Effect of Lime on California Bearing Ratio (CBR) of Soft Soils

by

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Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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July 2007

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NURMAZATUL NAJMIAH A RAZAP

ABSTRACT

Soft soils are well-known for their weak strength, compressibility and are considered of having poor engineering properties. These soils induce more construction problems to remove and replace the unsuitable soil. However, past researches had discovered that these soft soils could be treated and be made suitable for construction usages. One of the methods is through soil stabilization, where one or more soil properties is altered by mechanical or chemical means. Utilizing chemical stabilization, lime was added to the soil to improve the soil engineering properties. The addition of lime to a soil has a pronounced effect on its physical and chemical properties. Two main changes take place when lime is added to soil; the physical characteristics of the soil are altered and cementitious compound form resulting in some bonding of particles. The main research parameter is on the strength gain behaviour, or California Bearing Ratio (CBR) of the soil upon lime addition. Initial classification tests were conducted on the soil to obtain its initial characteristics and establish its initial value of strength parameter (CBR). CBR tests were conducted on the natural soil as well as with the addition of 2%, 3%, 4% and 6% lime to determine the strength development and swelling effects of the soil under soaked conditions. The treated soil was found out to have increasing CBR value with increasing lime content while the swelling behaviour decreases with respect to the amount lime used. From the testings, 3% of lime was found to be the optimum lime content in treating the soil.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Garber, Nicholas J., and Lester A. Hoel (2002), stated that from civil engineering point of view, soil is defined as the loose mass of mineral and organic materials covering the solid crust of granitic and basaltic rocks of the earth. Bowles, Joseph E. (1984), in his book stated that "*soil is one of the most readily available of construction materials at a site, and, when it can be use, it is usually the most economical. However, as with any other construction material, it must be used with quality control*". There are many types of soil and each of them has different characteristics and properties, where their field application and usage differs according to this. However, among these soils are soils with unfavorable properties and one of them are soft soils. Soft soils have been causing difficulties in the construction industry. Known for their weak strength and being considered as poor in engineering properties, soft soils behavior is defined by their mineralogical structure which in turn influences their physico-chemical and mechanical behavior. A research conducted by Nieuwolt (1982) summarized that most of the soil types in Malaysia could be categorized as soft, problematic soils. From the author's point of view, this research is very advantageous considering the findings from Nieuwolt (1982), since all the locations of these soils are not suitable for construction unless the soils are removed and replaced or treated. There are many methods designed to treat this weak soil and one of them is through soil stabilization.

Soil stabilization according to Das, Braja M. (2002), is a technique done by treating the soil either mechanically or chemically through the process of blending and mixing. There are many types of stabilization techniques; mechanical, chemical, thermal and others, with the commonly practiced are mechanical stabilization and also chemical stabilization. This research concentrate on chemical stabilization techniques where additives such as fly ash, bottom ash, bitumen, Portland cement, lime and others, are added to the soft soil to improve the soil's engineering properties. The author's research concerns mainly on lime stabilization. Lime has been used from ancient times to treat and stabilize soft soils, and in many cases, exhibit satisfactory results. From past researches and experiments, it was found out that lime application is mainly concentrated to fine soils. The application has been used to increase the soils' resistance and decrease their susceptibility to volumetric changes due to water content. Neoh, C.A. (1998) stated that there are abundant of lime supply in Malaysia where limestone formations are widespread in Pulau Langkawi, Kinta Valley, Gua Musang and Kuala Lumpur. These large formations contribute to huge amount of lime supply for various uses which might give good prospect of lime usage as a cost- effective soil stabilizer. According to Bell, F.G (1993), K.C. Kok and K. A. Kassim (2001), from their past researches on soil stabilization using lime, it was obtained that the optimum lime content is in the range of 3% to 6%.

This research investigates the suitability of lime as soft soil stabilizer and the optimum lime content for practical usage.

1.2 Problem Statement

Soft soils are well-known for having weak strength as well as low capability of load bearing. These poor engineering properties caused difficulties for construction where more costs will be involved to remove and replace the soils.

1.3 Objectives and Scope of Study

The main objective of this research is to investigate the effects of lime as a stabilizing agent on California Bearing Ratio (CBR) of Malaysian soft soils. Other objectives are to evaluate the suitability of lime as a stabilizer and also to evaluate different methods used for soil stabilization.

This project is a part of a bigger project which consists of researches on the effects of fly ash, bottom ash and lime on California Bearing Ratio (CBR) and shear strength of soft soils. The author is investigating the effects of lime on CBR.

This project involves mainly laboratory experiments. The test programs include classification tests and CBR tests.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Soft Soils in Malaysia

Soft soils are soils having low strength and high compressibility, subject to large volume changes and may be composed of loose sands and silts, wet clays, organic soils, or combinations of these materials such as disposal of waste materials. Usually, due to sedimentary process on different environments, both physical and engineering properties which are void ratio, water content, grain size distribution, compressibility, permeability and strength, show a significant variation. Further, they exhibit high compressibility, which includes an important secondary consolidation, reduced strength, low permeability and consequently low quality for construction.

According to Nieuwolt (1982), Malaysia is characterized by a humid tropical climate with heavy rainfall, average daily temperature of 21-32°C and humidity averaging about 85%. Soils in Malaysia could be divided into two groups; sedentary soils formed in the interior on a wide range of rock types, and coastal alluvial plains soils. Sedentary soils developed on igneous, sedimentary and metamorphic rock, and strongly weathered with mostly kaolinitic clay minerals. These soils fall under the classification order of Nirosols, Acrisols and Ferralsols (Ultisols and Oxisols). The second type is coastal alluvial soils, which fall under the categories of Gleysols, Cambisols, Podzols (Entisols, Inceptisols and Spodosols).

Coastal alluvial plains soils could be divided into four main types of soils. The first type is the predominantly fine-grained clay and clay loam soils covering large areas of the west coast of peninsular Malaysia. Soils on the east coast consist of mainly kaolinitic clays and are relatively coarse grained. Clay loam soils also found in small area in Sarawak. The second type is peat and organic soils, covering about 2.7 million hectares of Malaysia with 1.66 million hectares in Sarawak, 984,000 hectares in Peninsular Malaysia, and 86,000 in Sabah, summing up to about 8% of the total land area. The third type is acid sulphate soils scattered along the west coast plains in Peninsular Malaysia and the Sarawak River, covering approximately 100,000 hectares. The fourth type of soil is sandy soils, spreading along the east coast of the Peninsula and the coastal area of Sabah cover an area of just under 200,000 hectares with 155,400 hectares in Peninsular Malaysia and 40,400 hectares in Sabah. Peat, acid sulphate and sandy soils are problematic for agricultural activities. In geotechnical aspects as well, peat, organic, clayey and marine soils are problematic and are not suitable for construction.

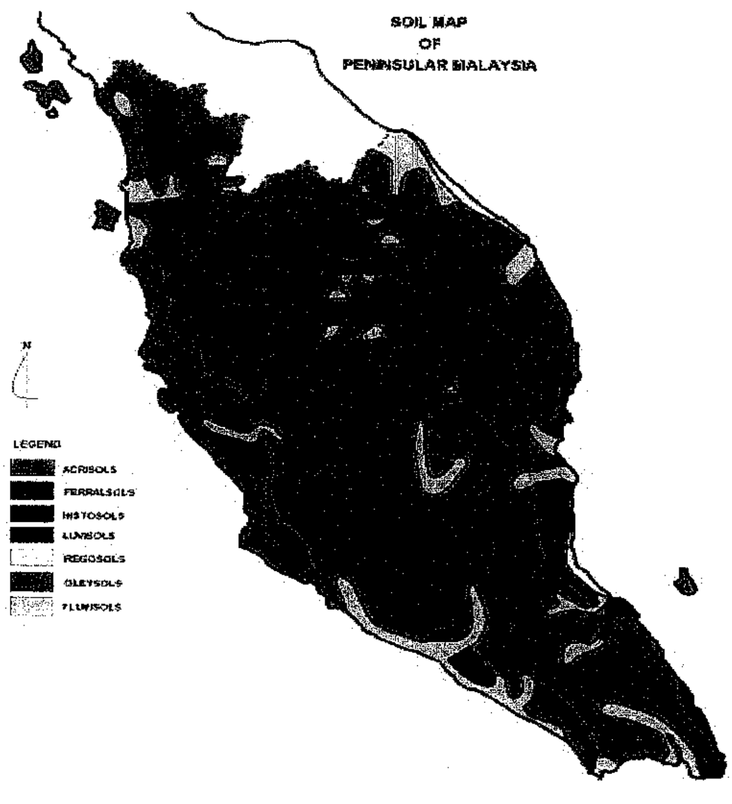

Figure 2.1. Soil Map of Peninsular Malaysia (www.fao.org)

