ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

PERFORMANCE OF UNCONVENTIONAL SOIL STABILIZERS IN STABILIZATION OF SUBSTANDARD MATERIALS FOR ROAD SUBGRADE & SUBBASE

BY

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By

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DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Dr. Mesele Haile and has not been presented as a thesis for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged.

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Symbols and Abbreviations

AASHTO - American Association of Highway and Transportation Officials

AACRA- Addis Ababa City Road Authority

ANSS- Anyway Natural Soil Stabilizer

ASTM- American Society for testing and Materials

CBR- California Bearing Ratio

CS- Clayey sand

ERA- Ethiopian Road Authority

GI - Group Index of AASHTO soil classification

LGC- Light grey clay

LL - Liquid Limit

MDD- Maximum Dry Density

OMC- Optimum Moisture Content

PI - Plastic Index

PL - Plastic Limit

RC- Red brown clay of Kolfe

SAS- Sub Arterial Street

SSC-Silty sand blended to red brown clay Kolfe

SS- Silty sand

USCS - Unified Soil Classification System

Abstract

Road connectivity is one of the key components for development, as it promotes access to economic and social services, generating increased income and employment. However, the construction of such economically vital sector is the most expensive of public works project undertaken by the society. Traditional pavement design and construction practices require high quality materials to fulfil minimum construction standards. In many of road projects it is very difficult to get standard materials with in economical haul distances.

There is an increasing effort around the world towards introducing innovative and unconventional road construction approaches that aim at reducing costs of construction by enabling use of marginal materials found with in the road route. One of proven technologies in connection to this effort is stabilization of soil. Stabilization can be derived from thermal, electrical, mechanical or chemical means. Chemical stabilizers can generally be categorized in to two broad categories: conventional and unconventional stabilizers. Traditional stabilizers such as cement lime, fly ash, and bituminous products have been intensely researched, and their fundamental stabilization mechanisms have been identified. Unconventional soil stabilization additives consist of a variety of chemical agents that are diverse in their composition and in the way they interact with the soil. Unfortunately, relatively little is known about their interaction with geotechnical materials or their fundamental stabilization mechanisms due to proprietary nature of commercial stabilization additives, their exact chemical compositions are not disclosed.

In this research two unconventional stabilizers were used for investigation of their effect on the engineering properties of soils that are deemed to be marginal for road subbase and subgrade. The two stabilizers used were: PURE CRETE and Anyway Natural Soil Stabilizer (ANSS). ANSS Natural Soil Stabilizer is claimed to be inorganic, hydration activated powder-based stabilizer that reacts with the soil particles to create layers that are interconnected through a complex inter-particle framework. The manufacturer claims PURE CRETE to be a complex non-bacterial concentrated multi-enzymatic formulation that alters the properties of earth materials, providing one of the most cost effective methods to stabilize roads and seal ponds and landfills.

The stabilizers were combined with a total of five different soils with classifications according to AASHTO as A-7-5, A-7-6, A-2-7, A-2-4, and A-2-6. ANSS stabilization induced the most improvement on engineering properties of all soils tested at manufacturer recommended dosages and PURE CRETE failed to show any improvement at manufacturer recommended application rate. However, at very high application rates modest effects were noticed.

It is recommended based on the results of this research that ANSS can be considered as a viable option for stabilization of subgrade soils after conducting durability tests. It will particularly help use of marginal materials where materials that met standard specifications are far away.

1. Introduction

1.1 Background

Road connectivity is one of the key components for nation's development, as it promotes access to economic and social services, generating increased agricultural income and productive employment. Rapid expansion of this important sector, however, is hampered by high budget required for construction. Absence of material that meets required specification within economical distance along the road route is among the leading reasons that owe to high construction cost. The problem is further exacerbated by social and environmental issues associated with excavation and disposal of substandard materials from the road section.

Traditional road design has centred on the use of gravel for construction, which provides a platform with increased load bearing capacity that is superior to the in-situ soil/material. This method of road construction has many limitations, especially when considering developing countries and regions. In many cases good quality gravel material for road construction is hard to find, or non-existent within an economically feasible distance to the site of construction, and requires heavy machinery that is not suited to labour-based practices [1].

The review of annual reports of road authorities and maintenance districts found in Ethiopia indicates that lack of adequate good construction materials that can be used for flexible pavement structure within reasonable distance along the road route is common constraint. This challenge made the issue to get due attention and resulted in the introduction of innovative approaches in roads building for achieving cost-effectiveness. One of the innovative technologies that enable use of soil and marginal aggregates along the road corridor is soil stabilization. In many parts of the world considerable research has been carried out following the paucity of good road making materials in an effort to find a cheap magical chemical which when added in small quantities to a soil, result in the rapid formation of a highly-stable pavement mixture.

Highway soil stabilization is a process by which a soil may be improved and made more stable. It includes treatments used to improve the strength of soil or waste material by reducing its susceptibility to the influence of water and/or traffic-irrespective of whether the process is performed in situ or applied to the material before or after it is placed in the roadway or embankment. The stabilized road material must offer sustained resistance to deformation under repeated loads in both wet and dry conditions. Stabilization is not similar with soil modification which is process of reducing plasticity and improving the texture of soil. However, stabilization includes the effect of modification with an additional long-term strength gain. Chemical stabilization is one of the methods widely used in highway soil stabilization. It involves mixing or injecting the soil with chemically active compounds such as Portland cement, lime, fly ash, calcium or sodium chloride or with viscoelastic materials such as bitumen. Chemical stabilizers according to Little and Nair [18] are broadly divided in to three groups:

1) Traditional stabilizers such as hydrated lime, Portland cement and Fly ash;
2) Non-traditional stabilizers comprised of sulfonated oils, ammonium chloride, enzymes, polymers, and potassium compounds; and
3) By-product stabilizers which include cement kiln dust, lime kiln dust etc.

Most of conventional soil stabilizers have well-established guidelines and well known stabilization mechanisms. As an alternative to these conventional bulk soil stabilizers, varieties of non traditional soil stabilizers, in concentrated liquid as well as powder form are supplied by different companies. It is quite difficult for users and researchers to independently assess the stabilization mechanism of unconventional soil stabilizers as the manufacturers understandably considered the chemical composition of their products to be proprietary. Some of manufacturers of these stabilizers are stating in their product information manuals that they will give performance warranties up to eight years for their products [26].

Ethiopia is distinguished for geographical diversities with mountains, hills, rivers, forest, wetlands, deserts, and scattered habitations in remote areas. Also, there exists a wide range in the subgrade soil types; these natural barriers augmented with financial constraints are becoming obstacles to those involving in the sector to improve rural as well as urban connectivity. These problems require adoption of different technologies based on site specific conditions. In this regard introducing technologies that enable use of locally available materials including marginal and industrial waste materials contribute a lot to reduce cost of road construction.

At present several new stabilization techniques have been developed in different countries. However, the use of such technologies is not widespread in our country. Therefore, there is a need to popularize these technologies and develop testing procedures for selecting appropriate stabilizers that can be used to build better rural roads with less cost.

1.2 Objective

The objective of this thesis is to investigate performance of two commercially available unconventional soil stabilizers in improving the engineering properties of soils that are deemed substandard for road subgrade and subbase construction in Ethiopia. It is also aimed at advancing current understanding of physical and chemical bonding mechanisms associated with these unconventional soil stabilizers.

1.3 Methodology

In order to achieve the objectives of this study the following approach is taken:

- Conducting qualitative analyses of stabilization mechanisms,
- Reviewing literature for supporting data,
- Conducting laboratory experiments on selected stabilization products to verify stabilization effect on the engineering properties of treated soil.

- The results of the laboratory test program were used to evaluate stabilization mechanisms, and pertinent conclusions were drawn about the potential of each material to stabilize soils
- Field visit to observe the application procedures in order to simulate the same to the extent possible during laboratory testing
- Analysis of test results.

1.4 Organization of the thesis

This thesis contains seven sections: Introduction, literature review, laboratory testing procedures and results, discussion, conclusions and recommendations, references, and annexes. A literature review containing description of soil stabilizers used in laboratory investigation, performance reports of unconventional stabilizers in different countries, and process of improving a soil's engineering properties is covered in section two. In the third section the testing procedures used during the study and the test results are presented. Discussion on the results is presented in the fourth section. In the fifth part conclusions and recommendations are given. Reference materials used in the research work are appropriately sited and listed in section six. The report closes with annexes which contain detail experimental results of laboratory investigation.

2. LITERATURE REVIEW

2.1 Process of improving engineering properties of highway soils

All types of soils are used to support and construct roads. Means to improve soil behaviour may be broken down into three major categories, with some overlap. The first category includes those methods that essentially mechanically rework materials, such as compaction. The second category, often referred to as modification, includes those methods that use agents to modify soil behaviour but do not necessarily increase shear strength or reduce compressibility. The third category, often called stabilization, includes the applications of agents, energy, or both to bind the soils together, primarily to improve shear strength and compressibility. Stabilization can be applied to all methods used but it implies a certain degree of long-term permanence of the improvement. The use of improvement of soil behaviour, with expected results, is the best way to describe soil treatment methods. Often it is more economical to provide such treatments to in situ and borrow materials, rather than replacing them or somehow avoiding them [2].

Soils are not inert materials; in fact they are chemical substances and will react with other chemicals if certain conditions are met. These reactions result from the attraction of positive and negative charges in the components of the soil and the chemical substances. If something happens to alter these charges, the reactions are changed and furthermore the properties of the materials are changed.

Acceptable road-building materials, particularly for low-volume roads, are becoming scarce, and consequently expensive, and in some cases environmental legislation practically prohibits the opening of gravel borrow pits. Some form of quality improvement needs to take place for poorer quality materials obtained in the road reserve to become usable in cost-effective pavements. Traditional stabilizers such as cement and lime are relatively expensive and become even more so when they have to be transported long distances to low-volume road construction sites [3].

2.2 Unconventional soil stabilizers

2.2.1 General classification and their behaviour

Currently various types of non traditional soil stabilizers are marketed. There is no well recognized classification for these products. Because of the proprietary nature of the commercial stabilization additives, their exact chemical compositions are also not disclosed. Different researchers tried to classify unconventional soil stabilizers into various categories. For example, Scholen classified them into two groups, i.e., chemical stabilizers and pozzolan stabilizers. The chemical stabilizers are in turn subdivided into five groups: sulfonated oils, ammonium chloride, enzymes, mineral pitches and acrylic polymers [4]. Based on their primary chemical components and proposed reinforcement properties, JS Tingle et al, classified most non-conventional additives into seven categories: ionic, enzymes, lignosulfonates, salts, petroleum resins, polymers, and tree resins [5]. The later classification is based on Scholen classification. In this research the second one has been adopted with some modification. A brief summary of each type of stabilizers is presented below.

i. Ionic stabilizers

These are petroleum products. Their reactive component behaves as surfactant, i.e., wetting agents that lower the surface tension of a liquid allowing easier spreading and lowering of the interfacial tension between to liquids. This reduces the surface tension of the compaction water and an ionic reactive material which contribute in neutralizing the exchangeable cation component of the soil and allows the adsorption of molecules with hydrophobic properties to the clay particles. The later behaviour, ionic exchange, is described by most of suppliers as the property that affects clay minerals and essentially waterproofs them against the deleterious effects of excessive soil moisture. Some of currently marketed non traditional soil stabilizers of this category are mentioned below.

Table 2.1: Ionic stabilizers found from literatures ([6], [4])

Item No	Name of Ionic stabilizer
1	Supersol (equivalent of Roadpacker from Canada)
2	Chem-road
3	CBR plus
4	Roadbond
5	Conaid classic
6	Roadamine (Roadplus in the Middle East)
7	Condor SS
8	SA44-LS40 (Dallas Roadway Product
9	EcSS 3000
10	ISS 2500

In the reaction process powerful hydrogen ions will be produced, which penetrate into the clay lattice, producing the breakdown of the structure and further release of moisture resulting in a dense soil structure [7]. Ionic stabilizers such as acids and alkaline additives have gained considerable attention due to small effective quantities used for stabilization as reported by commercial vendors [5].

ii. Enzyme stabilizers

An enzyme is by definition an organic catalyst that speeds up a chemical reaction, that otherwise would happen at a slower rate, without becoming a part of the end product. They are organic molecules that catalyze very specific chemical reactions if conditions are conducive to the reaction they facilitate. For an enzyme to be active in a soil, it must have mobility to reach a reaction site. The pore fluid provides means for mobility, the specific soil chemistry provides the reaction site, and time is needed for the enzyme to diffuse to the reaction site. In theory, an enzyme would stay active in a soil until there are no more reactions to catalyze. Enzymes would be expected to be very soil specific [5]. Each enzyme is specifically tailored to promote a chemical reaction within or between other molecules. The enzymes themselves are unchanged by these reactions; rather, they serve as a "host" or "matchmaker" for the other molecules, greatly accelerating the rate of normal chemical and physical reactions.

Researches reveal that the idea of using enzyme stabilization for roads was developed from the application of enzyme products used to treat soil in order to improve horticultural applications. A modification to the process produced a material, which was suitable for stabilization of poor ground for road traffic. When added to a soil, the enzymes increase the wetting and bonding capacity of the soil particles. The enzyme allows soil materials to become more easily wet and more densely compacted. These improve the chemical bonding that helps to fuse the soil particles together, creating a more permanent structure that is more resistant to weathering, wear and water penetration. Enzyme stabilization is commonly demonstrated by termites and ants in Latin America, Africa and Asia. Ant saliva, full of enzymes, is used to build soil structures, which are rock hard and meters high. These structures are known to stand firm despite heavy tropical rain seasons [7]. Some of the enzymes manufactured for soil stabilization and modification work of roads are given in Table 2.2 below.

Table 2.2: Some of enzyme products available [4]

Item No	Name of Enzyme	Supplier with Location
1	ClayPack / DuraPack	Soil Bond International, Texas
2	EMC^2	Soil Stabilization Products Co., Merced, California
3	Perma-Zyme 11X	ENFRA, LLC Anaheim, California (previously The Charbon Group, LLC)
4	*PSCS-320*	Alpha Omega Enterprises
5	Leviev ECOroads®	Leviev Development PLC, USA
6	Zym-tec	ECOMAX , Israeli Company
7	Fujibeton	Japan company

iii. Lignosulfonate Stabilizers

Lignosulfonate stabilization products including sodium, calcium, and ammonium lignosulfonates are derived from the lignin that binds cellulose fibres together. Because of the variations in the wood and plant source materials, the exact chemical composition of lignosulfonates varies. Lignosulfonates are primarily cementing agents with minor chemical effects depending on their composition. Most commercially available lignosulfonates are water soluble and susceptible to leaching under wet conditions [5].

Lignin is a major by-product of the paper-making industry. Pulp for the manufacture of paper and other products in the form of cellulose fibres has been produced from woody tissue by sulphite process which requires aqueous solutions of bisulphite and sulphurous acid to be used at high temperatures to dissolve lignin and some carbohydrates and leave behind the cellulose sulphite pulp fibres. The filtration process used to separate the pulp fibres leaves liquor which contains lignin sulphonates which are produced as calcium, magnesium, sodium or aluminium salts [8].

iv. Salt Stabilizers

Salt stabilizers generally consist of calcium, sodium and magnesium chloride compounds. Salts are hygroscopic, attracting moisture from the surrounding environment and maintaining the soil in a moist condition. Salts are very corrosive to metals and are susceptible to leaching because they are water soluble [5].

v. Petroleum resins

Two fundamentally different types of petroleum products that are commonly used for soil stabilization are: asphalt emulsions and synthetic isoalkane fluids. Typical asphalt emulsions consist of asphalt particles dispersed in water with an emulsifying agent, typically a surfactant that suspends the asphalt cement particles.

Synthetic fluids consisting of isoalkanes are also available that do not dry or cure with time. These products typically serve as a compaction aid by dispersing the soil particles and by reducing inter particle friction, allowing for rearrangement of the particles with less compactive effort. These products are also not miscible with water, serving as a waterproofing agent that reduces the moisture susceptibility of stabilized soils. Because these products do not offer a chemical or significant physical bonding, minimal improvement in strength would be expected. The evaluation carried out by Santoni et al on two of these types of additives with silty sand soil showed no discernible improvement in strength [5].

vi. Polymers

Polymer stabilizers are typically vinyl acetates or acrylic copolymers suspended in an emulsion by surfactants. It is reported that polymers typically used in soil stabilization have excellent tensile and flexural strength, producing physical bonds with excellent strength. As with asphalt cement, the polymers are resistant to water, providing excellent waterproofing of the coated particles and reducing susceptibility to moisture.

Table 2.3 Some of commonly marketed polymers [4]

Item No	Name of Polymer	Supplier with Location
1	ABS-65	Southwest Envirotech Services, Inc
2	Base Seal	Base-Seal International, Houston, Texas
3	Soil Seal	Soil Stabilization Product Co., California
4	*Top Seal*	Soils Control International, Killeen Texas
5	Top Shield	Base-Seal International, Houston, Texas

vii. Tree resins

Unlike lignosulfonates which are typically produced through controlled manufacturing processes, tree resins are relatively unprocessed by-products of the timber and paper industries. Emulsifying agents are added to prevent the premature coalescence of the resin.

Tree resin emulsions are used to coat individual soil particles with a film that binds the particles together.

viii. Molasses

Molasses used for highway soil stabilization purposes is a waste residue known as "black strap molasses" which is obtained as a by product of the manufacture of sugar cane. It is a very thick, syrupy liquid which contains resinous and some inorganic constituents which render it unfit for human consumption.

It has been reported that molasses are primarily used as a dust palliative and surface binder, usually in the form of surface treatments to roads which initially are mechanically stable. The outstanding limitation reported to its use is that it is readily soluble in water and will easily leach out of the pavement. However, with impermeable material used on the overlying layers, there appear to be no reason why molasses could not be used to improve the stabilities of soil-aggregate roadbases [8].

2.2.2 Information from supplier on unconventional stabilizers available in Ethiopia

In recent years various types of non traditional soil stabilizers have been introduced to Ethiopia by manufacturers and their agents. Most of these products are claimed to be proprietary as a result of which their composition is not known. Brief information obtained from manufacturers' manuals and application guidelines is discussed below.

a. CON-AID

The manufacturer claims that CON-AID has properties of a surface agent (surfacing related qualities). It is assumed that hydrophilic nature of the clayey material into hydrophobic nature. This reaction of CON-AID on clayey materials is particularly due to their ionic exchange capacities making clay particle spacing closer and transforming their properties. The owner claims that it is specially manufactured to ensure a long lasting stabilization of the soils. The product is reported to be totally water soluble with no solid residue, non-flammable, non-corrosive, non-toxic and safe, environment and user friendly [9].

The effect of Con-Aid on the Atterberg limits, moisture-density relationship and CBR of light grey clay subgrade soil samples collected from stations 31+720 up to 71+894 of Addis Ababa - Jimma road has been investigated in the laboratory by postgraduate student [10]. The result of this investigation indicated that the soil stabilizer did not cause significant effect on either of the soil properties when treated with manufacturer recommended rates. Besides this the Ethiopian Road Authority (ERA) has carried out field performance evaluation of Con-Aid on the road from Wolkite to Hossana. The Alemgena district of Ethiopian road authority carried out field evaluation and reported that satisfactory results have been obtained by using the stabilizer. However, ad-hoc committee established by ERA to evaluate the performance of the chemical based on Alemgena district did not agreed with what has been reported and recommended further investigation [11].

b. SA44/LS40 chemical

According to manufacturer user guideline SA-44 and LS-40 are proprietary soil stabilization products. SA-44 is distributed as a concentrated acid product and LS-40 is a concentrated lignin based product; lignins are organic based compounds which act as the "glue" in wood which bonds the wood cells. When SA-44 is diluted and mixed with soils containing 20% clay fines, or greater, the SA-44 creates a cation exchange with the clay molecule. When also mixed with LS-40 and structurally compacted immediately after application, a strong cementatious reaction occurs between the soil matrix as a result of both the chemical reaction and the lignin treatment. Long term road tests of clayey soils treated with SA-44/LS-40 show no appreciable loss of structural integrity when the roads are properly drained, but they will eventually rut under long-term action of standing water and repeated wheel loads over the road base. SA-44/LS-40 works with clayey sands, and both lean and fat clays. [12]. Laboratory evaluation has been carried out by postgraduate student and inconsistent results are obtained [13].

c. PURE CRETE

The product information manual [26] of the manufacturer states that PURE CRETE is a complex non-bacterial concentrated multi-enzymatic formulation that alters the properties of earth materials, providing one of the most cost effective methods to stabilize roads, seal ponds and landfill.

The manufacturer, PURE ONE Environmental Inc, claims that when mixed with water and applied prior to compaction, it acts upon organic fines contained in the soil through a catalytic bonding process, producing a strong cementation action. Unlike inorganic or petroleum based products which temporarily hold soil together, it causes the soil to bond during compaction into a dense permanent base which resists water penetration, weathering and wear. This process takes 72 hours under normal summer conditions. PURE CRETE formulation increases the wetting action of water for increased penetration to assist compaction to obtain greater soil densities. Also, it accelerates cohesive bonding of soil particles, creating a tight permanent stratum. In normal road construction methods, compaction in the 90 percent range is normal; however, with PURE CRETE compaction of up to 105 percent can be expected.

d. Zym-Tec Enzyme

Zym –tec is a synergistic mixture of enzymes, co-enzymes, binders, catalysts, wetting agents, surfactants and water which is introduced to Ethiopia in 2009 by i-Tec-W Ltd. According to the manufacturer, it is non-toxic and non combustible.

The underlying concept here is to complete the base layers using zym-Tec and apply Tec-pavement as a spray on topping. The materials to be used in the base layers is in situ natural soil or any recycled or waste materials.

A demonstration section of 300m long and 7m width has been constructed adjacent to Imperial Hotel on principal arterial street in Addis Ababa on a by this company in June 2009.

Although the duration after construction completion is not long, no defects have been observed up to the completion of this thesis work.

2.3 Mechanisms of stabilization of unconventional soil stabilizers

Conventional soil stabilizers like cement, lime, class c fly ash, and bituminous products have been intensely researched, and their basic stabilization mechanisms have been identified. In contrast to this, comparatively modest information is available about unconventional soil stabilizers mechanism of stabilization. Most laboratory and field experimentation with non traditional additives have focused on performance evaluation instead of mechanism identification as a result of which little literature is available concerning stabilization mechanisms [5].

It has been hypothesised by Scholen [14] that electrolytes or ionic stabilizers alter the electrolyte concentration of the pore fluid, which results in cation exchange and flocculation of the clay minerals. As the clay minerals attract stronger cations from the ionic electrolyte pore fluid, the higher valence cations collapse the clay structure into a more stable configuration exuding excess double-layer water in the process [14]. Adsorption of ions by soil particles, ionic reactions with soil constituents, and ion exchange alter the molecular structure of the soil. These reactions reduce the surface charge of the soil particles, resulting in loss of double-layer water and allowing for close packing or even flocculation of the soil particles. This process is illustrated in Fig 2.1

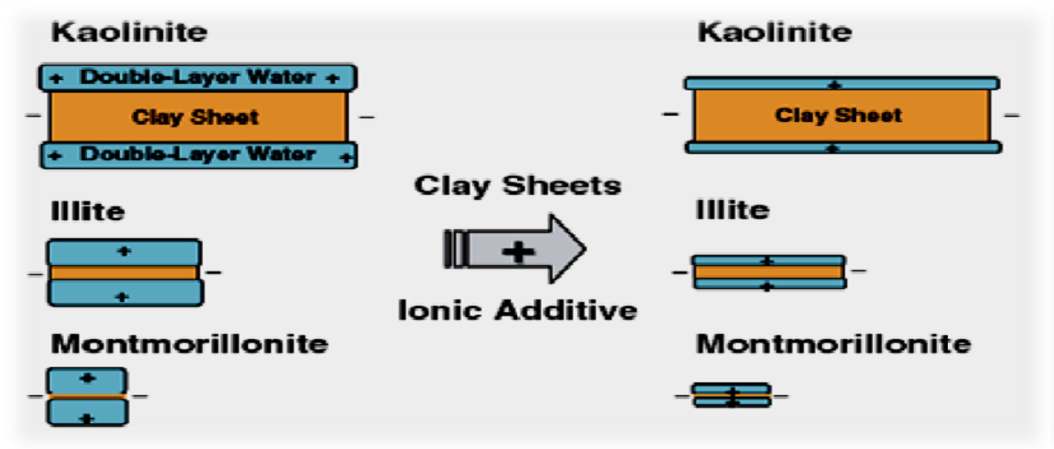


Figure 2.1: Proposed stabilization mechanism of ionic stabilizer [5]

The above mechanism of ionic stabilizers would be particularly important for smaller clay minerals such as montmorillonites where the double-layer water is significantly larger than the size of the montmorillonite particle sheets. The resulting clay material should demonstrate reduced plasticity, reduced swell potential, and reduced particle size. Unfortunately, the effect on the molecular structure due to changes in the electrolyte pore fluid from alkali to acidic or vice versa usually occurs over long periods of time [14].

The proposed mechanism for ionic stabilizers suggests that these additives are suitable only for fine-grained soils, silts, and clays, where the electrical charges of the particles and pore fluid significantly affects the soil behaviour. In addition, the ionic stabilizers should be more effective as the particle size decreases because of the increasing importance of the double-layer water in inter-particle behaviour. As this process requires cation exchange, the cation exchange capacity may be an important variable for evaluating the suitability of ionic additives for specific soils. Additionally, because of the varying chemical composition, very specific reactions may occur with one soil–product combination and not another. Thus, only certain soils would be expected to respond well to ionic stabilizers. Granular soils would be unsuitable for stabilization with ionic additives that rely on the mechanism described here [5].

Preliminary laboratory investigation of enzyme solution as a soil stabilizer done by the university of Minnesota department of civil engineering revealed that enzymes are adsorbed by the clay lattice, and then released upon exchange with metals cations. These have an important effect on the clay lattice, initially causing them to expand and then to tighten. According to this study enzymes can be absorbed also by colloids enabling them to be transported through the soil electrolyte media. The enzymes also help the soil bacteria to release hydrogen ions, resulting in pH gradients at the surfaces of the clay particles, which assist in breaking up the structure of the clay. This study indicated that enzyme combines with the large organic molecules to form a reactant intermediary, which exchanges ions with the clay structure, breaking down the lattice and causing the cover-up effect, which prevents further absorption of water and the loss of density. The enzyme is regenerated by the reaction and goes to react again. As the ions are large, little osmotic migration takes place and a good mixing process is required. Compaction of aggregates near the optimum moisture content by construction equipment produces the desired high densities characteristic of shale. The resulting surface has the properties of durable "shale" produced in a fraction of the time (millions of years) required by nature [7]. Scholen [14] proposed that the enzymes could bond with large organic molecules that would be attracted to the clay minerals' net negative surface charge. The large organic molecules would then surround the clay minerals, neutralizing the negative charge and reducing the clay's affinity for moisture. The end result of both proposed mechanisms is a more stable clay lattice structure and a reduced affinity for moisture [14]. The proposed mechanism would indicate that enzymes are appropriate only for use with clay materials that have an affinity for water, particularly high- plasticity clays with some organic content. Materials such as silts and granular soils would not possess a significant affinity for water and would be unsuitable for stabilization with enzyme products. The proposed mechanism suggests that the use of enzymes will also be critically dependent on the environmental conditions and may take considerable time to occur.

The literature available on stabilization mechanism of lignosulfonates indicates that they coat individual soil particles with a thin adhesive-like film which binds the particles together. Lignosulfonates are primarily cementing agents with minor chemical effects depending on their composition. The cementing effect stabilizes the soil by physically bonding soil particles together. However, as these products are also ionic, they have a capacity for ion exchange and reactions with some soils. Most commercially available lignosulfonates are water soluble and susceptible to leaching under wet conditions [5].

Salts, particularly chlorides, in water-soil mixtures cause an increase in the surface tension of the water. This, in turn, helps the water films to cause the compacted particles to tighten together thereby increasing the density and stability of the material. They are good soil lubricants with the result that given soils dry density can be obtained with less compactive effort than if water only is used [8].

The proposed stabilization mechanisms of salt additives suggest that the materials may be suitable for both granular and fine-grained soils. In granular soils, the hygroscopic characteristics of salt stabilizers may be used to aid compaction and the re-crystallization may form weak physical bonds between soil particles. Additional improvement in strength due to increased surface tension of pore water may also be disclosed. For fine-grained soils, particularly clays, the hygroscopic properties may improve the soil's cohesion by preventing the soil from drying. Cation exchange in clay soils can result in permanent stabilization effects. These mechanisms, with the exception of cation exchange, offer relatively moderate strength improvement benefits compared with other additives.

The polymer stabilizers coat soil particles, and physical bonds are formed when the emulsion water evaporates, leaving a soil–polymer matrix as reported in literature. As with asphalt emulsions, the emulsifying agent can also serve as a surfactant, improving penetration for topical applications and particle coating for admix conditions. Because the primary stabilization mechanism is physical bonding, the improvement in strength depends on the ability to coat the soil particles adequately and on the physical properties of the polymer. Thus, stabilization with polymer emulsions is suitable for granular materials but is less effective in fine grained soils because of reduced mixing efficiency resulting from their high specific surface area. [5].

Tree resins, like lignosulfonates are principally cementing agents that physically bond soil particles together. They are used to coat individual soil particles with a film that binds the particles together. Similar to polymer emulsions, tree resins are suitable for granular materials but are less effective in fine-grained soils because of reduced mixing efficiency as reported by different researchers [5].

Black strap molasses is a hygroscopic material and this enables it to take up moisture from the air and to control the evaporation of water from the soil-aggregate pavement as it is being compacted. It is also a cementing agent; unfortunately, however, the cement formed is water soluble, but if water can be kept away, the binding cation is very strong [8].

In summary, attempts to define the fundamental reinforcement mechanisms of non-traditional stabilization additives have been limited. Laboratory experimentation has focused on evaluating the effects of stabilized materials on engineering properties with minimal understanding of the stabilization mechanisms.

2.4 Minimum requirements of stabilized soils for road construction in Ethiopia

The ERA pavement design manual of 2002 sets the minimum requirements to be met by cement, lime and lime-Pozzolan treated materials depending on their position in pavement layers as shown in Table 2.4 below. The manual suggests stabilization of many natural materials to make them suitable for road pavements but this process is only economical when the cost of overcoming a deficiency in one material is less than the cost of importing another material which is satisfactory without stabilization. According to the ERA standard technical specification of 2002 the material to be stabilized shall have a minimum coefficient of uniformity of five. Besides this the manual suggested not to use these stabilizers for soils in which sulphates are present [15].

Table 2.4: Properties of Cement and Lime Stabilized Materials [15]

Code	Description	Unconfined compressive strength* (Mpa) (Cement Stabilized)	Minimum CBR Value* (%) (Lime stabilized)
CB1	Stabilized base course	3.0 - 6.0	100
CB2	Stabilized base course	1.5 - 3.0	80
CS	Stabilized sub-base	0.75 - 1.5	40

* Strength tests on 150 mm cubes

Note: CB1-Cement or lime stabilized roadbase1
CB2- Cement or lime stabilized roadbase2
CS- Cement or lime stabilized subbase

3. Laboratory testing procedures and results

In this section a description of the testing procedures followed as a part of this research will be discussed. Standard procedures of ASTM and AASHTO have been used where possible and adjustments to standard procedures are noted.

3.1 Materials Used

3.1.1 Native soil

The selection of test soil samples for laboratory investigation is carried out based on information obtained from previous researches [13] about the quality of prevailing soil types in the area for road construction. Based on this information two soil types that were used by previous postgraduate students of Addis Ababa University are collected from Bole and Kolfe High Schools found in Addis Ababa. In addition to this, to diversify types of soils for the investigation work, two additional types of soils were also brought from two road construction sites that were active at the time of sample collection. One of the two roads, Adje-Ropi RR 50 rural road, is found in West Arsi Zone of Oromia region at about 280kms from Addis Ababa. Soil samples are collected from the subgrade of this road. In order to meet the requirement of soil composition requirement for PURE CRETE treatment [27], laboratory blending was conducted, i.e., 80% of silty sand from Adje-Ropi RR 50 road subgrade material is blended with 20% red clay soil of Kolfe. Fig 3.1 gives information about the soils.

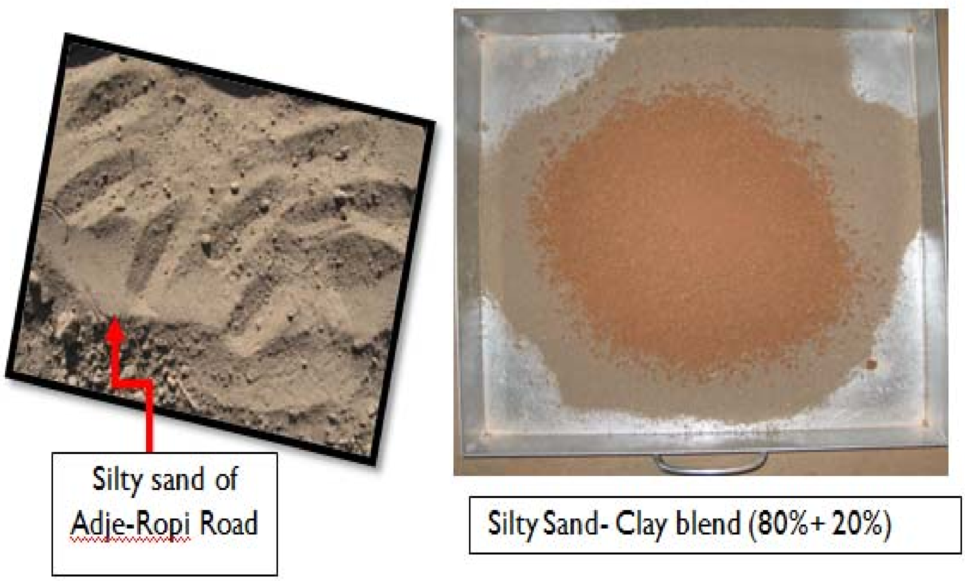


Figure 3.1 silty sand from Adje-Ropi rural road and silty sand –clay blend

The other road is sub arterial street (SAS-2) that was under construction by AACRA in between Ethiopian Civil Services College main and new campus in Addis Ababa. The material collected from this construction site is a waste to disposal material hauled to the site for grade adjustment as well as construction of stabilized subbase using ANSS. The sample is collected from the location shown in Fig 3.2.

Fig 3. 2: Picture of Sub Arterial Street of Civil Service College- source of clayey sand

The native soil properties have been determined according to standards listed in table 3.1 below.

Table 3.1: Standard testing procedures

No	Test Description	ASTM	AASHTO
1	Grain Size Analysis	D422-98,D2217-98	
2	Atterberg Limit	D4318-98	
3	Moisture- Density -Relationship	D698-98, D1557-98	
4	California Bearing Ratio (Laboratory)	D1883-98	T 193-93
5	Classification of soils	D3282	
6	Standard Guide for Evaluating Effectiveness of Chemicals for Soil Stabilization	D609-98	

3.1.2 Soil stabilizers investigated

Among commercially available stabilizer two of them are selected for laboratory investigation in this research. The criteria used for selection is willingness of agents to supply the product for laboratory investigation. PURE CRETE and ANSS are the two unconventional stabilizers selected. Brief discussion of products is given below.

i. PURE CRETE

As mentioned earlier PURE CRETE is proprietary, concentrated, biodegradable, non bacterial multi- enzymatic formulation. Procedure for calculation of application rates is given by manufacturer, PURE One Environmental Inc.

The PURE CRETE required for a section to be treated depends on the length, width and thickness of the road. According to technical manual of the manufacturer one litre of PURE CRETE enables to treat 33 cubic meter of soil. Typical calculation example given by the manufacturer is shown on Table 3.2 below.

Table 3.2: PURE CRETE application rate calculation work sheet

Item No	Item description	Unit	Quantity
1	Width of road to be treated	m	8
2	Length of road to be treated	m	1000
3	Thickness of pavement layer to be treated	m	0.152
4	Volume of material to be treated (Item1*Item2* Item3)	m^3	1216
5	Standard application rate of PURE CRETE per 33 cubic meter of soil	litre	1
6	PURE CRETE required for the volume of work in item 4 above (Item 4/ 33)	litre	36.85

The water required for materials found in the road section to bring up to optimum moisture content will be calculated from density-moisture-relationship and PURE CRETE obtained above will be mixed thoroughly in appropriate truck mounted water tanks or equivalent thereof. Typical example that helps on how to find application rate of the enzyme is shown in Table 3.3 below.

Table 3.3: PURE CRETE application rate calculation work sheet

Item No	Item description	Unit	Quantity (example)
A	Soil dry density	Kg/ m^3	1602
B	Optimum moisture determined in the laboratory	%	12
C	Existing moisture determined in the laboratory	%	2
D	Net moisture to be added (= Item B- Item C)	%	10
E	Water required per cubic meter of soil (=Item A * Item D)	litre/ m^3	160.2
F	Standard volume of material to be treated by one litre of PURE CRETE	m^3	33
G	Amount of water required for one litre of PURE CRETE (= Item E* Item F)	litre	5286.6

There fore, the application ratio (PURE CRETE: Water) for this typical example is 1:5287.

The application rate recommended by the manufacture was not able to show improvement on soil samples treated. As a result of this higher application rates, two times and four times manufacturer recommended rate, have been used in the performance evaluation process.

The manufacturer suggests that the application rate should not exceed 1: 500 for PURE CRETE water mixture to easily penetrate into the soil.

ii. Anyway Natural Soil Stabilizer (ANSS)

According to the manufacturer, dosage to be applied for stabilization depends on the type of soil. In this research no effort has been made to find appropriate dosage rate for different types of soils. Performance evaluation has been conducted based on the dosage currently in use by manufacture's Ethiopia agent for construction of roads in Addis Ababa. Accordingly for expansive light grey clay soils obtained from Bole senior secondary and preparatory school compound and clayey sand from sub arterial road, 6% by dry weight of ANSS has been used and for all other soils 4% by dry weight of soil sample has been used.

3.2 Laboratory Testing

3.2.1 Soil-Preparation

Since manufacturers technical manuals for both stabilizers under investigation did not recommended variation from the standard sample preparation methods, standard procedures were used for sample preparation. However, ANSS application manual recommends that the product should not be left open for more than one hour and should not be stored in wet surfaces. Soil samples brought from different locations were exposed to air at room temperature until dried thoroughly. The aggregation has been broken up using rubber hammer (mallet). Mixing of PURE CRETE with the water was performed using mechanical stirrer to obtain uniform mixture as shown in Fig 3.3 below. ANSS is mixed to soil manually as shown in Fig 3.4.

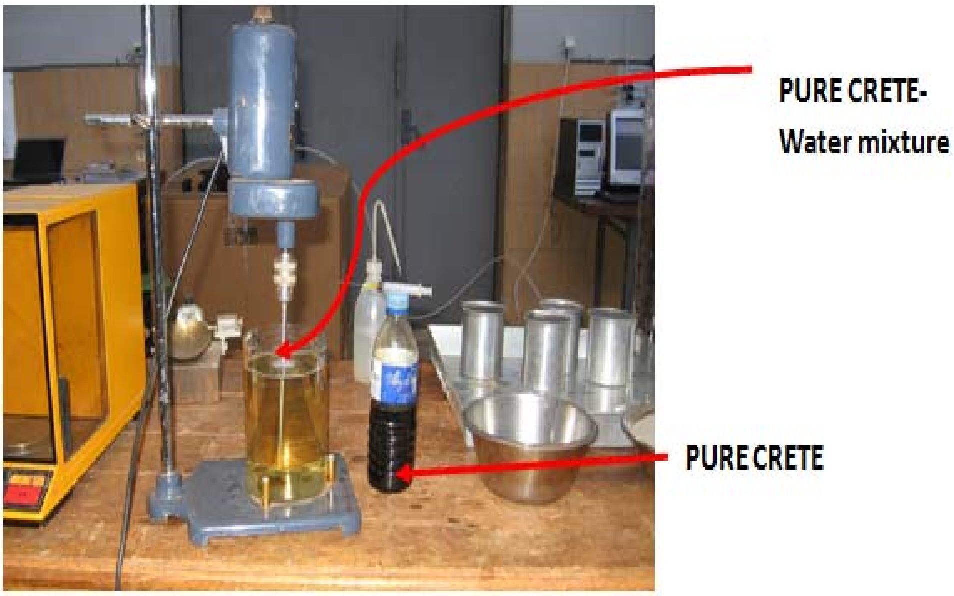


Figure 3.3: Laboratory mixing of PURE CRETE with water using mechanical stirrer

Figure 3.4: Mixing ANSS with soil for compaction test in the laboratory

3.2.2 Atterberg limit

Liquid and plastic limit tests were carried out on untreated as well as treated soil samples. For the tests, material passing No 40 (425μm) sieve were used. For soil samples treated with PURE CRETE, application rate of two and four time's manufacturer rate indicated on Table 3.4 were used.

Table 3.4: Application ratio with PURE CRETE used for Atterberg limit test

Item No	Soil type	Application rate (PURE CRETE: Water)
1	Light grey clay (LGC-2PC)	1:5676
2	Light grey clay (LGC-4PC)	1:2828
3	Red brown clay (RC-2PC)	1:5663
4	Red brown clay (RC-4PC)	1:2831
5	Silty sand blended with red clay (SSC-2PC)	1:5456
6	Silty sand blended with red clay (SSC-4PC)	1:2728
7	Clayey Sand from Civil Service (CS-2PC)	1:4541
8	Clayey Sand from Civil Service (CS-4PC)	1:2270

After consultation with the supplier's technical staff at Addis Ababa the following dosages were used for samples treated with ANSS.

Table 3.5: Application rates with ANSS used for Atterberg limit test

Item No	Soil type	Dilution rate (% of dry weight)
1	Light grey clay (LGC)	6
2	Red brown clay (RC)	4
3	Silty Sand blended with red clay (SSC)	4
4	Clayey Sand from Civil Service (CS)	6

The soil additives mixture was allowed to mellow at room temperature for 24hrs. In order to investigate performance of the additives with time seven days curing was allowed. In the duration of curing the samples were placed in glass desiccators so as to control moisture fluctuation. Atterberg limits were then determined in accordance with ASTM D4318. The summary of Atterberg limits test results for soil-additive mixtures are presented in Table 3.6. Detail results and graphs are given in Annex-B.

Table 3.6: Atterberg Limits Values with PURE CRETE

Soil Type	Curing in days	Liquid Limit			Plastic Limit			Plasticity Index		
		Without Treatment	Treated with two times manufacturer's application rate	Treated with four times manufacturer's application rate	Without Treatment	Treated with two times manufacturer's application rate	Treated with four times manufacturer's application rate	Without Treatment	Treated with two times manufacturer's application rate	Treated with four times manufacturer's application rate
Light grey clay	0	129.35	128.5	128.4	43.6	41.85	42.55	85.75	86.65	85.85
	7		107.5	118.9		43.68	42.65		63.82	76.25
Red clay	0	61.77	60.35	61.29	29.03	26.99	27.11	32.74	33.36	34.18
	7		60.54	58.77		29.7	32.15		30.80	26.62
Silty sand blended with red clay	0	40.28	39.1	39.36	26.97	26.56	26.35	13.31	12.54	13.01
	7		38.08	35.89		28.55	28.8		9.53	7.09
Clayey sand	0	54.83			29.50			25.33		
	7		49.02	48.80		26.0	25.90		23.02	22.9

In similar way Atterberg test results for soil samples that received ANSS treatment are presented in Table 3.7. Flow curves as well as detail results are presented in Annex B.

Table 3.7: Atterberg Limits results after treatment with ANSS

Soil Type	Curing in days	Liquid Limit		Plastic Limit		Plasticity Index	
		Without Treatment	Treated with 6% / 4% ANSS	Without Treatment	Treated with 6% / 4% ANSS	Without Treatment	Treated with 6% / 4% ANSS
Light grey clay	0	129.35		43.6		85.75	
	7		93.2		52		41.2
Red clay	0	61.77	54.79	29.03	36.47	32.74	18.32
	7		58.88		36.74		22.14
Silty sand blended with red clay	0	40.28		26.97		13.31	
	7		47.24		38.0		9.24
Clayey sand	0	54.83	58.95	29.50	44.89	25.33	14.05
	7		54.13		47.97		6.16

3.2.3 Grain size analysis and classification

The grain-size analysis is carried out to determine the relative proportions of different grain sizes which makes up a given soil mass. It is not actually possible to determine the individual soil sizes as the test only brackets various ranges of sizes [19]

Both mechanical sieve analyses as well as hydrometer analysis were conducted and summary of results are presented here in Table 3.8. All data with the corresponding graphs are shown in annex E.

