JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGH WAY ENGINEERING STREAM

Performance Improvement of Weak Sub-Grade Soil by Nylon Synthetic Fiber

A final thesis submitted to the school of graduate studies of Jimma University in partial fulfillment of the requirements for the degree of Master of Science in civil engineering (Highway Engineering)

By: Tarekegn Shumetie

June 1, 2021

Jimma, Ethiopia

JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGH WAY ENGINEERING STREAM

Performance Improvement of Weak Sub-Grade Soil by Nylon Synthetic Fiber

By: Tarekegn Shumetie

Main - Advisor: Prof. Dr. Ing. Esayas Alemayehu

Co -Advisor: Ing. Markos Tsegaye

June 1, 2021

Jimma, Ethiopia

JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGH WAY ENGINEERING STREAM

Performance Improvement of Weak Sub-Grade Soil by Synthetic Fiber

By: Tarekegn Shumetie

APPROVED BY BOARD OF EXAMINERS

1. ______________________________ _____________ ____/_____/____
   External Examiner Signature Date
2. ______________________________ ____________ ____/_____/____
   Internal Examiner Signature Date
3. ______________________________ ___________ ____/_____/____
   Chairman of Examiner Signature Date
4. Prof. Dr. Ing. Esayas Alemayehu ____________ ____/_____/____
   Main Advisor Signature Date
5. Ing. Markos Tsegaye (PhD Candidate) _____________ ____/_____/____
   Co-Advisor Signature Date

DECLARATION

I hereby declare that this thesis is entitled “Performance Improvement of Weak Sub-Grade Soil by Synthetic Fiber”. It is my original work and not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for these have been duly acknowledging.

Tarekegn Shumetie ____________ ____/____/______

Researcher Signature Date

As Master research Advisors, we hereby certify that we have read and evaluated this MSc research prepared under our guidance, by **Tarekegn Shumetie** entitled: “Performance Improvement of Weak Sub-Grade Soil by Synthetic Fiber”. We recommend that it can be submitted as fulfilling the MSc Thesis requirements.

Prof. Dr. Ing. Esayas Alemayehu ____________ ____/____/______

Main Advisor Signature Date

Ing. Markos Tsegaye (PhD Candidate) ____________ ____/____/______

Co-Advisor Signature Date

ACKNOWLEDGEMENT

Doing and coming up with this research will have been extremely difficult. I am most grateful for the grace and all courage given to me by God. This research will not have been successful without the support of many peoples next to God. I would like to record my sincere appreciation to my advisors Prof. Dr. Ing. Esayas Alemayehu and Ing. Markos Tsegaye (PhD Candidate) for their friendly advice, motivations, and their supports providing every necessary document for the completion of this research.

It gives me great pleasure to express my thanks to my family. They provide me everything so that I am much free to execute my work very comfortably.

Finally, I would like to express my gratitude to Jimma University's department of civil engineering (Highway Engineering stream chair) for allowing me to do all laboratory works and helping me to come up with this research to the end.

ABSTRACT

Improvement in subgrade has always been an area of concern to the highway and geotechnical engineers. In the case of a highway, a weak subgrade results in a greater thickness of pavement layer, which increases the cost of pavement construction. The important factor for the design and construction of pavement is the behavior of the underlying sub-grade. Large deformations in the sub-grade will lead to a continuous deterioration of the paved surface. As the subgrade soil is too weak to bear the load, engineering solutions such as replacement, chemical stabilizations, geo-reinforcement using geosynthetics which are earlier used in sub-grade improvement, and such experimental study is carried by previous authors. In this study, nylon synthetic fiber (NSF) was used to improve the weak sub-grade. Synthetic fibers mixed randomly with subgrade soil have a significant impact on the improvement of subgrade characteristics over the last decade. Keeping this in view an experimental study was conducted on locally available weak sub-grade soils by reinforcing with nylon synthetic fiber (NSF).