2.2 Soil Stabilization

Stabilization is the treatment of natural soil either by mechanical or chemical means through the process of blending and mixing to improve the soil engineering properties (Garber, Nicholas J., and Lester A. Hoel, 2002). According to Lambe, T.W (1962), soil stabilization is defined as the alteration of any property of a soil to improve its engineering performance. The alteration techniques include mechanical manipulation, removal of soil moisture and the addition of many types of materials. Soil stabilization is used to increase or decrease strength, or reduce the sensitivity of strength to environmental changes, especially moisture changes, or to increase or decrease permeability, or to reduce compressibility or to reduce frost susceptibility. There are many methods of stabilizing weak soil. Among them are mechanical stabilization, Portland cement stabilization, chemical stabilization, bituminous stabilization, addition or removal of soil particles, stabilization by drainage, electrical stabilization, thermal stabilization, and others.

- Mechanical Stabilization

    It is the process of altering soil properties by changing the gradation through mixing with other soils, densifying the soils using compaction efforts or undercutting the existing soils and replacing them with granular material (Indiana Department of Transportation, 2002). The densification of soils are done with various types of mechanical equipment such as rollers, falling weights, explosives, static pressure, fabrics, freezing, heating and others. The most common type of mechanical stabilization is through soil compaction. Among of the objectives of soil densification is to increase soil strength, to reduce shrinkage and also to reduce subsidence from reduced void ratio. (Bowles, Joseph E., 1984)

- Portland Cement Stabilization

Garber, Nicholas J. and Lester A. Hoel (2002) stated that soil stabilization using cement usually involves addition of 5% to 14% Portland cement by volume of the compacted mixture to the soils being stabilized. According to Bell, F.G. (1993), any type of cement could be used, but ordinary Portland cement is most widely used. This type of stabilization is suitable for any types of soil, with the exception of highly organic soils or highly plastic clays. Generally, well-graded granular soils that possess sufficient fines to produce homogenous mixture is the most suitable for Portland cement stabilization (Headquarters, Department of the Army, 1994).

- Chemical Stabilization

Chemical stabilization, as defined by Materials and Tests Division, Indiana Department of Transportation (2002), is the transformation of soil index properties by the addition of chemicals such as fly ash, lime, cement, combination of these additives and other suitable chemicals. This type of stabilization alters physical and chemical properties of the soil through two primary mechanisms; general increase in particle size, reduction in plasticity index, hydraulic conductivity and shrink or swell potential, and absorption and chemical binding of moisture.

Fly ash, also known as coal ash, is a mineral residual from combustion of pulverized coal. It is a fine-grained, pozzolanic material which contains silicon and aluminum compounds. Pulverized fly ash could be used by itself to improve physical properties of soil or in conjunction with lime or cement to form a binder (Bell, F.G., 1993). Fly ash could used to enhance soil strength, stabilize embankments, to control shrink swell properties of expansive soils and as drying agent to reduce soil moisture content to permit compaction. Fly ash is commonly used together with cement or lime, which is suitable for stabilizing sands and gravels with low clay contents.

Lime is effective for stabilizing plastic soils and can be used to reduce soils moistures, which improve their workability, limit volumetric changes and increase strength. According to Bell, F.G. (1993), "*lime usually reacts with most soils with a plasticity index ranging from 10 to 50%. Those soils with a plasticity index of less than 10% require a pozzolan for the necessary reaction with lime to take place, fly ash being commonly used*". When lime is added to fine-grained soils in the presence of water, a number of reactions occur which include cation exchange, flocculation, carbonation and pozzolanic reaction with clay particles that lead to the improvement of soil properties.

This research is a part of large research project which involves the utilizations of lime, fly ash and bottom ash as soil stabilizer and their effects on certain soil engineering properties. The author's part is to investigate the effect of lime on California Bearing Ratio (CBR) of soft soils.

2.3 Lime

Lambe, T.W. (1962) explained that lime is produced from natural limestone and each type of lime depends upon its parent material and production process. There are five basic types of lime which are high- calcium quicklime (CaO), dolomitic quicklime ($CaO + MgO$), hydrated high-calcium lime ($Ca(OH)_2$), normal hydrated dolomitic lime ($Ca(OH)_2 + MgO$) and pressure-hydrated dolomitic lime ($Ca(OH)_2 + Mg(OH)_2$). The most commonly form of lime is hydrated lime, or slaked lime and quicklime. Quicklime (CaO) is a product of calcination of limestone ($CaCO_3$) at high temperature (about 1315C), while hydrated lime is produced through treating quicklime with sufficient water to satisfy its chemical affinity to water. (Little, D.N., 1995)

Greaves, H. M. (1996) indicated that quicklime has several advantages over hydrated lime, where quicklime has a higher available lime content per unit mass than hydrated lime, it is denser, produces a large reduction in moisture content due to hydration and evaporation and is particularly beneficial for wet soils, and quicklime generates heat which accelerates strength gain, which is beneficial in temperate climate. However, it is more caustic and dangerous to laborers despite its cheap cost and effectiveness. (Little, D.N. 1995)

According to Little, D.N. et al. (2000), among the important soils engineering properties effects due to lime stabilization include improved strength, resistance to fracture, fatigue and permanent deformation, improved resilient properties, reduce swelling and resistance to damaging effects of moisture. Bergado, D.T., et al. (1996), through their research specified that the soil being stabilized should not contain less than 20% of clay and the sum of silt and clay fractions should preferably exceed 35% for lime stabilization to be successful. This is normally the case when plasticity index of the soil is greater than 10.

2.4 Mechanism of Lime Stabilization

There are phases of stabilization occur in soil – lime interaction; short term and long term. Short term reactions include hydration and flocculation, while the long term reactions are cementation and carbonation. The treated soil gains strength through three main reactions, which are dehydration of soil, ion exchange and pozzolanic reaction.

When lime is added to fine-grained soils, heat is released due to reaction with pore water of the soil. Natural moisture content of the soil is immediately lowered due to drying out of pore water by absorption during reaction with lime and evaporation due to the heat released.

$$CaO + H_2O \rightarrow Ca(OH)_2 + Heat$$

The product of quicklime hydration which is calcium hydroxide, dissociates in water, producing calcium ions and hydroxyl ions. These processes result in ion exchange, flocculation and pozzolanic reaction.

$$Ca(OH)_2 \rightarrow Ca^{++} + 2(OH)^-$$

The calcium ions tend to replace weaker ions such as sodium ions and potassium ions on the surface of clay particles in the soil. This This cation exchange process alters the structural components of the clay mineral. Within a period of a couple of minute up to some hours after mixing, calcium hydroxide transformed again due to presence of carbonic acid resulted from reactions of carbon dioxide in the soil with free water. This reaction results in dissociation of lime into calcium ions, magnesium ions and hydroxyl ions. The soil structure begins to transformed, where the soil particles flocculate and coagulate into larger sized particles.

Calcium hydroxide in the soil also reacts with silicates and aluminates in the soil forming binding material or cementitious materials, consisting of calcium silicates and calcium aluminates.

$$Ca^{++} + 2(OH)^- + SiO_2 \rightarrow CSH$$
$$Ca^{++} + 2(OH)^- + AL_2O_3 \rightarrow ASH$$

The gel of the hydrates binds the soil particles in a manner similar with the hydration of Portland cement, but lime cementing process is much slower reactions which require longer time. The main part of the reaction does not start until a couple of days after mixing the soil with lime. (Bergado, D.T, et. al. 1996)

Lime stabilization is more suitable for soils with high clay content and less suitable for granular soils (Little, D.N., 1995). However, the pozzolanic reaction which happens in the soil-lime-water mixture is the main key in strength gain for the treated soil. There are a number of factors affecting the soil-lime pozzolanic reactions with the major ones are organic carbon and sulfates. The other factors that might as well affect the reaction are clay content, clay mineralogy, weathering, pedology and geological and climatic effects.

