CERTIFICATE OF APPROVAL

Stabilization of peat soil using lime as a stabilizer

By

Atem Karlo Akol

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(Dr. Syed Baharom Azahar)

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Praise and glory to Almighty God for safeguarding and giving me strength to successfully complete this project. May His Name be glorified forever!

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ABSTRACT

Peat geotechnical properties such as low shear strength, high organic matter, low bearing capacity and high compressibility make it been regarded as difficult soil. Peat soil is considered by geotechnical engineers as an unfavourable soil for construction. It has covered approximately twenty-three (23) million hectares in South-East Asia with about three (3) million hectares or 8% of the total area in Malaysia. Peat soil has been regarded as problematic soil that poses significant threat to roads and building foundations stability due to its unique characteristics of high compressibility, low shear strength and consolidation settlements even when subjected to a moderate load.

Because of these geotechnical problems of peat soil, improvement mechanism is needed if peat soil is to be used as a soil foundation of a civil structure. Several methods of soil stabilization such as preloading with surcharge, sand column and corduroy among others have been tried by geotechnical engineers to improve peat behaviour. However, such methods were found uneconomical in term of time constraint. Therefore, lime has been taken as a choice for stabilization of peat soil in this paper. Lime material chosen for this research project was provided in Universiti Teknologi Petronas (UTP) laboratory. Eades and Grim test was conducted to determine the optimum percentage of lime that can be mixed with peat soil to provide optimum strength. Lime was mixed with peat soil in different eight (8) percentages: 10%, 12%, 14%, 16%, 18%, 20%, 22% and 24% respectively. The extruded samples were cured for a period of 7 and 14 days. After those respective curing periods, Unconfined compression test (UCT) was conducted on all samples to determine lime impact on peat properties in term of strength increase.

Having analyzed the laboratory test results, it was noticed that 16% lime provided the optimum lime percentage for stabilization of peat samples. An increment in the strength of peat specimens was noticed though the highest strength of 149.3kPa was realized with sample mixed with 14% lime and cured for 14 days. Therefore, lime can stabilize and improve the engineering properties of peat soil mainly strength and pH. Generally, unconfined compression test (UCT) indicates that, peat soil gained strength due to different lime percentages added.

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CHAPTER 1

INTRODUCTION

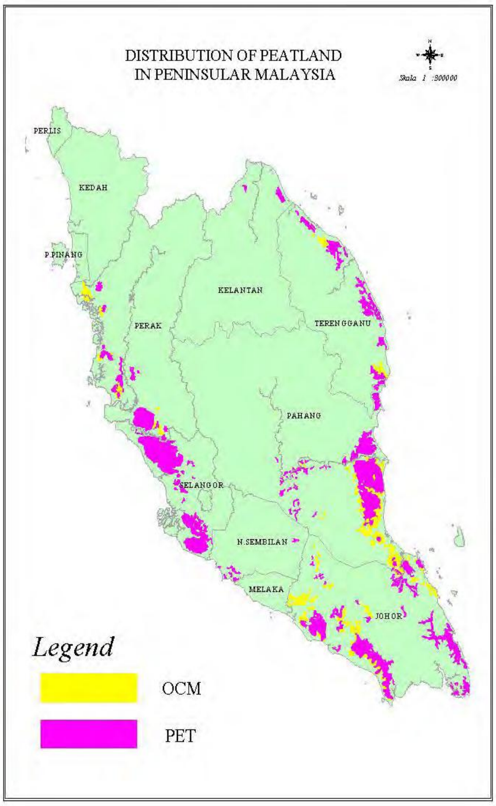
1.1 Introduction

Peat soil is identified as a very soft and difficult soil with low shear strength, high organic matter, low bearing capacity and high compressibility that exists in unconsolidated state. These characteristics cause excessive settlement which is very challenging to geotechnical engineers and the construction industry at large. Due to this problematic nature of peat soil, construction on it becomes a very challenging task to geotechnical and civil engineers and hence, the engineers regarded peat soil as the worst foundation soil for supporting the structures founded on it because of its unfavourable nature and behaviour. Peat is covering about 23 million hectares in South East Asia while three (3) million hectares or 8% of the total land area is found in Malaysia.

As demand for land increases and its supply becomes limited, constructions on weak soil such as peat soil can not be avoided. The research finding has shown that, peat soils experience instability and massive primary and long term consolidation settlements when subjected to even moderate load increase. There are many researches taking place to find the best method of stabilizing and improving peat soil. The methods are mainly concentrating on modification and stabilization peat soil. The stabilization of peat soil is meant to increase the strength of this soft and highly compressible soil. The purpose of stabilizing and modifying the peat soil is to improve its ability to perform well by increasing its strength and decreasing the excessive settlement when such soil is subjected to loads from structures.

There are many methods of stabilization and improvement of soft soil and one of them is using admixture. There are various types of admixtures that are available. Chemical admixtures or chemical stabilization always involved treatment of soft soil with some kind of chemical compounds, which when added to such soil will result in chemical reaction between the soil particles and chemical reagents. This chemical reaction enhances the physical and engineering properties of soil such as moisture content, consistency limits, strength and volume change among others. Replacement of peat soil with good quality soil is still widely practice when construction has to take place on peat deposit even though most probably this effort have led to uneconomical design because it requires transportation of large amount of good quality soil. Therefore, objectives of this research is to, measure some important engineering and index properties of peat soil and study the effect of different percentages of lime on peat soil in term of its strength change. Below is the extent of peatlands and contents of soils in Peninsular Malaysia.

Table 1.0.0: The Extent of Peatlands and Contents of soils in Peninsular Malaysia. (Source: Adapted from Soil Resource Management and Conservation Division Deparpartment of Agriculture Ministry of Agriculture, Malaysia.)



Extent of Peat According To States In Peninsular Malaysia (ha)

State	Peat	Organic Clay Muck	Total
Johor	228,960	69,540	298,500
Negeri Sembilan	6,300	-	6,300
Selangor	194,300	-	194,300
Perak	107,500	-	107,500
Pahang	219,561	62,939	282,500
Terenganu	81,245	6,755	88,000
Kelantan	7,400	-	7,400
Total	**845,266**	**139,234**	**984,500**

1.2 Background

Peat soil is formed by the decomposition or breakdown of plant and other organic materials. The characteristics and geotechnical properties of peat soil are mainly related to its high moisture content and high organic content respectively. Different peat soils have different geotechnical properties. Peat soil is identified as one of the common type of soil found in Malaysia. According to Huat (2004), there are 3 million hectares or 8% of the total area in Malaysia covered with peat soil. The increasing demand for space calls for engineering solutions to deal with adverse properties of this soft soil such as low strength and extreme compressibility that could provide stability for various civil engineering structures to be founded over the peat deposit. Several engineering practices such as replacing the peat soil with good quality soil is still being practiced when construction has to be carried out in areas covered with peat soil though this has been considered uneconomical design. However, other alternative stabilization and improvement methods such as surface reinforcement, sand or stone column, preloading, pre-fabricated vertical drains, use of piles and chemical stabilization are also commonly practiced. The selection of proper and the most suitable engineering technic and method have been based on the examination of engineering properties of particular soils. This implies that, behavior of peat soil is site specific. Hence, engineers have to assess the response of peat deposit to loading before carry out any construction at a particular site.

Peat soil is known for its low shear strength and high compressibility characteristics. The compressibility of peat soil depends on both deformation of the material and rearrangement of soild particles and distribution of pore water pressure from the soil in response to loading. Peat soil deformation may continue for a long period of time due to creep. At initial stage, peat soil shear strength could be low but keeps increasing as the soil is deforming and consolidating under apply load. The rate of strength increase due to the increase in load is almost one-fold for peat as compared to soft clay with a rate of strength increase of 0.3 (Noto, 1991).

In general, deformation of a peat soil is influenced by the orientation of solid particles in the soil. This arrangement of the particles controlled the way the particles are deposited. The particles arrangement influences the rate of water flow as water tries to escape from soil under loading. This shows that construction over peat soil is subjected to both primary and long term secondary settlement. Therefore, it is very important for the designer to have an idea about the characteristics of peat soil and interpret the compressibility parameters and other engineering characteristics of peat soil deposit.

Therefore, it is from the above facts that the primary objective of this research is to stabilize peat soil by using lime by first studying the important engineering and index properties of such soil. This has involved a literature review on different researches, site visit and laboratory testing to determine the exact properties of peat soil. The laboratory tests conducted include organic content, specific gravity, moisture content, pH, atterberg limit, unconfined compression test (UCT) and few others. For strength determination (confirming the stability and improvement of peat soil), a number of peat soil samples have been remolded with different percentage of lime and cure for 7 and 14 days. Then unconfined compressive strength was conducted on the cured peat soil samples to evaluate the strength gain. Hence, the results of treated and control samples have been analysed and conclusion drawn based on the objectives of this research topic.

1.3 Problem Statement

Peat soil has been identified by geotechnical and civil engineers as one of the most difficult and problematic soil in the world. It has become a great challenge to engineers and it often poses a serious problem to structures and construction industry at large due to its high compressibility and consolidation settlement. Peat soil is seen as a threat in the construction industry should an engineer design the structure over peat deposit without modifying its properties. The most renowned characteristics of peat soil are; low shear strength, high compressibility, high moisture content and high organic content which make peat soil considered as unsuitable soil type for construction activities.

In settlement analysis, in several occassions, the long term compressibility parameters of peat soil is either underestimated or neglected at all. This condition may result into problem pertaining the structure stability in the nearest future. Therefore, understanding and knowledge of compressive behavior and the shear strength of peat soil are very important. This knowledge enables the designers to understand the response of peat soil to load from structures and to suggest proper and suitable engineering solutions to overcome such problems.

1.4 Objectives and Significance of study

Based on the important properties of peat soil such as high compressibility, low shear strength and high moisture content characteristics obtained from the theoretical analysis and evaluation of peat soil response to loading, the following objectives are set forth for this research:

a.) To measure some important engineering and index properties of peat soil.

b.) To study the effect of different percentages of lime on peat soil in term of its strength and pH.

However, the significance of this research is to find ways of stabilizing and improving peat soil aiming at solving the problems pertaining marginal land. This will further knowledge on the behavior of peat soil for the purpose of geotechnical engineering applications.

1.5 Scope of study

The research covers the stabilization of peat soil by the use of admixture such as lime. Engineering and index properties of peat soil for instance; moisture content, atterberg limit, specific gravity and pH were determined before unconfined compression test (UCT) had been conducted.

The interpretation of the research results is limited to:

1.) Gathering site information (data) and sample collection at Hutan Melintang, Perak State.

2.) Visual identification and determination of important engineering and index properties of soil, both at site and in the laboratory through series of experiments.

3.) Determining strength attained by stabilized unconfined compression test (UCT) on the treated peat soil samples.

CHAPTER 2

LITERATURE REVIEW

2.1 Definition

Peat soil is a mixture of decomposed organic material derived from the disintegration of plant material under favourable climatic and topographic conditions. It is a soil with organic content of more than 75% (ASTMA, 1992, Kazemain and Huat, 2009a). Peat soil is known as one of the most problematic soil because it poses critical damages to structures founded on it due to its low shear strength. One of the unique behaviors of peat soil is its high compressibility making it unsuitable for construction activities. The high compressibility and low strength of peat soil often causes stability problem making the applied load limited or the load has to be placed in stages. Large deformation may occur during and after construction period both vertically and horizontally and this deformation sometimes may continue for a long time due to creep. Therefore, proper analysis and stabilization of peat soil are very important criteria to get good engineering design and solve this problem before embarking on real construction.

Previous researches have shown that, recently the utilization of peat-land in Malaysia is quite low although construction on marginal land such as peatland is becoming increasingly necessarily for economic reasons. Engineers are reluctant to construct on peat soil because of its unique characteristics and difficulty to access construction site. Huat (2004), stated that peat soil can be differentiated from other mineral soils such as clays by a) porosity, b) extreme compressibility, c) large change in properties under stress.

Several approaches have been developed to address the problems associated with construction over peat deposits (Hansbo, 1991). Alternative stabilization and construction methods such as chemical stabilization, surface reinforcement, preloading, sand or stone column, fabricated vertical drains and the use of piles available (Hartlen and Wolsky, 1996, Huat, 2004 and others). The selection of the most appropriate method for stabilization and improvement of peat soil should be based on the examination of engineering properties and characteristics of the soil.

The knowledge on the compression behavior and shear strength is very important since it enables designers to understand the response of the peat soil to load and to suggest appropriate solutions to overcome such problem.

The characterization of the peat soil has a significant effect for the strength as well as consolidation behavior of the peat soil. The research finding stated that, bearing capacity of peat soil was very low and was apparently influenced by water table and the present of subsurface woody debris (Islam et al., 2008 and Andriesse, 1988).

2.2 General properties of peat soil

Peat soil, like any other soil types has its owns physical, chemical and engineering properties. Peat soil has been identified as a kind of soil that owns a wide range of physical properties such as specific gravity, water content, texture, colour and density among others. Hobbs (1986) stated, those physical properties should be included in a full description of the peat soil. They are influenced by the main components of the formation such as mineral content, organic content, moisture content and air respectively. However, whenever one of these components changes, it will result in the change of the whole physical properties of peat soil. This variation in the characteristics of peat soil is related to differences in climate, water level, aging and the quantity of inorganic soil deposited during peat soil accumulation. The degree of decomposition affects porosity of peat soil and this porosity is controlled by both particle sizes and structure of the peat. This implies that, with an increase in the decomposition, the particle size of the organic matters decrease.

The chemical properties of peat are affected by the chemical composition of peat's components, the environment in which they are deposited and the extent of decomposition. The chemical characteristics of peat soils include chemical composition, carbon exchange capacity (CEC) and the acidity. The compositions of the peat varied with locations as its content is greatly depending on temperature and degree of decomposition (Deboucha et al., 2008).

The shear strength of the undisturbed peat soil is very low, however, peat soil strength could increase significantly upon stabilization and consolidation. The shear strength characteristics of peat soil are associated with several variables such as the origin of the soil, water content, organic content and the degree of decomposition.

The shear strength of the peat soil is determined based on the drained condition. Considering the presence of peat soil is almost frequently below ground water table, the determination of shear strength is also very important. The compression behavior of peat soil is different from clay soil. The research studies have shown that initial compressive strength occurs instantaneously after the load being applied, the primary and secondary compressions are time dependent. Compression of peat soil continues at a gradually decreasing rate under constant effective stress and this is known as the secondary compression. The secondary compression of the peat soil is thought to be due to further decomposition of fiber which is conveniently assumed to occur at a slower rate after the end of primary consolidation. Permeability is one of the most important physical properties of peat soil since it controls the rate of consolidation and increase in the shear strength of the soil. Research literatures have indicated that the peat soil is averagely porous and certifies the fact that peat soil has a medium degree of permeability.

2.3 Where is peat soil found in Malaysia?

Peat and other organic soils are the major group of problematic soils found in Malaysia. Malaysia has a total of three (3) million hectares of peat land. Peat soils occur both in the highlands and lowlands though the highland peat soils are not that extensive. The lowlands peat soil occurs almost entirely in low-lying, poorly drained depression or basins in the coastal areas.

In Peninsular Malaysia, peat is found in the Trans-Perak areas in the Perak Tengah and Hilir Perak district, coastal areas of West Johore, Kuantan and Pekan districts, Rompin-Endau area and Northwest Selangor.

According to Mutalib et al (1991) and Government of Sarawak (1990) the state of Sarawak has the largest peat area in the country with 16,500km^2 constituting 13% of the state with 90% of it being more than 1m deep.

Peat in Sarawak occurs mainly between the lower stretches of the main river courses and in poorly drained interior valleys. They are found in the administrative divisions of Kuching, Samarahan, Sri Aman, Sibu, Sarikei, Bintulu, Miri and Limbang. In Sabah, peat soils are found on coastal areas of the Klias Peninsular, Krah swamp in Kota Belud and Sugut.

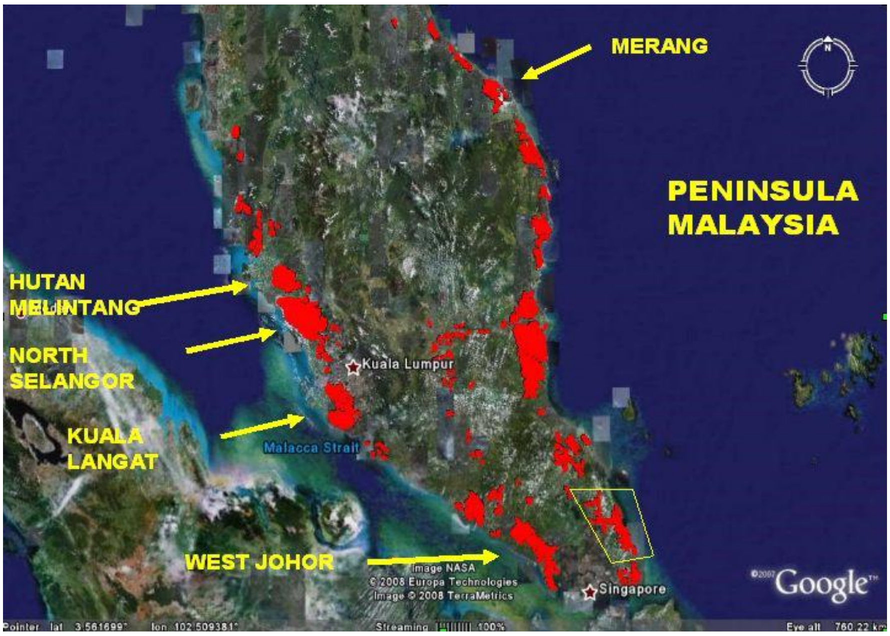


Figure 2.2.0: Peat Soil areas in Peninsular Malaysia

2.4 Problems with peat soil

Peat has been classified as one of the problematic soils in the view of design parameter by the geotechnical engineers because its engingineering properties are inferior to those of other soft soils which make peat soil unfavourable for construction in its originality. Peats are known to contain high organic matter and therefore, peats are generally associated with high compressibility, large deformation, poor strength characteristics and high magnitude and rates of creep (Haan and Kruse, 2006).