The soil samples were prepared with and without fiber reinforcement. The percentages of fibers by dry weight of soil were 0.5%, 1%, 1.5%, and 2.5% and the aspect ratio (fiber length of 10 mm and 20 mm, and the diameters were 0.3 mm and 0.4 mm). Field density, unconfined compression strength, natural moisture content, particle size distribution, Atterberg's limit, specific gravity, Proctor test, and soaked California bearing ratio (CBR) tests were performed on natural soil whereas Proctor test and soaked California bearing ratio (CBR) tests were performed on nylon synthetic fiber (NSF) reinforced with weak subgrade soil to investigate its suitability as subgrade material. Soil samples for California bearing ratio (CBR) tests were prepared at its maximum dry density corresponding to its optimum moisture content in the CBR mold without and with nylon synthetic fiber (NSF).

The effects of nylon synthetic fiber (NSF) on CBR and swells of the soil investigated, by varying its contents and aspect ratios (diameter and lengths) of the fiber. Results showed that there was a decrease in the value of swell with an increase in fiber content. From CBR test results, the CBR value of soil increases with the increase in nylon synthetic fiber (NSF) content and aspect ratio. It was also observed that increasing the diameter of NSF further increases the CBR value of reinforced soil, and this increase is substantial at a fiber content of 1.5% for an aspect ratio of 50 (length = 20 mm, diameter = 0.4 mm). The maximum enhancement in values of CBR is 4.42 times of the natural soil with 1.5% fiber reinforcement of 20 mm length and 0.4 mm diameter, under soaked conditions. Swelling of the soil decreases as increasing the percentage of fibers in the soil. It also observed that the optimum moisture content almost remains constant with the increase in nylon synthetic fiber (NSF) content and the maximum dry density increases with the increase in NSF content.

Keywords: *- Weak Soil, Nylon synthetic fiber, Aspect ratio, CBR, Subgrade improvement*

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURE

ACRONYMS

AR – Aspect Ratio

AASHTO – American Association of State Highway and Transportation Officials

ASTM – American Society for Testing and Materials

CBR – California Bearing Ratio

CC – Cubic Centimeter

DDBS – Dry Density before Soak

ERA – Ethiopian Road Authority

g/cc – Gram per Cubic centimeter

Max – Maximum

MCBS – Moisture Content before Soak

MDD – Maximum Dry Density

NSF – Nylon Synthetic Fiber

OMC – Optimum Moisture Content

Rdg. – Reading

CHAPTER ONE
INTRODUCTION

1.1 Background

Soil improvement is of major concern in construction activities due to the rapid growth of urbanization and industrialization. The term soil improvement is used for the techniques, which improve the index properties and another engineering characteristic of weak and soft soils. The main method of stabilization includes mixing the soil with the soil of higher strength or binding materials like limestone/cement/calcium or reinforcing with suitable element /fiber. Soil reinforcement improves soil strength, bearing capacity, ductility and inhibits deformations. Soil can be reinforced by the inclusion of high-strength metal strips/wire and relatively low modulus natural and/or synthetic fibers. During the last few decades, much works have been done to improve the engineering properties of soil and it has been established that the addition of fiber is an efficient way to enhance the overall engineering performance of soil. Fiber-reinforced soil is effective in all types of soils (i.e. sand, silt, and clay)[1]. The total coverage of expansive soils in Ethiopia is estimated to be 24.7 million acres [2]. The soil has a high plastic index and a small value of CBR.

Many studies have conducted relating to the behavior of soil reinforced with different types of fiber. A series of direct shear tests on dry sand reinforced with different synthetic, natural and metallic fiber to investigate the effects of parameters carried out such as fiber orientation, fiber content, fiber area ratios, and fiber stiffness on contribution to shear strength. Based on the test results, an increase in shear strength is directly proportional to the fiber area ratios and shear strength envelopes for fiber-reinforced sand clearly show the existence of a threshold confining stress below which the fiber tries to slip or pull out[3]. The application of Jute fiber in the improvement of subgrade characteristics, Jute fiber reinforcement reduces the maximum dry density and increases the optimum moisture content of the subgrade soil [4], [5]. Jute sheets used to improve the CBR value of fly ash and the experimental results the stress-strain behavior of soil that improved by the inclusion of coir-fiber into the soil and Jute sheets improved the California Bearing Ratio (CBR) value of fly ash significantly. They further concluded that the deviator stress at failure was increased up to 3.5 times over the plain soil[6].

