EVALUATING SUITABLE SOIL STABILIZATION METHOD FOR LOCAL ROAD CONSTRUCTION INDUSTRY

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(09/8060)

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DECLARATION

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ABSTRACT

There has been a rapid development in infrastructures in Sri Lanka since early 90s. Roads and related constructions are the major components of infrastructure development. Due to this construction boom, there is a heavy demand to the construction materials. Availability of natural resources is not sufficient to satisfy demand of the industry. Due to this reason there is a scarcity of good quality natural recourses like soil, metal etc. As a result of this scarcity, many road projects have been delayed in completion and costly.

Soil can be identified as one of the major construction material in road constructions. To overcome the dearth of suitable soil for construction, soil modification should be done in major scale. Soil stabilization is a well known soil modification method, commonly used in developed countries. But, soil stabilization is not popular technique in Sri Lanka. The aim of this research is to evaluate the suitable soil stabilization methods for local road construction industry.

To determine the real reasons for invisibility of this technology in Sri Lanka, questionnaire survey was done among the professional in the industry. Further, selected sandy clay soil with unsatisfactory engineering properties were used for the investigations. Extensive lab and field tests were conducted to examine the effect of mixing, mixing time and stabilizer type, delay compaction to evaluate the performance of stabilized soil. When consider the availability and suitability of the stabilizers, Cement and Lime are the most appropriate stabilizers for local conditions. Strength variation of cement and lime stabilized soil with the mixing time and degree of pulverization were determined. It was found that, degree of pulverization is a critical factor should be considered in the stabilization. Further, blending action is more effective than rolling action in soil mixing with stabilizers.

Influence of compaction delay was another important factor in soil stabilization. It was found in this study that the soil-stabilizer mixing should be done in dry condition and compaction should be done at the relevant optimum moisture content of the mixture at the time of compaction, for the maximum compressive strength. Finally, cost evaluation was carried out to compare the transport sub base material and soil stabilization. As the results of cost comparison, soil stabilization is most suitable for the soil which have properties just out from the specification.

DEDICATION

To My Dear

Father, Mother, Brother, Sister and my wife

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H.M.S.M. Herath

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CHAPTER 01

INTRODUCTION

1.1 General

After the Second World War, there was a rapid development in most technical fields. In the Civil Engineering Field, there were many innovations and technological developments in each and every section including Road and Building constructions.

Mainly in the late seventies, major scale of infrastructure development projects were started in Sri Lanka. At the beginning of this development projects, availability of the construction materials were not a major problem. But as a result of rapid infrastructure development in all over the country, presently there is a shortage of some construction materials like good quality soil and aggregate. Due to this scarcity of good quality materials, construction field has been faced severe problems like low quality, project delaying and cost increasing etc.

Road construction is a major industry of the local infrastructure field. There are several of ongoing road construction projects in every province, including few highways. Most of these projects are widening or new constructions projects. Therefore good quality soil demand is high and it has become the major problem in some provinces.

Soil stabilization has been used widely in developed countries to overcome scarcity of quality soil in past. Soil stabilization can be defined as any treatment applied to the soil to improve its strength and reduce its vulnerability to water. Mainly, there are two types of stabilization; Mechanical stabilization (granular stabilization) and admixture stabilization (blend with cementing materials such as cement, lime fly ash) etc. Soil stabilization has been used in Sri Lanka for certain roads in experimental level but the agencies have not adopted it as a method of road construction. Therefore, through this study, attempt to evaluate the suitability of soil stabilization methods was made local road construction industry.

1.2 Objectives

The main objectives of the research are

To evaluate the suitability of soil stabilization method for local road construction industry

To review suitable soil stabilization selection criteria

To develop a soil stabilization methodology for local road construction industry

1.3 Significance of the research

Soil stabilization is not commonly used in Sri Lanka. Various reasons cause to invisibility of this method in local construction sector. Therefore, it is very important to find out the reasons for non popularity of this technology.

Further, specifications which are used in local industry do not provide broad guideline to stabilizer selection. Under this study, analyse the stabilizer selection criteria found in the literature. Furthermore, degree of pulverization and mixing time are important parameters in soil stabilization. There have been few studies, which focused on these parameters. The effectiveness of degree of pulverization and mixing time for property of stabilized soil were considered in this study.

Effect of delayed compaction is a one of major factor should be considered in soil stabilization. As a part of this research, a series of laboratory tests were conducted to determine the effect of delayed compaction and moisture content on the stabilization.

In addition to laboratory investigations, field performances of stabilized soil were determined by the aid of pavements constructed using stabilized soil. As the final step of the study, cost evaluation was carried out to compare the cost effectiveness of this technology.

This research attempts to provide evaluation of suitability of soil stabilization method for local road construction industry.

1.4 Scope of the report

This thesis consists of seven chapters.

First chapter presents an introduction of the study with importance of soil stabilization as a technology to minimize scarcity of good quality soil.

Second chapter provides literature on historical background, soil stabilization methods and stabilization action, performance of stabilized soil, new invented stabilizers and current practices of soil stabilization.

Third chapter explains the methodology for questionnaire survey, laboratory scale investigation, field investigation and cost analysis for soil stabilization technology.

Fourth chapter presents investigation results obtained through laboratory, field tests and questionnaire survey.

Fifth chapter presents the analysis of investigation results obtained through questionnaire survey, laboratory and field testing.

By the sixth chapter, discuss about the cost comparison between stabilized soil and conventional subbase material.

Chapter seventh presents the conclusion and recommendation.

CHAPTER 02

LITRATURE REVIEW ON SOIL STABILIZATION

2.1 General

Soil stabilization is the alteration of the property of locally available soil to improve its engineering properties, such as strength, stiffness, compressibility, permeability, workability and sensitivity. In other words stabilization of soil, means limitation or removal of unacceptable soil properties. (Emilijan, Mladen , 1990) .This technique was used in nearly 2000 years ago in Romans in road construction.(Mallawarachchi, 1992)

Stabilization techniques can be divided into different categories mechanical, admixture (cement, lime, asphalt, chemical compound or combination of those), electrical or thermal based on the methodology / stabilizer used (Nagih and Samadi, 1995). Application of the stabilizer type is based on the original properties of soil to be stabilized. Both the advantages and disadvantages are together with each type of stabilization. The most common improvements which can be achieved through the stabilization are better soil gradation, reduction of plasticity index or swelling potential, and increases in durability, and strength. Further, structural layer coefficient can be increased using stabilization. Structural layer coefficient of natural subbase is taken as 0.1 and lime or cement stabilized layer 0.18. (AASHTO Guide for design of pavement structures,1993). Therefore, in the pavement designing, layer thicknesses of the soil layers can be reduced using stabilized soil pavements.Strength of the stabilized soil is depended on the type of stabilizer, the content of the stabiliser, degree of compaction, moisture content, the chemical composition of the material to be stabilised, degree of mixing the material with the stabiliser and subsequent external environmental effects.

2.2 Method of Stabilising

According to the original properties of soil, stabilization methods are varied. Further, for each stabilizer, stabilization mechanism is different. Mainly, stabilization can be divided into two categories; Mechanical stabilization and Admixture stabilization. Under admixture stabilization cement, lime, bitumen and other types of stabilizers (which strength gaining through chemical reactions) are categorized. The mechanism of strength gaining is varied from stabilizer type. Figure 2.1 shows the stabilization methods commonly available in literature.

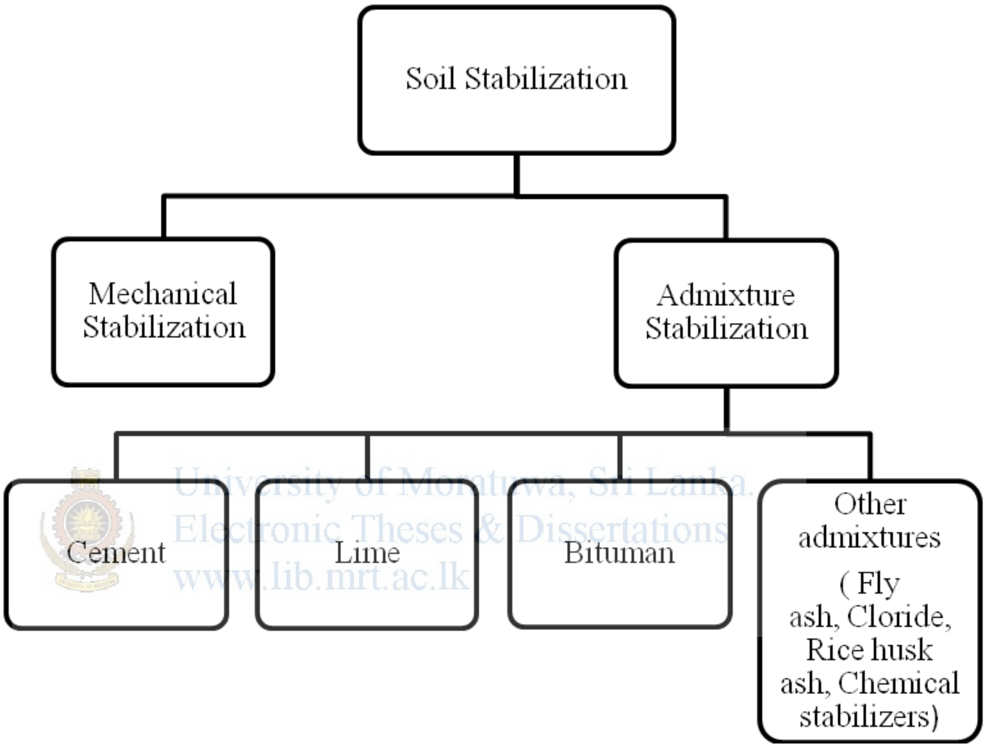


Figure 2.1 : Methods of Stabilization

2.2.1 Mechanical Stabilization

Mechanical Stabilization is also known as “Soil – Aggregate Stabilization” and “Granular stabilization” (Flaherty C.A.2006). The aim of mechanical stabilization is achieving dense homogeneous mass when compacted through improving the gradation of raw soil. Here, the physical properties of the soil will be changed.

Mechanical stabilization is accomplished by mixing two or more soil with various gradations to obtain specified properties.

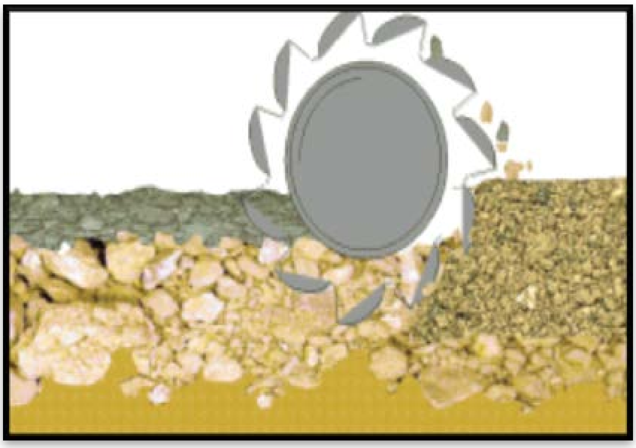


Figure 2.2: Mechanism of granular stabilization

Estimation of blending proportions is a trial and error process. Gradation and plastic properties are the important factors in soil blending. Equations 2.1 – 2.2 provide guideline to determine the initial proportions of blending, to give desired plasticity index (Flaherty, C.A, 2006)

$$a = 100S_B\,(P-P_B)/\,[(S_B(P-P_B)-S_A(P-P_A)] \quad \text{.................. Eq. 2.1}$$

$$b = 100 - a \quad \text{.................. Eq. 2.2}$$

a - Amount of soil A in the blended mix (%)

b - Amount of soil B in the blended mix (%)

P- Desired Pi of the blended mix

P_A- PI of soil A

P_B- PI of soil B

S_A- Amount of soil A passing the 425 micron sieve (%)

S_B- Amount of soil B passing the 425 micron sieve (%)

The maximum density grading is given by Fuller’s law (Flaherty, C.A, 2006)

$$P=100(d/D)^{n} \quad \text{.................. Eq. 2.3}$$

p- Percentage by weight of the total sample passing any given sieve size

Aperture of that sieve (mm)

D- Size of the largest particle in the sample (mm)

n- An exponent between 0.33 and 0.5

The proportion of material added to the soil, usually 10% to 50%. Mix in plant, travelling plant and stationary plant methods are normally used in mechanical stabilization. The main advantage of this type of stabilization is low cost. Major applications of the mechanically stabilized soils are,

Unsealed surface courses, road base and subbases of lightly trafficked roads

Subbases and road bases in single carriageway roads with bituminous surfacing

Subbases and capping layers in heavily trafficked roads. (Flaherty, C.A, 2006)

2.2.2 Admixture Stabilization

Rather than changing the physical properties of the materials, chemical reactions are the strength gaining mechanisms of admixture stabilization. Cement, Lime and Bitumen are the most popular chemical stabilizers in the road construction industry. In addition to those stabilizers, fly ash, chlorides, rice husk ash and other cementation mixtures are also used in minor scale.

2.2.2.1. Cement Stabilization

The first controlled soil- cement mixture was used in road construction in 1915 (Dallas et al, 2000). Cement stabilization is the most common method which use in the industry due to availability in most countries, availability of more technical information, less care respect to other stabilizers and provision to use with wide range of soil. Gradation and plasticity index of the soil are the most important parameters that should be considered in cement stabilization. It is not economical to use cement as stabilizer for heavy clays.

Cement stabilized materials fall into two categories Soil cement and cement modified soil. Soil cement is a mixture of pulverized soil material and aggregate, measured amount of Portland cement, and water that is compacted into high density. Cement treated aggregate bases and recycle flexible pavement are known as soil-cement product. Cement modified soil is a mixture of soil or aggregate with a small amount of cement (less proportion). Cement modified soil is used to improve subgrade soil (Dallas et al, 2000).

In the soil cement stabilization, moisture content of mixture is a critical factor influence to the dry density and unconfined compressive strength. Therefore, stabilization process should be carried out at the optimum moisture content. Further, by increasing the cement content of the mixture, higher compressive strength can be obtained. Unconfined strength increase lineally with the cement content as shown in figure 2.3

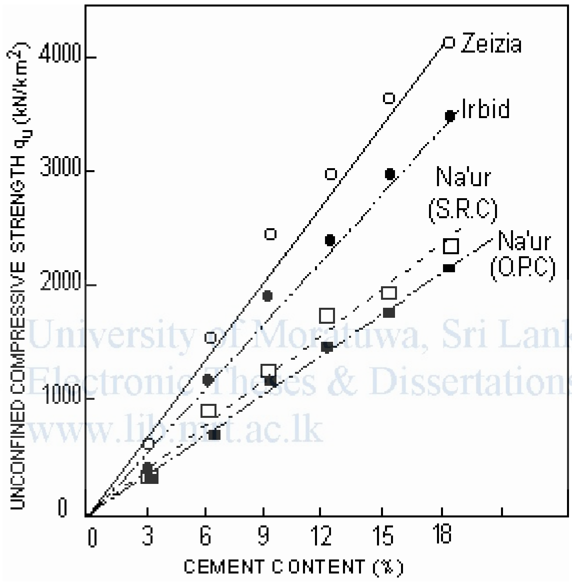


Figure 2.3: Effect of cement content on the unconfined compressive strength (Rawi and Samadi, 1995)

Reactions in cement stabilization

Dry soil + Cement + Water ⟶ Calcium Silicate + Calcium Aluminate Hydrate + Hydrated Lime

As a result of above primary reaction, calcium silicate and calcium aluminates hydrate bind soil particles together. This reaction takes short time and therefore immediately soil gains significant strength. The hydrated lime will be entered to secondary reaction to further inter particle bonding by react with any reactive elements in first reactions. Further, there is a reaction with cation of soil to reduce the plasticity of soil.

Strength of cement stabilized soil

The strength of cement stabilized soil is depend on the chemical composition of the material to be stabilised, the stabiliser content, the degree of compaction achieved, the moisture content, the success of mixing the material with the stabiliser, subsequent external environmental effects. Further, it is directly proportional to the amount of cement admix. Normally strengthening period is very long for the cement stabilized soil.

Stabilizer Amount

Determination of optimum cement content for the stabilization is a trial and error method (Soil Stabilization Pavements, 2004). But In practice, it is usually less than 5 %.

Cement stabilized soil could be used as subgrade capping layers and subbase layers in major road pavements and Subbases and road bases in secondary roads.

Note – It is never use as a surface cause due to poor resistance to the abrasion.

2.2.2.2 Lime Stabilization

Lime was used in road construction as a stabilizer in early roman roads (Flaherty C.A, 2006). There are few types of lime can use as a stabilizer, such as hydrated high calcium lime, $Ca(OH)_2$ and calcitic quick lime. Lime can be used in both dust and liquid form to mix with soil. Main differences between lime and cement stabilization are the nature and rate of lime soil reaction. Further, it is not advisable to use lime with cohesionless or less cohesive soil.

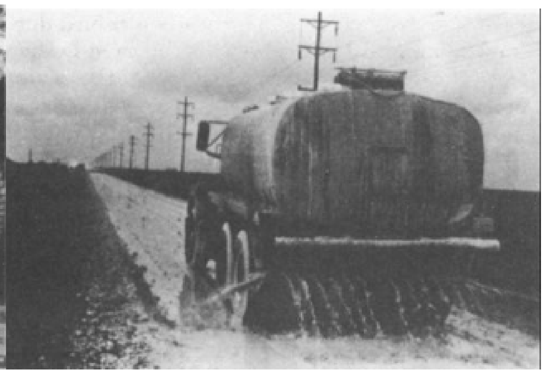


Figure2.4: Spreading of quick lime   Figure 2.5: Spreading of Lime slurry

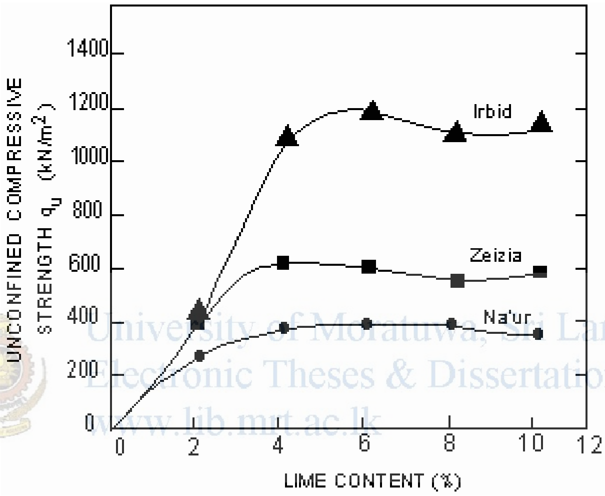


Figure 2.6: Behaviour of UCS with Lime Content (Rawi and Samadi, 1995)

Reactions in lime stabilization

1. Cation Exchange: This process is immediately take placed and caused the individual clay particle to change from a state of mutual repulsion to mutual attraction. This has immediate positive effect on promoting flocculation of the particles and a change in soil texture. Therefore, cation reaction improves the gradation, handing properties and permeability of soil.

2. Pozzolonic reaction; Pozzolonic reaction is slower than cationic reaction and form cementations products that have long term strength, volume stability and resistance to frost action in stabilized soil.

3. Carbonation: This is a reaction between carbon dioxide from air and rain water with free calcium, magnesium oxides and hydroxides is known as carbonation. This causes to lower strength in soil lime mixture. Therefore, long intensive mixing and long term processing to be avoided if high strength gain is objected.

Strength of Lime stabilized soil

In general, the early strength (first 7 day) gaining occurs quickly (low speed than cement) and after that increases more slowly until finish free lime. Further, curing time and curing temperature also affect to the strength of lime stabilized soil. (Techniques to Improve Local Materials for Rural Road Pavements in Cambodia , 2008).

Stabilizer Amount

Minimum lime amount for stabilization is varied for different type of soil, according to their properties. There is a standard guideline provided by American Society for Testing and Materials (ASTM D6276-99a) to estimate the minimum lime requirement to stabilization (National Lime Association, 2004).
Lime stabilized soil use as a subbase and subgrade in roads pavements and base stabilizer in new roads. Note- It is never use as surface cause due to the dust generation.

2.2.2.3 Bituminous Stabilization

Emulsion, hot bitumen and cutback bitumen could be used in soil stabilization. When considering the stabilization mechanism, it is totally deferent from cement and lime stabilization. The basic mechanism is waterproofing phenomena in fine grain soil. The bitumen coated soil particles or soil agglomerates decrease the water penetration and it prevents the strength loss from the soil. The second mechanism is adhesion, bitumen acts as glue between the soil particles. Shear strength of soil is increased due to this action.

To obtain expected results from bitumen stabilization, bituminous materials should be thoroughly, uniformly mixed at the higher temperature and allowed sufficient time after mixing and before compacting to aerate properly.