Peat soil is subjected to problem of instability, for instance, local sinking and development of slip failure. It also experienced significant primary and long term secondary settlements when subjected to even moderate increase load. Peat poses difficulties in accessing the construction sites, a wide varation in material properties coupled with difficulty in sampling. There is also possibility of chemical and biological changes in these materials with time. For instance, the organic constituents upon further humification may change the mechanical properties of peat such as the hydraulic conductivity shear strength and compressibility, (Huat, 2004).

Andriesse (1988) and Islam and Hashim (2008a and 2008b) stated that the bearing capacity of peat soil is very low and it fails in different ways. The bearing capacity was affected by the high water table and the presence of wood debris in soil. Lowering of water table may result in shrinkage and oxidation of peat soil, hence leading to humification with an increase in compressibility and permeability. However, even if the failure can be handled, it is inevitable that peat soil takes longer time to settle when loaded due to embankment or soil fill. Under such conditions, the embankment will settle continually into the ground below even if the soil do not fail by displacement. Therefore, it can be concluded that, untreated peat soil is not suitable for construction because it is very weak to support the foundation.

2.5 What have other researchers done on the problem of peat soil?

Construction on peat soil has proven to be a challenging task to civil engineers as this organic soil is highly compressible. Construction on soft soils like peat soil is frequently accompanied by high geotechnical risks and costs (D.Aden Hamer, 2012). D.Aden Hamer proposed a novel stabilization method which takes infiltration and reactive transport as the starting point. He said, the goal of this method was to strengthen the soil matrix without significant loss of porosity. He said, the aim was to create a silicate coating which encloses or at least connects the peat fibers, hence refers to as fiber encapsulation. Encapsulation of the fiber alters the mechanical and chemical properties of peat soil. D. Aden said, stabilization have been achieved by infiltration and transport of the reactive components (in-situ process).

Kolay P.K and Pui M.P (April, 2010), used gypsum and fly ash to stabilize local peat soil from Matang, Sarawak. They added different percentages of gypsum and fly and after curing for 7day, 14days and 28days, they concluded that peat soil has increased in strength due to the addition of different percentages of these two admixtures (gypsum and fly ash).

Mena I. Souliman and Claudia Zapata (2011) are other researchers who have done peat stabilization by deep mixing method. They said, deep mixing method is emphasized on column type techniques using lime/cement. They emphasized that deep soil stabilization method is often economically attractive alternative to removal deep peat or use of piles as deep foundation (Hebib and Farrel, 2003). Generally, deep mixing method is today world-wide accepted as a ground improvement technology in order to improve the strength, permeability and deformation properties of the peat soil.

2.6 Mechanism of lime stabilization

Whenever lime is incorporated into any type of soil, the stabilization of soil by lime is achieved through flocculation, agglomeration, lime carbonation, cation exchange and pozzolanic reactions. Agglomeration, flocculation and cation exchange reactions take place rapidly and cause faster changes in soil properties such as pH, strength and plasticity index, whereas, pozzolanic reaction is time dependent. This pozzolanic reaction involves interaction between soil silica/alumina and lime to form various types of cementitious product hence, improving the soil strength. Therefore, it has to be emphasized that chemical interaction plays significant role in the lime stabilization of soils. Below are some of the basic reactions that take place when lime is added to peaty, clayey or silty soils:

a.) Pozzolanic reactions

$$Ca^{++} + 2(OH)^{-} + SiO_2 \rightarrow CSH$$

$$Ca^{++} + 2(OH)^{-} + Al_2O_3 \rightarrow CAH$$

b.) Carbonation reaction

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

c.) Cation exchange

$$Ca^{++} + Clay \rightarrow Ca^{++}Clay + (Na^{+}, K^{+})$$

d.) Flocculation and Agglomeration reactions.

All these reactions improve the physical, chemical and engineering properties of soil. However, some reactions, for instance, carbonation reaction in most cases gives weak cementing in comparison to the rest of reactions. The pozzolanic reaction is time dependent and it is mainly responsible for improvement in soil characteristics. The long term physio-chemical improvements are due to pozzolanic reactions. The pozzolanic reactions are facilitated by the lime creating highly alkaline soil pore chemistry. These reactions result in the increase in soil strength and reduction in permeability. However, strength gained in peat soil is due to flocculation and cation exchange reactions.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

This project is an experimental-based research which focuses on the stabilization of peat soil by the use of lime. The literature research that has been done was to provide a foundation of the research topic and to gather adequate information regarding the lime and peat soil. The peat soil sample was collected from a peat deposit area at Hutan Melintang, Perak State. The laboratory testing procedures of this study were carried out based on British (BS 1377, 1990) and US (ASTM, 1995) standards. The experimental research concentrated much on laboratory testing to determine the important properties of the peat soil and the suitable dosage/proportion of stabilizer (lime) that should be economically applied to give effective stabilization of the peat soil in term of strength. Soil physical and index properties such as specific gravity, atterberg limits (liquid limit, plastic limit and plasticity index), moisture content, particle size distribution and soil pH were determined to establish the basic characteristics of the peat soil. The engineering property such as unconfined compression (UCT) was also tested on both treated and untreated soil samples. An appropriate proportion of stabilizer (lime) that improves peat soil sample most in term of strength and other engineering properties, had also been determined based on Eades and Grim Test. Tests on control (original) peat soil was conducted in order to assess the strength gain (improvement) by the peat soil samples in comparsion to stablised ones.

3.2 Site Information and Sample Collection

Important short site visit was made to Hutan Melintang, Perak State to assess the conditions that favor the formation of peat soil and collect the specimen for laboratory test. The site investigations helped to gather general information about peat soil formation and development. In the site visited, it was noticed that climatic factors such as temperature, humidity, rainfall, among others are the most important factors beyond peat soil formation and development. These factors are found to have direct and indirect influence on peat soil formation, development and its characteristics.

Among these climatic factors, humidity and temperature were identified as the most important factors that facilitate the decomposition, transformation and development of organic matter. Soil conditions for instance; soil temperature, soil microbes; soil humidity and soil pH value directly influence the decomposition degree of organic matter, hence, influencing peat soil formation. Several combined factors of water and temperature dictate the balance between decomposition and accumulation of peat soil.

The information of site investigations were used to have rough idea about the soil physical properties such as colour, texture, profile and ground water condition. This prominant site at Hutan Melintang has provided very important data for the analysis of peat soil physical properties. At that site, adequate quantity of peat soil sample was collected for test in the laboratory. The sample was put in the polyethylene bags and tied tightly to prevent the escape of the moisture. The sample was disturbed using hoe and collected with trowel. The colour of collected peat soil sample was black to dark-brown with smelly odour. Another important characteristics realized at site was that, peat soil was spongy and highly compressible, which makes peat soil distinctive from inorganic soils such as clays and sand which are made up mainly of silicate-solid particles.

Figure 3.1.1: Sample site at Hutan Melintang

3.3 Laboratory works

The peat soil samples that were used for this research were collected in a peat deposit area at Hutan Melintang in Perak State. The stabilizing agent that was used to stabilize peat soil samples is lime. The laboratory works for this study is divided into two (2) parts:

a) Laboratory works to determine the physical and index properties of peat soil,

b) Laboratory works to determine the strength and pH of the stabilized peat soil.

Physical properties tests were conducted in order to determine the physical or index properties of original peat soil. This testing of physical properties of peat soil consists of soil pH, moisture content, particle size distribution (seive analysis), specicfic gravity and atterberg limit (liquid limit, plastic limit & plasticity index). Unconfined compression test was conducted to determine the strength (engineering properties) gained by the peat soil mixed with lime. The strengths of both peat soil samples, the one treated with lime and original (control) peat soil samples were compared. The strength test was conducted on peat soil samples that were cured at different period; that is, 7 and 14 days respectively.

3.4 Laboratory works to determine the physical and index properties

These laboratory tests have been conducted to determine geotechnical properties of peat soil. These geotechnical properties of stabilized peat soil depend on physical and chemical of natural peat soil and properties of stabilizer (lime). The most important geotechnical properties of peat soil have been determined in the follow tests. A test was conducted to establish the suitability of lime as stabilizer and determine optimum quantity of lime stabilizer. A number of tests have been conducted to assess the strength-deformation properties of stabilized peat soil. Lime stabilization initiates long-term stabilization reactions, for instance; pozzolanic reactions may continue for years after completion of actual work. Below are some selected tests for this project;

3.5 Soil pH Test

pH tests has been conducted in order to evaluate the alkalinity of untreated and stabilized peat soils in order to establish the suitability of stabilizer (lime) for stabilizing peat soil. Laboratory digital pH meter was used in the determination of pH of both stabilized and untreated peat soil samples. Linking the pH with electric voltage, digital pH meter measured the pH of soil based on the voltage indicator.

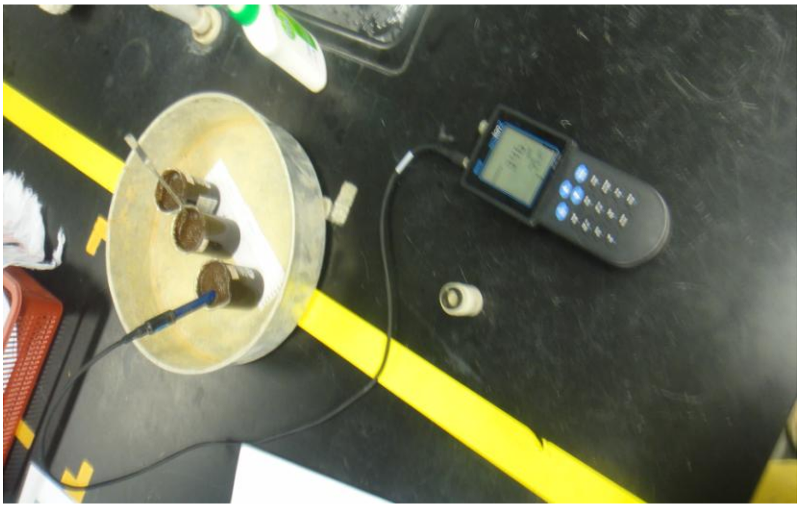


Figure 3.3.1: Determination of peat soil pH

3.5.1 Eades and Grim pH Test

Eades and Grim Test (ASTM 1995) was performed with the aim of determining the approximate optimum lime content or to determine lime demand for that matter. The test provides foundation for approximating the peat soil-lime proportionality for the stabilization of weak peat soil. This test indicates the lime quantity demanded to satisfy immediate lime-soil reactions. This still provides great residual calcium and a high pH of about 12.40 at 25°C. This is very essential since it provides suitable conditions for long-term pozzolanic reaction which is believed to be responsible for strength and stiffness development in peat soil. However, the optimum soil-lime rationality for peat soil stabilization was determined by tests of specific characteristic of stabilized peat soil, for instance unconfined compression test (UCT).

Figure 3.3.2: Eades and Grim test

3.5.2 Moisture Content

Water is present in most naturally occuring soil, including peat soil. The amount of water, expressed as a proportion by mass of the dry solid particles known as the moisture content, has a profound effect on soil behavior. Therefore, a soil is "dry" when no further water can be removed at a temperature not exceeding 110°C.

Moisture content is required as a guide to classification of natural peat soils and measure on samples used for laboratory test. The moisture content of peat soil samples has been determined per the procedures outlined in BS 1337: Part 2: 1990: 3.2. This method is known as 'oven-drying' method. The moisture content of the soil is expressed as a percentage of its dry mass. The moisture content of the soil sample, w, is calculated as follows:

$$w = \frac{m_1 - m_2}{m_3 - m_1} \times 100\%$$

w = moisture content (%), m_1 = mass of container (g),

m_2 = mass of container + wet soil (g), m_3 = mass of container + dry soil (g).

3.5.3 Organic Content Test (organic matter content test)

Organic matter content test is a very important test in classification of peat soil and other organic soil. The organic content is expressed as percentage of the mass of organic matter in a given mass of soil to the mass of dry soil solids. Organic matter influences physical and chemical properties of soil such as compressibility, structure, and shear strength. Organic matter also affects water holding capacity among others. Oven-dried samples from moisture content were weighed and placed in muffle furnace set at 440°C for twenty-four (24) hours. After twenty-four hours, samples were removed from muffle furnace, and then organic content and ash content have been determined. Figure below show the weighing of samples from muffle furnace.

Figure 3.3.4: Muffle Furnace for determinating peat organic content

3.5.4 Particle Size Distribution

In the determination of soil class for engineering purposes, engineers ought to know the grain size distribution in any given soil mass. This helps in the determination of some soil engineering properties. There are three (3) methods used in the determination of particle size distribution of the fine particles such peat soil. These methods are the pipette, sieve analysis and hydrometer methods respectively. The two measure the density of the soil suspension at various intervals.

In this study, sieve analysis method is preferred over pipette method. Particle size distribution was conducted on peat soil samples. The results obtained were plotted on the log-scale and the grain distribution curves were interpreted to give useful information that was used to determine the suitability of peat soil for road construction, building foundation and airport construction. The information that was obtained from this particle size distribution test was used to predict soil water movement.

Figure 3.3.5: A set of sieves

3.5.5 Specific Gravity (Gs)

Specific gravity (Gs) is an important soil test that gives the value of particle density. Though there are three (3) methods for determining the specific gravity of the soil, here I preferred to use pyknometer method. The specific gravity test of peat soil or any other highly organic soils, was based on the procedures outlined in BS 1337: Part 2: 1990: 8.2. Two (2) tests were conducted and the average of those tests was determined in order to minimize errors and ensure the accuracy.

The specific gravity (Gs) is calculated from the following Equation:

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

Where, m_1 = mass of bottle and stopper (g)

m_2 = mass of bottle, stopper and dry soil (g)

m_3 = mass of bottle, stopper, soil and water (g)

m_4 = mass of bottle, stopper when full of water only (g)

3.5.6 Atterberg Limits (liquid limit, plastic limit and plasticity index)

The atterberg limits are used for basic determination of nature of fine-grained soil. This implies that, peat soil is one of those fine-grained soils and therefore, there is a need to use atterberg limits test to measure the nature of peat soil. Depending on the water content of the particular soil, the atterberg limits may appear in four (4) states; solid, semi-solid, plastic and liquid respectively. Therefore, the boundary between each state can be defined based on the change in soil's behavior. Atterberg limits are important tests that can be used to differentiate between silt and clay and it can also differentiate between various types of silts and clays.

The important atterberg limits (consistency limits) are defined as follows:

1.) The shrinkage limit (SL) is an arbitrarily defined value that represents the moisture content at which a particular soil stops acting like a solid and begins acting like a semi-solid.

2.) The plastic limit (PL) represents the change from semi-solid to a plastic state.

3.) The liquid limit (LL) represents the change from a plastic state to that of a liquid state. The liquid limit of soil samples was determined using cone penetrometer based on BS 1337: Part 2.

4.) The plasticity index (PI) is defined as the range of water content within which the soil exhibits plastic properties; that is, it is the difference between liquid and plastic limits respectively.

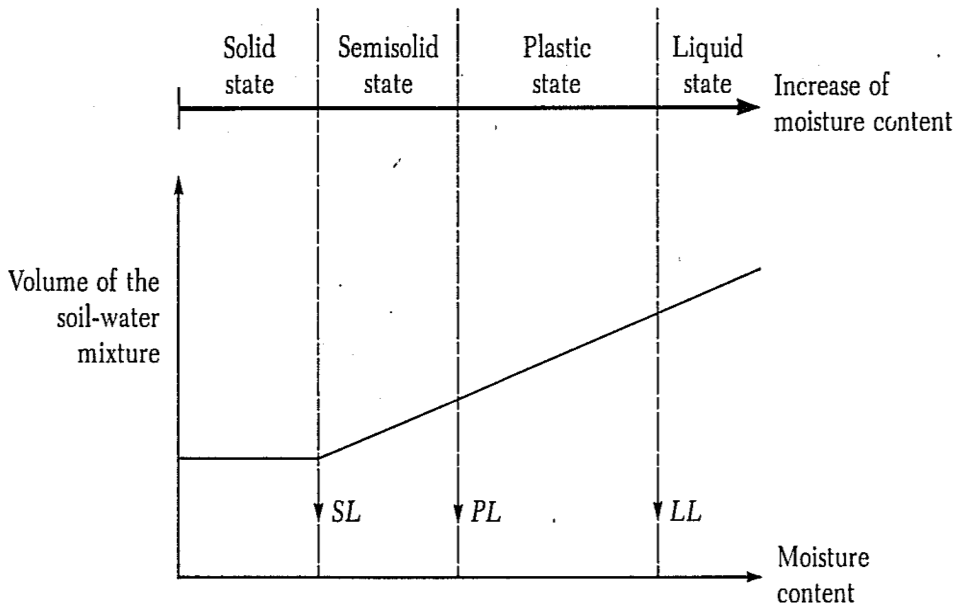


Figure 3.3.7: Atterberg's limits definition

3.5.7 Standard Proctor Compaction Test

In the construction of various structures such as structural foundation, retaining walls road embankments among other facilities, loose and weak soil must be compacted to increase its density. Compaction is described as the process of densifying soil under controlled moisture conditions by the application of a given amount and type of energy. Compaction is one of the most common and important method of stabilizing soil. Soil compaction increases the density of loose soil, which intent leads to:-

- An increase in the strength and stiffness characteristics of the soil
- Decrease in the amount of undesirable settlement of structures under both static and dynamic loads.
- Compaction reduces soil permeability
- Compaction increases the stability of slopes and embankments.

