050128	0.062312
8hrs	0.032306	0.038344	0.050230	0.064050
24hrs	0.032380	0.040164	0.052036	0.064356

c. Void ratio

Initial void ratio, $e_o = 1.926$

Volume of solid in specimen, $V_s = 29.96\ cm^3$

Area of specimen, $A = 43.83\ cm^2$

Height of solid in specimen, $H_s = 0.684$ cm

Pressure, P (kPa)	Deformation dial reading representing 100% primary consolidation (mm)	Change in thickness of specimen, ΔH (cm)	Change in void ratio, Δe ($\Delta e = \Delta H/Hs$)	Void ratio, e ($e = e_o - \Delta e$)
0	0	0	0	1.926
11.41	0.032380	0.003238	0.00473	1.921
22.82	0.040164	0.004016	0.00587	1.920
45.63	0.052036	0.005204	0.00761	1.918
91.26	0.064356	0.006436	0.00941	1.916

G2

Consolidation Test

Sample No :M2 Description :Peat soil + 10% sand

Location :Matang Tested by :Arasavindiran. M

Depth :1 meter

d. Specimen data

Beginning of test

Type of specimen = Compacted to optimum moisture content

Diameter of specimen = 7.47 cm

Area of specimen, A = 43.83 cm^2

Initial height of specimen, H_o = 2 cm

Initial volume of specimen = 87.65 cm^3

Weight of specimen ring + specimen = 202.74 g

Weight of specimen ring = 114.53 g

Initial wet weight of specimen = 88.21 g

Initial wet unit weight = 1.01 g/cm^3

Initial moisture content = 77.5 % (optimum moisture content)

Initial dry weight of specimen = 49.7 g

Specific gravity of soil = 1.274

Volume of solid in soil specimen = 39.01 cm^3

Volume of void in soil specimen = 48.64 cm^3

Volume of water in soil specimen = 38.51 cm^3

(Note : unit weight of water = 1 g/cm^3)

Initial degree of saturation = 79.17 %

End of test

Weight of can = 9.69 g

Weight of can + wet specimen = 99.72 g

Weight of can + dry specimen = 61.16 g

Final dry weight of specimen = 51.47 g

Final moisture content = 74.92 %

Final degree of saturation = 100 %

Initial void ratio

Volume of solid in specimen = 40.40 cm^3

Initial volume of specimen = 87.65 cm^3

Initial volume of void in specimen = 47.25 cm^3

Initial void ratio, e_o = 1.170

e. Time versus Deformation data

Loading

Date	19/9/2004	20/9/2004	21/9/2004	22/9/2004
time/Load	Deformation for 11.41 kpa (mm)	Deformation for 22.82 kpa (mm)	Deformation for 45.63 kpa (mm)	Deformation for 91.26 kpa (mm)
0s	0.000000	0.014362	0.018364	0.026186
10s	0.010300	0.016202	0.022022	0.028336
20s	0.012044	0.016224	0.022068	0.028394
30s	0.012112	0.016236	0.022094	0.030030
40s	0.012156	0.016244	0.022116	0.030058
50s	0.012184	0.016252	0.022130	0.030082
1min	0.012202	0.016258	0.022142	0.030100
2min	0.012282	0.016282	0.022194	0.030172
4min	0.012360	0.016306	0.022248	0.030246
8min	0.014030	0.016338	0.022304	0.030326
15min	0.014088	0.016368	0.022362	0.032004
30min	0.014150	0.018006	0.024034	0.032096
1hr	0.014188	0.018046	0.024116	0.032200
2hrs	0.014224	0.018096	0.024218	0.032324
4hrs	0.014252	0.018158	0.024340	0.034138
8hrs	0.014284	0.018226	0.024364	0.034226
24hrs	0.014362	0.018364	0.026186	0.036096