Table 3.8: Sieve analysis results for untreated samples before and after compaction

Item No	Soil type	Percent passing #200 sieve	Percent passing #40 sieve	Percent passing #10 sieve
1	Light grey clay (LGC)	97.83	99.83	100
2	Red brown clay (RC)	94.87	99.30	100
3	Silty sand (SS)	26.5	74.53	98.12
4	Clayey sand from Civil Service College (CS)	33.24	64.44	82.73

The grain size analysis with additives was not tested as the washing as well as pulverization process will damage the bonding that might be developed during curing.

To classify the soils in to appropriate categories grain size analyses as well as Atterberg limit tests have been used. Based on these results the soil samples are categorized with the help of standard practice for classification of soils, ASTM D2487-98 and ASTM D-3282-93. The Unified Soil Classification System (ASTM D-2487-98) describes a system for classifying mineral and organo-mineral soils for engineering purposes based on laboratory determination of particle-size characteristics, liquid limit and plasticity index and used when precise classification is required [23]. Based on analysis carried out using the above two ASTM standard practices, resulting classifications are presented in Table 3.9 below.

Table 3.9: Classification of soil samples investigated

Standard Practice	Location and classification of samples collected				
	Bole High School	Kolfe High School	Sub Arterial Street (SAS-2) between Ethiopian Civil Service College Campuses	Adje-Ropi RR-50 road subgrade material	Material blended in the laboratory *(20% Kolfe +80% Adje-Ropi)*
ASTM D 2487-98 (Unified soil classification System	CH (Fat clay)	CH (Fat Clay)	Clayey sand	Silty Sand	Silty sand
ASTM D3282-98 (Classification for Highway construction)	A-7-6(41)	A-7-5(19)	A-2-7(2)	A-2-4	A-2-6

In addition to the above classification visual inspection carried out during sampling indicates that fat clay from Bole secondary school compound has light grey colour as a result the term “Light Grey Clay” with designation of “LGC” is used in this research. In similar fashion, the sample from Kolfe secondary school is termed as “Red Cay” with designation of “RC”; for soil from Sub Arterial Street (SAS-2) that passes between the two campuses of Ethiopian Civil Service College the term “clayey sand” with designation of CS is used; the soil from Adje-Ropi is designated as “SS” which stands for silty sand; and the material blended in the laboratory is given a name “silty sand clay blend” with a designation of “SSC”.

3.2.4 Moisture- density relationships

After determining natural moisture content of native (untreated) soil, the samples were compacted according to ASTM D698 to find moisture-density relationships of untreated soil samples.

The PURE CRETE-water mixture at two and four times manufacturer application ratio was added to soil samples and mixed to a uniform consistency. The samples were set aside for overnight prior to compaction to simulate standard construction delay. After the 12-hour delay period, the samples were compacted according to ASTM D698. However, the results obtained with PURE CRETE treatment even at very high application rates has shown no difference from untreated soil samples and as a result the data is not incorporated to this report to overcome page limitation of the thesis.

The soil and ANSS were dry mixed together and water was added to bring the moisture content up to the target percent. After mixing, soil-ANSS mixtures were placed in airtight container to mellow overnight before compaction.
By curing treated samples for seven days in sealed water tight containers and then compacting, effect of curing on optimum moisture content and dry density were investigated. The summary of optimum moisture content and maximum dry density for untreated as well as ANSS treated samples are presented in Table 3.10 below. Dry density against moisture content graphs and results are shown in annex C in detail.

Table 3. 10: Optimum moisture contents and maximum dry densities for untreated samples

Soil Type	Curing in days	Optimum moisture content %		Maximum dry density in g/cc	
		Without Treatment	Treated with 6%ANSS / 4% ANSS	Without Treatment	Treated with 6%ANSS / 4% ANSS
Light grey clay	0	38		1.22	
	7		35		1.285
Red clay	0	30.5		1.362	
	7		29		1.42
Silty sand blended with red clay	0	29		1.248	
	7		25		1.42
Clayey sand	0	28		1.426	
	7		26		1.54

3.2.5 California Bearing Ratio (CBR) test

The CBR test measures the shearing resistance of a soil under controlled moisture and density conditions. The CBR number is used to rate the performance of soils primarily for use as bases and subgrades beneath pavements for roads and airfields [19]. CBR tests were made on the specimens at the optimum moisture value for the soil as determined using standard compaction. In order to compare the results with previous studies both one point and multiple point CBR tests were carried according to AASHTO T193-93 and ASTM D1883-98. All CBR tests samples are compacted in the molds with standard hammer. To investigate the effect of additives on the specimens, compacted specimens were given 7 days curing in CBR molds at room temperature as shown in Fig 3.5. During curing period the compacted specimens were subjected to surcharge loads to simulate the overlying load in the actual pavement section. At the start and end of curing period weight of specimens were measured to note effect of curing on the samples.

Figure 3.3: Samples under curing at room temperature in CBR molds

Summary of normalized CBR results for untreated and PURE CRETE treated are presented in Table 3.11 below and detail information including plot of load versus penetration for soaked samples are shown in Annex D. In addition to this swell measurement were also taken.

Table 3.11: Summary of CBR for PURE CRETE treated and untreated samples

Soil Type	Curing in days	CBR of untreated and PURE CRETE treated soil specimens		
		Without Treatment	Treated with 2 times manufacturer's application rate	Treated with 4 times manufacturer's application rate
Light grey clay	0	0.97	0.96	0.92
	7	1.16	1.23	0.92
Red clay	0	7.63	7.5	7.73
	7	8.7	9.0	11.3
Silty sand blended with red clay	0	16.9	17.17	17.17
	7	18.1	24.67	31.63
Clayey sand	0	2.3	2.27	2.27
	7	2.9	3.2	3.4

The average results obtained for ANSS treated specimens are presented in Table 3.12 and for details annex D can be referred.

Table 3.12: Summary of CBR for ANSS treated samples

Soil Type	Curing in days	CBR of untreated and ANSS treated soil specimens	
		Without Treatment	Treated with 6% or 4% ANSS
Light grey clay	0	0.97	Not performed
	7	1.16	15.2
Red clay	0	7.63	14.49
	7	8.7	30.0
Silty sand blended with red clay	0	16.9	Not performed
	7	18.1	99.8
Clayey sand	0	2.3	13.19
	7	2.9	14.2

3.2.6 Swelling properties

Swelling refers to the localized volume changes in expansive soils as they absorb moisture. Swelling or expansive soils are susceptible to volume change (shrink and swell) with seasonal fluctuations in moisture content. The magnitude of this volume change is dependent on the type of soil (shrink-swell potential) and its change in moisture content. A loss of moisture will cause the soil to shrink, while an increase in moisture will cause it to expand or swell. This volume change of clay type soils can result in longitudinal cracks near the pavement's edge and significant surface roughness (varying swells and depressions) along the pavement's length [21]. Studies conducted by postgraduate student indicate that expansive soils pose very significant problem in many parts of Ethiopia and are responsible for the application of premature maintenance and rehabilitation activities on many kilometres of roadway each year [20]. Expansive soils are especially a problem when deep cuts are made in a dense (over-consolidated) clay soil.

As noted from previous studies the light grey clay from Bole senior secondary and preparatory school is highly expansive. On the other hand red clay of Kolfe is found to be less-expansive and due to this reason odometer test for swelling properties investigation is carried out for light grey clay soil samples only. Detail results as well as curves of odometer test are shown in annex F and the summary is presented in Table 3.14. In addition to this free swell cylinder tests are conducted for all types of soils and summary of results are shown in Table 3.13. However, the results of free swell testing are deemed to be very approximate because the volume is highly sensitive to the hygroscopic moisture and method of pouring the sample into the test cylinders.

Table 3.13: Results of swelling properties of soils with and with out treatment- Free Swell

Item No	Soil type	Percent swell for Untreated soil	Percent swell for 4x PURE CRETE treated soil	Percent swell for ANSS (6%) treated soil
1	Light grey clay (LGC)	135	132.5	120
2	Red brown clay (RC)	52.5	50	42.5
3	Silty sand blended with red clay (SSC)	20	20	17.5
4	Clayey sand (CS)	65	63	45

Table 3.14: Results of swelling pressure tests in kPa for treated and untreated samples

Soil type	Untreated	Treated with 6% ANSS
Light grey clay (LGC)	290	120.67

Besides free swell and odometer test, swell property investigation was also carried out on all specimens soaked for four days during CBR laboratory testing. The swell measurement carried out on treated as well as untreated test samples are shown in Table 3.15.

Table 3.15: CBR swell test results for treated as well as untreated samples

Soil Type	Curing in days	% CBR Swell of untreated and PURE CRETE treated soil samples			Percent CBR Swell of 6%/4% ANSS treated soil samples
		Without Treatment	Treated with two times manufacturer's application rate	Treated with two times manufacturer's application rate	
Light grey clay	0	7.33	7.03	7.21	Not performed
	7	6.30	6.37	6.26	1.545
Red clay	0	0.85	0.76	0.71	0.52
	7	0.63	0.56	0.52	0.16
Silty sand blended with red clay	0	0.08	0.07	0.07	Not performed
	7	0.06	0.03	0.03	0.04
Clayey sand	0	3.38	3.37	3.38	2.58
	7	1.255	3.25	3.27	0.175

4. Discussion of results obtained

In this section discussion on the results of various soil-additive combinations presented in the preceding parts are covered.

4.1 Evaluation of the native soils quality for road subgrade and subbase construction

According to the 2002 ERA manual for flexible pavement and gravel road design [15] the light grey clay soil from Bole school with a CBR of 1%, and a group index of 41 is categorized under subgrade strength class S1 whose rating as subgrade is poor. The light grey clay also does not fulfil the requirement of standard specification of ERA 2002 [24] for a fill material in embankment which requires a minimum CBR of 4%, swelling value of 1.5%, a liquid limit not exceeding 60 and a plasticity index less than 30. By the same token, the light grey clay can not fulfil the strength as well as gradation requirement as road subbase.

The red clay sample from Kolfe with CBR of 7.73% categorized as subgrade strength class S3. However, the material fails to meet the requirement of embankment fill as its plasticity index is more than 30. The soil sample does not meet gradation as well as CBR requirement for subbase materials.

The clay sand which has a CBR of 2.3 is categorized under S1subgrade strength class. The Atterberg results of this soil are high due to presence of light grey clay. The material can not meet the requirement of embankment fill as its CBR value is less than 4% and CBR swell is greater than 1.5%. The CBR as well as gradation requirement makes the material unsuitable for road subabse. The silty sand from Adje-Ropi with CBR of 39 can be classified into subgrade strength class S6.

As discussed in section two the PURE CRETE manufacturer suggested use of the product in coarse grained soils that contain 15% to 30% cohesive fines. To meet this requirement laboratory blending of silty sand from Adje-Ropi road subgrade material with red clay of Kolfe have been carried out. The blended soil has a CBR of 16.9% that categorizes it under S5 subgrade strength class. Due to gradation problem the material can be considered as unfit as road subbase.

Besides the collection of material for laboratory investigation, soil sample that has been used as borrow to fill material in the Adje-Ropi RR 50 rural road construction was brought to laboratory. This material is collected for the purpose of comparing engineering properties of the soil with chemically treated subgrade material. From laboratory test the soil is silty sand with gravel having CBR of 42% and meets the gradation requirement of subbase material as well as the requirement of embankment to fill.

4.2 Effects of the stabilization on Atterberg limits and maximum density

For perspective in considering results of Atterberg, it is helpful to note the typical variability encountered in measuring. As indicated in the ASTM D 4318-98 standard, determinations of the liquid limit (LL) of a particular soil by a single technician can be expected to vary by 2.4 and determinations by multiple laboratories can vary by 9.9. Similarly, determinations of the plastic limit (PL) by a single technician and multiple laboratories can vary by 2.6 and 10.6, respectively. Hence, much of the difference in LL and PL between the untreated and PURE CRETE treated soil samples with out curing can be attributed to the usual variability encountered in these laboratory measurements. Note that the ASTM criteria listed above was determined from tests on a soil with a LL of 64 (ASTM 1998e); much greater variability can be expected for soils with much higher liquid limits, such as light grey clay of Bole used in this study. However, with curing treated samples has shown a reduction in liquid limit of 8 to 17% for light grey clay, 4.86% for red brown clay at twice manufacturer application rate, 5.46 to 10.9% for silty sand blended with red brown clay, and 10.6 to 11% for material to clayey sand from Civil Service College. On the other hand the plastic limit of samples treated with PURE CRETE and cured for seven days has shown erratic results. For instance, plastic limit of red brown clay of Kolfe has shown 10.75% increase over untreated samples and silty sand blended with red brown clay has shown an increase of 6.79%. The plasticity index, however, tended to reduce for all soil types with maximum reduction of 48% for silty sand blended with red brown clay. Here it is important to note that at manufacturer recommended rate, no effect was observed both on liquid and plastic limits of all soil samples treated. A bar chart comparison of PURE CRETE treated as well as untreated samples is shown on Fig 4.1.

The plasticity index of all soils treated with Anyway Natural Soil Stabilizer (ANSS) at manufacturer recommended dosage and cured for seven days has shown substantial reduction. Light grey clay plasticity index reduced by 52% where as red brown clay and silty sand blended with red clay has shown reduction of 32% and 31% respectively. Application of 6% ANSS on soil sample from Civil Service College has shown reduction of 76% upon curing for seven days at constant moisture content with in desiccators. Fig 4.2 show the comparison of results of ANSS treated and untreated soil samples. The increase in plastic limit PURE CRETE treated samples, increase in plastic limit was observed for all samples.

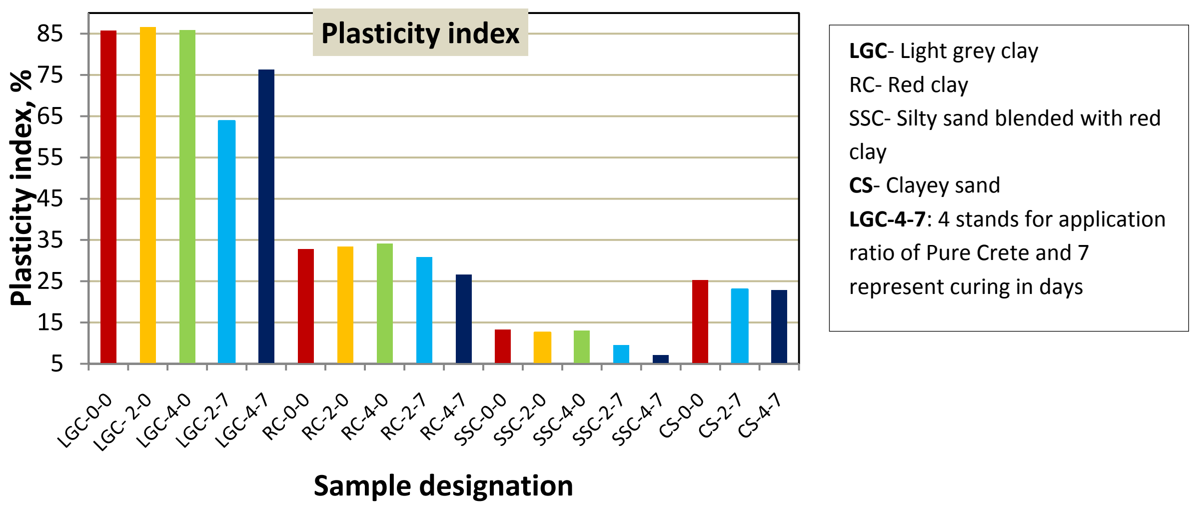
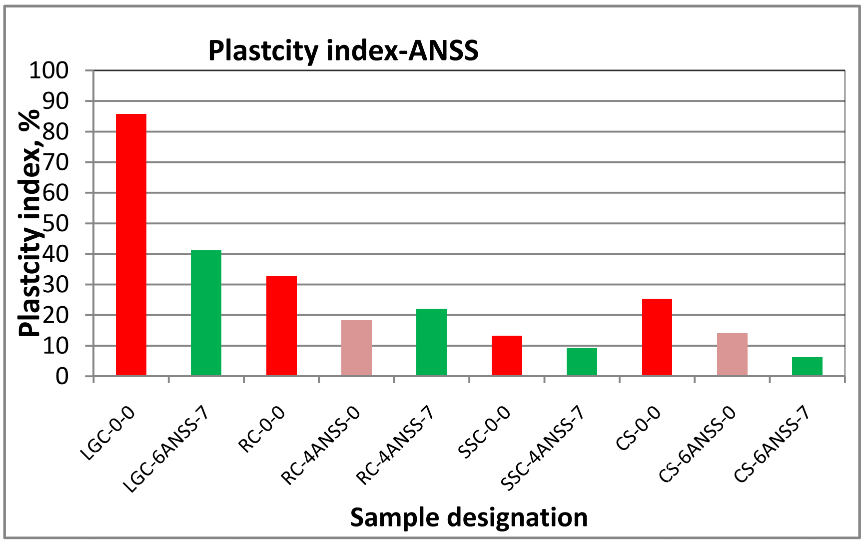


Figure 4.1: Atterberg limit results of untreated & PURE CRETE treated samples

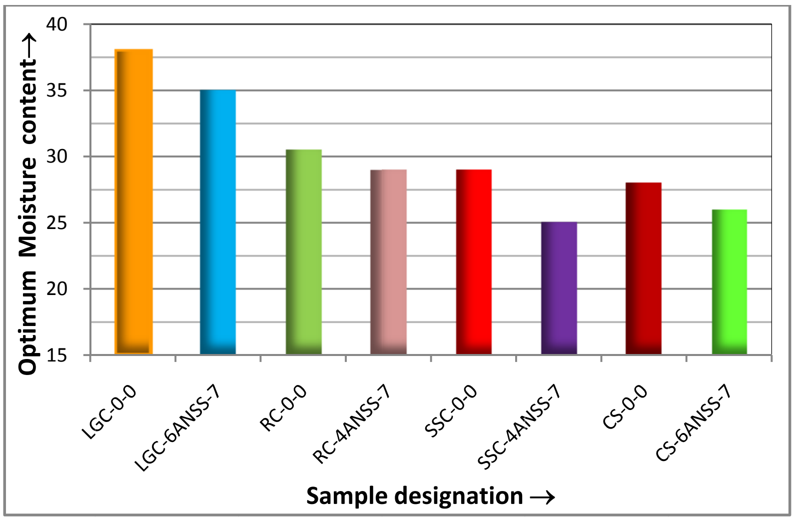


LGC- Light grey clay
RC- Red clay
SSC- Silty sand blended with red clay
CS- Clayey sand

RC-4ANS-7: 4 ANSS stands for treatment with 4% ANSS and 7 represent curing in days

Figure 4.2: Atterberg limit results of untreated & ANSS treated samples

The maximum density for ANSS treated samples increased and the optimum moisture content tended to decrease over the untreated samples optimum moisture content which is consistent with the literature. The dry density has shown increase by 5.33% for light grey clay treated with 6% ANSS, 5.73% for red brown clay treated with 4% , 13.78% for silty sand treated with 4% ANSS, and 7.99% for Civil Service College materials treated with 6% ANSS. The increases in dry densities are obtained at optimum moisture contents below untreated samples. The behaviour of PURE CRETE treated samples was erratic and as mentioned in the preceding sections no significant effects were observed. One of the advantages claimed by the manufacturer of PURE CRETE was reduction in amount of water required for compaction though test results failed to prove this advantage. The effects brought on the sample tests are presented in Fig 4.3 and Fig 4.4 below.



LGC- Light grey clay
RC- Red clay
SSC- Silty sand blended with red clay
CS- Clayey sand

RC-4ANS-7: 4 ANSS stands for treatment with 4% ANSS and 7 represent curing in days

Figure 4. 3: Effect ANSS treatment on optimum moisture content of soil samples

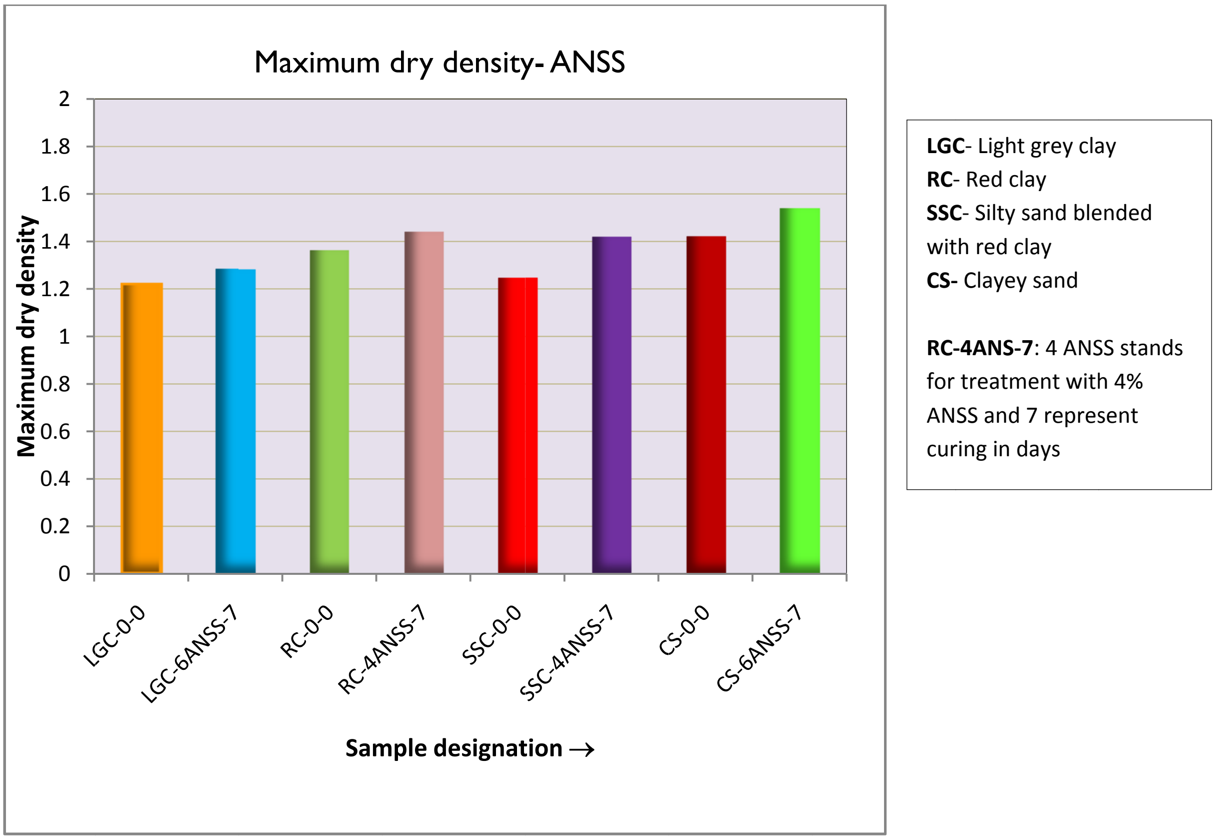


Figure 4. 4: Effect ANSS treatment on maximum dry density of soil samples

4.3 Impact of stabilization on strength tests

The strength tests most often used for road subgrades are unconfined compression test, the California Bearing Ratio test, and the Plate-Bearing Test. Of these tests, the one that simulates field conditions better is the Plate-Bearing Test. The expense of this test prevents it from being applied to optimize the use of agents requiring multiple tests. Therefore, one or both of the other two tests mentioned is almost always used. Their use is supported by design methodologies that readily apply their results.

4.3.1 California Bearing Ratio

Soil specimens treated with PURE CRETE at supplier application rate could not show significant effect on CBR values. However, at very high PURE CRETE application rates modest increase in CBR had been observed. The effect of curing has been pronounced from the investigation carried out. As stated by the supplier, for PURE CRETE to be effective the soil should be granular and should contain cohesive fines of 15% -30%. As can be seen from Fig 4.5 through Fig 4.8, the application of PURE CRETE improved the CBR of light grey clay by 3.25%, red brown clay by 29%, silty sand blended with red brown clay by 74%, and material from Civil Service college by 17.2% at application rates of four times manufacturer recommended rates.

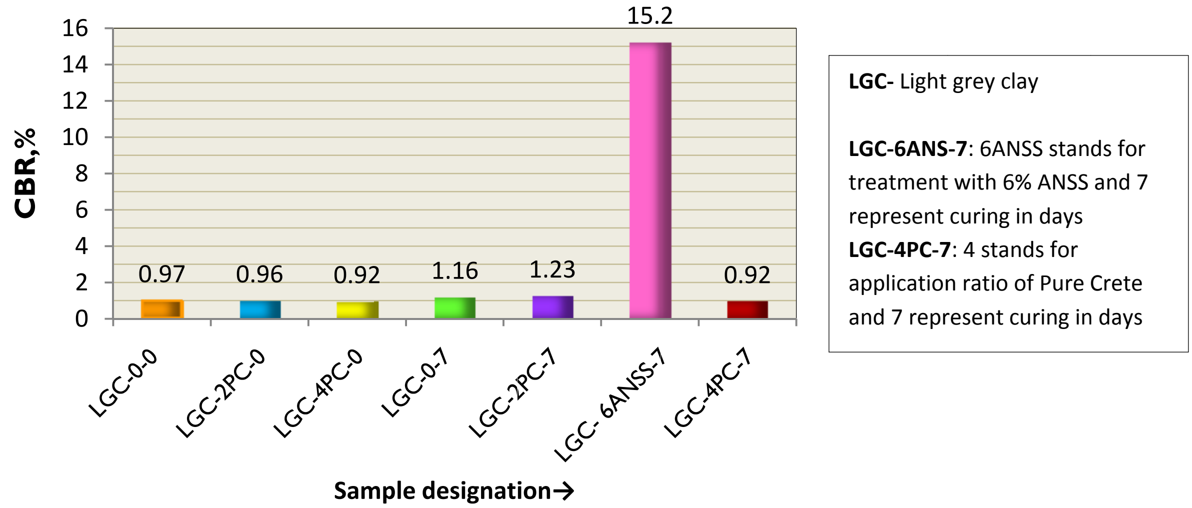


Figure 4.5: CBR results of untreated and treated light grey clay soil samples from Bole

For light grey clay soil samples, tests carried out without curing has shown decrease in CBR though the amount of reduction is insignificant as can be seen from Fig 4.5 above. On the other hand with 6% ANSS treatment, the CBR increased by 1201% (twelve folds).

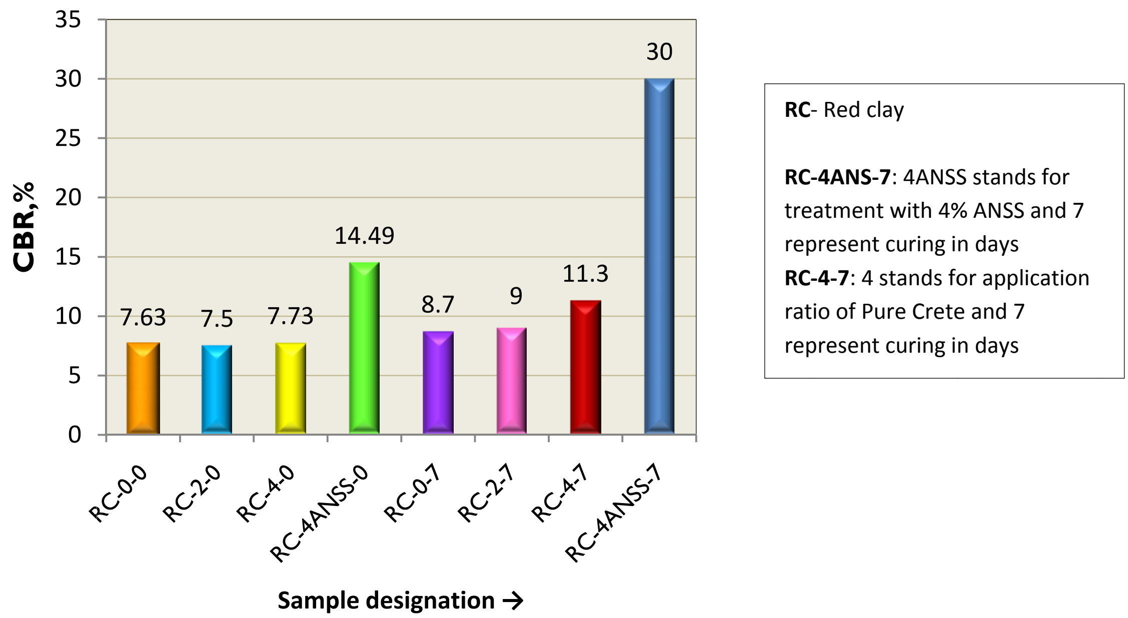
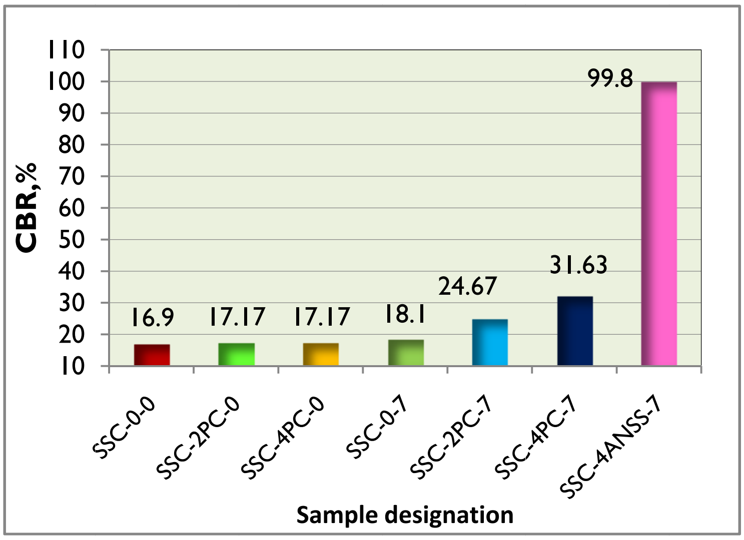


Figure 4.6: CBR results of untreated and treated red brown clay soil samples from Kolfe

The CBR of red brown clay has shown an increase of 245% upon curing after treatment with 4% ANSS for seven days before soaking. Even without curing it has been possible to get an increase by 95% over untreated red brown clay soil samples.



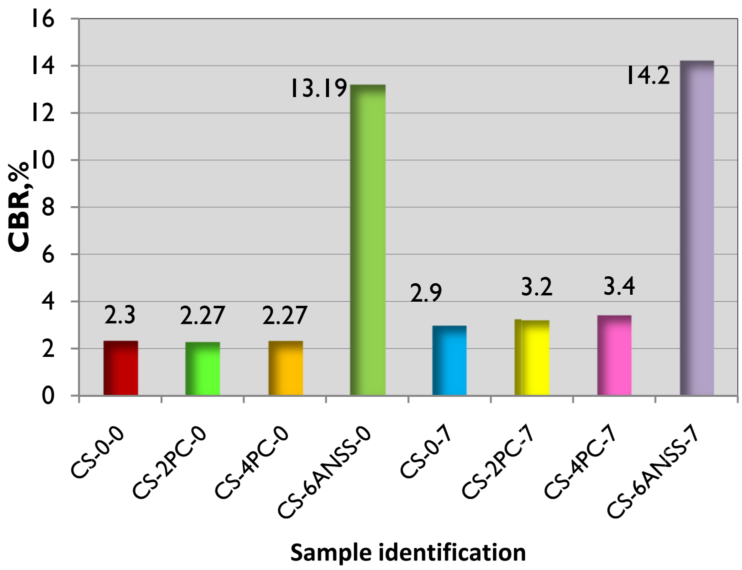
SSC- Silty sand blended with clay

SSC-4ANS-7: *4ANSS stands for treatment with 4% ANSS and 7 represent curing in days*

SSC-4PC-7: 4 stands for application ratio of Pure Crete and 7 represent curing in days

Figure 4.7: CBR results of untreated and treated silty sand blended with red brown clay soil

The silty sand brought from subgrade of Adjie-Ropi RR 50 rural road construction blended with red brown clay of Kolfe has shown CBR increase of 451% over untreated control specimens after treatment with 4% ANSS and curing for seven days before soaking. As it can be seen from Fig 4.7, the ANSS treatment resulted in more than three fold effect on CBR over the treatment with the natural enzyme.



CS- Clayey sand

CS-6ANS-7: *6ANSS stands for treatment with 6% ANSS and 7 represent curing in days*

CS-4PC-7: 4 stands for application ratio of Pure Crete and 7 represent curing in days

Figure 4.8: CBR results of untreated and treated clayey sand of Civil Service College

The clayey sand soil sample collected from secondary arterial road site of Civil Service College was treated with 6% ANSS in the laboratory. The specimens soaked without curing after treatment with the stabilizer has shown 473% increment in CBR when compared with untreated specimens of the same source. With seven days curing the increase was further increased to 517% as shown in Fig 4.8.

Investigation has also been carried out to see the effect of ANSS on silty sand of the subgrade soil collected from RR-50 Adje-Ropi road with out blending with red brown clay of Kolfe. The result presented in Fig 4.9 below indicated the possibility to increase the CBR up to 97.74% from 39.1% by treating the sample with only 4% of ANSS.

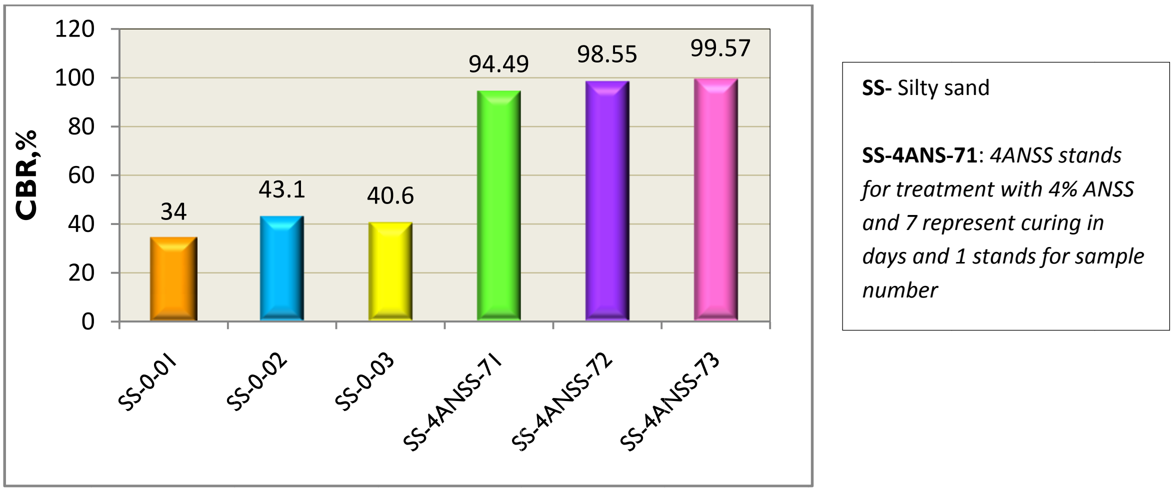


Figure 4.9: CBR results of untreated and treated silty sand from Adje-Ropi rural road subgrade

The Adje-Ropi 36 km RR-50 rural road was under construction at the time of sample collection in July, 2009 by Oromia Rural Road Enterprise. The subgrade of the entire road is silty sand. The construction work consists of placement of 20cm borrowed fill material over the silty sand subgrade after shaping to proper grade and cross slope, and then a 15cm thick scoria (known as red ash) follows which serves as surfacing course, which is traditionally known by many of regional rural road construction authorities of Ethiopia as a subbase layer. Investigation carried out in the course of this research revealed that the borrowed material to fill is found to be silty sand with gravel having a soaked CBR value of 42%. The material is hauled from an average distance of 15 to 20 kms from the road corridor. From CBR point of view only, it seems the silty sand found with in the road route can be utilized without trucking other materials from faraway. However, this is very preliminary research and a lit bit comprehensive study may be necessary.

4.4 Effect of the additives on the swelling properties

To investigate the effect of additives on the swelling property of the soil, three methods: free swell cylinder test, Odometer test, and CBR swell test have been used. The free tube swell test with all its constraints has shown a reduction of 1.85%, 4.75%, and 3.2% of swell for light grey clay, red brown clay and clayey sand respectively. On the other hand treatment with addition of ANSS to the soil samples induced a reduction of 11% for light grey clay soil; 19% for red brown clay soil; 12.5% for silty sand blended with red brown clay and 31% for clayey sand from Civil Service College arterial road.

During curing as well as soaking the CBR test samples were loaded with a surcharge rings to simulate the field loading condition. The measurements of percent swell of soil samples in the CBR molds indicated that with the application of ANSS at manufacturer recommended rate, the swell amount reduced by 80% to 95% in comparison with the control untreated samples. In similar manner PURE CRETE treated specimens has also shown modest reduction upon curing the CBR samples for seven days before soaking. The effect of ANSS on the swelling pressure was also investigated for light grey clay soil and a reduction of 58% was observed from one-dimensional consolidometer.

4.5 Evaluation of treated soil samples quality for road subgrade and subbase construction

As shown in Tables 4.1 and 4.2 below, the treatment with unconventional soil stabilizers brought a shift in soil classification. For instance the light grey soil which was fat clay before treatment changed to elastic silt after treatment with 6% ANSS. However, it is worthy to note here that the sieve analysis result was not changed. This can be taken as the limitation of the classification.

The effect of stabilizers is highly pronounced in the case of CBR test. The light grey clay soil which was classified under S1 subgrade strength class shifted to S4 class after treatment with 6% ANSS and the CBR swell reduced from 7.73% to 1.5%. Based on this shift, the soil is found to meet the ERA standard subgrade requirement and also meets the embankment fill requirement. The red brown clay, which was found to be unsuitable subbase material according to the requirement of standard for natural subbase materials, has shown remarkable increase in CBR value with an average value of 30 after treatment with ANSS makes it to fall with in the range suitable for subbase construction. The silty sand blended with red clay after receiving ANSS treatment changed to very hard rock like material having an average CBR of 100%. The application of 6% ANSS on clayey sand induced significant increase in CBR values and there is a change in subgrade strength from S1 to S4.

Table 4. 1: Classification of soil samples treated with PURE CRETE and cured for 7 days

Standard Practice	Samples treated			
	Light grey clay	Red brown clay	Clayey Sand from Sub Arterial Street	Silty sand blended to clay
ASTM D 2487-98 (Unified soil classification System	MH (Elastic silt)	MH (Elastic silt)	Clayey sand	Silty sand
ASTM D3282-98 (Classification for Highway construction)	A-7-5(45)	A-7-6(30)	A-7-6 (2)	A-4

Table 4. 2: Classification of soil samples treated with ANSS and cured for 7 days

Standard Practice	Samples treated			
	Light grey clay	Red brown clay	Clayey Sand from Sub Arterial Street	Silty sand blended to clay
ASTM D 2487-98 (Unified soil classification System	MH (Elastic silt)	MH (Elastic silt)	silty sand	Silty sand
ASTM D3282-98 (Classification for Highway construction)	A-7-5(55)	A-7-6(27)	A-2-5(0)	A-5(0)

The performance of PURE CRETE is found to be modest in comparison with ANSS treatment. Considering the CBR criterion only ANSS treatment converted the material which was not even suitable for an embankment fill to a level where it can fulfil the criteria for stabilized base course as shown in Table 4.2. The silty sand of Adje-Ropi after treatment with 4%ANSS was found to qualify as stabilized base having CBR of 90%.

4.6 Field performance evaluation

Recently ERA prepared test section on Morocho – Leku rural road whose investigation is underway. Because of the fact that field performance evaluation takes a number of months it is not possible to incorporate the results in the thesis. But still it can be easily deduced that at manufacturer application rate promising results may not be obtained using this enzyme. Although there are a lot of constraints with the application of conventional laboratory testing methods for evaluation of the performance of unconventional liquid stabilizers, there should be changes in engineering properties at high application rates.

Anyway Natural Soil Stabilizer is being used by AACRA in collaboration with the manufacturer in Sub arterial streets and collector roads found in Addis Ababa since December 2009. One low volume traffic road around Bole high school having seven meter width and 800m length is completed.

Figure 4.10: Soil transported to the road section for grade adjustment & stabilization (Around Bole High School)

The existing path is excavated, scarified and compacted with out adding ANSS. Then to adjust road bed grade and slope soil that has been disposed from various constructions and dumped in the road vicinity is hauled to the road construction. The hauled material is spread uniformly with grader and then compacted with smooth wheeled roller. Following compaction, ANSS bags each weighing 25kg are spread uniformly over the compacted surface after calculating the required dosage for the road section that enable to stabilize the top 20cm of the compacted layer as shown in Fig 4.11.

Figure 4.11: ANSS bags spread over the road section to be stabilized (Around Bole High School)

The bags were opened by daily labourers and spreading has been carried out with the help of grader. To obtain uniform mixing rotavator was used. Using the compactors and water trucks the ANSS-soil mixture was compacted at optimum moisture content. Then after three to seven days of curing base course is placed over stabilized soil. This street is paved with 5cm thick asphalt and become open to traffic the next day.

In similar manner about one kilometre collector street around 'Bisrete Gebriel' area is also stabilized using ANSS. The next site that will be stabilized is Sub Arterial Street found adjacent to Ethiopian Civil Service College from where clayey sand was colleted. The construction of these roads creates good opportunity for future evaluation of the stabilizer's field performance for all interested. The absence of control sections in all of the above constructions will be major problem. Until compilation of this thesis report, visual inspection was carried out on two stabilized roads and no visible defects were observed.

Figure 4.12: Spreading of ANSS over the surface to be stabilized and mixing with Rotovator

4.7 Comparison of results with previous similar studies

Soil stabilization studies for improving engineering properties of soils for highway construction purpose were conducted by different postgraduate students of civil engineering department of Addis Ababa University. Most studies focused on expansive soils of Addis

Ababa and subgrades of roads failed after construction. Study results on stabilization of light grey and red clay of subgrade soil using SA-44/LS-40 chemical and lime [13] by Argu Y are used to compare with the results of this research. The light grey clay sample used by Argu is collected from Bole school which is also the source of the same soil used in this study. The red clay used by Argu was from Addisu Gebeya area that has closely related geotechnical property with red clay of Kolfe. It seems reasonable to compare the ANSS treatment results with lime treatment as both stabilizers are supplied in solid (powder) form. As can be seen from Table 4.3, the effect of ANSS on the CBR result by far exceeds the effect induced by lime of the same dosage.

Table 4. 3: Comparison of results of stabilization of light grey clay

Items	Results from Yohannes Argu Research [13]				Results from this research		
	Native soil	8% Lime	4% Lime	4% lime & 0.15lit SA-44/LS-40	Native Soil	6% ANSS	4 times PURE CRETE
Light grey clay of Bole High School							
CBR	2.89	5.51	3.98	11.46	0.97	15.2	1.23
Liquid limit	109	72	85	86	129.35	93.2	118.9
Plastic limit	42	48	46	49	43.6	52.0	42.65
Plasticity index	67	24	39	37	85.75	41.2	76.25
Percent Swell (CBR)	5.95	0.4	1.47	0.67	7.33	1.5	6.26
Soil Classification-USCS	CH	-	-	-	CH	-	-
Soil Classification-AASHTO	A-7-5	-	-	-	A-7-5	-	-
Optimum moisture content,%	37.09	-	-	-	38.0	-	-
Maximum dry density, g/cc	1.23	-	-	-	1.22	-	-
Red brown clay of Kolfe							
CBR	6.99	4.44	12.13	15.94	7.63	30*	11.30
Liquid limit	62	51	50	49	61.77	58.88*	58.77
Plastic limit	30	35	33	31	29.03	36.47*	32.15
Plasticity index	32	16	17	18	32.74	18.32*	26.62
Percent Swell (CBR)	0.4	0.14	0.53	0.36	0.85	0.16*	0.52
Soil Classification-USCS	CH	-	-	-	CH	-	-
Soil Classification-AASHTO	A-7-5	-	-	-	A-7-6	-	-
Optimum moisture content,%	34.87	-	-	-	30.5	-	-
Maximum dry density, g/cc	1.33	-	-	-	1.362	-	-

*-For Red brown clay the results are for 4% ANSS treatment

5. Conclusions and Recommendation

5.1 Conclusion

In this study the following conclusions were drawn:

1. Laboratory investigations using the powder product, ANSS, on five soil types has shown substantial effect on the engineering properties of the five soil types treated. The effect of curing after treatment with the stabilizer on test samples has been clearly observed. Clayey sand treated with 6% ANSS and cured for seven days has shown 56% improvement in plasticity index over uncured sample that received the same proportion of treatment. Similarly, the CBR for red brown clay has shown 100% increment when compared to uncured specimens after applying the same percentage of ANSS. Its effect is more pronounced in the case of light grey clay soil where up to 1201% increment in CBR was observed. Of course it is too early to judge that ANSS is an all-cure for all substandard soils for use in highway subgrade and subbase stabilization. However, the results obtained are promising both from social as well as environmental point of view. The product may allow use of marginal materials that are usually carted away from many construction sites which in turn contribute to minimize the duration of construction as well as cost.