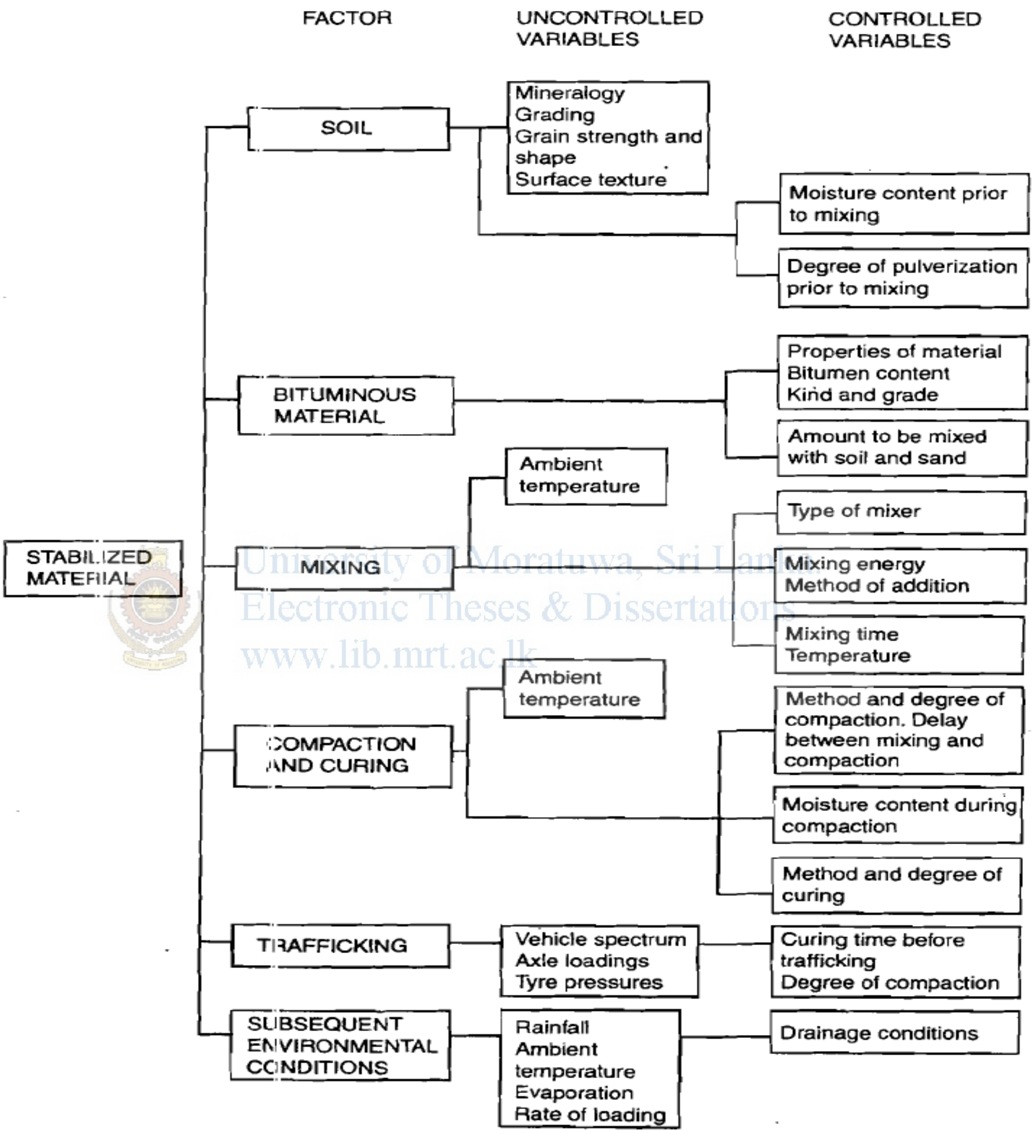


Figure 2.7: Factors affecting the design and behaviour of bitumen stabilized material (O'Flaherty -2006)

2.2.2.4. Other stabilizers for soil stabilization

Coal fly ash stabilization

Fly ash is a product of combustion of bituminous. Anthracite and lignite coal are pozzolonic but not self cementing. To produce cementations products cement or lime activator should be added. By burning low sulphur coal, self cementing fly ash could be obtained.Fly ash is a pozzolanic material, consisting mainly of silicon and aluminum compounds that, when mixed with lime and water, forms a hardened cementitious mass capable of obtaining high compressive strengths . Therefore, lime and fly ash mixture can often be used successfully in stabilizing granular materials having few fines since the fly ash provides an agent with which the lime can be reacted. In addition to lime and fly ash, a small amount of Portland cement is also added to accelerate and increase strength gain

Chlorides

Sodium Chloride (NaCl) and Calcium Chloride ($CaCl_2$) are the most common chloride types which are used in unsealed granular stabilized pavement. For the best results chlorides should be added with mechanically stabilized pavement. Further, chloride filtering to the bottom part of the pavement should be prevented. The hygroscopic and deliquescent properties of the chloride are act major role in soil stabilization. Due to hygroscopic behaviour, chloride absorbs water from the air and due to deliquescent dissolve in moisture. Due to these properties chloride can maintains a dust free surface of unsealed gravel road by absorbing water from the atmosphere.

Rice husk ash (RHA) stabilization

Rice husk is an agricultural waste obtained from milling of rice. Ash has been categorized under pozzolana, with about 67 – 70 % silica, about 4.9% aluminium oxide and 0.95% iron oxides. (Oyetola and Abdullahi, 2006). When increase the rise husk ash percentage in soil ash mixture maximum dry density is decreased due to the lower density of RHA. (Osula 1991) . Further, there is an increase of the OMC with increase of RHA content. (Ola 1975, Osinubi 1999 and Musa 2008). The influence of RHA content for the MDD, OMC, soaked and unsoaked CBR,

Unconfined Compressive Strength are shown in following figure 2.8, 2.9 and 2.10 respectively.

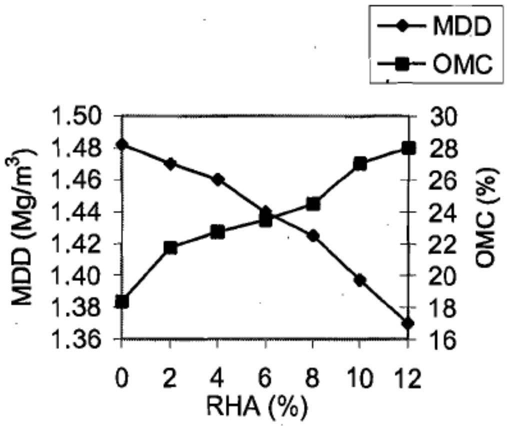


Figure 2.8: Variation of MDD, OMC (Musa, 2008)

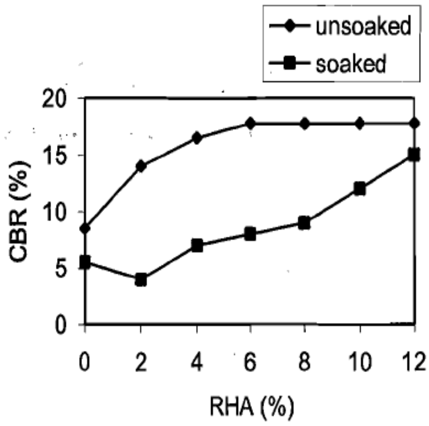


Figure 2.9: Variation of CBR with RHA Content (Musa, 2008)

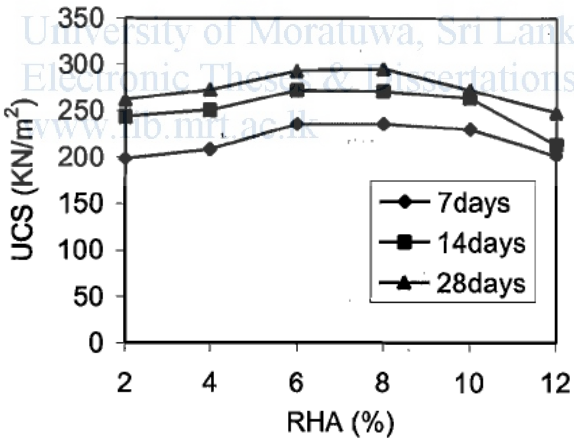


Figure 2.10: Variation of UCS with RHA (Musa -2008)

Quarry Dust Stabilization

Quarry dust is a by product of metal crushers widely use in the construction industry. Quarry dust is commonly used India as a soil improving agent (Soosan 2005). Further, it has been found that quarry dust with cement provide higher improvement of engineering properties of unsuitable soil (Priyankara et al. 2008). But the influence of small percentage of quarry dust is minimum for the CBR. (Soaked as well as Unsoaked). Figure 2.11 and 2.12 presents the MDD, OMC variation and CBR variation with the quarry dust percentage respectively

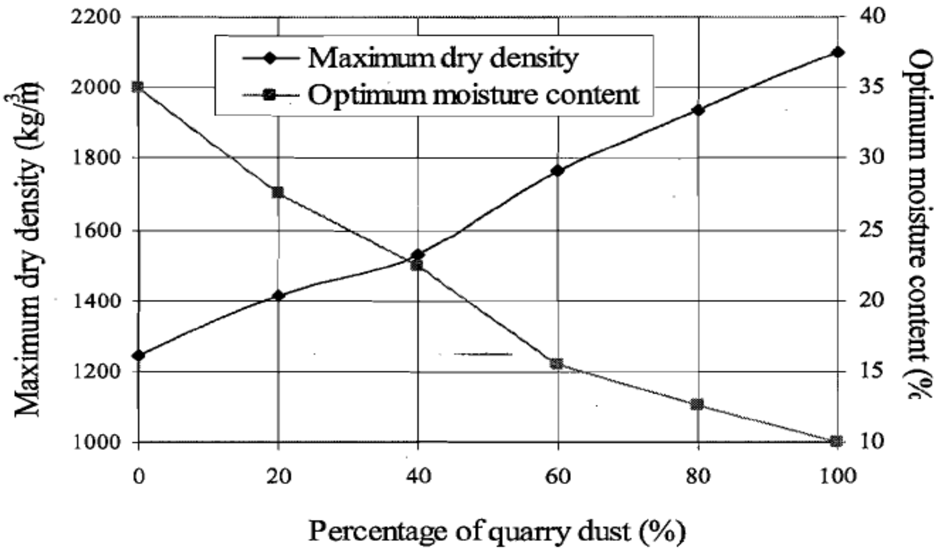


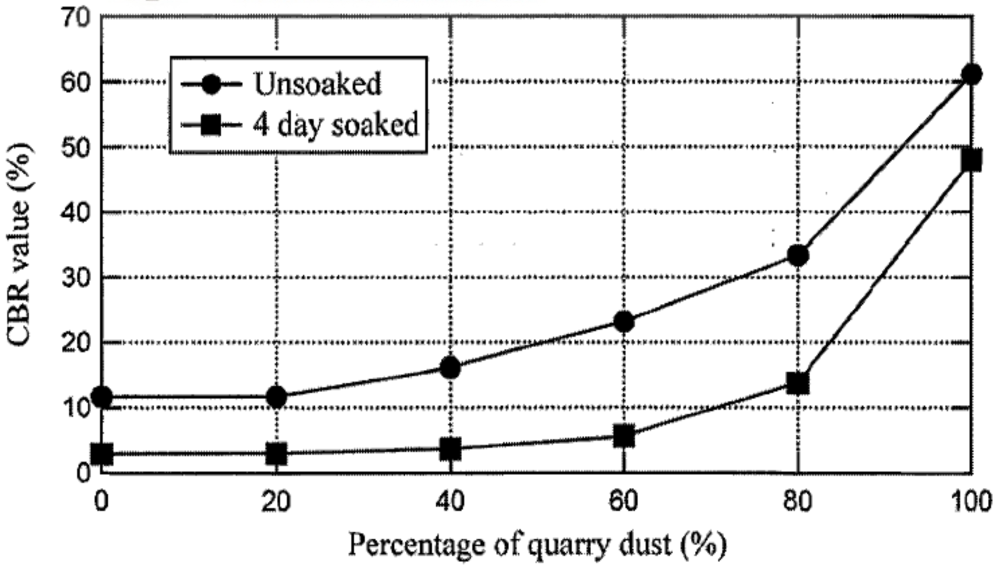
Figure 2.11: Variation of MDD, OMC with Quarry dust percentage of Soil – Quarry dust mixture (Priyankara et al.,2008)

Figure 2.12: Variation of CBR with different percentages of quarry dust (Priyankara et al.,2008)

2.3 Local experiments and experience in soil stabilization.

In Sri Lanka, stabilized soil has been used in road construction since early 1970s (Mallawarachchi, D.P, 1992). Research and Development Division of Road Development Authority is the leading organization which carried out researches on soil stabilization and test road sections.

Lime is mainly used in researches in Sri Lanka because of it has been found that most of soil except coastal and beach sand and peat soil can be stabilized with lime (Mallawarchchi, D.P 1992). In Negambo area 2km length of road has constructed using lime stabilized soil, In 1981, 100m section of Yaggalpitiya Uyandana (in Kurunegala area) road has surfaced using soil lime mixture. Few sections of Palavi-



Kalladi and Kohuwela- Papiliyana road were constructed with lime stabilized soil.

Cement soil stabilization also has been used in few instances in road construction. Approach road at Puttlam cement factory and section of Kohuwela Pepiliyana road are few experiences in soil cement stabilization. Recently in Putlam Padeniya road, cement stabilized soil has been used in shoulder construction in few areas. In 1970 at Angulana area road section was constructed using bitumen stabilized soil. Further, few road sections has been constructed with mechanical stabilized soil in Sri Lanka (Ceremonial Pathway at Katharagamab,Bangadeniya – Anamaduwa Road).

In addition to researches and road sections mentioned above, there may be few applications of soil stabilization in Sri Lanka. Due to the unavailability of proper documentation, it has been difficult to collect those data for studies.

2.4 Studies on Degree of Pulverization of Soil in Stabilization.

Soil Pulverization is an important parameter which should be considered in the soil stabilization. But only few studies have been done on this topic. Ilukner Bozbey and Sanan Garaiisayev have done few studies in 2009 on effect of soil pulverization quality on lime stabilization. Furthermore few studies have been done by Petry and Little in 2002, and Petry and Wohlegemuth in 1988. They have concluded that degree of pulverization is an important parameter in chemical stabilization.

Variations of Optimum Moisture Content with the various lime percentages which obtained by Ilukner are shown in figure 2.13. (Ilukner & Sanan, 2009). Further, Figure 2.14 and 2.15 present the variation in strength values for different pulverization qualities with 6% and 9% lime addition respectively. Here, soil pulverization has defined as good, average and poor.

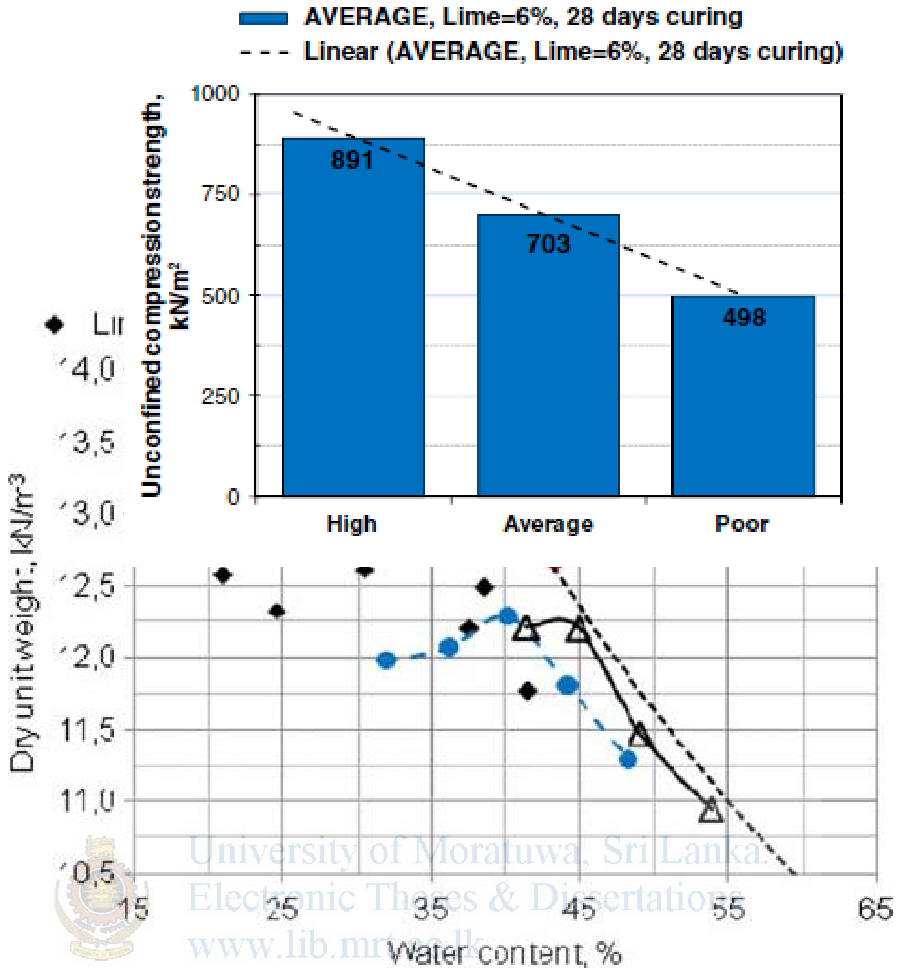


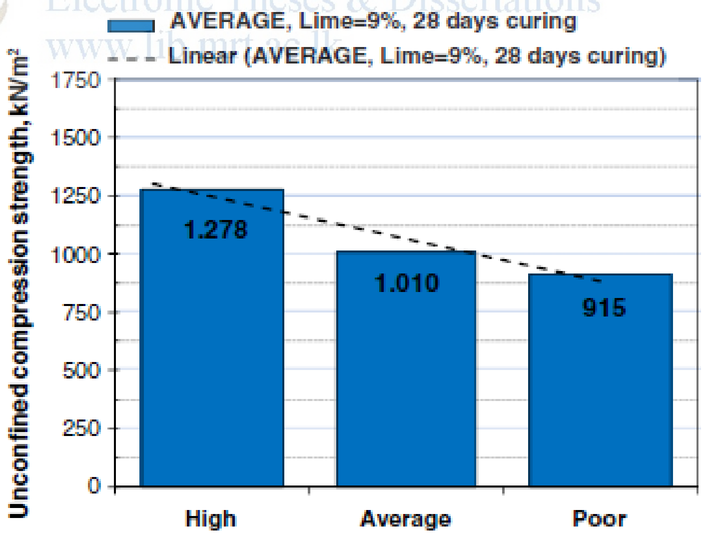
Figure 2.13: Compaction curves for natural and lime stabilized soil (Ilukner & Sanan, 2009)

Degree of Pulverization

Figure 2.14: Variation of UCS with Degree of Pulverization 6% Lime (Ilukner and Sanan, 2009)

Degree of Pulverization

Figure 2.15: Variation of UCS with Degree of Pulverization 9% Lime (Ilukner and Sanan, 2009)



CHAPTER 03

METHODOLOGY

3.1 Questionnaire Survey

3.1.1. General

Soil stabilization is a very popular technology in developed countries. In Sri Lanka this technology has been used in laboratory research and minor construction for more than 40 years (Mallawarachchi, D.P. 1992). However, this technology is not use in local industries as a common practice. Specially, in road construction industry soil is a major construction material. In a high demand situation like present condition, professionals in the industry do not promote to use stabilized soil. Therefore, as the first step of the methodology, carried out a questionnaire survey. The main objectives of the questionnaire survey was find out the factors which have been affect to the non popularity of soil stabilization in local road construction industry.

The questionnaire survey is a set of questions given to a sample of people to gather information about the people's attitudes, thoughts, behaviours, and so forth. Then the authors have compiled the answers of the people in the sample in order to know how the group as a whole thinks or behaves. Followings are the main advantages of questionnaires survey.

Easy to analysing

Participants have to answer same questions and in most questions answers have to be selected from given. Therefore, variation of answers is very low compare with the descriptive questions.

Reduce bias

There is uniform question presentation and no middle-man bias. The researcher's own opinions will not influence the respondent to answer questions in a certain manner. There are no verbal or visual clues to influence the respondent.

Less intrusive than telephone or face-to-face surveys

There is enough time to complete the paper and no any interrupting from the researcher.

Familiar to most people

Nearly everyone has had some experience completing questionnaires and they generally do not make people apprehensive.

Cost effective

Questionnaires are very cost effective when compare with the face to face or telephone conversation.

3.1.2 Selection of the survey sample

People who respond to the questionnaires are known as survey sample. The results obtain by analysing the questionnaires are definitely based on the survey sample. This questionnaire survey was mainly focused on road construction industry. The survey sample was selected from the professionals who directly engaged with road construction to collect more detail about the present status of the road construction industry. Therefore, survey sample has consisted of Road Engineers and Technicians.

3.1.3 Preparation of questions

At the beginning of the questionnaire paper, basic details of the respondent have been included. (Ex. Name, Designation, Experience in road construction industry etc). Then some questions have been included to find out the usage of soil, supplying method and distance to the borrow pit, storage time prior to the use in construction in their projects. Next questions were based on the engineering properties of available soil and specified soil. At the end, questionnaire was consisted of the questions which related to soil stabilization. Sample survey form is attached in APPENDIX A.

3.2 Review of stabilizer selection criteria.

3.2.1 General

Stabilizer selection is a most important and critical factor in the stabilization process. As mentioned in earlier chapter (Chapter 2) there are various types of stabilizers for soil stabilization. The effect of stabilizer on a specified soil is depended on the stabilizer type. There is no opportunity to achieve target results with every type of stabilizers. To overcome this problem, previous studies have introduced several guidelines for stabilizer selection, based on the original properties of the soil. Details of the guidelines are given in section 3.2.2- 3.2.4.

3.2.2 Overseas Road Note 31 guideline

Overseas Road Note 31 is a guide to the structural design of the bitumen surfaced road in tropical and sub tropical countries and published by the overseas centre of Transport Research Laboratory (TRL). Further, these guidelines are based on the research conducted by the TRL in the tropical countries.

3.2.3 US Army Guideline

This guideline is introduced by the department of the army, the navy and the air force in USA by publication named “Soil Stabilization for Pavements”.

3.2.4 Flaherty Guideline

C.A. Flaherty, pavement engineer has introduced method for stabilizer selection based on his experiences and technical detail. This guideline has been mentioned in the “HIGHWAYS” text book written by C.A. Flaherty.

3.3 Selection of soil for the study

When selecting the soil for the study, soils with marginally out of properties were specially considered. As the first step of the stabilizing procedure; original properties of soil were checked. As specified in ICTAD standard specification for road and bridge maintenances liquid limit ,plasticity Index, maximum Dry Density and California Bearing Ratio (CBR) soaked and sieve analysis were checked for all three soil types. Following table 3.1 presents the original properties of soil used for the study.

Table 3.1: Original Properties of soil used for study

Soil Type	LL %	PI %	CBR% (Soaked)	AASHTO-Soil Classification
1	45	16	12	A-2-7
2	58	17	22	A-2-7
3	63	18	18	A-2-7

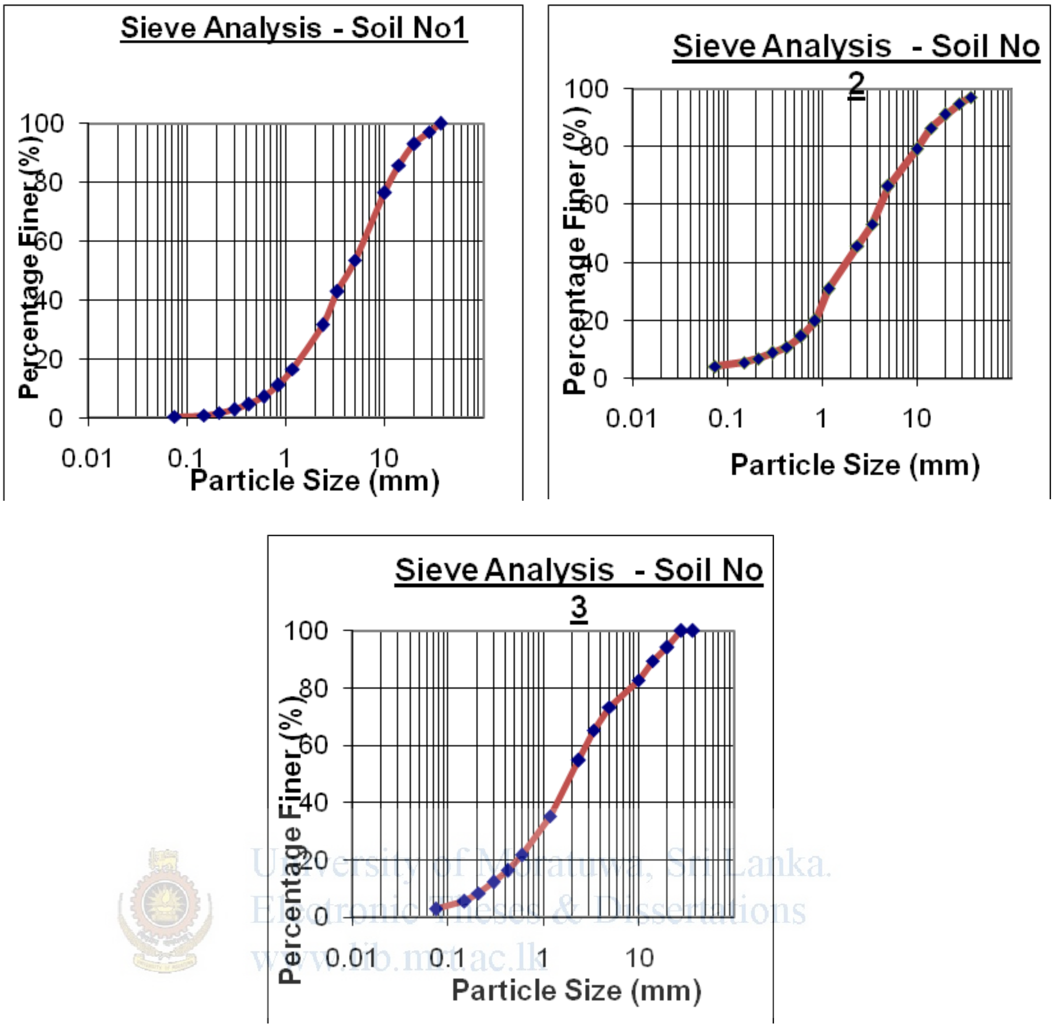


Figure 3.1: Sieve Analysis of soil used for the study

According to the original properties of 3 soil types as shown in table 3.1, those soil not comply with the specification. Further, when evaluate the stabilize selection by three guidelines cement and Lime are suitable for stabilizing above three soils.