In the laboratory test, density of compacted soil is measured in term of the dry unit weight of the soil. The dry unit weight of the soil is a measure of the amount of solid materials present a unit volume of soil. The greater the amount of solid materials, the stronger and more stable the soil will be. The design specifications usually state the required density (Maximum Density) and the water content. On the other hand, Optimum Moisture Content (OMC) is water content results in the greatest density. This Proctor Test has been conducted in accordance to BS 1377: Part 4: 1990 with the aim to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the peat soil samples.

After following series of steps, the values of dry density and its corresponding moisture contents for plotting the curve has been calculated as stated below;

$$\rho_d = \frac{\rho_w}{\frac{w}{100} + \frac{1}{Gs}}$$

Where ;

ρ_d $= dry\ density\ of\ soil\ grams\ per\ cm^3$

G_s $= Specific\ gravity\ of\ the\ soil\ being\ tested$

ρ_w $= Density\ of\ water\ in\ grams\ per\ cm^3$

The figures were calculated and tabulated per tests conducted in the laboratory and the optimum moisture content (OMC) and maximum dry density (MDD) identified and reported.

Figure 3.3.8: Standard proctor test

3.6 Laboratory works to determine the strength.

3.7 Unconfined Compression Test (UCT)

Unconfined compression (UCT) stands for load per unit area at which unconfined cylindrical specimen of soil sample has been tested in a simple compression test. For this study, unconfined compression (UCT) was conducted on both the natural peat soil samples as well as on peat soil samples stabilized with the stabilizer (lime). Unconfined compression test (UCT) is regarded as one of the important tests used to determine the shear strength of remolded peat soil; both stabilized and untreated soil samples. This unconfined compression test (UCT) has been conducted as per the guidelines outlined in BS 1337: 1990 and ASTM D 2166. In this test, extruded samples from mould were trimmed to height of 76mm and the internal diameter of mould which is also the diameter of samples was 38mm. The natural peat soil samples that were used for unconfined strength test, were determined at their original moisture contents. Since peat soil contains other materials, it was sieved first before being mixed with the stabilizer (lime). Unconfined compression tests was carried out on samples cured at different time intervals; 0, 7 and 14 days respectively.

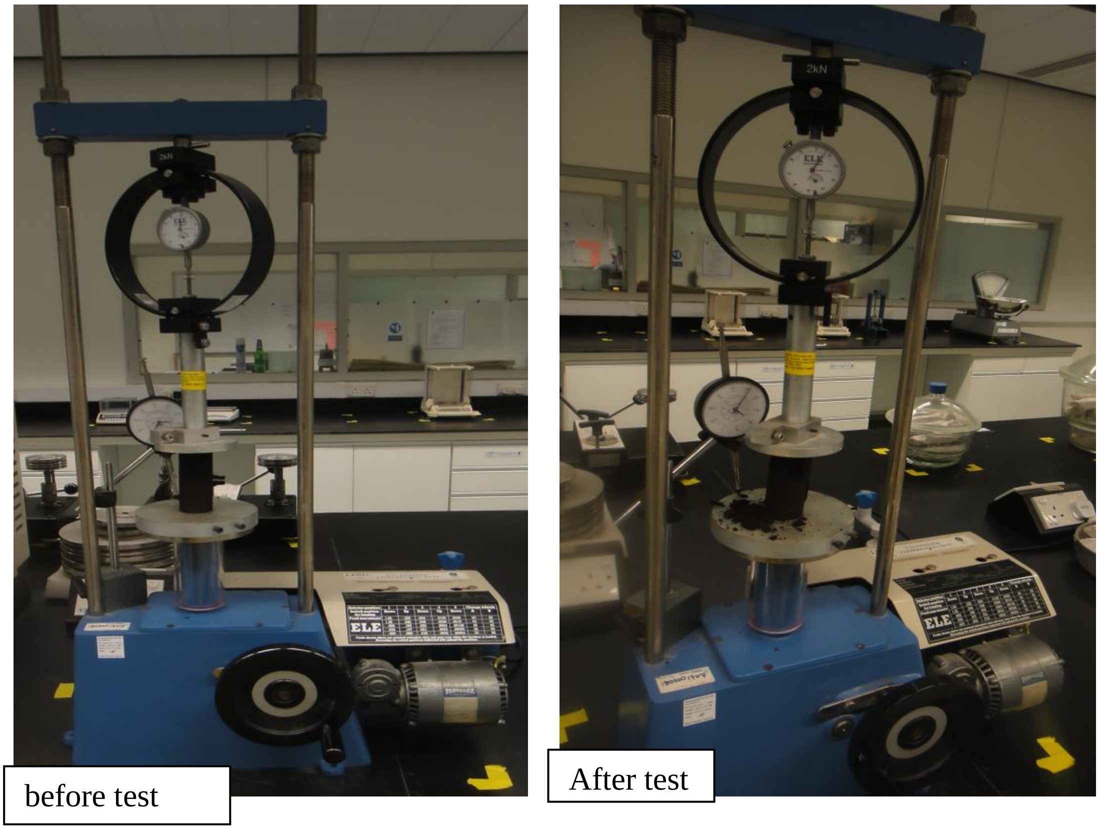
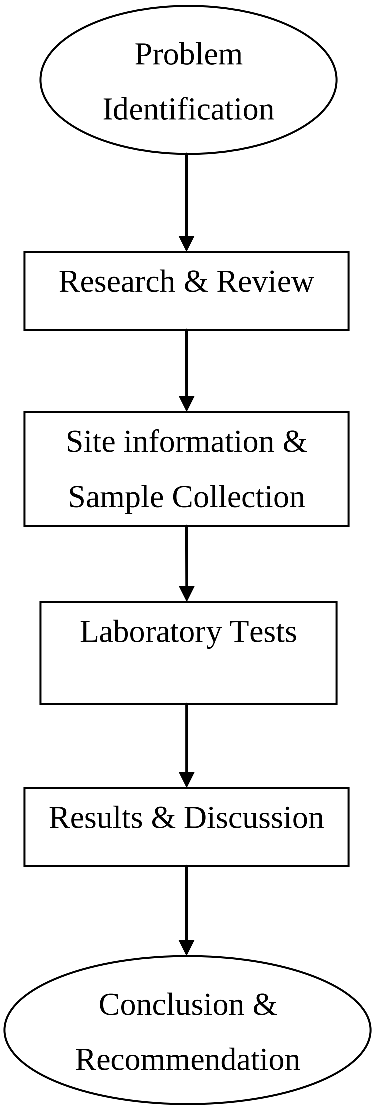


Figure 3.4.0: Unconfined compression test (UCT)

3.8 SUMMARY OF RESEARCH METHODOLOGY

Below is the flowchart summarizing the Research Methodology



CHAPTER 4

RESULTS AND DISCUSSION

4.0 Laboratory Testing

The conducted laboratory tests have provided essential and sufficient information about geotechnical, physical and chemical properties of peat soil. These tests on peat soil samples have been conducted in order to determine and understand peat soil responds to imposed loads. From these tests, it can be deduced that, types of peat soil behavior depend on strength, compressibility and index properties such as PI.

4.1.1 Proctor compaction test

The results of proctor compaction test tabulated below have shown that moisture content increases with increase in dry density of peat soil to the maximum **(800kg/m³) MDD** and **(40%) OMC**, and then starts to fall. This is due to the fact that peat soil absorbs high amount of water to fill up large voids and another factor is exothermic reaction that could arise from organic reaction. The optimum moisture content (OMC) is very important as a basis for determining the right volume of water requires for mixing of soil sample and the lime. Below is the table summarizing proctor compaction test results;

4.1.2 Soil pH test

pH test was a very important test conducted to determine the pH values of original peat soil sample and peat soil samples mixed with different percentage of lime. The pH values of original and mixed peat soil samples have been determined by electrometric method which gave direct readings of the pH values of the peat soil samples suspension in water. The pH results of the test on original peat samples shows that, peat soil in its originality is acidic while mixed peat soil samples pH values increase with increase in the proportion of the lime. Below are the tables summarizing the result of pH tests.

Table 4.1.2: pH results of peat soil.

Sample number	**1**	**2**	**3**
pH of the peat soil sample before treatment	3.45	3.36	3.37
pH of peat soil sample after treatment	11.5	12.4	12.42

However, after stabilization, the pH of treated specimens was found to be within the range of 8.21 to 12.42. The pH has been noticed to have increased with the increase in the lime percentage up to 18% after which it starts to drop.

4.1.3 Moisture Content

The moisture content of soil in general is termed as the ratio of the weight of water in the sample to the weight of soil solids. Moisture content is very important in the determination of soil properties which are correlated to compressibility, settlement, strength and workability. A number of wet peat soil samples were weighted and then oven-dried at a temperature not exceeding 110°C. The weights after drying are the weights of soil solids. Therefore, the change in weights that have happened during drying are equivalent to the weights of water, hence moisture content. The natural moisture content obtained from the laboratory tests are tabulated below;

Table 4.1.3: moisture content result

sampl No	**1**	**2**	**3**	**4**	**5**	**6**
Mass of container (m_1)	20.9	20.55	18.59	18.77	18.59	18.86
Mass of container plus wet soil (m_2)	60.9	60.55	58.59	58.77	58.59	58.86
Mass of container plus dry soil (m_3)	29.9	29.8	27.8	26.8	26.7	26.9
Moisture content (%)	344	332	334	398	393	398

The average of the above moisture contents is 367% which shows that peat soil has high water-holding capacity. The above moisture content results are within the range of peat soil moisture content obtained by other researchers, for instance, Huat (2004), research on peat soil indicated that moisture content of peat soil ranges from 200 percent to 700 percent (200% - 700%). The value of moisture content is that high because it was noticed at site during sampling that groundwater table exists at shallow depth.

4.1.4 Organic content test

Organic soils such as peat soils show undesirable engineering characteristics, for instance, high compressibility, low strength and long-term settlements. Engineering analysis indicate that characteristics of organic soils with organic contents less than 20% by weight is generally governed by the mineral composition of the soil. However, when the organic contents exceed 20%, the behavior of the soil is controlled by the organic composition of the soil. This peat soil was easily identified at the site its dark to dark-brown, musty smell and compressibility. Organic content test (also known as Ignition Loss Test) has been performed to measure peat sample's mass burned off when peat sample was placed in a muffle furnace. The results have been expressed as the percentage of the total peat sample mass. The results below show that peat soil collected has high organic content. However, what remained in the porcelain dish was a fined grained material known as ash. Ash was a resultant residue of peat soil samples combustion. Sometimes, the composition of ash varies depending on the combustion process. The average result of organic content is approximately **82%** which showed that the sample contains high organic matter. The results of organic content are very significant in the classification of peat soil or any other organic soils.

Table 4.1.4: Organic matter content

Porcelain dish number	**1**	**2**
Mass of empty, clean porcelain dish (g)	62.03	56.22
Mass of dish plus dry soil (g)	82.03	76.22
Mass of dish plus ash (burned soil) (g)	67.75	62.9
Mass of ash only (g)	5.72	1.68
Mass of organic matter (g)	14.28	18.32
Ash Content (%)	**29**	**8**
Organic Matter (%)	**71**	**92**

4.1.5 Specific gravity (Gs)

Specific gravity (Gs) of any soil is performed to relate mass or weight of that soil to its volume. It is a ratio and therefore, it has no unit though it is very important in the determination of weight-volume relationship of the soil. As defined in BS 1377: 1990, Gs is the ratio of mass in air of a given volume of soil particles to the mass in air of an equal volume of de-aired distilled water. The specific gravity data below were determined by means of calibrated pycnometer by which the mass of de-aired distilled water was measured. The specific gravity of water is assumed unity (1). The results for this test are tabulated below.

Table 4.1.5: Specific gravity (Gs) of peat soil

Sample No	**1**	**2**
Specific gravity (Gs)	1.24	1.3

4.1.6 Particles size distribution (PSD)

Particle size distribution also known as sieve analysis has been conducted to determine the grain size of the particles of the soil which helped in soil classification. The particle size distribution information is very essential in the analysis of the soil engineering properties, for instance, porosity, permeability, strength, erosion but, main importantly, particles size distribution determine the suitability of material for foundation, earthwork construction and backfill. Sieve analysis test has provided the direct measurement of the particle size distribution of peat soil samples. The peat samples passed through a stock of sieves with progressively smaller openings of the sieves. The results obtained indicated that samples were uniformly graded.

Table 4.1.6: Particle size distribution (PSD) result

Sieve size (mm)	Weight retained (g)	%Retained	%Finer	Cumulative %passing
3.35	2.6	0.52	99.48	0.52
2	20.4	4.08	95.4	4.6
1.18	160.4	32.08	63.32	36.68
0.6	163	32.6	30.72	69.28
0.425	59.3	11.86	18.86	81.14
0.3	32.3	6.46	12.4	87.6
0.212	15.4	3.08	9.32	90.68
0.15	11.4	2.28	7.04	92.96
0.063	17.9	3.58	3.46	96.54
Pan	17.3	3.46	0	100
Total Mass	**500**			

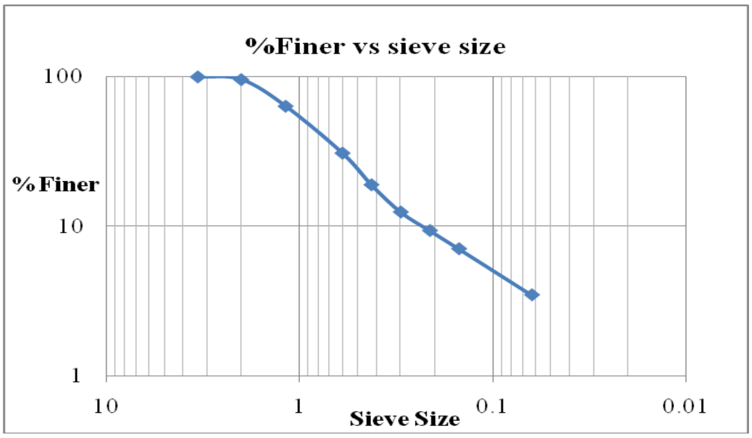


Figure 4.1.6: Particle size distribution (PSD) curve

From the graph, since small particles are more than 10%, this soil can be stabilized with lime.

4.1.7 Atterberg limits (LL, PL & PI)

Atterberg limits comprise of liquid limit (LL), plastic limit (PL), plasticity index (PI) and shrinkage limit (SL). These are index tests used to confirm visual descriptions. These tests are conducted on soil samples to determine the suitable amount of water need to achieve a range of behavioral characteristics. The calculations of Atterberg limits data (and others) are in the appendices. The liquid limit of Hutan Melintang peat soil obtained from Laboratory Cone Penetration Test is 144.3%. This liquid limit (LL) is the moisture content when the dial gauge reading of the cone penetrometer is 20. However, the plastic limit (PL) that has been determined from the oven-dried peat soil sample is 115.25%. Therefore, the plasticity index (PI) of the sample is calculated as follows;

PI = LL – PL

PI = 144.3 – 115.25

PI **= 29.05**

Therefore, peat soil is suitable to stabilize with lime since its plasticity index (PI) is greater than 10.

4.1.8 Eades and Grim Tests

This test has been performed to estimate the peat soil-lime proportion requirement for the stabilization of peat soil. Eades and Grim Test method is necessary for the determination of the lowest percentage of lime that has resulted in soil-lime pH of 12.42. This implies that, the lowest percentage (16%) of lime in peat soil that gave a pH of 12.42 and this was the necessary lime percentage for the stabilization of this soil sample. This is essential to allow for appropriate conditions for long-term pozzolanic and flocculation reactions which are responsible for development of soil strength and stiffness.