2. In the study conducted using the enzyme product, PURE CRETE, samples from four soil types were mixed with the stabilizer at supplier's recommended application rate and randomly selected very high application rates. Atterberg limits, compacted unit weight, California Bearing Ratio, and free swell potential were measured and compared for untreated and treated soils. Overall, no marked changes in these engineering properties were observed following enzyme treatment in these tests. Although individual cases can be identified in which the stabilizer appeared to improve a property of a particular soil, no consistent trend was observed. Higher application rates, in excess of the supplier recommendations, are not also able to produce more significant, beneficial effects.

3. As learned from comparison of ANSS with one of the conventional powder based stabilizer, lime, the effect brought by ANSS on engineering properties of soil tested by far exceed the changes that result due to application of lime. However, this comparison is restricted to two types of soils only.

5.2 Recommendation

Specific recommendations for conducting future evaluations of unconventional soil stabilizers include the following:

1. The investigation of performance of ANSS was conducted only using supplier recommended rate only. This time it is not known what will happen at higher and lower recommended application rates. Further investigation using higher and lower application rates may be necessary.

2. Pavement performance is closely related to the stiffness of the underlying base and subgrade materials. Tests to measure the stiffness of untreated and treated soils, such as resilient modulus tests, should be considered in the future researches.

3. As mentioned earlier ANSS is powder based product which may make it not feasible to haul to long distances. In connection to this, studies that can compare ANSS with already available conventional soil stabilizers like cement has to be conducted.

4. Application of ANSS on some of the soil types used in this study resulted in increase of plastic limit which is quite surprising. Even upon conducting repeated tests, the same result has been obtained. This needs further investigation using different ANSS application rates. This may be due to the nature of testing procedure. It seems that Atterberg Limit tests and grain size analysis are not appropriate tests for evaluation of stabilization effects of chemicals.

5. Some unconventional soil stabilizers are available as a by product of industrial process like molasses in our country. Hence, it is advisable to conduct investigation on such products to see if they can be used as potential soil stabilizer.

6. Durability testing of conventional stabilizers like cement, lime, and class c fly ash can be investigated using standard testing procedures developed by ASTM. For unconventional stabilizers there is no well established standard durability testing procedures but different researchers used durability testing procedure of conventional stabilizers and leaching test which involve leaching distilled water through a soil sample under a constant head of 150cm and with a confining pressure of 10 pounds per square inch for 28 days [25]. Both tests are not performed due to lack of appropriate testing facilities in this research and further researches in this area are highly recommended.

7. Until issues related with stabilization mechanisms have been resolved, it is recommended that users insist on a product performance guarantee for longer duration including retention of payment against a measure of future performance defined in quantitative terms.

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7. ANNEXES

Annex A. Dilution rate calculation for PURE CRETE application

Table A.1: Application rate calculation of PURE CRETE for light grey clay

Item No	Item description	Unit	Quantity
A	Soil dry density	Kg/ m^3	1220
B	Optimum moisture determined in the laboratory	%	38
C	Existing moisture determined in the laboratory	%	9.8
D	Net moisture to be added (= Item B- Item C)	%	28.2
E	Water required per cubic meter of soil (=Item A * Item D)	litre/ m^3	344.04
F	Standard volume of material to be treated by one litre of PURE CRETE	m^3	33
G	Amount of water required for diluting one litre of PURE CRETE (= Item E* Item F)	litre	11353
H	Amount of water required for mixing PURE CRETE at twice manufacturer application rate	litre	5676
I	Amount of water required for mixing PURE CRETE at four times manufacturer application rate	litre	2838

Table A.2: Application rate calculation of PURE CRETE for red brown clay from Kolfe

Item No	Item description	Unit	Quantity
A	Soil dry density	Kg/ m^3	1362
B	Optimum moisture determined in the laboratory	%	30.5
C	Existing moisture determined in the laboratory	%	5.3
D	Net moisture to be added (= Item B- Item C)	%	25.2
E	Water required per cubic meter of soil (=Item A * Item D)	litre/ m^3	343.224
F	Standard volume of material to be treated by one litre of PURE CRETE	m^3	33
G	Amount of water required for mixing one litre of PURE CRETE (= Item E* Item F)	litre	11326
H	Amount of water required for dilution for twice manufacturer rate	litre	5663
I	Amount of water required for dilution for four times manufacturer rate	litre	2831

Table A.3: Application rate calculation of PURE CRETE for silty sand blended with red brown clay of Kolfe

Item No	Item description	Unit	Quantity
A	Soil dry density	Kg/ m^3	1248
B	Optimum moisture determined in the laboratory	%	29
C	Existing moisture determined in the laboratory	%	2.5
D	Net moisture to be added (= Item B- Item C)	%	26.5
E	Water required per cubic meter of soil (=Item A * Item D)	litre/ m^3	330.72
F	Standard volume of material to be treated by one litre of PURE CRETE	m^3	33
G	Amount of water required for mixing at manufacturer application rate for one litre of PURE CRETE (= Item E* Item F)	litre	10913
H	Amount of water required for mixing for twice manufacturer application rate	litre	5456
I	Amount of water required for mixing for four times manufacturer application rate	litre	2728

Table A.4: Application rate calculation of PURE CRETE for clayey sand from Civil Service College

Item No	Item description	Unit	Quantity
A	Soil dry density	Kg/ m^3	1426
B	Optimum moisture determined in the laboratory	%	28
C	Existing moisture determined in the laboratory	%	8.7
D	Net moisture to be added (= Item B- Item C)	%	19.3
E	Water required per cubic meter of soil (=Item A * Item D)	litre/ m^3	275.218
F	Standard volume of material to be treated by one litre of PURE CRETE	m^3	33
G	Amount of water required for mixing one litre of PURE CRETE at manufacturer application rate (= Item E* Item F)	litre	9082
H	Amount of water required for mixing PURE CRETE for twice manufacturer application rate	litre	4541
I	Amount of water required for mixing PURE CRETE at four times manufacturer application rate	litre	2270

Annex B: Atterberg limits test results

Table B.1: Atterberg limits of untreated light grey clay soil- LGC-0-0

First trial- LGC-0-01						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	6	12	21	29		
Container no.	D25	D15	C18	24	C15	76
Mass of wet soil + container (m_2) g	28.95	27.73	22.16	27.06	15.28	16.7
Mass of dry soil + container (m_3) g	21.08	20.6	17.28	20.61	14.86	16.36
Mass of container (m_1) g	15.87	15.59	13.54	15.63	13.9	15.56
Mass of moisture (m_2- m_3)g	7.87	7.13	4.88	6.45	0.42	0.34
Mass of dry soil (m_3- m_1)g	5.21	5.01	3.74	4.98	0.96	0.8
Moisture content = (m2-m3)/(m3- m1)*100 %	151.06	142.32	130.48	129.52	43.75	42.50
Liquid Limit/Plastic Limit	130.3				43.1	
Second trial- LGC-0-02						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	8	15	23	32		
Container no.	38	D34	B-1	D361	A9	53
Mass of wet soil + container (m_2) g	29.87	28.65	24.32	24.54	18.36	17.79
Mass of dry soil + container (m_3) g	21.38	20.89	19.28	19.53	17.45	17.09
Mass of container (m_1) g	15.59	15.34	15.31	15.53	15.36	15.52
Mass of moisture (m_2- m_3)g	8.49	7.76	5.04	5.01	0.91	0.70
Mass of dry soil (m_3- m_1)g	5.79	5.55	3.97	4	2.09	1.57
Moisture content = (m2-m3)/(m3- m1)*100 %	146.63	139.82	126.95	125.25	43.54	44.59
Liquid Limit/Plastic Limit	128.4				44.1	

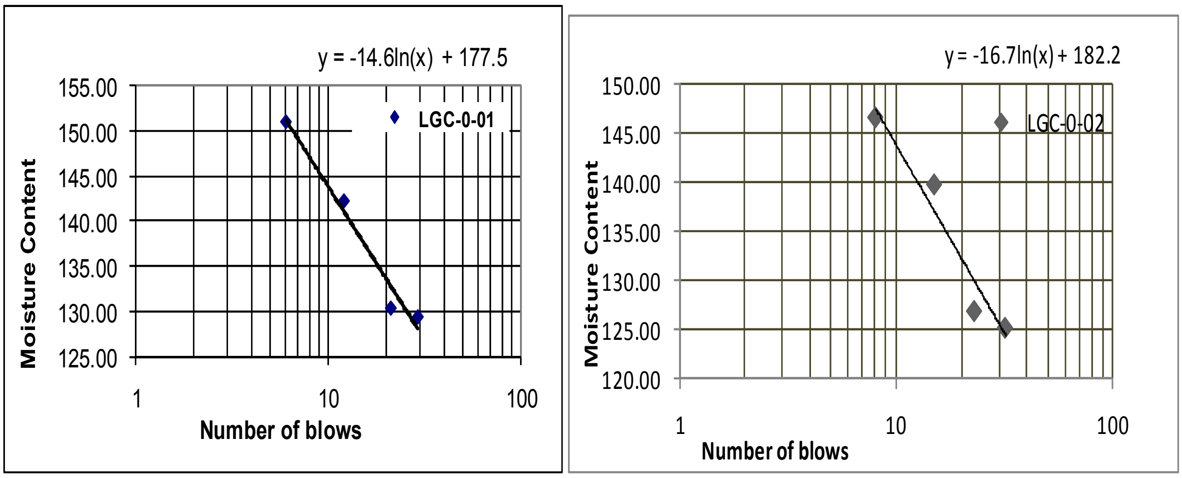
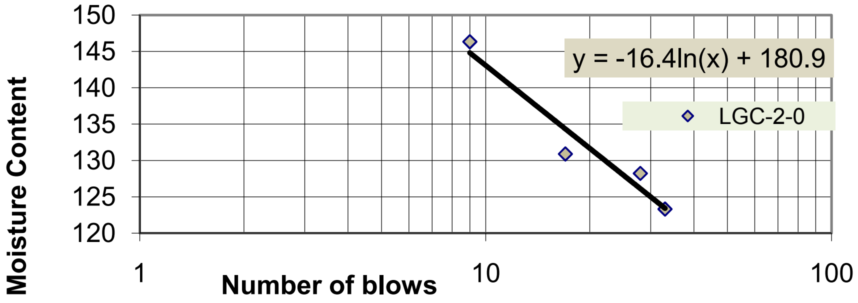


Figure B.1: Flow curves for LGC-0-0

Table B.2: Atterberg limits of PURE CRETE treated light grey clay soil - LGC-2PC-0

First trial- LGC-2PC-01						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	9	17	28	33		
Container no.	95	C-19	103	51	36	C-16
Mass of wet soil + container (m_2) g	25.96	24.66	24.65	24.06	14.55	14.95
Mass of dry soil + container (m_3) g	19.8	18.6	19.56	19.51	14.35	14.72
Mass of container (m_1) g	15.59	13.97	15.59	15.82	13.85	14.19
Mass of moisture (m_2- m_3)g	6.16	6.06	5.09	4.55	0.2	0.23
Mass of dry soil (m_3- m_1)g	4.21	4.63	3.97	3.69	0.5	0.53
Moisture content = (m2-m3)/(m3- m1)*100 %	146.32	130.89	128.21	123.31	40.00	43.40
Liquid Limit/Plastic Limit	128.1				41.7	
Second trial- LGC-2PC-02						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	10	15	27	32		
Container no.	D-16	23	100	C-21	C-13	69
Mass of wet soil + container (m_2) g	32.61	28.72	31.1	31.87	15.63	16.46
Mass of dry soil + container (m_3) g	22.49	21.35	22.32	21.92	15.23	16.22
Mass of container (m_1) g	15.53	15.64	15.43	14.18	14.29	15.64
Mass of moisture (m_2- m_3)g	10.12	7.37	8.78	9.95	0.4	0.24
Mass of dry soil (m_3- m_1)g	6.96	5.71	6.89	7.74	0.94	0.58
Moisture content = (m2-m3)/(m3- m1)*100 %	145.40	129.07	127.43	128.55	42.55	41.38
Liquid Limit/Plastic Limit	128.9				42.0	



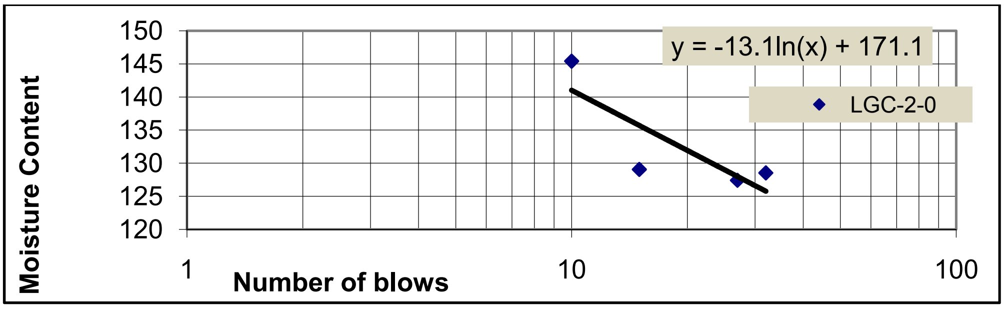
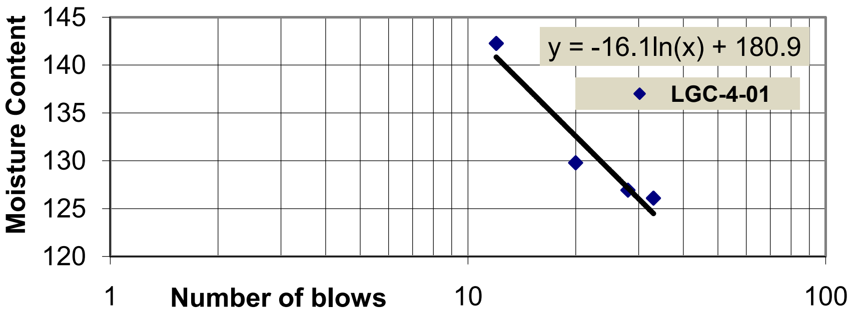


Figure B.2: Flow curves for LGC-2PC-0

Table B.3: Atterberg limits of PURE CRETE treated light grey clay soil - LGC-4PC-0

First trial- LGC-4PC-01						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	12	20	28	33		
Container no.	38	B-1	D-22	20	A-14	8
Mass of wet soil + container (m_2) g	27.63	26.73	29.66	32.32	18.27	17.92
Mass of dry soil + container (m_3) g	20.56	20.28	21.88	22.99	17.49	17.23
Mass of container (m_1) g	15.59	15.31	15.75	15.59	15.65	15.62
Mass of moisture (m_2- m_3)g	7.07	6.45	7.78	9.33	0.78	0.69
Mass of dry soil (m_3- m_1)g	4.97	4.97	6.13	7.4	1.84	1.61
Moisture content = (m2-m3)/(m3- m1)*100 %	142.25	129.78	126.92	126.08	42.39	42.86
Liquid Limit/Plastic Limit	129.1				42.6	
Second trial- LGC-4PC-02						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	9	16	29	34		
Container no.	H4	80	71	A10	A29	C21
Mass of wet soil + container (m_2) g	26.95	26.63	25.15	25.37	17.28	16.33
Mass of dry soil + container (m_3) g	20.29	20.48	19.77	19.91	16.71	15.69
Mass of container (m_1) g	15.74	15.69	15.53	15.51	15.37	14.18
Mass of moisture (m_2- m_3)g	6.66	6.15	5.38	5.46	0.57	0.64
Mass of dry soil (m_3- m_1)g	4.55	4.79	4.24	4.4	1.34	1.51
Moisture content = (m2-m3)/(m3- m1)*100 %	146.37	128.39	126.89	124.09	42.54	42.38
Liquid Limit/Plastic Limit	127.7				42.5	



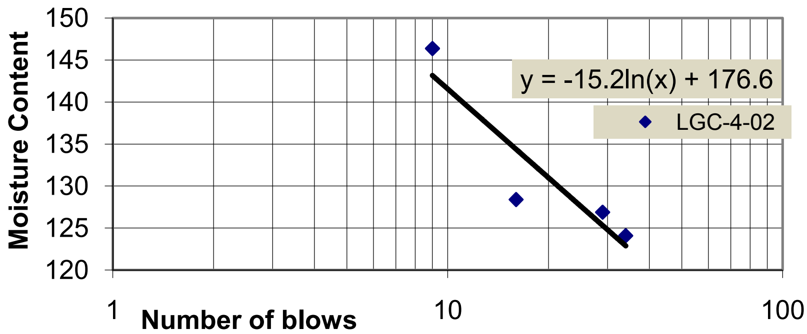
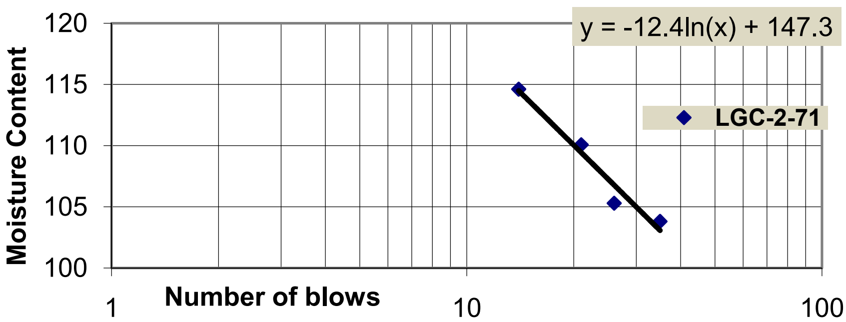


Figure B. 3: Flow curves for LGC-4PC-0

Table B.4: Atterberg limits of PURE CRETE treated light grey clay soil- LGC-2PC-7

First trial- LGC-2PC-71						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	14	21	26	35		
Container no.	C35	A14	B1	D361	38	20
Mass of wet soil + container (m_2) g	31.33	32.54	29.68	31.62	17.17	17.57
Mass of dry soil + container (m_3) g	22	23.69	22.32	23.44	16.668	16.97
Mass of container (m_1) g	13.86	15.65	15.33	15.56	15.61	15.60
Mass of moisture (m_2- m_3)g	9.33	8.85	7.36	8.18	0.50	0.60
Mass of dry soil (m_3- m_1)g	8.14	8.04	6.99	7.88	1.06	1.37
Moisture content = (m2-m3)/(m3- m1)*100 %	114.62	110.07	105.29	103.81	47.45	43.80
Liquid Limit/Plastic Limit	107.39				45.62	
Second trial- LGC-2PC-72						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	16	22	29	34		
Container no.	51	85	42	C-10	C-13	D5
Mass of wet soil + container (m_2) g	28.61	29.67	30.47	29.39	16.34	17.57
Mass of dry soil + container (m_3) g	21.79	22.44	22.77	22.37	15.74	17.01
Mass of container (m_1) g	15.82	15.84	15.39	15.61	14.29	15.68
Mass of moisture (m_2- m_3)g	6.82	7.23	7.7	7.02	0.60	0.56
Mass of dry soil (m_3- m_1)g	5.97	6.6	7.38	6.76	1.45	1.33
Moisture content = (m2-m3)/(m3- m1)*100 %	114.24	109.55	104.34	103.85	41.38	42.11
Liquid Limit/Plastic Limit	107.60				41.74	



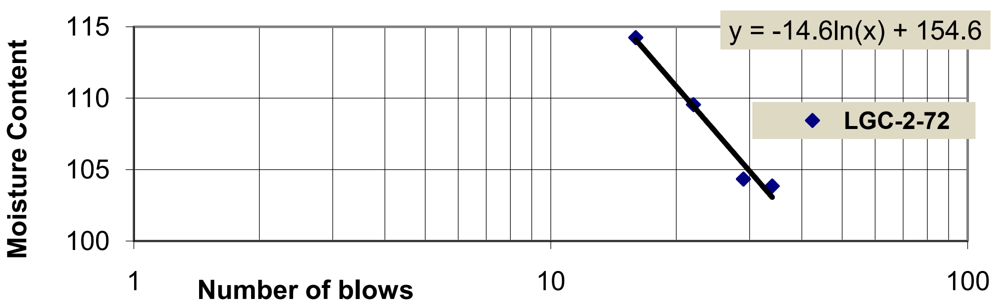
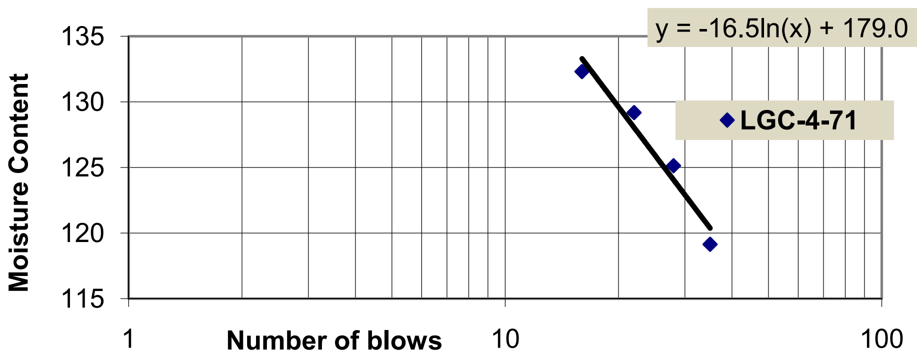


Figure B.4: Flow curves for LGC-2PC-7

Table B.5: Atterberg limits of PURE CRETE treated light grey clay soil - LGC-4PC-7

First trial- LGC-4PC-71						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	16	22	28	35		
Container no.	B1	2	72	1A	C-10	D-8
Mass of wet soil + container (m_2) g	34.24	35.49	35.91	34.28	15.46	17.15
Mass of dry soil + container (m_3) g	23.47	24.29	24.66	23.95	14.97	16.65
Mass of container (m_1) g	15.33	15.62	15.67	15.28	13.84	15.50
Mass of moisture (m_2- m_3)g	10.77	11.2	11.25	10.33	0.49	0.50
Mass of dry soil (m_3- m_1)g	8.14	8.67	8.99	8.67	1.13	1.15
Moisture content = (m2-m3)/(m3- m1)*100 %	132.31	129.18	125.14	119.15	43.36	43.48
Liquid Limit/Plastic Limit	125.9				43.4	
Second trial- LGC-4PC-72						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	16	23	29	37		
Container no.	C19	82	85	A36	34	D-11
Mass of wet soil + container (m_2) g	33.21	32.15	33.78	33.22	17.04	16.24
Mass of dry soil + container (m_3) g	22.84	23.22	24.39	24.09	16.61	15.69
Mass of container (m_1) g	13.96	15.37	15.85	15.53	15.63	14.31
Mass of moisture (m_2- m_3)g	10.37	8.93	9.39	9.13	0.43	0.55
Mass of dry soil (m_3- m_1)g	8.88	7.85	8.54	8.56	0.98	1.38
Moisture content = (m2-m3)/(m3- m1)*100 %	116.78	113.76	109.95	106.66	43.88	39.86
Liquid Limit/Plastic Limit	111.90				41.90	



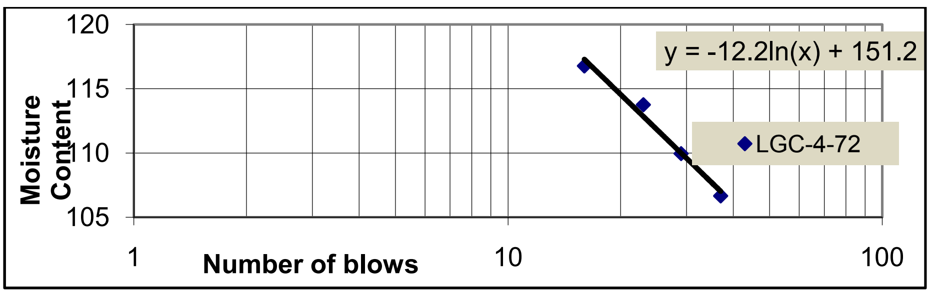
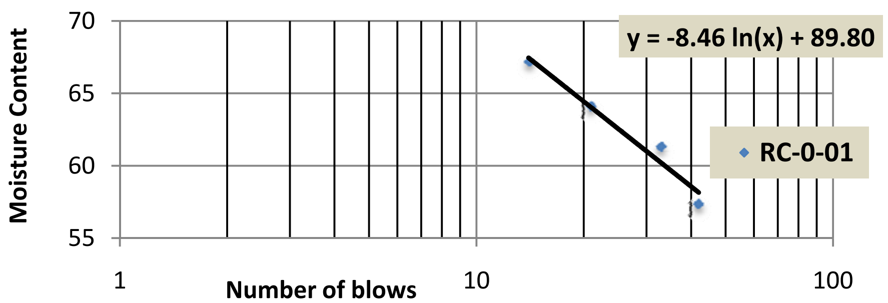


Figure B.5: Flow curves for LGC-4PC-7

Table B.6: Atterberg limits of the untreated red clay soil- RC-0-0

First trial- RC-0-01						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	14	21	33	42		
Container no.	D22	69	H4	34	A19	B1
Mass of wet soil + container (m_2) g	30.72	29.49	27.98	27.51	17.88	17.27
Mass of dry soil + container (m_3) g	24.7	24.09	23.34	23.18	17.38	16.83
Mass of container (m_1) g	15.74	15.66	15.77	15.62	15.58	15.32
Mass of moisture (m_2- m_3)g	6.02	5.4	4.64	4.33	0.50	0.44
Mass of dry soil (m_3- m_1)g	8.96	8.43	7.57	7.56	1.80	1.51
Moisture content = (m2-m3)/(m3- m1)*100 %	67.19	64.06	61.29	57.28	27.78	29.14
Liquid Limit/Plastic Limit	62.54				28.46	
Second trial- RC-0-02						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	16	21	28	36		
Container no.	76	56	C10	D37	77	33
Mass of wet soil + container (m_2) g	32.58	36.06	32.08	31.92	16.97	17.99
Mass of dry soil + container (m_3) g	25.7	27.98	25.31	26.17	16.62	17.47
Mass of container (m_1) g	15.57	15.77	13.84	15.36	15.44	15.71
Mass of moisture (m_2- m_3)g	6.88	8.08	6.77	5.75	0.35	0.52
Mass of dry soil (m_3- m_1)g	10.13	12.21	11.47	10.81	1.18	1.76
Moisture content = (m2-m3)/(m3- m1)*100 %	67.92	66.18	59.02	53.19	29.66	29.55
Liquid Limit/Plastic Limit	60.99				29.6	



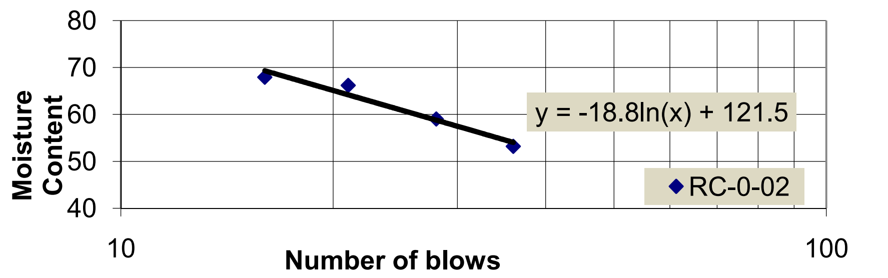


Figure B.6: Flow curves for RC-0-0

Table B.7: Atterberg limits of the PURE CRETE treated red clay soil- RC-2PC-0

First trial- RC-2PC-01						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	11	19	27	35		
Container no.	A-14	1A	D26	D361	B-5	D-22
Mass of wet soil + container (m_2) g	31.81	32.25	29.53	31.53	16.85	16.84
Mass of dry soil + container (m_3) g	25.2	25.47	24.39	25.95	16.52	16.61
Mass of container (m_1) g	15.65	15.26	15.72	15.53	15.31	15.75
Mass of moisture (m_2- m_3)g	6.61	6.78	5.14	5.58	0.33	0.23
Mass of dry soil (m_3- m_1)g	9.55	10.21	8.67	10.42	1.21	0.86
Moisture content = (m2-m3)/(m3- m1)*100 %	69.21	66.41	59.28	53.55	27.27	26.74
Liquid Limit/Plastic Limit	59.9				27.01	
Second trial- RC-2PC-02						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	13	22	29	34		
Container no.	82	A-34	15	C21	A9	20
Mass of wet soil + container (m_2) g	29.2	33.42	29.86	30.65	16.85	16.78
Mass of dry soil + container (m_3) g	23.7	26.34	24.53	24.9	16.53	16.53
Mass of container (m_1) g	15.72	15.64	15.50	14.18	15.36	15.59
Mass of moisture (m_2- m_3)g	5.5	7.08	5.33	5.75	0.32	0.25
Mass of dry soil (m_3- m_1)g	7.98	10.7	9.03	10.72	1.17	0.94
Moisture content = (m2-m3)/(m3- m1)*100 %	68.92	66.17	59.03	53.64	27.35	26.60
Liquid Limit/Plastic Limit	60.8				26.97	

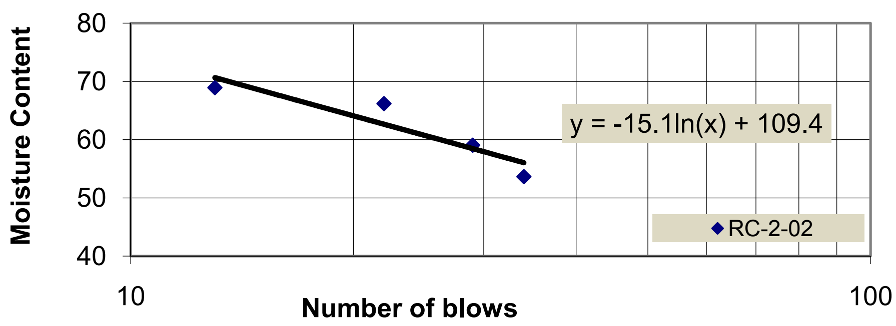
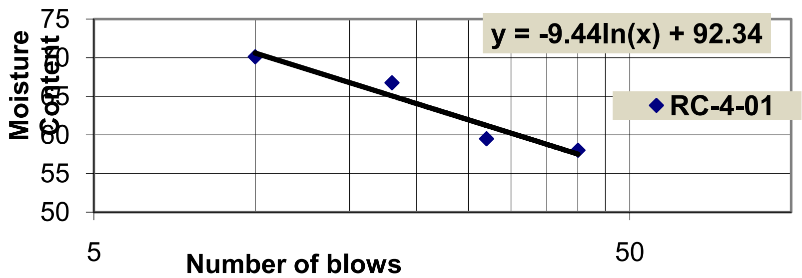


Figure B.7: Flow curves for RC-2PC-0

Table B.8: Atterberg limits of the PURE CRETE treated red clay soil- RC-4PC-0

First trial- RC-4PC-01						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	10	18	27	40		
Container no.	A-11	95	2	12	24	C-30
Mass of wet soil + container (m_2) g	29.91	28.53	28.75	28.24	17.85	16.75
Mass of dry soil + container (m_3) g	24.07	23.35	23.65	23.68	17.33	16.51
Mass of container (m_1) g	15.74	15.59	15.08	15.82	15.45	15.62
Mass of moisture (m_2- m_3)g	5.84	5.18	5.1	4.56	0.52	0.24
Mass of dry soil (m_3- m_1)g	8.33	7.76	8.57	7.86	1.88	0.89
Moisture content = (m2-m3)/(m3- m1)*100 %	70.11	66.75	59.51	58.02	27.66	26.97
Liquid Limit/Plastic Limit	61.87				27.31	
Second trial- RC-4PC-02						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	9	23	28	35		
Container no.	80	69	D-11	3	42	A-28
Mass of wet soil + container (m_2) g	33.48	34.25	30.8	29.72	16.97	16.95
Mass of dry soil + container (m_3) g	26.1	26.85	25.11	24.82	16.63	16.62
Mass of container (m_1) g	15.69	15.64	15.51	15.64	15.39	15.37
Mass of moisture (m_2- m_3)g	7.38	7.4	5.69	4.9	0.34	0.33
Mass of dry soil (m_3- m_1)g	10.41	11.21	9.6	9.18	1.24	1.25
Moisture content = (m2-m3)/(m3- m1)*100 %	70.89	66.01	59.27	53.38	27.42	26.40
Liquid Limit/Plastic Limit	60.70				26.90	



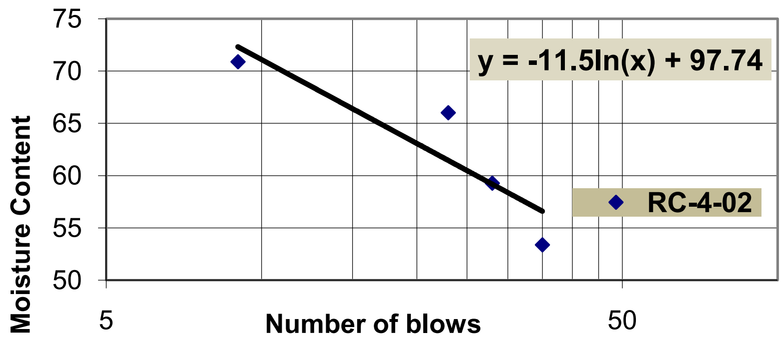
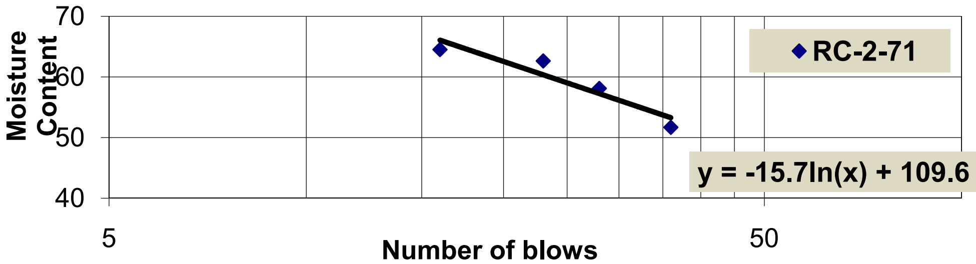


Figure B.8: Flow curves for RC-4PC-0

Table B.9: Atterberg limits of the PURE CRETE treated red clay soil- RC-2PC-7

First trial- RC-2PC-71						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	16	23	28	36		
Container no.	A14	D-20	C-29	108	15	102
Mass of wet soil + container (m_2) g	34.8	33.62	37.62	37.32	17.87	18.088
Mass of dry soil + container (m_3) g	27.29	26.65	28.95	29.93	17.32	17.53
Mass of container (m_1) g	15.65	15.52	14.03	15.63	15.49	15.67
Mass of moisture (m_2- m_3)g	7.51	6.97	8.67	7.39	0.55	0.558
Mass of dry soil (m_3- m_1)g	11.64	11.13	14.92	14.3	1.83	1.86
Moisture content = (m2-m3)/(m3- m1)*100 %	64.52	62.62	58.11	51.68	30.05	30.00
Liquid Limit/Plastic Limit	59.1				30.1	
Second trial- RC-2PC-72						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	8	20	29	40		
Container no.	D-35	16	A17	C9	C-13	B-7
Mass of wet soil + container (m_2) g	32.74	31.54	31.62	33.56	17.45	16.52
Mass of dry soil + container (m_3) g	25.52	25.21	25.54	26.98	16.73	16.24
Mass of container (m_1) g	15.34	15.67	15.27	15.57	14.29	15.28
Mass of moisture (m_2- m_3)g	7.22	6.33	6.08	6.58	0.72	0.28
Mass of dry soil (m_3- m_1)g	10.18	9.54	10.27	11.41	2.44	0.96
Moisture content = (m2-m3)/(m3- m1)*100 %	70.92	66.35	59.20	57.67	29.51	29.17
Liquid Limit/Plastic Limit	61.97				29.3	



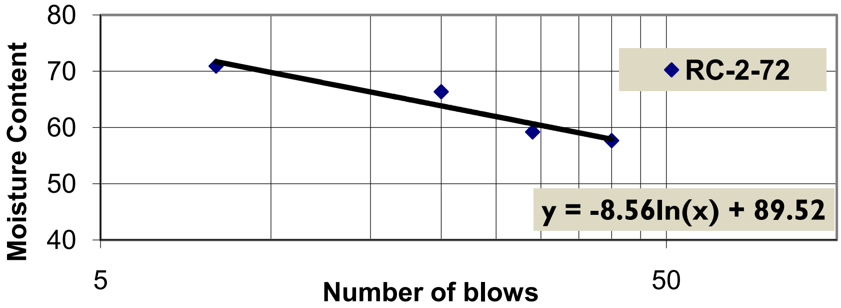
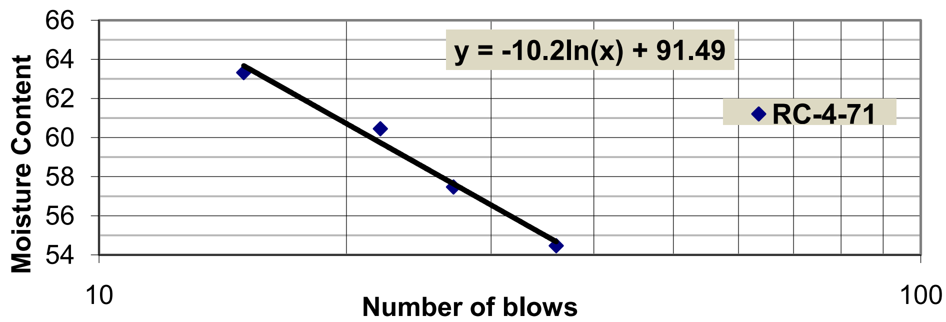


Figure B.9: Flow curves for RC-2PC-7

Table B.10: Atterberg limits of the PURE CRETE treated red clay soil- RC-4PC-7

First trial- RC-4PC-71						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	15	22	27	36		
Container no.	C-35	A-21	C-20	75	C-31	86
Mass of wet soil + container (m_2) g	34.7	32.83	30.86	31.05	15.61	17.00
Mass of dry soil + container (m_3) g	26.62	26.41	24.63	25.63	15.23	16.65
Mass of container (m_1) g	13.86	15.79	13.79	15.68	14.04	15.58
Mass of moisture (m_2- m_3)g	8.08	6.42	6.23	5.42	0.38	0.35
Mass of dry soil (m_3- m_1)g	12.76	10.62	10.84	9.95	1.19	1.07
Moisture content = (m2-m3)/(m3- m1)*100 %	63.32	60.45	57.47	54.47	31.93	32.71
Liquid Limit/Plastic Limit	58.70				32.3	
Second trial- RC-4PC-72						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	11	20	28	38		
Container no.	52	D97	37	71	32	72
Mass of wet soil + container (m_2) g	29.71	28.95	32.22	29.88	16.52	15.96
Mass of dry soil + container (m_3) g	23.95	23.93	26.19	24.85	15.91	15.79
Mass of container (m_1) g	15.39	15.82	15.68	15.53	13.96	15.27
Mass of moisture (m_2- m_3)g	5.76	5.02	6.03	5.03	0.61	0.17
Mass of dry soil (m_3- m_1)g	8.56	8.11	10.51	9.32	1.95	0.52
Moisture content = (m2-m3)/(m3- m1)*100 %	67.29	61.90	57.37	53.97	31.28	32.69
Liquid Limit/Plastic Limit	58.83				31.99	



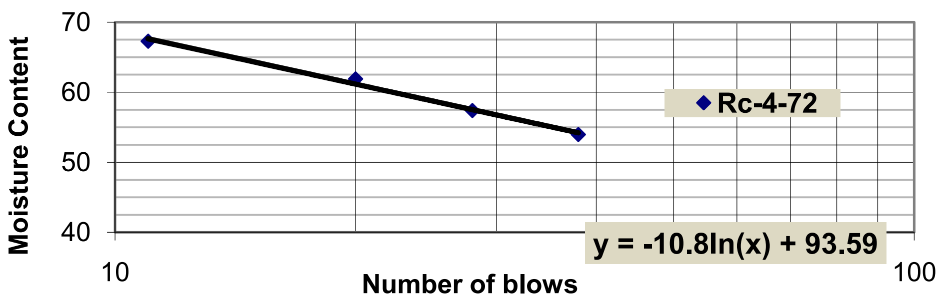
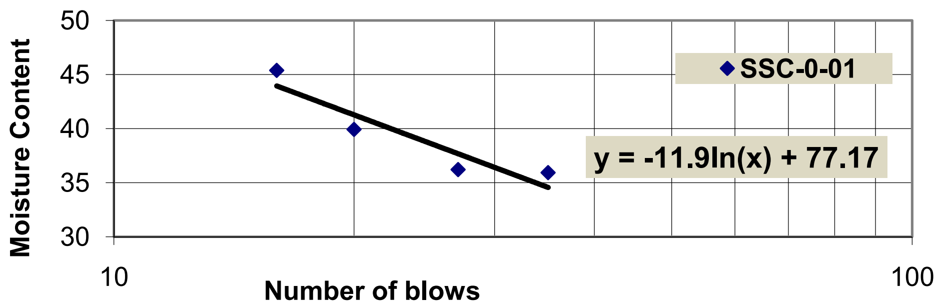


Figure B.10: Flow curves for RC-4PC-7

Table B.11: Atterberg limits of untreated silty sand blended with red clay soil- SSC-0-0

First trial- SSC-0-01						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	16	20	26	35		
Container no.	57	C10	77	2	47	20
Mass of wet soil + container (m_2) g	41.13	36.01	34.62	38.99	23.74	24.80
Mass of dry soil + container (m_3) g	30.996	30.08	29.52	32.81	21.89	22.67
Mass of container (m_1) g	15.28	13.83	15.44	15.61	15.67	13.8
Mass of moisture (m_2- m_3)g	10.134	5.93	5.1	6.18	1.85	2.13
Mass of dry soil (m_3- m_1)g	15.716	16.25	14.08	17.2	6.22	8.87
Moisture content = (m2-m3)/(m3- m1)*100 %	64.48	36.49	36.22	35.93	29.74	24.01
Liquid Limit/Plastic Limit	41.14				26.88	
Second trial- SSC-0-02						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	13	22	29	38		
Container no.	H-4	1A	D-361	B-1	A-10	D-16
Mass of wet soil + container (m_2) g	33.91	30.52	32.66	33.5	22.65	23.82
Mass of dry soil + container (m_3) g	27.86	26.21	28.12	28.76	21.16	22.02
Mass of container (m_1) g	15.74	15.26	15.53	15.31	15.51	15.53
Mass of moisture (m_2- m_3)g	6.05	4.31	4.54	4.74	1.49	1.8
Mass of dry soil (m_3- m_1)g	12.12	10.95	12.59	13.45	5.65	6.49
Moisture content = (m2-m3)/(m3- m1)*100 %	49.92	39.36	36.06	35.24	26.37	27.73
Liquid Limit/Plastic Limit	39.41				27.05	



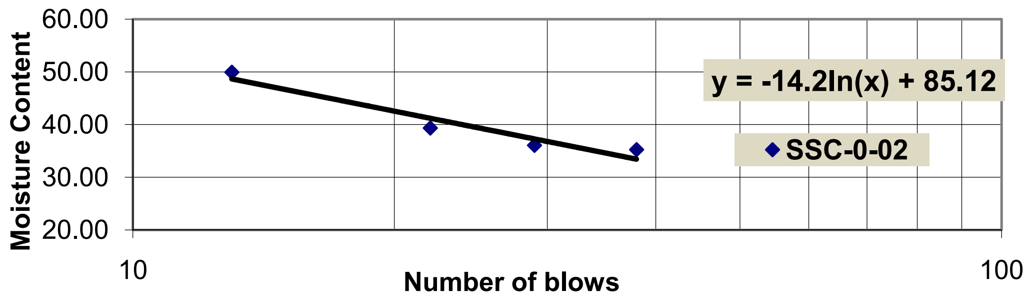


Figure B.11: Flow curves for SSC-0-0

Table B.12: Atterberg limits of PURE CRETE treated silty sand blended with red clay soil- SSC-2PC-0

First trial- SSC-2PC-01						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	14	22	28	37		
Container no.	103	12	A-28	A-11	20	16
Mass of wet soil + container (m_2) g	35.45	31.74	32.65	35.44	18.78	19.70
Mass of dry soil + container (m_3) g	29.16	27.25	28.02	30.28	18.1	18.87
Mass of container (m_1) g	15.59	15.82	15.37	15.76	15.60	15.67
Mass of moisture (m_2- m_3)g	6.29	4.49	4.63	5.16	0.68	0.83
Mass of dry soil (m_3- m_1)g	13.57	11.43	12.65	14.52	2.50	3.2
Moisture content = (m2-m3)/(m3- m1)*100 %	46.35	39.28	36.60	35.54	27.20	25.94
Liquid Limit/Plastic Limit	39.09				26.57	
Second trial- SSC-2PC-02						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	11	21	30	39		
Container no.	23	D-16	D-15	C-21	85	30
Mass of wet soil + container (m_2) g	38.51	34.72	29.8	31.15	21.07	20.63
Mass of dry soil + container (m_3) g	30.97	29.24	26.03	26.74	19.99	19.62
Mass of container (m_1) g	15.64	15.53	15.58	14.18	15.84	15.89
Mass of moisture (m_2- m_3)g	7.54	5.48	3.77	4.41	1.08	1.01
Mass of dry soil (m_3- m_1)g	15.33	13.71	10.45	12.56	4.15	3.73
Moisture content = (m2-m3)/(m3- m1)*100 %	49.18	39.97	36.08	35.11	26.02	27.08
Liquid Limit/Plastic Limit	39.11				26.55	