The purpose of this research is to stabilize the weak sub-grade soil reinforcing with NSF of different aspect ratios and dosages so that it can improve the engineering properties of soil.

1.2 Statement of the Problem

Improving weak sub-grade soil is not an easy task, especially to achieve the desired strength of Subgrade. Many scholars and researchers are conducting to find out suitable materials to improve subgrade soil to get the acceptable strength of subgrade.

Expansive soils are present in their natural state at the construction site, which does not have suitable strength. It may have swell and shrinkage distinctiveness and causes significant damage to pavement structures. This damage could be attributed to moisture fluctuations caused by seasonal discrepancies. Volumetric changes weaken the subgrade by inducing cracks that damage the overlying structures. For imparting a high amount of strength and stability soil thus needs to be stabilized [7].

Problems associated with these construction materials have been reported in Africa, Australia, Europe, India, and South America, the United States as well as some regions in Canada. In the United States alone, expansive clay soils have been estimated to produce at least two billion dollars of damage annually[8].

The above problems are extensively occurring in Ethiopia. The aerial coverage of expansive soils in Ethiopia is estimated to be 24.7 million acres[2]. As a result, Pavement failure in Ethiopia is becoming a common problem and great challenge, consuming a lot of budgets[9]. Expansive clay soil is available in different parts of Ethiopia. However, the utilization of such soil in the construction of the road is limited due to their substandard qualities. Especially in urban areas, borrow earthen soil is not easily available which has to be hauled from long distance. To utilize such expansive soils conventional stabilizing agents commonly used in expensive soil and replacement of the inferior subgrade soils by borrow materials are expensive. These soils are a consequence of expansive and unstable subgrade soil. As a result, they make pavement structure failure.   Hence, the aim of this study is to reinforce weak subgrade soils with NSF to improve the engineering properties of substandard soils used as sub-grade materials.

1.3 Research Questions

The main research questions answered by the research include the following

1. How can NSF affect the performance of weak subgrade soil that could be implemented in the Road Construction project?
2. Which critical fiber aspect ratios improve the performance of weak subgrade?
3. What are the remedial measures to improve the existing weak subgrade soil?

1.4 Objectives

1.4.1 General Objective

The general objective of the study is to assess the stabilization of weak subgrade soil using NSF to improve the engineering properties of soil.

1.4.2 Specific Objectives

1. To assess NS fiber on the performance improvement of weak subgrade soil that could be implemented in road construction projects.
2. To determine the critical fiber aspect ratios on engineering properties of weak sub-grade.
3. To recommend the remedial measure to improve the performance of weak subgrade soil.

1.5 Scopes of the Study

In this research, the soil samples were prepared with and without fiber reinforcements. The percentage of fibers used by dry weight of soil was 0%, 0.5%, 1%, 1.5%, and 2.5%, and the aspect ratio (fiber length of 10 mm & 20 mm, and the diameter of the fiber was 0.3 mm & 0.4 mm which was considered for each fiber length).

The type of subgrade material used in the investigation was weak subgrade soil collected from locality Jimma Town, Merkato, near Woma Hotel. The result of this research will help for the improvement of subgrade soil in Ethiopia to understand how to implement the concept of improving weak sub-grade soils using NSF effectively.

1.6 Research Gap

The rationale for conducting this study was providing the benchmarks under which the strength of subgrade soil is improved. Facts show that; in Ethiopia, there is a limitation in reinforcing subgrade soils using natural and synthetic fibers. To mitigate the problem of weak subgrade soil contractors and owners are facing problems to improve subgrade soils. However, it may be a chance to solve these problems, but it needs different investigation and experimental analysis. A literature review, as well as a gap, provides opportunities that allow further research to be done on a specific topic of study. Literature gaps develop research that evolves into the foundations of further research.