Lime stabilization mechanism requires the presence of clay minerals to provide alumina and silica to support pozzolanic reactions for long term strength gain (Rollings & Rollings 1996). Although lime stabilization gives large effect in moisture reduction of high-moisture soils, however the effectiveness might decrease with the presence of organic matter in the treated soil. Based on research by Little, D.N. (1995), the presence of organic matter in excess of 1% will interfere with pozzolanic reaction, where the organic matter absorbs calcium ions that are necessary for cation exchange process and pozzolanic reactions.

2.5 California Bearing Ratio (CBR)

California Bearing Ratio (CBR) is a penetration test for evaluation of the mechanical strength of road subgrades. It was developed by the California Division of Highways. The CBR rating was developed for measuring the load-bearing capacity of soils used for constructions. The test is performed by measuring the pressure required to penetrate a soil sample with a plunger with standard area. The test is described in ASTM D 1883 and D4429. The results obtained by CBR tests are used with empirical curves to determine pavement thickness and its layers components.

Table 2.1. Typical Ratings of CBR Value

CBR Number	General Rating	Uses
0-3	Very Poor	Subgrade
3-7	Poor to Fair	Subgrade
7-20	Fair	Subbase
20-50	Good	Base, Subbase
>50	Excellent	Base

2.6 Stabilization with lime and effects on CBR of soft soil

There are numerous research conducted on lime stabilization and its effects on California Bearing Ratio of the selected soil type. One of the researches is conducted by Nicholson et al. (1994), where lime was utilized to improve tropical Hawaiian soils. The initial CBR tests of all the samples exhibited low CBR values. The Hawaiian soils were then mixed with 3%, 5% and 7% hydrated lime and the soil – lime mixtures were cured for 24 hours. The treated soils were tested, including test for swell, and the results were increased in strength of the soils and large decrease in swell. The characteristics of the treated soil was found out to had change, where addition of lime decreases the soils plasticity and the plastic soil samples changed to be non-plastic.

Another research done by De Rezende & Carvalho (2003) utilizes moisturized calcite lime to treat Brazilian lateritic clay soils. From their studies, it was discovered that lime was ineffective in reducing plasticity of the soil sample but effective in increasing soil strength (CBR).

2.7 Previous Research

Many researches regarding lime stabilization was carried. However, each of the researches are different in terms of location of sampling, types of soils being used and some of them were carried out to determine effects of lime stabilization on certain engineering properties only. For example, research done by Collotta, T., Borgonovo, L. and Papale, S., for example, was conducted in Italy, where the soil samples were marly-sandy and clay lithotypes from Emilia Romagna, and sandy-silty and argillites from Tuscany. The research was to investigate the correlation among CBR, fines and quicklime content. The climate in Emilia Romagna is continental, with cold and foggy during winter and hot and humid during summer, while in Tuscany it is very mild, Mediterranean climate (www.italiantourism.com). The research conducted in Hawaii by Nicholson et al. 1994 is a two season's location; summer and winter.

Difference in humidity, climate and geological characteristics of each research locations give differences in each research findings and results. These differences might affect the research findings, where the final results might be or might not be the same as researched conducted in other country.

2.8 Soil Classification

Soil classification is the first step in any field or laboratory soil investigation which can be used as a preliminary prediction of the potential engineering properties and performances. There are many soil classification systems that are used by soil engineers. Among them are American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS). Both systems are based on the texture and plasticity of soils. AASHTO classified soils into seven (7) major groups; A-1 through A-7, and provides no place for organic soils identification, while USCS is more descriptive of the soil properties by using variety of symbols like GW for Gravel Well Graded, OL for Organic Low Plasticity and others.

Since this project involves soft soils which might be composed of organic soils, USCS is used to predict the name of the soil, as well as to identify the soils suitability as construction material. Its method of classification is based on the soil particle size distribution and Atterberg's limits.

- Moisture Content

  Moisture content which is also called water content is the ratio of the weight of water to the weight of the solids in a given mass of soil. This ratio is usually expressed in percentage. Natural moisture is essential in all studies as it will give an idea about the states and conditions of soil in the field. One method of determining soil moisture content is through microwave oven heating.

- Particle – Size Analysis

This is a mechanical analysis of soil where the size range of particles in a soil is determined and expressed as percentage of the total dry weight. There are two methods that are commonly used to determine the particle – size distribution of soil, which are sieve analysis and hydrometer analysis. As specified by the ASTM, the distribution of particle sizes larger than 75 µm is determined by sieving, while the distribution of particle sizes smaller than 75µm is determined by sedimentation process, using a hydrometer.

- Liquid Limit

There are two methods of conducting liquid limit test, which are Fall Cone test and another one using Casagandre methods, according to British Standard (BS1377) and ASTM 4318 respectively.

Since Casagandre's device is not available in Universiti Teknologi PETRONAS (UTP) Geotechnical Laboratory, fall cone method is used to determine specimen's soil liquid limit. According to Das, Braja M. (2002), "in this test the liquid limit is defined as the moisture content at which a standard cone of apex angle 30 and weigh of 0.78N will penetrate a distance d = 20mm in 5 seconds when allowed to drop from a position of point contact with the soil surface". Four more tests at different moisture content are conducted to determine the fall cone penetration, d. A semilogarithmic graph is plotted with moisture content versus cone penetration, resulting in a straight-line.

Table 2.2. Description of Liquid Limit, LL

Description	LL
Low Plasticity	< 35
Intermediate Plasticity	35 – 50
High Plasticity	50 – 70
Very High Plasticity	70 – 90
Extremely High Plasticity	> 90

- Plastic Limit

According to ASTM D 4318, the plastic limit is determined by alternately pressing together and rolling into 3.2-mm diameter thread a small portion of plastic soil until its water content is reduced to a point at which the thread crumbles and can no longer be pressed together and re-rolled. The water content of the soil at this point is reported as the plastic limit.

- Plasticity Index

According to ASTM D 4318, the plasticity index is calculated as the difference between the liquid limit and the plastic limit.

PI = LL – PL

Plasticity Index is very important in classifying fine-grained soils. From the Plasticity Index Chart (Figure 2), the properties of the soils could be determined according to the soils plastic limit, liquid limit as well as plasticity index values. Tabulated in Table 5 are the descriptions of plasticity index.

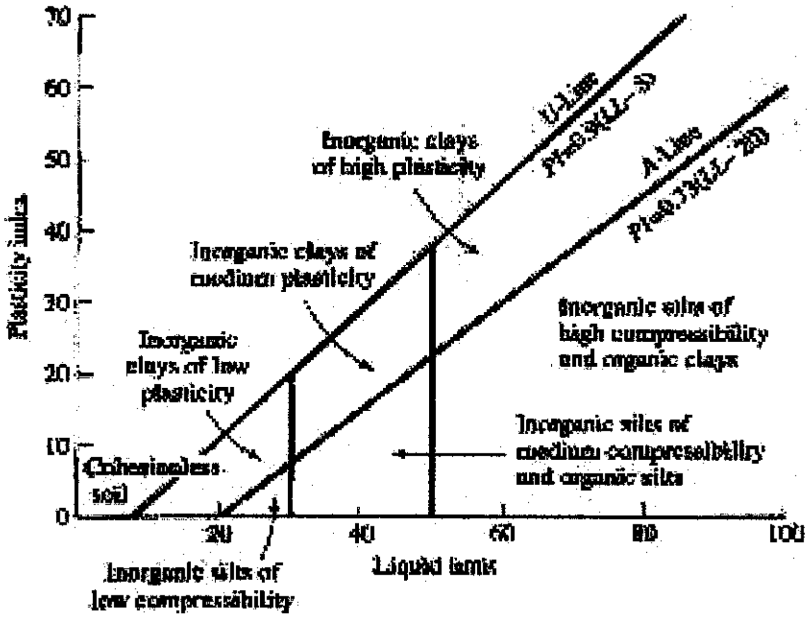

Figure 2.2. Plasticity Index Chart (Das, Braja M., 2002)

Table 2.3. Description of Plasticity Index, PI (Das, Braja M., 2002)

Description	PI
Non-plastic	0
Slightly Plastic	1-5
Low Plasticity	5-10
Medium Plasticity	10-20
High Plasticity	20-40
Very High Plasticity	>40

CHAPTER 3
METHODOLOGY / PROJECT WORK

A sequence of methodology had been developed in carrying out this project. The approaches are basically divided into two type; analytical approach and experimental approach.