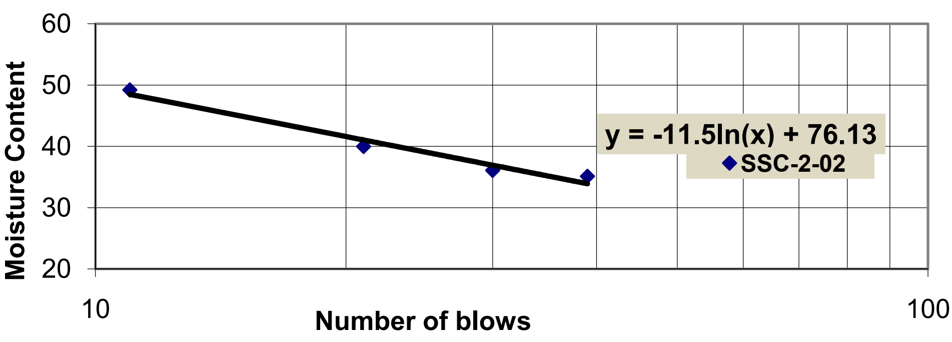


Figure B.12: Flow curves for SSC-2PC-0

Table B.13: Atterberg limits of PURE CRETE treated silty sand blended with red clay soil- SSC-4PC-0

First trial- SSC-4PC-01						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	12	22	29	37		
Container no.	97	C-13	D-37	GHI	C-27	D-8
Mass of wet soil + container (m_2) g	37.32	34.29	30.88	38.83	21.52	22.05
Mass of dry soil + container (m_3) g	30.26	28.53	26.73	32.71	19.95	20.67
Mass of container (m_1) g	15.85	13.9	15.35	15.59	14.03	15.5
Mass of moisture (m_2- m_3)g	7.06	5.76	4.15	6.12	1.57	1.38
Mass of dry soil (m_3- m_1)g	14.41	14.63	11.38	17.12	5.92	5.17
Moisture content = (m2-m3)/(m3- m1)*100 %	48.99	39.37	36.47	35.75	26.52	26.69
Liquid Limit/Plastic Limit	39.45				26.61	
Second trial- SSC-4PC-02						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	14	23	30	41		
Container no.	C19	100	B1	D22	38	D33
Mass of wet soil + container (m_2) g	32.37	31.73	33.8	35.29	24.43	22.19
Mass of dry soil + container (m_3) g	26.54	27.12	28.91	30.23	22.59	20.81
Mass of container (m_1) g	13.95	15.42	15.30	15.74	15.58	15.49
Mass of moisture (m_2- m_3)g	5.83	4.61	4.89	5.06	1.84	1.38
Mass of dry soil (m_3- m_1)g	12.59	11.7	13.61	14.49	7.01	5.32
Moisture content = (m2-m3)/(m3- m1)*100 %	46.31	39.40	35.93	34.92	26.25	25.94
Liquid Limit/Plastic Limit	39.26				26.09	

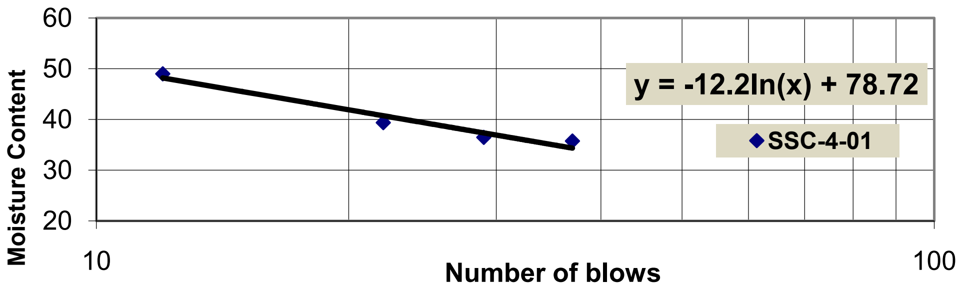
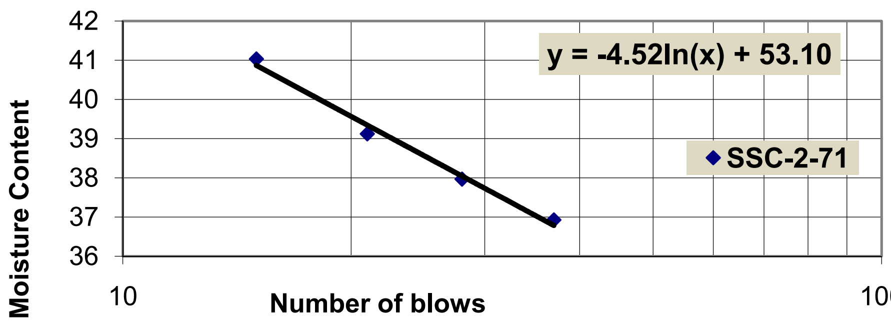


Figure B.13: Flow curves for SSC-4PC-0

Table B.14: Atterberg limits of PURE CRETE treated silty sand blended with red clay soil- SSC-2PC-7

First trial- SSC-2PC-71						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	15	21	28	37		
Container no.	A1	97	D8	A36	24	72
Mass of wet soil + container (m_2) g	42.23	40.59	36.24	31.01	17.62	17.92
Mass of dry soil + container (m_3) g	34.52	33.63	30.53	26.83	17.17	17.43
Mass of container (m_1) g	15.73	15.84	15.49	15.51	15.62	15.67
Mass of moisture (m_2- m_3)g	7.71	6.96	5.71	4.18	0.45	0.49
Mass of dry soil (m_3- m_1)g	18.79	17.79	15.04	11.32	1.55	1.76
Moisture content = (m2-m3)/(m3- m1)*100 %	41.03	39.12	37.97	36.93	29.03	27.84
Liquid Limit/Plastic Limit	38.55				28.44	
Second trial- SSC-2PC-72						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	15	22	27	35		
Container no.	D29	H2	D22	71	74	A10
Mass of wet soil + container (m_2) g	35.44	33.96	29.68	34.39	18.27	18.11
Mass of dry soil + container (m_3) g	29.77	28.93	25.92	29.36	17.71	17.56
Mass of container (m_1) g	15.46	15.7	15.77	15.57	15.84	15.55
Mass of moisture (m_2- m_3)g	5.67	5.03	3.76	5.03	0.56	0.55
Mass of dry soil (m_3- m_1)g	14.31	13.23	10.15	13.79	1.87	2.01
Moisture content = (m2-m3)/(m3- m1)*100 %	39.62	38.02	37.04	36.48	29.95	27.36
Liquid Limit/Plastic Limit	37.60				28.65	



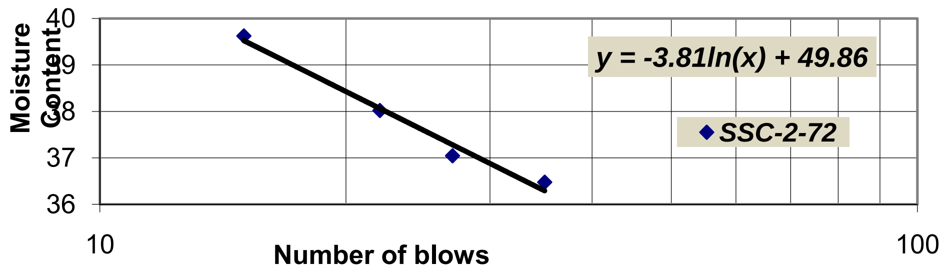
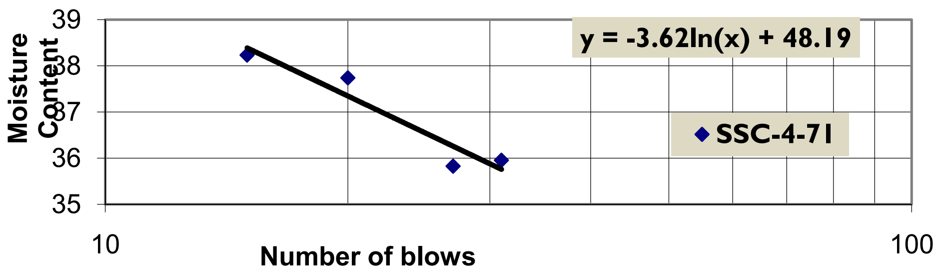


Figure B.14: Flow curves for SSC-2PC-7

Table B.15: Atterberg limits of PURE CRETE treated silty sand blended with red clay soil- SSC-4PC-7

Second trial- SSC-4PC-72						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	15	21	26	32		
Container no.	C21	GHI	24	2	57	100
Mass of wet soil + container (m_2) g	32.83	30.77	35.08	31.63	17.23	17.74
Mass of dry soil + container (m_3) g	27.85	26.82	30.0	27.5	16.81	17.24
Mass of container (m_1) g	14.17	15.6	15.63	15.62	15.28	15.44
Mass of moisture (m_2- m_3)g	4.98	3.95	5.08	4.13	0.42	0.5
Mass of dry soil (m_3- m_1)g	13.68	11.22	14.37	11.88	1.53	1.8
Moisture content = (m2-m3)/(m3- m1)*100 %	36.40	35.20	35.35	34.76	27.45	27.78
Liquid Limit/Plastic Limit	35.23				27.61	
First trial- SSC-4PC-71						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	15	20	27	31		
Container no.	32	C9	47	70	20	16
Mass of wet soil + container (m_2) g	29.08	29.80	34.85	29.04	17.63	18.15
Mass of dry soil + container (m_3) g	25.36	25.46	29.72	25.52	17.16	17.58
Mass of container (m_1) g	15.63	13.96	15.40	15.73	15.60	15.67
Mass of moisture (m_2- m_3)g	3.72	4.34	5.13	3.52	0.47	0.57
Mass of dry soil (m_3- m_1)g	9.73	11.5	14.32	9.79	1.56	1.91
Moisture content = (m2-m3)/(m3- m1)*100 %	38.23	37.74	35.82	35.96	30.13	29.84
Liquid Limit/Plastic Limit	36.54				29.99	



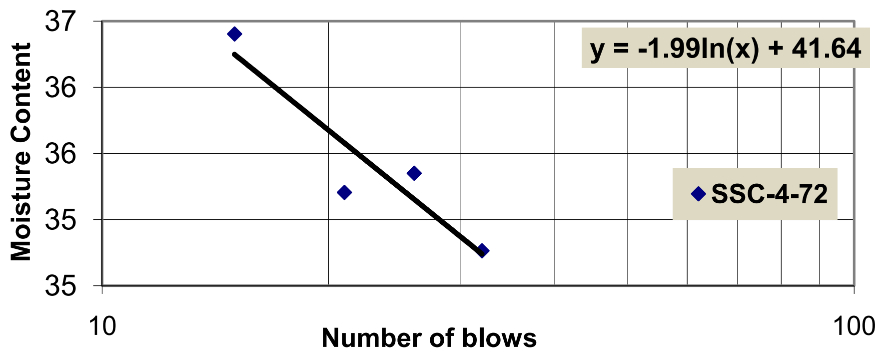
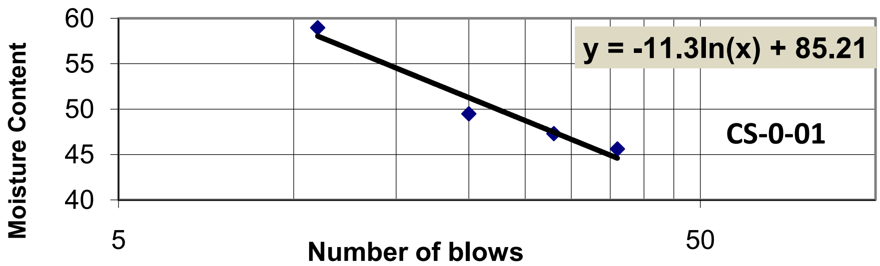


Figure B.15: Flow curves for SSC-4PC-7

Table B.16: Atterberg limits of untreated clayey sand from civil service college- CS-0-0

First trial- CS-0-01						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	16	22	29	38		
Container no.	H2	24	70	C29	80	D16
Mass of wet soil + container (m_2) g	33.9	32.45	34.36	32.69	16.92	16.75
Mass of dry soil + container (m_3) g	27.28	26.35	27.78	26.32	16.64	16.47
Mass of container (m_1) g	15.69	15.6	15.72	13.92	15.69	15.54
Mass of moisture (m_2- m_3)g	6.62	6.1	6.58	6.37	0.28	0.28
Mass of dry soil (m_3- m_1)g	11.59	10.75	12.06	12.4	0.95	0.93
Moisture content = (m2-m3)/(m3- m1)*100 %	57.12	56.74	54.56	51.37	29.47	30.11
Liquid Limit/Plastic Limit	54.96				29.79	
Second trial- CS-0-02						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	14	21	31	40		
Container no.	103	A-11	2	C-29	A29	12
Mass of wet soil + container (m_2) g	31.28	30.43	31.92	31.55	17.29	17.75
Mass of dry soil + container (m_3) g	25.52	25.11	26.05	25.64	16.85	17.32
Mass of container (m_1) g	15.59	15.76	15.08	14.02	15.37	15.82
Mass of moisture (m_2- m_3)g	5.76	5.32	5.87	5.91	0.44	0.43
Mass of dry soil (m_3- m_1)g	9.93	9.35	10.97	11.62	1.48	1.5
Moisture content = (m2-m3)/(m3- m1)*100 %	58.01	56.90	53.51	50.86	29.73	28.67
Liquid Limit/Plastic Limit	54.69				29.20	



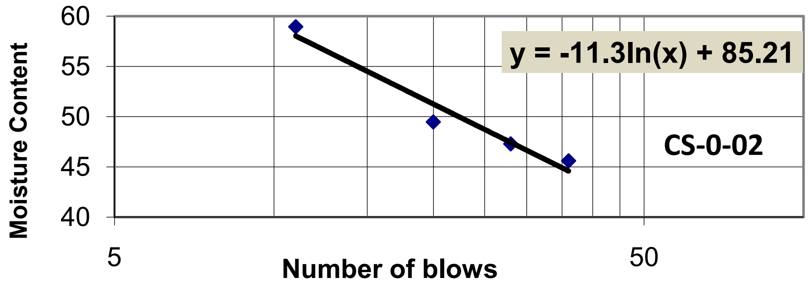
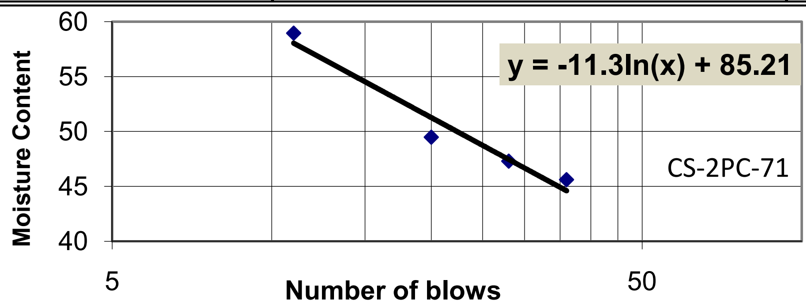


Figure B.16: Flow curves for CS-0-0

Table B.17: Atterberg limits of PURE CRETE treated clayey sand from civil service college-CS-2PC-7

First trial- CS-2PC-71						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	11	20	28	36		
Container no.	C-19	D-5	100	95	C-20	75
Mass of wet soil + container (m_2) g	32.17	34.11	32.84	31.36	16.32	17.27
Mass of dry soil + container (m_3) g	25.42	28.01	27.25	26.42	15.79	16.95
Mass of container (m_1) g	13.97	15.68	15.43	15.59	13.79	15.68
Mass of moisture (m_2- m_3)g	6.75	6.1	5.59	4.94	0.53	0.32
Mass of dry soil (m_3- m_1)g	11.45	12.33	11.82	10.83	2	1.27
Moisture content = (m2-m3)/(m3- m1)*100 %	58.95	49.47	47.29	45.61	26.50	25.20
Liquid Limit/Plastic Limit	48.84				25.85	
Second trial- CS-2PC-72						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	14	22	29	40		
Container no.	C-13	C-16	51	85	34	28
Mass of wet soil + container (m_2) g	31.11	30.82	30.98	29.78	17.59	17.42
Mass of dry soil + container (m_3) g	25.06	25.34	26.13	25.47	17.18	17.03
Mass of container (m_1) g	14.29	14.19	15.82	15.84	15.61	15.54
Mass of moisture (m_2- m_3)g	6.05	5.48	4.85	4.31	0.41	0.39
Mass of dry soil (m_3- m_1)g	10.77	11.15	10.31	9.63	1.57	1.49
Moisture content = (m2-m3)/(m3- m1)*100 %	56.17	49.15	47.04	44.76	26.11	26.17
Liquid Limit/Plastic Limit	49.2				26.14	



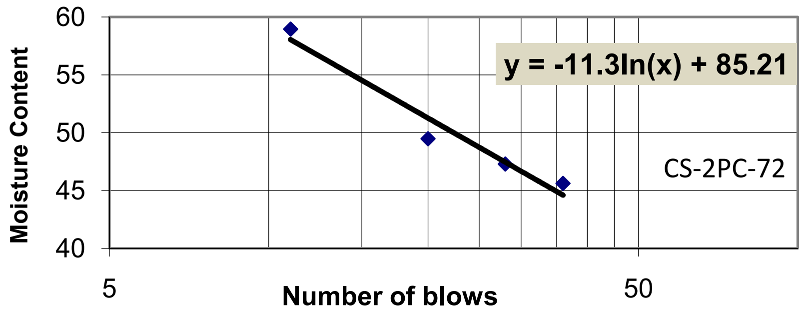
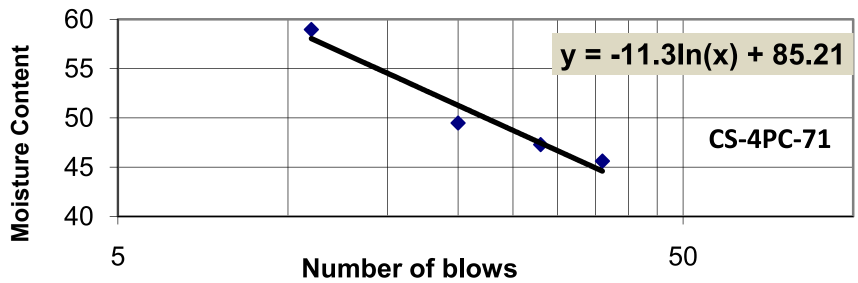


Figure B.17: Flow curves for CS-2PC-7

Table B.18: Atterberg limits of PURE CRETE treated clayey sand from civil service college- CS-4PC-7

First trial- CS-4PC-71						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	12	21	28	41		
Container no.	D-16	D-15	H-4	80	42	23
Mass of wet soil + container (m_2) g	33.55	31.29	29.53	32.63	18.15	17.59
Mass of dry soil + container (m_3) g	26.94	26.11	25.1	27.46	17.58	17.19
Mass of container (m_1) g	15.53	15.58	15.74	15.69	15.39	15.64
Mass of moisture (m_2- m_3)g	6.61	5.18	4.43	5.17	0.57	0.4
Mass of dry soil (m_3- m_1)g	11.41	10.53	9.36	11.77	2.19	1.55
Moisture content = (m2-m3)/(m3- m1)*100 %	57.93	49.19	47.33	43.93	26.03	25.81
Liquid Limit/Plastic Limit	48.84				25.92	
Second trial- CS-4PC-72						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	6	12	21	29		
Container no.	D25	D15	C18	24	C15	76
Mass of wet soil + container (m_2) g	28.95	27.73	22.16	27.06	15.28	16.7
Mass of dry soil + container (m_3) g	21.08	20.6	17.28	20.61	14.86	16.36
Mass of container (m_1) g	15.87	15.59	13.54	15.63	13.9	15.56
Mass of moisture (m_2- m_3)g	7.87	7.13	4.88	6.45	0.42	0.34
Mass of dry soil (m_3- m_1)g	5.21	5.01	3.74	4.98	0.96	0.8
Moisture content = (m2-m3)/(m3- m1)*100 %	151.06	142.32	130.48	129.52	43.75	42.50
Liquid Limit/Plastic Limit	48.75				25.87	



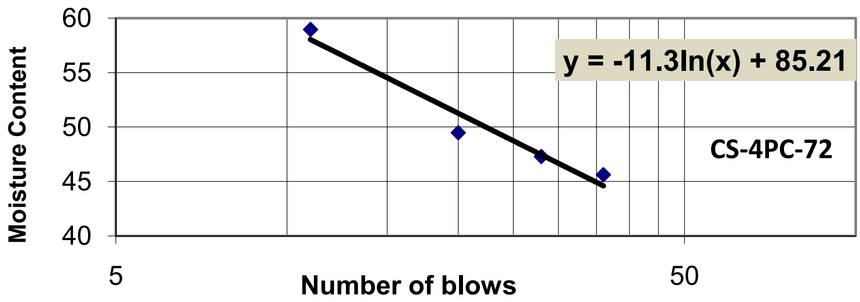


Figure B.18: Flow curves for CS-4PC-7

Table B.19: Atterberg limits of ANSS treated light grey clay soil - LGC-6ANSS-7

First trial- LGC-6ANSS-71						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	16	23	29	37		
Container no.	B1	C10	100	D-29	D22	C-15
Mass of wet soil + container (m_2) g	30.16	33.82	32.38	34.82	17.75	16.00
Mass of dry soil + container (m_3) g	22.9	24.07	24.24	25.84	17.06	15.28
Mass of container (m_1) g	15.30	13.81	15.42	15.86	15.74	13.90
Mass of moisture (m_2- m_3)g	7.26	9.75	8.14	8.98	0.69	0.72
Mass of dry soil (m_3- m_1)g	7.6	10.26	8.82	9.98	1.32	1.38
Moisture content = (m2-m3)/(m3- m1)*100 %	95.53	95.03	92.29	89.98	52.27	52.17
Liquid Limit/Plastic Limit	93.2				52.2	
Second trial- LGC-6ANSS-72						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	12	21	28	35		
Container no.	A9	53	59	15	D5	2
Mass of wet soil + container (m_2) g	32.25	29.82	33.42	35.59	17.35	16.75
Mass of dry soil + container (m_3) g	23.97	22.84	24.7	26.02	16.78	16.18
Mass of container (m_1) g	15.36	15.52	15.29	15.50	15.68	15.08
Mass of moisture (m_2- m_3)g	8.28	6.98	8.72	9.57	0.57	0.57
Mass of dry soil (m_3- m_1)g	8.61	7.32	9.41	10.52	1.10	1.1
Moisture content = (m2-m3)/(m3- m1)*100 %	96.17	95.36	92.67	90.97	51.82	51.82
Liquid Limit/Plastic Limit	93.2				51.8	

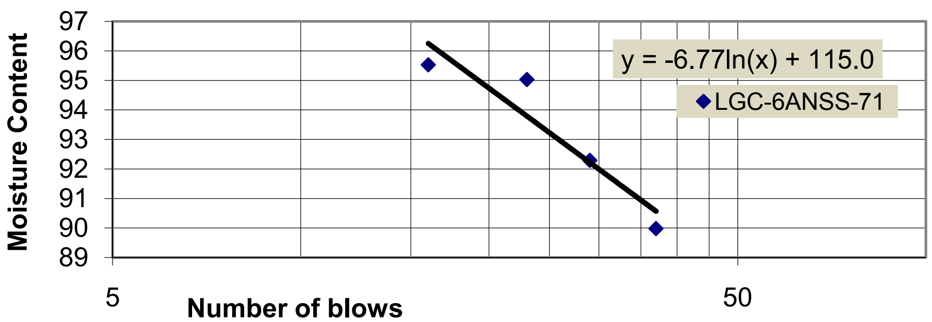


Figure B.19: Flow curves for LGC-6ANSS-7

Table B.20: Atterberg limits of ANSS treated red clay soil- RC-4ANSS-0

First trial- RC-4ANSS-01						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	16	21	29	36		
Container no.	C26	A34	62	C16	D16	D20
Mass of wet soil + container (m_2) g	31.28	34.25	30.66	28.61	17.71	17.65
Mass of dry soil + container (m_3) g	25.11	27.63	25.37	23.55	17.08	17.11
Mass of container (m_1) g	14.14	15.64	15.61	14.15	15.52	15.48
Mass of moisture (m_2- m_3)g	6.17	6.62	5.29	5.06	0.63	0.54
Mass of dry soil (m_3- m_1)g	10.97	11.99	9.76	9.4	1.56	1.63
Moisture content = (m2-m3)/(m3- m1)*100 %	56.24	55.21	54.20	53.83	40.38	33.13
Liquid Limit/Plastic Limit	54.81				36.76	
Second trial- RC-4ANSS-02						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	11	20	28	40		
Container no.	76	36	1A	20	38	C-15
Mass of wet soil + container (m_2) g	32.62	28.62	31.94	34.06	17.29	16.13
Mass of dry soil + container (m_3) g	26.32	23.34	26.05	27.21	16.85	15.52
Mass of container (m_1) g	15.56	13.85	15.26	14.15	15.59	13.89
Mass of moisture (m_2- m_3)g	6.3	5.28	5.89	6.85	0.44	0.61
Mass of dry soil (m_3- m_1)g	10.76	9.49	10.79	13.06	1.26	1.63
Moisture content = (m2-m3)/(m3- m1)*100 %	58.55	55.64	54.59	52.45	34.92	37.42
Liquid Limit/Plastic Limit	54.77				36.17	

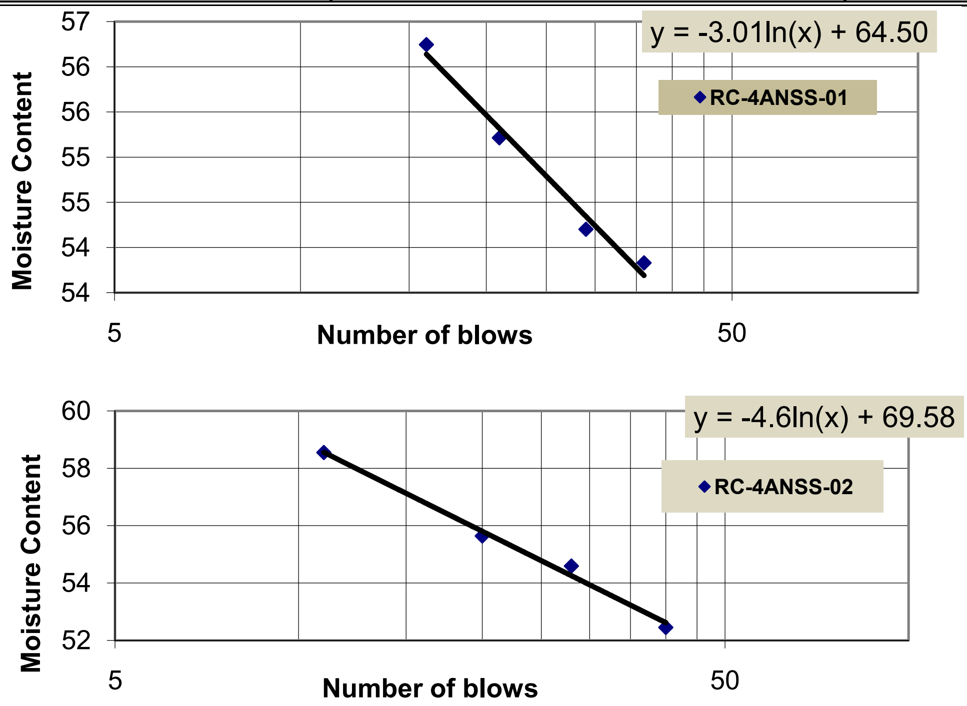


Figure B.20: Flow curves for RC-4ANSS-0

Table B.21: Atterberg limits of ANSS treated red clay soil- RC-4ANSS-7

First trial- RC-4ANSS-71						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	15	21	27	33		
Container no.	A16	8	74	D361	71	97
Mass of wet soil + container (m_2) g	35.31	30.91	32.19	28.26	17.40	17.88
Mass of dry soil + container (m_3) g	27.74	25.12	26.10	23.68	16.90	17.33
Mass of container (m_1) g	15.69	15.64	15.51	15.64	15.54	15.85
Mass of moisture (m_2- m_3)g	7.57	5.79	6.09	4.58	0.5	0.55
Mass of dry soil (m_3- m_1)g	12.05	9.48	10.59	8.04	1.36	1.48
Moisture content = (m2-m3)/(m3- m1)*100 %	62.82	61.08	57.51	56.97	36.76	37.16
Liquid Limit/Plastic Limit	58.94				36.96	
Second trial- RC-4ANSS-72						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	11	20	27	40		
Container no.	103	A-11	2	C-29	A-29	12
Mass of wet soil + container (m_2) g	32.23	32.46	30.77	31.6	17.45	17.89
Mass of dry soil + container (m_3) g	25.35	26.12	25.13	25.43	16.90	17.33
Mass of container (m_1) g	15.59	15.76	15.08	14.02	15.37	15.82
Mass of moisture (m_2- m_3)g	6.88	6.34	5.64	6.17	0.55	0.56
Mass of dry soil (m_3- m_1)g	9.76	10.36	10.05	11.41	1.53	1.51
Moisture content = (m2-m3)/(m3- m1)*100 %	70.49	61.20	56.12	54.08	35.95	37.09
Liquid Limit/Plastic Limit	58.81				36.52	

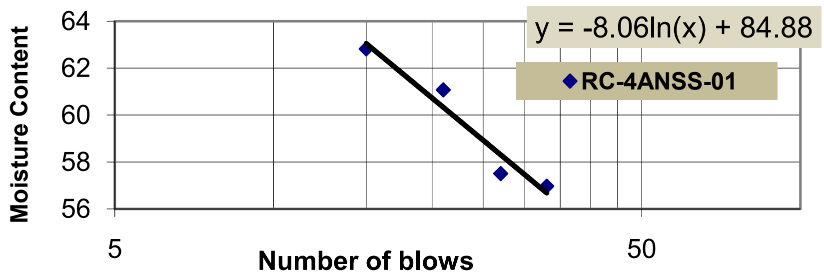
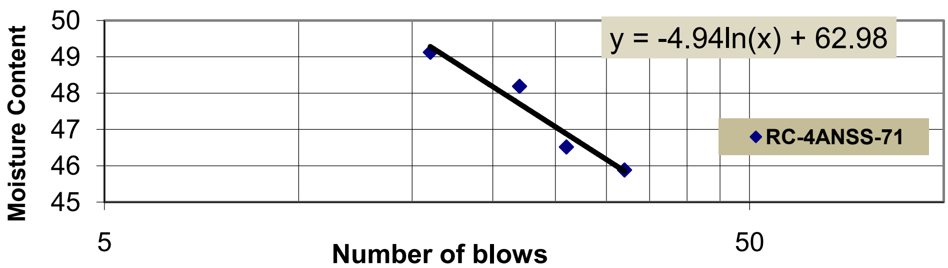


Figure B.21: Flow curves for RC-4ANSS-7

Table B.22: Atterberg limits of ANSS treated silty sand blended with red clay soil- SSC-4ANSS-7

First trial- SSC-4ANSS-71						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	16	22	26	32		
Container no.	C19	76	36	15	GHI	D-37
Mass of wet soil + container (m_2) g	33.56	31.07	28.38	31.24	18.72	18.54
Mass of dry soil + container (m_3) g	27.10	26.02	23.77	26.28	17.86	17.66
Mass of container (m_1) g	13.95	15.54	13.86	15.47	15.59	15.35
Mass of moisture (m_2- m_3)g	6.46	5.05	4.61	4.96	0.86	0.88
Mass of dry soil (m_3- m_1)g	13.15	10.48	9.91	10.81	2.27	2.31
Moisture content = (m2-m3)/(m3- m1)*100 %	49.13	48.19	46.52	45.88	37.89	38.10
Liquid Limit/Plastic Limit	47.08				37.99	
Second trial- SSC-4ANSS-72						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	14	21	28	37		
Container no.	D-15	A10	C-21	D-20	23	D-16
Mass of wet soil + container (m_2) g	31.21	33.51	30.45	32.63	17.94	18.31
Mass of dry soil + container (m_3) g	25.89	27.62	25.32	27.31	17.31	17.54
Mass of container (m_1) g	15.58	15.51	14.18	15.50	15.64	15.53
Mass of moisture (m_2- m_3)g	5.32	5.89	5.13	5.32	0.63	0.77
Mass of dry soil (m_3- m_1)g	10.31	12.11	11.14	11.81	1.67	2.01
Moisture content = (m2-m3)/(m3- m1)*100 %	51.60	48.64	46.05	45.05	37.72	38.31
Liquid Limit/Plastic Limit	47.40				38.02	



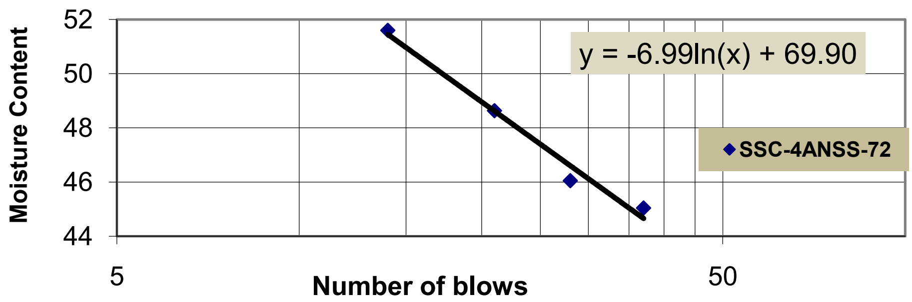
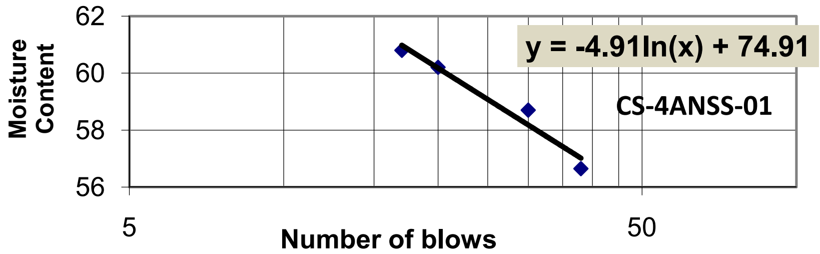


Figure B.22: Flow curves for SSC-4ANSS-7

Table B.23: Atterberg limits of ANSS treated clayey sand from civil service college- CS-6ANSS-0

First trial- CS-6ANSS-01						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	17	20	30	38		
Container no.	71	74	A10	38	C-10	D-5
Mass of wet soil + container (m_2) g	33.99	34.73	35.32	28.65	15.68	17.78
Mass of dry soil + container (m_3) g	27.01	27.62	28.00	23.92	15.1	17.14
Mass of container (m_1) g	15.53	15.81	15.53	15.57	13.83	15.67
Mass of moisture (m_2- m_3)g	6.98	7.11	7.32	4.73	0.58	0.64
Mass of dry soil (m_3- m_1)g	11.48	11.81	12.47	8.35	1.27	1.47
Moisture content = (m2-m3)/(m3- m1)*100 %	60.80	60.20	58.70	56.65	45.67	43.54
Liquid Limit/Plastic Limit	59.11				44.60	
Second trial- CS-6ANSS-02						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	14	23	31	37		
Container no.	A-34	56	GHI	D-26	8	52
Mass of wet soil + container (m_2) g	29.11	31.52	29.96	32.60	17.09	17.27
Mass of dry soil + container (m_3) g	23.98	25.63	24.65	26.56	16.64	16.78
Mass of container (m_1) g	15.64	15.78	15.56	15.72	15.62	15.72
Mass of moisture (m_2- m_3)g	5.13	5.89	5.31	6.04	0.45	0.49
Mass of dry soil (m_3- m_1)g	8.34	9.85	9.09	10.84	1.02	1.06
Moisture content = (m2-m3)/(m3- m1)*100 %	61.51	59.80	58.42	55.72	44.12	46.23
Liquid Limit/Plastic Limit	58.79				45.17	



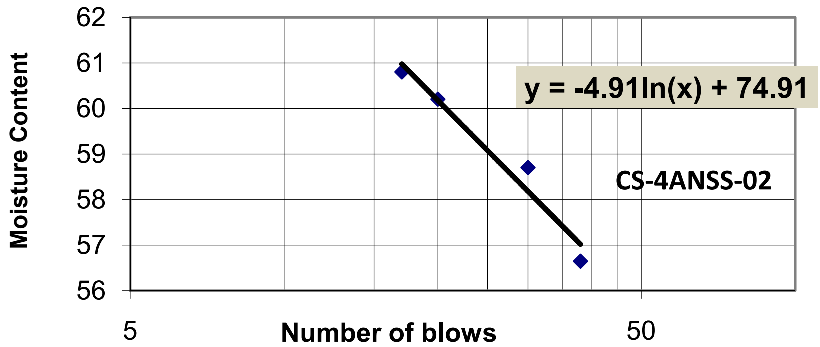
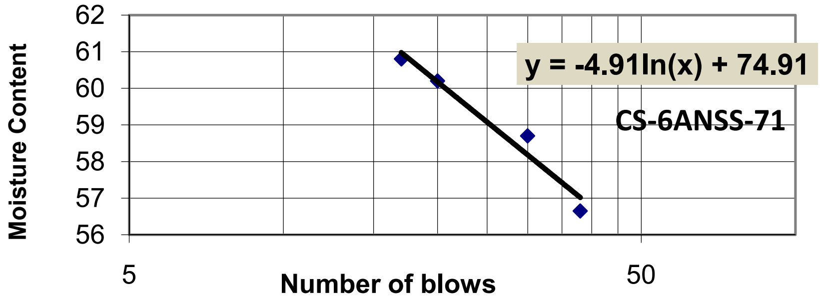


Figure B.23: Flow curves for CS-6ANSS-0

Table B.24: Atterberg limits of ANSS treated clayey sand from civil service college- CS-6ANSS-7

First trial- CS-6ANSS-71						
Item description	Liquid Limit trials				Plastic Limit trial	
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	14	21	30	35		
Container no.	C-16	56	59	D-22	34	42
Mass of wet soil + container (m_2) g	32.14	34.21	33.16	29.85	17.37	17.15
Mass of dry soil + container (m_3) g	25.46	27.92	26.62	25.17	16.81	16.61
Mass of container (m_1) g	14.19	15.78	15.29	15.75	15.61	15.39
Mass of moisture (m_2- m_3)g	6.68	6.29	6.54	4.68	0.56	0.54
Mass of dry soil (m_3- m_1)g	11.27	12.14	11.33	9.42	1.2	1.22
Moisture content = (m2-m3)/(m3- m1)*100 %	59.27	51.81	57.72	49.68	46.67	44.26
Liquid Limit/Plastic Limit	54.23				45.46	
Second trial- CS-6ANSS-72						
Test no.	#1	#2	#3	#4	#1	#2
Number of blows	16	22	27	32		
Container no.	38	C-20	A10	A14	D33	33
Mass of wet soil + container (m_2) g	34.19	31.76	31.18	32.80	17.28	16.12
Mass of dry soil + container (m_3) g	27.3	25.79	25.42	26.46	16.78	15.33
Mass of container (m_1) g	15.51	14.18	15.5	13.82	15.49	14.06
Mass of moisture (m_2- m_3)g	6.89	5.97	5.76	6.34	0.5	0.79
Mass of dry soil (m_3- m_1)g	11.79	11.61	9.92	12.64	1.29	1.27
Moisture content = (m2-m3)/(m3- m1)*100 %	58.44	51.42	58.06	50.16	38.76	62.20
Liquid Limit/Plastic Limit	54.03				50.48	



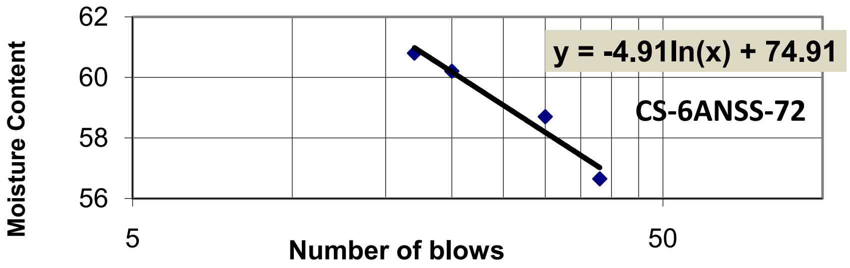


Figure B.24: Flow curves for CS-6ANSS-7

Annex C: Moisture –density relationship for treated and untreated soil samples

Table C. 1: Moisture –density relationship for light grey clay of Bole with standard effort

Items	Trials for LGC-0-0				Trials for LGC-6ANSS-7			
	1	2	3	4	1	2	3	4
Wt of mold, g	5604	5604	5604	5604	4731	4731	4731	4731
Wt of mold & compacted soil, g	6982	7198	7260	7089	5954	6341	6373	5846
Moisture can number	50	29	21	38	38	77	41	8
Wt of moisture can, g	5.16	5.16	5.3	5.31	5.3	5.2	5.3	5.3
Wt of can & wet soil, g	212	214	219	213	248.3	204.4	219.7	203.1
Wt of can & dry soil, g	169	160	154	140	210	155.1	151.3	126.3
Wt of water, g	43	54	65	73	38.3	49.3	68.4	76.8
Wt of dry soil,	163.84	154.84	148.7	134.69	204.7	149.9	146	121
Moisture content of compacted soil, %	26.2	34.9	43.7	54.2	18.71	32.9	46.8	63.5
Initial moisture content of sample, %	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
Weight of soil in mold, g	1378	1594	1656	1485	1223	1610	1642	1115
Volume of mold, cm3	972.878	972.878	972.878	972.878	944	944	944	944
Wet density, g/cc	1.416	1.638	1.702	1.526	1.296	1.706	1.739	1.181
Dry density, g/cc	1.122	1.215	1.184	0.990	1.091	1.283	1.184	0.723
Optimum moisture content, %	38				35.0			
Maximum dry density, g/cc	1.22				1.285			
Treatment & curing condition	Untreated and not cured				Treated with 6% ANSS & cured for 7 days			

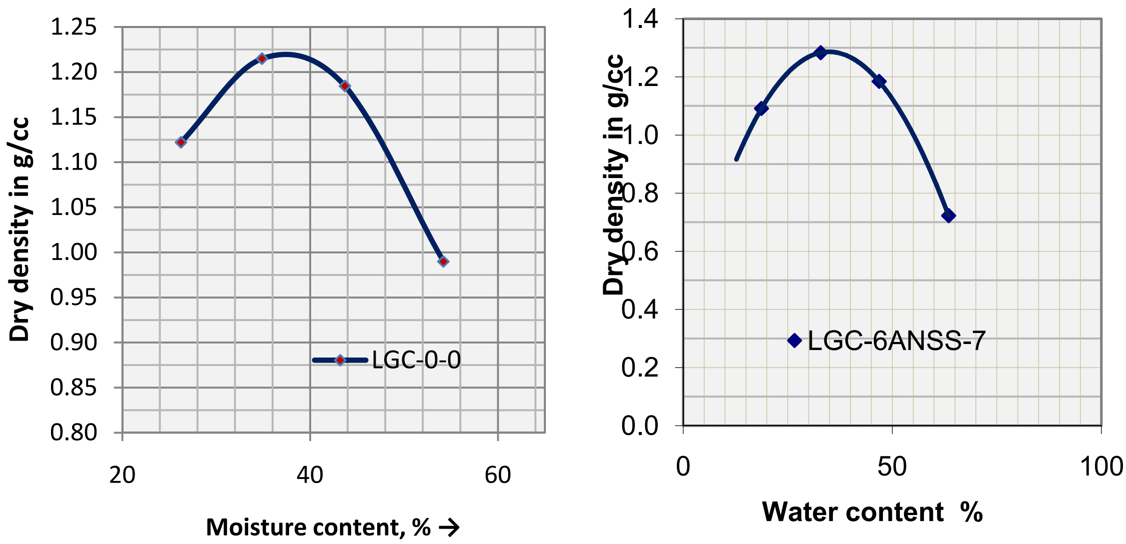


Figure C. 1: Moisture-dry density curves for light grey clay of Bole- LGC-0-0 & LGC-6ANSS-7