Table 4.1.8: Eades and Grim Test result

%Lime	10	12	14	16	18	20	22	24
PH	9.18	9.44	12.1	12.42	11.98	10.67	11.97	11.83

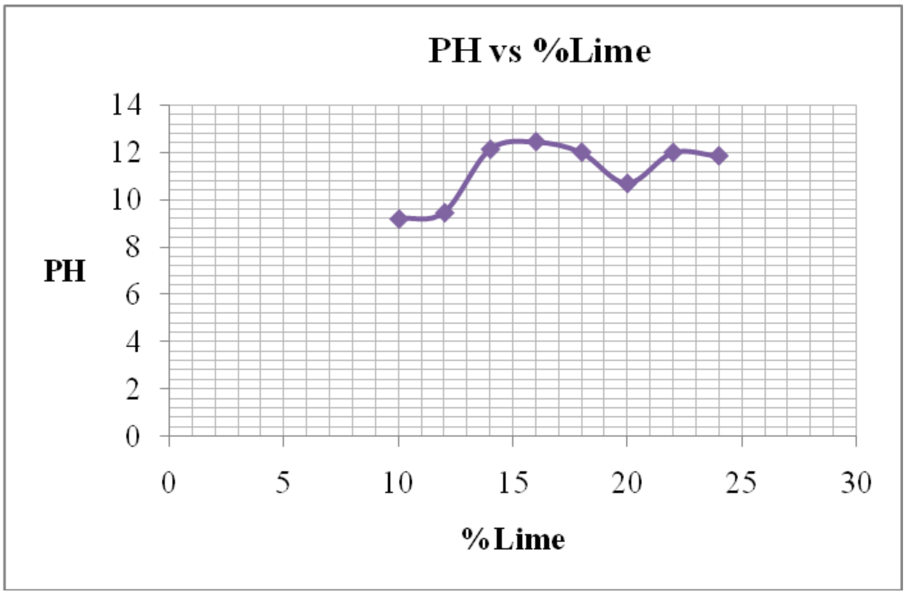


Figure 4.1.8:Relationship between pH and lime (Eades & Grim test)

4.1.9 Unconfined compression test (UCT)

The main objective of this project is to determine the maximum strength attained by soil samples as a result using lime as stabilizer. Unconfined compression test (UCT) is a very important test method for determining the strength of stabilized peat soil. In this test, cylindrical samples of peat soil were each subjected to a steadily increasing axial load until failure occurs. Each of the samples was 38mm in diameter and trimmed to 76mm in length. After performing several unconfined compression tests on stabilized peat soil samples stabilized with varying proportions of lime and cured for 0, 7 and 14 days, optimum strengths have been noticed within the range of 14%, 16% and 18% of lime proportions when plotting the maximum strengths from the ten (10) samples. However, the highest strength of 149.3kpa was realized with 14% of lime cured for 14 days. This implies that strength of stabilized peat soil is expected to increase with increase in curing duration. This is because calcium-based stabilizer (lime) contains certain amount of free lime (CaO or $Ca(OH)_2$) that reacts pozzolanically with fine particles. Four (4) graphs of stress (kPa) versus strain (ε) and stress (kPa) versus %lime, with different curing duration have been plotted below while the rest of unconfined compression test results are in the appendices.

Table 4.1.9: UCT results of peat specimen mixed with 14% lime & cured for 7 days

Unconfined Compression Test Data **14% lime & cured for 7 days**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	22	0.2	0.003	0.26	0.02	14.3
40	35	0.4	0.005	0.53	0.03	22.7
60	54	0.6	0.008	0.79	0.04	35
80	68	0.8	0.011	1.05	0.05	44.1
100	82	1	0.013	1.32	0.06	53.2
120	95	1.2	0.016	1.58	0.07	61.7
140	102	1.4	0.018	1.84	0.08	66.2
160	116	1.6	0.021	2.11	0.09	75.3
180	130	1.8	0.024	2.37	0.1	84.4
200	148	2	0.026	2.63	0.11	96.1
220	164	2.2	0.029	2.89	0.12	106
240	180	2.4	0.032	3.16	0.13	117
260	194	2.6	0.034	3.42	0.14	126
280	202	2.8	0.037	3.68	0.15	131
300	210	3	0.039	3.95	0.15	136
320	210	3.2	0.042	4.21	0.15	136
340	204	3.4	0.045	4.47	0.15	132
360	197	3.6	0.047	4.74	0.14	128
380	186	3.8	0.05	5	0.14	121
400	175	4	0.053	5.26	0.13	114

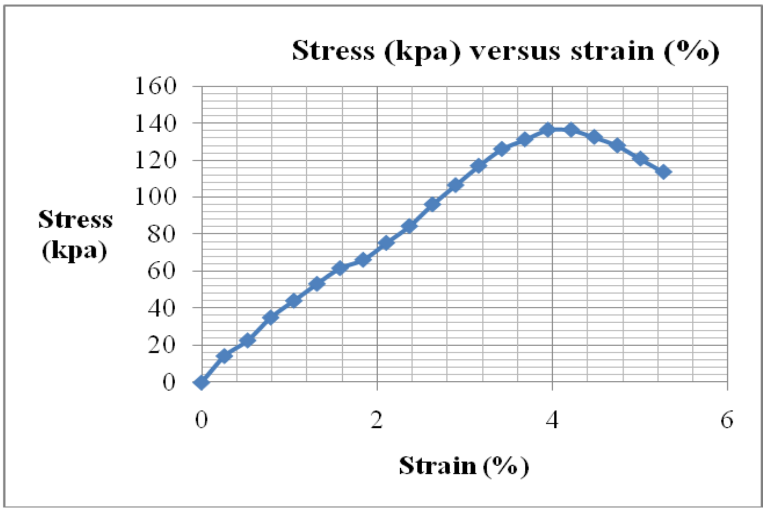


Figure 4.1.9: Stress (kpa) versus strain (%) of peat specimen mixed with 14% lime & cured for 7 days.

Table 4.2.0: UCT results of peat specimen mixed with 14% lime & cured for 14 days

Unconfined Compression Test Data **14% lime & cured for 14 days**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	20	0.2	0.003	0.26	0.01	12.98
40	38	0.4	0.005	0.53	0.03	24.66
60	56	0.6	0.008	0.79	0.04	36.35
80	74	0.8	0.011	1.05	0.05	48.03
100	92	1	0.013	1.32	0.07	59.71
120	130	1.2	0.016	1.58	0.1	84.37
140	140	1.4	0.018	1.84	0.1	90.86
160	160	1.6	0.021	2.11	0.12	103.8
180	180	1.8	0.024	2.37	0.13	116.8
200	196	2	0.026	2.63	0.14	127.2
220	208	2.2	0.029	2.89	0.15	135
240	216	2.4	0.032	3.16	0.16	140.2
260	224	2.6	0.034	3.42	0.16	145.4
280	230	2.8	0.037	3.68	0.17	149.3
300	225	3	0.039	3.95	0.17	146
320	215	3.2	0.042	4.21	0.16	139.5
340	208	3.4	0.045	4.47	0.15	135
360	195	3.6	0.047	4.74	0.14	126.6
380	190	3.8	0.05	5	0.14	123.5

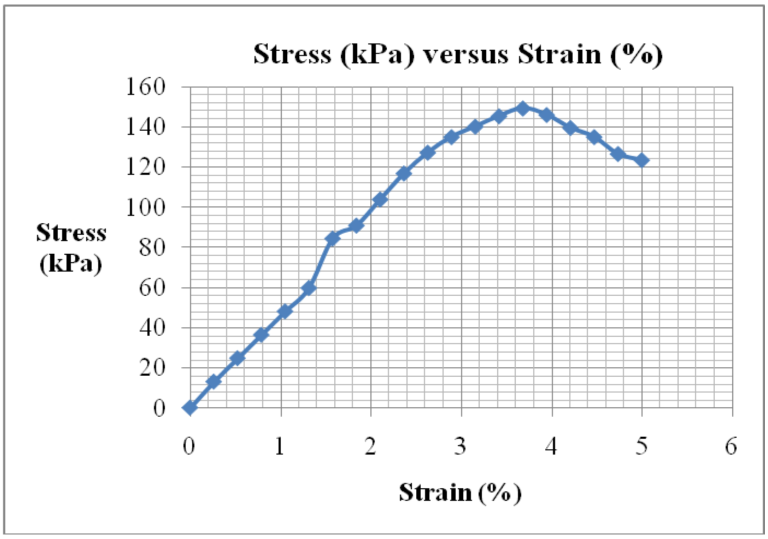


Figure 4.2.0: Stress (kpa) versus strain (%) of peat specimen mixed with 14% lime & cured for 14 days.

Table 4.2.1: Summary of UCT results of peat specimens mixed with 0%, 10% to 24%lime & cured for 0 and 7 days.

unconfined compression test data
(Deformation Dial: 1unit = 0.01mm; Load Dial: 1unit = 0.736N)

%Lime	Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
Control	220	146	2.2	0.029	2.89	0.107	94.76
10	240	158	2.4	0.032	3.16	0.116	102.5
10	320	170	3.2	0.042	4.21	0.125	110.3
12	340	183	3.4	0.045	4.47	0.135	118.8
14	300	210	3	0.039	3.95	0.155	136.3
16	340	217	3.4	0.045	4.47	0.16	140.8
18	360	218	3.6	0.047	4.74	0.16	141.5
20	340	190	3.4	0.045	4.47	0.14	123.3
22	380	200	3.8	0.05	5	0.147	129.8
24	360	160	3.6	0.047	4.74	0.118	103.8

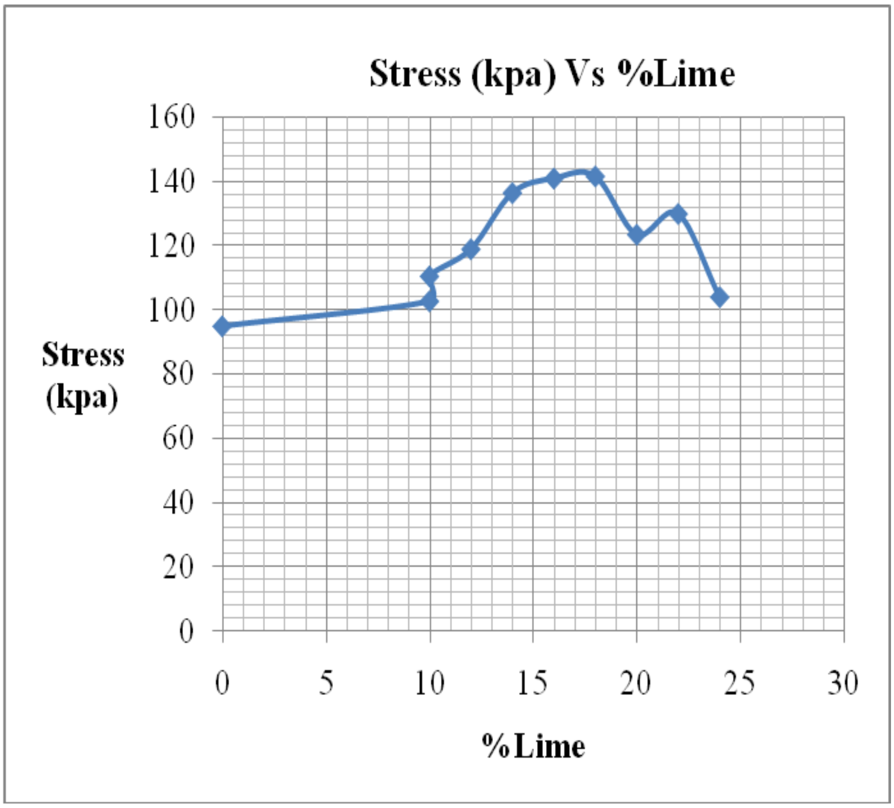


Figure 4.2.1: Stress (kpa) versus lime (%) of peat specimen mixed with 0%, 10% to 24% lime & cured for 0 & 7 days

Table 4.2.2: Summary of UCT results of peat specimens mixed with 0%, 10% to 24%lime & cured for 0 and 14 days.

Unconfined compression test (UCT) data
(Deformation Dial: 1unit = 0.01mm; Load Dial: 1unit = 0.736N

%Lime	Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
Control	220	146	2.2	0.029	2.89	0.107	94.76
10	240	158	2.4	0.032	3.16	0.116	102.5
10	340	183	3.4	0.045	4.47	0.135	118.8
12	320	215	3.2	0.042	4.21	0.158	139.5
14	280	230	2.8	0.037	3.68	0.169	149.3
16	320	227	3.2	0.042	4.21	0.167	147.3
18	340	222	3.4	0.045	4.47	0.163	144.1
20	320	216	3.2	0.042	4.21	0.159	140.2
22	320	202	3.2	0.042	4.21	0.149	131.1
24	300	172	3	0.039	3.95	0.127	111.6

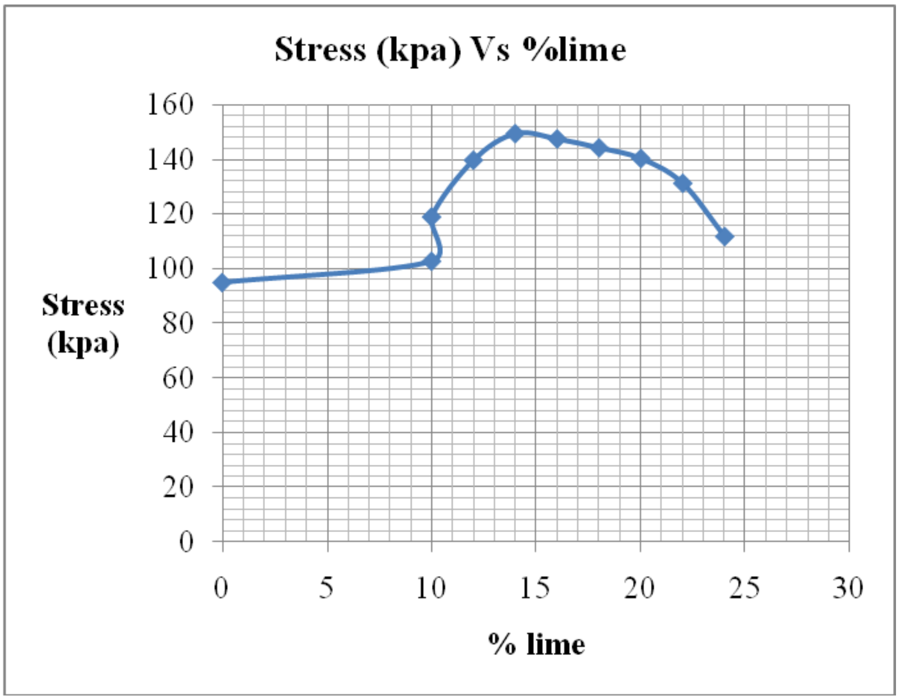


Figure 4.2.2: Stress (kpa) versus lime (%) of peat specimen mixed with 0%, 10% to 24% lime & cured for 0 & 14 days.

Table 4.2.0 shows the results of unconfined compression test (UCT) of peat soil sample mixed with 14% lime and cured for 14 days. The test results showed that samples cured for 14 days have gained higher strength compare to samples cured for 7 days and the control samples. Therefore, this implies that, strength progressively increases with increase in lime percentage added and curing period with the highest strength realized in sample mixed with 14% lime and cured for 14 days. Thereafter, the strengths of the rest of samples mixed with 16%, 18%, 20%, 22%, and 24% and cured for the same period have slowly dropped as seen in tables 4.2.0 and 4.2.2 respectively.

4.2.0 Summary of Properties of peat soil from Hutan Melintang

Table 4.2.3: properties of Peat soil laboratory testing

Properties	
Moisture content (MC)	350%-400%
Organic content (OC)	82%
Ash content	18%
Specific gravity Gs)	1.3
pH before treatment	3.45
pH after treatment	8.24-12.42
Liquid limit (LL)	144.3
Plastic limit (PL)	113.25
Plasticity index (PI)	29.05
Optimum moisture content (OMC)	40%
Maximum dry density (MDD)	800kg/m³

Table 4.2.4: Summary of UCT laboratory testing

Unconfined Compression Test (UCT)			
Lime	Curing Period		
Lime (%)	**0 day**	**7 days**	**14 days**
Control **(0)**	94.7584kPa		
10	102.547kPa	110.335kPa	118.772kPa
12		118.772kPa	139.541kPa
14		136.296kPa	149.277kPa
16		140.84kPa	147.33kPa
18		141.489kPa	144.085kPa
20		123.316kPa	140.19kPa
22		129.806kPa	131.104kPa
24		103.845kPa	111.633kPa

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Based on the laboratory testing and analysis of the engineering and index properties of natural peat soil (untreated peat soil) and impact of different lime proportions on the engineering and index properties of stabilized peat soil cured for 7 and 14 days, the following conclusions can be drawn:

a.) Peat soil specimens collected from Hutan Melintang location have high organic content, with average 82% and low ash content 18%. This implies that peat soil shows some unique geotechnical properties that make it different from those of inorganic soils such as clay and sand that compose mainly of inorganic soil particles.

b.) pH of untreated peat soil sample is within the range of 3.37 to 3.45 while the pH of all stabilized peat samples ranges from 8.24 to 12.42 meaning that the acidic nature of black to black-brown color peat soil was effectively neutralized by the lime. This test proved that peat soil is more acidic than inorganic soil such as clay or sand.

c.) Literally, the moisture content of peat soil is very high and the moisture content of the soil specimen tested in this laboratory investigation is in the range of **300%** to **400%.**

d.) The results of standard proctor test conducted on untreated soil specimen indicated that maximum dry density (MDD) higher was realized at point where optimum moisture content (OMC) was low.

e.) Most importantly, unconfined compressive strength of stabilized peat soil samples formed by mixing peat soil with different lime percentages was higher than that of original peat soil (control specimen). But after optimum lime content (within the range of 14%, 16%, 18% of lime), strength started to drop despite increase in lime percentage. However, the overall results indicated that, stabilized peat specimen with 14% lime and cured for 14 days yielded the highest strength of **149.3kpa** among all the stabilized and untreated peat soil specimens tested in unconfined compression test (UCT), though all the results of unconfined compression test increase significantly with increase in curing period (that is, 0, 7 & 14 days). Proper curing time significantly improved the stabilized peat soil engineering and index properties, meaning, increment in curing duration causes the increase of soil strength by **57.5%**, specific gravity and unit weight and decreases the soil moisture content, soil acidity (i.e., raise soil pH) and organic content among others. This is due to the fact that certain amount of free lime ($Ca(OH)_2$) reacts pozzolanically with fine particles of peat, hence, enhancing soil engineering properties.