3.1 Analytical Approach

Research – based activities fall under the analytical approach. At the beginning of the project, researches were more concentrated in acquiring information on the project background, scope of study, problems definitions and general literature review. Information regarding materials for this project was also gathered during this stage. Along with the progress of the project, more researches were conducted to continuously gather information on literature review and related matters.

3.2 Experimental Approach

Through analytical approach, information on laboratory testings was acquired, which were used to develop the testing program. The program started with materials gathering and continued with laboratory testings.

3.3 Type of tests

The test program involves classification tests and also California Bearing Ratio (CBR) tests. Classification tests was conducted on both soil and lime, while for CBR tests, the testings were conducted on raw soil and on soil with the addition of lime at different percentage.

3.4 Approach

As a part of bigger project involving several persons with different additives applications but using the same soil, teamwork was the main approach to conduct the raw soil classification tests. For these tests, the results in terms of the raw soil properties are same. However, for the main test program, each of the team members conducted the main testings separately.

As for the author, the main test program was CBR tests using lime as stabilizer. Lime contents of 0%, 2%, 3%, 4% and 6% were utilized. These lime content percentages were estimated based on optimum lime content obtained from previous researches.

At the end of the project, the final results were compared with existing data from previous researches and with other additives usages to evaluate lime effectiveness as soil stabilizer.

3.5 Materials

- Soft Soil

  This is the most important material for this project. The soil was taken from a project at Batu Gajah area. Total of soft soils taken is approximately 500 kg for five persons, with approximately 100kg of soils allocated per person for the usage until the end of the project.

- Safety Equipments and Precautions

The classification tests involved the soil in dried and crushed condition. Since this soil is fine – grained soil, it produces dust which is harmful to the respiratory system. Hence, protection mask wearing is a must. Gloves also must be worn for handling lime to avoid possible side effects from touching it with bare hands.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Untreated Soil

Summary of basic classification tests on the soft soils are tabulated as in **Table 4.1** below.

Table 4.1. Properties of Soft Soil Used

1. Physical Properties					
Moisture Content (%)	46.89 ~ 54.49				
Plastic Limit (%)	45				
Liquid Limit (%)	28				
Plasticity Index	17				
Specific Gravity (Mg/m3)	2.73				
Organic Content (%)	5.43 ~ 10.09				
2. Chemical Properties					
Element	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3
Composition (%)	55.10	36.70	2.62	0.40	0.17
3. Soil Classification					
Sandy Clay					

The value of moisture content in **Table 4.1** is obtained after several days the soil being transported to the laboratory. However, based on the range, it is anticipated that the natural moisture content of the soil could be higher than the obtained range. **Table 2.3** in the previous chapter classified the soil as having medium plasticity. Based on Bell, F.G (1993) in his book stated that lime stabilization is suitable for treating soils with plasticity index (PI) ranges between 10 – 50%. The main composition of the soil is silicon oxide (SiO2) with about 55% and 37% of aluminum oxide (Al2O3). These two elements, based on the theory of lime stabilization, will involve actively with lime (CaO) upon addition of lime into soil with presence of water. Calcium oxide, being the pozzolan exists in small amount in the soil, which is 0.4%.

Compaction test was conducted on the untreated soil, and 21% of Optimum Moisture Content (OMC) was obtained with the Maximum Dry Density (MDD) of 1.62 kN/m^3. The OMC obtained from the compaction of untreated soil (after this will be referred as 0% lime) was utilized for California Bearing Ratio (CBR) tests for immediate testing, 24 hours curing and 96 hours soaking. The respective CBR values are 26.8, 26.05 and 2.7. The soaked CBR value fall into the very poor strength class, which means it needs to be treated to improve its strength (**Table 2.1**). **Figure 4.1** shows the graphs of penetration resistance of untreated soil.

Figure 4.2 shows the swell characteristics of the untreated soil, where after being soaked for 96 hours, the percentage of swell is 5.6% or 7.2 mm.

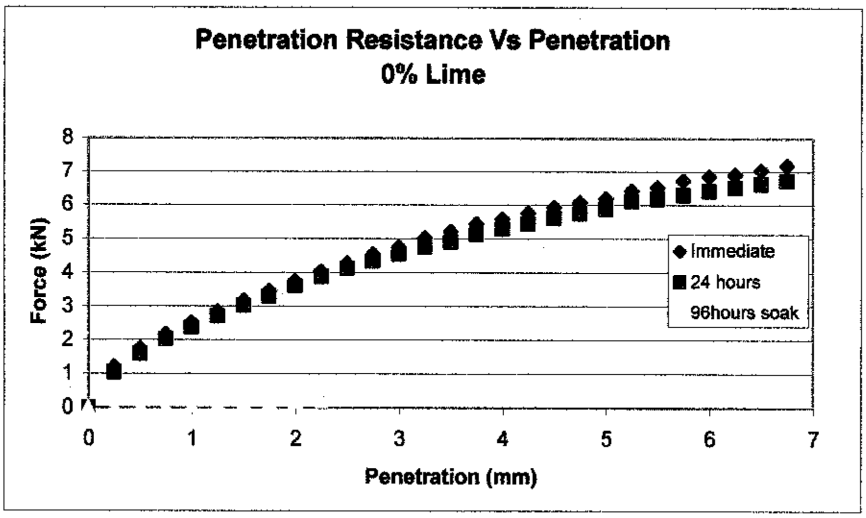

Figure 4.1. Penetration Resistance for Soil without Lime at OMC = 21%

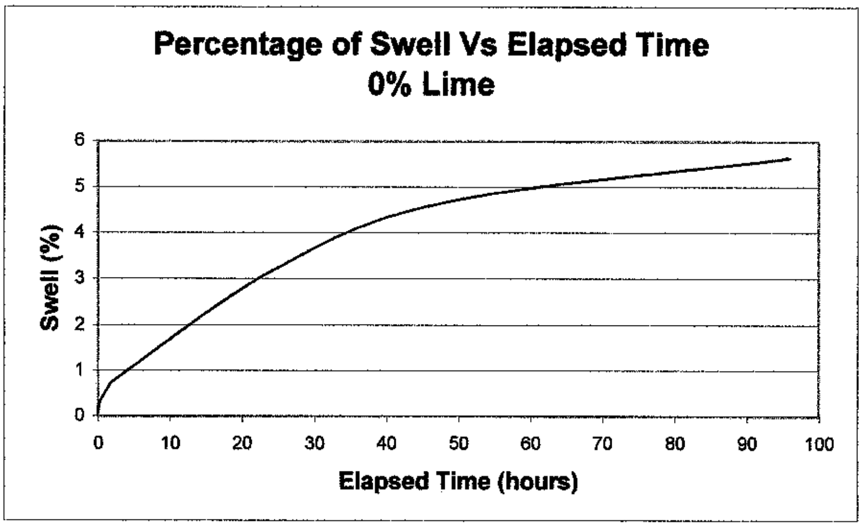

Figure 4.2. Percentage of Swell for 0% Lime (96 hours soak)

4.2 Treated Soil

The type of lime used in the research is quicklime. Table 4.2 shows the chemical composition of the quicklime.

Table 4.2. Chemical Composition of Lime

Elements	SiO2	Al2O3	Fe2O3	CaO	MgO
Composition %	0.260	0.143	0.132	97.6	1.37

From the table, the quicklime has high content of calcium oxide (CaO); 98%, which means the lime is almost pure lime.