f. Void ratio

Initial void ratio, $e_o = 1.170$

Volume of solid in specimen, $V_s = 40.40\ cm^3$

Area of specimen, $A = 43.83\ cm^2$

Height of solid in specimen, $H_s = 0.922\ cm$

Pressure, P (kPa)	Deformation dial reading representing 100% primary consolidation (mm)	Change in thickness of specimen, ΔH (cm)	Change in void ratio, Δe ($\Delta e = \Delta H/Hs$)	Void ratio, e ($e = e_o - \Delta e$)
0	0	0	0	1.170
11.41	0.014362	0.001436	0.00156	1.168
22.82	0.018364	0.001836	0.00199	1.168
45.63	0.026186	0.002619	0.00284	1.167
91.26	0.036096	0.003610	0.00392	1.166

G3

Consolidation Test

Sample No :M3 Description :Peat soil + 20% sand

Location :Matang Tested by :Arasavindiran. M

Depth :1 meter

g. Specimen data

Beginning of test

Type of specimen = Compacted to optimum moisture content

Diameter of specimen = 7.47 cm

Area of specimen, A = 43.83 cm^2

Initial height of specimen, H_o = 2 cm

Initial volume of specimen = 87.65 cm^3

Weight of specimen ring + specimen = 212.48 g

Weight of specimen ring = 114.53 g

Initial wet weight of specimen = 97.95 g

Initial wet unit weight = 1.118 g/cm^3

Initial moisture content = 58.8 % (optimum moisture content)

Initial dry weight of specimen = 61.68 g

Specific gravity of soil = 1.346

Volume of solid in soil specimen = 45.82 cm^3

Volume of void in soil specimen = 41.83 cm^3

Volume of water in soil specimen = 36.27 cm^3

(Note : unit weight of water = 1 g/cm^3)

Initial degree of saturation = 86.71 %

End of test

Weight of can = 9.66 g

Weight of can + wet specimen = 109.83 g

Weight of can + dry specimen = 72.25 g

Final dry weight of specimen = 62.59 g

Final moisture content = 60.04 %

Final degree of saturation = 100 %

Initial void ratio

Volume of solid in specimen = 46.50 cm^3

Initial volume of specimen = 87.65 cm^3

Initial volume of void in specimen = 41.15 cm^3

Initial void ratio, e_0 = 0.885

h. Time versus Deformation data

Loading

Date time/Load	26/9/2004 Deformation for 11.41 kpa (mm)	27/9/2004 Deformation for 22.82 kpa (mm)	28/9/2004 Deformation for 45.63 kpa (mm)	29/9/2004 Deformation for 91.26 kpa (mm)
0s	0.000000	0.010030	0.014028	0.020356
10s	0.008024	0.010350	0.016126	0.024280
20s	0.008058	0.010362	0.016170	0.024344
30s	0.008082	0.010374	0.016196	0.024398
40s	0.008096	0.010384	0.016214	0.026032
50s	0.008108	0.010394	0.016230	0.026060
1min	0.008116	0.010398	0.016242	0.026084
2min	0.008156	0.012022	0.016292	0.026180
4min	0.008192	0.012050	0.016344	0.026282
8min	0.008232	0.012082	0.018006	0.026390
15min	0.008264	0.012116	0.018064	0.028094
30min	0.008300	0.012156	0.018138	0.028224
1hr	0.008336	0.012208	0.018222	0.028348
2hrs	0.008366	0.012260	0.018330	0.030068
4hrs	0.008394	0.012308	0.020072	0.030202
8hrs	0.010010	0.012332	0.020132	0.030292
24hrs	0.010030	0.014028	0.020356	0.032114

i. Void ratio

Initial void ratio, $e_o = 0.885$

Volume of solid in specimen, $V_s = 46.50\ cm^3$

Area of specimen, $A = 43.83\ cm^2$

Height of solid in specimen, $H_s = 1.061\ cm$

Pressure, P (kPa)	Deformation dial reading representing 100% primary consolidation (mm)	Change in thickness of specimen, ΔH (cm)	Change in void ratio, Δe ($\Delta e = \Delta H/Hs$)	Void ratio, e ($e = e_o - \Delta e$)
0	0	0	0	0.885
11.41	0.010030	0.001003	0.00095	0.884
22.82	0.014028	0.001403	0.00132	0.884
45.63	0.020356	0.002036	0.00192	0.883
91.26	0.032114	0.003211	0.00303	0.882