Peat soil is a kind of soil with unique behaviors and characteristics, and because of these, there is a tendency in construction industry to either neglect or try to avoid such problematic soil. In order to overcome these unique characteristics of peat soil, lime stabilization method is one of the most economical methods which require less time to overcome the geotechnical problems of peat soil. Therefore, from the UCT results, one can draw conclusion by saying that, addition of lime has enhanced the engineering properties of peat soil. Lime has improved the strength of natural peat soil and this implies that the objectives of the project have been achieved.

5.2 RECOMMENDATION

Modification and improvement of peat soil should start after analyzing the index and physical properties of it. This will put researcher in better position to choose the right modification method. Lime can only be used as the stabilizer when the organic content is not more than 75%. Study also needs to be conducted at site to have full knowledge of peat soil nature as this can also justify the laboratory test results. The accuracy of the laboratory results is only achieved by avoiding any single error when carrying out the laboratory test. Incorrect way of taking readings, wrong way of recording data and errors due to wrong calculation are examples that contribute to inaccuracy of the results. These can be avoided through reading data and practices more than one time. Other errors such as improper symbols can be avoided by using correct symbols and the utilization of proper standards.

PROJECT GANTT CHART

		Duration (Weeks)													
No	**Activities**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Site visit & sample collection														
2	Conducting MC, OC & pH lab tests														
3	Atterberg limits and sieve analysis, & specific gravity tests														
4	Standard proctor & Eades-Grim tests														
5	conducting UCT on control samples														
6	conducting UCT on stabilized samples														
7	conducting UCT on stabilized & cured for 7 days samples														
8	conducting UCT on stabilized & cured for 14 days samples														
9	Poster preparation														
10	Technical and Final Reports														
11	Viva preparation & presentation														

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APPENDICES

1.) Atterberg Limit

Liquid Limit (Cone Penetrometer Method)

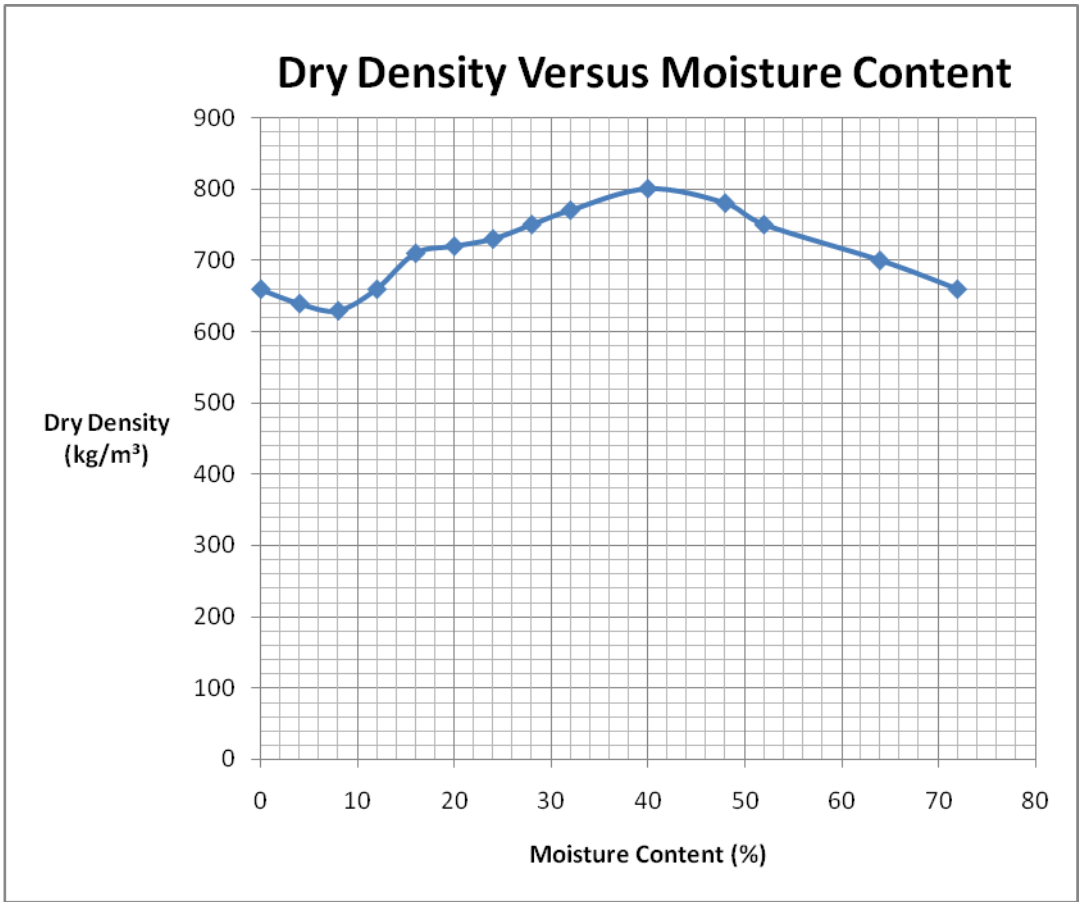
Test No	**1**			**2**		**3**		**4**	
Dial gauge reading (mm)	12	12	12	18.4	17.8	25.8	26.2	21.2	21
Average penetration (mm)	12			18		26		21	
Mass of wet soil + container (g)	30.92			30.95		28.65		28.85	
Mass of dry soil + container (g)	25.16			24.8		22.8		22.7	
Mass of container (g)	20.9			20.55		18.76		18.59	
Mass of moisture (g)	5.74			4.65		4.02		4.35	
Mass of dry soil (g)	4.26			5.75		5.86		5.91	
Moisture content (%)	**135**			**144**		**144.4**		**148**	

Plastic Limit

Test No	**1**	**2**	**3**	**4**	**Average**
Mass of wet soil + container (g)	28.6	29	32.3	29.2	
Mass of dry soil + container (g)	23.1	24	26.9	24	
Mass of container (g)	18.6	19	22.2	19.2	
Mass of moisture (g)	4.5	4.6	4.65	4.78	
Mass of dry soil (g)	5.5	5.4	5.35	5.22	
Moisture content (%)	**122**	**116**	**115**	**108**	**115.25**

2.) Proctor compaction test

Mass of mould+base+compacted specimen (kg)	Mass of compacted specimen alone (kg)	Optimum Moisture Content (%)	Maximum Dry Density (kg/m³)
5.71	0.67	0	660
5.72	0.68	4	640
5.73	0.69	8	630
5.79	0.75	12	660
5.87	0.83	16	710
5.91	0.87	20	720
5.96	0.92	24	730
6.01	0.97	28	750
6.06	1.02	32	770
6.17	1.13	40	800
6.21	1.17	48	780
6.19	1.15	52	750
6.2	1.16	64	700
6.18	1.14	72	660



3.) Unconfined compression test (UCT) laboratory results.

a.)

Sample data: **Samples cured for 7 days**

Diameter (d)	38mm
Length (L0)	76mm
Mass	115.0g

Moisture Content determination

Sample no. (Lime %)	10	12	14	16	18	20	22	24
Mass of empty clean can, m_1 (g)	20.9	20.9	21	18.6	20.8	18.7	19.8	22.1
Mass of can and moist soil, m_2 (g)	56.6	78	86.6	66.7	68.3	58.2	56.8	74.1
Mass of can and dry soil, m_3 (g)	44.2	58.4	64.8	51.2	53.4	45.8	45.4	56.8
Mass of soil solids (g)	23.3	37.5	43.8	32.6	32.6	27.1	25.6	34.7
Mass of pore water (g)	12.4	19.6	21.8	15.5	14.9	12.4	11.4	17.3
pH	8.21	8.23	8.28	9.42	9.78	10.1	10.5	11.35
W = Water content, w%	53	52	50	48	46	46	45	50
Dry density ρ_d	0.86	0.87	0.89	0.9	0.91	0.91	0.92	0.89

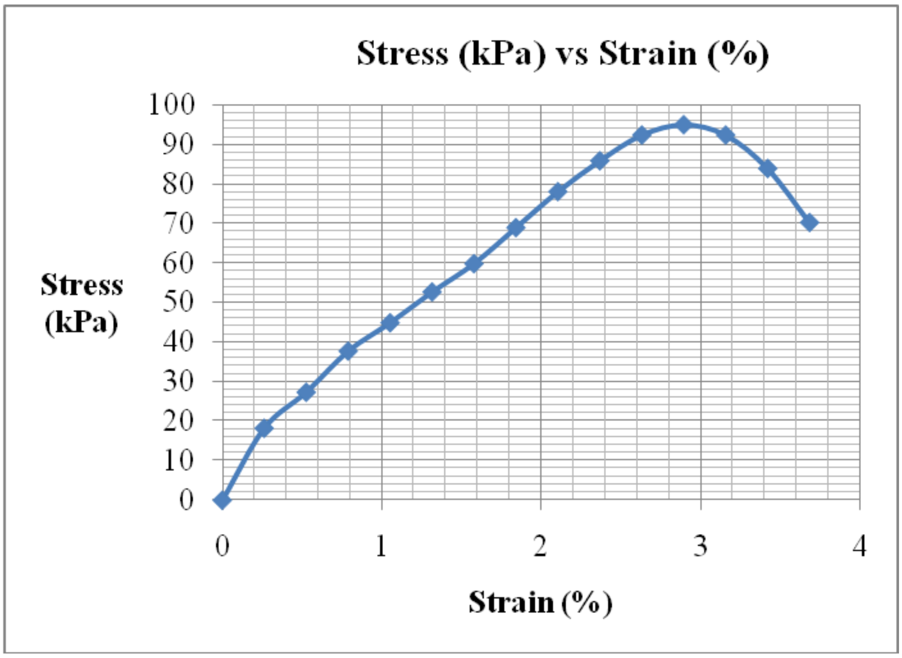
Area (A_0) $(A_0) = \pi/4\ (d^2) = \pi/4\ (3.8^2) = 11.34\text{cm}^2$

Volume (V) $V = \pi/4\ (d^2 h) = \pi/4\ (3.8^2 \times 7.6) = 86.2\text{cm}^3$

Wet density $\rho = 115.0/86.2 = 1.33\text{g/cm}^3$

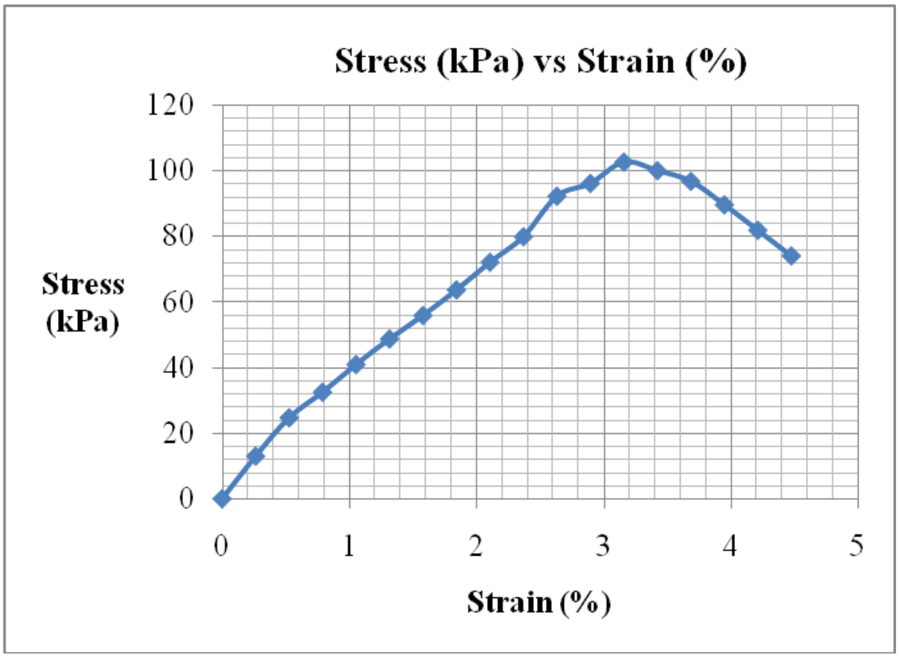
Unconfined compression test (UCT) data **(0% Lime)**
(Deformation Dial: 1unit = 0.01mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	28	0.2	0	0.3	0.02	18
40	42	0.4	0.01	0.5	0.03	27
60	58	0.6	0.01	0.8	0.04	38
80	69	0.8	0.01	1.1	0.05	45
100	81	1	0.01	1.3	0.06	53
120	92	1.2	0.02	1.6	0.07	60
140	106	1.4	0.02	1.8	0.08	69
160	120	1.6	0.02	2.1	0.09	78
180	132	1.8	0.02	2.4	0.1	86
200	142	2	0.03	2.6	0.1	92
220	146	2.2	0.03	2.9	0.11	95
240	142	2.4	0.03	3.2	0.1	92
260	129	2.6	0.03	3.4	0.09	84
280	108	2.8	0.04	3.7	0.08	70



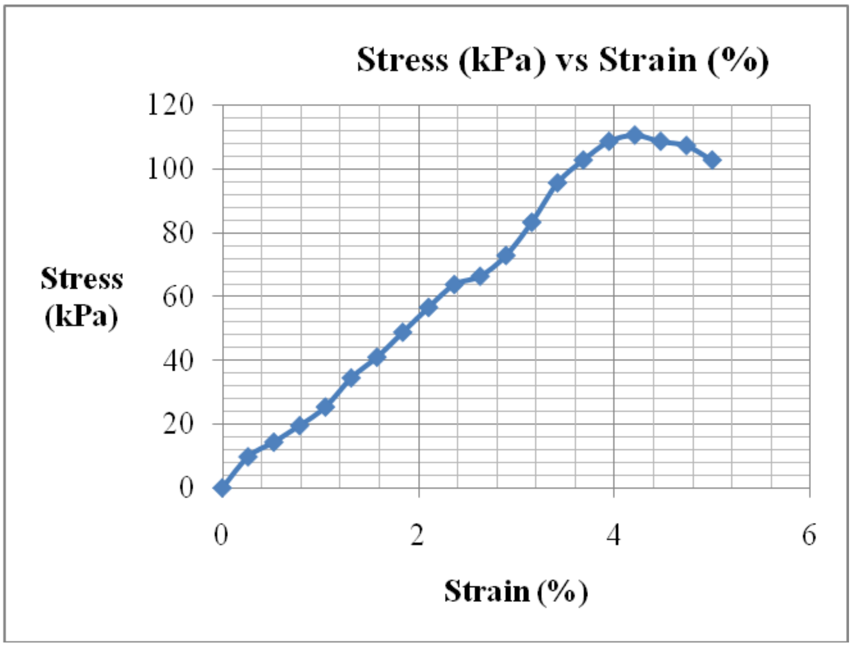
Unconfined Compression Test Data **(10% lime, cured for 0day)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	20	0.2	0	0.3	0	13
40	38	0.4	0.01	0.5	0	24.7
60	50	0.6	0.01	0.8	0	32.5
80	63	0.8	0.01	1.1	0	40.9
100	75	1	0.01	1.3	0.1	48.7
120	86	1.2	0.02	1.6	0.1	55.8
140	98	1.4	0.02	1.8	0.1	63.6
160	111	1.6	0.02	2.1	0.1	72
180	123	1.8	0.02	2.4	0.1	79.8
200	142	2	0.03	2.6	0.1	92.2
220	148	2.2	0.03	2.9	0.1	96.1
240	158	2.4	0.03	3.2	0.1	103
260	154	2.6	0.03	3.4	0.1	100
280	149	2.8	0.04	3.7	0.1	96.7
300	138	3	0.04	3.9	0.1	89.6
320	126	3.2	0.04	4.2	0.1	81.8
340	114	3.4	0.04	4.5	0.1	74