Figure 4.3 below shows the compaction test results for 0% lime addition and treated soil with addition of 2%, 3%, 4% and 6% of lime. The respective values of OMC and MDD for different lime content are tabulated in **Table 4.3.**

Table 4.3. Summary of Compaction Test Results

Lime Content (%)	0	2	3	4	6
OMC (%)	21.33	21.88	22.00	23.00	23.42
MDD (kN/m^3)	16.24	15.66	15.60	15.52	15.32

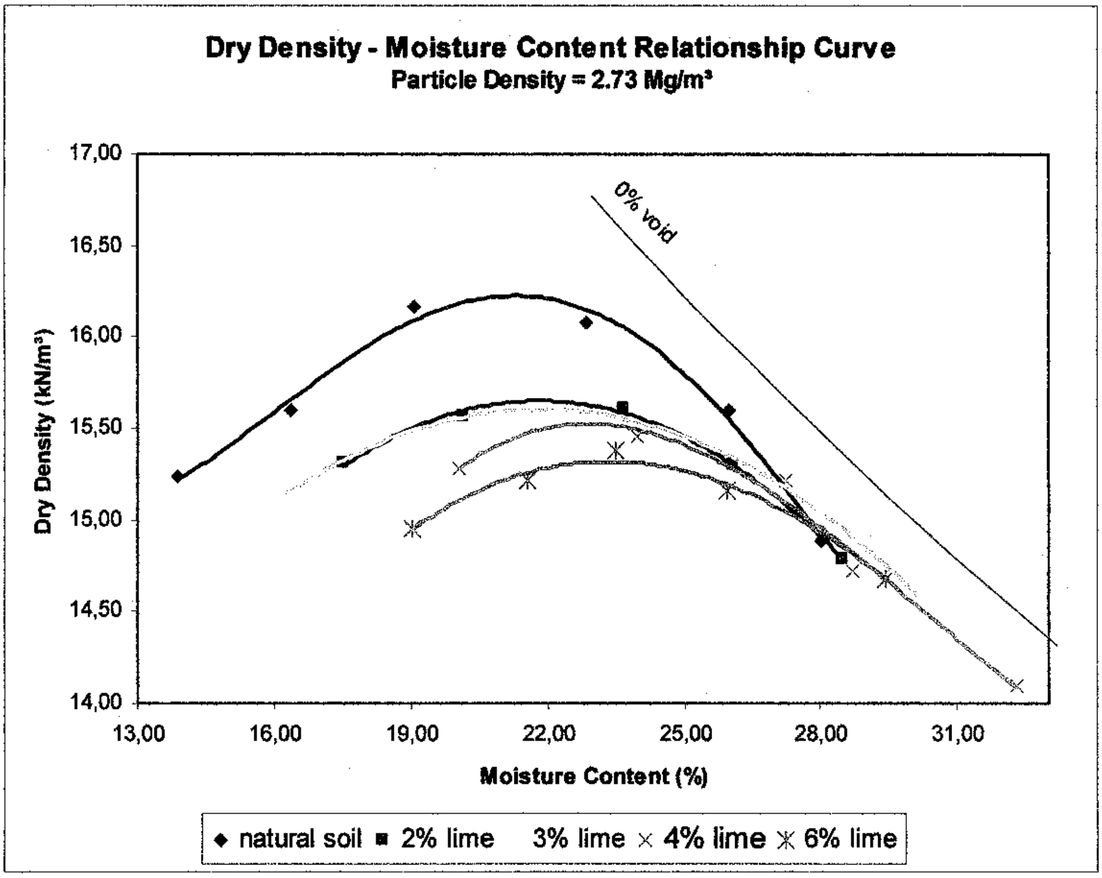

Figure 4.3. Compaction Curve for Various Lime Content Addition

From the compaction results, two trends are identified, where with increasing of lime content, the OMC increases while the MDD decreases.

California Bearing Ratio (CBR) tests were conducted by utilizing the above OMC for each lime percentage. The samples were tested top and bottom for immediate testing, 24 hours cure and also 96 hours soak. The results of CBR for all the samples are as shown in **Table 4.4** while **Figure 4.4** shows one of the plots of penetration resistance obtained from CBR test versus penetration of plunger. From the plot, the value of penetration resistance (force) at 2.5 mm penetration is taken for the calculation of CBR value.

Table 4.4. Summary of CBR Test Results

Lime content (%)	Top			Bottom		Swell (%)
	Immediate	24 hours	96 hours	Immediate	24 hours	
0	27.50	26.44	2.05	33.42	31.29	5.64
2	39.68	44.70	30.76	45.54	58.18	0.20
3	56.41	68.26	53.18	56.81	77.12	0.15
4	43.94	55.36	39.39	48.33	52.97	0.09
6	52.12	56.87	47.27	51.74	55.75	0.22

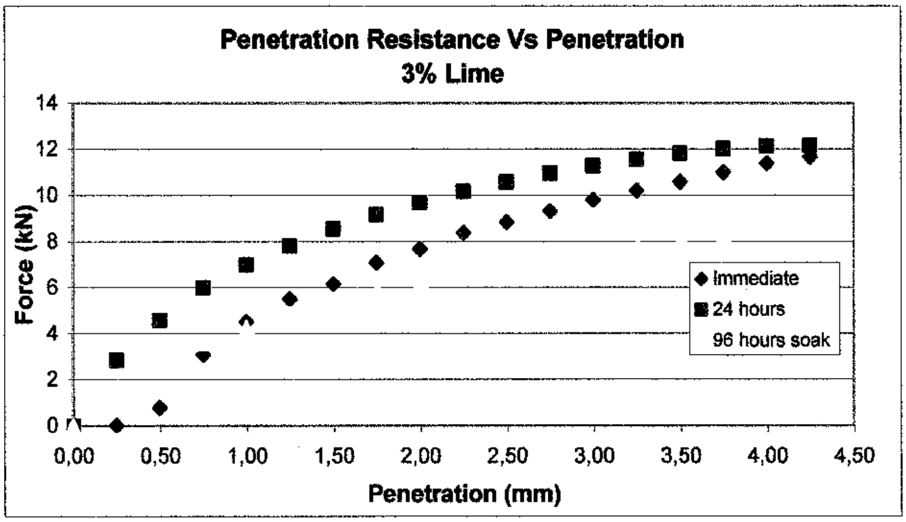

Figure 4.4. Graphs of Penetration Resistance vs. Penetration of Plunger for 3% Lime

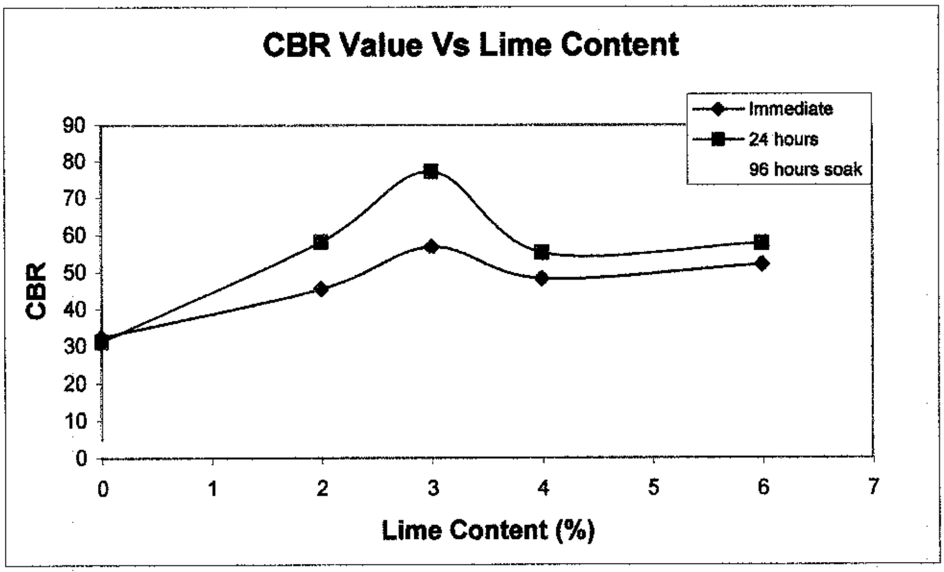

Figure 4.5. Graphs of CBR Values vs. Lime Content

From **Figure 4.5**, it could be observed that generally the trend or behavior of the treated soil either under the immediate testings, or 24 hours cure or 96 hours soak, is same, where, initially CBR values increases with increase of lime content. The curves have a peak value of CBR at 3% lime content and after that point CBR value decreases. It also could be seen that the immediate testing curve is between the 24 hours cure and 96 hours soak curves. The highest value of CBR is from the 24 hours cure curve. Although the sample is under soak condition, the CBR value increases with increase of lime content and the values are a lot higher than the 0% lime content. This clearly shows that addition of lime improves strength of the soil.