Table C. 2: Moisture –density relationship for red brown clay of Kolfe

Items	Trials for RC-0-0				Trials for RC-4ANSS-7				
	1	2	3	4	1	2	3	4	5
Wt of mold, g	5662	5662	5662	5662	4731	4731	4731	4731	4731
Wt of mold & compacted soil, g		7238	7396	7383	5864	6115	6414	6400	6007
Moisture can number	28	43	25	26	88	49	11--18	28	10
Wt of moisture can, g	5.32	5.15	186	248	5.2	5.2	5.2	5.4	5.2
Wt of can & wet soil, g	194	186	524	625	275.1	271.6	245.7	257.6	277
Wt of can & dry soil, g	170	152	444	524	235.37	226	195.62	190.29	192.4
Wt of water, g	24	34	80	101	39.73	45.6	50.08	67.31	84.6
Wt of dry soil,	164.68	146.85	258	276	230.17	220.8	190.42	184.89	187.2
Moisture content of compacted soil, %	14.6	23.2	31.0	36.6	17.3	20.7	26.3	36.4	45.2
Initial moisture content of sample, %	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
Weight of soil in mold, g	1390	1576	1734	1721	1133	1384	1683	1669	1276
Volume of mold, cm3	972.878	972.878	972.878	972.878	1.200	1.466	1.783	1.768	1.352
Wet density, g/cc	1.429	1.620	1.782	1.769	1.024	1.215	1.412	1.296	0.931
Dry density, g/cc	1.247	1.315	1.360	1.295	1.200	1.466	1.783	1.768	1.352
Optimum moisture content, %	30.5				29.0				
Maximum dry density, g/cc	1.362				1.44				
Treatment & curing condition	Untreated and not cured				Treated with 4% ANSS & cured for 7 days				

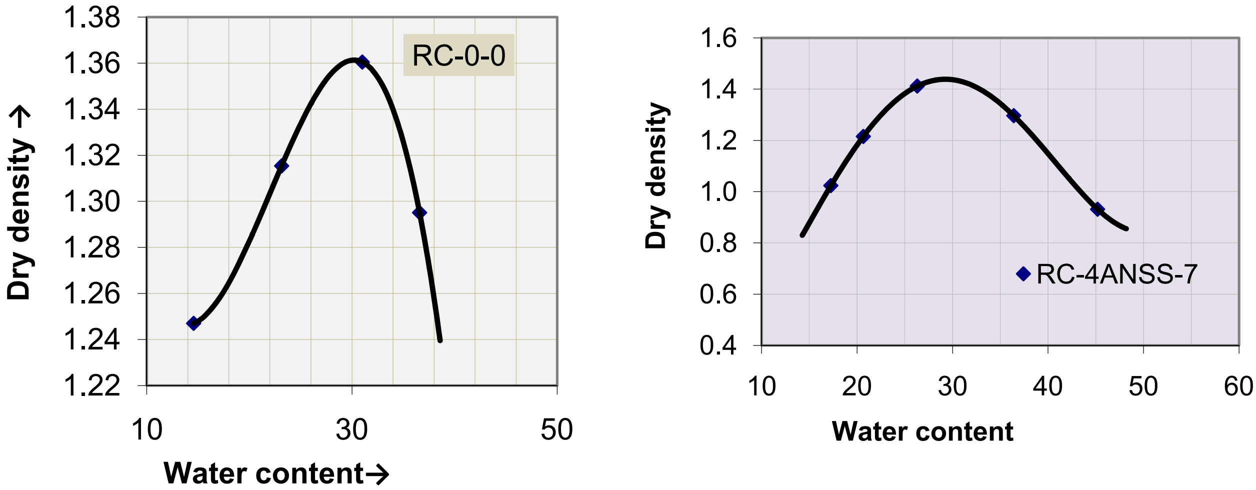


Figure C. 2: Moisture-dry density curves for red brown clay of Kolfe

Table C. 3: Moisture –density relationship for silty sand blended with red clay

Items	Trials for SSC-0-0					Trials for SSC-4ANSS-7				
	1	2	3	4	5	1	2	3	4	5
Wt of mold, g	5660	5660	5660	5660	5660	4731	4731	4731	4731	4731
Wt of mold & compacted soil, g	6868	6906	7062	7112	7186	5728	6127	6442	6174	5739
Moisture can number	36	10	44	6	CMC 5	22	74	44	CMC-4	71
Wt of moisture can, g	5.27	5.28	5.17	5.24	5.27	5.3	5.2	5.2	5.2	5.3
Wt of can & wet soil, g	208	194	214	228	260	233.6	213.4	199.4	201.8	237.6
Wt of can & dry soil, g	191	174	179	187	187	210.6	183.8	159.1	151.73	174
Wt of water, g	17	20	35	41	73	23	29.6	40.3	50.07	63.6
Wt of dry soil,	185.73	168.72	173.83	181.76	181.73	205.3	178.6	153.9	146.53	168.7
Moisture content of compacted soil, %	9.2	11.9	20.1	22.6	40.2	11.2	16.6	26.2	34.2	37.7
Initial moisture content of sample, %	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Weight of soil in mold, g	1208	1246	1402	1452	1526	997	1396	1711	1443	1008
Volume of mold, cm3	972.878	972.878	972.878	972.878	972.878	944	944	944	944	944
Wet density, g/cc	1.242	1.281	1.441	1.492	1.569	1.056	1.479	1.813	1.529	1.068
Dry density, g/cc	1.138	1.145	1.200	1.218	1.119	0.950	1.269	1.436	1.139	0.775
Optimum moisture content, %	29					25				
Maximum dry density, g/cc	1.248					1.42				
Treatment & curing condition	Untreated and not cured					Treated with 4% ANSS & cured for 7 days				

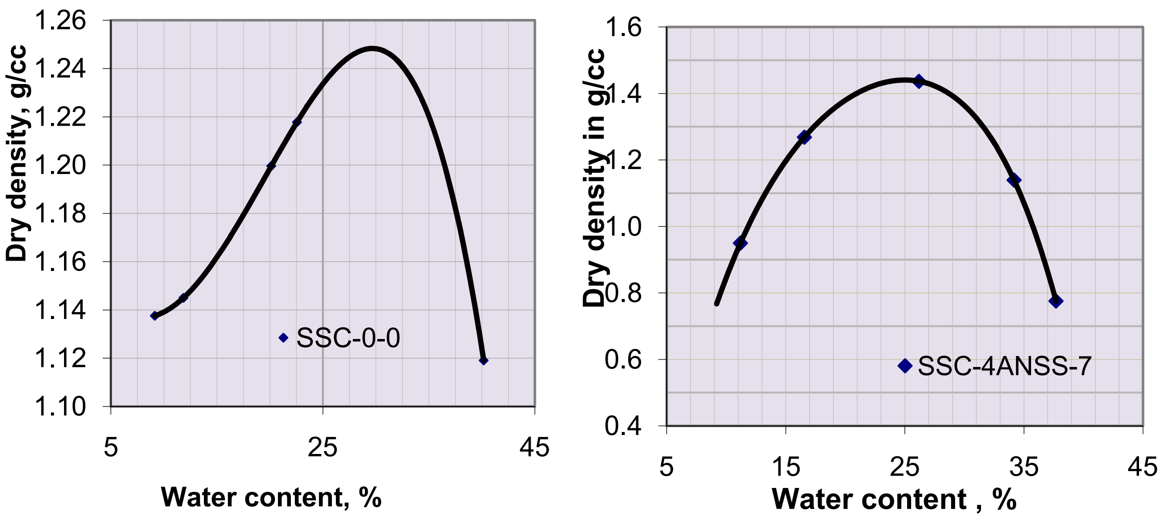
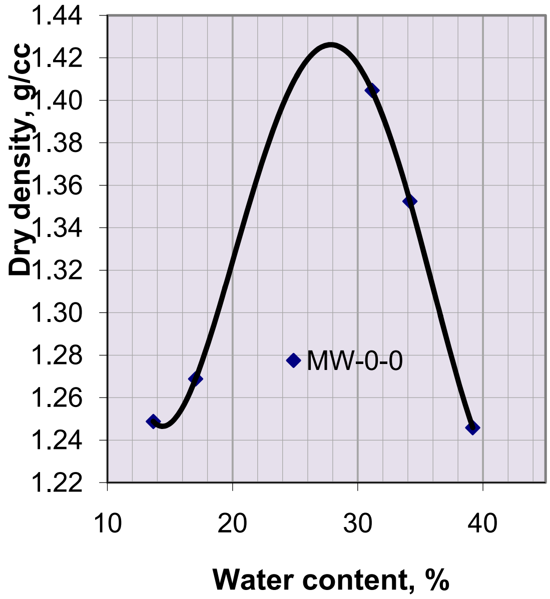


Figure C. 3: Moisture-dry density curves for silty sand of Adje blended with red clay of Kolfe

Table C. 4: Moisture –density relationship for clayey sand from Civil Service College- standard effort

Items	Trials for CS-0-0					Trials for CS-6ANSS-7				
	1	2	3	4	5	1	2	3	4	5
Wt of mold, g	4541	4541	4541	4541	4541	4731	4731	4731	4731	4731
Wt of mold & compacted soil, g	5881	5943	6280	6254	6178	5787	6193	6472	6251	5667
Moisture can number	30	77	TA-1	CMC-3	34	6	47	36	CMC-5	30
Wt of moisture can, g	5.2	5.1	5.3	5.3	5.3	5.3	5.2	5.2	5.2	5.3
Wt of can & wet soil, g	209.8	199.4	216.7	203.2	197.1	263.6	232.8	221.1	228.4	257.4
Wt of can & dry soil, g	185.2	171.1	166.5	152.8	143.1	228.3	194.71	170.8	173.17	189.3
Wt of water, g	24.6	28.3	50.2	50.4	54	35.3	38.09	50.3	55.23	68.1
Wt of dry soil,	180	166	161.2	147.5	137.8	223	189.51	165.6	167.97	184
Moisture content of compacted soil, %	13.7	17.0	31.1	34.2	39.2	15.8	20.1	30.4	32.9	37.0
Initial moisture content of sample, %	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7
Weight of soil in mold, g	1340	1402	1739	1713	1637	1056	1462	1741	1520	936
Volume of mold, cm3	944	944	944	944	944	944	944	944	944	944
Wet density, g/cc	1.419	1.485	1.842	1.815	1.734	1.119	1.549	1.844	1.610	0.992
Dry density, g/cc	1.249	1.269	1.405	1.352	1.246	0.966	1.290	1.415	1.212	0.724
Optimum moisture content,	28					26				
Maximum dry density, g/cc	1.426					1.54				
Treatment & curing condition	Untreated and not cured					Treated with 6% ANSS & cured for 7 days				



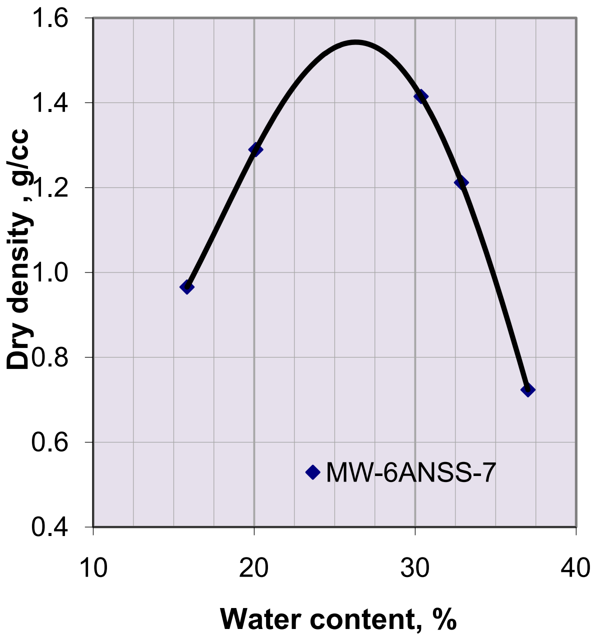


Figure C. 4: Moisture-dry density curves for clayey sand from Civil Service College-standard effort

Table C. 5: Moisture -density relationship for silty sand blended with red clay soil

Items	Trials for SS-0-0				
	1	2	3	4	5
Weight of mold, g	5644	5644	5644	5644	5644
Weight of mold & compacted soil, g	6804	6884	6970	7134	7112
Moisture can number	31	66	8	88	78
Weight of moisture can, g	5.29	5.28	5.32	5.2	5.25
Weight of can & wet soil, g	164	174	180	178	210
Weight of can & dry soil, g	150	155	156	132	152
Weight of water, g	14	19	24	46	58
Weight of dry soil,	144.71	149.72	150.68	126.8	146.75
Moisture content of compacted soil, %	9.7	12.7	15.9	36.3	39.5
Initial moisture content of sample, %	2	2	2	2	2
Weight of soil in mold, g	1160	1240	1326	1490	1468
Volume of mold, cm3	972.878	972.878	972.878	972.878	972.878
Wet density, g/cc	1.192	1.275	1.363	1.532	1.509
Dry density, g/cc	1.087	1.131	1.176	1.124	1.081
Optimum moisture content	24.0				
Maximum dry density, g/cc	1.23				
Treatment & curing condition	Untreated and not cured				

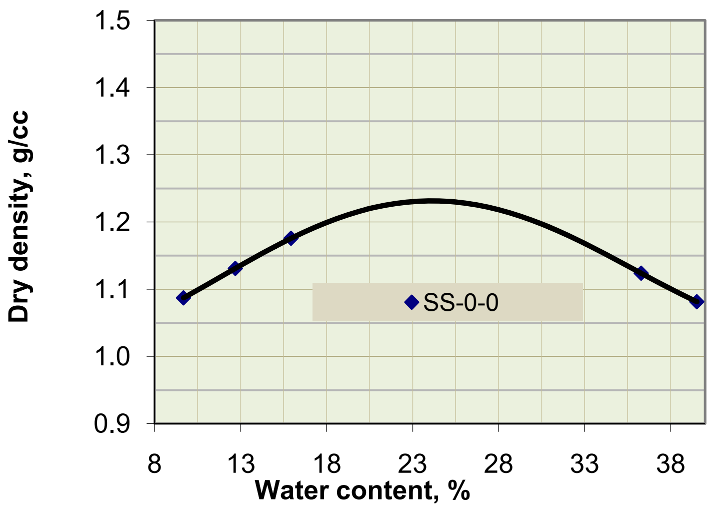


Figure C. 5: Moisture-dry density curves for silty sand

Annex D: California Bearing Ratio test results of untreated as well as treated soil samples

Table D.1: CBR for untreated Light Grey Clay

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0.00	0	0.00	0.00	0
0.64		3	0.04	2.5	0.03	2.50	0.03
1.27		4	0.05	3.2	0.04	3.30	0.04
1.91		5	0.07	4	0.05	4.00	0.05
2.54	6.9	6	0.08	4.5	0.06	4.70	0.06
3.81		6	0.08	5	0.07	5.60	0.07
5.08	10.3	6.7	0.09	5.2	0.07	6.20	0.08
7.62		7	0.09	6	0.08	6.80	0.09
10.16		8	0.11	7	0.09	7.40	0.10
12.7		9	0.12	7.5	0.10	8.00	0.11
CBR at 2.54			**1.16**		**0.87**		**0.87**
CBR at 5.08			**0.87**		**0.68**		**0.78**
Average CBR for LGC-0-0			0.97%				
Dry Density in g/cm3			1.22		1.19		1.19
Sample Identification		LGC-0-01		LGC-0-02		LGC-0-03	

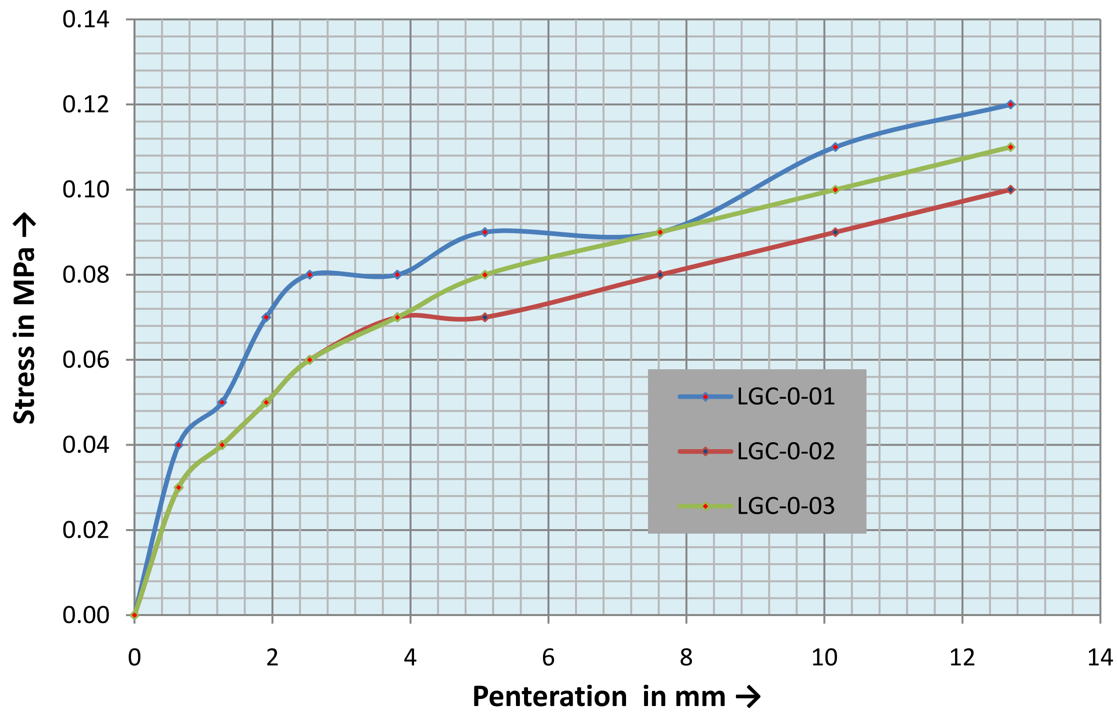


Figure D. 1: Load-Penetration curve for LGC-0-0

Table D.2: CBR of Light grey clay treated with PURE CRETE at two times manufacturer application rate

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0.00	0	0.00	0.00	0
0.64		2.5	0.03	3	0.04	2.00	0.03
1.27		4	0.05	3.5	0.05	2.70	0.04
1.91		4.5	0.06	4.6	0.06	3.80	0.05
2.54	6.9	5	0.07	5	0.07	4.50	0.06
3.81		6	0.08	5.7	0.08	5.50	0.07
5.08	10.3	6.5	0.09	6.5	0.09	6.00	0.08
7.62		7.5	0.10	7.2	0.10	7.00	0.09
10.16		8	0.11	8.3	0.11	7.80	0.10
12.7		9.5	0.13	9.2	0.12	8.00	0.11
CBR at 2.54			**1.01**		**1.01**		**0.87**
CBR at 5.08			**0.87**		**0.87**		**0.78**
Average CBR for LGC-2PC-0			**0.96%**				
Dry Density in g/cm3		1.23		1.22		1.20	
Sample Identification		**LGC-2PC-01**		**LGC-2PC-02**		**LGC-2PC-03**	

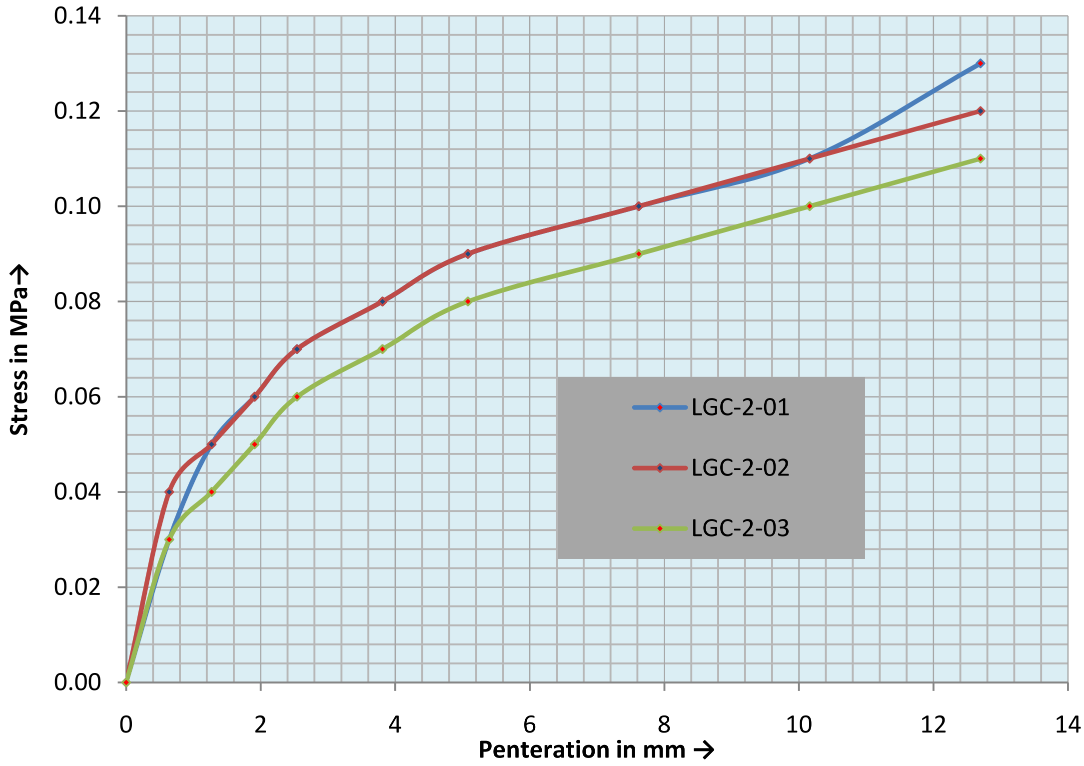


Figure D. 2: Load- Penetration curve for LGC-2PC-0

Table D.3: CBR of Light grey clay treated with PURE CRETE at four times manufacturer application rate

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0.00	0	0.00	0.00	0
0.64		2	0.03	3	0.04	2.50	0.03
1.27		2.8	0.04	3.5	0.05	3.00	0.04
1.91		3.5	0.05	4.4	0.06	3.50	0.05
2.54	6.9	4.2	0.06	5	0.07	4.50	0.06
3.81		5.5	0.07	6	0.08	5.50	0.07
5.08	10.3	6.2	0.08	6.8	0.09	6.50	0.09
7.62		7	0.09	7.5	0.10	7.60	0.1
10.16		7.8	0.10	8	0.11	8.50	0.11
12.7		8.5	0.11	9	0.12	9.50	0.13
CBR at 2.54			**0.87**		**1.01**		**0.87**
CBR at 5.08			**0.78**		**0.87**		**0.87**
Average CBR for LGC-4PC-0			**0.92%**				
Dry Density in g/cc		1.23		1.22		1.20	
Sample Identification		**LGC-4PC-01**		**LGC-4PC-02**		**LGC-4PC-03**	

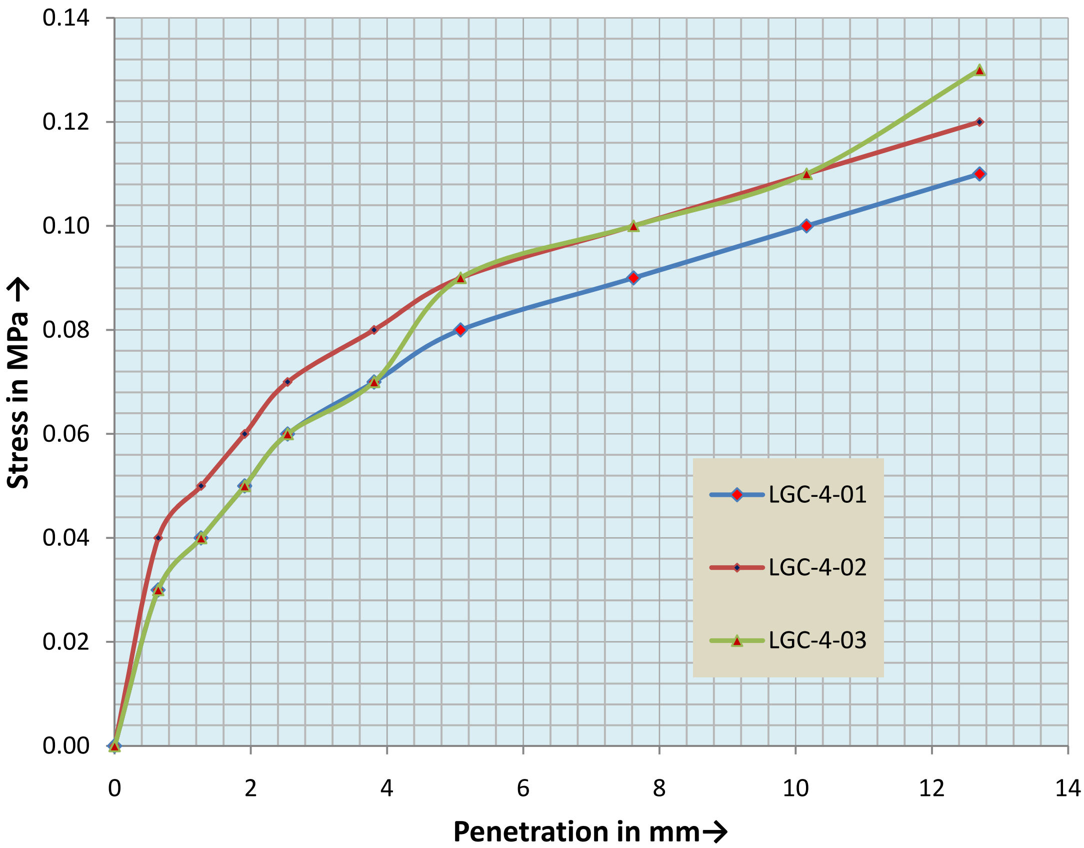


Figure D. 3: Load- Penetration curve for LGC-4PC-0

Table D.4: CBR for untreated Light Grey Clay cured for 7 days

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0.0	0.00	0.0	0.00	0.0	0.00
0.64		2.0	0.03	3.8	0.05	2.2	0.03
1.27		3.5	0.05	5.0	0.07	4.2	0.06
1.91		4.5	0.06	5.7	0.08	6.0	0.08
2.54	6.9	5.5	0.07	6.2	0.08	6.5	0.09
3.81		6.0	0.08	7.0	0.09	7.2	0.10
5.08	10.3	6.5	0.09	7.5	0.10	8.0	0.11
7.62		7.0	0.09	8.1	0.11	8.9	0.12
10.16		7.5	0.10	9.0	0.12	9.5	0.13
12.7		8.0	0.11	10.0	0.13	10.0	0.13
CBR at 2.54			**1.01**		**1.16**		**1.3**
CBR at 5.08			**0.87**		**0.97**		**1.07**
Average CBR for LGC-0-7			**1.16%**				
Dry Density in g/cc		1.22		1.22		1.22	
Sample Identification		**LGC-0-71**		**LGC-0-72**		**LGC-0-73**	

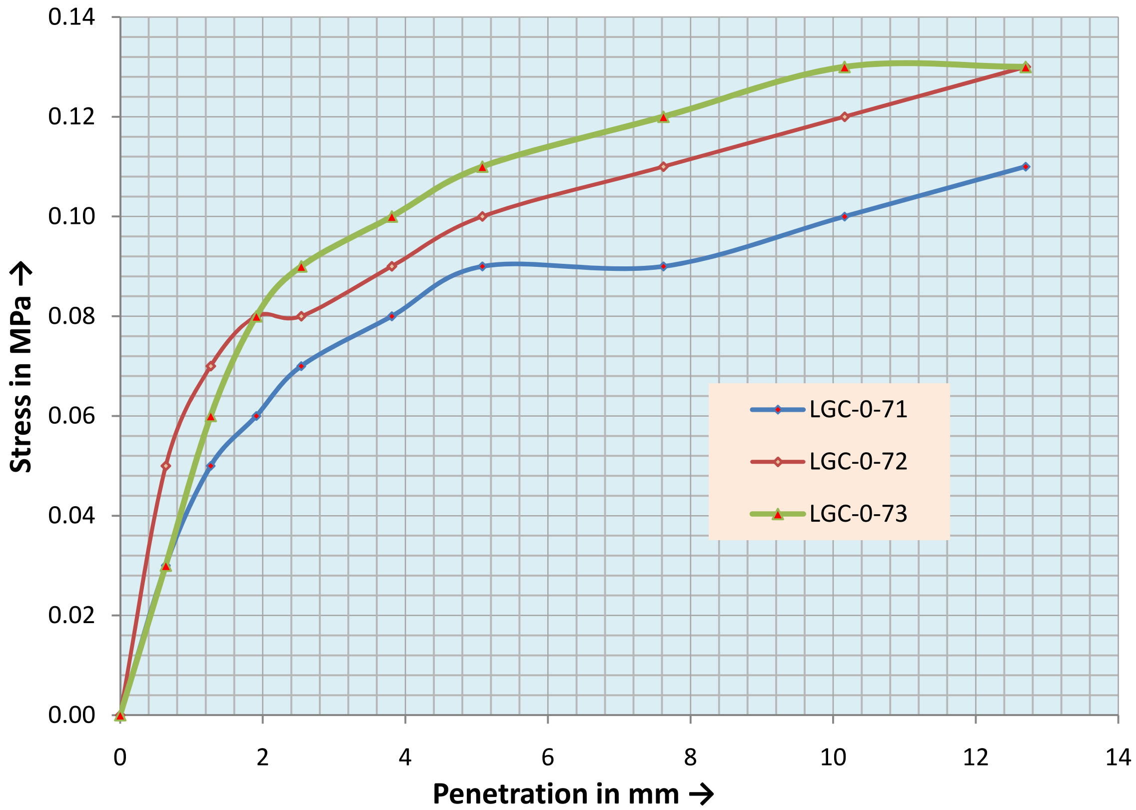


Figure D. 4: Load- Penetration curve for LGC-0-7

Table D.5: CBR of Light grey clay treated with PURE CRETE at twice manufacturer rate and cured for 7 days

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	CBR at 2.54 & 5.08	Piston reading	Load (MPa)	CBR at 2.54 & 5.08
0		0.0	0.00	0.0	0.00	0.0	0.00
0.64		2.0	0.03	2.5	0.03	2.0	0.03
1.27		3.0	0.04	3.5	0.05	3.0	0.04
1.91		4.0	0.05	4.3	0.06	4.5	0.06
2.54	6.9	4.8	0.06	5.0	0.07	5.0	0.07
3.81		5.7	0.08	5.5	0.07	6.0	0.08
5.08	10.3	6.0	0.08	6.0	0.08	6.5	0.09
7.62		6.8	0.09	6.5	0.09	7.0	0.09
10.16		7.0	0.09	6.7	0.09	7.5	0.10
12.7		7.8	0.10	7.2	0.10	8.0	0.11
CBR at 2.54			**0.87**		**1.01**		**1.01**
CBR at 5.08			**0.78**		**0.78**		**0.87**
Average CBR for LGC-2PC-7			**0.96%**				
Dry Density in g/cc		1.17		1.23		1.18	
Sample Identification		**LGC-2PC-71**		**LGC-2PC-72**		**LGC-2PC-73**	

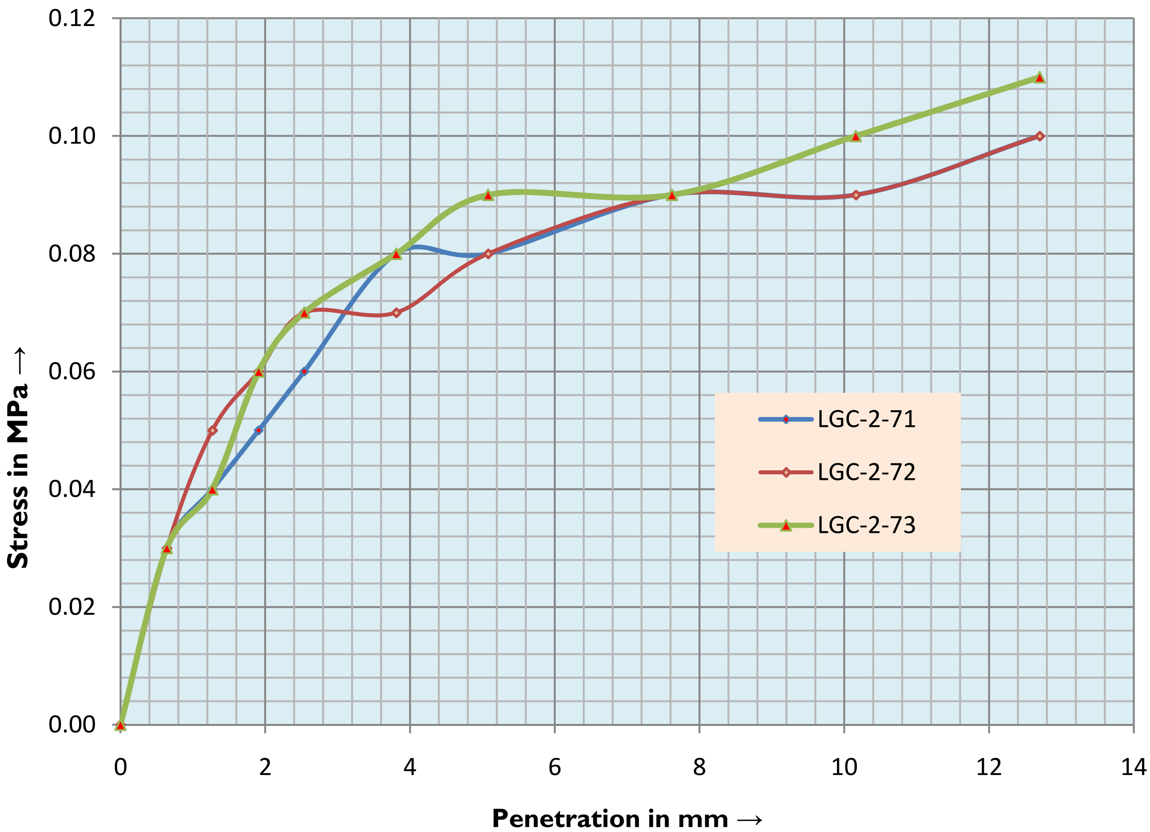


Figure D. 5: Load- Penetration curve for LGC-2PC-7

Table D.6: CBR of Light grey clay treated with PURE CRETE at four times manufacturer rate and cured for 7 days

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0.0	0.00	0.0	0.00	0.0	0.00
0.64		2.5	0.03	3.0	0.04	2.0	0.03
1.27		3.0	0.04	3.5	0.05	3.0	0.04
1.91		4.0	0.05	4.5	0.06	4.0	0.05
2.54	6.9	4.5	0.06	5.0	0.07	4.5	0.06
3.81		5.5	0.07	6.0	0.08	5.5	0.07
5.08	10.3	6.0	0.08	6.5	0.09	6.5	0.09
7.62		7.0	0.09	7.3	0.10	7.4	0.10
10.16		8.0	0.11	8.0	0.11	8.0	0.11
12.7		8.5	0.11	9.0	0.12	8.7	0.12
CBR at 2.54			**0.87**		**1.01**		**0.87**
CBR at 5.08			**0.78**		**0.87**		**0.87**
Average CBR for LGC-2PC-7			**0.92%**				
Dry Density in g/cc		**1.18**		**1.22**		**1.19**	
Sample Identification		**LGC-4PC-71**		**LGC-4PC-72**		**LGC-4PC-73**	

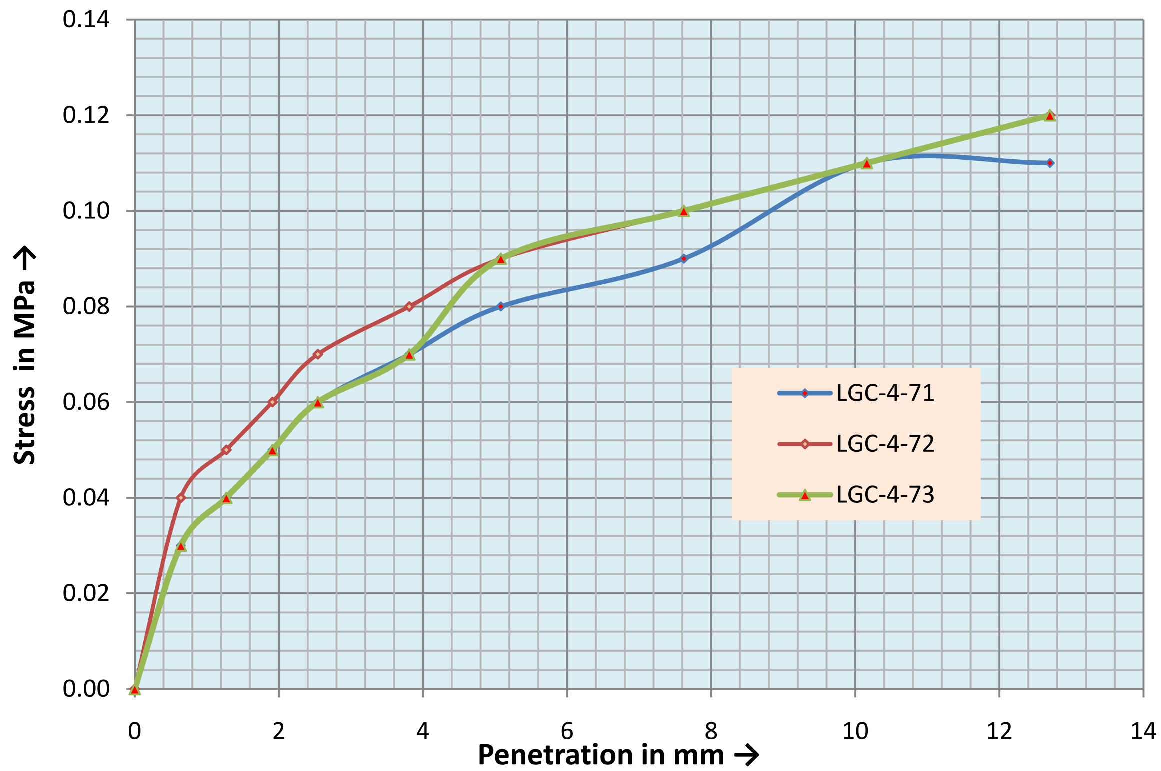


Figure D. 6: Load- Penetration curve for LGC-4PC-7

Table D.7: CBR for untreated Red Clay

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0	0	0	0	0
0.64		16	0.21	19.5	0.26	16	0.21
1.27		29	0.39	31	0.41	26.5	0.35
1.91		35.5	0.47	38.5	0.51	32	0.43
2.54	6.9	40.5	0.54	41.5	0.55	37	0.49
3.81		47	0.62	48.5	0.64	42.5	0.56
5.08	10.3	51	0.68	52.5	0.7	46.5	0.62
7.62		58	0.77	60.2	0.8	52	0.69
10.16		62.5	0.83	66	0.88	57	0.76
12.7		67.5	0.90	71	0.94	60.5	0.8
CBR at 2.54			7.83		7.97		7.1
CBR at 5.08			6.6		6.8		6.02
Average CBR for RC-0-0			7.63%				
Dry Density in g/cc		1.47		1.45		1.46	
Sample Identification		RC-0-01		RC-0-02		RC-0-03	

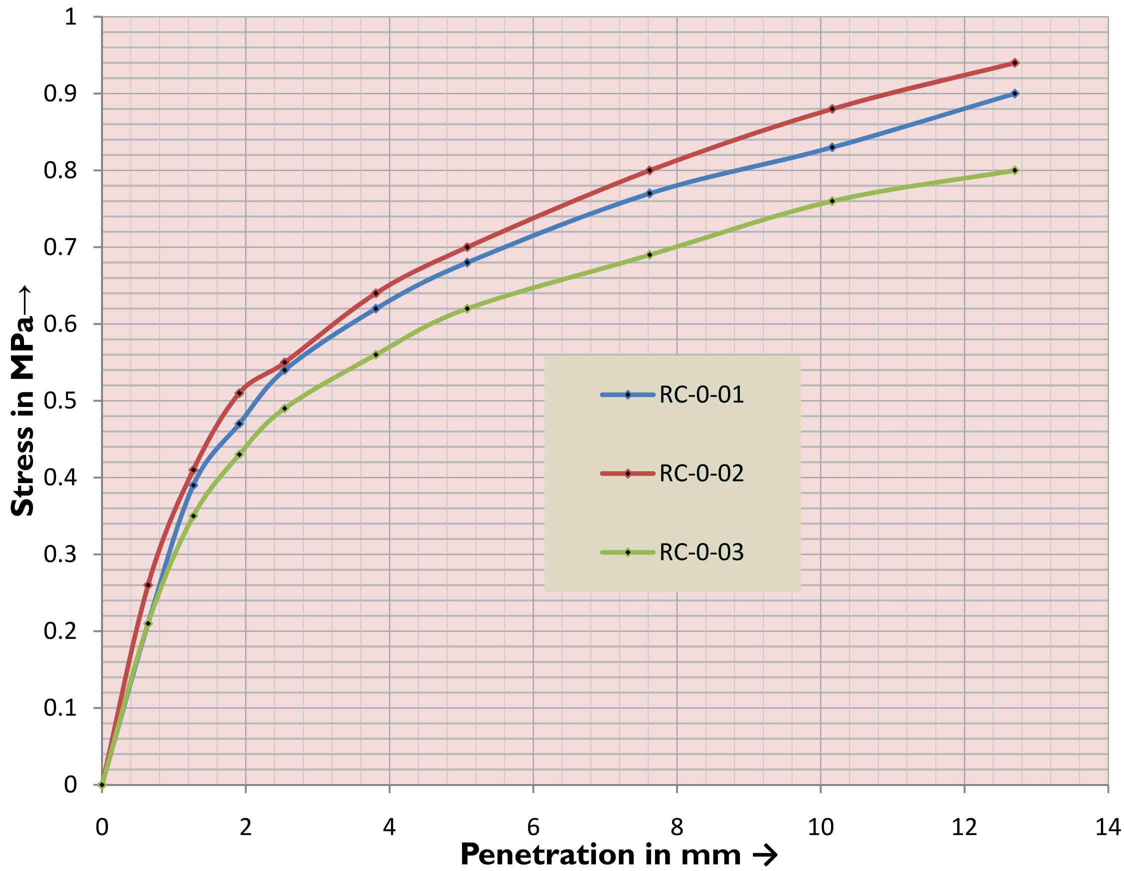


Figure D. 7: Load- Penetration curve for RC-0-0

Table D.8: CBR of Red clay treated with PURE CRETE at two times manufacturer dilution rate

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0	0	0	0	0
0.64		13	0.17	17	0.23	15	0.2
1.27		24	0.32	28	0.37	24	0.32
1.91		33	0.44	36	0.48	32	0.43
2.54	6.9	38	0.5	42	0.56	38	0.5
3.81		46	0.61	49	0.65	44	0.58
5.08	10.3	49.5	0.66	54	0.72	48	0.64
7.62		57	0.76	62	0.82	54	0.72
10.16		64	0.85	67	0.89	61	0.81
12.7		68	0.90	71	0.94	69	0.92
CBR at 2.54			7.2		8.1		7.2
CBR at 5.08			6.4		7		6.2
Average CBR for RC-2PC-0			7.5%				
Dry Density in g/cc		1.45		1.47		1.44	
Sample Identification		RC-2PC-01		RC-2PC-02		RC-2PC-03	

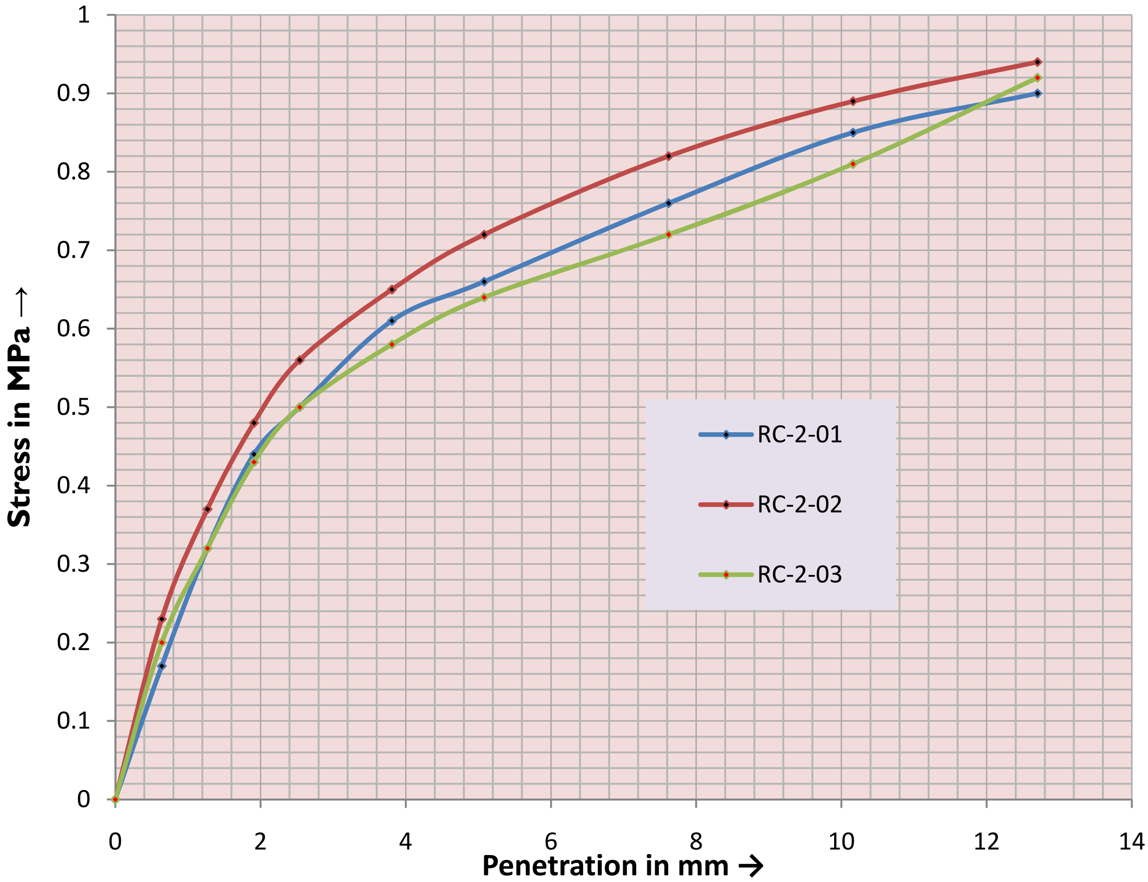


Figure D. 8: Load- Penetration curve for RC-2PC-0

Table D.9: CBR of Red clay treated with PURE CRETE at four times manufacturer dilution rate