1.7 Significant of the Study

The significance of the research was to use NSF as a stabilizer by reinforcing weak sub-grade soil. It also uses an alternative stabilizer, which is environmentally friendly during construction as compared to chemical stabilization. Conclusions draw out which dry weight percentages and aspect ratio of NSF more effective for the improvement of weak subgrade soil. This shall provide an opportunity to overcome or mitigate the problems of weak Subgrade soil on road construction in Ethiopia.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Sub-grade Soil

The word 'soil' has different meanings for different professions. To the agriculturist, soil is the top thin layer of earth within which organic forces are predominant and which is responsible for the support of plant life. To the geologist, soil is the material in the top thin zone within which roots occur. From the point of view of an engineer, soil includes all earth materials, organic and inorganic, occurring in the zone overlying the rock crust [10].

The safety of any geotechnical structure is dependent on the strength of the soil. If the soil fails, a structure founded on it can collapse, endangering lives and causing economic damages.

The performance of a road significantly affected by the characteristics of the subgrade soils. Desirable properties of the sub-grade soil include strength, stiffness, drainage, ease of compaction and low compressibility. These properties can have a significant influence on road performance and long-term maintenance. The sub-grade must be strong enough to resist shear failure and have adequate stiffness to minimize vertical deflection. It should also form a suitable platform to achieve the required compaction of the pavement layers above sub-grade level. Stronger and stiffer materials provide a more effective foundation for the riding surface and will be more resistant to stresses from repeated loadings and environmental conditions[11].

Sub-grade: is the surface upon which the pavement structure and shoulders are constructed. It is the top portion of the natural soil, either undisturbed (but re-compacted) local material in cut sections, or soils excavated in cut or borrow areas and placed as compacted embankment. The strength of the road subgrade for flexible pavements commonly assessed in terms of the California Bearing Ratio (CBR) and this is dependent on the type of soil, its density, and its moisture content. All other factors are control by means of specifications i.e. by setting minimum acceptable values for the key properties. However, even when the variability of subgrade strength and pavement material properties is taking into account, there often remains a considerable variation in performance between nominally identical pavements. Optimum design therefore remains partly dependent on knowledge of the performance of in-service roads and quantification of the variability of the observed performance itself. Thus there is always scope for improving designs based on local experience[12].

2.1.1 Design CBR and Design Subgrade Strength Class

Class	**CBR Range (%)** [12]
S1	< 3
S2	3, 4
S3	5, 6, 7
S4	8 - 14
S5	15 - 30
S6	> 30

2.1.2 Subgrade Conditions

Subgrade is the surface upon which the pavement structure and shoulders are constructed. Fundamental to any road construction is the preparation of the sub-grade to meet the pavement design requirements. Normally, the pavement engineer prepares a design based on the information obtained from the exploration programs for design. However, characterizing the sub-grade completely in the design phase is often difficult, and unexpected field conditions could appear later during construction. Additional investigations of the sub-grade conditions are, therefore, necessary to determine whether or not soil conditions encountered in construction correspond to those visualized in the original design; and to ensure that the pavement design is carried through in the construction phase[11].

Generally, sub-grade performance depends on three basic characteristics; strength, moisture content and swelling, all of which can be checked by trial pits and trenches. In some circumstances, such as soft deposits and deep sub-grade cuts, borings shall also consider. The plan for sub-grade investigation at the time of construction should relate to the plan of exploration employed earlier during site characterization. Hence, the previous locations of pits and borings, the different logs and field memos, and the site investigation report for design thoroughly revised. The location of pits, trenches and borings should be such that the information obtained will assist in filling any gap that exists. The locations and sampling frequencies should also be at such intervals to allow the identification of all soil types, the level of the water table and the depth to the bed-rock [11].