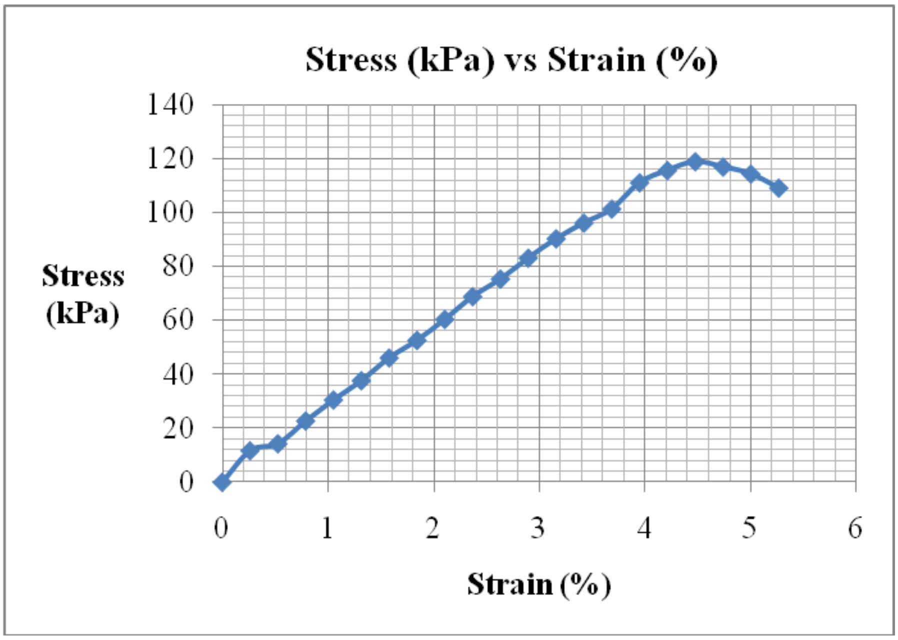
Unconfined Compression Test Data **(10% lime, cured for 7days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	15	0.2	0.003	0.26	0.01	9.74
40	22	0.4	0.005	0.53	0.02	14.3
60	30	0.6	0.008	0.79	0.02	19.5
80	39	0.8	0.011	1.05	0.03	25.3
100	53	1	0.013	1.32	0.04	34.4
120	63	1.2	0.016	1.58	0.05	40.9
140	75	1.4	0.018	1.84	0.06	48.7
160	87	1.6	0.021	2.11	0.06	56.5
180	98	1.8	0.024	2.37	0.07	63.6
200	102	2	0.026	2.63	0.08	66.2
220	112	2.2	0.029	2.89	0.08	72.7
240	128	2.4	0.032	3.16	0.09	83.1
260	147	2.6	0.034	3.42	0.11	95.4
280	158	2.8	0.037	3.68	0.12	103
300	167	3	0.039	3.95	0.12	108
320	170	3.2	0.042	4.21	0.13	110
340	167	3.4	0.045	4.47	0.12	108
360	165	3.6	0.047	4.74	0.12	107
380	158	3.8	0.05	5	0.12	103



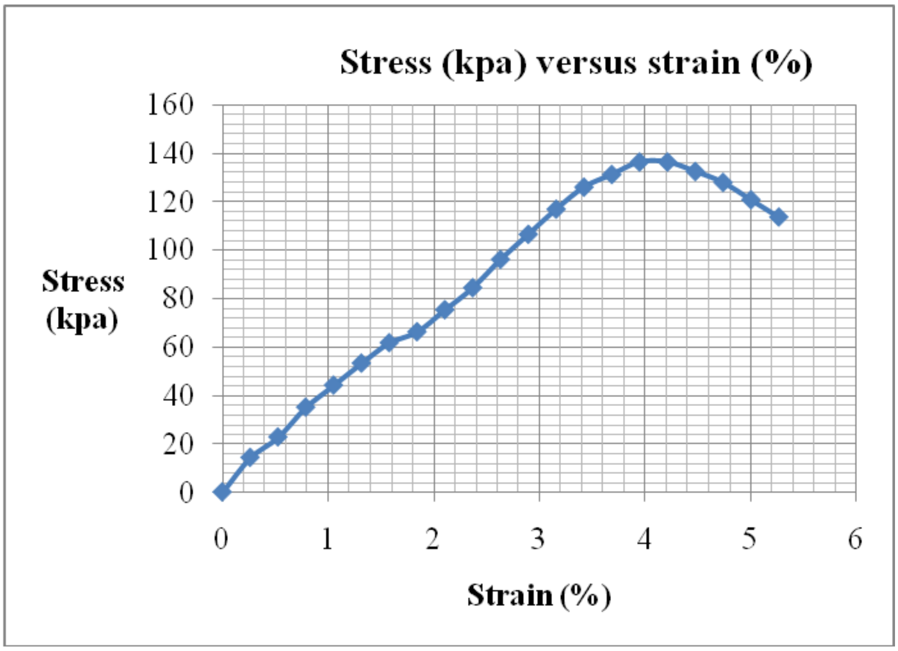
Unconfined Compression Test Data (**12% lime, cured for 7days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	18	0.2	0	0.3	0.01	12
40	22	0.4	0.01	0.5	0.02	14
60	35	0.6	0.01	0.8	0.03	23
80	47	0.8	0.01	1.1	0.03	31
100	58	1	0.01	1.3	0.04	38
120	71	1.2	0.02	1.6	0.05	46
140	81	1.4	0.02	1.8	0.06	53
160	93	1.6	0.02	2.1	0.07	60
180	106	1.8	0.02	2.4	0.08	69
200	116	2	0.03	2.6	0.09	75
220	128	2.2	0.03	2.9	0.09	83
240	139	2.4	0.03	3.2	0.1	90
260	148	2.6	0.03	3.4	0.11	96
280	156	2.8	0.04	3.7	0.11	101
300	171	3	0.04	3.9	0.13	111
320	178	3.2	0.04	4.2	0.13	116
340	183	3.4	0.04	4.5	0.13	119
360	180	3.6	0.05	4.7	0.13	117
380	176	3.8	0.05	5	0.13	114
400	168	4	0.05	5.3	0.12	109



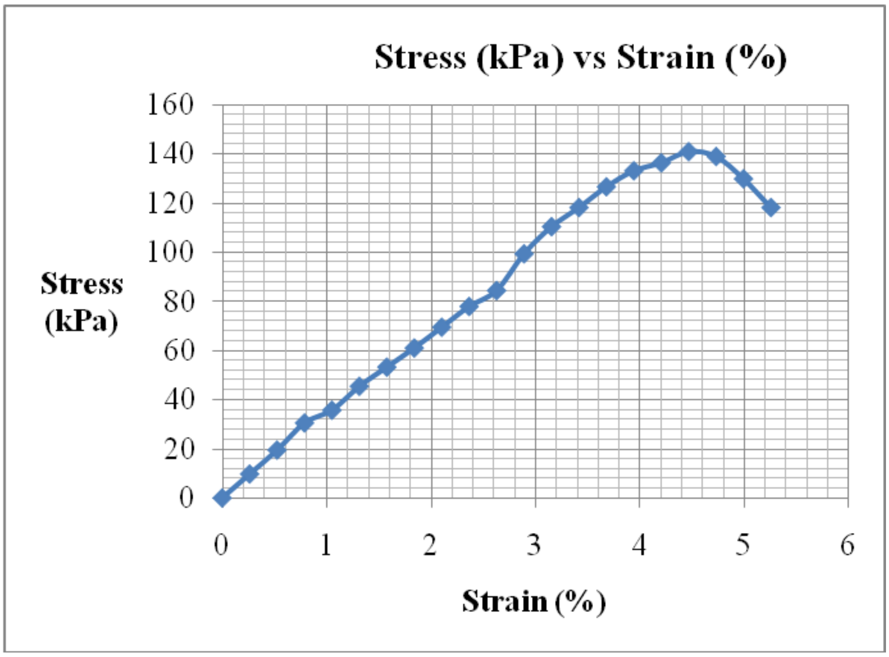
Unconfined Compression Test Data (**14% lime, cured for 7days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	22	0.2	0.003	0.26	0.02	14.3
40	35	0.4	0.005	0.53	0.03	22.7
60	54	0.6	0.008	0.79	0.04	35
80	68	0.8	0.011	1.05	0.05	44.1
100	82	1	0.013	1.32	0.06	53.2
120	95	1.2	0.016	1.58	0.07	61.7
140	102	1.4	0.018	1.84	0.08	66.2
160	116	1.6	0.021	2.11	0.09	75.3
180	130	1.8	0.024	2.37	0.1	84.4
200	148	2	0.026	2.63	0.11	96.1
220	164	2.2	0.029	2.89	0.12	106
240	180	2.4	0.032	3.16	0.13	117
260	194	2.6	0.034	3.42	0.14	126
280	202	2.8	0.037	3.68	0.15	131
300	210	3	0.039	3.95	0.15	136
320	210	3.2	0.042	4.21	0.15	136
340	204	3.4	0.045	4.47	0.15	132
360	197	3.6	0.047	4.74	0.14	128
380	186	3.8	0.05	5	0.14	121
400	175	4	0.053	5.26	0.13	114



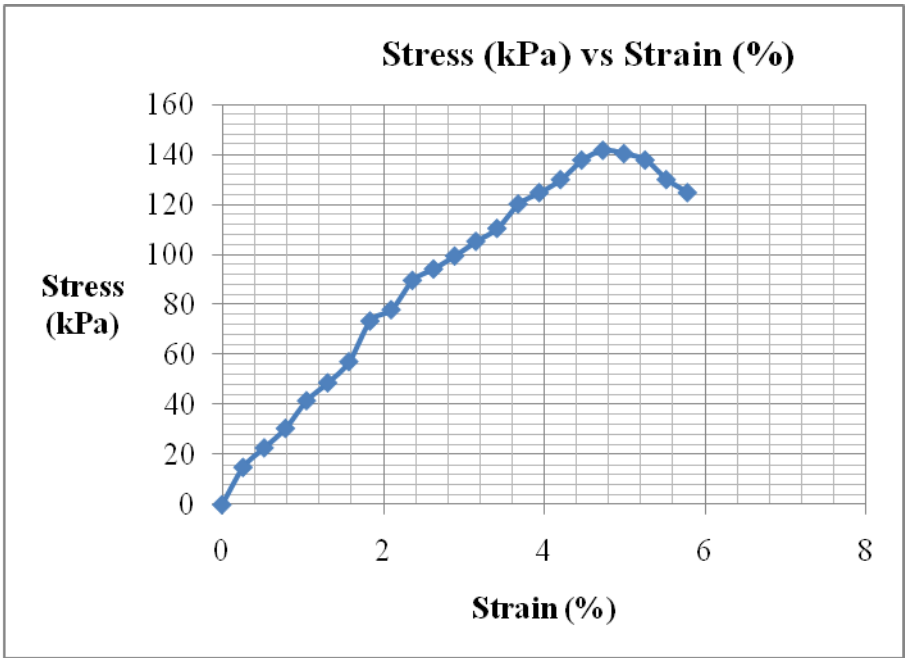
Unconfined Compression Test Data(**16% lime, cured for 7days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	15	0.2	0.003	0.3	0.01	9.74
40	30	0.4	0.005	0.5	0.02	19.5
60	47	0.6	0.008	0.8	0.03	30.5
80	55	0.8	0.011	1.1	0.04	35.7
100	70	1	0.013	1.3	0.05	45.4
120	82	1.2	0.016	1.6	0.06	53.2
140	94	1.4	0.018	1.8	0.07	61
160	107	1.6	0.021	2.1	0.08	69.4
180	120	1.8	0.024	2.4	0.09	77.9
200	130	2	0.026	2.6	0.1	84.4
220	153	2.2	0.029	2.9	0.11	99.3
240	170	2.4	0.032	3.2	0.13	110
260	182	2.6	0.034	3.4	0.13	118
280	195	2.8	0.037	3.7	0.14	127
300	205	3	0.039	3.9	0.15	133
320	210	3.2	0.042	4.2	0.15	136
340	217	3.4	0.045	4.5	0.16	141
360	214	3.6	0.047	4.7	0.16	139
380	200	3.8	0.05	5	0.15	130
400	182	4	0.053	5.3	0.13	118



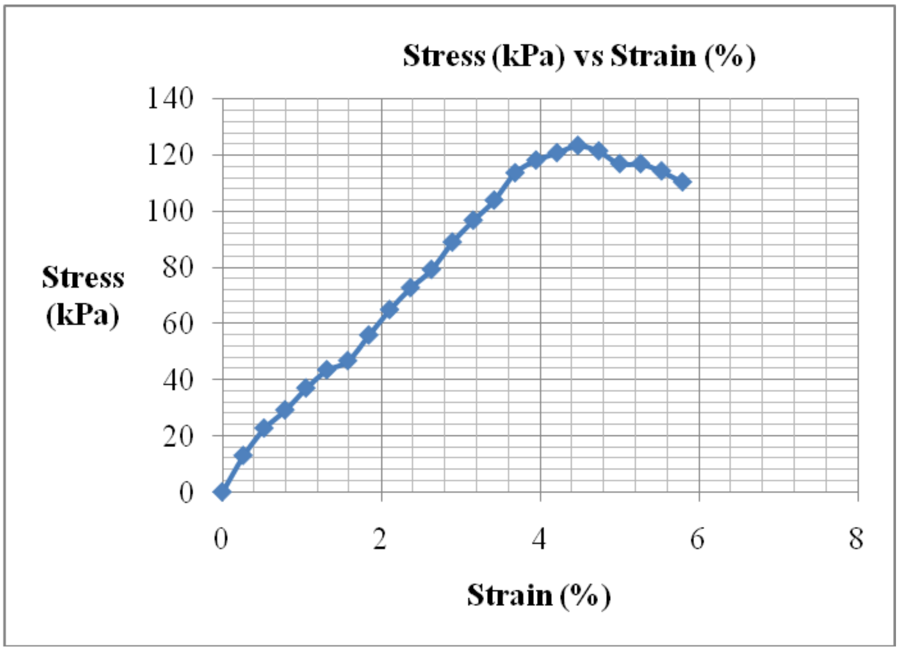
Unconfined Compression Test Data (**18% lime, cured for 7days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	23	0.2	0	0.26	0.02	14.9
40	35	0.4	0.01	0.53	0.03	22.7
60	47	0.6	0.01	0.79	0.03	30.5
80	64	0.8	0.01	1.05	0.05	41.5
100	75	1	0.01	1.32	0.06	48.7
120	88	1.2	0.02	1.58	0.06	57.1
140	113	1.4	0.02	1.84	0.08	73.3
160	120	1.6	0.02	2.11	0.09	77.9
180	138	1.8	0.02	2.37	0.1	89.6
200	145	2	0.03	2.63	0.11	94.1
220	153	2.2	0.03	2.89	0.11	99.3
240	162	2.4	0.03	3.16	0.12	105
260	170	2.6	0.03	3.42	0.13	110
280	185	2.8	0.04	3.68	0.14	120
300	192	3	0.04	3.95	0.14	125
320	200	3.2	0.04	4.21	0.15	130
340	212	3.4	0.04	4.47	0.16	138
360	218	3.6	0.05	4.74	0.16	141
380	216	3.8	0.05	5	0.16	140
400	212	4	0.05	5.26	0.16	138
420	200	4.2	0.06	5.53	0.15	130
440	192	4.4	0.06	5.79	0.14	125



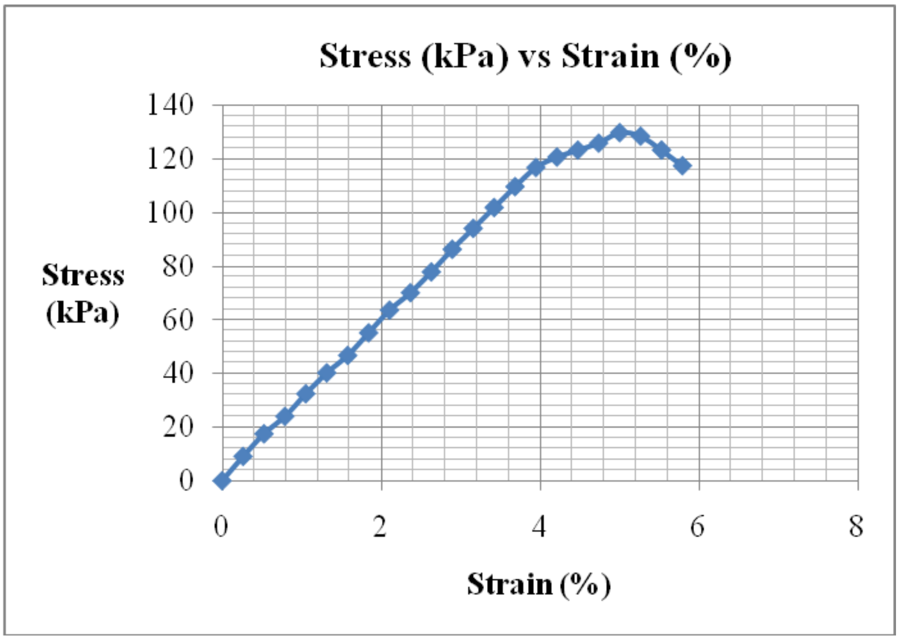
Unconfined Compression Test Data (**20% lime, cured for 7days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	20	0.2	0	0.26	0	13
40	35	0.4	0.01	0.53	0	23
60	45	0.6	0.01	0.79	0	29
80	57	0.8	0.01	1.05	0	37
100	67	1	0.01	1.32	0	43
120	72	1.2	0.02	1.58	0.1	47
140	86	1.4	0.02	1.84	0.1	56
160	100	1.6	0.02	2.11	0.1	65
180	112	1.8	0.02	2.37	0.1	73
200	122	2	0.03	2.63	0.1	79
220	137	2.2	0.03	2.89	0.1	89
240	149	2.4	0.03	3.16	0.1	97
260	160	2.6	0.03	3.42	0.1	104
280	175	2.8	0.04	3.68	0.1	114
300	182	3	0.04	3.95	0.1	118
320	186	3.2	0.04	4.21	0.1	121
340	190	3.4	0.04	4.47	0.1	123
360	187	3.6	0.05	4.74	0.1	121
380	180	3.8	0.05	5	0.1	117
400	180	4	0.05	5.26	0.1	117
420	176	4.2	0.06	5.53	0.1	114
440	170	4.4	0.06	5.79	0.1	110