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0	0	0	0	0
0.64		14	0.19	15	0.2	18	0.24
1.27		26	0.35	27	0.36	29	0.39
1.91		34	0.45	36	0.48	37	0.49
2.54	6.9	37	0.49	43	0.57	41	0.54
3.81		45	0.6	48	0.64	47	0.62
5.08	10.3	50	0.66	53	0.7	51	0.68
7.62		56	0.74	61	0.81	58	0.77
10.16		64	0.85	67	0.89	62	0.82
12.7		70	0.93	74	0.98	69	0.92
CBR at 2.54			7.1		8.3		7.8
CBR at 5.08			6.4		6.8		6.6
Average CBR for RC-4PC-0			7.73%				
Dry Density in g/cc		1.46		1.47		1.44	
Sample Identification		RC-4PC-01		RC-4PC-02		RC-4PC-03	

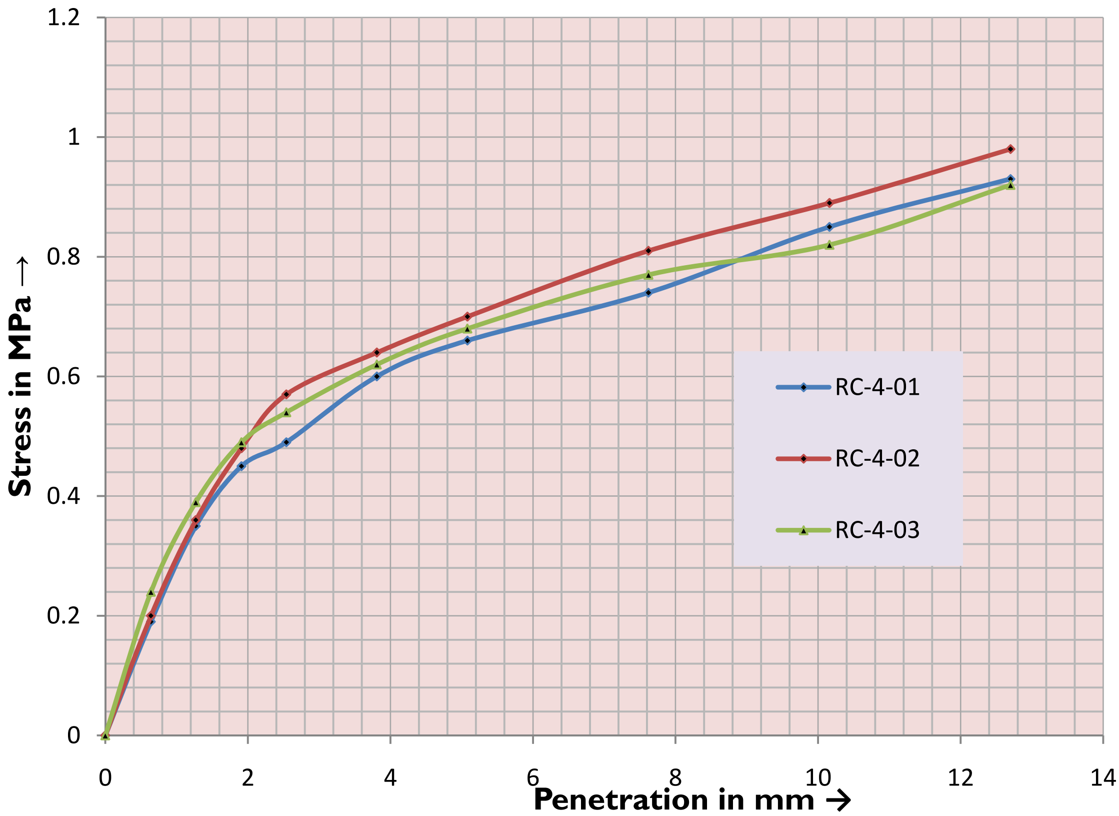


Figure D. 9: Load- Penetration curve for RC-4PC-0

Table D. 10: CBR of untreated Red clay cured for 7 days

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0.00	0	0	0	0	0
0.64		14.00	0.19	15.5	0.21	18	0.24
1.27		32.50	0.43	27	0.36	31	0.41
1.91		43.00	0.57	36	0.48	39	0.52
2.54	6.9	50.50	0.67	42	0.56	43	0.57
3.81		58.50	0.78	49	0.65	51	0.68
5.08	10.3	65.00	0.86	56	0.74	58	0.77
7.62		69.00	0.92	62	0.82	63	0.84
10.16		74.50	0.99	67	0.89	69	0.92
12.7		80.00	1.06	71	0.94	73	0.97
CBR at 2.54			9.7		8.1		8.3
CBR at 5.08			8.3		7.2		7.5
Average CBR for RC-0-7			8.7%				
Dry Density in g/cc		1.45		1.43		1.45	
Sample Identification		RC-0-71		RC-0-72		RC-0-73	

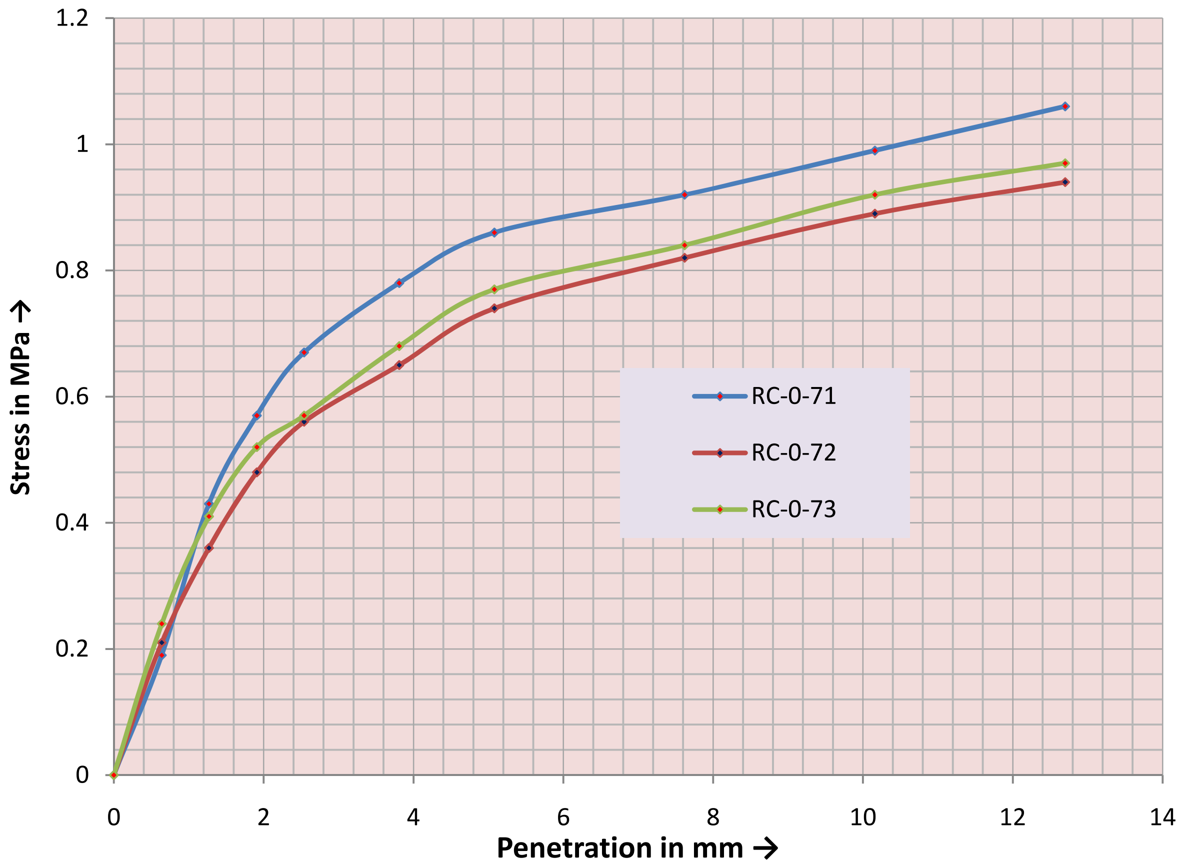


Figure D. 10: Load- Penetration curve for RC-0-7

Table D. 11: CBR of Red clay treated with PURE CRETE at two times manufacturer dilution rate and cured for 7 days

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0.00	0	0	0	0	0
0.64		22.00	0.29	24	0.32	20.5	0.27
1.27		32.00	0.43	34	0.45	31.5	0.42
1.91		39.00	0.52	42	0.56	41.5	0.55
2.54	6.9	45.00	0.60	47	0.62	48	0.64
3.81		49.00	0.65	52	0.69	54.5	0.72
5.08	10.3	53.00	0.7	55.5	0.74	59.2	0.79
7.62		56.50	0.75	61.6	0.82	65.5	0.87
10.16		61.60	0.82	67.5	0.9	71	0.94
12.7		67.00	0.89	73.5	0.98	75	1
CBR at 2.54			8.7		9.0		9.3
CBR at 5.08			7.0		7.0		8.0
Average CBR for RC-2PC-7			9%				
Dry Density in g/cc		1.46		1.44		1.47	
Sample Identification		RC-2PC-71		RC-2PC-72		RC-2PC-73	

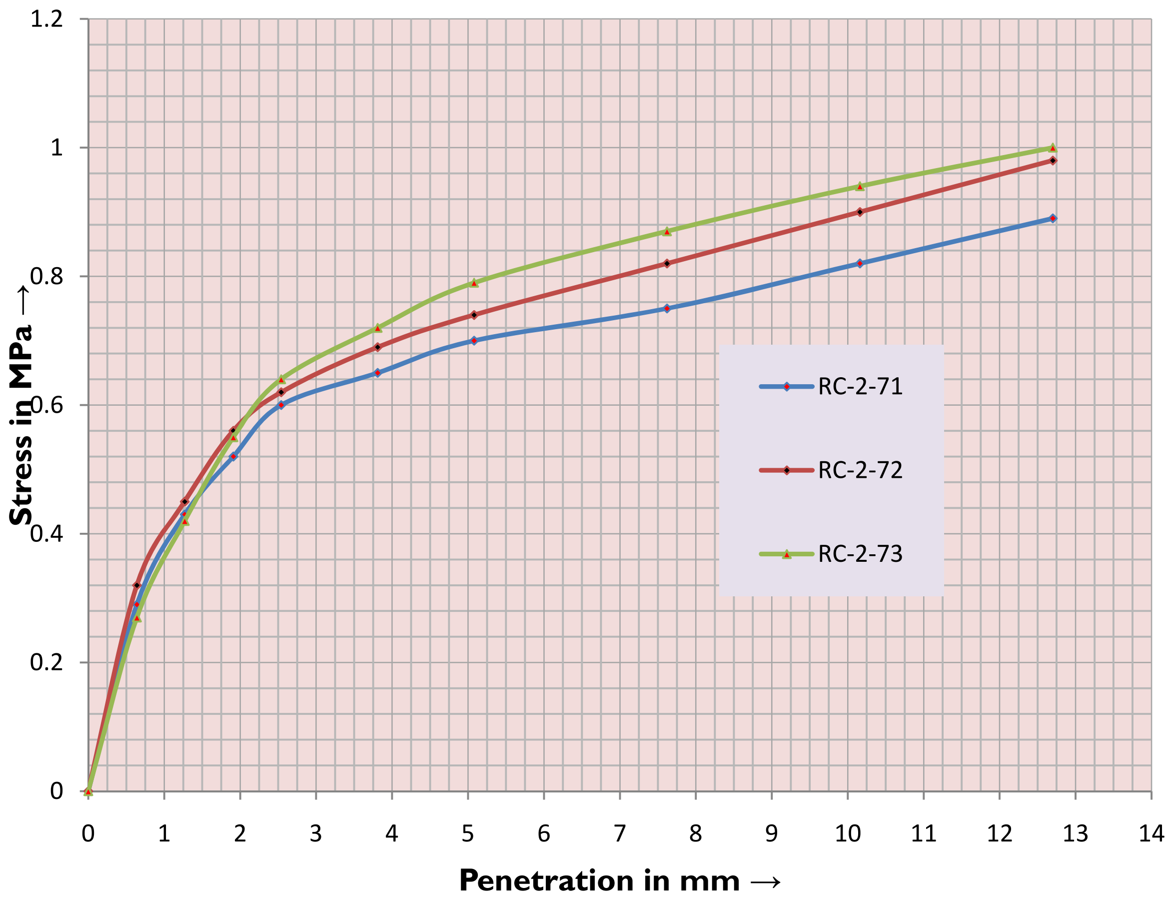


Figure D. 11: Load- Penetration curve for RC-2PC-7

Table D. 12: CBR of Red clay treated with PURE CRETE at four times manufacturer application rate

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0.00	0	0	0	0	0
0.64		38.00	0.5	41	0.54	27	0.36
1.27		45.00	0.6	65	0.86	37.5	0.5
1.91		50.00	0.66	72	0.96	43	0.57
2.54	6.9	53.50	0.71	76.5	1.02	45	0.6
3.81		59.00	0.78	80.5	1.07	49.5	0.66
5.08	10.3	62.50	0.83	85	1.13	53.5	0.71
7.62		68.50	0.91	90	1.2	60	0.8
10.16		74.00	0.98	96.5	1.28	66.5	0.88
12.7		79.00	1.05	103	1.37	73	0.97
CBR at 2.54			10.3		14.8		8.7
CBR at 5.08			8.1		11		6.9
Average CBR for RC-4PC-7			11.3%				
Dry Density in g/cc		1.47		1.47		1.46	
Sample Identification		RC-4PC-72		RC-4PC-72		RC-4PC-73	

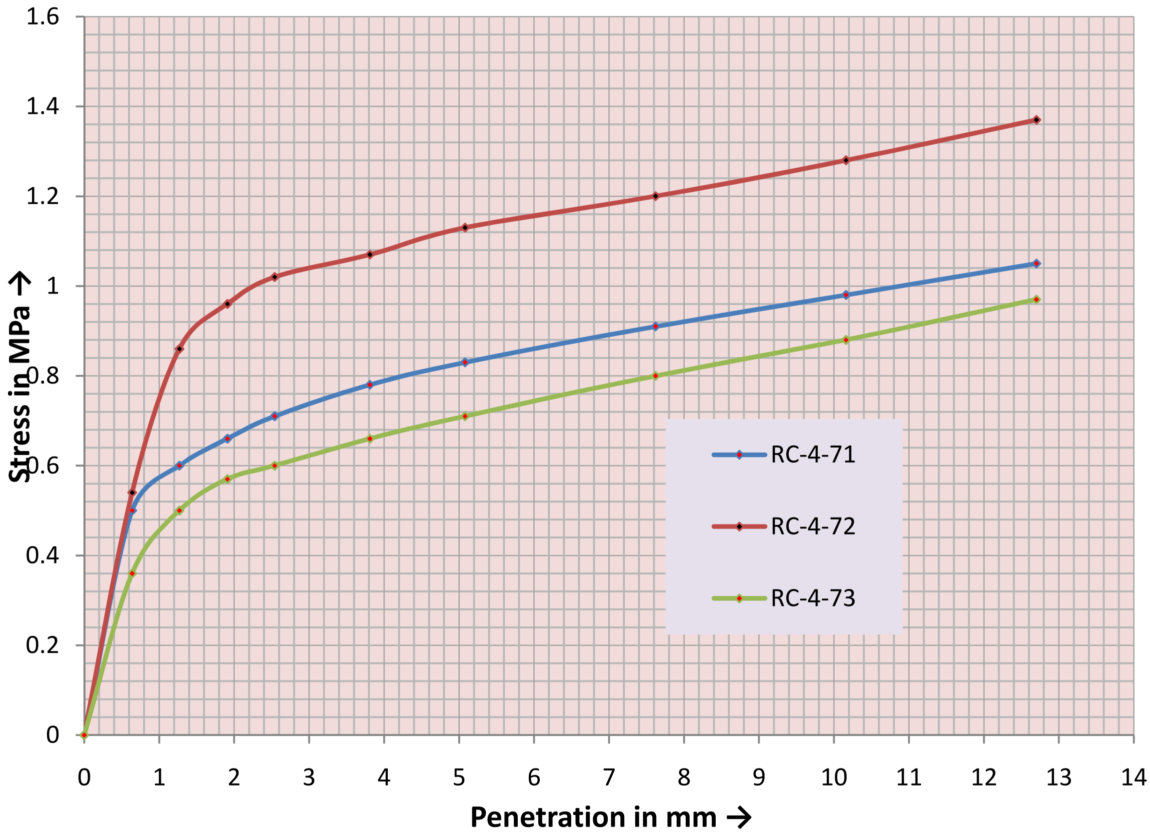


Figure D. 12: Load- Penetration curve for RC-4PC-7

Table D. 13: CBR of untreated silty sand blended with red clay

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0.00	0	0	0	0	0
0.64		8.00	0.11	7	0.09	5	0.07
1.27		19.00	0.25	17	0.23	23	0.31
1.91		31.00	0.41	36	0.48	41	0.54
2.54	6.9	48.00	0.64	55	0.73	63	0.84
3.81		82.00	1.09	87	1.16	96	1.28
5.08	10.3	113.00	1.5	114	1.51	128	1.7
7.62		159.00	2.11	168	2.23	176	2.34
10.16		192.00	2.55	199	2.64	205	2.72
12.7		204.00	2.71	217	2.88	213	2.83
CBR at 2.54-corrected			13		14.5		15.9
CBR at 5.08- corrected			16.5		16.3		17.9
Average CBR for SSC-0-0			16.9%				
Dry Density in g/cc		1.24		1.23		1.24	
Sample Identification		SSC-0-01		SSC-0-02		SSC-0-03	

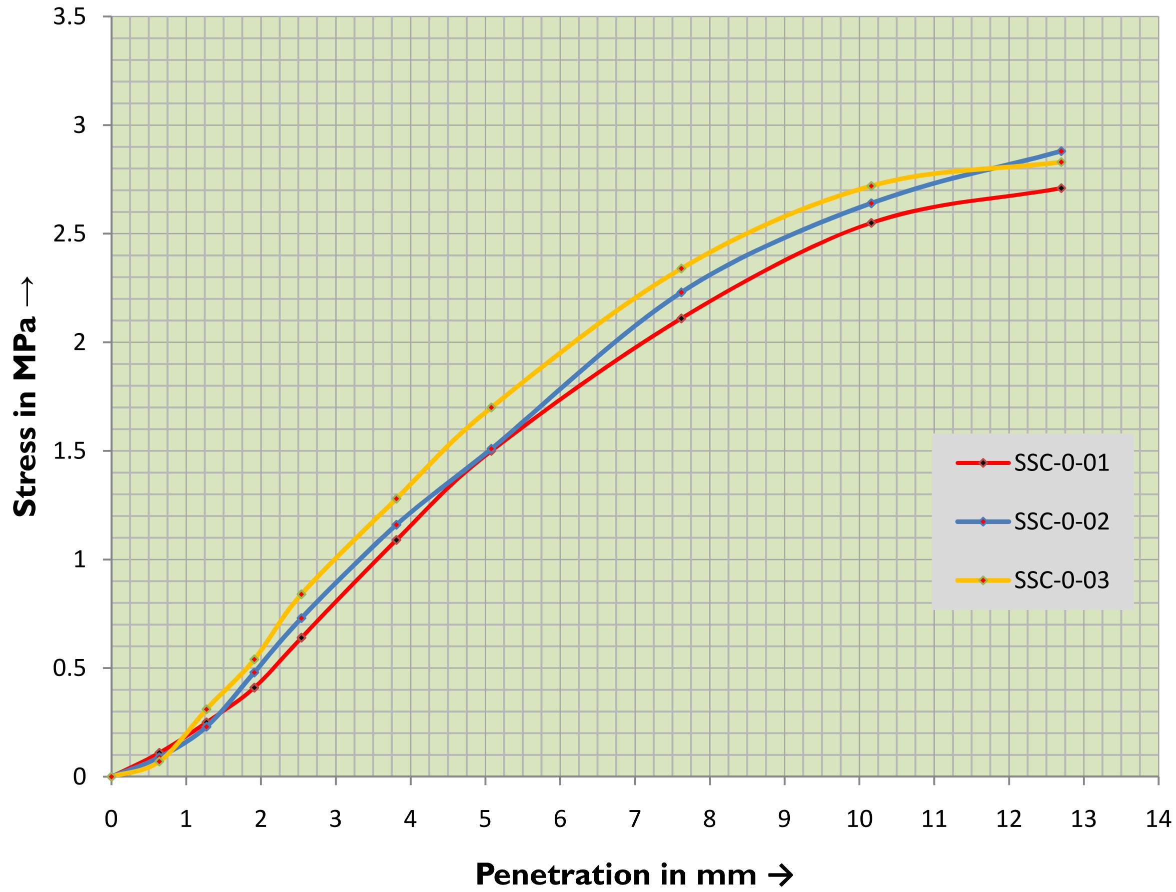


Figure D. 13: Load- Penetration curve for SSC-0-0

Table D. 14: Soaked CBR of silty sand blended with red clay after treatment with PURE CRETE at twice manufacturer application rate

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0.00	0	0.00	0	0.00
0.64		10	0.13	6	0.08	8	0.11
1.27		21	0.28	17.5	0.23	12	0.16
1.91		37	0.49	38	0.50	29	0.39
2.54	6.9	52	0.69	56	0.74	47	0.62
3.81		79	1.05	84	1.12	74	0.98
5.08	10.3	100	1.33	109	1.45	93	1.24
7.62		141	1.87	151.5	2.01	137	1.82
10.16		177	2.35	187	2.48	169	2.25
12.7		223	2.96	207	2.75	212	2.82
CBR at 2.54-corrected			11.4		14.2		12.3
CBR at 5.08- corrected			13.8		23.8		13.9
Average CBR for SSC-2PC-0			17.17				
Dry Density in g/cc		1.22		1.235		1.23	
Sample Identification		SSC-2PC-01		SSC-2PC-02		SSC-2PC-03	

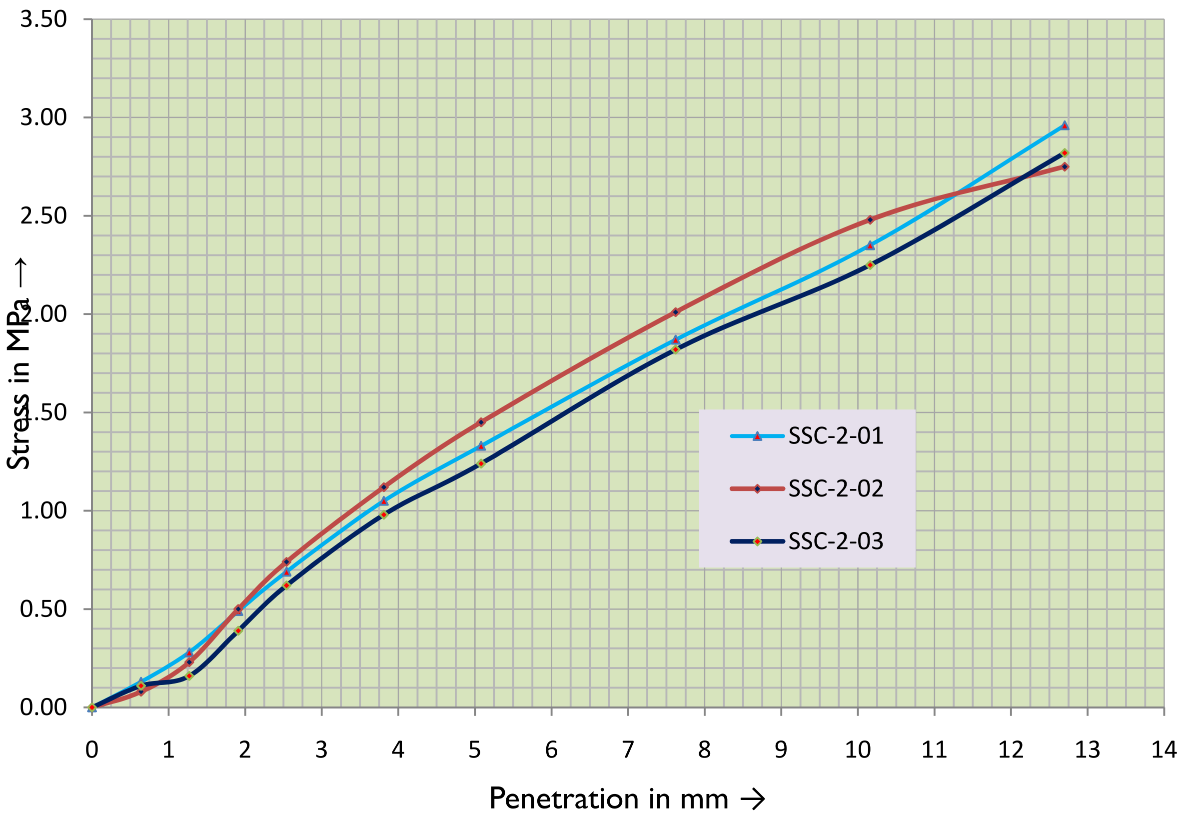


Figure D. 14: Load- Penetration curve for SSC-2PC-0

Table D. 15: Soaked CBR of silty sand blended with red clay after treatment with PURE CRETE at four times manufacturer application rate

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0.00	0	0	0	0	0
0.64		4.00	0.05	7	0.09	13	0.17
1.27		14.00	0.19	18	0.24	33	0.44
1.91		29.00	0.39	35	0.46	52	0.69
2.54	6.9	43.00	0.57	54	0.72	72	0.96
3.81		67.00	0.89	92	1.22	127	1.69
5.08	10.3	89.00	1.18	119	1.58	165	2.19
7.62		131.00	1.74	164	2.18	223	2.96
10.16		169.50	2.25	194	2.58	249	3.31
12.7		200.00	2.66	226	3	289	3.84
CBR at 2.54-corrected			10.4		13.8		16.7
CBR at 5.08- corrected			12.6		16.8		22.1
Average CBR for SSC-4PC-0			17.17				
Dry Density in g/cc		1.23		1.23		1.24	
Sample Identification		SSC-4PC-01		SSC-4PC-02		SSC-4PC-03	

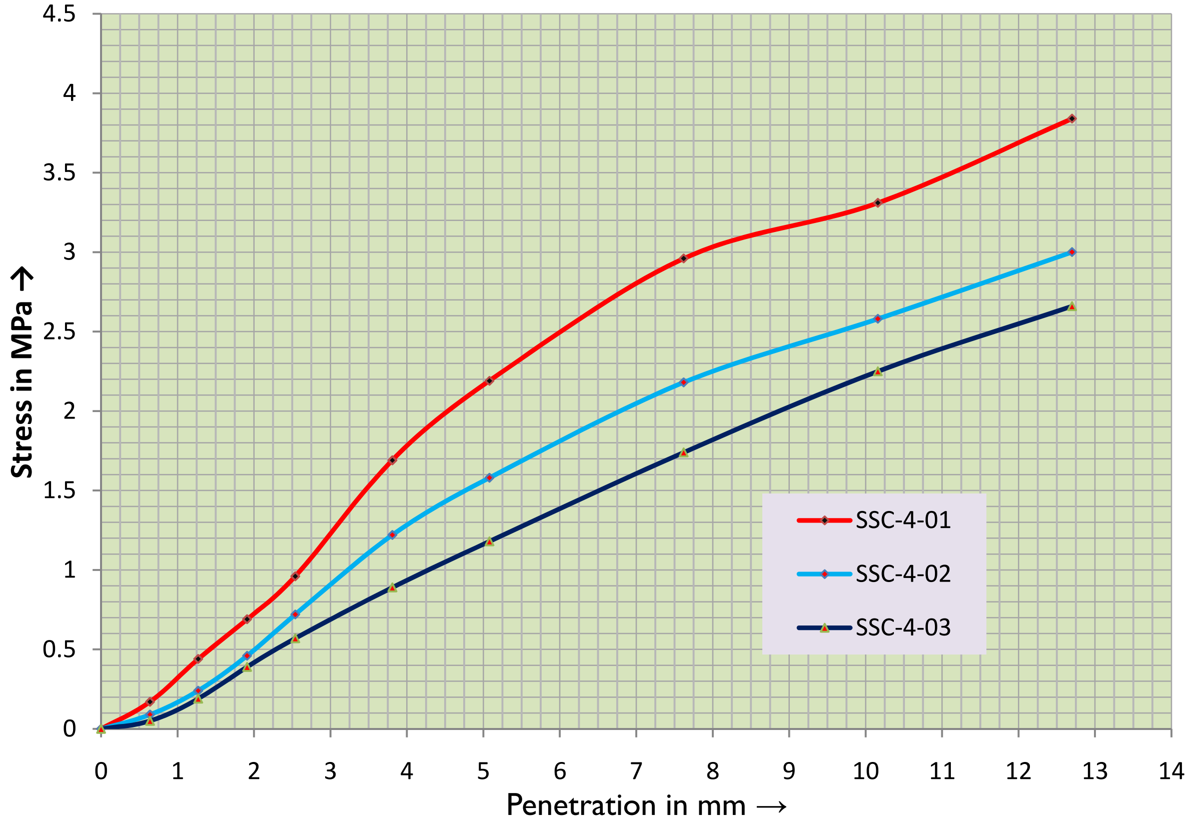


Figure D. 15: Load- Penetration curve for SSC-4PC-0

Table D. 16: CBR of untreated silty sand blended with red clay cured for 7 days

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0.00	0	0	0	0	0
0.64		6.00	0.08	3	0.04	7	0.09
1.27		11.50	0.15	8.5	0.11	12	0.16
1.91		23.50	0.31	18	0.24	26	0.35
2.54	6.9	38.00	0.50	30.5	0.41	39	0.52
3.81		71.00	0.94	63	0.84	74	0.98
5.08	10.3	104.50	1.39	102	1.36	106	1.41
7.62		178.00	2.36	170	2.26	182	2.42
10.16		229.00	3.04	231	3.07	228	3.03
12.7		267.00	3.55	271	3.6	263	3.49
CBR at 2.54-corrected			11.9		13.5		13.6
CBR at 5.08- corrected			17.3		18.6		18.4
Average CBR for SSC-0-7			18.1				
Dry Density in g/cc		1.232		1.24		1.237	
Sample Identification		SSC-0-71		SSC-0-72		SSC-0-73	

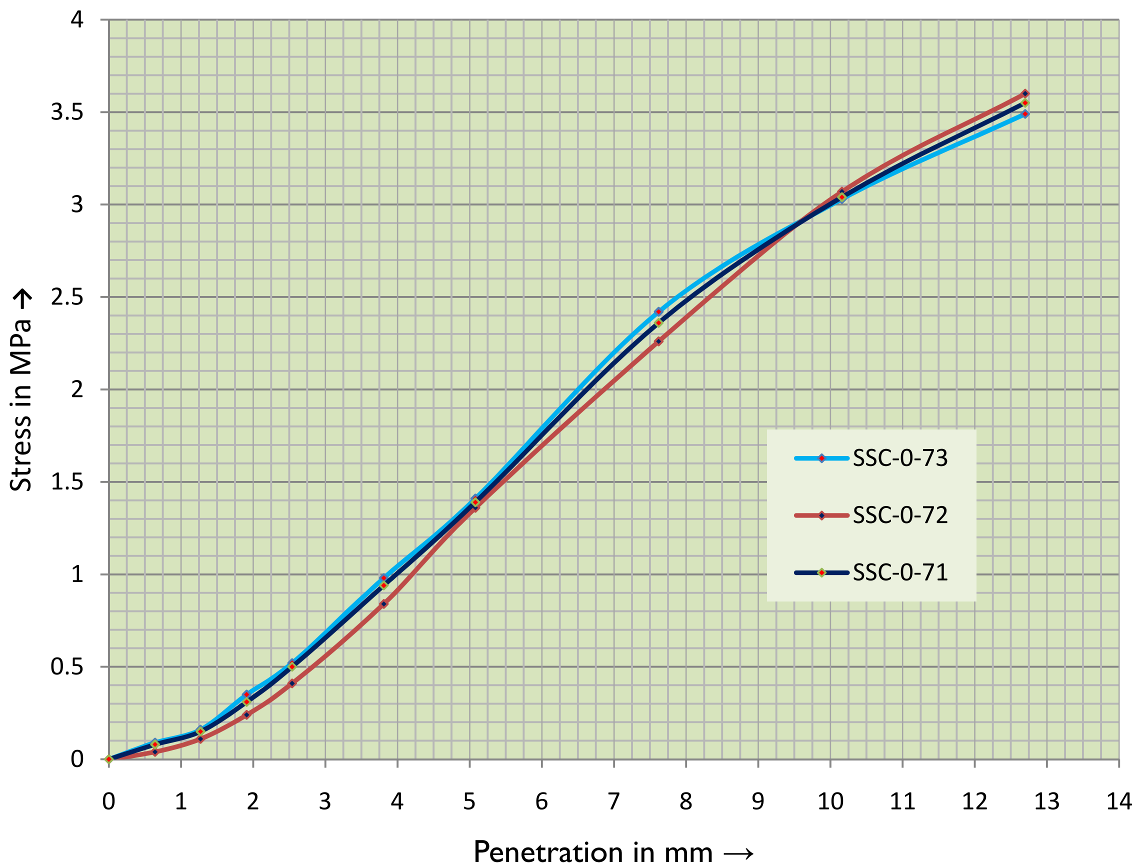


Figure D. 16: Load- Penetration curve for SSC-0-7

Table D. 17: Soaked CBR of silty sand blended with red clay after treatment with PURE CRETE at two times manufacturer application rate and curing for 7 days

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0	0	0	0	0
0.64		10.5	0.14	9.5	0.13	6.50	0.09
1.27		24	0.32	19.00	0.25	13.00	0.17
1.91		38	0.5	30.00	0.4	24.00	0.32
2.54	6.9	56	0.74	49.00	0.65	38.50	0.51
3.81		101.5	1.35	99.00	1.32	78.00	1.04
5.08	10.3	152.8	2.03	142.00	1.89	125.00	1.66
7.62		247	3.28	227.0	3.02	215.00	2.86
10.16		320.2	4.25	315.00	4.18	289.00	3.84
12.7		381.5	5.07	359.00	4.77	345.00	4.58
CBR at 2.54-corrected			19.1		19.4		17.1
CBR at 5.08- corrected			25.7		24.7		23.6
Average CBR for SSC-2PC-7			24.67				
Dry Density in g/cc		1.241		1.238		1.235	
Sample Identification		SSC-2PC-71		SSC-2PC-71		SSC-2PC-71	

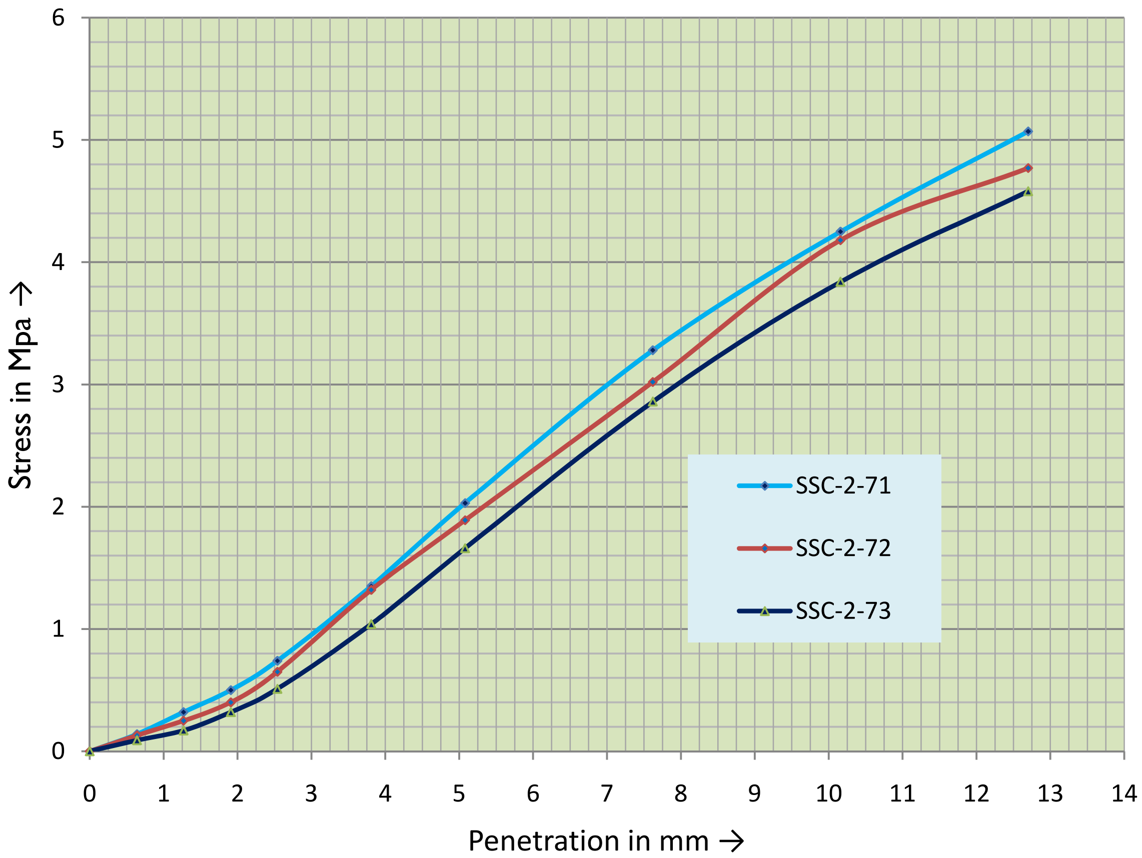


Figure D. 17: Load- Penetration curve for SSC-2PC-7

Table D. 18: Soaked CBR of silty sand blended with red clay after treatment with PURE CRETE at four times manufacturer application rate and curing for 7 days

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0.00	0	0	0	0	0
0.64		31.00	0.41	46	0.61	40	0.53
1.27		65.00	0.86	80	1.06	77	1.02
1.91		106.00	1.41	126	1.67	129	1.71
2.54	6.9	145.00	1.93	145	1.93	149	1.98
3.81		208.00	2.76	193	2.56	201	2.67
5.08	10.3	263.50	3.5	235	3.12	232	3.08
7.62		342.50	4.55	296	3.93	289	3.84
10.16		406.40	5.4	329	4.37	331	4.4
12.7		463.50	6.16	397	5.27	392	5.21
CBR at 2.54-corrected			29.4		28.0		28.7
CBR at 5.08- corrected			34.7		30.3		29.9
Average CBR for SSC-4PC-7			31.63				
Dry Density in g/cc		1.24		1.235		1.239	
Sample Identification		SSC-4PC-71		SSC-4PC-72		SSC-4PC-73	

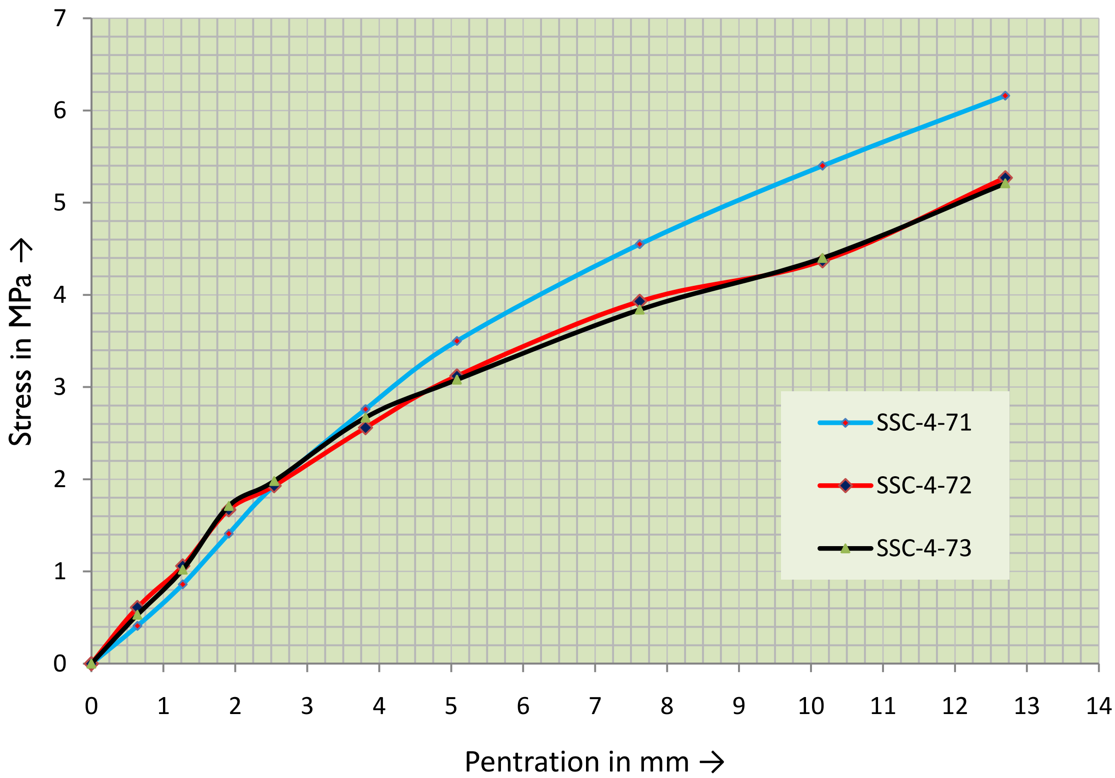


Figure D. 18: Load- Penetration curve for SSC-4PC-7

Table D. 19: Soaked CBR of untreated clayey sand from Civil Service College

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0.00	0	0.00	0	0.00
0.64		4	0.05	4	0.05	3	0.04
1.27		6	0.08	6	0.08	6	0.08
1.91		8.5	0.11	8.5	0.11	8.5	0.11
2.54	6.9	10	0.13	11	0.15	10.5	0.14
3.81		14	0.19	16	0.21	14.5	0.19
5.08	10.3	17.5	0.23	19	0.25	18	0.24
7.62		22.5	0.30	24	0.32	23	0.31
10.16		26	0.35	27.5	0.37	27	0.36
12.7		29	0.39	31	0.41	31	0.41
CBR at 2.54-corrected			1.9		2.2		2.0
CBR at 5.08- corrected			2.2		2.4		2.3
Average CBR for CS-0-0			2.3				
Dry Density in g/cc		1.356		1.337		1.346	
Sample Identification		CS-0-01		CS-0-03		CS-0-03	