3.4 Laboratory Tests

3.4.1 Introduction

Soil is used as subgrade, Embankment, subbase, shoulder materials and base materials (rarely) in road construction. The required standard for each case varies according to the specifications which use in the industry. Specification published by the Institute for Construction Training and Development (ICTAD) is the widely used standard for construction and maintenance of roads and bridges in Sri Lanka. The summary of the required properties of original soil and stabilized soils in the ICTAD specification are given in Table 3.2and .3.3.

Table 3.2 - Requirements of Embankment Material

Property	**Embankment Type 1**	**Embankment Type II**
Liquid Limit (LL)	Not Exceed 50%	Not Exceed 55%
Plastic Index (PI)	Not Exceed 25%	Not Exceed 25%
Maximum Dry Density (Modified)	Not less than 1,600 kg/m3	Not less than 1,500 kg/m3
4 day soaked CBR at 95% MDD (Modified)	Not less than 7%	Not less than 5%

Table 3-3 -Requirements of Upper Sub bas

Property	**Upper Subbase**	
	Flexible Pavement	**Rigid Pavement**
Liquid Limit (LL)	Not Exceed 40%	Not Exceed 25%
Plastic Index (PI)	Not Exceed 15%	Not Exceed 6%
Maximum Dry Density (Modified)	Not less than 1,750 kg/m3	
4 day soaked CBR at 95% MDD (Modified)	Not less than 30% Not less than 5%	

Evaluate the suitability of original soil, following tests have been conducted.

Table 3.4 – Standard tests for soil property determination

Test Name	**ASTM Standard No.**
Sieve Analysis	D 422 - 98
Liquid limit	D 4318 -00
Plastic Index	D 4318 -00
Optimum Moisture Content	D 1557 -00
Maximum Dry Density	D 1557 -00
California Bearing Ratio	D 1883 -99

According to the results obtained by above tests it was found that properties are not complied with the specification. Therefore that soil was used for the stabilization. (Test reports are attached in Appendix B)

Specified properties for stabilized soil as a subbase are presented in the table 3.5.

Table 3.5 – Properties of stabilized soil (Subbase)

Property	**Upper Subbase**
Liquid Limit (LL)	Not Exceed 40%
Plastic Index (PI)	Not Exceed 15%
Maximum Dry Density (Modified)	Not less than 1,750 kg/m3
Unconfined Compressive Strength	750 -1500kN/m2

3.4.2. Determination of the optimum percentage of stabilizer.

Soil – Lime mixing

Standard test method of ASTM 6276 can be used to determine the optimum lime amount for stabilization. This test method provides the optimum soil-lime proportion for stabilization of a soil. This test is performed on soil passing 425-μm sieve. A series of specimens is prepared with various amount of lime percentages. pH value of the soil lime slurries were checked to determine minimum lime content of the soil-lime mixture to obtain the pH value of 12.4. The lime content which shows the 12.4 pH value is known as the minimum lime amount for stabilization.

3.4.3. Degree of Pulverization

Degree of Pulverization (DOP) of soil is one of the most important factor effects to the mixing quality with stabilizer. The standard test method to determine the DOP is given in BS 1924 -2. As described in the BS 1924 – 2, testing procedure of determining of DOP as given in step 1 - 5.

Step 1 – Take 1 kg (approximately) of mixed soil sample (m_1)

Step 2 – Spread soil on 5mm sieve and shake gently

Step 3 – Determine the mass of retaining on 5mm sieve (m_2)

Step 4 – Break all lumps until separate particles individually.

Step 5 – Shake the broken sample and determine the mass of retained sample (m_3)

Degree of Pulverization of Sample,

$P = 100 (m_1 – m_2)/(m_1 – m_3)$ ------------------------------ Eq. 3.1

Where,

m_1 is the total mass of the sample (in g);

m_2 is the mass of the unbroken material retained on the sieve (in g);

m_3 is the mass of the material finally retained on the sieve (in g).

3.4.4. Unconfined Compressive Strength (UCS)

According to the ICTAD standard specification, Unconfined Compressive Strength (UCS) of stabilized soil should be checked.BS 1924 part 2 describes the test methods for determine the engineering properties of materials stabilized with cement or lime .

Test procedure

Cubic samples with 150 mm * 150mm *150 mm dimensions were casted to test the compressive strength of the stabilized soil. When preparing test specimens, constant compaction energy was applied for each sample. Further, sample were compacted at the optimum moisture content in 3 layers with 35 blows for each.4.5 kg weight hammer with, 45mm squire face and 450mm controlled height was used for the compaction. Curing of samples should be done using a curing tins or air sealed containers to prevent removing water from samples. After the curing period samples were crushed at 7 days and 28 days loading rate of 2.5 – 4.5 MPa/min.

3.5 Field Tests

3.5.1. Introduction

Evaluation of applicability of laboratory findings for field condition is important in civil engineering field. Therefore, performances of stabilized soil were measured in field condition. For the mixing purpose, rotary mixture was used with 600mm (2 feet) width and 18 blades. Rotating speed was 90 rpm. Stabilized soil parameters, DOP and UCS were measured with mixing time.

3.5.2 Test Pavements

Eight test pavement sections were constructed in the university premises to test the performance of cement and lime stabilized soil. Four test sections from each were constructed with 3m (10 feet) length, 1.2m (4 feet) width and 0.15m(6 inch) thickness. Width of the pavement section was selected considering the width of the rotary used. Length was selected to be able to record the mixing time. Test pavement and mixing with stabilizer are shown in figure 3.2 and 3.3 respectively.

Figure 3.2: Test pavement

Figure 3.3 : Rotary mixing in field

To determine the optimum mixing time and DOP, various mixing cycles were used in each pavement. Further, six samples were collected from each pavement for laboratory test. DOP, UCS were checked in each sample. Compaction of test pavements was done using a plate vibrator under optimum moisture content.

3.6 Effect of delay compaction to the UCS of stabilized soil

It is found in literature (Kolawole J. Osinubi , Charles M. O. Nwaiwu, 2006), compaction time is crucial factor in strength gaining of stabilized soil. Stabilizer mixed under OMC condition and air dried condition for both cement and lime stabilizer. To determine the effect of delay compaction on UCS, compaction time was delayed up to 0 to 6 hours in both stabilizing and measured the UCS of delayed compacted sample.

CHAPTER 4

OBSERVATIONS AND RESULTS

4.1 Evaluating stabilizer selection criteria.

4.1.1 Road Note 31 method

Type of Stabilizer	Soil Properties					
	More than 25% passing the 0.075mm sieve			Less than 25% passing the 0.075mm sieve		
	PI=<10	10<PI< 20	PI>20	PI=<6 PP=<60	PI=<10	PI>10
Cement	Yes	Yes	*	Yes	Yes	Yes
Lime	*	Yes	Yes	No	*	Yes
Lime-Pozzolan	Yes	*	No	Yes	Yes	*

PP – Plasticity Product

Figure 4.1: Stabilizer selection criteria (Road Note 31,1993)

Road note 31 provides guideline for selecting Cement, Lime and Lime pozzolan as stabilizers. Further, plasticity Index (P1) and 0.075mm passing percentage are the major factors in selecting the stabilizer.

4.1.2. US Army method.

This guideline provides direction for selecting lime, Portland cement, bituminous and lime-cement-fly ash stabilizer

According to the figure 4.2, material type can be selected based on percentage of materials passing no 200 sieve and material passing no 4 sieve and retained on no 200 sieve. (Ex-Sands, Gravels etc.) Column 1, in figure 4.3 presents the relevant area of the figure 4.2. And column 2, 3 provides soil class and type of stabilizing additive recommended respectively. Column 4 and 5 provide restriction on LL& PI and percentage passing no 200 sieve respectively, for the stabilizer selection.

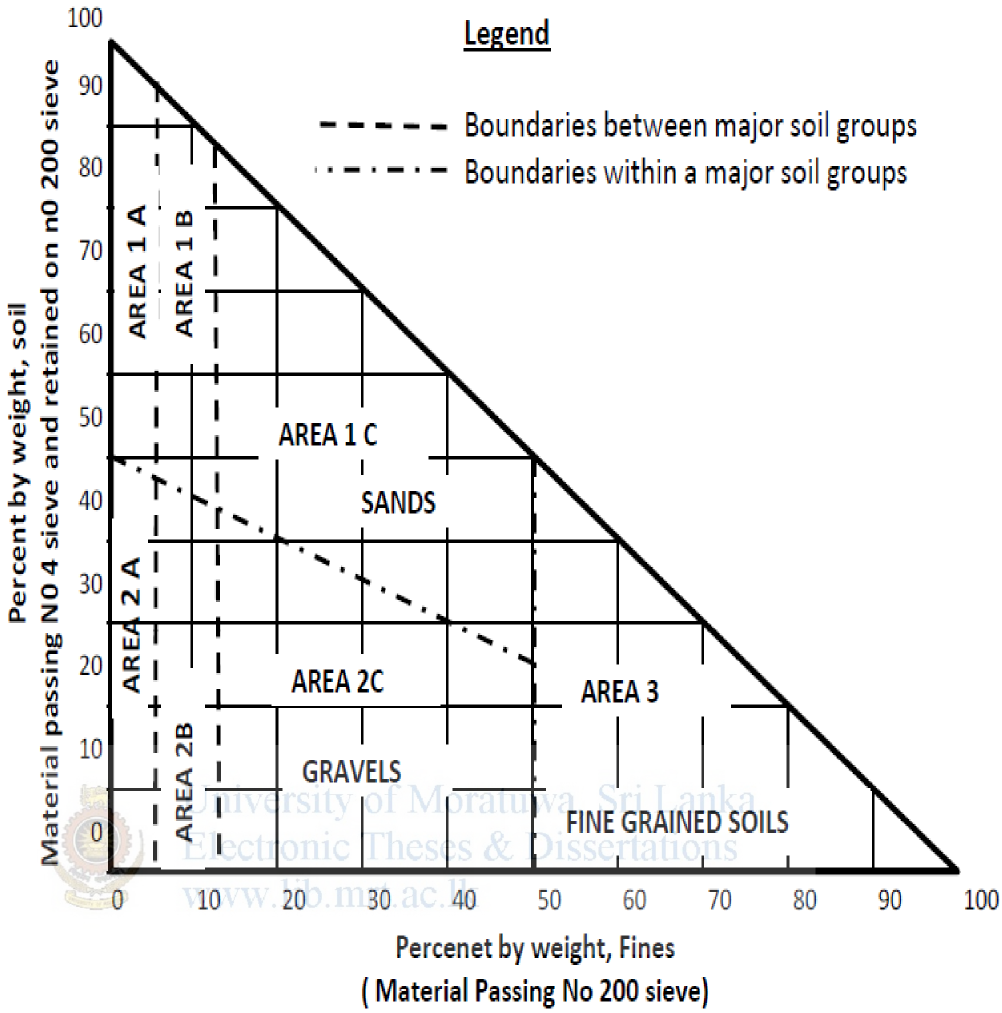


Figure 4.2: Sub group of soil based on sieve sizes (Soil Stabilization Pavements, 2004)

Area	Soil Class.[a]	Type of Stabilizing Additive recommended	Restriction on LL and PI of Soil	Restriction on Percent Passing No. 200 Sieve[a]	Remarks
1A	SW or SP	(1) Bituminous			
		(2) Portland cement			
		(3) Lime-cement-fly ash	PI not to exceed 25		
1B	SW-SM or SP-SM or SW-SC or SP-SC	(1) Bituminous	PI not to exceed 10		
		(2) Portland cement	PI not to exceed 30		
		(3) Lime	PI not to exceed 12		
		(4) Lime-cement-fly ash	PI not to exceed 25		
1C	SM or SC or SM-SC	(1) Bituminous	PI not to exceed 10	Not to exceed 30% by weight	
		(2) Portland cement	--b		
		(3) Lime	PI not less than 12		
		(4) Lime-cement-fly ash	PI not to exceed 25		
2A	GW or GP	(1) Bituminous			Well-graded material only
		(2) Portland cement			Material should contain at least 45% by weight of material passing No. 4 sieve
		(3) Lime-cement-fly ash	PI not to exceed 25		
2B	GW-GM or GP-GM or GW-GC or GP-GC	(1) Bituminous	PI not to exceed 10		Well-graded material only
		(2) Portland cement	PI not to exceed 30		Material should contain at least 45% by weight of material passing No. 4 sieve
		(3) Lime	PI not less than 12		
		(4) Lime-cement-fly ash	PI not to exceed 25		
2C	GM or GC or GM-GC	(1) Bituminous	PI not to exceed 10	Not to exceed 30% by weight	Well-graded material only
		(2) Portland cement	--b		Material should contain at least 45% by weight of material passing No. 4 sieve
		(3) Lime	PI not less than 12		
		(4) Lime-cement-fly ash	PI not to exceed 25		
3	CH or CL or MH or ML or OH or OL or ML-CL	(1) Portland	LL less than 40 and PI less than 20		Organic and strongly acid soils falling within this area are not suceptible to stabilization by ordinary means
		(2) Lime	PI not less than 12		

[a]Soil classification corresponds to MIL-STD-619B. Restriction on liquid (LL) and plasticity index (PI) is in accordance with material 103 in MIL-STD-621A.

[b] $$PI \le 20 + \frac{50 - \text{percent passing No. 200 sieve}}{4}$$

Figure 4.3: Stabilizer selection method based on soil type and LL and PI (Soil Stabilization Pavements, 2004)

4.1.3. C.A.O'Flaherty guideline.

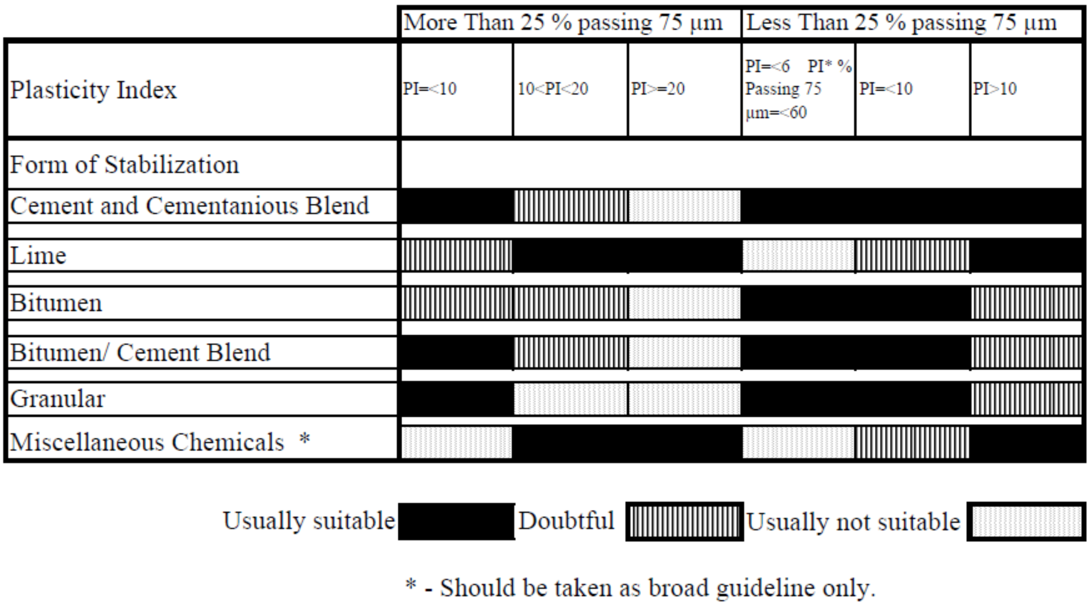


Figure 4.4: O' Flaherty guideline to stabilizer selection (O'Flaherty,2006).

C.A.O Flaherty has developed a guideline for the stabilizer selection, based on research and technical data. Lime, Bitumen, Bitumen/cement blends, Granular, cement and cementations blend and miscellaneous chemicals could be selected for stabilizing using Flaherty method. Plasticity Index (PI) and the percentage passing 0.075mm sieve are the basic factors consider in selection.

4.2 Laboratory Results.

4.2.1 Effect of mixing time on UCS and DOP

Mixing time was changed 1 minutes to 9 minutes and determined the relevant Degree of pulverization. For each mixing time, 6 cubes were tested to determine the UCS at 7 days and 28 days. Following table 4.1, 4.2 and 4.3 present the UCS value, DOP percentage with mixing time.

Table 4.1: DOP and UCS with mixing time (Soil no 1 stabilized with lime 6%)

Mixing Time (Mins)	Degree of Pulverization (%)	7 Days Unconfined Compressive Strength (kN/m^2)			28 Days Unconfined Compressive Strength (kN/m^2)		
		Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
1	74	784.0	845.0	818.8	897.2	845.0	853.7
3	85	862.4	871.1	879.8	897.2	906.0	897.2
6	80	845.0	845.0	827.6	862.4	871.1	862.4
9	78	810.1	792.7	792.1	818.8	810.1	801.4

Table 4.2: DOP and UCS with mixing time (Soil no 2 stabilized with lime 7%)

Mixing Time (Mins)	Degree of Pulverization (%)	7 Days Unconfined Compressive Strength (kN/m^2)			28 Days Unconfined Compressive Strength (kN/m^2)		
		Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
1	78	897.2	827.6	757.9	1027.9	966.9	932.1
3	79	862.4	897.2	827.6	1080.2	1036.6	1097.6
6	72	845.0	862.4	845.0	1027.9	1036.6	1019.2
9	68	845.0	836.3	845.0	1001.8	984.4	993.1

Table 4.3: DOP and UCS with mixing time (Soil no 3 stabilized with lime 7%)

Mixing Time (Mins)	Degree of Pulverization (%)	7 Days Unconfined Compressive Strength (kN/m^2)			28 Days Unconfined Compressive Strength (kN/m^2)		
		Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
1	77	706.5	670.8	688.2	897.2	853.7	862.4
3	82	792.7	766.6	775.3	888.5	906.0	871.1
6	80	731.7	723.0	731.7	810.1	784.0	801.4
9	75	714.3	714.3	731.7	749.2	740.4	740.4

Same test procedure was repeated for soil-cement mixing. Tables 4.4, 4.5, 4.6 present the behaviour of DOP and UCS with various mixing time for soil no 1, 2, and 3 respectively.

Table 4.4: DOP and UCS with mixing time (Soil no 1 stabilized with Cement 5%)

Mixing Time (Mins)	Degree of Pulverization (%)	7 Days Unconfined Compressive Strength (kN/m^2)			28 Days Unconfined Compressive Strength (kN/m^2)		
		Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
1	60	1045.3	1289.2	1284.9	1742.2	1350.2	1393.8
3	84	1237.0	1341.5	1289.2	1633.3	1568.0	1698.7
6	83	1306.7	1411.2	1332.8	1676.9	1742.2	1698.7
9	78	1184.7	1027.9	1158.6	1524.4	1480.9	1568.0

Table 4.5: DOP and UCS with mixing time (Soil no 2 stabilized with Cement 4%)

Mixing Time (Mins)	Degree of Pulverization (%)	7 Days Unconfined Compressive Strength (kN/m^2)			28 Days Unconfined Compressive Strength (kN/m^2)		
		Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
1	70	1149.9	1123.7	1071.5	1402.5	1446.0	1489.6
3	80	1176.0	1141.2	1132.4	1480.9	1507.0	1480.9
6	72	1115.0	1106.3	1080.2	1385.1	1385.1	1402.5
9	65	1010.5	1045.3	1027.9	1245.7	1263.1	1228.3

Table 4.6: DOP and UCS with mixing time (Soil no 3 stabilized with Cement 5%)

Mixing Time (Mins)	Degree of Pulverization (%)	7 Days Unconfined Compressive Strength (kN/m^2)			28 Days Unconfined Compressive Strength (kN/m^2)		
		Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
1	75	958.2	1010.5	1062.8	1393.8	1498.3	1446.0
3	82	1019.2	1045.3	1045.3	1541.9	1576.7	1559.3
6	77	862.4	879.8	888.5	1393.8	1437.3	1376.4
9	69	801.4	801.4	775.3	1298.0	1332.8	1324.1

4.2.2 Effect of Delay compaction and moisture content for the UCS.

UCS was measured by delaying the compaction of stabilized mixture. Further, delayed sample were compacted at OMC and at the prevailing moisture content. Table 4.7 and 4.8 shows the 7 days and 28 days UCS of lime and cement stabilized soil compacted at prevailing condition.

Table 4.7: UCS values of delay compacted lime stabilized under OMC

Cube No.	Delayed Time	7 Days Strength (kN/m^2)	28 Days Strength (kN/m^2)
1	Just After Mixing	862.4	1149.9
2		879.8	1115.0
3		879.8	1167.3
1	After 1 Hour	818.8	1071.5
2		801.4	1054.0
3		792.7	1045.3
1	After 2 Hour	740.4	1019.2
2		757.9	993.1
3		731.7	871.1
1	After 4 Hour	679.5	949.5
2		688.2	810.1
3		670.8	801.4
1	After 6 Hour	618.5	731.7
2		601.1	749.2
3		627.2	731.7

Table 4.8: UCS values of delay compacted cement stabilized under OMC

Cube No.	Delayed Time	7 Days Strength (kN/m^2)	28 Days Strength (kN/m^2)
1	Just After Mixing	1358.9	1559.3
2		1062.8	1585.4
3		1132.4	1515.7
1	After 1 Hour	1019.2	1341.5
2		993.1	1350.2
3		1010.5	1324.1
1	After 2 Hour	958.2	1271.8
2		932.1	1263.1
3		923.4	1271.8
1	After 4 Hour	975.6	1210.8
2		888.5	1193.4
3		923.4	1176.0
1	After 6 Hour	792.7	1001.8
2		662.0	984.4
3		740.4	949.5

OMC of stabilized soils, which had been air dried due to delayed compaction were found. Table 4.9 shows the OMC of lime and cement stabilized soil with the delayed (air dried) for compaction.