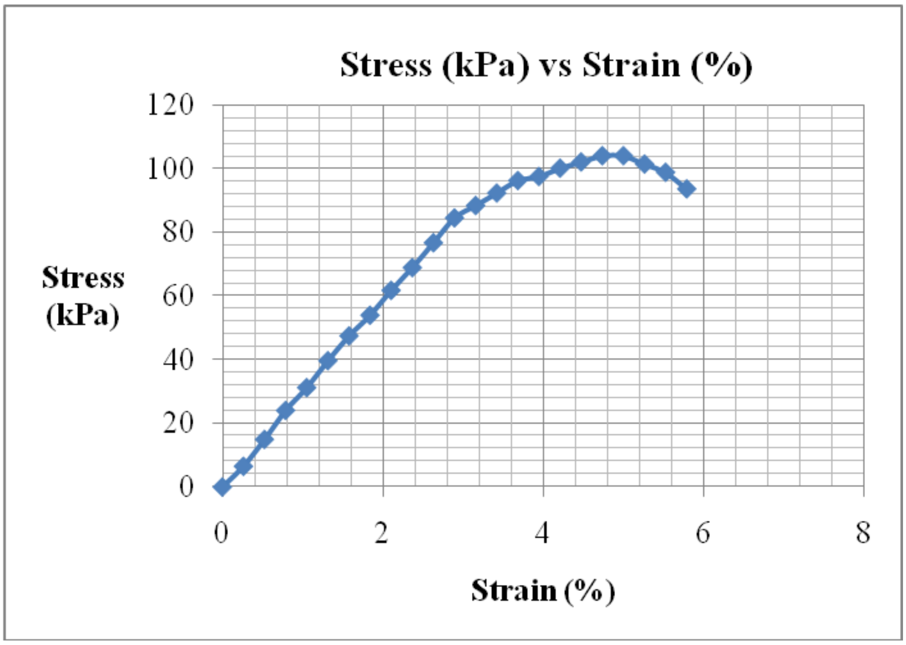
Unconfined Compression Test Data (**22% lime, cured for 7days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	14	0.2	0	0.26	0.01	9.09
40	27	0.4	0.01	0.53	0.02	17.5
60	37	0.6	0.01	0.79	0.03	24
80	50	0.8	0.01	1.05	0.04	32.5
100	62	1	0.01	1.32	0.05	40.2
120	72	1.2	0.02	1.58	0.05	46.7
140	85	1.4	0.02	1.84	0.06	55.2
160	98	1.6	0.02	2.11	0.07	63.6
180	108	1.8	0.02	2.37	0.08	70.1
200	120	2	0.03	2.63	0.09	77.9
220	133	2.2	0.03	2.89	0.1	86.3
240	145	2.4	0.03	3.16	0.11	94.1
260	157	2.6	0.03	3.42	0.12	102
280	169	2.8	0.04	3.68	0.12	110
300	180	3	0.04	3.95	0.13	117
320	186	3.2	0.04	4.21	0.14	121
340	190	3.4	0.04	4.47	0.14	123
360	194	3.6	0.05	4.74	0.14	126
380	200	3.8	0.05	5	0.15	130
400	198	4	0.05	5.26	0.15	129
420	190	4.2	0.06	5.53	0.14	123
440	181	4.4	0.06	5.79	0.13	117



Unconfined Compression Test Data (**24% lime, cured for 7days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	10	0.2	0	0.26	0.01	6.49
40	23	0.4	0.01	0.53	0.02	14.9
60	37	0.6	0.01	0.79	0.03	24
80	48	0.8	0.01	1.05	0.04	31.2
100	61	1	0.01	1.32	0.04	39.6
120	73	1.2	0.02	1.58	0.05	47.4
140	83	1.4	0.02	1.84	0.06	53.9
160	95	1.6	0.02	2.11	0.07	61.7
180	106	1.8	0.02	2.37	0.08	68.8
200	118	2	0.03	2.63	0.09	76.6
220	130	2.2	0.03	2.89	0.1	84.4
240	136	2.4	0.03	3.16	0.1	88.3
260	142	2.6	0.03	3.42	0.1	92.2
280	148	2.8	0.04	3.68	0.11	96.1
300	150	3	0.04	3.95	0.11	97.4
320	154	3.2	0.04	4.21	0.11	100
340	157	3.4	0.04	4.47	0.12	102
360	160	3.6	0.05	4.74	0.12	104
380	160	3.8	0.05	5	0.12	104
400	156	4	0.05	5.26	0.11	101
420	152	4.2	0.06	5.53	0.11	98.7
440	144	4.4	0.06	5.79	0.11	93.5



b.)

Sample data: **Samples cured for 14 days**

Diameter (d)	38mm
Length (L0)	76mm
Mass	118.0g

Moisture content determination

Sample no. (Lime %)	10	12	14	16	18	20	22	24
Mass of empty clean can, m_1 (g)	20.6	21.8	21.4	18.6	21.1	21.7	20.8	22.1
Mass of can and moist soil , m_2 (g)	52.6	56.8	53.8	52.6	53.1	55.7	54.8	54.1
Mass of can and dry soil, m_3 (g)	41.8	45.4	43.6	42.4	43.2	45.2	44.4	44.2
Mass of soil solids (g)	21.2	23.6	22.2	23.8	22.1	23.5	23.6	22.1
Mass of pore water (g)	10.8	11.4	10.2	10.2	9.9	10.5	10.4	9.9
pH	10.46	11.5	12.4	12.42	12.42	12.4	12.41	12.4
W = Water content, w%	51	48	46	43	45	45	44	45
Dry density	0.9	0.92	0.94	0.96	0.95	0.95	0.95	0.92

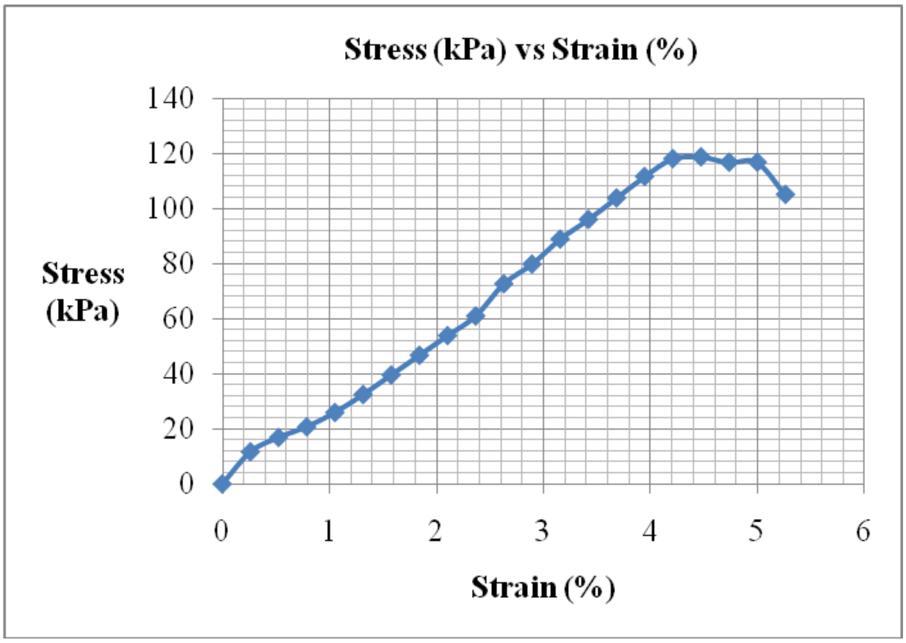
Area (A_o) $A_o = \pi/4\ (d^2) = \pi/4\ (3.8^2) = 11.34cm^2$

Volume (V) $V = \pi/4\ (d^2 h) = \pi/4\ (3.8^2 \times 7.6) = 86.2cm^3$

Wet density $\rho = 118.0/86.2 = 1.37g/cm^3$

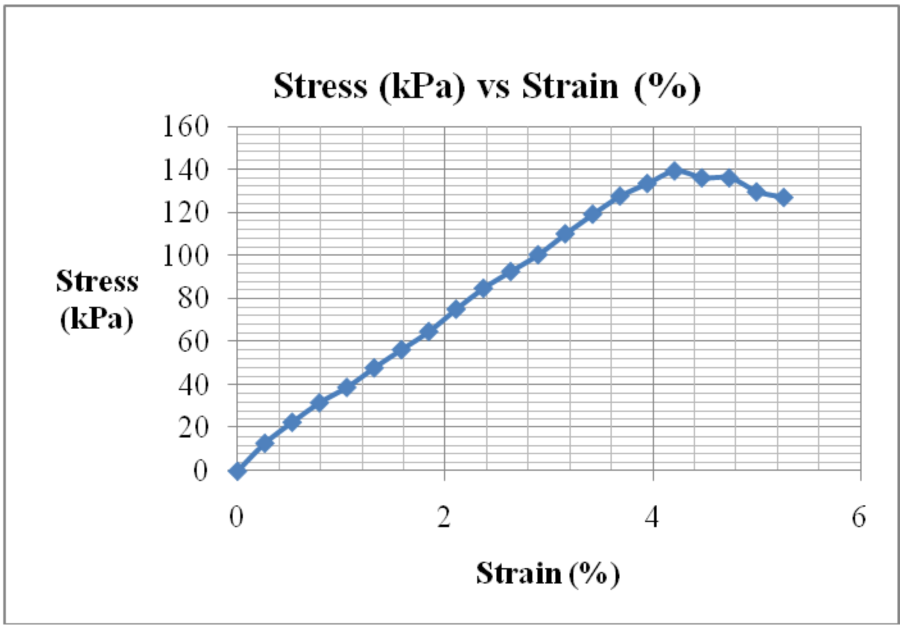
Unconfined Compression Test Data (**10% lime, cured for 14days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	18	0.2	0.003	0.26	0.013	11.7
40	26	0.4	0.005	0.53	0.019	16.9
60	32	0.6	0.008	0.79	0.024	20.8
80	40	0.8	0.011	1.05	0.029	26
100	50	1	0.013	1.32	0.037	32.5
120	61	1.2	0.016	1.58	0.045	39.6
140	72	1.4	0.018	1.84	0.053	46.7
160	83	1.6	0.021	2.11	0.061	53.9
180	94	1.8	0.024	2.37	0.069	61
200	112	2	0.026	2.63	0.082	72.7
220	123	2.2	0.029	2.89	0.091	79.8
240	137	2.4	0.032	3.16	0.101	88.9
260	148	2.6	0.034	3.42	0.109	96.1
280	160	2.8	0.037	3.68	0.118	104
300	172	3	0.039	3.95	0.127	112
320	182	3.2	0.042	4.21	0.134	118
340	183	3.4	0.045	4.47	0.135	119
360	180	3.6	0.047	4.74	0.132	117
380	180	3.8	0.05	5	0.132	117
400	162	4	0.053	5.26	0.119	105



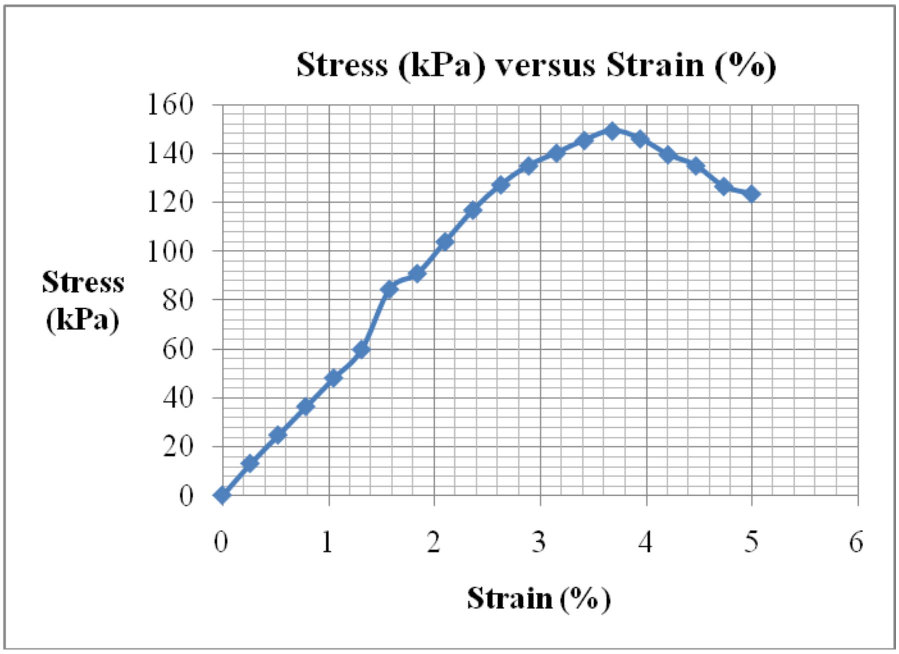
Unconfined Compression Test Data (**12% lime, cured for 14days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	20	0.2	0	0.26	0.01	13
40	35	0.4	0.01	0.53	0.03	22.7
60	49	0.6	0.01	0.79	0.04	31.8
80	60	0.8	0.01	1.05	0.04	38.9
100	74	1	0.01	1.32	0.05	48
120	87	1.2	0.02	1.58	0.06	56.5
140	100	1.4	0.02	1.84	0.07	64.9
160	116	1.6	0.02	2.11	0.09	75.3
180	131	1.8	0.02	2.37	0.1	85
200	143	2	0.03	2.63	0.11	92.8
220	155	2.2	0.03	2.89	0.11	101
240	170	2.4	0.03	3.16	0.13	110
260	184	2.6	0.03	3.42	0.14	119
280	197	2.8	0.04	3.68	0.14	128
300	206	3	0.04	3.95	0.15	134
320	215	3.2	0.04	4.21	0.16	140
340	210	3.4	0.04	4.47	0.15	136
360	210	3.6	0.05	4.74	0.15	136
380	200	3.8	0.05	5	0.15	130
400	196	4	0.05	5.26	0.14	127



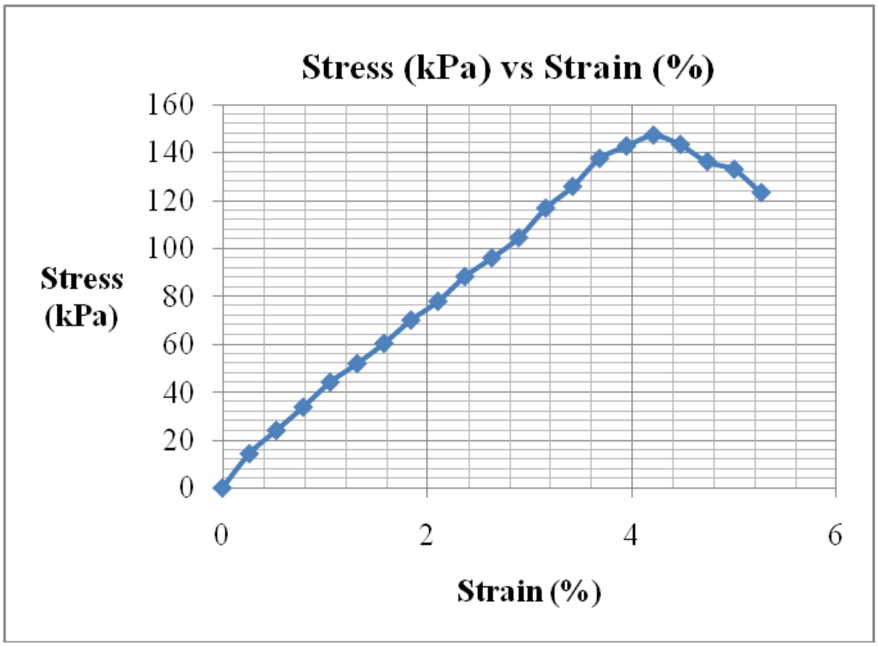
Unconfined Compression Test Data (**14% lime, cured for 14days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	20	0.2	0.003	0.26	0.01	12.98
40	38	0.4	0.005	0.53	0.03	24.66
60	56	0.6	0.008	0.79	0.04	36.35
80	74	0.8	0.011	1.05	0.05	48.03
100	92	1	0.013	1.32	0.07	59.71
120	130	1.2	0.016	1.58	0.1	84.37
140	140	1.4	0.018	1.84	0.1	90.86
160	160	1.6	0.021	2.11	0.12	103.8
180	180	1.8	0.024	2.37	0.13	116.8
200	196	2	0.026	2.63	0.14	127.2
220	208	2.2	0.029	2.89	0.15	135
240	216	2.4	0.032	3.16	0.16	140.2
260	224	2.6	0.034	3.42	0.16	145.4
280	230	2.8	0.037	3.68	0.17	149.3
300	225	3	0.039	3.95	0.17	146
320	215	3.2	0.042	4.21	0.16	139.5
340	208	3.4	0.045	4.47	0.15	135
360	195	3.6	0.047	4.74	0.14	126.6
380	190	3.8	0.05	5	0.14	123.5