G4

Consolidation Test

Sample No :M4

Location :Matang

Depth :1 meter

Description :Peat soil + 40% sand

Tested by :Arasavindiran. M

j. Specimen data

Beginning of test

Type of specimen = Compacted to optimum moisture content

Diameter of specimen = 7.47 cm

Area of specimen, A = 43.83 cm^2

Initial height of specimen, H_o = 2 cm

Initial volume of specimen = 87.65 cm^3

Weight of specimen ring + specimen = 230.43 g

Weight of specimen ring = 114.53 g

Initial wet weight of specimen = 115.90 g

Initial wet unit weight = 1.322 g/cm^3

Initial moisture content = 38.0 % (optimum moisture content)

Initial dry weight of specimen = 83.99 g

Specific gravity of soil = 1.535

Volume of solid in soil specimen = 54.72 cm^3

Volume of void in soil specimen = 32.93 cm^3

Volume of water in soil specimen = 31.91 cm^3

(Note : unit weight of water = 1 g/cm^3)

Initial degree of saturation = 96.90 %

End of test

Weight of can = 9.79 g

Weight of can + wet specimen = 128.22 g

Weight of can + dry specimen = 89.14 g

Final dry weight of specimen = 79.35 g

Final moisture content = 49.25 %

Final degree of saturation = 100 %

Initial void ratio

Volume of solid in specimen = 51.69 cm^3

Initial volume of specimen = 87.65 cm^3

Initial volume of void in specimen = 35.96 cm^3

Initial void ratio, e_o = 0.696

k. Time versus Deformation data

Loading

Date	11/9/2004	12/9/2004	13/9/2004	14/9/2004
time/Load	Deformation for 11.41 kpa (mm)	Deformation for 22.82 kpa (mm)	Deformation for 45.63 kpa (mm)	Deformation for 91.26 kpa (mm)
0s	0.000000	0.008208	0.012130	0.018102
10s	0.006196	0.010068	0.014140	0.022108
20s	0.006236	0.010084	0.014172	0.022170
30s	0.006260	0.010092	0.014190	0.022220
40s	0.006276	0.010096	0.014204	0.022254
50s	0.006284	0.010102	0.014216	0.022282
1min	0.006294	0.010108	0.014220	0.022302
2min	0.006336	0.010130	0.014260	0.022394
4min	0.006368	0.010146	0.014300	0.024084
8min	0.008010	0.010170	0.014328	0.024182
15min	0.008036	0.010194	0.014390	0.024276
30min	0.008068	0.010226	0.016042	0.024388
1hr	0.008094	0.010260	0.016102	0.026102
2hrs	0.008124	0.010310	0.016176	0.026244
4hrs	0.008156	0.010378	0.016246	0.026316
8hrs	0.008172	0.010388	0.016312	0.028014
24hrs	0.008208	0.012130	0.018102	0.028340

1. Void ratio

Initial void ratio, $e_o = 0.696$

Volume of solid in specimen, $V_s = 51.69\ cm^3$

Area of specimen, $A = 43.83\ cm^2$

Height of solid in specimen, $H_s = 1.174$ cm

Pressure, P (kPa)	Deformation dial reading representing 100% primary consolidation (mm)	Change in thickness of specimen, ΔH (cm)	Change in void ratio, Δe ($\Delta e = \Delta H/Hs$)	Void ratio, e ($e = e_o - \Delta e$)
0	0	0	0	0.696
11.41	0.008208	0.000821	0.00070	0.695
22.82	0.012130	0.001213	0.00103	0.695
45.63	0.018102	0.001810	0.00154	0.694
91.26	0.028340	0.002834	0.00241	0.693