2.2 Soil Classification System

Soil classification is the arrangement of soil in to groups which have similar behavior[13]. The main objective of any soil classification system is predicting the engineering properties and behavior of a soil based on a few simple laboratory or field tests. Based on the laboratory or field test results, identify the soil and categorized into groups with similar engineering characteristics. Although there are many classification systems like particle size, textural, AASHTO and USCS classification, the last two classification systems are more common.

2.2.1 AASHTO Classification System

American Association of State Highway and Transportation Officials (AASHTO) classification system is useful for Highways. According to AASHTO, the Particle size analysis and plasticity characteristics are required to classify soil for both coarse-grained and fine-grained soil. In this system, the soils are divided in to 7 types, designed as A-1 to A-7[13].

Table 2.1: AASHTO Soil Classification System[13]

General Classification	Granular material 35% or less passing No. 200 (0.075mm)							Silt-Clay Materials More than 35% passing No. 200(0.075mm)			
Group Classification	A-1		A-3	A-2					A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7	A-4			A-7-5 A-7-6
(a)Sieve Analysis: % passing											
(i)2.00 mm	50 max										
(ii)0.425mm	30 max	50 max	51 min								
(iii)0.075 mm	15 max	25 max	10max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min

(b) Characteristics of fraction passing 0.425mm										
(i) LL			40max	41min	40max	41 min	40 max	41 min	40 max	41 min
(ii) PI	6 max	N.P.	10 max	10 max	11min	11 min	10 max	10 max	11 min	11 min*
Usual types of significant constituent materials	Stone fragments gravel and sand	Fine sand	Silty or clayey gravel sand				Silty soil		Clayey soil	
General rating as subgrade	Excellent to good						Fair to poor			

*If PI < LL-30 the soil is A-7-5 (i.e. PL>30%

If PI > LL-30 the soil is A-7-6 (i.e. PL<30%

2.2.2 USCS Classification System

Unified soil classification system (USCS) first developed by Casagrande in 1948 and modified by Bureau of Reclamation and crop engineers of USA. The system has also adopted by American Society of Testing Materials (ASTM). The system is the most popular for use in all types of engineering problems involving soil. The various symbols used are given in Table 2.2.[13]

Table 2.2 Symbols used in USCS[13]

	Symbols	Descriptions
Primary	G	Gravel
	S	Sand
	M	Silt
	C	Clay
	O	Organic
	Pt	Peat
Secondary	W	Well-graded
	P	Poorly Graded
	M	Non-Plastic fines
	C	Plastic fines
	L	Low Plasticity
	H	High plasticity

The system uses both the particle size analysis and plasticity characteristics of soil, like AASHTO system. In this system, the soils classified in to 15 groups (Table 2.3). The soils are first classified into two categories.[13]

1. **Coarse –grained soils** – the coarse-grained soils are designated as gravel (G) if 50% or more of coarse fraction (plus 0.075 mm) is retained on No. 4(4.75 mm) sieve; otherwise it is termed sand (S).
2. **Fine-grained soils**- Fine-grained soils further divided into two types: (1) soils of low compressibility (L) if the liquid limit is 50% or less and given the symbols ML, CL, and OL. (2) Soils of high compressibility (H) if the liquid limit is more than 50% and given the symbols MH, CH, and OH.

Table 2.3 Unified soil Classification System [13]

Major group	Sub-group	Symbol	Description
Coarse-grained soil (>50% retained #200 sieve)	**Gravels** (>50% coarse fraction retained on #4 sieve)	GW	Well-graded gravels and gravel-sand mixtures (little or no fines)
		GP	Poorly-graded gravels and gravel-sand mixtures (little or no fines)
		GM	Silty gravels (gravel-sand-silt mixtures)
		GC	clayey gravels (gravel-sand-clay mixtures)
	Sands (>=50% coarse fraction pass through #4 sieve	SW	Well-graded sands and gravelly-sands mixtures (little or no fines)
		SP	Poorly-graded sands and gravelly-sands mixtures (little or no fines)
		SM	Silty sands (sand-silt mixtures)
		SC	clayey sands (sand-clay mixtures)
Fine-grained soil (>=50% pass through #200 sieve	**Silts and Clays** (with Liquid Limit <50%)	ML	Inorganic silt (very fine sands, silty or clayey sands
		CL	Inorganic clays of low-to medium plasticity
		OL	organic silts and silty-clay of low plasticity
	Silts and Clays (with Liquid Limit >=50%)	MH	Inorganic silts, elastic silts
		CH	Inorganic clay of high plasticity
		OH	Organic clay of medium-to high plasticity
		PT	Peat muck and other organic soil