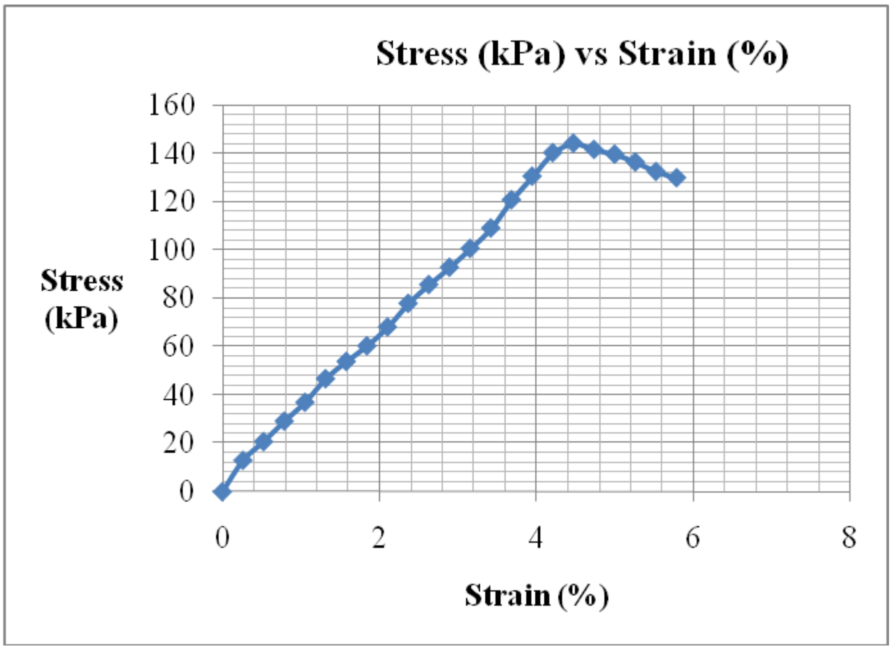
Unconfined Compression Test Data (**16% lime, cured for 14days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	22	0.2	0.003	0.3	0.02	14.3
40	37	0.4	0.005	0.5	0.03	24
60	52	0.6	0.008	0.8	0.04	33.7
80	68	0.8	0.011	1.1	0.05	44.1
100	80	1	0.013	1.3	0.06	51.9
120	93	1.2	0.016	1.6	0.07	60.4
140	108	1.4	0.018	1.8	0.08	70.1
160	120	1.6	0.021	2.1	0.09	77.9
180	136	1.8	0.024	2.4	0.1	88.3
200	148	2	0.026	2.6	0.11	96.1
220	161	2.2	0.029	2.9	0.12	104
240	180	2.4	0.032	3.2	0.13	117
260	194	2.6	0.034	3.4	0.14	126
280	212	2.8	0.037	3.7	0.16	138
300	220	3	0.039	3.9	0.16	143
320	227	3.2	0.042	4.2	0.17	147
340	221	3.4	0.045	4.5	0.16	143
360	210	3.6	0.047	4.7	0.15	136
380	205	3.8	0.05	5	0.15	133
400	190	4	0.053	5.3	0.14	123



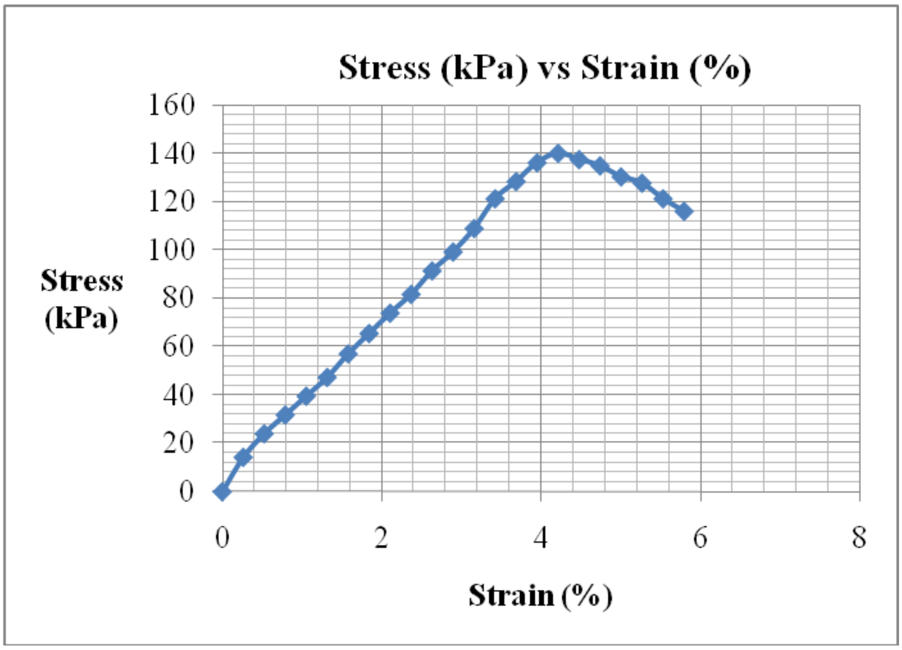
Unconfined Compression Test Data (**18% lime, cured for 14days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	20	0.2	0.003	0.3	0.01	13
40	32	0.4	0.005	0.5	0.02	20.8
60	45	0.6	0.008	0.8	0.03	29.2
80	57	0.8	0.011	1.1	0.04	37
100	72	1	0.013	1.3	0.05	46.7
120	83	1.2	0.016	1.6	0.06	53.9
140	93	1.4	0.018	1.8	0.07	60.4
160	105	1.6	0.021	2.1	0.08	68.1
180	120	1.8	0.024	2.4	0.09	77.9
200	132	2	0.026	2.6	0.1	85.7
220	143	2.2	0.029	2.9	0.11	92.8
240	155	2.4	0.032	3.2	0.11	101
260	168	2.6	0.034	3.4	0.12	109
280	186	2.8	0.037	3.7	0.14	121
300	201	3	0.039	3.9	0.15	130
320	216	3.2	0.042	4.2	0.16	140
340	222	3.4	0.045	4.5	0.16	144
360	218	3.6	0.047	4.7	0.16	141
380	215	3.8	0.05	5	0.16	140
400	210	4	0.053	5.3	0.15	136
420	204	4.2	0.055	5.5	0.15	132
440	200	4.4	0.058	5.8	0.15	130



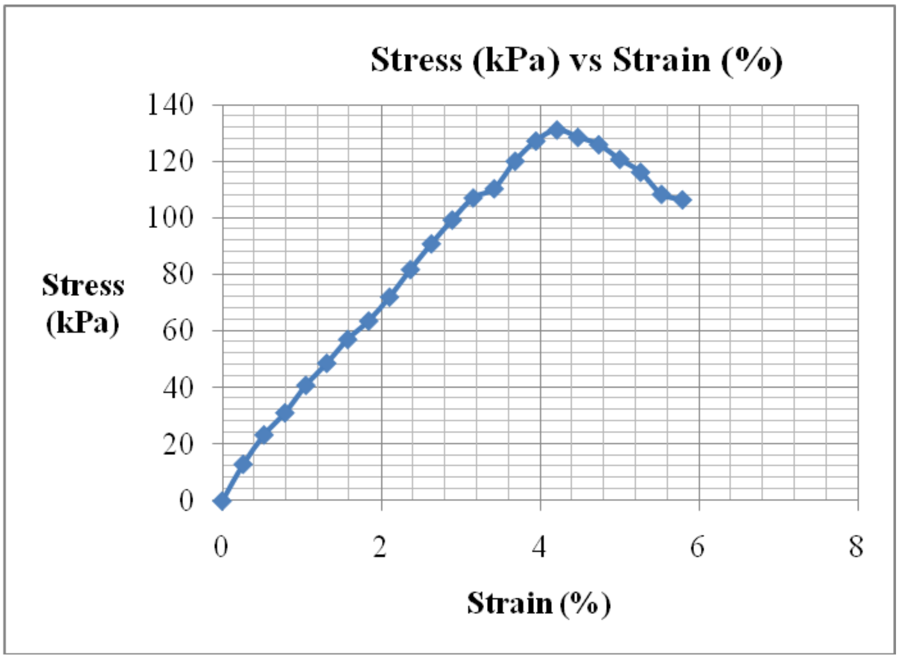
Unconfined Compression Test Data (**20% lime, cured for 14days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	22	0.2	0.003	0.26	0.02	14.3
40	37	0.4	0.005	0.53	0.03	24
60	49	0.6	0.008	0.79	0.04	31.8
80	61	0.8	0.011	1.05	0.04	39.6
100	73	1	0.013	1.32	0.05	47.4
120	88	1.2	0.016	1.58	0.06	57.1
140	101	1.4	0.018	1.84	0.07	65.6
160	114	1.6	0.021	2.11	0.08	74
180	126	1.8	0.024	2.37	0.09	81.8
200	141	2	0.026	2.63	0.1	91.5
220	153	2.2	0.029	2.89	0.11	99.3
240	168	2.4	0.032	3.16	0.12	109
260	187	2.6	0.034	3.42	0.14	121
280	198	2.8	0.037	3.68	0.15	129
300	210	3	0.039	3.95	0.15	136
320	216	3.2	0.042	4.21	0.16	140
340	212	3.4	0.045	4.47	0.16	138
360	208	3.6	0.047	4.74	0.15	135
380	201	3.8	0.05	5	0.15	130
400	197	4	0.053	5.26	0.14	128
420	187	4.2	0.055	5.53	0.14	121
440	179	4.4	0.058	5.79	0.13	116



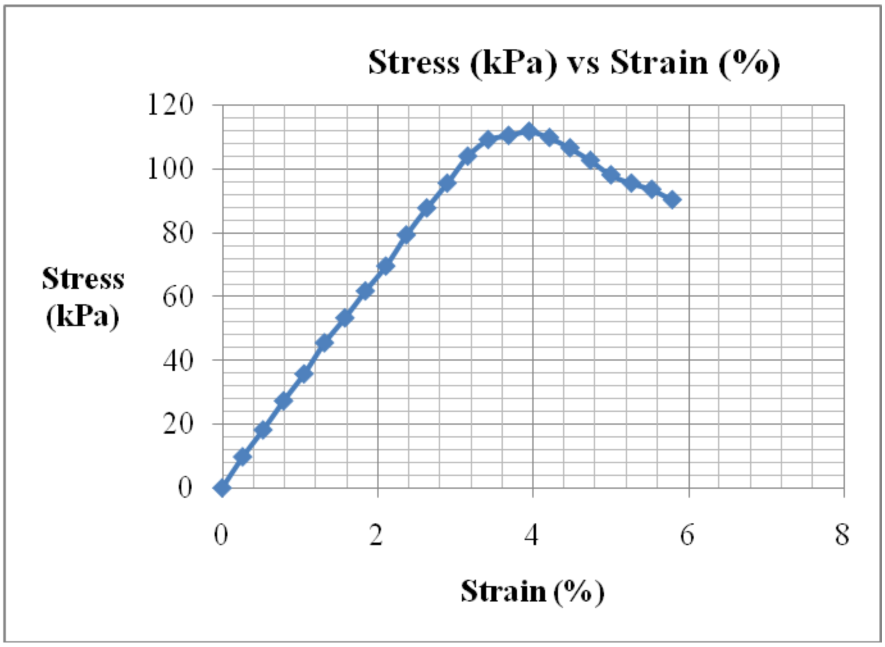
Unconfined Compression Test Data (**22% lime, cured for 14days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	20	0.2	0.003	0.3	0.01	13
40	36	0.4	0.005	0.5	0.03	23.4
60	48	0.6	0.008	0.8	0.04	31.2
80	63	0.8	0.011	1.1	0.05	40.9
100	75	1	0.013	1.3	0.06	48.7
120	88	1.2	0.016	1.6	0.06	57.1
140	98	1.4	0.018	1.8	0.07	63.6
160	111	1.6	0.021	2.1	0.08	72
180	126	1.8	0.024	2.4	0.09	81.8
200	140	2	0.026	2.6	0.1	90.9
220	153	2.2	0.029	2.9	0.11	99.3
240	165	2.4	0.032	3.2	0.12	107
260	170	2.6	0.034	3.4	0.13	110
280	185	2.8	0.037	3.7	0.14	120
300	196	3	0.039	3.9	0.14	127
320	202	3.2	0.042	4.2	0.15	131
340	198	3.4	0.045	4.5	0.15	129
360	194	3.6	0.047	4.7	0.14	126
380	186	3.8	0.05	5	0.14	121
400	179	4	0.053	5.3	0.13	116
420	167	4.2	0.055	5.5	0.12	108
440	164	4.4	0.058	5.8	0.12	106



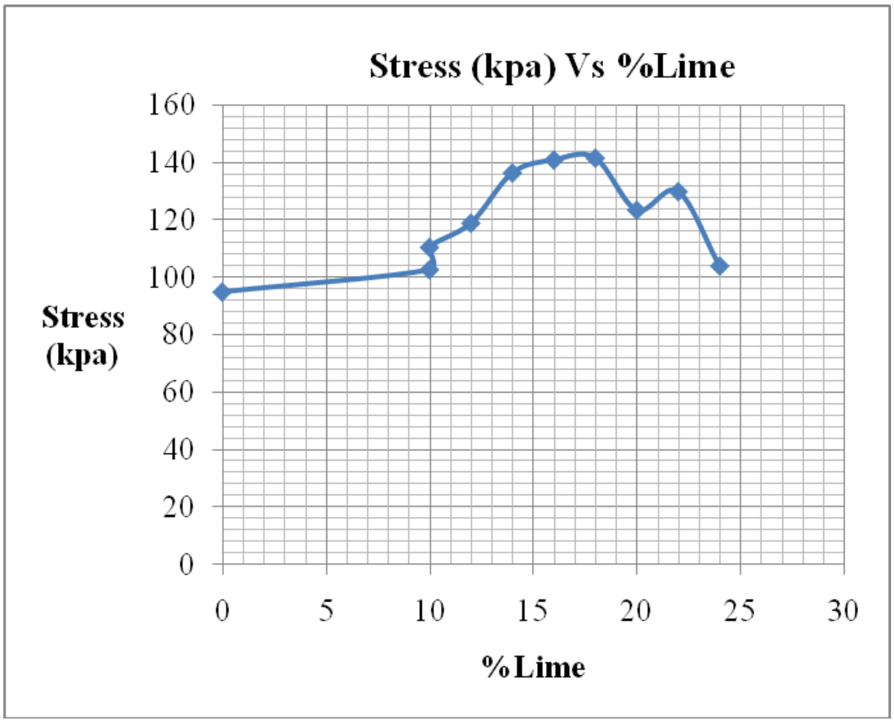
Unconfined Compression Test Data (**24% lime, cured for 14days)**
(Deformation Dial: 1 unit = 0.010mm; Load Dial: 1unit = 0.736N)

Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
0	0	0	0	0	0	0
20	15	0.2	0.003	0.3	0.01	9.74
40	28	0.4	0.005	0.5	0.02	18.2
60	42	0.6	0.008	0.8	0.03	27.3
80	55	0.8	0.011	1.1	0.04	35.7
100	70	1	0.013	1.3	0.05	45.4
120	82	1.2	0.016	1.6	0.06	53.2
140	95	1.4	0.018	1.8	0.07	61.7
160	107	1.6	0.021	2.1	0.08	69.4
180	122	1.8	0.024	2.4	0.09	79.2
200	135	2	0.026	2.6	0.1	87.6
220	147	2.2	0.029	2.9	0.11	95.4
240	160	2.4	0.032	3.2	0.12	104
260	168	2.6	0.034	3.4	0.12	109
280	170	2.8	0.037	3.7	0.13	110
300	172	3	0.039	3.9	0.13	112
320	169	3.2	0.042	4.2	0.12	110
340	164	3.4	0.045	4.5	0.12	106
360	158	3.6	0.047	4.7	0.12	103
380	151	3.8	0.05	5	0.11	98
400	147	4	0.053	5.3	0.11	95.4
420	144	4.2	0.055	5.5	0.11	93.5
440	139	4.4	0.058	5.8	0.1	90.2



Unconfined Compression Test Data **(Samples cured for 0 & 7 days)**
(Deformation Dial: 1unit = 0.01mm; Load Dial: 1unit = 0.736N)

%Lime	Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
Control	220	146	2.2	0.029	2.89	0.107	94.76
10	240	158	2.4	0.032	3.16	0.116	102.5
10	320	170	3.2	0.042	4.21	0.125	110.3
12	340	183	3.4	0.045	4.47	0.135	118.8
14	300	210	3	0.039	3.95	0.155	136.3
16	340	217	3.4	0.045	4.47	0.16	140.8
18	360	218	3.6	0.047	4.74	0.16	141.5
20	340	190	3.4	0.045	4.47	0.14	123.3
22	380	200	3.8	0.05	5	0.147	129.8
24	360	160	3.6	0.047	4.74	0.118	103.8



Unconfined compression test (UCT) data **(Samples cured for 0 & 14 days)**
(Deformation Dial: 1unit = 0.01mm; Load Dial: 1unit = 0.736N

%Lime	Deformation Dial Reading	Load Dial Reading	Sample Deformation Δl (mm)	Strain (ε)	Strain (%)	Load (kN)	Stress (kPa)
Control	220	146	2.2	0.029	2.89	0.107	94.76
10	240	158	2.4	0.032	3.16	0.116	102.5
10	340	183	3.4	0.045	4.47	0.135	118.8
12	320	215	3.2	0.042	4.21	0.158	139.5
14	280	230	2.8	0.037	3.68	0.169	149.3
16	320	227	3.2	0.042	4.21	0.167	147.3
18	340	222	3.4	0.045	4.47	0.163	144.1
20	320	216	3.2	0.042	4.21	0.159	140.2
22	320	202	3.2	0.042	4.21	0.149	131.1
24	300	172	3	0.039	3.95	0.127	111.6