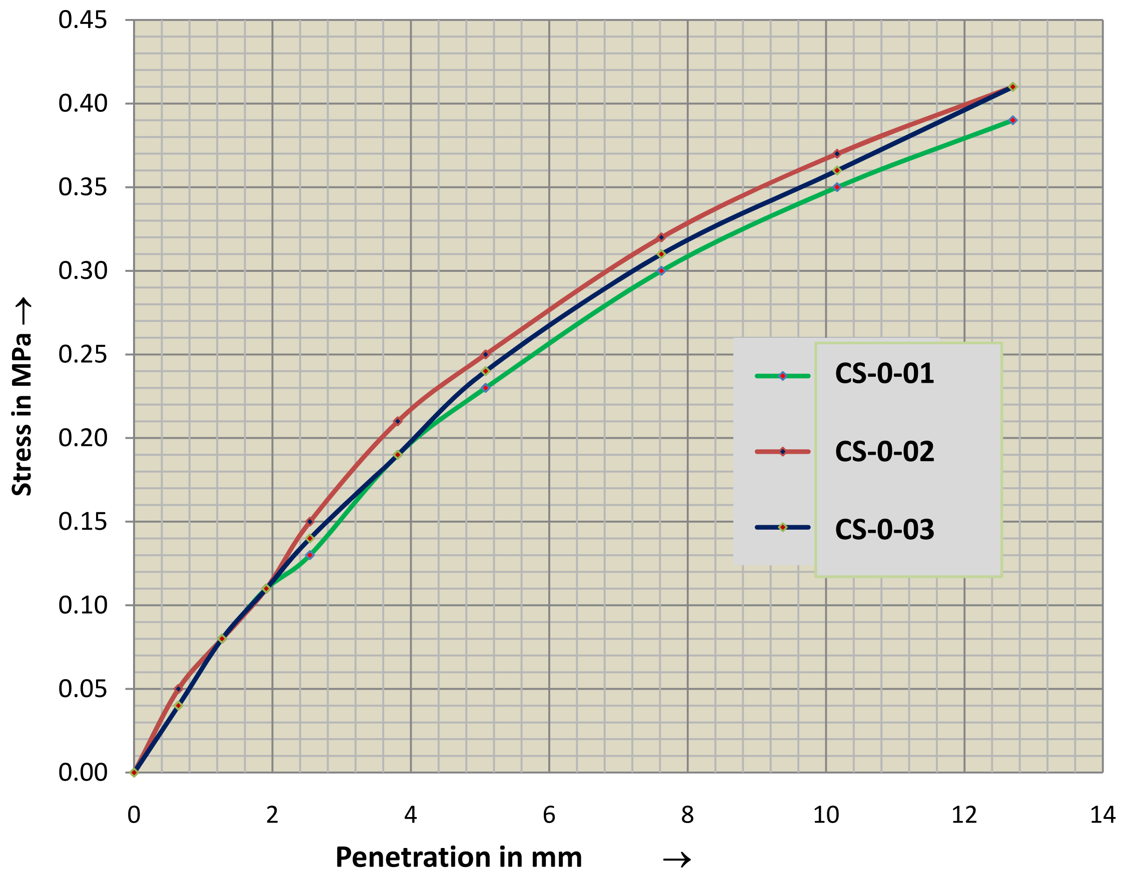


Figure D. 19: Load- Penetration curve for CS-0-0

Table D. 20: Soaked CBR of clayey sand treated with PURE CRETE at twice application rate of manufacturer

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0.00	0	0.00	0	0.00
0.64		3	0.04	4	0.05	3.5	0.05
1.27		5	0.07	7	0.09	6	0.08
1.91		8	0.11	9	0.12	8	0.11
2.54	6.9	10	0.13	11.5	0.15	10	0.13
3.81		13.5	0.18	15	0.20	14	0.19
5.08	10.3	17	0.23	19	0.25	17	0.23
7.62		22	0.29	23.5	0.31	21	0.28
10.16		25.5	0.34	26	0.35	25	0.33
12.7		28	0.37	28.5	0.38	28	0.37
CBR at 2.54-corrected			1.9		2.2		1.9
CBR at 5.08- corrected			2.2		2.4		2.2
Average CBR for CS-2PC-0			2.27				
Dry Density in g/cc		1.36		1.35		1.358	
Sample Identification		CS-2PC-01		CS-2PC-02		CS-2PC-03	

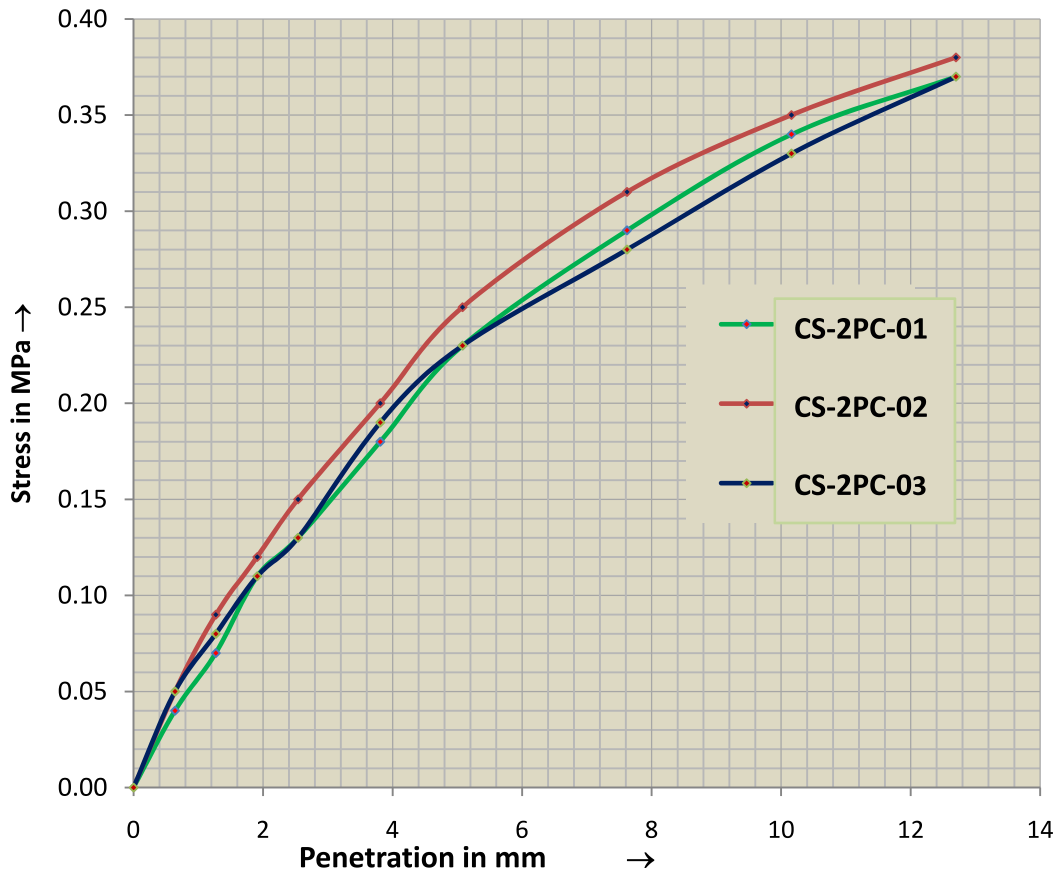


Figure D. 20: Load- Penetration curve for CS-2PC-0

Table D. 21: Soaked CBR of clayey sand treated with PURE CRETE at four times application rate of manufacturer

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0.00	0	0.00	0	0.00
0.64		4	0.05	3	0.04	3	0.04
1.27		6	0.08	6	0.08	5.5	0.07
1.91		9	0.12	8	0.11	7.5	0.10
2.54	6.9	11	0.15	10.5	0.14	10	0.13
3.81		14.5	0.19	14	0.19	13.5	0.18
5.08	10.3	18	0.24	18	0.24	17	0.23
7.62		23	0.31	22.5	0.30	22	0.29
10.16		26	0.35	25	0.33	25.5	0.34
12.7		28.5	0.38	28	0.37	28	0.37
CBR at 2.54-corrected			2.2		2.0		1.9
CBR at 5.08- corrected			2.3		2.3		2.2
Average CBR for CS-4PC-0			2.27				
Dry Density in g/cc		1.354		1.336		1.347	
Sample Identification		CS-4PC-01		CS-4PC-02		CS-4PC-03	

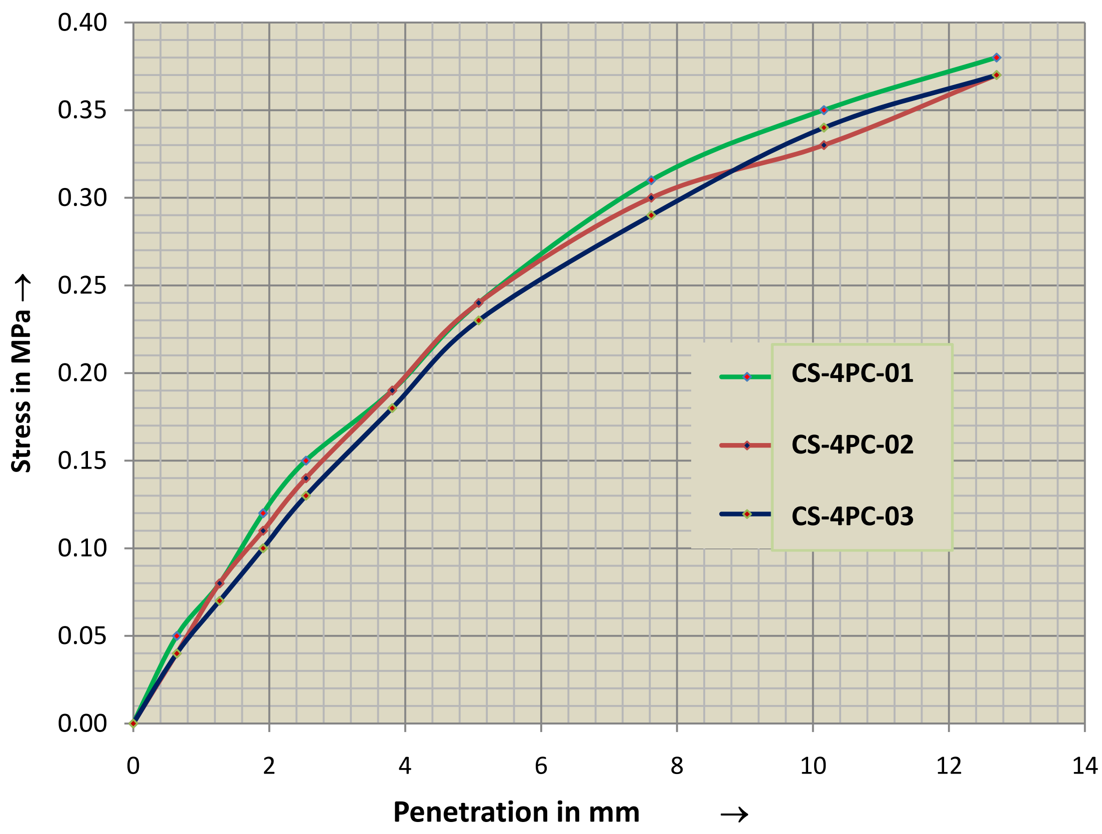


Figure D. 21: Load- Penetration curve for CS-4PC-0

Table D. 22: Soaked CBR of untreated clayey sand from Civil Service College cured for 7 days

Penet- ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0.00	0	0.00	0	0.00
0.64		7	0.09	7	0.09	6	0.08
1.27		9	0.12	10	0.13	9	0.12
1.91		12	0.16	13	0.17	12.5	0.17
2.54	6.9	14	0.19	16	0.21	15	0.20
3.81		17.5	0.23	19	0.25	18.5	0.25
5.08	10.3	21	0.28	22	0.29	22.5	0.30
7.62		26	0.35	27	0.36	28	0.37
10.16		29	0.39	30	0.40	31	0.41
12.7		32	0.43	34	0.45	35	0.46
CBR at 2.54-corrected			2.8		3.0		3.0
CBR at 5.08- corrected			2.7		2.8		2.9
Average CBR for CS-0-7			2.9%				
Dry Density in g/cc		1.35		1.349		1.35	
Sample Identification		CS-0-71		CS-0-72		CS-0-73	

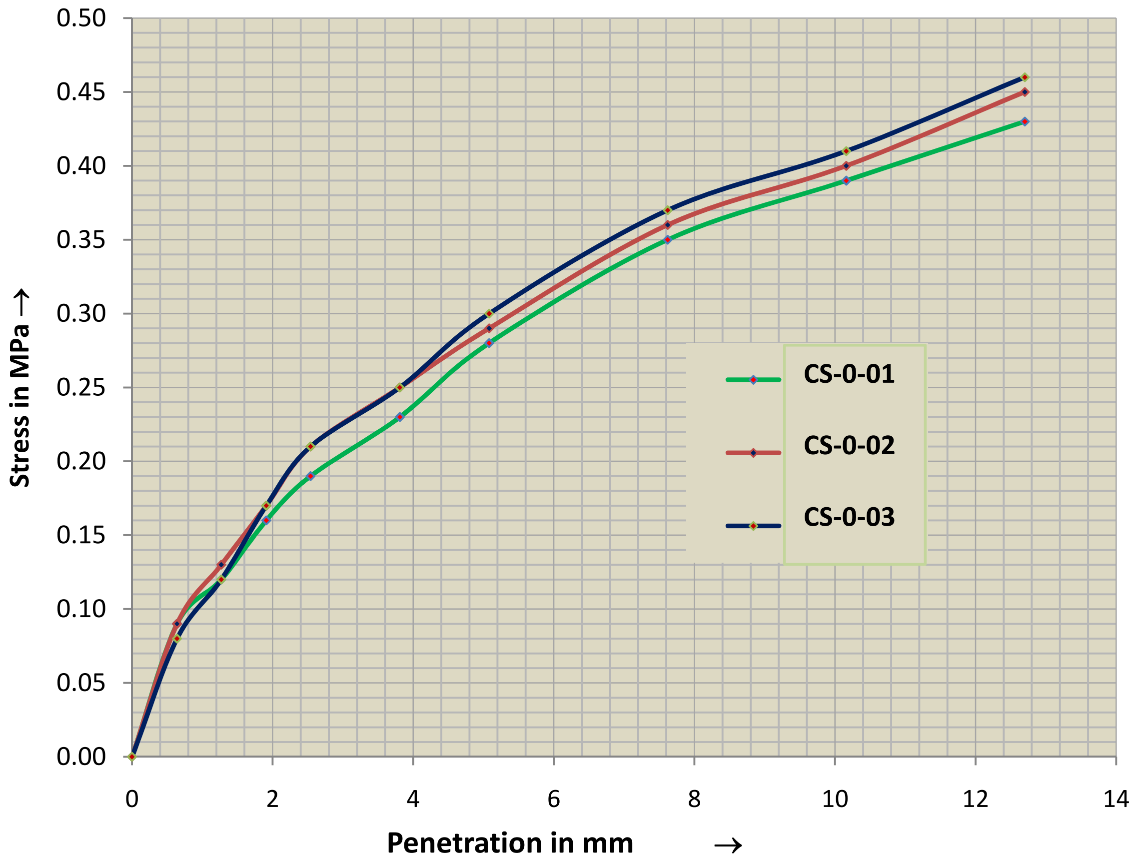


Figure D. 22: Load- Penetration curve for CS-0-7

Table D. 23: Soaked CBR of clayey sand from Civil Service College treated with PURE CRETE at twice application rate of manufacturer cured for 7 days

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0.00	0	0.00	0	0.00
0.64		6.3	0.08	7	0.09	8	0.11
1.27		10	0.13	11	0.15	12	0.16
1.91		14	0.19	13.3	0.18	16	0.21
2.54	6.9	16.5	0.22	15.5	0.21	18.2	0.24
3.81		19.5	0.26	19	0.25	22	0.29
5.08	10.3	22.5	0.30	22	0.29	24	0.32
7.62		27	0.36	25	0.33	28	0.37
10.16		31	0.41	27	0.36	30	0.40
12.7		35	0.46	29.5	0.39	33	0.44
CBR at 2.54-corrected			3.2		3.0		3.5
CBR at 5.08- corrected			2.9		2.8		3.1
Average CBR for CS-2PC-7			3.2%				
Dry Density in g/cc		1.355		1.349		1.357	
Sample Identification		CS-2PC -71		CS-2PC -72		CS-2PC -73	

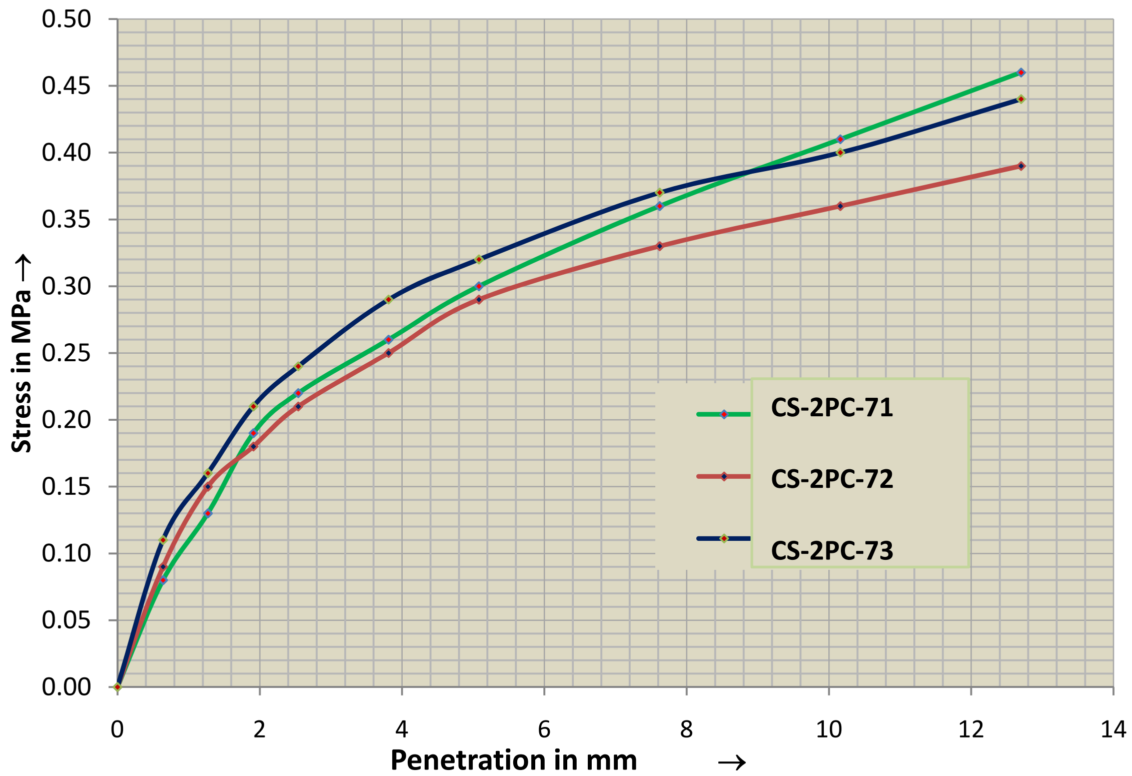


Figure D. 23: Load- Penetration curve for CS-2PC -7

Table D. 24: Soaked CBR of clayey sand from Civil Service College treated with PURE CRETE at four times application rate of manufacturer cured for 7 days

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0.00	0	0.00	0	0.00
0.64		7	0.09	8	0.11	7	0.09
1.27		11	0.15	12	0.16	10.5	0.14
1.91		15	0.20	15	0.20	16	0.21
2.54	6.9	17	0.23	18	0.24	17.5	0.23
3.81		21	0.28	21	0.28	20.5	0.27
5.08	10.3	24	0.32	24.5	0.33	23	0.31
7.62		26	0.35	27	0.36	25.5	0.34
10.16		29	0.39	29	0.39	27.5	0.37
12.7		32	0.43	33	0.44	30.6	0.41
CBR at 2.54-corrected			3.3		3.5		3.3
CBR at 5.08- corrected			3.1		3.2		3.0
Average CBR for CS-4PC-7			3.4%				
Dry Density in g/cc		1.357		1.354		1.35	
Sample Identification		CS-4PC-71		CS-4PC-72		CS-4PC-73	

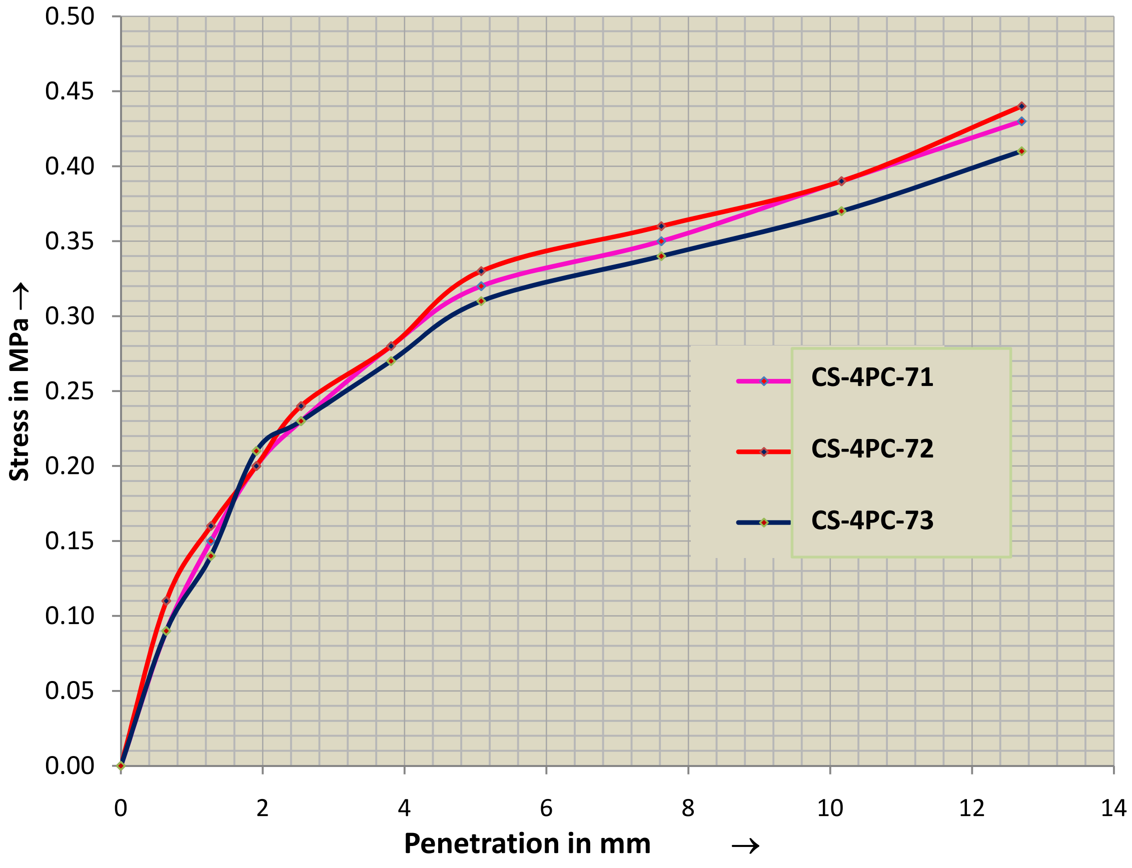


Figure D. 24: Load- Penetration curve for CS-4PC-7

Table D. 25: Soaked CBR of Light grey clay treated with 6% ANSS cured for 7 days

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0.0	0	0.0	0	0.0	0.00
0.64		32.0	0.43	44.0	0.58	35.0	0.46
1.27		41.0	0.54	64.0	0.85	51.0	0.68
1.91		51.0	0.68	78.0	1.04	69.0	0.92
2.54	6.9	60	0.80	92.0	1.22	84.0	1.12
3.81		76.0	1.01	110.0	1.46	99.0	1.32
5.08	10.3	89.0	1.18	123.0	1.63	109.0	1.45
7.62		109.0	1.45	133.0	1.77	127.0	1.69
10.16		116.0	1.54	134.5	1.79	131.0	1.74
12.7		117.5	1.56	135.0	1.79	133.0	1.77
CBR at 2.54			11.6		17.7		16.2
CBR at 5.08			11.5		15.8		14.1
Average CBR for LGC-6ANSS-7			15.2%				
Dry Density in g/cc		1.16		1.19		1.18	
Sample Identification		LGC-6ANSS-71		LGC-6ANSS-72		LGC-6ANSS-73	

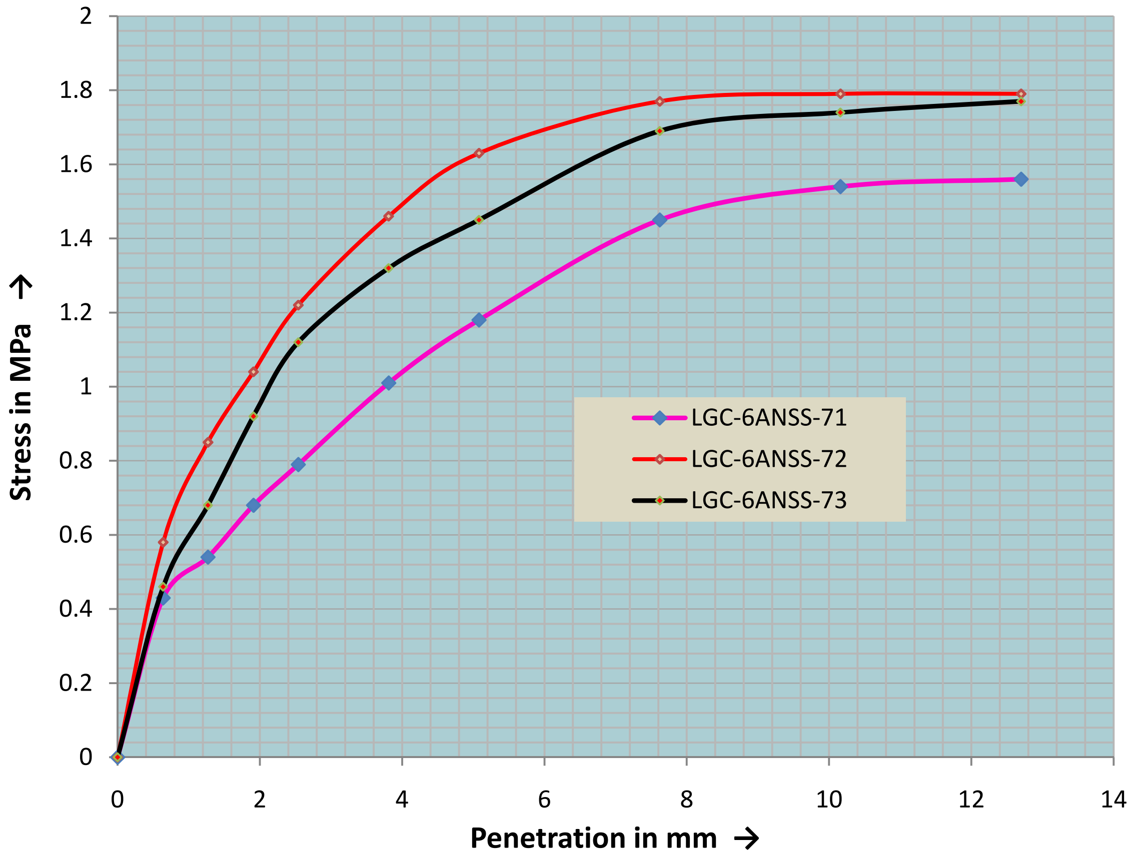


Figure D. 25: Load- penetration curve for LGC-6ANSS-7

Table D. 26: Soaked CBR of Red clay treated with 4% ANSS- without curing

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0.00	0	0.00	0	0.00
0.64		54	0.72	24	0.32	47	0.62
1.27		69	0.92	36	0.47	62	0.82
1.91		79	1.05	45	0.60	73	0.97
2.54	6.9	89	1.18	54	0.72	82	1.09
3.81		100	1.33	70	0.93	93	1.24
5.08	10.3	108	1.43	82	1.09	102	1.36
7.62		118.5	1.57	105	1.39	114	1.51
10.16		130.5	1.73	122	1.61	128	1.70
12.7		141	1.87	132	1.75	136	1.81
CBR at 2.54			17.1		10.58		15.8
CBR at 5.08			13.88		10.49		13.2
Average CBR for RC-4ANSS-0			14.49				
Dry Density in g/cc		1.302		1.289		1.293	
Sample Identification		RC-4ANSS-01		RC-4ANSS-02		RC-4ANSS-03	

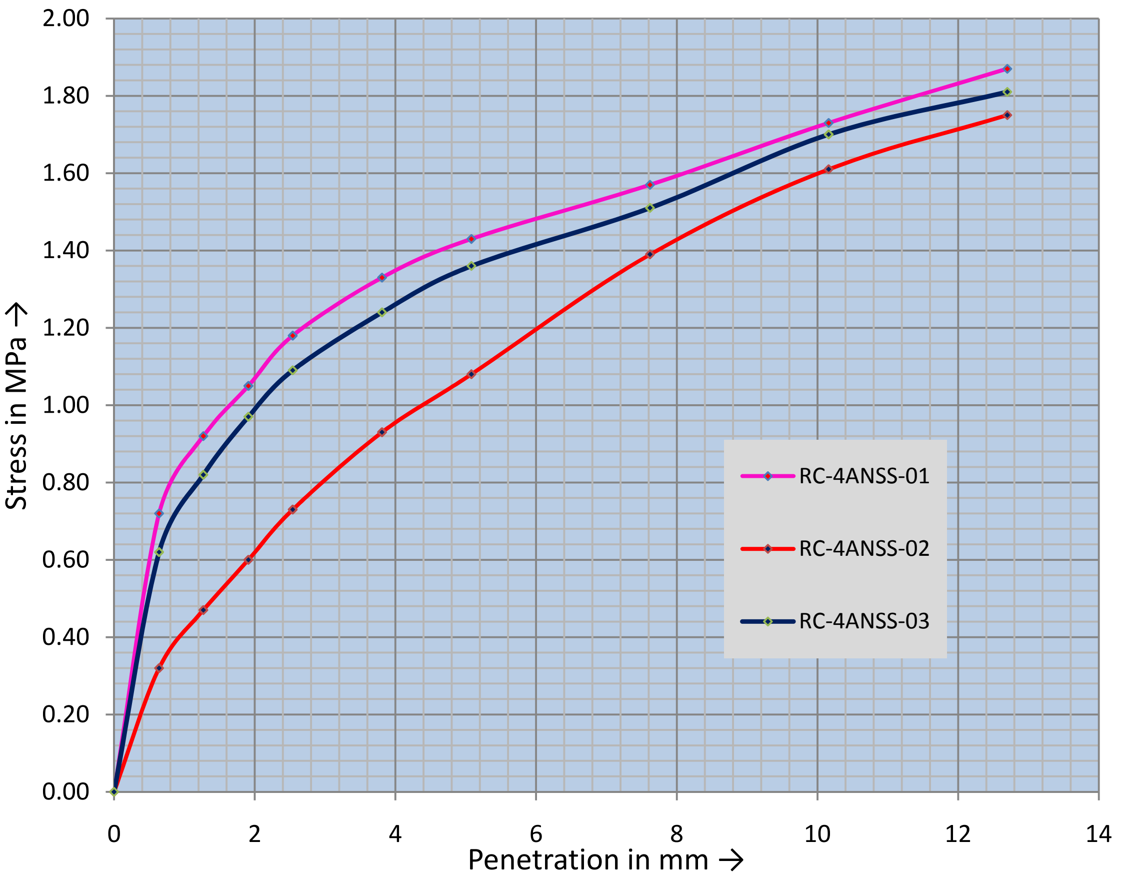


Figure D. 26: Load-penetration curve for RC-4ANSS-0

Table D. 27: Soaked CBR of Red clay treated with 4% ANSS cured for 7 days

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0.00	0	0.00	0	0.00
0.64		35	0.46	58	0.77	49	0.65
1.27		160	2.13	89	1.18	84	1.12
1.91		174	2.31	118	1.57	113	1.50
2.54	6.9	180	2.39	139	1.85	142	1.89
3.81		187	2.48	160	2.13	157	2.09
5.08	10.3	196	2.60	162	2.15	169	2.25
7.62		220	2.92	171	2.27	183	2.43
10.16		243	3.23	183	2.43	201	2.67
12.7		261	3.47	197	2.62	220	2.92
CBR at 2.54 corrected			35.07		26.81		27.39
CBR at 5.08 corrected			25.73		20.87		21.84
Average CBR for RC-4ANSS-7			30%				
Dry Density in g/cc		1.32		1.31		1.32	
Sample Identification		RC-4ANSS-71		RC-4ANSS-72		RC-4ANSS-73	

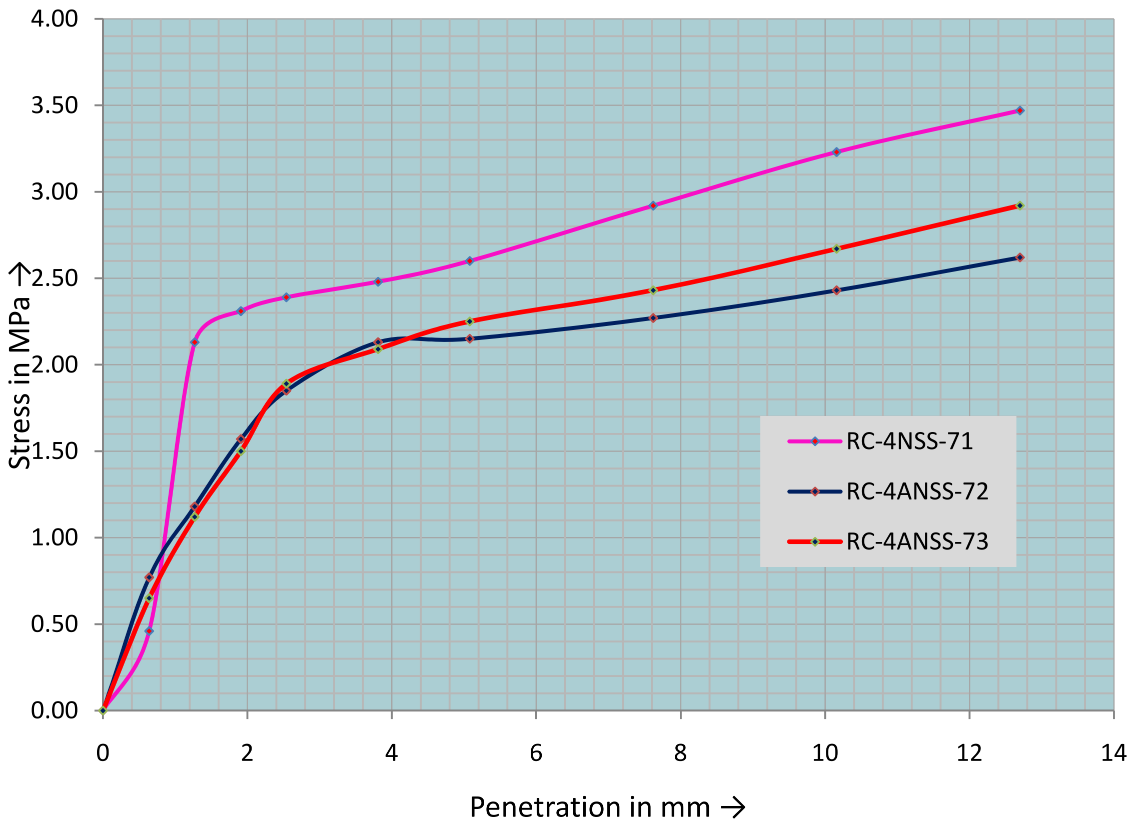


Figure D. 27: Load- penetration curve for RC-4ANSS-7

Table D. 28: Soaked CBR of silty sand blended with red clay treated with 4% ANSS and cured for 7 days

Penet- ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0.00	0	0.00	0.0	0.00
0.64		244	3.24	230	3.06	225.0	2.99
1.27		384	5.10	339.00	4.50	354.0	4.70
1.91		474	6.30	420.00	5.58	433.0	5.75
2.54	6.9	543	7.21	490.00	6.51	522.0	6.93
3.81		665	8.83	591.00	7.85	615.0	8.17
5.08	10.3	756	10.04	678.00	9.01	715.0	9.50
7.62		913	12.13	820.0	10.89	862.0	11.45
10.16		1043	13.86	941.00	12.50	975.0	12.95
12.0		**	**	*1023.0	13.59	*1030.0	13.68
CBR at 2.54 corrected			104.5		94.4		100.4
CBR at 5.08 corrected			97.5		87.5		92.2
Average CBR for SSC-4ANSS-7			99.8%				
Dry Density in g/cc		1.168		1.156		1.162	
Sample Identification		SSC-4ANSS-71		SSC-4ANSS-72		SSC-4ANSS-73	

Note:

* *Reading taken at 12mm penetration due to CBR machine load reading limit using 28KN vertical stress*

** *Reading not taken as it will exceed the CBR machine load setup used for penetration*

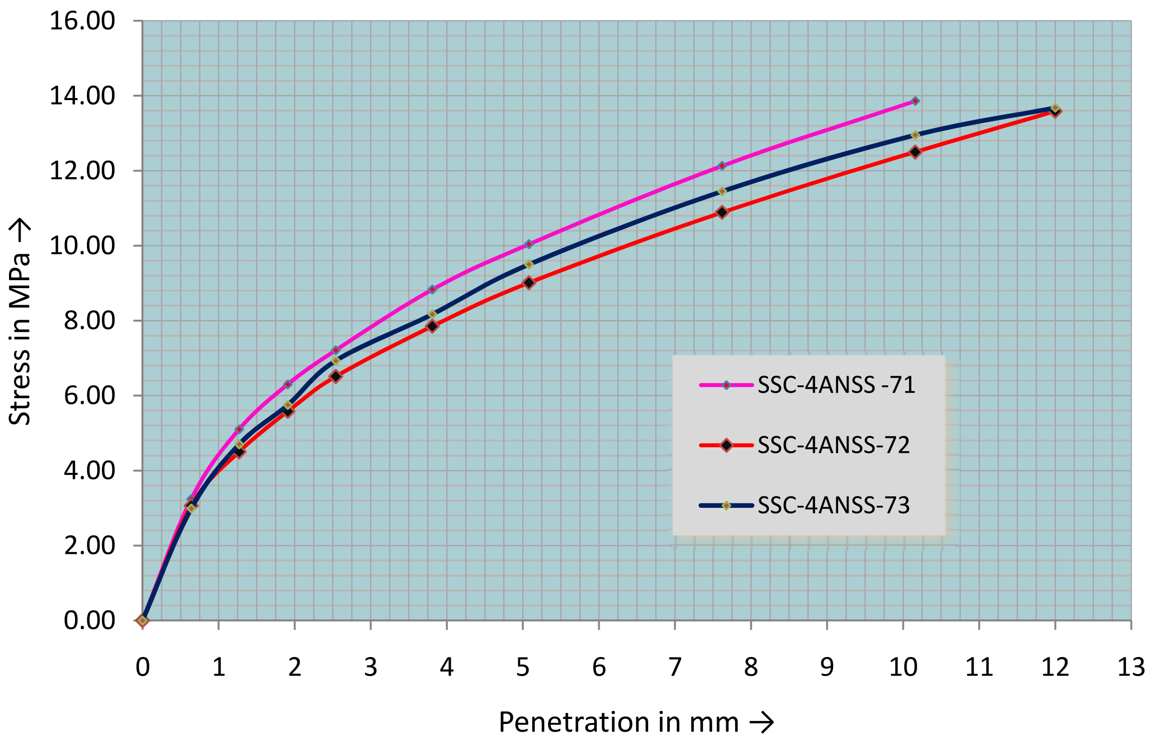


Figure D. 28: Load-penetration curve for SSC-4ANSS-7

Table D. 29: Soaked CBR of clayey sand from Civil Service College treated with 6% ANSS without curing

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0.0	0.00	0.0	0.00	0.0	0.00
0.64		32.0	0.43	41.0	0.54	29.0	0.39
1.27		45.0	0.60	55.0	0.73	43.0	0.57
1.91		54.0	0.72	68.5	0.91	56.0	0.74
2.54	6.9	63.5	0.84	78.0	1.04	64.0	0.85
3.81		78.0	1.04	97.0	1.29	78.0	1.04
5.08	10.3	89.0	1.18	112.0	1.49	91.0	1.21
7.62		109.0	1.45	135.0	1.79	113.0	1.50
10.16		123.0	1.63	151.5	2.01	128.0	1.70
12.7		130.0	1.73	161.5	2.15	136.0	1.81
CBR at 2.54			12.17		15.10		12.30
CBR at 5.08			11.50		14.47		11.75
Average CBR for CS-6ANSS-0			13.19				
Dry Density in g/cc		1.262		1.270		1.267	
Sample Identification		CS-6ANSS-01		CS-6ANSS-02		CS-6ANSS-03	

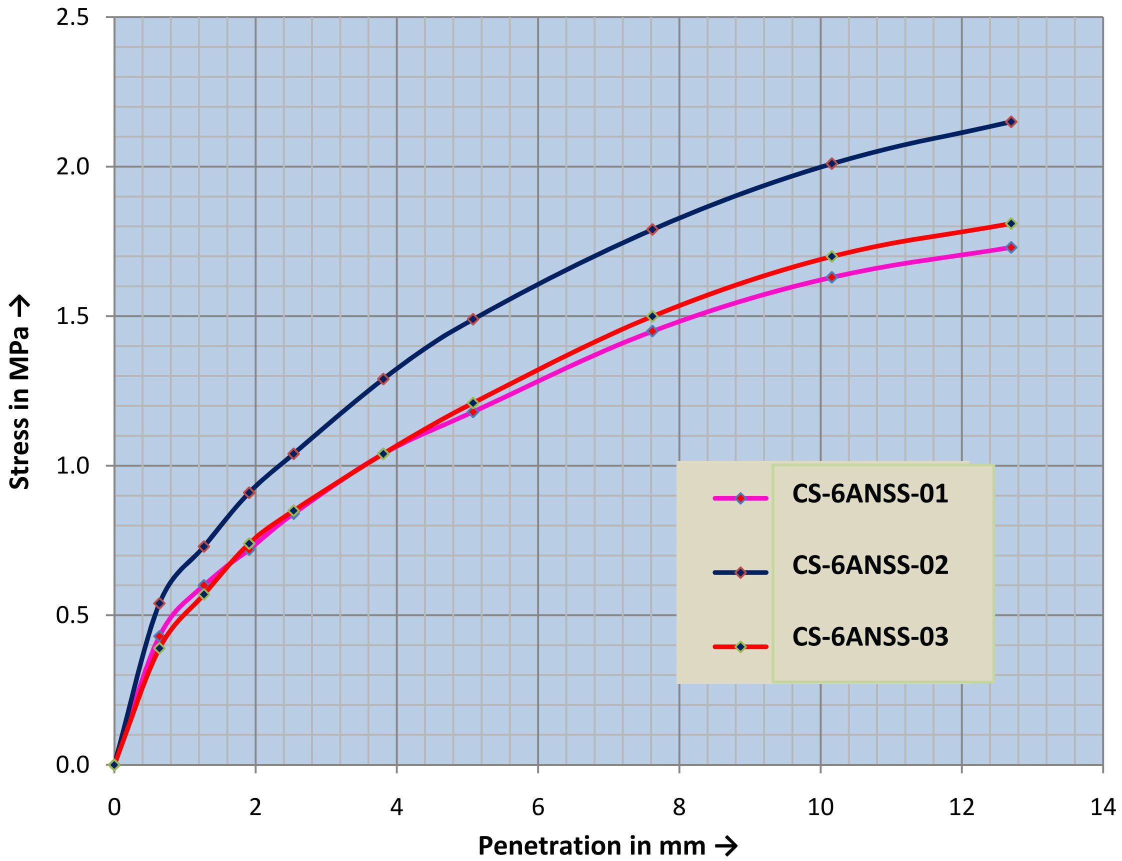


Figure D. 29: Load-penetration curve for CS-6ANSS-0

Table D. 30: Soaked CBR of clayey sand from Civil Service College treated with 6% ANSS cured for 7 days

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0	0.00	0	0.00	0	0.00
0.64		34	0.45	32	0.43	30	0.40
1.27		49	0.65	45	0.60	48	0.64
1.91		61	0.81	58	0.77	62	0.82
2.54	6.9	76	1.01	70	0.93	75	1.00
3.81		92	1.22	84	1.12	92	1.22
5.08	10.3	113	1.50	101	1.34	106	1.41
7.62		147	1.95	132	1.75	138	1.83
10.16		175	2.32	160	2.13	159	2.11
12.7		184	2.44	178	2.36	175	2.32
CBR at 2.54 corrected			14.64		13.48		14.5
CBR at 5.08 corrected			14.56		13.01		13.7
Average CBR for CS-6ANSS-7			14.2%				
Dry Density in g/cc		1.625		1.596		1.61	
Sample Identification		CS-6ANSS-71		CS-6ANSS-72		CSW-6ANSS-73	