In term of swell parameter, untreated soil gives the highest swell. But as the lime content increases, percentage of swell decreases, with the lowest value is at 4% lime content **(Figure 4.6)**. From these results as well, it could be said that addition of lime almost eliminates swell in the soil.

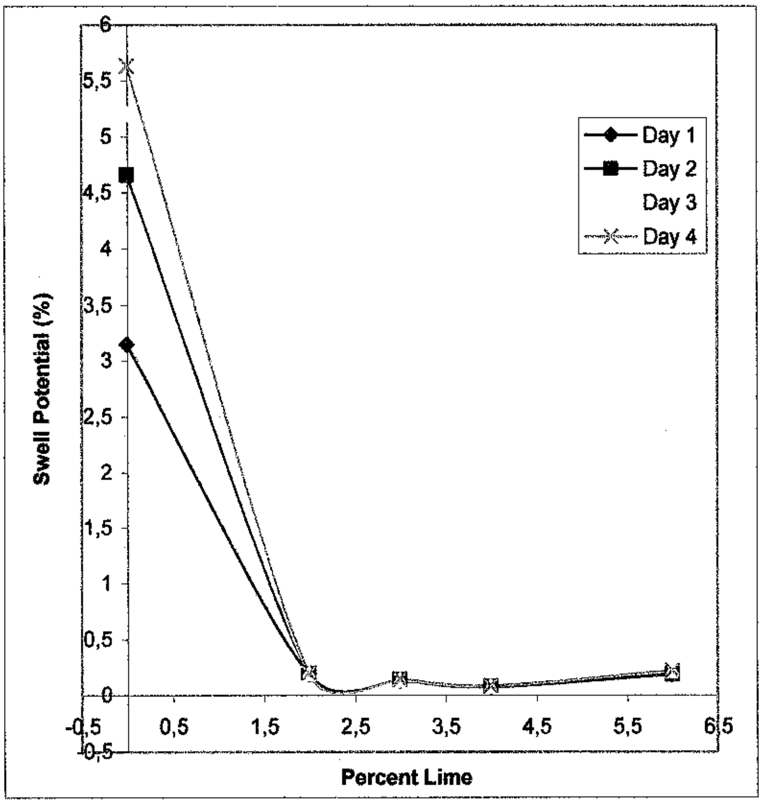

Figure 4.6. Effect of Lime on Swell Potential of the Soil

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the results, it can be concluded that:

- The optimum moisture content of the soil increase with increasing lime content
- Maximum dry density decreases with the increase of lime percentage
- CBR value increase with increasing lime usage, which indicates strength gain of the soil through lime addition
- Addition of lime also decreases the swell of the soil
- Treated soil using 3% lime additions gives the highest CBR value

5.2 Recommendation

The author would like to give some recommendations to Civil Engineering Department as well as UTP Laboratory Facilities and Services Unit.

Civil Engineering Department

- Throughout the author's time conducting the laboratory sessions, it was observed that, every time the treated soil sample is prepared, the wet sample produces an odor that somehow attracts flies to the samples. However, this matter is subject to further investigation and clarification either the flies are attracted to the treated soil sample or it was just coincidences. However, if the treated soil is the source, it would be an interesting research topic.

UTP Laboratory Facilities and Services Unit

- There is a number of equipment in the laboratory, however only one available for use. Hence the broken equipments should be repaired and serviced so that laboratory activities could be done effectively and efficiently.
- The equipments in the laboratory are rarely calibrated. This somehow affects the credibility of the experimental results using respective equipments. Calibration should be done periodically so as to ensure the credibility of the results obtained from the testings using the equipments

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APPENDICES

'PENDIX A. TESTS RESULTS FOR SOIL CLASSIFICATION TESTS

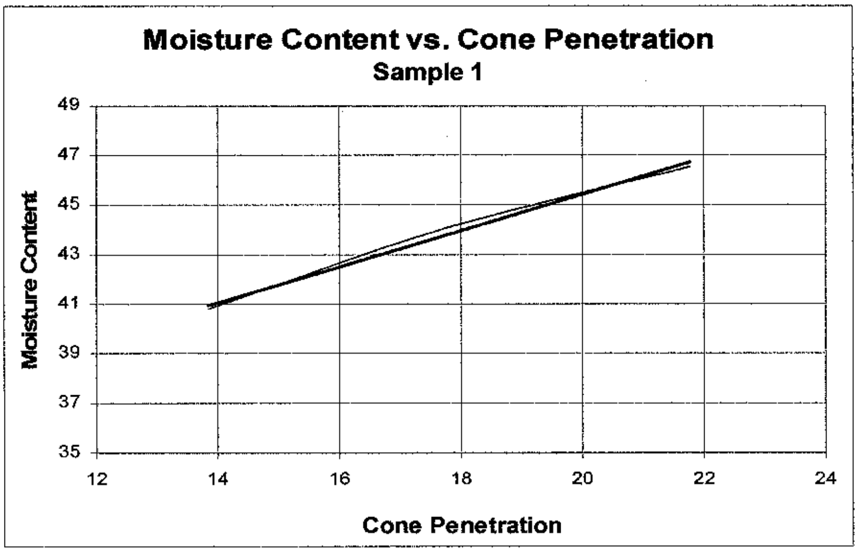
Table A.1 Moisture Content Results

Sample no.		1	2	3	4	5	6
Mass of wet soil + container (m_2)	(g)	93.56	91.96	113.38	137.48	71.76	93.38
Mass of dry soil + container (m_3)	(g)	71.90	70.71	81.91	99.43	57.16	73.02
Mass of container (m_1)	(g)	29.26	29.19	29.05	29.17	29.20	29.59
Mass of moisture (m_2-m_3)	(g)	21.66	21.25	31.47	38.05	14.60	20.36
Mass of dry soil (m_3- m_1)	(g)	42.64	41.52	52.86	70.26	27.96	43.43
Moisture content $w = [(m_2-m_3) / (m_3- m_1)]x\ 100$	(%)	50.80	51.18	59.53	54.16	52.22	46.88

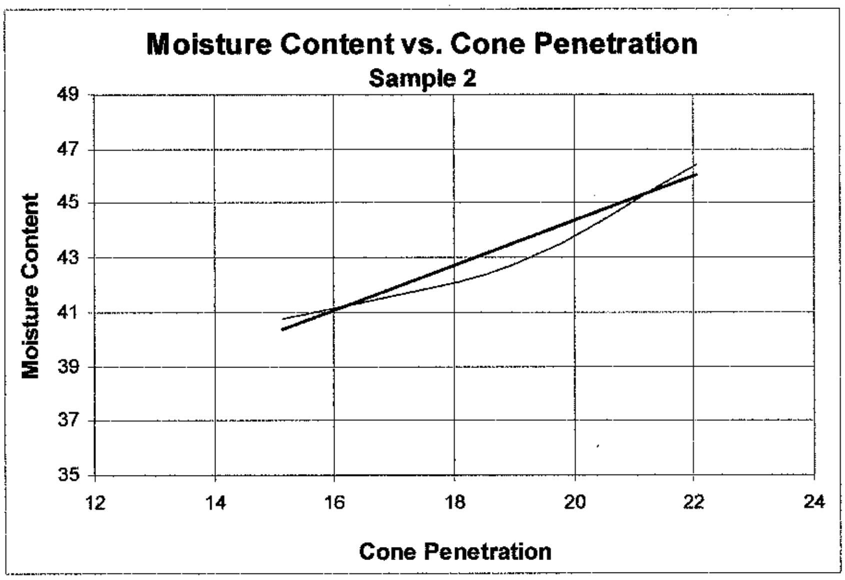
Table A.2(a). Liquid Limit of Sample 1

mple no.	1		2		3	
tial dial gauge reading	0	0	0	0	0	0
ıal dial gauge reading	13.60	14.10	17.90	17.70	21.70	21.80
'erage penetrometer	13.85		17.80		21.75	
ntainer no.	**11**	**12**	**21**	**22**	**31**	**32**
ass of wet soil + container	50.88	48.17	48.48	57.59	86.83	81.73
ass of dry soil + container	44.62	42.68	42.63	48.93	68.59	67.75
ass of container	29.22	29.28	29.39	29.26	29.65	37.53
ass of moisture	6.26	5.49	5.85	8.66	18.24	13.98
ass of dry soil	15.40	13.40	13.24	19.67	38.94	30.22
oisture content	40.65	40.97	44.18	44.03	46.84	46.26
'erage moisture content	40.81		44.11		46.55	