Table 4.9: OMC of air dried stabilized soil

Delay Time (Air Dried Hours)	OMC (%)	
	Cement Stabilized	Lime Stabilized
0	25.5	26
1	24	25.5
2	23	24.5
4	21	23.5
6	20	22

UCSS were obtained at the correspondent OMC for the delayed sample. UCS of delayed sample of lime and cement are shown in table 4.10 and 4.11 respectively.

Table 4.10: UCS values of lime stabilized soil compacted at OMC condition

Cube No.	Delayed Time	7 Days Strength (kN/m^2)	28 Days Strength (kN/m^2)
1 2 3	Just After Mixing	932.1 906.0 879.8	1149.9 1184.7 1210.8
1 2 3	After 1 Hour	888.5 897.2 879.8	1158.6 1123.7 1097.6
1 2 3	After 2 Hour	845.0 871.1 853.7	1062.8 1080.2 1045.3
1 2 3	After 4 Hour	810.1 836.3 845.0	1036.6 1027.9 1019.2
1 2 3	After 6 Hour	801.4 784.0 810.1	993.1 949.5 993.1

Table 4.11: UCS values of lime stabilized soil compacted at air dried condition

Cube No.	Delayed Time	7 Days Strength (kN/m^2)	28 Days Strength (kN/m^2)
1 2 3	Just After Mixing	1271.8 1254.4 1315.4	1507.0 1515.7 1489.6
1 2 3	After 1 Hour	1237.0 1219.6 1228.3	1411.2 1480.9 1446.0
1 2 3	After 2 Hour	1202.1 1141.2 1123.7	1376.4 1385.1 1376.4
1 2 3	After 4 Hour	1062.8 1036.6 1080.2	1263.1 1228.3 1237.0
1 2 3	After 6 Hour	993.1 1010.5 975.6	1184.7 1167.3 1132.0

4.3 Stabilization of soil in field condition.

In the field test, rotary tractor was used for mixing of soil and the stabilizer. The UCS and DOP were measured against the mixing cycles. Table 4.12 and 4.13 present the DOP &UCS variation with mixing cycles for both lime and cement stabilizer respectively.

Table 4.12 : UCS value of soil lime mixture (Rotary mixing)

No of Mixing Cycle	Mixing Time	Degree of Pulverization	7 Days Compressive Strength (kN/m^2)	28 Days Compressive Strength (kN/m^2)
1	0:41:00	81.5	740.4	958.2
2	1:23:39	85.6	805.8	993.1
3	2:12:16	92.2	814.5	1010.5
4	3:01:39	92.2	788.4	1010.5
5	3:26:10	92.3	805.8	966.9
6	4:28:58	92.5	766.6	1019.2
7	5:17:28	92.8	805.8	1019.2

Table 4.13: UCS value of soil cement mixture (Rotary mixing)

No of Mixing Cycle	Mixing Time	Degree of Pulverization	7 Days Compressive Strength (kN/m^2)	28 Days Compressive Strength (kN/m^2)
1	0:41:78	84.8	1733.5	1890.3
2	1:22:59	87	1742.2	1994.8
3	2:05:05	90.3	1746.6	2021.0
4	2:51:12	93.2	1750.7	2055.8
5	3:30:35	94.1	1750.9	2082.0
6	4:09:49	93.9	1742.2	2073.2
7	4:55:42	94.2	1768.4	2082.0

CHAPTER 05

ANALYSIS OF DATA

5.1 Findings of the Questionnaire Survey

40 numbers of professionals in road construction industry participated for the survey**.** Survey results shows that soil has been used as subgrade, subbase and shoulder all the projects. However, use of soil as a base material as not found in this survey. Soil has been supplied by either soil supplier or the contractor or the both contractor and soil suppliers in the projects. Percentage of supply by the soil supplier, contractor and both supplier and contractor in projects were 60%, 17.5% and 22.5% respectively. The average storage time of the soil at the site before use is 3 days.

Experience and knowledge of the soil stabilization among the professional were gathered in the survey. Table 5.1 shows the analyzed results of experience and knowledge of the professionals involved in road construction projects.

Table 5.1: Categorized surveyed sample based on year of experience and knowledge

Experience and knowledge of soil stabilization	**Experience in Road Construction (Years)**				
	0-5	**6-10**	**11-15**	**16-20**	**21-25**
Professionals with Experienced and good Knowledge of soil stabilization	1	1	4	4	4
Professionals with no Experienced and fair Knowledge of soil stabilization	8	4	2	0	0
Professionals with no Experienced and no Knowledge of soil stabilization	7	4	1	0	0
Sample Size	16	9	7	4	4

Survey result shows that soil stabilization has been used by professionals who have more than 16 years of experience. Most of the professionals with less than 16 years experience have not used soil stabilization and did not have sufficient knowledge of soil stabilization. Further survey results show that, only 35% had the soil stabilization experience and good technical knowledge. 35% had the fair knowledge without experience. Further 30 % did not have experience or knowledge on soil stabilization.

72% of survey participants expressed as the extra cost is the main reason for non popularity of this technology in Sri Lanka.55% of the participants expressed as quality controlling will be a problem in soil stabilization.

5.2.1 Evaluation Stabilizer Selection Criteria

As mentioned in chapter 3 and 4, three stabilizer selection criteria (ORN 31, US ARMY and O'Flaherty method) were considered. It can be seen that, basic parameters considered in stabilizer selection are same in all three method such as.

Sieve Analysis and

Plasticity index of the soil

Sieve Analysis

ORN 31 has been divided soil into two categories in soil stabilization (more than or less than 25 passing the 0075mm sieve). US Army method, soil has been divided in to sub section based on the, percentage passing the 0.075mm sieve and passing percentage the 4.75mm and retaining 0.075 sieve (Figure 4.2). O'Flaherty method is same as ORN 31. When consider these three guide lines, 0.075mm passing is a main factor which consider as a basic parameter in selecting stabilizer. (Simply, fine amount of the soil is important factor in stabilizer selecting)

Plasticity Index of soil

Other common factors used in the three guidelines are plasticity index of the soil. Once soil is selected based on sieve analysis, soil is further subdivided based on plasticity index. ORN 31 and 0' Flaherty plasticity limitation are same and US army provide slightly different categorization based on plasticity index.

5.2.2. Limitation of Guidelines.

It can be seen that stabilizer types used in stabilization varied in guideline. Table 5.2 shows the stabilizers used in the guidelines. It can be seen that O' Flaherty guideline provide more variety of stabilizers. US Army has used bitumen for certain soil. ORN 31 has used only cement, lime and lime pozzolan.

Table 5.2 – Limitation of stabilizer in guidelines

ORN 31	US ARMY	O' FLAHERTY
Cement	Potland Cement	Cement and Cementanoius Blend
Lime- Pozzolan	Lime – Cement – Fly ash	Lime
Lime	Lime	Bitumen
	Bituminous	Bitumen/ Cement Blend
		Granular
		Miscellaneous Chemicals

When the three guidelines are considered, 0' Flaherty method provides greater verity of stabilizers for stabilization. Most important thing is that, it provides brief guideline to select chemical stabilizers which has being popular in recent past.

5.2.3. Effect of stabilizer selection on different soil types

Table 5.3 presents the limits of soil which could be used for various applications in road construction. Table 5.4 presents the suitable stabilizers, selected from the three guideline and describe in section 5.2.1

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Table 5.3: PI limits of soil for road construction

Construction Stage	Plastic Index
Shoulders & Gravel Surfacing (Wet Zone)	4-15
Shoulder & Gravel Surfacing (Dry Zone)	6 -25
Embankment Type 1	<25
Embankment Type 2	<25
Subbase (Flexible Pavement)	<15
Subbase (Rigid Pavement)	< 6

In Road construction as well as Soil stabilization, Plastic Index (PI) is an important parameter which should be considered in stabilizer selection. Table 5.4 presents the suitable stabilizer types based on each guideline. For this explanation, soil types were selected based on the Plastic Index which suitable for different construction stages in road construction. Table 5.4 shows that lime is the common stabilizer for soil with high PI (26% & 27%) values. All three stabilizer selection methods show same behaviour for above soil types. Further according to the all stabilizer selection method, lime is the common stabilizer for soil category with 15<PI<25 (16% and 17%). However, cement also could be used as a stabilizer at many cases in this category. But, common stabilizer could not be identified for the soil with PI value between 6 and 15 (7% , 8%). According to the RN 31 and Flaherty method cement is the common stabilizer for above soil category. Therefore, when consider the three stabilizer selection criteria RN 31 and Flaherty method indicate similar behaviour in most cases.

Table 5.4: Type of Stabilizer based on PI and Sieve Size

Plastic Index (PI)	**Road Note 31 Method**		**US Army Method**		**Flaherty Method**	
	0.075 mm Passing <25%	**0.075 mm Passing >25%**	**0.075 mm Passing <25%**	**0.075 mm Passing >25%**	**0.075 mm Passing <25%**	**0.075 mm Passing >25%**
>25 (26,27)	Cement Lime	Lime	Cement Lime	Cement Lime	Cement Lime Chemicals	Lime Chemicals
15>PI> 25 (16,17)	Cement Lime	Cement Lime	Lime Lime Cement	Lime Lime Cement	Cement Lime Chemicals	Lime Chemicals
6>PI> 15 (7,8)	Cement Lime Pozolans	Cement Lime Pozolans	Bitumen	Bitumen	Cement Bitumen Cement Bitumen	Cement Cement Bitumen Blend

5.3 Behaviour of Degree of Pulverization, Unconfined Compressive Strength with Mixing Time

It has mentioned in literature (Bozbey, Garaisyev, 2009), pulverization property of soil in stabilization is not a well researched area and only few research has been conducted on this topic. Therefore, Degree of Pulverization (DOP) with mixing time and respective Unconfined Compressive Strength (UCS) were determined as one of the objective characteristics of this research. Properties of the mixers were described in chapter 4. Pre determined amount of cement were applied on each sample and mixed using a mixture for 1, 3, 6, 9 mins. Relative DOPs, 7 and 28 days UCS were measured at sample mixed in different mixing cycle.

Results for cement stabilized soil of no 1, 2 and 3 are presented in table 5.5, 5.6 and 5.7 respectively. Column 3 and column 5 of the table present the average UCS value obtained from 6 cubes crushing at 7 days and 28 days. The standard deviation of 7 days and 28 days average UCSS are tabulated in next columns. Figure 5.1, 5.2 and

5.3 describe the behaviour of UCS (primary Y axis), DOP (secondary Y axis) with mixing time (X axis). The standard deviation is also depicted in the plot.

Table 5.5: Properties of 5% cement stabilized with soil no 1

Mixing Time (Min.)	Degree of Pulverization	AVG. Com. Strength (7 Days) (kN/m^2)	Standard Deviation (7 Days)	AVG. Com. Strength (28 Days) (kN/m^2)	Standard Deviation (28 Days)
1	60	1206.5	139.6	1495.4	214.9
3	84	1289.2	52.3	1633.3	65.3
6	83	1350.2	54.4	1705.9	33.3
9	78	1123.7	84.0	1524.4	43.6

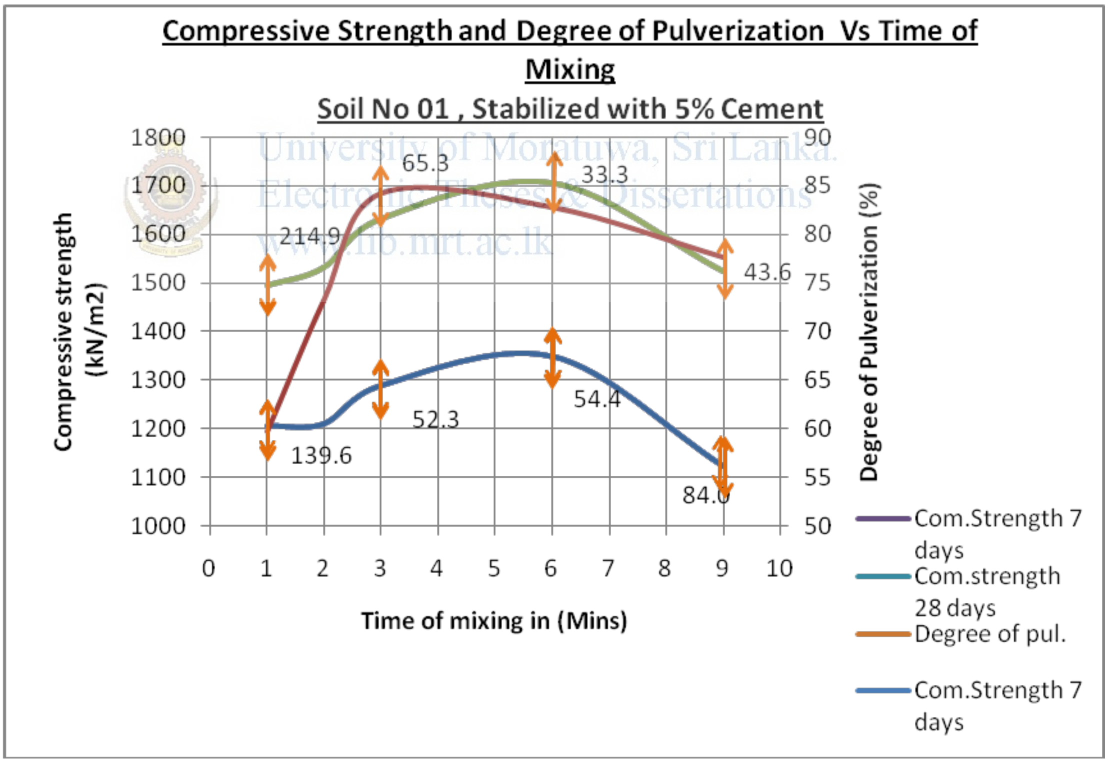


Figure 5.1 – Relationship among of DOP, UCS and mixing time 5 % cement with soil no 1

Table 5.6: Properties of 4% cement stabilized with soil no 2

Mixing Time (Min.)	Degree of Pulverization	AVG. Com. Strength (7 Days) (kN/m^2)	Standard Deviation (7 Days)	AVG. Com. Strength (28 Days) (kN/m^2)	Standard Deviation (28 Days)
1	70	1115.0	39.9	1446.04	43.56
3	80	1149.9	23.0	1489.60	15.09
6	72	1100.5	18.1	1390.87	10.06
9	65	1027.9	17.4	1245.69	17.42

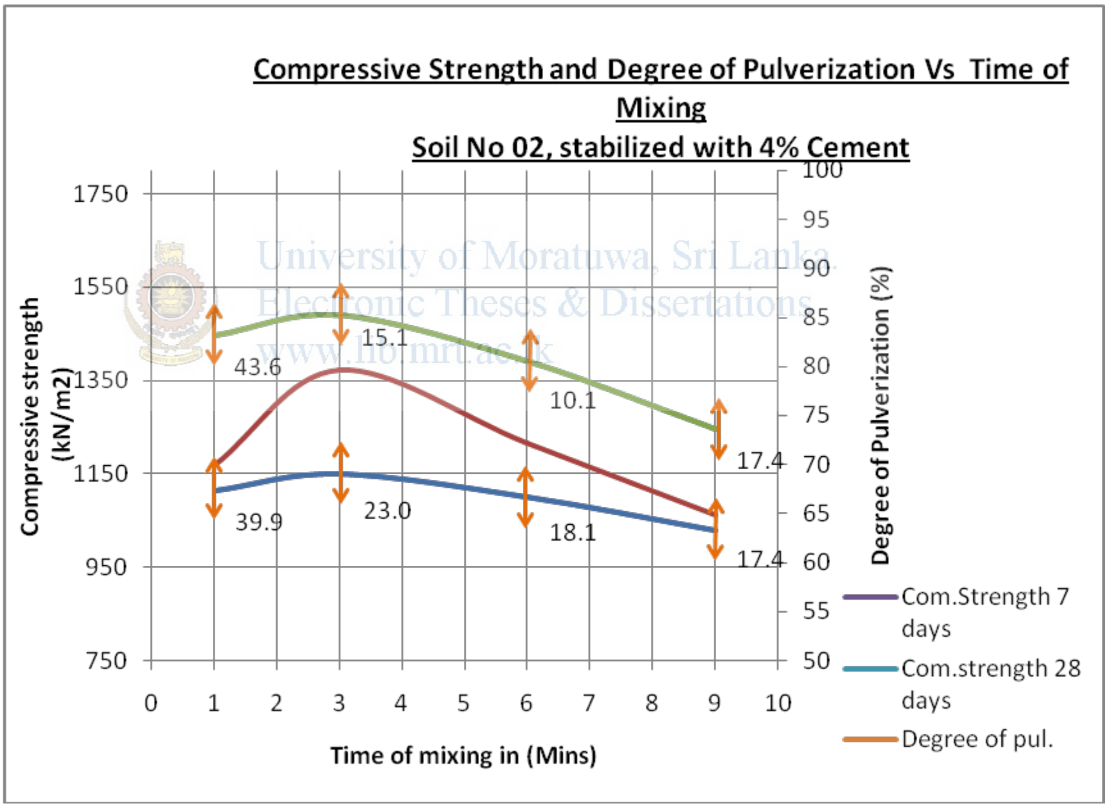


Figure 5.2– Relationship among of DOP, UCS and mixing time 4 % cement with soil no 2

Table 5.7: Properties of 5% cement stabilized with soil no 3

Mixing Time (Min.)	Degree of Pulverization	AVG. Com. Strength (7 Days) (kN/m^2)	Standard Deviation (7 Days)	AVG. Com. Strength (28 Days) (kN/m^2)	Standard Deviation (28 Days)
1	75	1010.5	52.3	1446.04	52.3
3	82	1036.6	15.1	1559.29	17.4
6	77	876.9	13.3	1402.49	31.4
9	69	792.7	15.1	1318.28	18.1

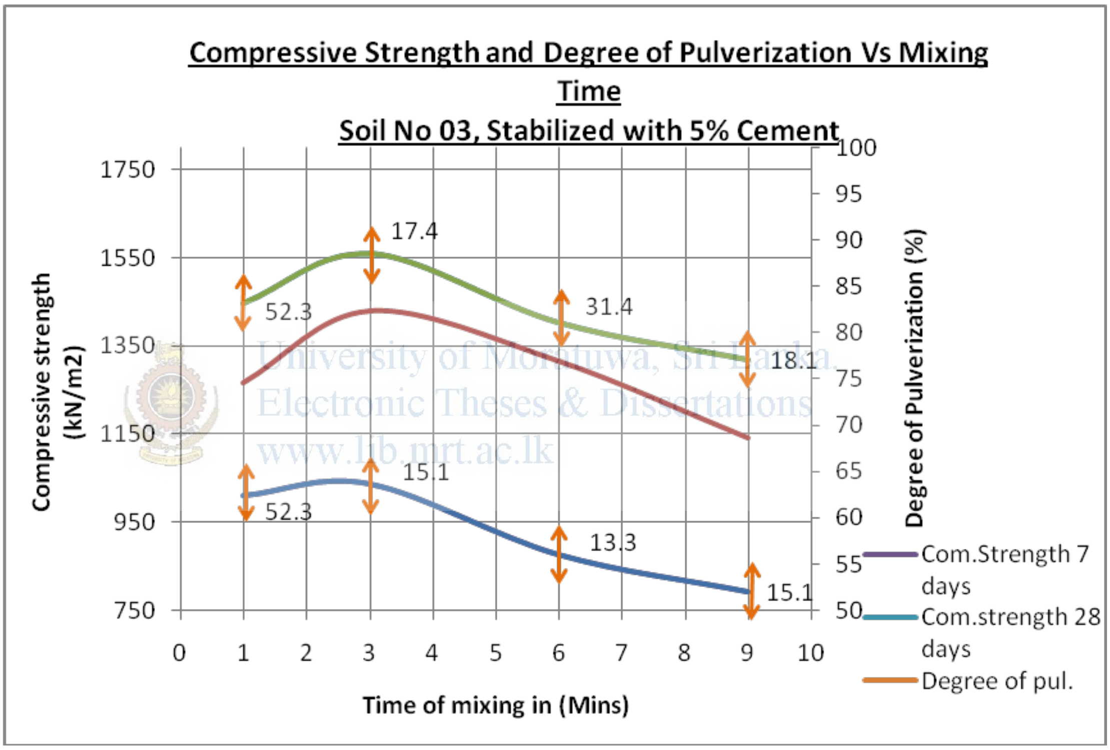


Figure 5.3 – Relationship among of DOP, UCS and mixing time 5 % cement with soil no 3

Figure 5.1-5.3, show that maximum DOP and UCS is achieved at the 3 minutes of mixing time (Except Soil no 1). Up to 3 minutes, DOP and UCS are increased gradually and at the further mixing tend to decrease both properties. Standard Deviation of UCS was at high at 1 minute mixing and the standard deviation reduces as the mixing time increase. Same tests were conducted for the soil lime mixing. Pre determined amount of lime mixed with same soil samples, DOP and UCS with mixing time were measured. Obtained results are tabulated in Table 5.8, 5.9 and 5.10 for soil no 1, 2 and 3 respectively. . Figure 5.4, 5.5 and 5.6 describe the behaviour of UCS (primary Y axis), DOP (secondary Y axis) with mixing time (X axis).