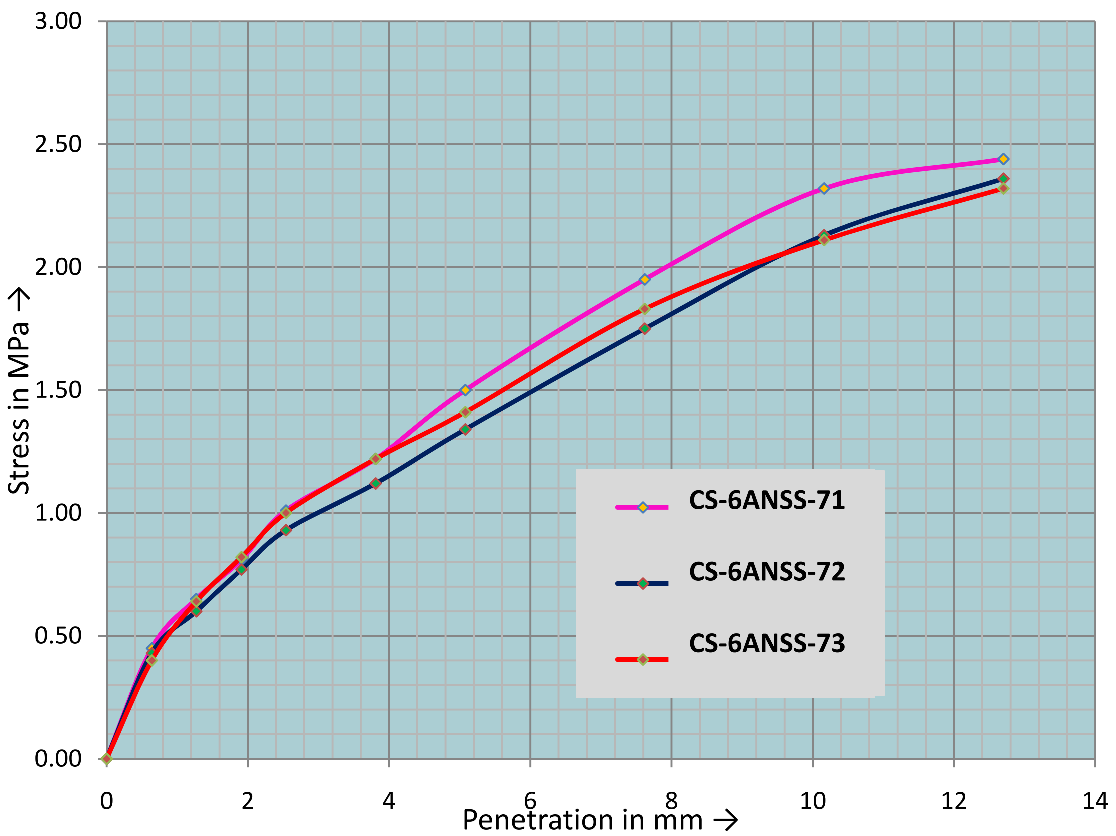


Figure D. 30: Load-penetration curve for CS-6ANSS-7

Table D. 31: Soaked CBR of untreated silty sand

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0.0	0.00	0.0	0.00	0.0	0.00
0.64		36.0	0.48	40.0	0.53	31.0	0.41
1.27		86.0	1.14	109.0	1.45	89.0	1.18
1.91		127.0	1.69	166.0	2.21	141.0	1.87
2.54	6.9	161.0	2.14	205.0	2.72	183.0	2.43
3.81		210.0	2.79	271.0	3.60	245.0	3.25
5.08	10.3	260.0	3.45	329.0	4.37	298.0	3.96
7.62		340.0	4.52	426.0	5.66	382.0	5.07
10.16		405.0	5.38	508.0	6.75	462.0	6.14
12.7		468.0	6.22	591.0	7.85	525.0	6.97
CBR at 2.54 corrected			33		40.6		38.4
CBR at 5.08 corrected			34		43.1		40.6
Average CBR for SS-0-0			39.10				
Dry Density in g/cc		1.465		1.479		1.450	
Sample Identification		SS-0-01		SS-0-02		SS-0-03	

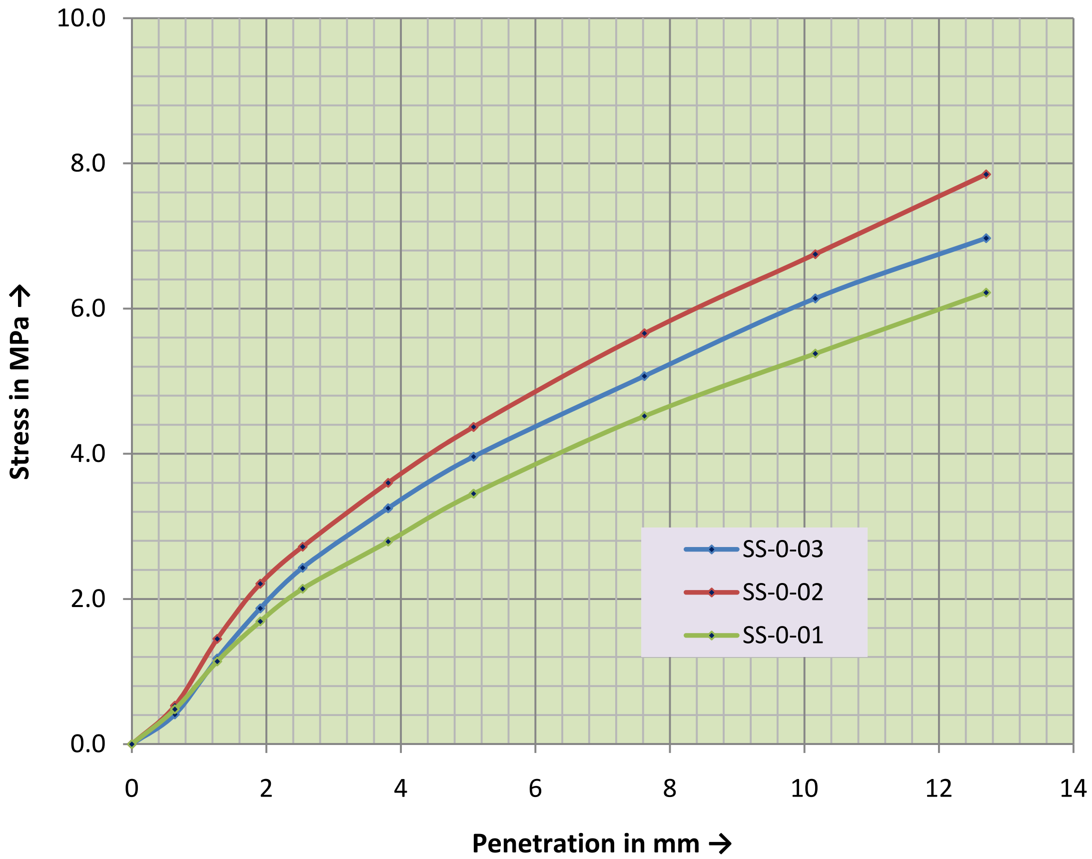


Figure D. 31: Load-penetration curve for SS-0-0

Table D. 32: Soaked CBR of silty sand from Adje-Ropi Road treated with 4% ANSS and cured for 7 days

Penet-ration (mm)	Standard load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)	Piston reading	Load (MPa)
0		0.0	0.00	0.0	0.00	0.0	0.00
0.64		259.0	3.44	237.0	3.15	243.0	3.23
1.27		358.0	4.76	332.0	4.41	349.0	4.64
1.91		426.0	5.66	443.0	5.89	439.0	5.83
2.54	6.9	491.0	6.52	512.0	6.80	517.0	6.87
3.81		595.0	7.90	614.0	8.16	620.0	8.24
5.08	10.3	687.0	9.13	697.0	9.26	710.0	9.43
7.62		791.0	10.51	832.0	11.05	828.0	11.00
10.16		958.0	12.73	982.0	13.05	996.0	13.23
12.7		1040.0	13.82	**		**	
CBR at 2.54			94.49		98.55		99.57
CBR at 5.08			88.64		89.90		91.55
Average CBR for SS-4ANSS-7			97.54%				
Dry Density in g/cc		1.077		1.074		1.08	
Sample Identification		SS-4ANSS-71		SS-4ANSS-72		SS-4ANSS-73	

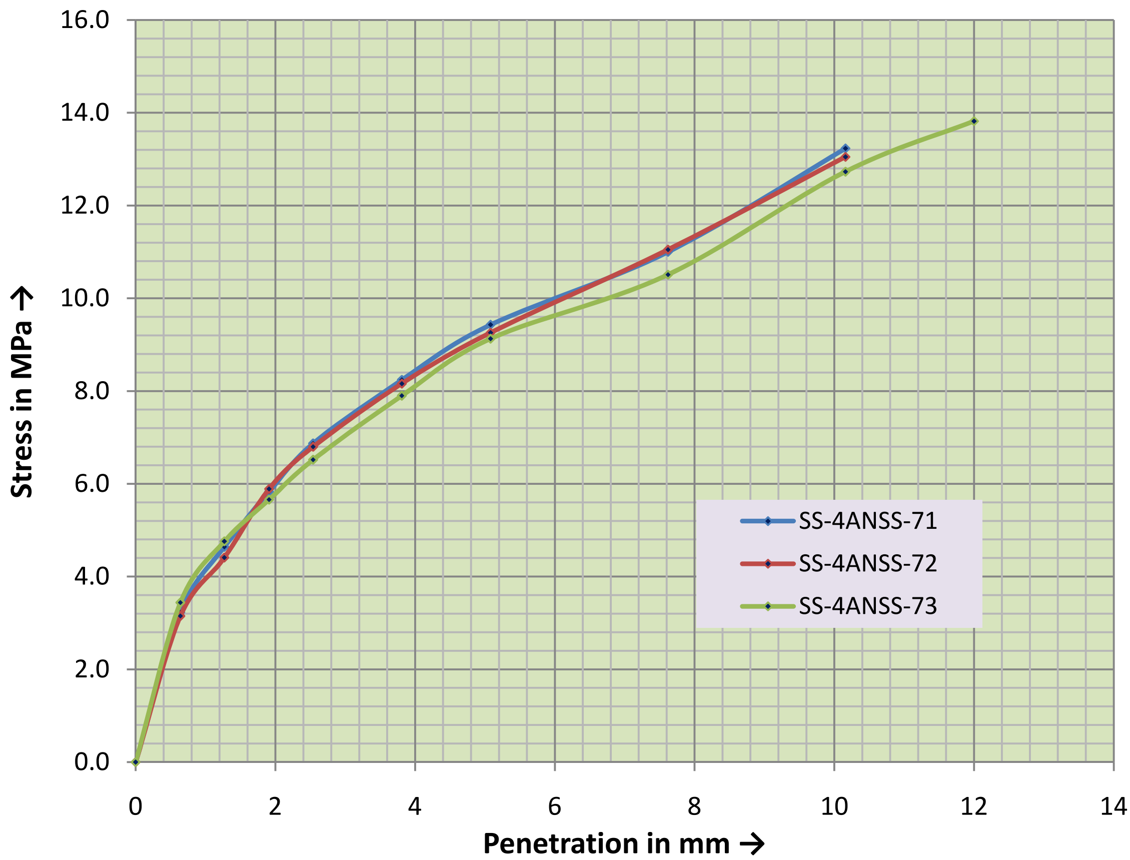


Figure D. 32: Load-penetration curve for SS-4ANSS-7

Annex E. Grain size analysis

Table E. 1: Sieve analysis results for untreated light grey clay

Sieve number	Sieve opening (mm)	Weight of sieve (g)	Weight of sieve + retained soil (g)	Weight of retained soil (g)	Percentage retained %	Cumulative percentage retained (%)	Percent passing %
3"	*75.0*	424.0	424.0	0.0	0.00	0.00	100.00
2"	*50.0*	434.0	434.0	0.0	0.00	0.00	100.00
1.5"	*37.5*	469.0	469.0	0.0	0.00	0.00	100.00
1"	*25.0*	455.0	455.0	0.0	0.00	0.00	100.00
3/4"	*19.0*	443.0	443.0	0.0	0.00	0.00	100.00
1/2"	*12.5*	441.0	441.0	0.0	0.00	0.00	100.00
3/4"	*9.5*	441.0	441.0	0.0	0.00	0.00	100.00
No.4	*4.75*	451	451	0.0	0.00	0.00	100.00
No 8	*2.36*	389	389	0.0	0.00	0.00	100.00
No 10	*2*	390	390	0.0	0.00	0.00	100.00
No 16	1.18	356	356	0.0	0.00	0.00	100.00
No 30	0.6	325	325.1	0.1	0.09	0.09	99.91
No 40	0.425	305	305.1	0.1	0.09	0.17	99.83
No 50	0.3	291	292.0	1.0	0.87	1.04	98.96
No 100	0.15	270	270.2	0.2	0.17	1.22	98.78
No 200	0.075	258	259.2	1.2	1.04	2.26	97.74
Pan	-	256	368.3	112.3	97.65	99.91	0.00

Table E. 2: Hydrometer analysis results for untreated light grey clay

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Finer combined (%)
0.5	1.0330	-0.0027	1.0303	7.57	0.013164	0.0512	95.03	92.80
1	1.0315	-0.0027	1.0288	7.97	0.013164	0.0372	90.33	88.21
2	1.0305	-0.0027	1.0278	8.23	0.013164	0.0267	87.19	85.14
4	1.0300	-0.0027	1.0273	8.36	0.013164	0.0190	85.62	83.61
8	1.0295	-0.0027	1.0268	8.50	0.013164	0.0136	84.05	82.08
15	1.0285	-0.0027	1.0258	8.76	0.013164	0.0101	80.92	79.02
30	1.0275	-0.0027	1.0248	9.03	0.013164	0.0072	77.78	75.95
60	1.0265	-0.0027	1.0238	9.29	0.013164	0.0052	74.65	72.90
120	1.0250	-0.0027	1.0223	9.69	0.013164	0.0037	69.94	68.30
240	1.0245	-0.0027	1.0218	9.82	0.013164	0.0027	68.37	66.76
480	1.0225	-0.0027	1.0198	10.35	0.013164	0.0019	62.10	60.64
1440	1.0220	-0.0027	1.0193	10.48	0.013164	0.0011	60.53	59.11

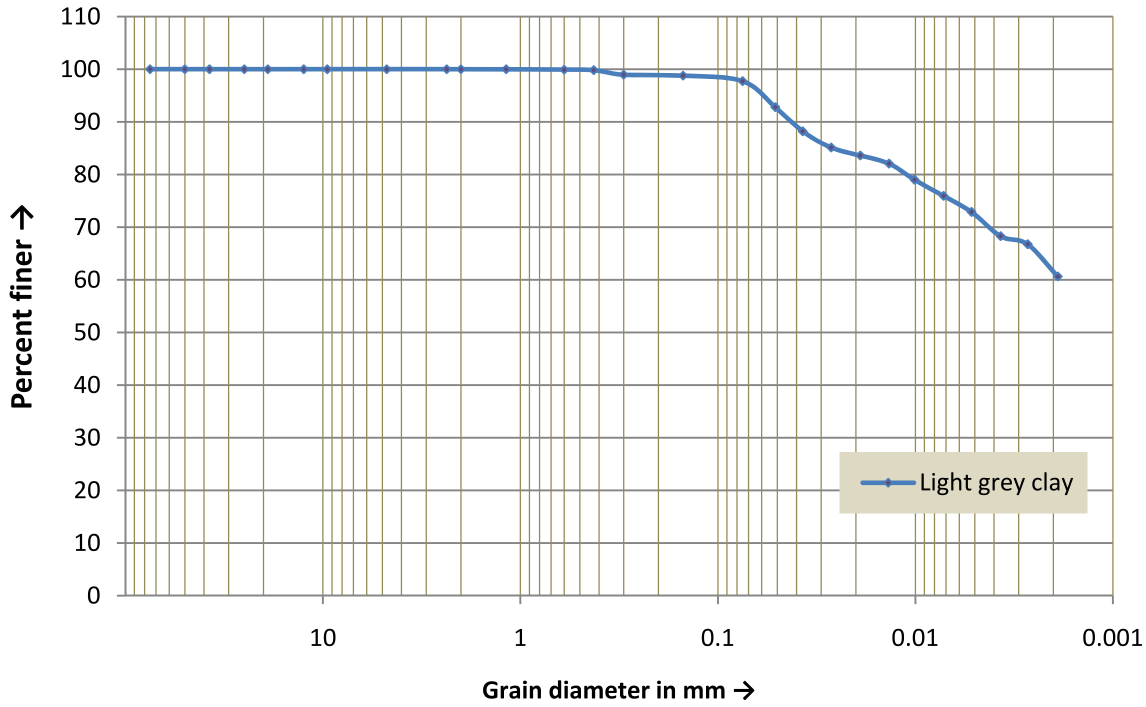


Figure E. 1: Grain-size curves for untreated light grey clay

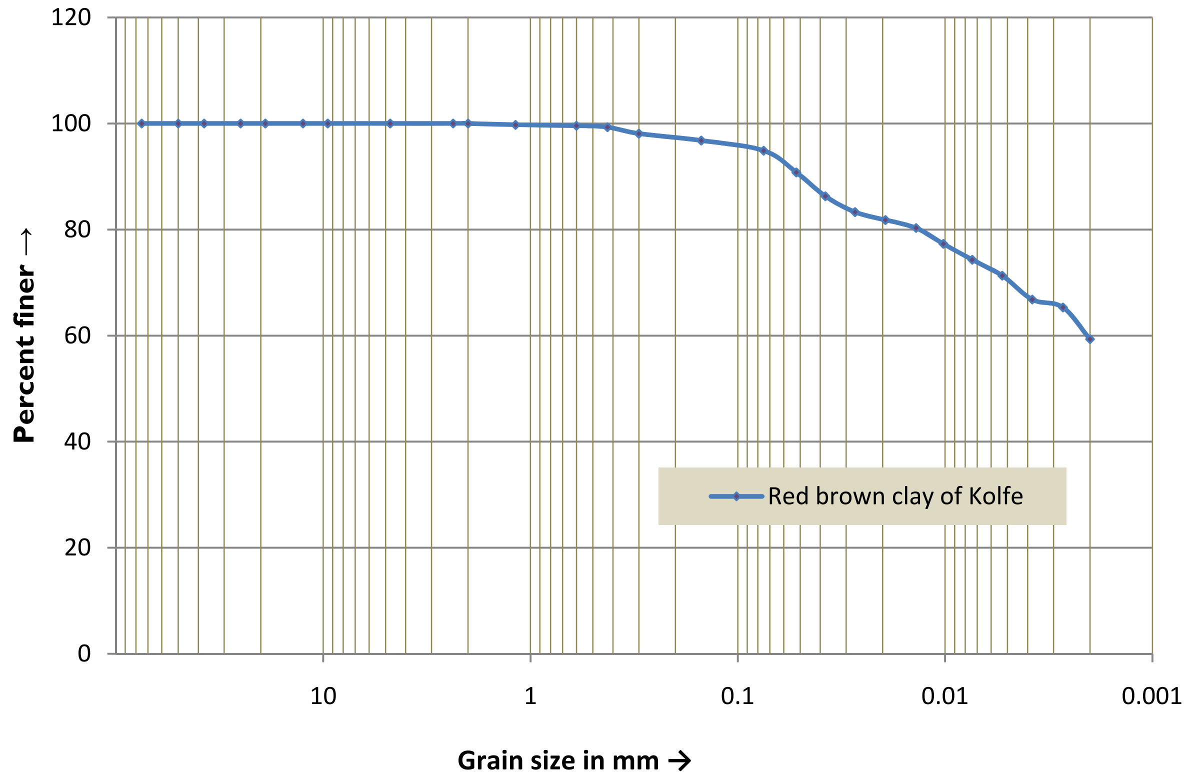


Figure E. 2: Grain-size curves for untreated red brown clay of Kolfe

Table E. 3: Sieve analysis results for untreated red brown clay of Kolfe

Sieve number	Sieve opening (mm)	Weight of sieve (g)	Weight of sieve + retained soil (g)	Weight of retained soil (g)	Percentage retained %	Cumulative percentage retained (%)	Percent passing %
3"	*75.0*	424.0	424.0	0.0	0.00	0.00	100.00
2"	*50.0*	434.0	434.0	0.0	0.00	0.00	100.00
1.5"	*37.5*	469.0	469.0	0.0	0.00	0.00	100.00
1"	*25.0*	455.0	455.0	0.0	0.00	0.00	100.00
3/4"	*19.0*	443.0	443.0	0.0	0.00	0.00	100.00
1/2"	*12.5*	441.0	441.0	0.0	0.00	0.00	100.00
3/4"	*9.5*	441.0	441.0	0.0	0.00	0.00	100.00
No.4	*4.75*	451	451	0.0	0.00	0.00	100.00
No 8	*2.36*	389	389	0.0	0.00	0.00	100.00
No 10	*2*	390	390	0.0	0.00	0.00	100.00
No 16	1.18	356	356.3	0.3	0.26	0.26	99.74
No 30	0.6	325	325.2	0.2	0.17	0.43	99.57
No 40	0.425	305	305.3	0.3	0.26	0.70	99.30
No 50	0.3	291	292.40	1.4	1.22	1.91	98.09
No 100	0.15	270	271.50	1.5	1.30	3.22	96.78
No 200	0.075	258	260.2	2.2	1.91	5.13	94.87
Pan	-	256	364.7	108.7	94.52	99.65	0.00

Table E. 4: Hydrometer analysis results for untreated red brown clay of Kolfe

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	%age finer combined
0.5	1.0330	-0.0027	1.0303	7.57	0.01340	0.0522	96.04	90.78
1	1.0315	-0.0027	1.0288	7.97	0.01340	0.0378	91.28	86.28
2	1.0305	-0.0027	1.0278	8.23	0.01340	0.0272	88.11	83.29
4	1.0300	-0.0027	1.0273	8.36	0.01340	0.0194	86.53	81.79
8	1.0295	-0.0027	1.0268	8.50	0.01340	0.0138	84.95	80.29
15	1.0285	-0.0027	1.0258	8.76	0.01340	0.0102	81.78	77.30
30	1.0275	-0.0027	1.0248	9.03	0.01340	0.0074	78.61	74.30
60	1.0265	-0.0027	1.0238	9.29	0.01340	0.0053	75.44	71.30
120	1.0250	-0.0027	1.0223	9.69	0.01340	0.0038	70.68	66.81
240	1.0245	-0.0027	1.0218	9.82	0.01340	0.0027	69.10	65.31
480	1.0225	-0.0027	1.0198	10.35	0.01340	0.0020	62.76	59.32
1440	1.0220	-0.0027	1.0193	10.48	0.01340	0.0011	61.17	57.82

Table E. 5: Sieve analysis results for untreated silty sand from Adje-Ropi rural road subgrade

Sieve number	Sieve opening (mm)	Weight of sieve (g)	Weight of sieve + retained soil (g)	Weight of retained soil (g)	Percent age retained %	Cumulative percentage retained (%)	Percent passing %
3"	*75.0*	424.0	424.0	0.0	0.00	0.00	100.00
2"	*50.0*	434.0	434.0	0.0	0.00	0.00	100.00
1.5"	*37.5*	469.0	469.0	0.0	0.00	0.00	100.00
1"	*25.0*	455.0	455.0	0.0	0.00	0.00	100.00
3/4"	*19.0*	443.0	443.0	0.0	0.00	0.00	100.00
1/2"	*12.5*	441.0	441.0	0.0	0.00	0.00	100.00
3/4"	*9.5*	441.0	441.0	0.0	0.00	0.00	100.00
No.4	*4.75*	451	451.0	0.0	0.00	0.00	100.00
No 8	*2.36*	389	399.0	10.0	0.85	0.85	99.15
No 10	*2*	390	402.0	12.0	1.03	1.88	98.12
No 16	1.18	356	396.0	40.0	3.42	5.30	94.70
No 30	0.6	325	447.0	122.0	10.43	15.73	84.27
No 40	0.425	305	419.0	114.0	9.74	25.47	74.53
No 50	0.3	291	507.0	216.0	18.46	43.93	56.07
No 100	0.15	270	476.0	206.0	17.61	61.54	38.46
No 200	0.075	258	398.0	140.0	11.97	73.50	26.50
Pan	-	256	562.0	306	26.15	99.66	0.00

Table E. 6: Hydrometer analysis results for untreated silty sand from Adje-Ropi rural road subgrade

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Percentage finer combined
0.5	1.0280	-0.0027	1.0253	8.89	0.01375	0.0410	81.83	21.40
1	1.0260	-0.0027	1.0233	9.42	0.01375	0.0298	75.37	19.71
2	1.0220	-0.0027	1.0193	10.48	0.01375	0.0223	62.43	16.33
4	1.0180	-0.0027	1.0153	11.54	0.01375	0.0165	49.49	12.94
8	1.0160	-0.0027	1.0133	12.07	0.01375	0.0123	43.02	11.25
15	1.0105	-0.0027	1.0078	13.52	0.01375	0.0092	25.23	6.60
30	1.0090	-0.0027	1.0063	13.92	0.01375	0.0066	20.38	5.33
60	1.0060	-0.0027	1.0033	14.71	0.01375	0.0068	10.67	2.79
120	1.0055	-0.0027	1.0028	14.85	0.01375	0.0048	9.06	2.37
240	1.0050	-0.0027	1.0023	14.98	0.01375	0.0034	7.44	1.95
480	1.0043	-0.0027	1.0016	15.18	0.01375	0.0024	5.01	1.31
1440	1.0043	-0.0027	1.0016	15.18	0.01375	0.0014	5.01	1.31

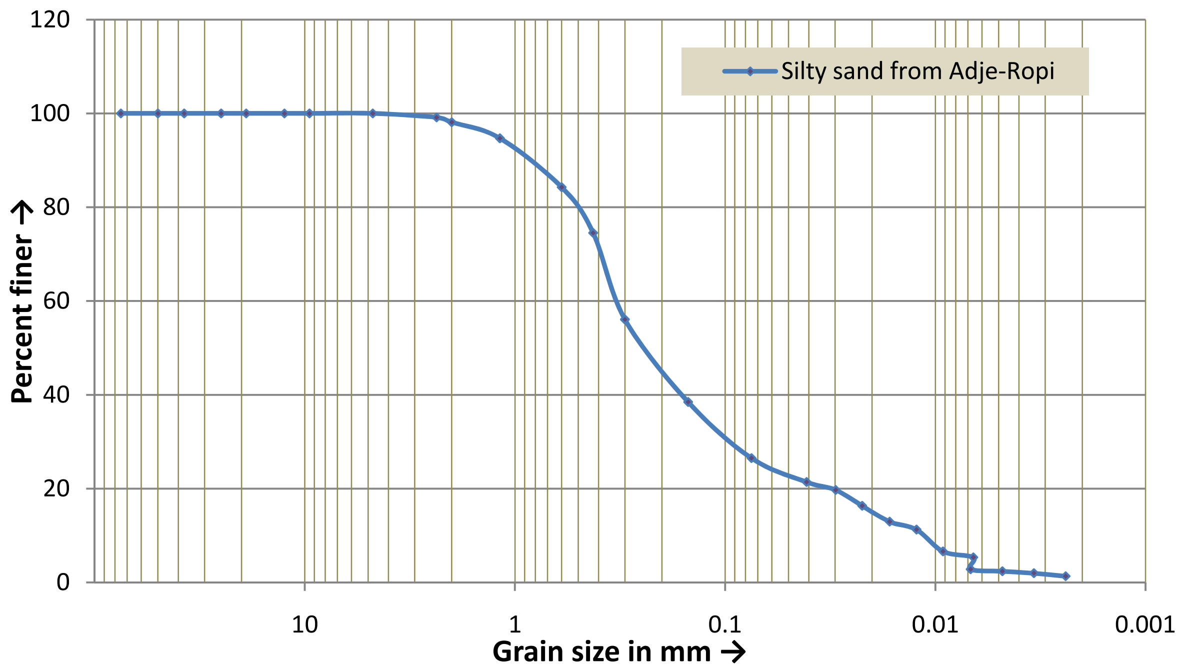


Figure E. 3: Grain-size curves for untreated silty sand from Adje-Ropi rural road subgrade

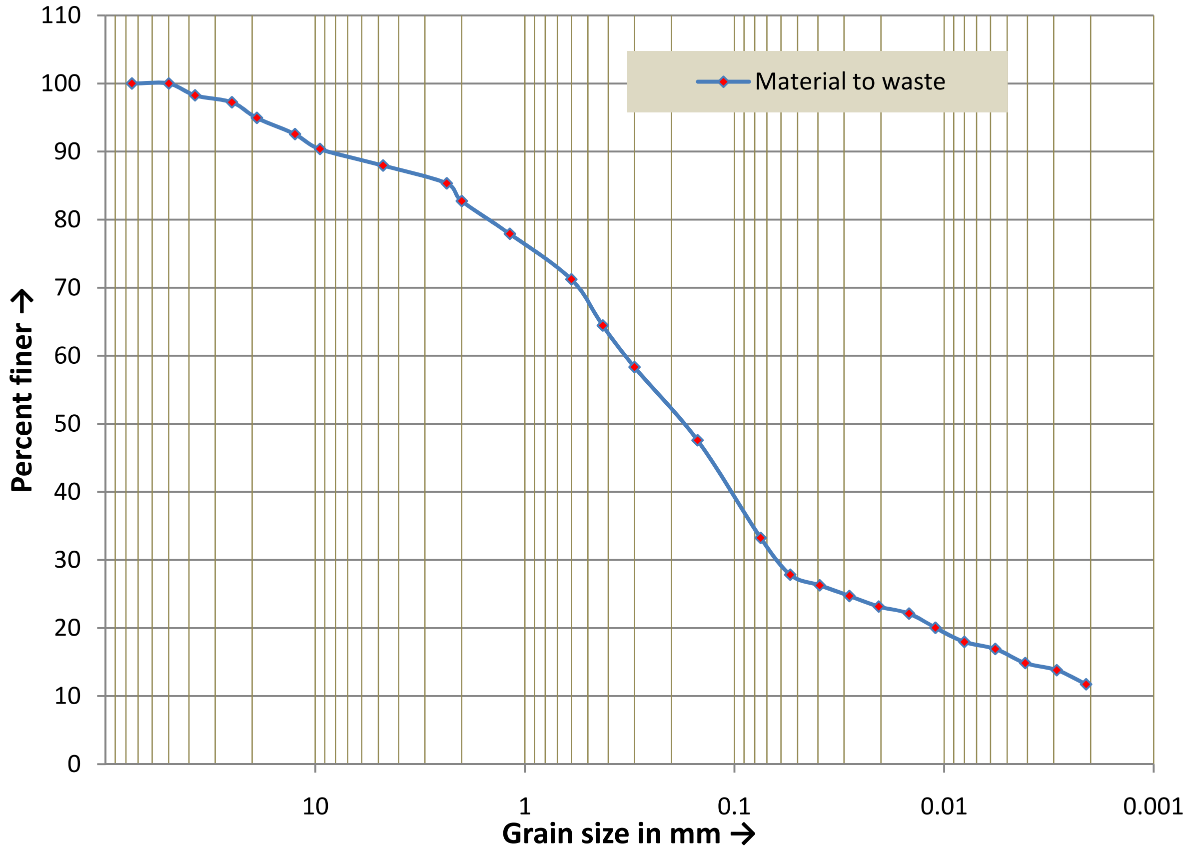


Figure E. 4: Grain-size curves for untreated material to waste from Civil Service College

Table E. 7: Sieve analysis results for untreated clayey sand from Civil Service College

Sieve number	Sieve opening (mm)	Weight of sieve (g)	Weight of sieve + retained soil (g)	Weight of retained soil (g)	Percentage retained %	Cumulative percentage retained (%)	Percent passing %
3"	*75.0*	424.0	424.0	0.0	0.00	0.00	100.00
2"	*50.0*	434.0	434.0	0.0	0.00	0.00	100.00
1.5"	*37.5*	469.0	520.0	51.0	1.74	1.74	98.26
1"	*25.0*	455.0	485.0	30.0	1.02	2.76	97.24
3/4"	*19.0*	443.0	510.0	67.0	2.29	5.05	94.95
1/2"	*12.5*	441.0	511.0	70.0	2.39	7.44	92.56
3/4"	*9.5*	441.0	505.0	64.0	2.18	9.62	90.38
No.4	*4.75*	451	522.0	71.0	2.42	12.05	87.95
No 8	*2.36*	389	466.0	77.0	2.63	14.68	85.32
No 10	2	390	466.0	76.0	2.59	17.27	82.73
No 16	1.18	356	497.0	141.0	4.81	22.08	77.92
No 30	0.6	325	521.0	196.0	6.69	28.77	71.23
No 40	0.425	305	504.0	199.0	6.79	35.56	64.44
No 50	0.3	291	470.0	179.0	6.11	41.67	58.33
No 100	0.15	270	585.0	315.0	10.75	52.42	47.58
No 200	0.075	258	678.0	420.0	14.33	66.76	33.24
Pan	-	256	1228.0	972	33.17	99.93	0.00

Table E. 8: Hydrometer analysis results for untreated clayey sand from Civil Service College

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Percentage finer combined
0.5	1.0295	-0.0027	1.0268	8.50	0.01315	0.0542	83.88	27.83
1	1.0280	-0.0027	1.0253	8.89	0.01315	0.0392	79.19	26.27
2	1.0265	-0.0027	1.0238	9.29	0.01315	0.0283	74.49	24.71
4	1.0250	-0.0027	1.0223	9.69	0.01315	0.0205	69.80	23.15
8	1.0240	-0.0027	1.0213	9.95	0.01315	0.0147	66.67	22.12
15	1.0220	-0.0027	1.0193	10.48	0.01315	0.0110	60.41	20.04
30	1.0200	-0.0027	1.0173	11.01	0.01315	0.0080	54.15	17.96
60	1.0190	-0.0027	1.0163	11.27	0.01315	0.0057	51.02	16.92
120	1.0170	-0.0027	1.0143	11.80	0.01315	0.0041	44.76	14.85
240	1.0160	-0.0027	1.0133	12.07	0.01315	0.0029	41.63	13.81
480	1.0140	-0.0027	1.0113	12.60	0.01315	0.0021	35.37	11.73
1440	1.0135	-0.0027	1.0108	12.73	0.01315	0.0012	33.80	11.21

Annex F. Swelling properties

Table F. 1 Swelling pressure for untreated light grey clay soil samples

Specimen number	LGC-0-01	LGC-0-02	LGC-0-03	Seating load
Initial dial reading	6.00	8.00	5.00	7 kPa
Final dial reading	7.53	9.51	6.47	
Swell, %	7.65	7.55	7.35	
Average swell, %	7.52			
LGC-0-01				
Items	Load increment			
	First increment	Second increment	Third increment	Fourth increment
Applied load, kg	1.00	1.00	2.00	2.00
Total applied load, kg	1.00	2.00	4.00	6.00
Dial reading at the end	7.05	6.81	6.43	5.98
Initial dial reading	7.53	7.53	7.53	7.53
Expansion reduction	0.48	0.72	1.10	1.55
Percent remaining expansion	68.63	52.94	28.10	-1.31
Applied pressure kPa	50	100	200	300
Swelling pressure kPa	282			
LGC-0-02				
Items	Load increment			
	First increment	Second increment	Third increment	Fourth increment
Applied load, kg	1.00	1.00	2.00	2.00
Total applied load, kg	1.00	2.00	4.00	6.00
Dial reading at the end	9.05	8.86	8.32	7.99
Initial dial reading	9.51	9.51	9.51	9.51
Remaining expansion	0.46	0.65	1.19	1.52
Percent remaining expansion	69.54	56.95	21.19	-0.66
Applied pressure kPa	50	100	200	300
Swelling pressure kPa	291			
LGC-0-03				
Items	Load increment			
	First increment	Second increment	Third increment	Fourth increment
Applied load, kg	1.00	1.00	2.00	2.00
Total applied load, kg	1.00	2.00	4.00	6.00
Dial reading at the end	5.98	5.78	5.25	4.98
Initial dial reading	6.47	6.47	6.47	6.47
Remaining expansion	0.49	0.69	1.22	1.49
Percent remaining expansion	66.67	53.06	17.01	-1.36
Applied pressure kPa	50	100	200	300
Swelling pressure kPa	297			

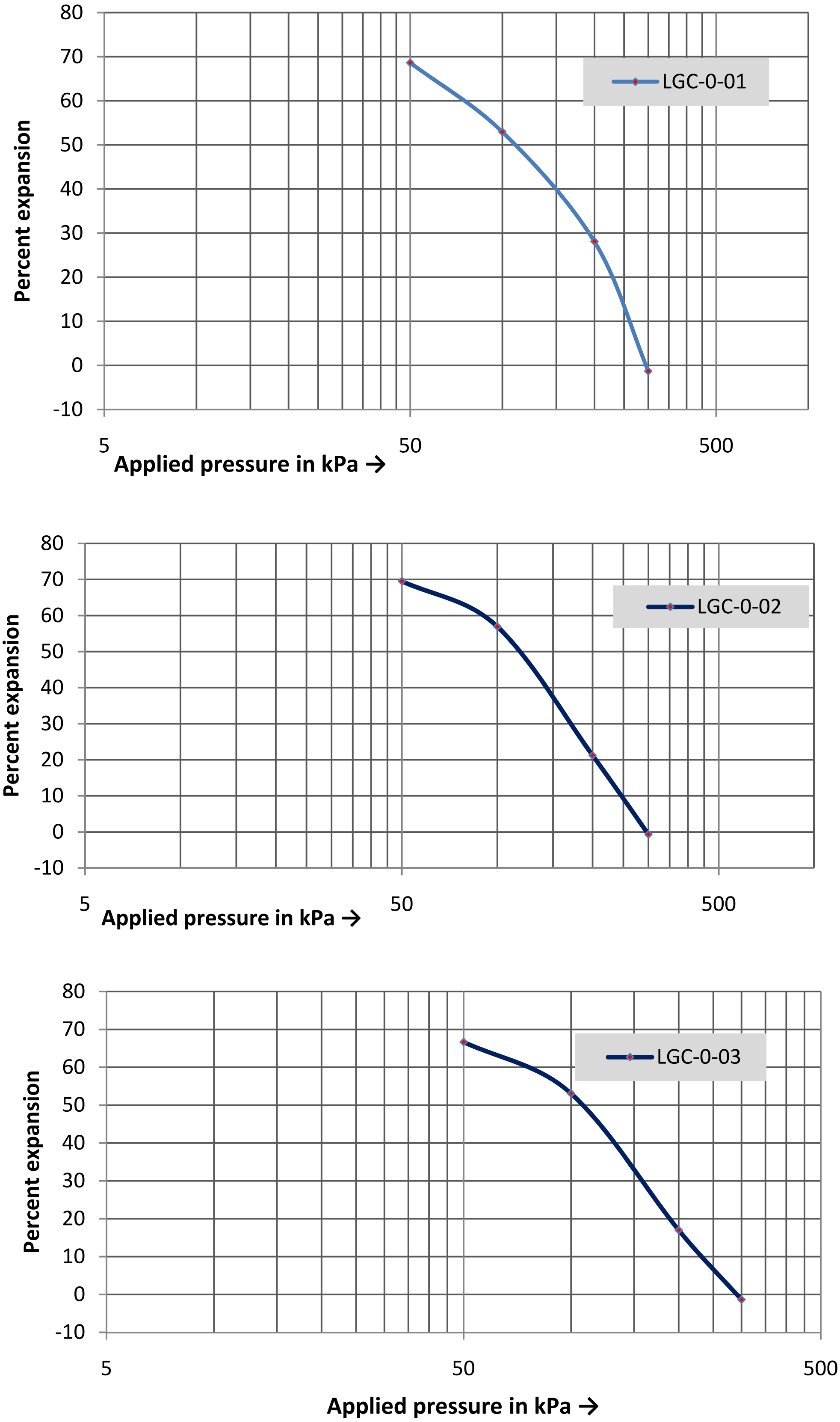


Figure F. 1: Swelling pressure versus percent expansion curves for untreated light grey clay soil

Table F.2: Swelling pressure of light grey clay soil samples treated with 6% ANSS

Specimen number	LGC-6ANSS-71	LGC-6ANSS-72	LGC-6ANSS-73
Initial dial reading	8.00	4.00	9.00
Final dial reading	8.61	4.72	9.58
Swell, %	3.05	3.60	2.90
Average swell, %	3.18		
LGC-6ANSS-71			
Items	Load increment		
	First increment	Second increment	Third increment
Applied load, kg	1.00	1.00	0.50
Total applied load, kg	1.00	2.00	2.50
Dial reading at the end	8.38	8.15	7.98
Initial dial reading	8.61	8.61	8.61
Expansion reduction	0.23	0.46	0.63
Percent remaining expansion	62.30	24.59	-3.28
Applied pressure kPa	50	100	125
Swelling pressure kPa	121		
LGC-6ANSS-72			
Items	Load increment		
	First increment	Second increment	Third increment
Applied load, kg	1.00	1.00	0.75
Total applied load, kg	1.00	2.00	2.75
Dial reading at the end	4.47	4.28	3.99
Initial dial reading	4.72	4.72	4.72
Remaining expansion	0.25	0.44	0.73
Percent remaining expansion	65.28	38.89	-1.39
Applied pressure kPa	50	100	137.5
Swelling pressure kPa	132		
LGC-6ANSS-73			
Items	Load increment		
	First increment	Second increment	Third increment
Applied load, kg	0.75	1.00	0.50
Total applied load, kg	0.75	1.75	2.25
Dial reading at the end	9.44	9.18	8.99
Initial dial reading	9.58	9.58	9.58
Remaining expansion	0.14	0.40	0.59
Percent remaining expansion	75.86	31.03	-1.72
Applied pressure kPa	37.5	87.5	112.5
Swelling pressure kPa	109		

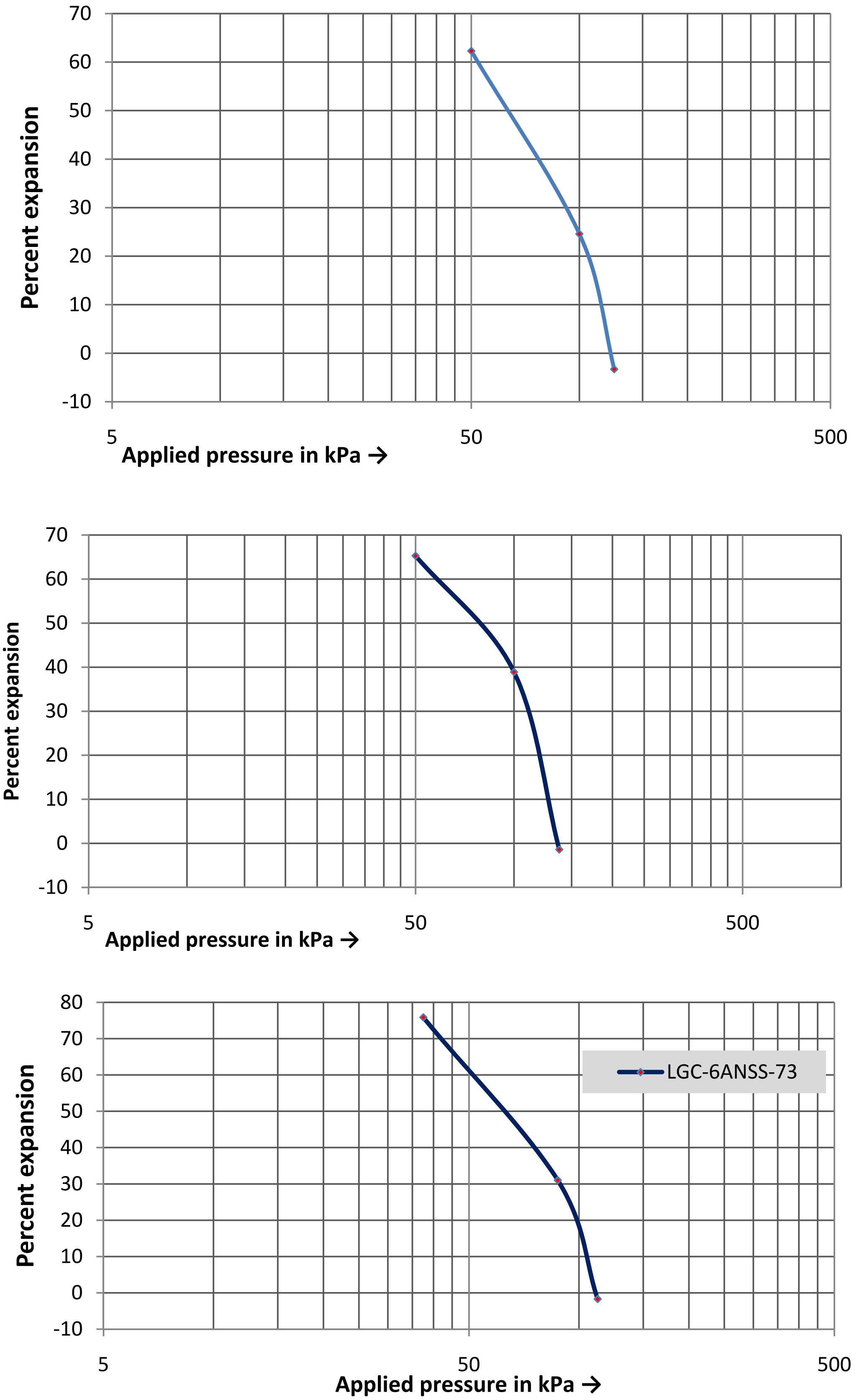


Figure F. 2: Swelling pressure versus percent expansion curves of light grey clay soil samples treated with 6% ANSS