Moisture content at 20mm penetration 45.40%



(a)



(b)

Figure A.1(a)&(b). Determination of Moisture Content at 20mm Penetration

Table A.2(b). Liquid Limit of Sample 2

;ample no.	1		2		3	
nitial dial gauge reading	0	0	0	0	0	0
;inal dial gauge reading	15.40	14.90	19.20	18.70	22.00	22.10
\verage penetrometer	15.15		18.95		22.05	
;ontainer no.	**a**	**b**	**c**	**d**	**e**	**f**
vlass of wet soil + container	48.27	44.94	75.29	73.01	65.13	65.34
vlass of dry soil + container	42.79	40.38	61.50	59.98	53.84	53.88
vlass of container	29.27	29.25	29.18	29.48	29.49	29.25
vlass of moisture	5.48	4.56	13.79	13.03	11.29	11.46
vlass of dry soil	13.52	11.13	32.32	30.50	24.35	24.63
vloisture content	40.53	40.97	42.67	42.72	46.37	46.53
\verage Moisture content	40.75		42.70		46.45	

Moisture content at 20mm penetration 44.40%

Table A.3(a). Plastic Limit of Sample 1

Sample no.		**1**	**2**	**3**	**4**
Mass of wet soil + container (m_2)	(g)	36.10	35.86	34.81	35.58
Mass of dry soil + container (m_3)	(g)	34.51	34.31	33.62	34.12
Mass of container (m_1)	(g)	29.20	29.26	29.25	29.20
Mass of moisture (m_2-m_3)	(g)	1.59	1.55	1.19	1.46
Mass of dry soil (m_3- m_1)	(g)	5.31	5.05	4.37	4.92
Moisture content $w = [(m_2-m_3) / (m_3- m_1)] x 100$	(%)	29.94	30.69	27.23	29.68
Average	(%)	29.39			

Table A.3(b) Plastic Limit of Sample 2

Sample no.		1	2	3	4
Mass of wet soil + container (m_2)	(g)	35.29	35.85	35.03	35.94
Mass of dry soil + container (m_3)	(g)	34.02	34.39	33.72	34.54
Mass of container (m_1)	(g)	29.20	29.46	29.17	29.51
Mass of moisture (m_2-m_3)	(g)	1.27	1.46	1.31	1.40
Mass of dry soil (m_3- m_1)	(g)	4.82	4.93	4.55	5.03
Moisture content $w = [(m_2-m_3) / (m_3- m_1)] \times 100$	(%)	26.35	29.62	28.79	27.83
Average	(%)	28.15			

Table A.4. Organic Content

Sample no.		1	2
Moisture content	(%)	59.53	54.16
Mass of aluminium foil (m_2)	(g)	1.1824	1.1847
Mass of dry soil + aluminium foil (m_3)	(g)	21.470	23.820
Mass of burnt soil + aluminium foil (m_1)	(g)	20.4313	22.7523
Mass of dry soil (m_3- m_2)	(g)	20.2875	22.6353
Ash Content = $[m_1/m_3] \times 100$	(%)	95.1621	95.5176
Organic content = 100.00 – ash content	(%)	4.8379	4.4824

Table A.5. Particle Density

Sample no.	1	2	3
Mass of jar + cap (g)	537.33	536.55	536.65
Mass of jar + cap + soil (g)	937.38	936.47	937.08
Mass of jar + cap + soil+ water (g)	1805.23	1804.95	1807.56
Mass of jar + water (g)	1551.11	1552.54	1553.29
Particle Density, ρs (g/cm3)	2.741	2.711	2.740
Average Particle Density, ρs (g/cm3)		2.73	

Table A.6. Sieve Analysis

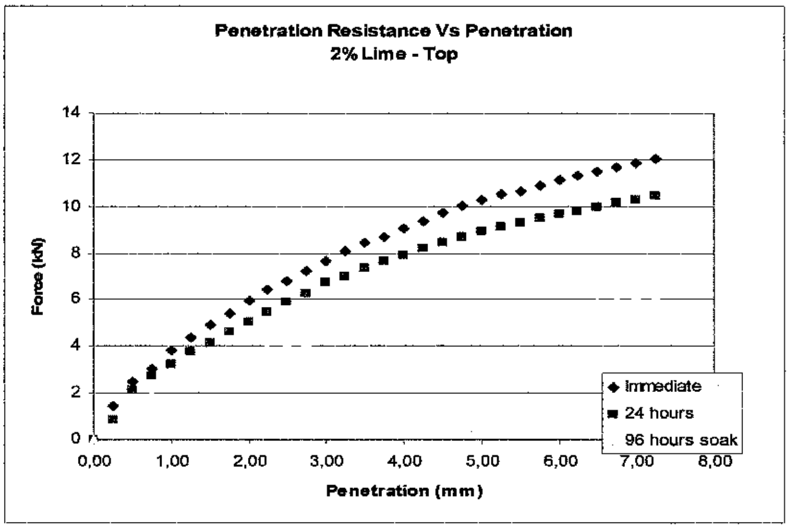
Sieve Size / Particle Size	Sample 2				
	Mass of Sieve (kg)	Mass Retained		%Retained	Cumulative %Passing
		Gross	Net		
2.00mm	0.46	0.61	0.16	25.83	74.17
1.18mm	0.43	0.45	0.02	4.00	70.17
600 μm	0.41	0.49	0.08	13.83	56.33
425 μm	0.38	0.41	0.04	5.83	50.50
300μm	0.29	0.31	0.03	4.50	46.00
212μm	0.35	0.38	0.04	6.00	40.00
150μm	0.28	0.33	0.05	9.00	31.00
63μm	0.33	0.45	0.12	19.67	11.33
Pan	0.25	0.27	0.02	3.33	8.00

PPENDIX B. TESTS RESULTS FOR COMPACTION

Table B.1 Compaction Test Results

ercentage of Lime Added (%)	Added Moisture Content (%)	Mass of Mould + Base + Compacted Specimen (kg)	Mass of Compacte	Bulk Density	Actual Moisture	Dry Density	Optimum Moisture Content (%)	Maximum Dry Density (Mg/m³)
0 (Natural Soil)							21,33	1,624
	13	8,11	1,73	1,74	13,89	15,24		
	16	8,19	1,81	1,82	16,37	15,60		
	19	8,30	1,92	1,93	19,10	16,17		
	22	8,35	1,97	1,98	22,86	16,08		
	25	8,34	1,96	1,97	25,99	15,60		
	28	8,28	1,90	1,91	28,00	14,89		
2	18	8,07	1,80	1,80	17,56	15,31	21,875	1,566
	21	8,14	1,87	1,87	20,17	15,56		
	24	8,20	1,93	1,93	23,67	15,61		
	27	8,20	1,93	1,93	26,11	15,30		
	30	8,17	1,90	1,90	28,48	14,79		
3	18	8,13	1,75	1,76	16,31	15,09	22	1,56
	21	8,22	1,84	1,85	18,75	15,54		
	24	8,26	1,88	1,89	21,05	15,58		
	27	8,31	1,93	1,94	24,07	15,60		
	30	8,29	1,91	1,92	26,63	15,13		
	33	8,28	1,90	1,91	30,14	14,64		
4	21	8,21	1,83	1,84	20,08	15,29	23	1,552
	24	8,29	1,91	1,92	23,97	15,45		
	27	8,31	1,93	1,94	27,27	15,21		
	30	8,27	1,89	1,90	28,72	14,73		
	33	8,24	1,86	1,87	32,31	14,10		
6	18	8,05	1,78	1,78	19,04	14,95	23,42	1,532
	21	8,12	1,85	1,85	21,6	15,21		
	24	8,17	1,90	1,90	23,53	15,38		
	27	8,18	1,91	1,91	25,94	15,17		
	30	8,17	1,90	1,90	29,45	14,68		