Table 5.8: Properties of 6% Lime stabilized with soil no 1

Mixing Time (Min.)	Degree of Pulverization	AVG. Com. Strength (7 Days) (kN/m^2)	Standard Deviation (7 Days)	AVG. Com. Strength (28 Days) (kN/m^2)	Standard Deviation (28 Days)
1	74	815.94	30.6	865.30	28.0
3	85	871.11	8.7	900.15	5.0
6	80	839.17	10.1	865.30	5.0
9	78	798.52	10.1	810.13	8.7

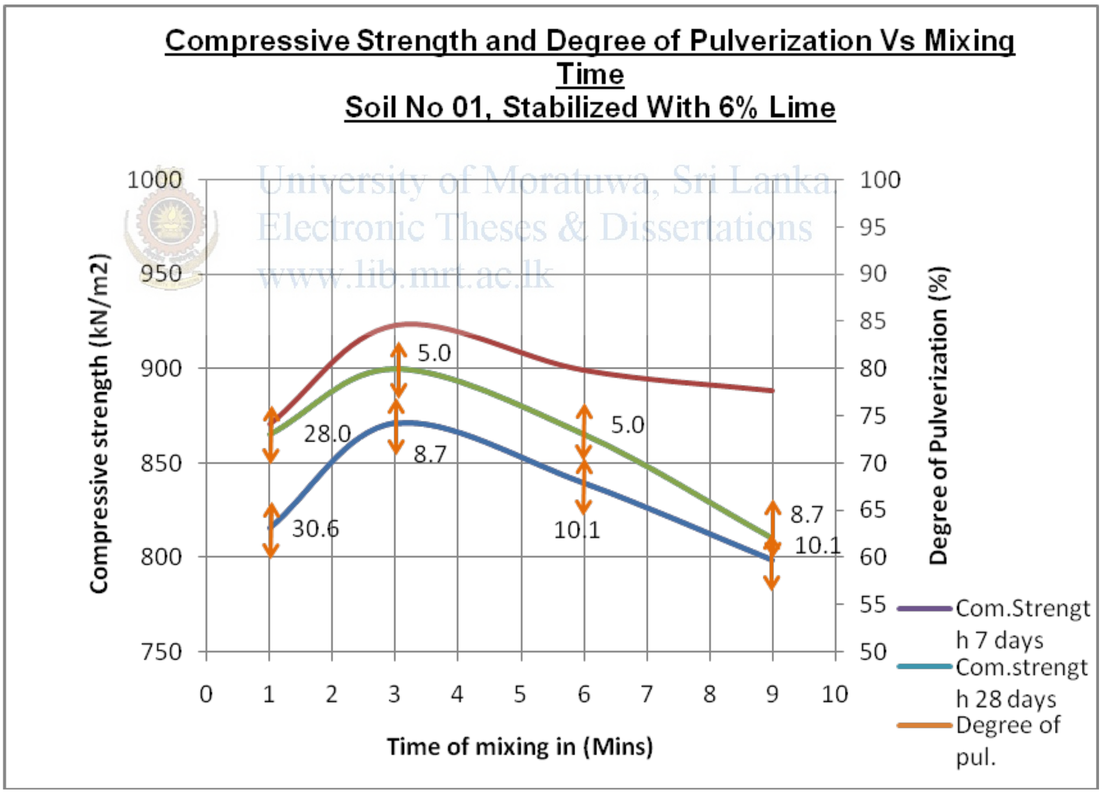


Figure 5.4 – Relationship among of DOP, UCS and mixing time 6 % lime with soil no 1

Table 5.9: Properties of 7% Lime stabilized with soil no 2

Mixing Time	**Degree of Pulverization**	**AVG. Com. Strength (7 Days) (kN/m^2)**	**Standard Deviation (7 Days)**	**AVG. Com. Strength (28 Days) (kN/m^2)**	**Standard Deviation (28 Days)**
1	78	827.56	69.69	975.64	48.5
3	79	862.40	34.84	1071.47	31.4
6	72	850.79	10.05	1027.91	8.7
9	68	842.07	5.03	993.07	8.7

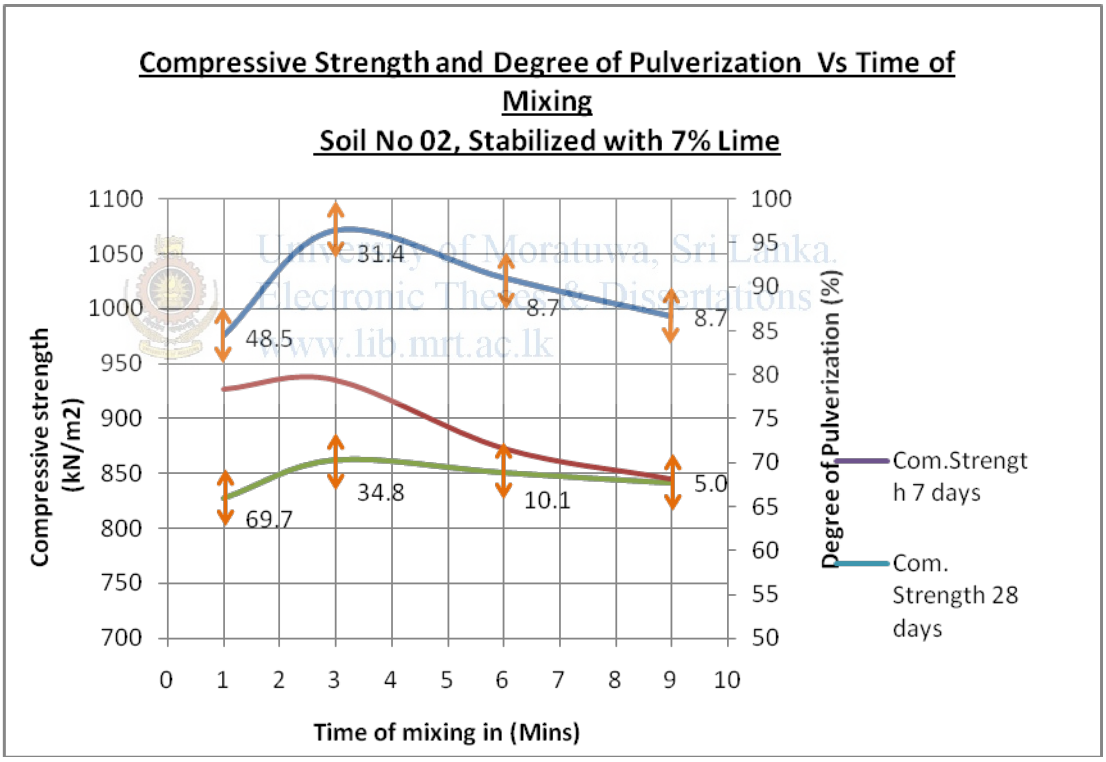


Figure 5.5- Relationship among of DOP, UCS and mixing time 7 % lime with soil no 2

Table 5.10: Properties of 7% Lime stabilized with soil no 3

Mixing Time	**Degree of Pulverization**	**AVG. Com. Strength (7 Days) (kN/m2)**	**Standard Deviation (7 Days)**	**AVG. Com. Strength (28 Days) (kN/m2)**	**Standard Deviation (28 Days)**
1	77	688.47	17.9	871.11	23.0
3	82	778.19	13.3	888.53	17.4
6	80	728.83	5.0	798.52	13.3
9	75	720.12	10.0	743.35	5.0

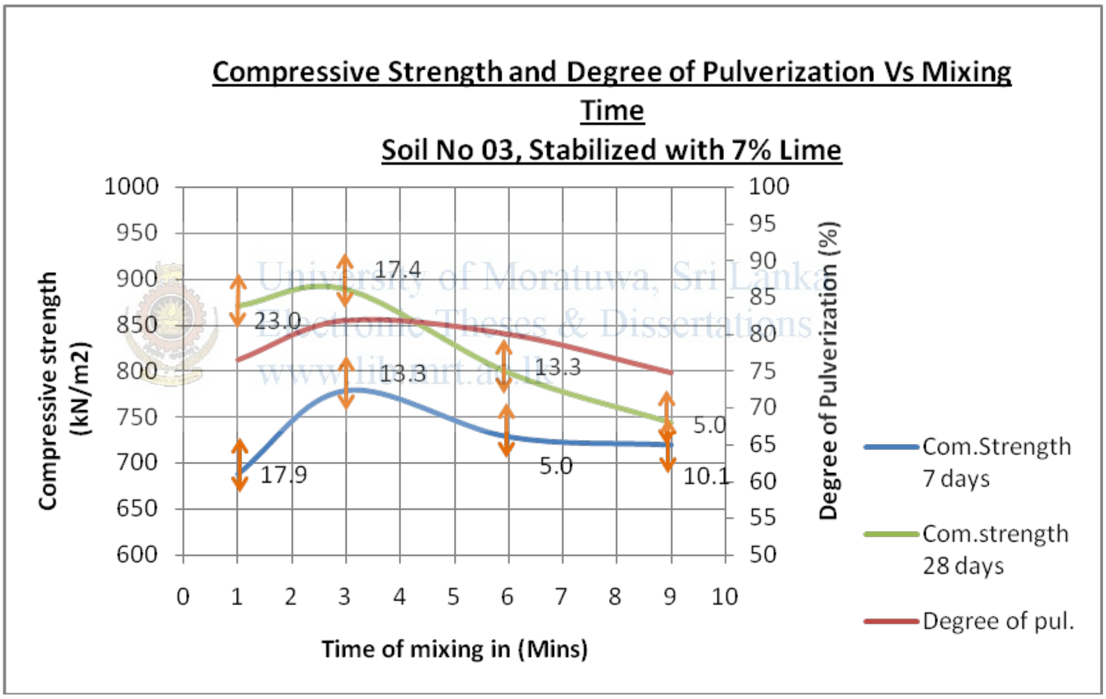


Figure 5.6 – Relationship among of DOP, UCS and mixing time 7% lime with soil no 3

Soil lime mixing, DOP and UCS increased with the mixing time up to 3 minutes and after achieving the maximum values decreased gradually (Same behaviour as soil cement mixing). Standard deviation of the UCS is highest at 1 minute mixing and decrees at the mixing time increase. Figure 5.7(a), 5.7(b), 5.7(c) and 5.7(d) showed the formation of soil balls at the each mixing time.

Figure 5.7(a)
1 minute mixing

Figure 5.7(b)
3 minutes mixing

Figure 5.7(c)
6 minutes mixing

Figure 5.7(d)
9 minutes mixing

Figure 5.7: Formation of soil lump with mixing time

Figures 5.7(a) – 5.7(d) shows the formation of the soil lumps in mixing with stabilizers. Increase of mixing time caused to make clay lumps in the laboratory mixing. When the soil stabilizer is get mixed uniformly, UCS value of test cubes become almost same. Therefore, standard deviation decreases as the mixing time increase. But, UCS value decreases as the DOP decrease.

5.4 Effect on delay compaction to UCS and OMC

5.4.1 Soil – Cement, Lime mix under Prevailing Moisture Content

Table 5.11and 5.12 shows the Densities and UCS values (7 days and 28 days) of stabilized soil compacted several hours after mixing. So stabilized soil were mixed at the OMC, determined for the stabilized soil. Figure 5.8 and 5.9 show the UCS values of stabilized soil compacted after several hours of delay (0 – 6 hours). However stabilized soil was compacted at the prevailing moisture content.

Table 5.11: Properties of delayed compacted Cement Soil, mixed under OMC

Delayed Time	Avg. Weight (7 Days) (Kg)	M.C. (%)	Avg. Bulk Density (7 Days) (kN/m^2)	Avg. Dry Density (7 Days) (kN/m^2)	Avg. Strength (7 Days) (kN/m^2)	Avg. Weight (28 Days) (Kg)	Avg. Bulk Density (28 Days) (kN/m^2)	Avg. Dry Density (28 Days) (kN/m^2)	Avg. Strength (28 Days) (kN/m^2)
Just After Mixing	6.90	25.28	2044.44	1631.84	1184.71	6.90	2044.44	1631.84	1553.48
After 1 Hours	6.73	24.58	1995.06	1601.46	1007.59	6.73	1995.06	1601.46	1338.61
After 2 Hours	6.62	23.56	1960.49	1586.69	937.90	6.60	1955.56	1582.69	1268.92
After 4 Hours	6.45	22.98	1911.11	1553.95	929.19	6.40	1896.30	1541.90	1193.42
After 6 Hours	6.18	21.78	1832.10	1504.48	731.73	6.25	1851.85	1520.70	978.55

Table 5.12: Properties of delayed compacted Lime Soil, mixed under OMC

Delayed Time	Avg.Weight (7 Days) (Kg)	M.C (%)	Avg. Bulk Density (7 Days) (kN/m^2)	Avg. Dry Density (7 Days) (kN/m^2)	Avg. Strength (7 Days) (kN/m^2)	Avg. Weight (28 Days) (Kg)	Avg. Bulk Density (28 Days) (kN/m^2)	Avg. Dry Density (28 Days) (kN/m^2)	Avg. Strength (28 Days) (kN/m^2)
Just After Mixing	6.55	26.09	1940.74	1539.20	874.01	6.58	1950.62	1547.03	1144.06
After 1 Hour	6.43	25.81	1906.17	1515.16	804.33	6.47	1916.05	1523.01	1056.95
After 2 Hours	6.37	25.58	1886.42	1502.20	743.35	6.32	1871.60	1490.40	961.13
After 4 Hours	6.12	24.48	1812.35	1455.88	679.47	6.15	1822.22	1463.82	853.69
After 6 Hours	5.90	23.16	1748.15	1419.40	615.59	5.93	1758.02	1427.42	737.54

Average weight, moisture contents, density and UCS decreases at the compaction delay increases for both cement and lime stabilization. It is essential to compact the stabilized soil just after mixing to get the optimum performance.

5.4.2 Soil – Cement, Lime mix under delayed OMC condition

Table 5.13, 5.14 present the Densities, UCSS (7 days and 28 days) of delayed compacted soil cement and lime mixed under air dried condition and added water at the compaction time to get the relevant OMC.

Table 5.13: Properties of delayed compacted Cement Soil, mixed under air dried condition

Delayed Time	**Average Weight (7 Days) (Kg)**	**M.C. (%)**	**Avg. Bulk Density (7 Days) (kN/m^2)**	**Avg. Dry Density (7 Days) (kN/m^2)**	**Avg. Stre. (7 Days) (kN/m^2)**	**Avg. Weight (28 Days) (Kg)**	**Avg. Bulk Density (28 Days) (kN/m^2)**	**Avg. Dry Density (28 Days) (kN/m^2)**	**Avg. Strength (28 Days) (kN/m^2)**
Just After Mixing	6.73	25.22	1995.06	1593.30	1280.53	6.73	1995.06	1593.30	1504.12
After 1 Hour	6.62	24.30	1960.49	1577.28	1228.27	6.62	1960.49	1577.28	1446.04
After 2 Hours	6.52	23.11	1930.86	1568.39	1155.67	6.53	1935.80	1572.41	1379.26
After 4 Hours	6.42	20.91	1901.23	1572.40	1059.85	6.48	1920.99	1588.74	1367.64
After 6 Hours	6.37	20.15	1886.42	1570.05	993.07	6.42	1901.23	1582.38	1347.32

It can be seen that strength has increased compared with soil which has been compacted at the OMC of original stabilized soil (Just after mixing). OMC of the air dried soil is relatively lower than the OMC of the original stabilized soil. So, delayed stabilized soil strength can be slightly increased by compacted at the OMC of the air dried soil.

Table 5.14: Properties of delayed compacted Lime Soil, mixed under air dried condition

Delayed Time	Average Weight (7 Days)	M.C. (%)	Avg. Bulk Density (7 Days) (kN/m^2)	Avg. Dry Density (7 Days) (kN/m^2)	Avg. Strength (7 Days) (kN/m^2)	Avg. Weight (28 Days) (Kg)	Avg. Bulk Density (28 Days) (kN/m^2)	Avg. Dry Density (28 Days) (kN/m^2)	Avg. Strength (28 Days) (kN/m^2)
Just After Mixing	6.73	25.84	1995.06	1585.44	932.09	6.67	1975.31	1569.74	1181.81
After 1 Hour	6.63	25.68	1965.43	1563.79	888.53	6.63	1965.43	1563.79	1126.64
After 2 Hour	6.58	24.51	1950.62	1566.66	844.98	6.55	1940.74	1558.73	1062.76
After 4 Hour	6.47	23.49	1916.05	1551.56	810.13	6.53	1935.80	1567.55	1027.91
After 6 Hour	6.40	22.16	1896.30	1605.13	801.42	6.43	1906.17	1560.42	978.55

Density of the air dried soil has been reduced with the delayed compaction. So the laboratory compaction in a delayed time tends to change the gradation of the soil. In addition, stabilizers have reacted with available water and air in the stabilized soil. Figure 5.8 – 5.9 and table 5.15 – 5.16 shows the relationship of UCS and deduction of UCS with compaction delay of both cement and lime stabilized soil.

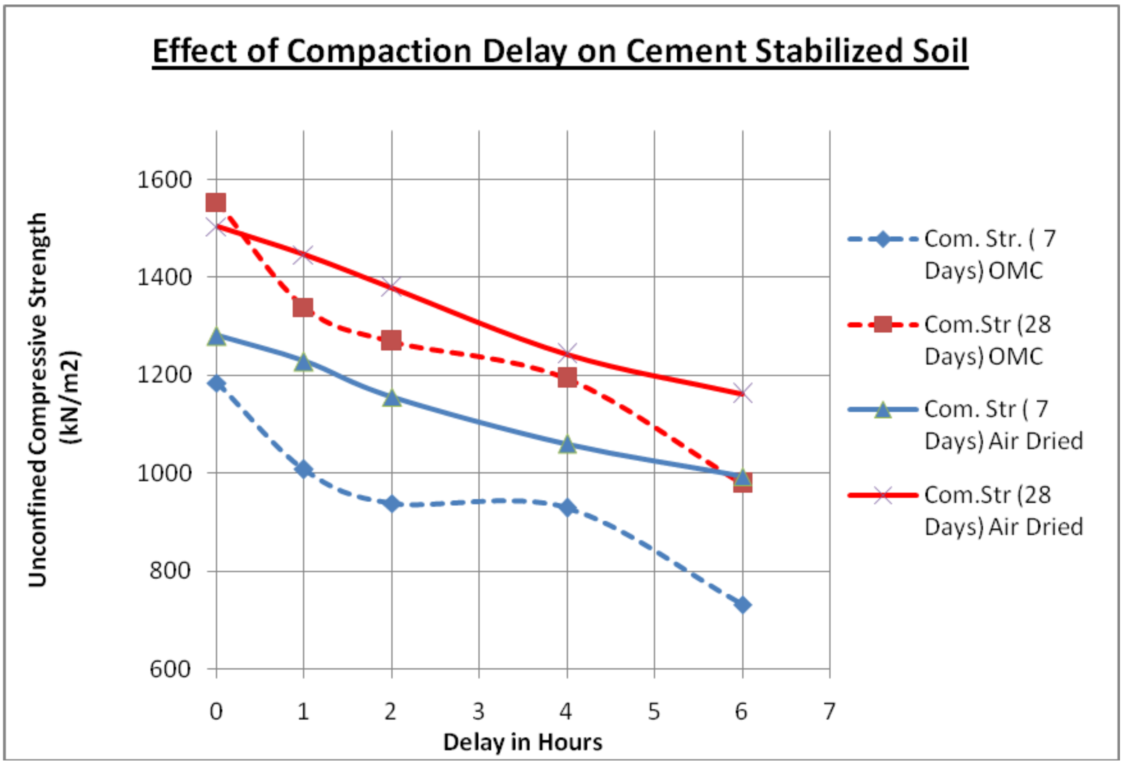


Figure 5.8: Relationship of UCS of Soil Cement mix with compaction delay

Table 5.15: Deduction percentages of UCSS (Soil – Cement Mixing)

Delay Time	Deduction of UCS (Compacted under prevailing M.C.)		Deduction of UCS (Compacted under relevant OMC)	
	7 Days	28 Days	7 Days	28 Days
0				
1	14.95%	13.83%	4.08%	3.86%
2	20.83%	18.32%	9.75%	8.30%
4	21.57%	23.18%	17.23%	17.37%
6	38.24%	37.01%	22.45%	22.78%

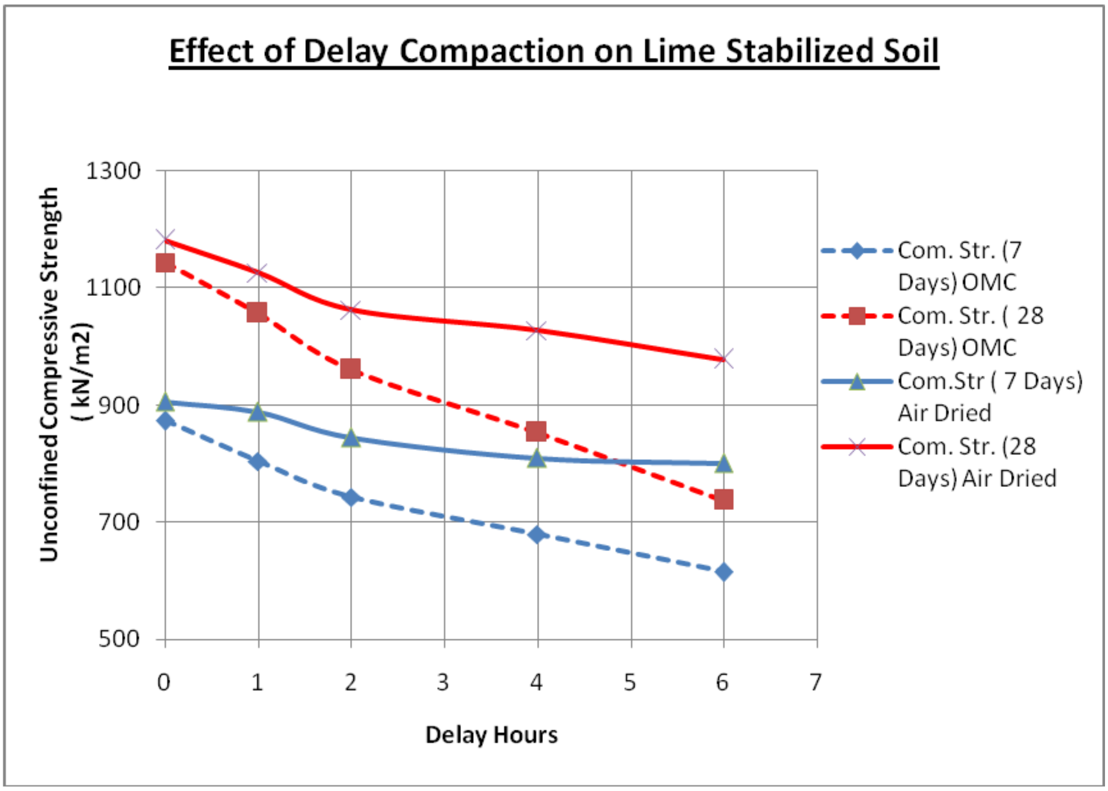


Figure 5.9: Relationship of UCS of Soil Lime mix with compaction delay

Table5.16: Deduction percentages of UCSS (Soil – Lime Mixing)

Delay Time	**Deduction of UCS (Compacted under prevailing M.C.)**		**Deduction of UCS (Compacted under relevant OMC)**	
	7 Days	**28 Days**	**7 Days**	**28 Days**
0				
1	7.97%	7.61%	1.92%	4.67%
2	14.95%	15.99%	6.73%	10.07%
4	22.26%	25.38%	10.58%	13.02%
6	29.57%	35.54%	11.54%	17.20%

Table 5.15 and 5.16 shown the deduction of UCSS value with the compaction delay. It can be shown that deduction percentage is high at the mixing of stabilized at OMC condition. 6 hour deduction is around 1/3 from the 0 hour UCS in both cement and lime stabilizing. At the air dried mixing it is around 1/5 in soil cement mixing and

1/7 in soil lime mixing. Reason for the higher deduction in soil cement is initial cemntanious reaction occurred with the available water in air dried soil.