2.3 Expansive Soil

Expansive soil is a soil that has the possibility for swelling and shrinking due to fluctuating moisture condition. Expansive soils reasons for more damage to constructions particularly pavements and light buildings than any other natural hazard, including earthquakes and floods. It has been reported that the damage caused by these soils contribute significantly to the burden that the natural hazard poses on the economy of countries where the occurrence of these soils is significant [14]. Ethiopia is one the list of countries where the occurrence and spatial distribution known as significant. Expansive soils could be found everyplace in the world but they restricted to semi– arid and arid regions. These areas obviously characterized by marked dry and wet seasons with low rainfall, poor drainage and exceedingly great heat. The climate condition is such that the annual evapo-transpiration exceeds the precipitations [15].

The two groups of parent materials have been associated with for cause as formation of expansive soils. The first group encompasses sedimentary rocks of volcanic origin which can be found in North America, South Africa and Israel, while the second groups of parent materials are basic igneous rocks found in India and Southwestern USA [14]. The most known example for expansive soils is black cotton soil, which is dark grey to black in color and the name originated from India where locations of these soils are also favorable for growing cotton.

2.3.1 Origin of Expansive Soil

The source of expansive soils are related to a combination of conditions and processes that result in the formation of clay minerals having a particular chemical makeup, which when in contact with water, expands. Differences in the conditions and processes could also for mother clay minerals, most of which are non-expansive. The conditions or processes, which determine the clay mineralogy, include the composition of the parent material and degree of physical and chemical weathering to which the materials subjected.

2.3.2 Distribution of Expansive Soil

Expansive soils are widespread in the African continent, occurring in South Africa, Ethiopia, Kenya, Mozambique, Morocco, Ghana, Nigeria, etc. In other parts of the world case of expansive soils has been widely reported in countries like USA, Australia, Canada, India, Spain, Israel, Turkey, Argentina and Venezuela[16] . The aerial coverage of expansive soils in Ethiopia is estimated to be 23.7 million acres [2].

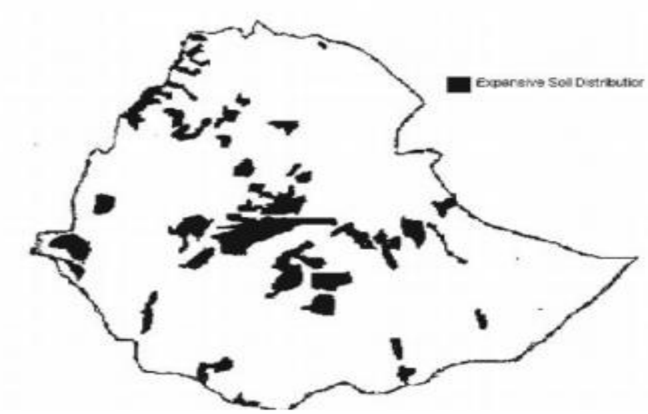


Figure 2.1 Distribution of expansive soil in Ethiopia[16]

They are widely spread in central part of Ethiopia following the major truck roads like Addis-Ambo, Addis-Wolliso, Addis– Debrebirhan, Addis-Gohatsion, and Addis-Modjo roads covered in expansive soils. Also, areas like Mekele, Gambella and south west Ethiopia are covered by expansive soil [16].

2.3.3 Identification and Classification of Expansive Soil

Investigation of expansive soils normally consists of two important stages. The first is the recognition and identification of the soil as expansive and the second is sampling and measurement of material properties used as the basis for design. The theme of this topic is to discuss tests and classification procedures that commonly used to identify expansion potential.