PPENDIX C. TESTS RESULTS FOR CALIFORNIA BEARING RATIO (CBR)



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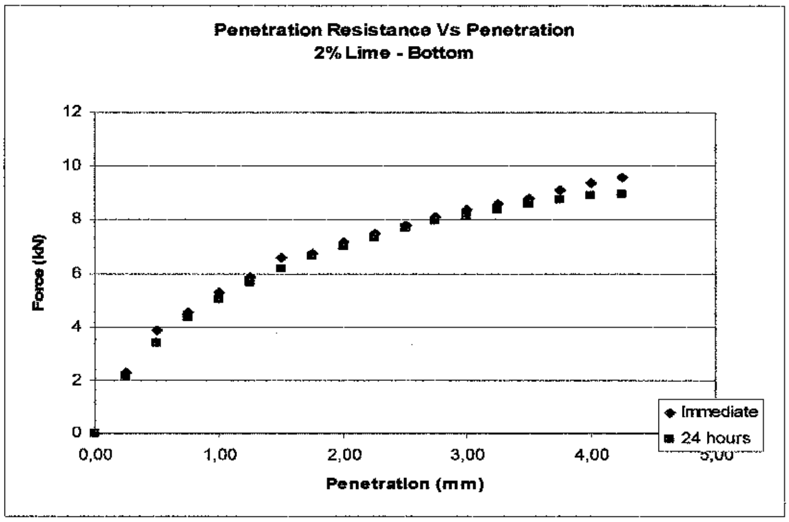
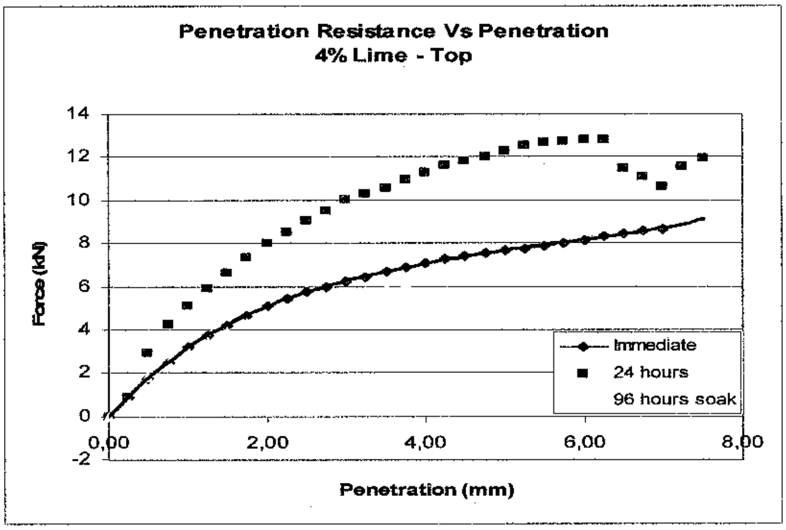


(b)

Figure C.1 (a)&(b). Penetration Resistance vs. Penetration Plot for 2% Lime



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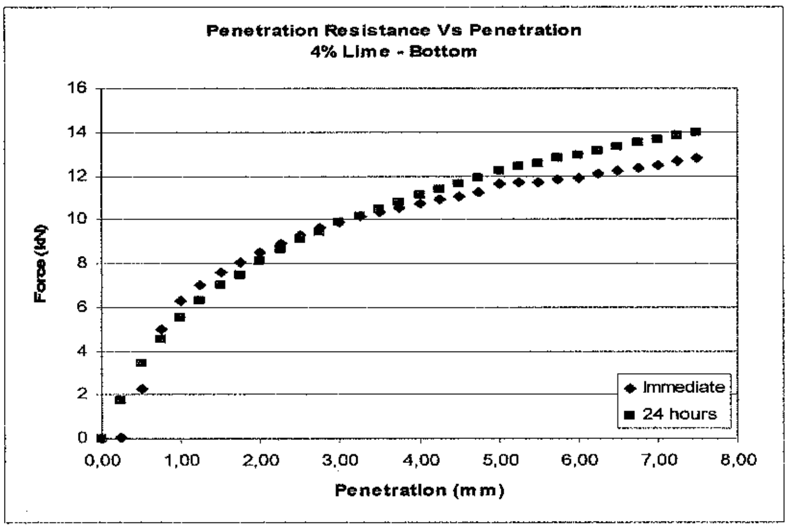
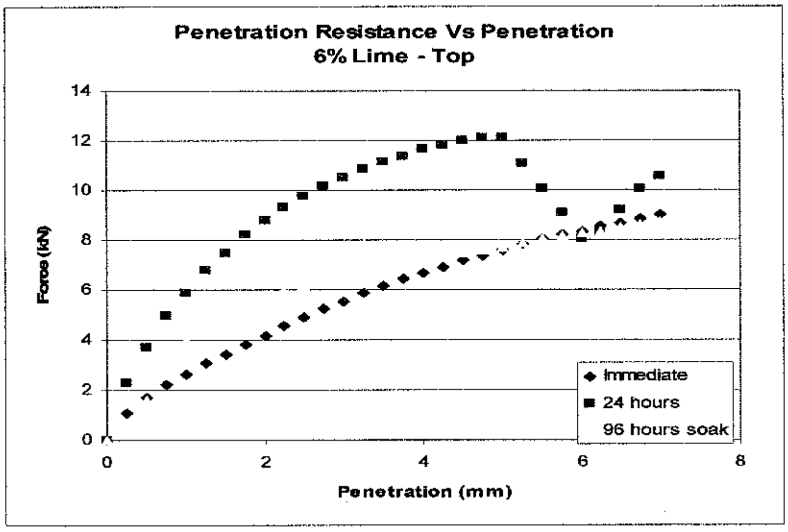


(b)

Figure C.2 (a)&(b). Penetration Resistance vs. Penetration Plot for 4% Lime



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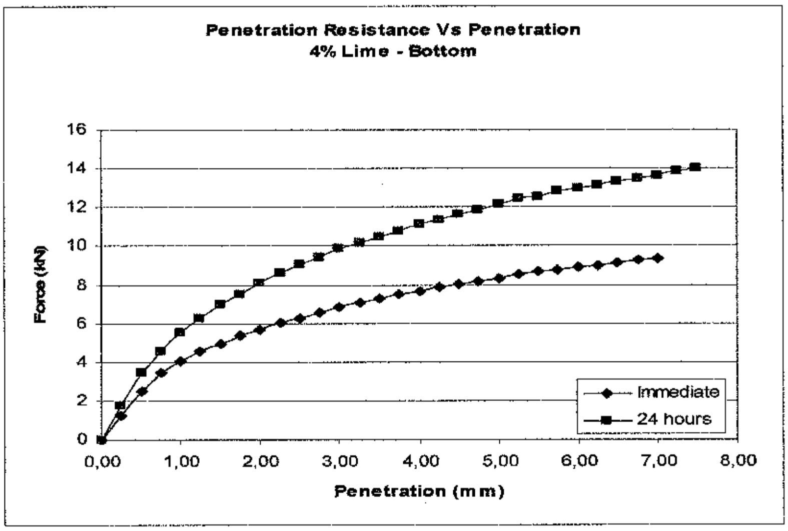

(b)

Figure C.3 (a)&(b). Penetration Resistance vs. Penetration Plot for 6% Lime