5.5 Field Test

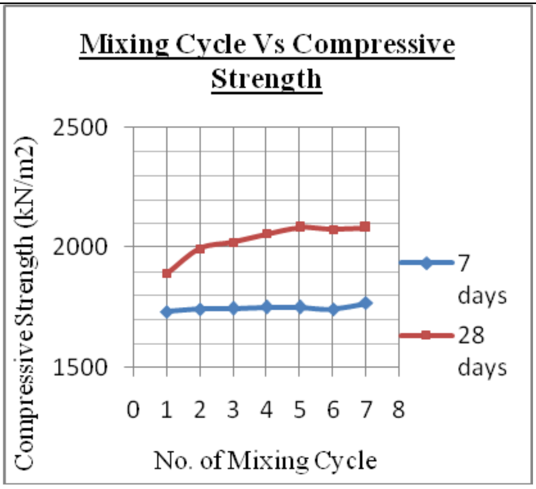
5.5.1 Cement Stabilized Pavement Section

Table 5.17 shows the mixing time, DOP and UCS values obtained through the cement soil mixing using a rotary mixer.

Table 5.17: Field test results (Soil Cement Mixing)

No of Mixing Cycle	Mixing Time	DOP	Comp. Strength kN/m^2 (7 Days)	St. Deviation	Comp. Strength kN/m^2 (28 Days)	St. Deviation
1	41:78	84.8	1733.5	17.4	1890.3	15.1
2	1:22:59	87.0	1742.2	8.7	1994.8	15.1
3	2:05:05	90.3	1746.6	7.5	2021.0	8.7
4	2:51:12	93.2	1750.7	8.7	2055.8	8.7
5	3:30:35	94.1	1750.9	5.0	2082.0	8.7
6	4:09:49	93.9	1742.2	8.7	2073.2	8.7
7	4:55:42	94.2	1768.4	8.7	2082.0	4.4

Figure 5.10 and 5.11 shows that compressive strength and DOP increase at a higher rate in the first few cycle and lower rate after the 4th mixing cycle. It can be seen that after the 4th cycle strength of stabilized soil remain constant. It is evidant that , further mixing will not increase the strength. However there is not a decrease in the strength and DOP with further mixing as laboratory condition.



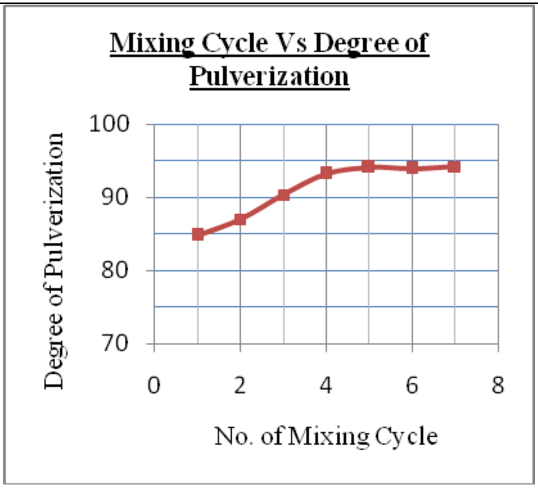


Figure 5.10 Behaviour of UCS with No. Mixing Cycles

Figure 5.11: Behaviour of DOP with No. Mixing Cycles

5.5.2. Lime Stabilized Pavement Section

Following table 5.18 shows the results obtained for DOP, UCSS with mixing time in soil lime mixing using a rotary mixture.

Table 5.18: Field test results (Soil Lime Mixing)

No of Mixing Cycle	Mixing Time	DOP	Comp. Strength kN/m^2 (7 Days)	St. Deviation	Comp. Strength kN/m^2 (28 Days)	St. Deviation
1	41:00	81.5	740.4	15.1	958.2	17.4
2	1:23:39	85.6	805.8	13.1	993.1	8.7
3	2:12:16	92.2	814.5	15.7	1013.4	11.0
4	3:01:39	92.2	801.4	17.4	1010.5	8.7
5	3:26:10	92.3	805.8	11.5	966.9	53.0
6	4:28:58	92.5	766.6	61.0	1019.2	8.7
7	5:17:28	92.8	805.8	11.5	1019.2	4.4

Figure no 5. 12 and 5.13 could be obtained using above test results.Figure 5.12 and 5.13 show the UCSS and DOP are incresed with no of mixing cycles. At the initial stage increasing rate is high and after certain point (3 mixing cycle) increasing rate is vary low.

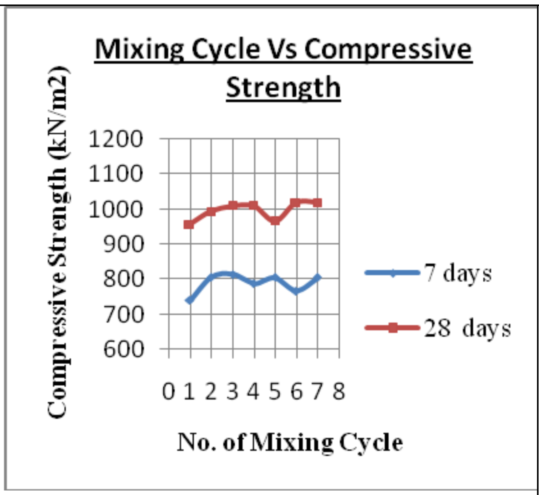


Figure 5.12- Behaviour of UCS with No. Mixing Cycles

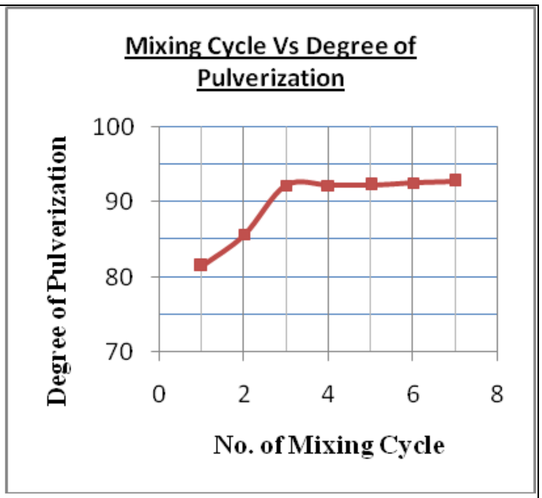
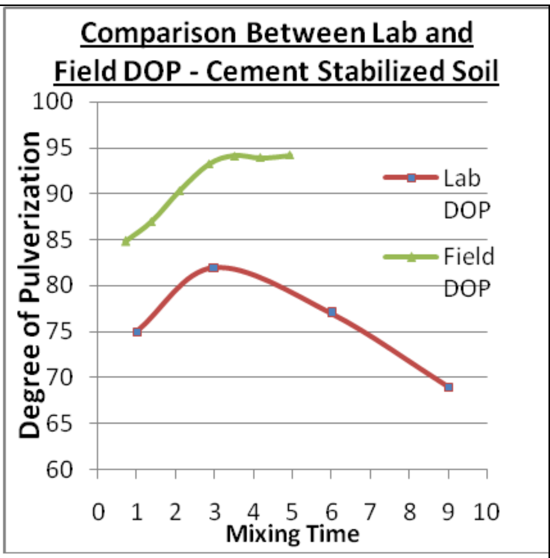


Figure 5.13- Behaviour of DOP with No. Mixing Cycles

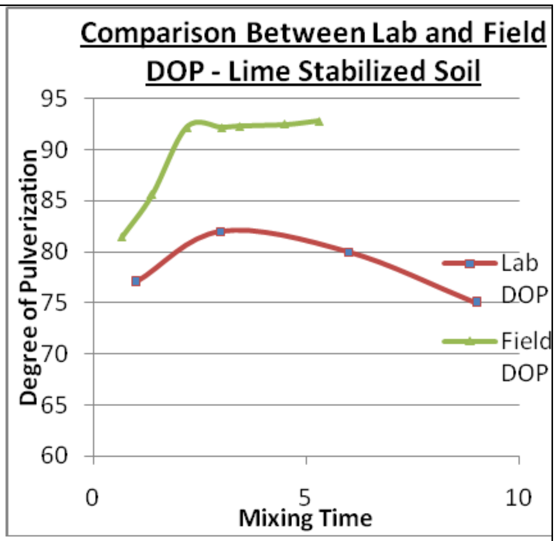
Field test results shows, that DOP increase at the mixing period or mixing cycles increase with the rotary mixer. Similar behaviour has been observed for UCS. Both UCS and DOP increases at a high rate initially and slower rate at the later stage.

5.6 Comparison between Laboratory results and Field Results

Following table 5.14, 5.15 shown the comparison of DOP between laboratory and field test for the cement stabilized soil and lime stabilized soil respectively.



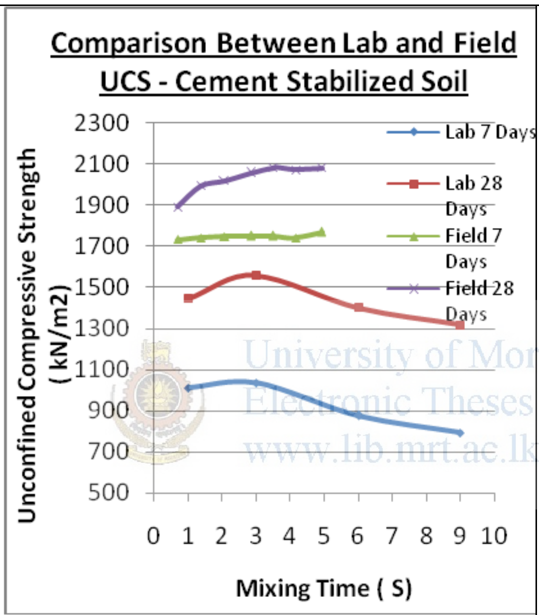
5.14 DOP with mixing time of Cement stabilized soil



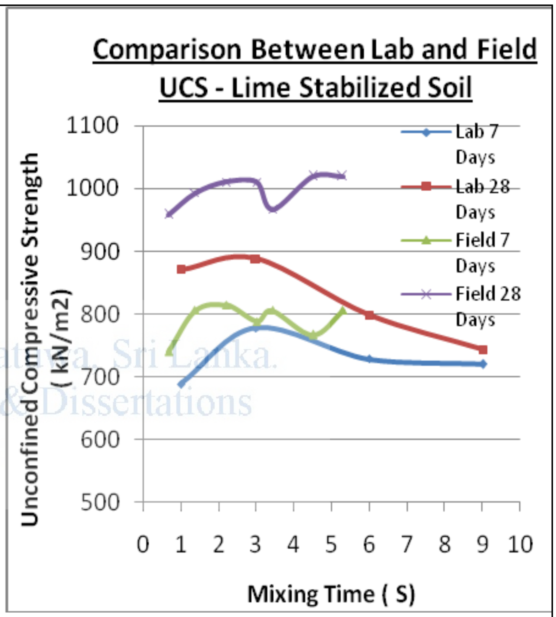
5.15 DOP with mixing time of Lime Stabilized Soil

When compare the Laboratory DOP and Field DOP, in both cement and lime stabilized soils, field DOP takes higher values than Laboratory DOP. Further DOP behaviour with mixing time is different in laboratory and field condition. Main reason for this variation is the mixing action of the mixers which used in the stabilization. (Breaking action in Field condition and rolling action in Laboratory Condition)

UCS (7 Days and 28 Days) of cement stabilizes and lime stabilized soil are presented in following figure 5.16 and 5.17 respectively.



5.16 UCS with mixing time of Cement stabilized soil



5.17 DOP with mixing time of Lime Stabilized Soil

When compare UCS of the laboratory and field condition, field UCS takes higher value than laboratory condition UCS. Further, in the field condition highest UCS value obtain at the lesser time than lab condition.

CHAPTER 06

ECONOMICAL ANALYSIS

6.1 General

Cost is a main factor which affect to the popularity of a technology. That means the quality and cost of the final product should be within the acceptable limits. Therefore when introduce a new technology, it is important to do a cost analysis. This chapter mainly focus on comparison of the cost between soil stabilization and good quality soil for subbase and embankment construction. It was found from our survey soil borrow pits are usually located in 15- 20 km distance from the job site in most of project. So I considered the travelling distance of 20 km for cost analysis. And available substituted soil to be improved located in 5 km distance for the analysis. Further, rates used for the analysis are taken from the Highway Schedule Rates (HSR) 2009.

6.2 Cost Analysis

6.2.1 Estimation of cost for transportation and laying good quality soil.

Cost for 1m3 of material

Approve soil (Type 1 & 11) excavation using machineries

Cost for bases & Shoulder Construction including loading and stock piling

	= Rs. 230.45
1 m3 Subbase material (Loos Volume)	= Rs.186.00
1 m3 Subbase material (Compacted Volume)	= 1.42 * 186.00
	= Rs. 264.12
Transport Cost	
Soil transport and the stock pile in the site (20 km)	= Rs.18.50*20
	= Rs.370.00

Spreading and compacting 1 m3 at site

Approved soil spread and rolled using machinery (Compacted) = Rs152.90 * 1.42

= Rs. 217.12

Total Cost for 1 cu.m of subbase material compaction in site

=Rs.1081.69

6.3 Cost analysis for lime and cement stabilization with soil within 5km distance.

Lime Stabilization

Volume of pavement subjected to stabilization in field tests = 3*1*0.15

=0.45 m3

Required lime weight (7% by dry weight of lime) = 45.36 kg

Cost for lime = 45.36*12

= Rs. 544.32

Cost for lime spreading (15 minutes spent for lime spreading)

= 491.07/8/60*15

= Rs.15.35

Hourly rate of rotary mixer = Rs. 625.00

Optimum mixing cycles no: 3 and mixing time =2:12:16

Cost for mixing =Rs.625/60*2:12:16

=Rs.22.92

Total cost for stabilization process (0.45 m3) = Rs.582.59

Cost for stabilize 1.0 m3 soil = Rs 582.59 /0.45

= Rs. 1294.64

Cost for stabilized 1.o m3 soil (Compacted) = Rs.1.42 * 1294.64

= Rs.1838.39

Cement Stabilization

Volume of pavement subjected to stabilization	= 3*1*0.15
	= 0.45 m3
Required cement weight (5% by dry weight of Cement)	= 32.4 kg
Cost for cement	= 32.4*14.80
	= Rs. 479.52

Cost for cement spreading (15 minutes spent for cement spreading

	= 491.07/8/60*15
	= Rs.15.35
Hourly rate of rotary mixer	= Rs. 625.00
Optimum mixing cycles no: 4 and mixing	=2:51:12
Cost for mixing	=Rs.625/60*2:51:12
	= Rs. 29.79

Total cost for stabilization process (0.45 m3)	=Rs. 524.66
Cost for stabilize 1.0 m3 soil	= Rs. 524.66/0.45
	= Rs.1165.91
Cost for stabilized 1.o m3 soil (Compacted)	= Rs.1.42 * 1165.91
	= Rs.1655.59

Addition

Approve soil (Type 1 & 11) excavation using machineries

	= Rs. 230.45

For bases & Shoulder Construction including loading and pilling

1 cu.m Embankment material (Loose)	= Rs.163.75
1 cu.m Embankment material (Compacted)	=163.75*1.42
	=Rs. 232.52
Transport cost 5km (19.55*5)	=Rs. 97.75

Approved soil spread and rolled using machinery (Compacted)

= Rs152.90 * 1.42

= Rs. 217.12

Cost for lime stabilization process = Rs.1838.39

Cost for cement stabilization process = Rs. 1655.59

Cost for complete subbase using lime stabilized soil 1m3

= Rs. 2612.95

Cost for complete subbase using Cement stabilized soil 1m

= Rs. 2434.38

Following table 6.1 and 6.2 present the total cost of the cement and lime stabilized soil (per 1 cu.m) for different stabilizer percentage. Further, final rows describe the increase of total cost for 1 cu.m stabilized soil compare with the natural subbase soil. It shows, when increase the stabilizer amount, increasing percentage of cost takes higher values and not economical further.

Table 6.1: Cost Comparison for Deferent Cement Percentages.

Cement Percentage	**1%**	**2%**	**3%**	**4%**	**5%**	**6%**
Cement Cost (Rs.)	302.63	605.26	907.89	1210.52	1513.15	1815.78
Spreading Cost (Rs.)	48.44	48.44	48.44	48.44	48.44	48.44
Mixing Cost(Rs.)	93.78	93.78	93.78	93.78	93.78	93.78
Cost for embankment material(Rs.)	232.52	232.52	232.52	232.52	232.52	232.52
Excavation, Loading, Pilling Cost(Rs.)	230.45	230.45	230.45	230.45	230.45	230.45
Transport Cost(Rs.)	97.75	97.75	97.75	97.75	97.75	97.75
Spread and compaction cost(Rs.)	217.12	217.12	217.12	217.12	217.12	217.12
Total Cost (Rs.)	1222.69	1525.32	1827.95	2130.58	2434.38	2735.84
Increase of cost as a percentage (compare with natural subbase)	**13.04**	**41.01**	**68.99**	**96.97**	**124.95**	**152.92**

Table 6.2: Cost Comparison for Deferent Lime Percentages.

Lime Percentage	**1%**	**2%**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**
Lime Cost (Rs.)	245.38	490.75	736.13	981.50	1226.88	1472.26	1717.63	1963.01
Spreading Cost(Rs.)	48.44	48.44	48.44	48.44	48.44	48.44	48.44	48.44
Mixing Cost(Rs.)	72.33	72.33	72.33	72.33	72.33	72.33	72.33	72.33
Cost for embankment material(Rs.)	232.52	232.52	232.52	232.52	232.52	232.52	232.52	232.52
Excavation, Loading, Pilling Cost(Rs.)	230.45	230.45	230.45	230.45	230.45	230.45	230.45	230.45
Transport Cost(Rs.)	97.75	97.75	97.75	97.75	97.75	97.75	97.75	97.75
Spread and compaction cost(Rs.)	217.12	217.12	217.12	217.12	217.12	217.12	217.12	217.12
Total Cost(Rs.)	1143.98	1389.36	1838.39	1880.11	2125.49	2370.86	2616.24	2861.61
Increase of cost as a percentage (compare with natural subbase)	**5.76**	**28.44**	**51.13**	**73.81**	**96.50**	**119.18**	**141.87**	**164.55**

CHAPTER 07

CONCLUSION AND RECOMENDATIONS

7.1 Conclusion

This study was conducted with the objective to develop quality control measures in soil stabilization and review the stabilizer selection criteria. Improving the quality and popularity of soil stabilization in local road construction industry were main concern in this study. Several reasons for non popularity were found in the survey. Questionnaire Survey results shows that

(1) Lack of knowledge and experience in industrial profession,

(2) 55% expressed that non awareness of quality control methods for soil stabilization, and

(3) 72% expressed that Extra Cost as the main reason for non popularity of soil stabilization in the industry.

This study was based on laboratory and field experiments. Soil parameters and mixing parameters were investigated under laboratory condition. For the laboratory mixing, Belle mini mix 150 concrete mixer was used with 24 rpm. According to the original properties of the selected soil are A-2-7 (AASHTO classification). Mixing behaviour of the concrete mixture is not a blending and it is simply rolling with the stabilizer. In stabilizer selection criteria, Three (3) methods are analyzed (In chapter three (3) discussed)Sieve sizes and plasticity index of the soil were basic factors to be considered in stabilizer selection C.A. O' Flaherty guide lines provides simply and expanded variety of stabilizer. Selected 3 soil types for the experiment, were suitable for cement and lime stabilization as per the three guidelines. Relevant percentages of stabilizer were determined using PH test and trial and error method for lime and cement respectively. Behaviour of Degree of pulverization and unconfined compressive strength were determined with the various mixing time. All soil types showed a similar behaviour on DOP and UCS with mixing time. The maximum UCS was obtained at the maximum DOP values (Except soil type 1 mixing with cement) and DOP is increased with the mixing time and decreased with further mixing. Maximum UCS and DOP were achieved at 3 minutes mixing time for both lime and cement stabilizing. (UCS also has the same pattern with mixing time).

Effect of delay compaction was studied under two scenarios.

Stabilizer mixing under optimum moisture content and air dried condition

Mixing was conducted until achieve the optimum mixing time and used same mixer as above mentioned.

Compaction time was delayed from zero (0) to six (6) hours. Seven (7) days and Twenty Eight (28) days UCS were measured. There was a considerable deduction of the UCS of both lime and cement. (17% and 22% respectively)

Eight number of test pavements were constructed (soil-lime 4 pavements and soil cement 4 pavements). Tractor rotary (2 feet width 18 blades and 90 rpm) was used for the stabilizing. Mixing time was varying for each pavement and checked the DOP and UCS with mixing time. It found that up to certain point DOP and UCS is increased with mixing time and after further mixing, both factors increase in minor rates. Highest UCS values are 2082 kN/m^2 and 1019.2 kN/m^2 for cement stabilized and lime stabilized pavement respectively (Highest DOP for cement stabilized and lime stabilized soil are 94.2 % and 92.8% respectively).

In the cost analysis, 2009 Highway schedule rates were used for the analysis. It shows that soil stabilization is economical when the stabilizer percentage is lower. Even in the stabilizer percentages are low, cost is higher than natural subbase transporting. But the time is a very crucial factor in any type of project. Therefore, when consider the delaying time to overall process of borrowing subbase from far away; soil stabilization will be a good alternative.

7.2 Future Study

Due to time constraints of this study certain aspects have not been covered adequately. The following could be recommended for future work.

In this research, it is not possible to determine the Engineering Properties and performance of the stabilized soil pavements under long term traffic load. It is very important to determine the behaviour of stabilized pavement under traffic and should be constructed a road section using stabilized soil to measure the long term performance under local condition.

Further, it is recommended to popular this technology among the professionals in the road construction industry through workshops and training programmes.

7.3 Recommendation

Soil stabilization should be well promoted among the professionals in local road construction industry as a solution for the problem of scarcity of soil with good quality. The Promotion should be done through improving their knowledge and loyalty on stabilization technology.

Degree of Pulverization (DOP) is a severe factor in soil stabilization. It directly affects to the Unconfined Compressive Strength (UCS) of stabilized material.

Mixing time is not directly affects to the UCS of stabilized material. But, it should be extended until obtain the optimum DOP.

After getting the optimum DOP, DOP variation with the mixing time is lower.

Mixing method of the mixers is important in stabilization. Here, breaking method is more appropriate rather than rolling method. Therefore, rotary mixers are suitable for the soil - stabilizer mixing.

For the higher UCS values, compaction should be done soon as mixing completed. Therefore, site mixing is appropriate rather than central plant mixing.

The moisture content of the soil should be maintained lower at the mixing time and when compacting, it should be relevant optimum moisture content.

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APPENDIX A

SURVEY FORM

Survey Form

Project Title – Evaluating suitable soil stabilization method for local road construction industry

Name :

Designation :

Location of the site/ Office :

Road Construction experience (Years) :

1.Use of soil in your project.

O Sub grade O Sub base O Base O Shoulder

2. What is the present supplying method?

O Self supplying O By soil supplier

3. What is the location and distance to the borrow pit from the site?

4. What is the storage time of soil at the site before use?

5. What are the properties of soil?

Use of Soil	CBR	LL	PI

6. What is the Distance to nearest borrow pit in which soil properties were checked but not comply with the specification?

7. What are the properties of the soil in above borrow pit?

Use of Soil	CBR	LL	PI	Price (1Cu.m)

8. Do you have an idea about soil Stabilization? (Y/ N)

9. Do you have any experience about soil stabilization? (Where, for what, stabilizers used)

10. What are the identified/ expecting difficulties or constrains in soil stabilizing in Sri Lanka? (If (8) Yes)

i.
ii.
iii.
iv.

APPENDIX B

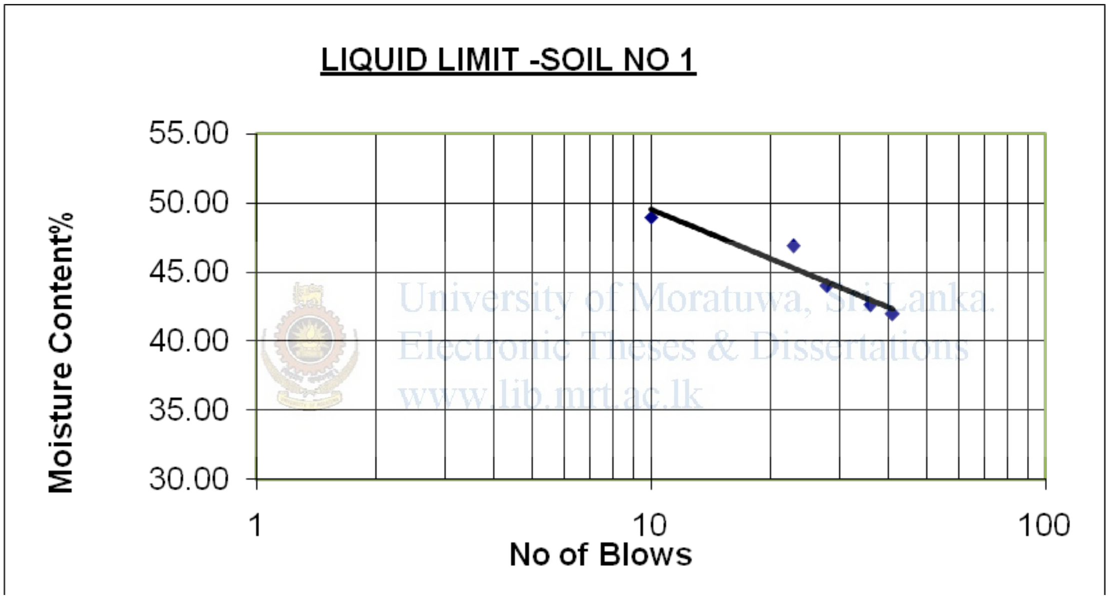
ORIGINAL PROPERTIES OF SOIL

Calculation for Liquid Limit and Plastic Index

Soil no : 1

Soil Condition : Natural

No. of Drops	Weight of wet Soil + Can	Weight of Dry Soil +	Weight of empty can	M.C (%)
41	55.09	47.83	30.53	41.97
36	54.21	47.37	31.32	42.62
28	60.11	51.25	31.12	44.01
23	58.7	50.01	31.48	46.90



Moisture content at the 25 drops = LL of soil

LL of soil =45

Weight of wet Soil + Can	Weight of Dry Soil + Can	Weight of empty can	M.C (%)
43.93	41.08	31.35	29.29
44.12	41.35	31.75	28.85

Plastic Limit of Soil = 29

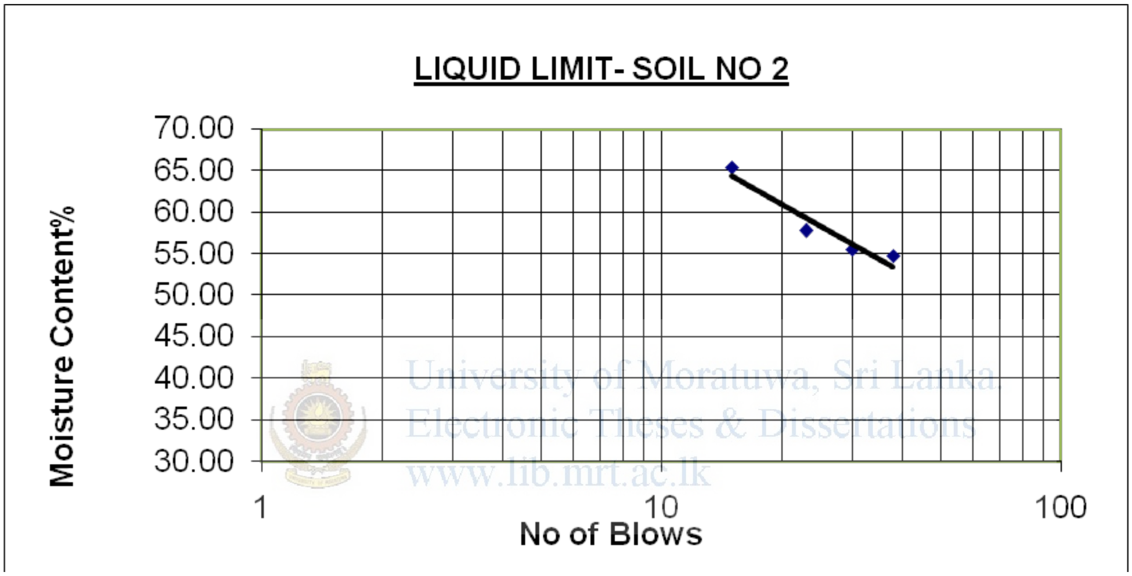
PI of soil =16

Calculation for Liquid Limit and Plastic Index

Soil no : 2

Soil Condition : Natural

No. of Drops	Weight of wet Soil + Can	Weight of Dry Soil + Can	Weight of empty can	M.C (%)
38	52.01	44.7	31.35	54.76
30	61.99	50.78	30.6	55.55
23	48.69	42.33	31.32	57.77
15	68.39	53.83	31.56	65.38



Moisture content at the 25 drops = LL of soil

LL of soil =58

Weight of wet Soil + Can	Weight of Dry Soil + Can	Weight of empty can	M.C (%)
29.68	26.23	17.8	40.93
42.69	39.18	30.64	41.10

Plastic Limit of Soil = 41

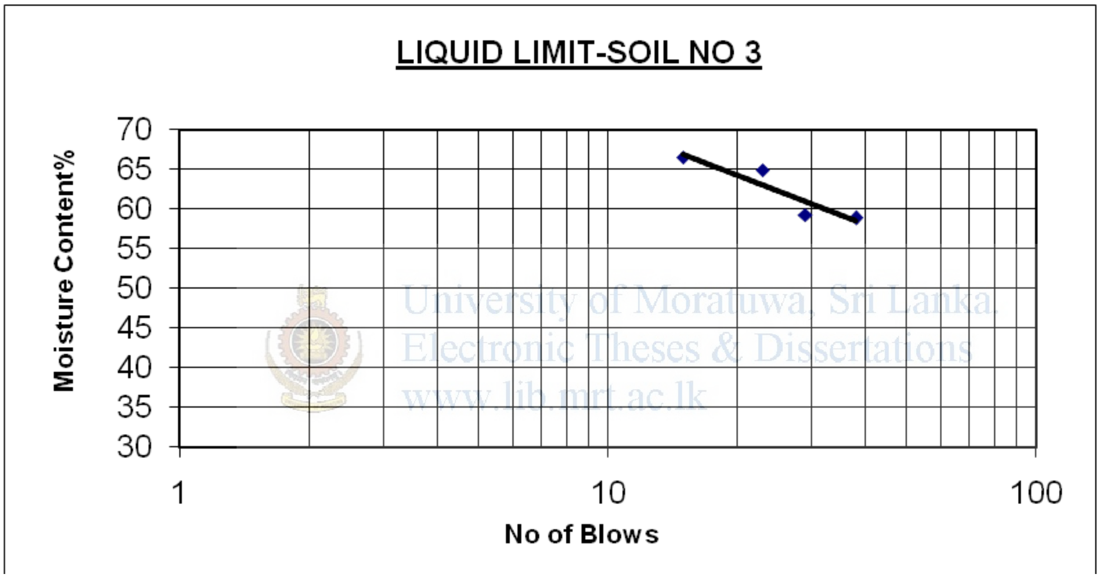
PI of soil =17

Calculation for Liquid Limit and Plastic Index

Soil no : 3

Soil Condition : Natural

No. of Drops	Weight of wet Soil + Can	Weight of Dry Soil + Can	Weight of empty can	M.C
38	70.92	56.25	31.35	58.92
29	67.09	53.42	30.36	59.28
23	59.74	48.61	31.48	64.97
15	56.76	46.31	30.6	66.52



Moisture content at the 25 drops = LL of soil

LL of soil =63

Weight of wet Soil + Can	Weight of Dry Soil + Can	Weight of empty can	M.C (%)
42.38	38.84	30.88	44.47
43.65	39.1	28.91	44.65

Plastic Limit of Soil = 45

LI of soil =18

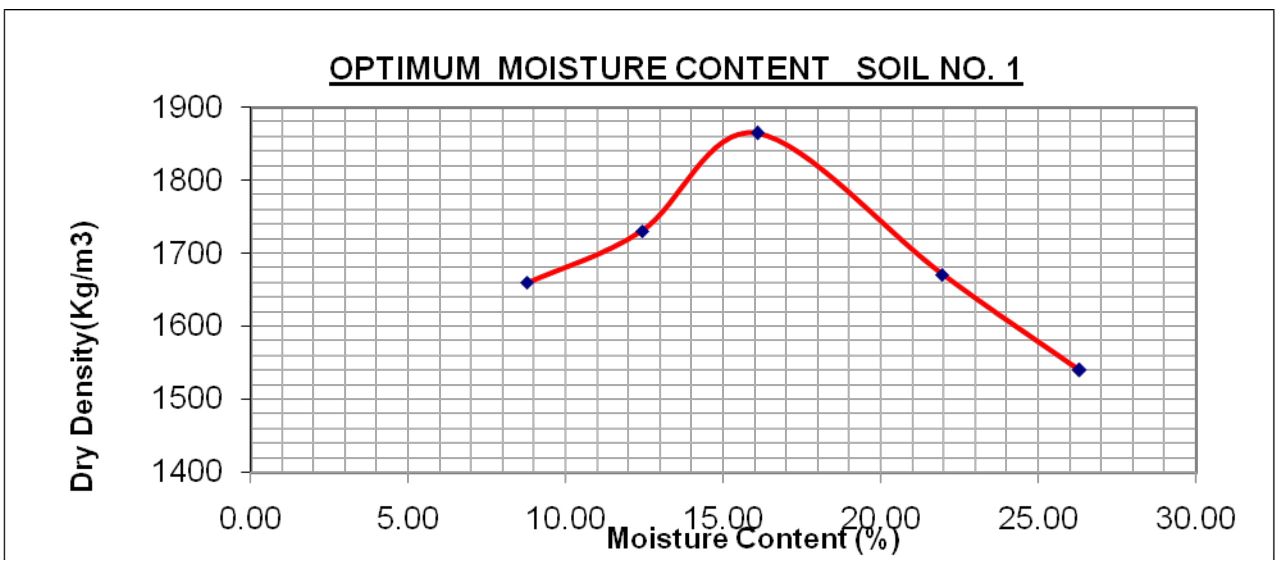
Calculation for OMC and MDD

Soil no : 1

Soil Condition : Natural

Can weight (g)	Can + Wet Soil (g)	Can+ Dry Soil (g)	Moisture Content (%)
30.4	131.22	123.1	8.76
30.48	159.2	144.98	12.42
30.1	108.39	97.55	16.07
30.6	107.57	93.72	21.94
30.53	112.25	95.23	26.31

Sample	m1 Kg (mould + Base plate)	m2 Kg (m1+ soil)	Ah	□wet□=(m2-m1)/Ah*1000	m.c%	□dry=s wet/(100+w)
1	4.084	5.788	0.000944	1805.08	8.76	1659.70
2	4.084	5.92	0.000944	1944.92	12.42	1730.06
3	4.084	6.127	0.000944	2164.19	16.07	1864.54
4	4.084	6.007	0.000944	2037.08	21.94	1670.52
5	4.084	5.92	0.000944	1944.92	26.31	1539.84



Optimum Moisture Content – 16%

Maximum Dry Density – 1838 Kg/m3

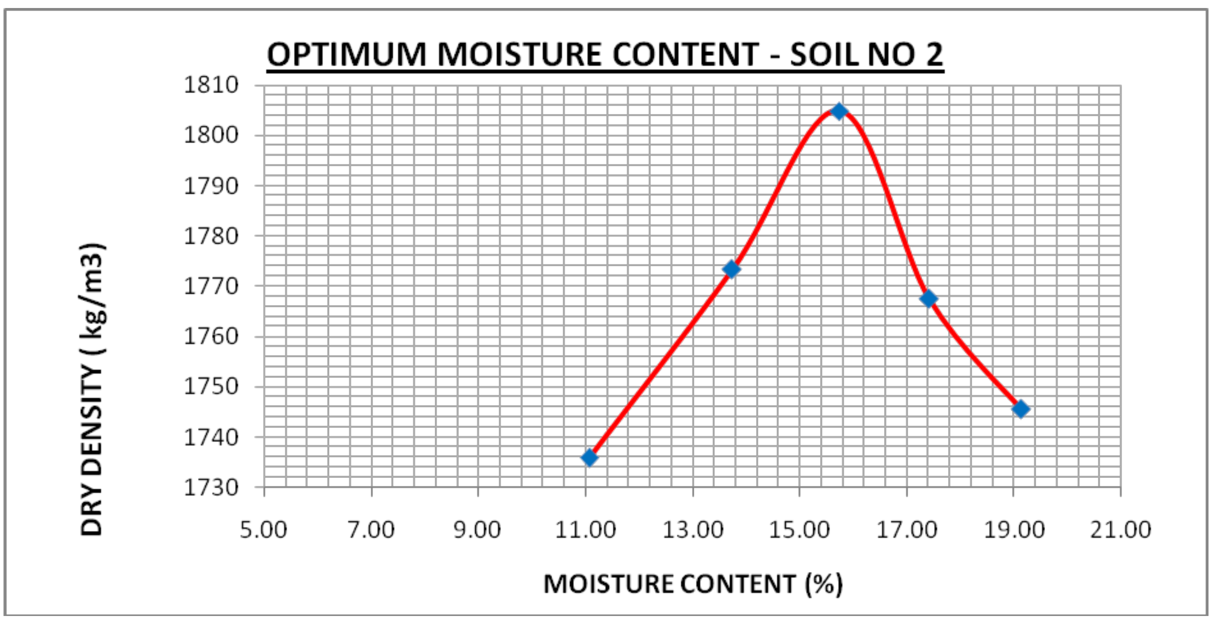
Calculation for OMC and MDD

Soil no : 2

Soil Condition : Natural

Can weight (g)	Can + Wet Soil (g)	Can+ Dry Soil (g)	Moisture Content (%)
31.38	132.02	121.99	11.07
30.53	131.05	118.91	13.74
31.32	116.54	104.95	15.74
31.42	132.56	117.56	17.41
31.56	102.56	91.16	19.13

Sample	m1 Kg (mould + Base plate)	m2 Kg (m1+ soil)	Ah	□wet□=(m2-m1)/Ah*1000	m.c%	□dry=s wet/(100+w)
1	1.9	3.72	0.000944	1927.97	11.07	1735.82
2	1.9	3.804	0.000944	2016.95	13.74	1773.36
3	1.9	3.872	0.000944	2088.98	15.74	1804.88
4	1.9	3.859	0.000944	2075.21	17.41	1767.44
5	1.9	3.863	0.000944	2079.45	19.13	1745.57



Optimum Moisture Content – 16% Maximum Dry Density – 1805 Kg/m3

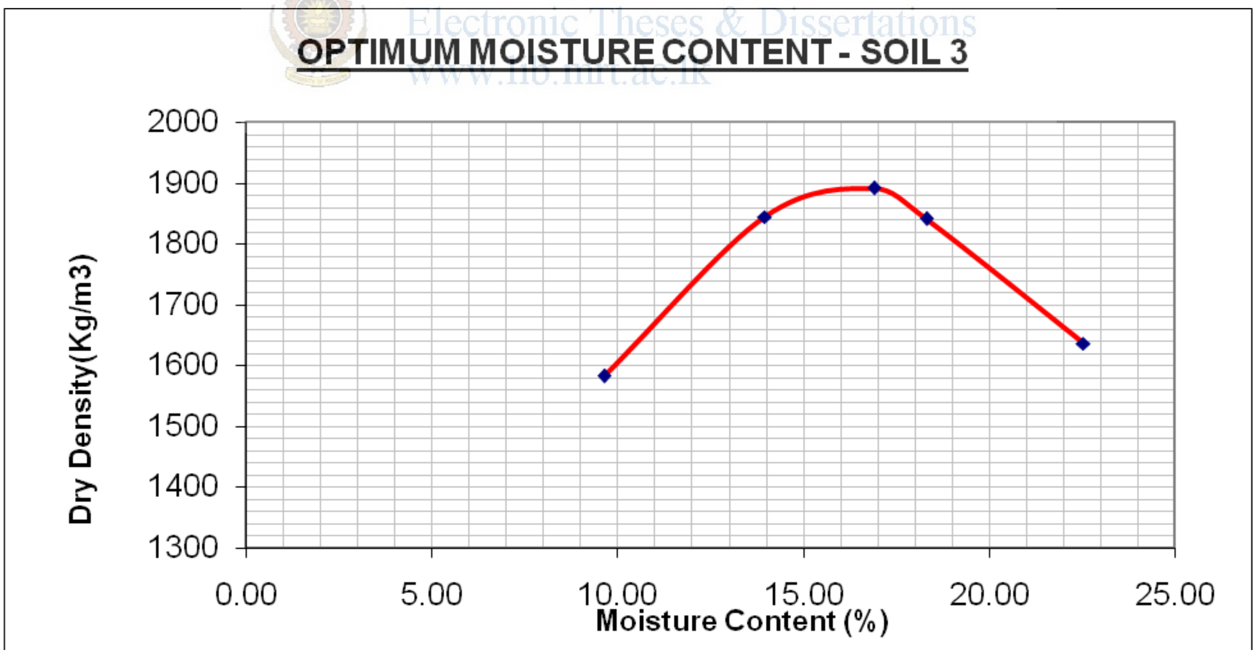
Calculation for OMC and MDD

Soil no : **3**

Soil Condition : **Natural**

Can weight (g)	Can + Wet Soil (g)	Can+ Dry Soil (g)	Moisture Content (%)
30.24	124.76	116.45	9.64
30.62	128.45	116.47	13.95
31.16	138.45	122.94	16.90
31.74	132.67	117.05	18.31
31.17	128.4	110.52	22.53

Sample	m1 Kg (mould)	m2 Kg (m1+ soil)	Ah	□wet□=(m2-m1)/Ah*1000	m.c%	□dry=s wet/(100+w)
1	1.8994	3.537	0.000944	1734.75	9.64	1582.23
2	1.8994	3.884	0.000944	2102.33	13.95	1844.88
3	1.8994	3.987	0.000944	2211.44	16.90	1891.75
4	1.8994	3.956	0.000944	2178.60	18.31	1841.44
5	1.8994	3.792	0.000944	2004.87	22.53	1636.19



Optimum Moisture Content – 16.5% Maximum Dry Density – 1880 Kg/m3

California Bearing Ratio Test (CBR)

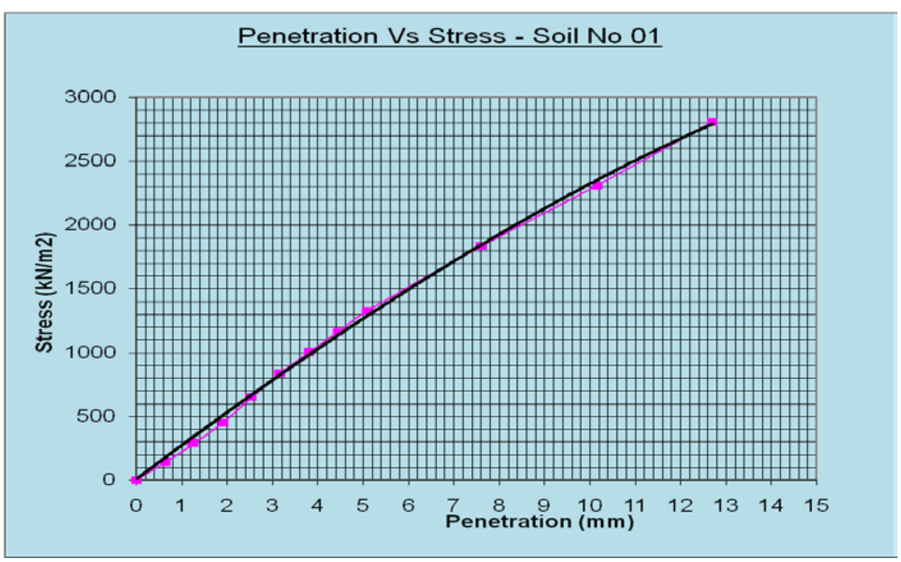
Soil Type : No 01 Original

Condition : Soaked

Penetration(mm)	Reading.	Load (kN)	Stress(KN/mm2)	Stress(KN/m2)
0	0	0	0	0
0.64	12	0.265	0.0001375	137.4816
1.27	23	0.551	0.0002859	285.858
1.91	35	0.863	0.0004477	447.7231
2.54	50	1.253	0.0006501	650.0545
3.18	64	1.617	0.0008389	838.8971
3.81	76	1.929	0.0010008	1000.762
4.45	88	2.241	0.0011626	1162.627
5.08	100	2.553	0.0013245	1324.493
7.62	138	3.541	0.0018371	1837.065
10.16	173	4.451	0.0023092	2309.172
12.7	210	5.413	0.0028083	2808.256

Dia. Of penetration rod 49.53mm

Area of the rod 1927.531mm2



CBR – 12

APPENDIX C

PROPERTIES OF STABILIZED SOIL

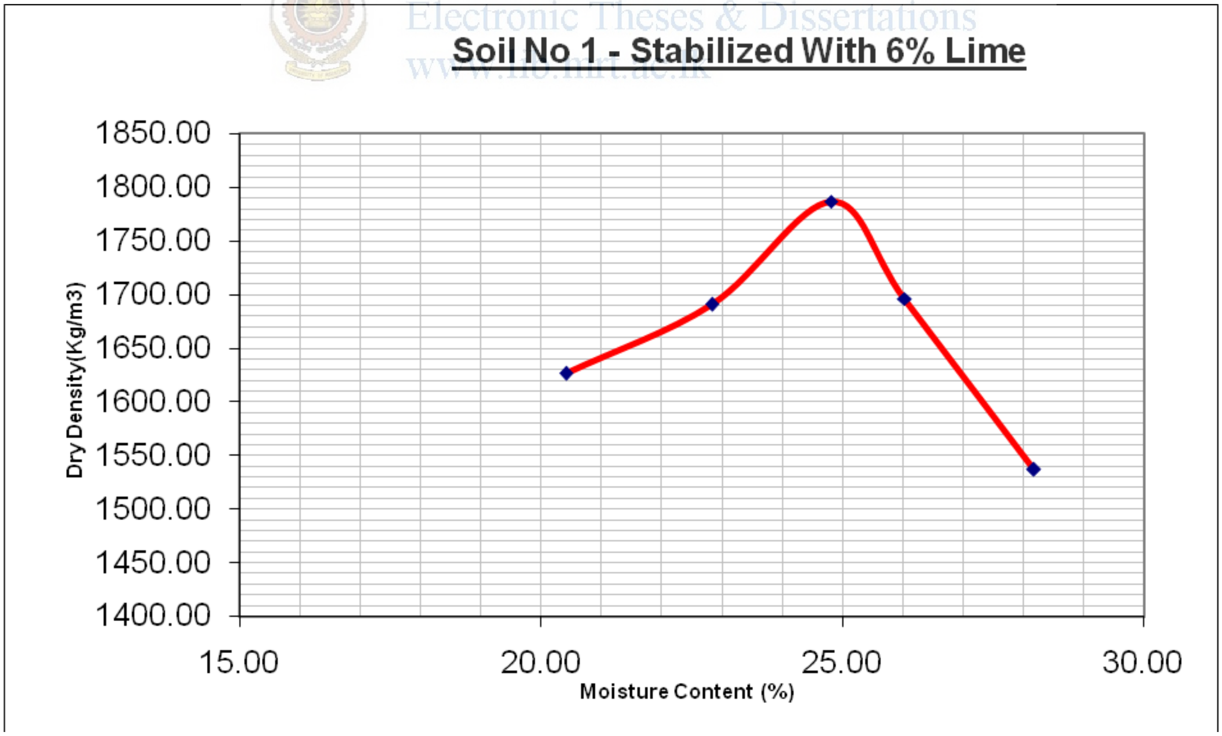
Calculation for OMC and MDD

Soil no : 1

Soil Condition : Stabilized With 6% Lime

Can weight (g)	Can + Wet Soil (g)	Can+ Dry Soil (g)	Moisture Content (%)
31.35	114.89	100.73	20.41
31.48	124.16	106.93	22.84
31.12	108.3	92.96	24.81
31.56	121.57	102.98	26.03
31.33	116.76	97.98	28.18

Sample	m1 Kg (mould)	m2 Kg (m1+ soil)	Ah	σwet =(m2-m1)/Ah*1000	m.c%	σdry=s wet/(100+w)
1	4.084	5.933	0.000944	1958.69	20.41	1626.69
2	4.084	6.045	0.000944	2077.33	22.84	1691.14
3	4.084	6.189	0.000944	2229.87	24.81	1786.67
4	4.084	6.102	0.000944	2137.71	26.03	1696.20
5	4.084	5.944	0.000944	1970.34	28.18	1537.20



Optimum Moisture Content – 24.5%

Maximum Dry Density – 1790 Kg/m3

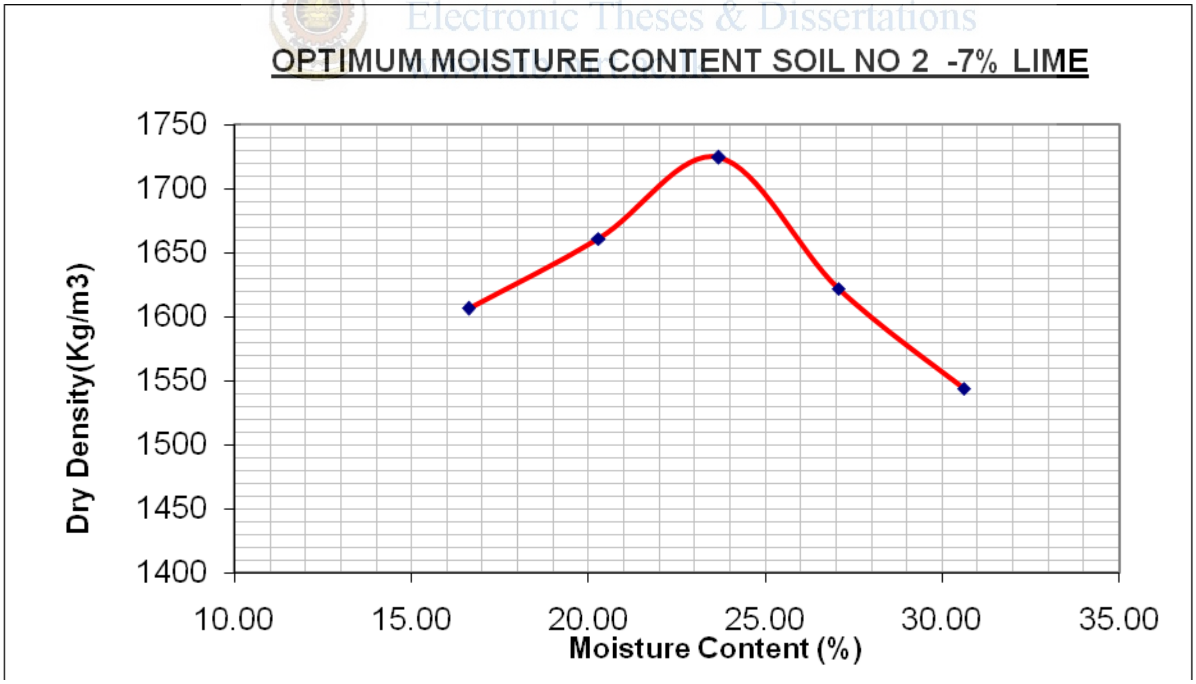
Calculation for OMC and MDD

Soil no : 2

Soil Condition : Stabilized With 7% Lime

Can weight (g)	Can + Wet Soil (g)	Can+ Dry Soil (g)	Moisture Content (%)
30.53	129.5	115.4	16.61
30.65	108.85	95.66	20.29
31.32	104.2	90.24	23.69
31.6	134.34	112.45	27.07
31.35	148.91	121.36	30.61

Sample	m1 Kg (mould)	m2 Kg(m1+ soil)	Ah	σwet =(m2-m1)/Ah*1000	m.c%	σdry=s wet/(100+w)
1	1.8994	3.6678	0.000944	1873.31	16.61	1606.42
2	1.8994	3.7852	0.000944	1997.67	20.29	1660.72
3	1.8994	3.913	0.000944	2133.05	23.69	1724.47
4	1.8994	3.845	0.000944	2061.02	27.07	1621.89
5	1.8994	3.803	0.000944	2016.53	30.61	1543.96



Optimum Moisture Content – 23.5%

Maximum Dry Density – 1725 Kg/m3

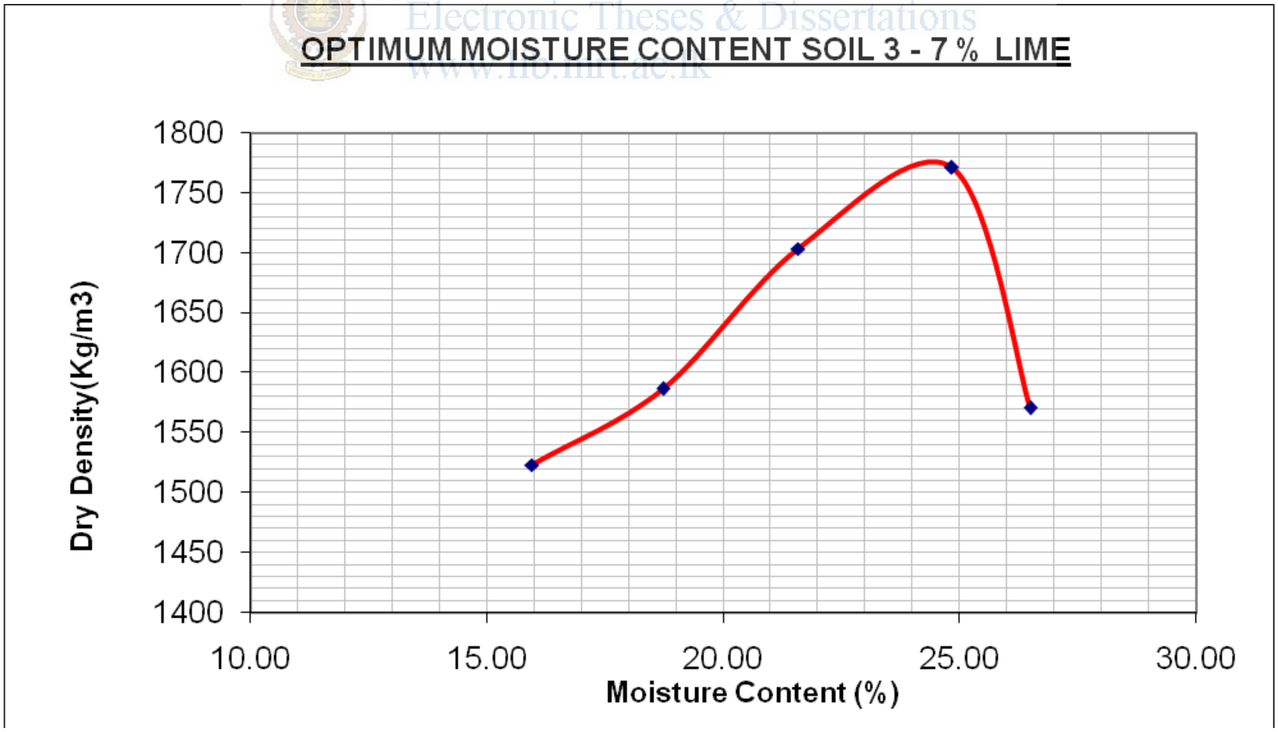
Calculation for OMC and MDD

Soil no : 3

Soil Condition : Stabilized With 7% Lime

Can weight (g)	Can + Wet Soil (g)	Can+ Dry Soil (g)	Moisture Content (%)
31.3	140.73	125.67	15.96
30.62	139.67	122.47	18.73
30.52	129.52	111.94	21.59
30.6	141.02	119.05	24.84
30.6	115.25	97.52	26.49

Sample	m1 Kg (mould)	m2 Kg(m1+ soil)	Ah	σwet =(m2-m1)/Ah*1000	m.c%	σdry=s wet/(100+w)
1	1.8994	3.567	0.000944	1766.53	15.96	1523.41
2	1.8994	3.678	0.000944	1884.11	18.73	1586.94
3	1.8994	3.855	0.000944	2071.61	21.59	1703.74
4	1.8994	3.987	0.000944	2211.44	24.84	1771.44
5	1.8994	3.775	0.000944	1986.86	26.49	1570.71



Optimum Moisture Content – 24.5%

Maximum Dry Density – 1775 Kg/m3

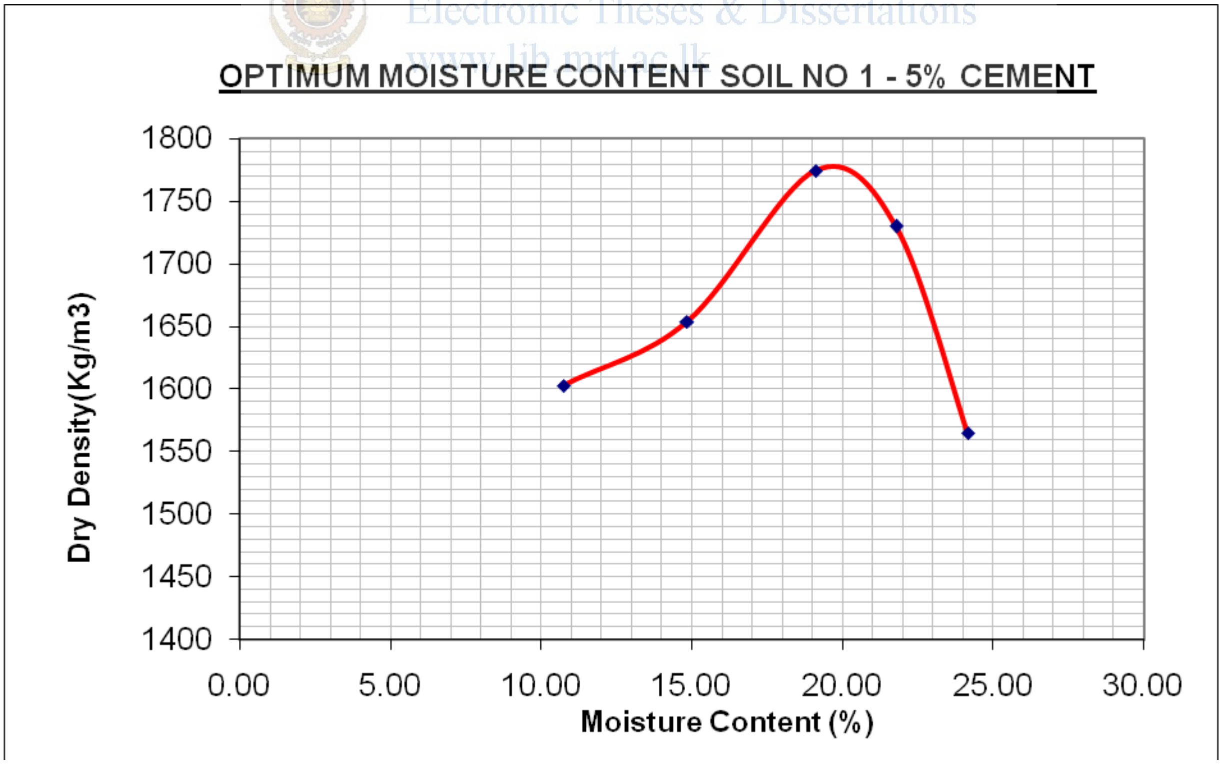
Calculation for OMC and MDD

Soil no : 1

Soil Condition : Stabilized With 5% Cement

Can weight (g)	Can + Wet Soil (g)	Can+ Dry Soil (g)	Moisture Content (%)
31.14	156.13	144	10.75
30.52	133.01	119.76	14.85
31.33	118.93	104.88	19.10
30.49	114.11	99.15	21.79
30.48	104.6	90.18	24.15

Sample	m1 Kg (mould)	m2 Kg(m1+ soil)	Ah	σwet =(m2-m1)/Ah*1000	m.c%	σdry=s wet/(100+w)
1	1.900	3.576	0.000944	1775.42	10.75	1603.12
2	1.900	3.693	0.000944	1899.36	14.85	1653.81
3	1.900	3.895	0.000944	2113.35	19.10	1774.39
4	1.900	3.889	0.000944	2106.99	21.79	1730.04
5	1.900	3.734	0.000944	1942.80	24.15	1564.83



Optimum Moisture Content – 20%

Maximum Dry Density – 1780 Kg/m3

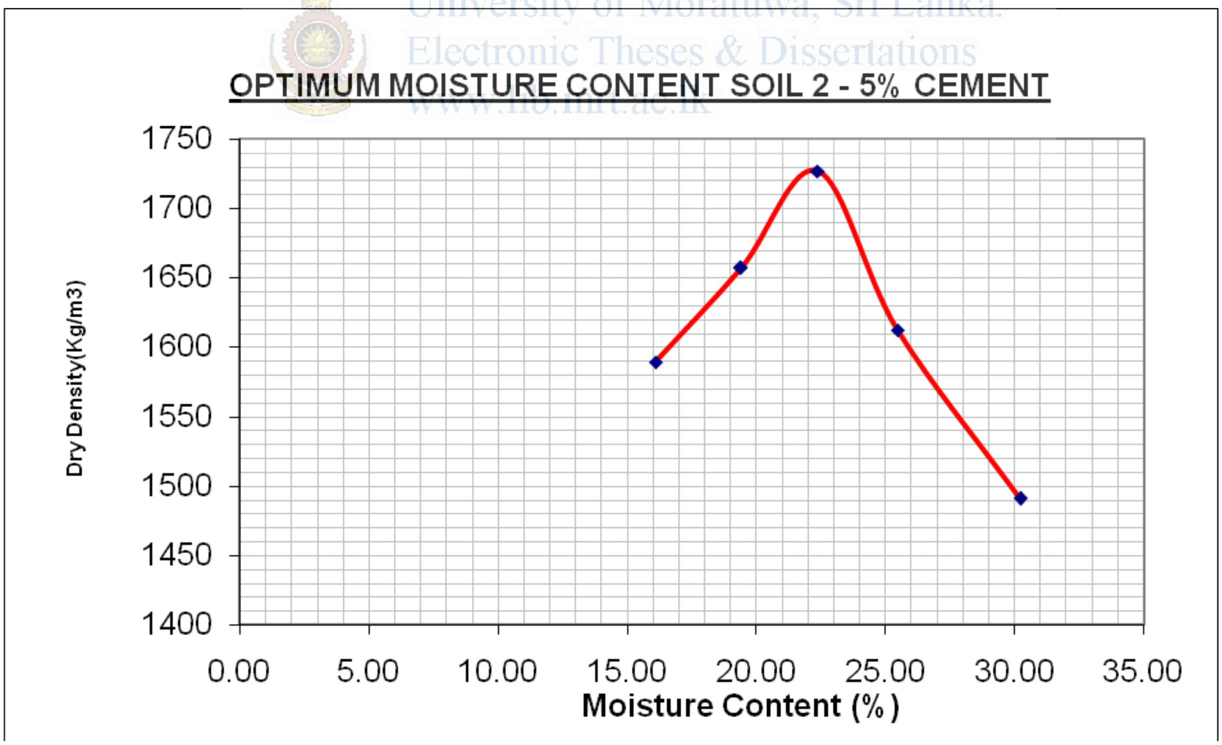
Calculation for OMC and MDD

Soil no : 2

Soil Condition : Stabilized With 5% Cement

Can weight (g)	Can + Wet Soil (g)	Can+ Dry Soil (g)	Moisture Content (%)
31.14	144.43	128.73	16.09
30.6	133.35	116.66	19.39
30.65	162.12	138.08	22.38
30.88	149.54	125.45	25.47
31.32	154.58	125.98	30.21

Sample	m1 Kg (mould)	m2 Kg(m1+ soil)	Ah	σwet =(m2-m1)/Ah*1000	m.c%	σdry=s wet/(100+w)
1	1.8994	3.641	0.000944	1844.92	16.09	1589.24
2	1.8994	3.767	0.000944	1978.39	19.39	1657.03
3	1.8994	3.894	0.000944	2112.92	22.38	1726.56
4	1.8994	3.809	0.000944	2022.88	25.47	1612.20
5	1.8994	3.732	0.000944	1941.31	30.21	1490.87



Optimum Moisture Content – 22%

Maximum Dry Density – 1730 Kg/m3

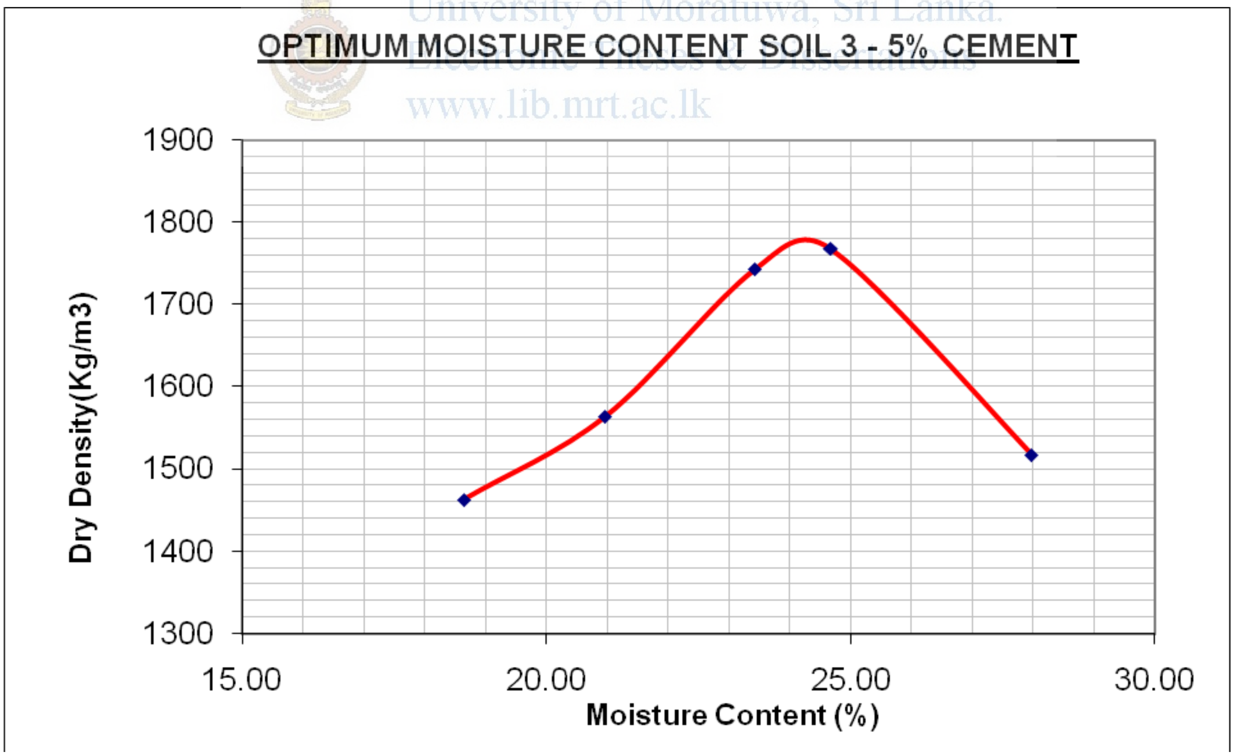
Calculation for OMC and MDD

Soil no : 3

Soil Condition : Stabilized With 5% Cement

Can weight (g)	Can + Wet Soil (g)	Can+ Dry Soil (g)	Moisture Content (%)
30.63	125.56	110.64	18.65
30.6	120.03	104.53	20.97
30.6	135.53	115.62	23.42
30.89	161.75	135.85	24.68
18.07	58.42	49.6	27.97

Sample	m1 Kg (mould)	m2 Kg(m1+ soil)	Ah	σwet =(m2-m1)/Ah*1000	m.c%	σdry=s wet/(100+w)
1	1.8994	3.5378	0.000944	1735.59	18.65	1462.81
2	1.8994	3.6856	0.000944	1892.16	20.97	1564.21
3	1.8994	3.93	0.000944	2151.06	23.42	1742.91
4	1.8994	3.98	0.000944	2204.03	24.68	1767.80
5	1.8994	3.7321	0.000944	1941.42	27.97	1517.05



Optimum Moisture Content – 24% Maximum Dry Density – 1780 Kg/m3