2.3.3.1 Filed Identification

Soils that can show high swelling potential identified by field observations, mainly during reconnaissance and preliminary investigation stages. Important observations include[14].

- ✓ Usually have a color of black or gray.
- ✓ Wide or deep shrinkage cracks.
- ✓ High dry strength and low wet strength.
- ✓ Stickiness and low traffic ability when wet.
- ✓ Cut surfaces have a shiny appearance.
- ✓ Appearance of cracks in nearby structures.

Arid and semiarid areas are specifically trouble spots because of large variations in rainfall and temperature.

2.3.3.2 Laboratory Identification

Generally, there are three different methods of identifying expansive soil in the laboratory

Mineralogical Identification

This method used for identifying the mineralogy of clay particles such as characteristic crystal dimensions, characteristic reaction to heat treatment, size and shape of clay particles and charge deficiency and surface activity of clay particle. These properties are a fundamental factor controlling expansive soil behavior[14].

The various techniques under these methods are

- ✓ X-ray diffraction
- ✓ Differential thermal analysis
- ✓ Dye adsorption
- ✓ Chemical analysis
- ✓ Electron microscope resolution

Using combinations of these methods, the different types of clay minerals present can evaluated quantitatively. However, these methods are not suitable for routine tests because of the following reason; they are time consuming, require expensive test equipment and, the results are interpreted by specially trained technicians.

1. **Direct Methods**

The swelling pressure and volume changes of soils are measured directly using representative undisturbed samples. The swelling pressure is determined by measuring the pressure needed to prevent heaving of sample under the given condition of moisture, density and confinement. Swelling tests provide complete swelling but due to varying initial conditions of moisture, density, etc. it is difficult to assess the swelling expected in the field. The methods provide quantitative information, which are very useful for engineers to design.

2. Indirect Methods

In this method, the simple soil property tests can be used to evaluation of swelling potential of expansive soils. Such tests are easy to do and should be included as routine tests in the investigation of expansive soils. Such tests may include[14].

A. Density Determination [17] [18]

This lab performed to determine the in-place density of undisturbed soil obtained by pushing or drilling a thin-walled cylinder. The bulk density is the ratio of mass of moist soil to the volume of the soil sample, and the dry density is the ratio of the mass of the dry soil to the volume the soil sample.

This test used to determine the in-place density of soils. This test can also use to determine density of compacted soils used in the construction of structural fills, highway embankments, or earth dams. This method not recommended for organic or friable soils.

B. Atterberg Limits [19]

In this method, the measurements of the Atterberg limits of the soil are perform for identification of entirely soils and provide a wide acceptable means of rating. Particularly when they combined with other tests, they can used to classify expansive soils. The relationship between the swelling potential of clays and the plasticity index are show below in Table 2.4.

Table 2.4: Relationship between the swelling potential of clays and the plasticity index

Swell potential	Plasticity Index	Liquid Limit
Low	0-15	<29
Medium	10-35	29-40
High	19-55	40-60
Very High	55 and above	>60

While it may be true that high swelling soil will manifest high index property, the converse is Not true[2].

C. Unconfined Compression (UC) Test [20]

Purpose: The primary purpose of this test is to determine the unconfined compressive strength, which then used to calculate the unconsolidated un-drained shear strength of the clay under unconfined conditions. According to the ASTM standard, the unconfined compressive strength (q_u) defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. In addition, in this test method, the unconfined compressive strength taken as the maximum load attained per unit area, or the load per unit area at 15% axial strain, whichever occurs first during the performance of test.

Table 2.5 Consistency and Unconfined Compression Strength of Clay [21]

Consistency	**qu (KN/m^2)**	**qu (lb/ft^2)**
Very Soft	0 - 25	0 – 500
Soft	25 - 50	500 – 1000
Medium	50 – 100	1000 – 2000
Stiff	100 – 200	2000 – 4000
Very Stiff	200 – 400	4000 – 8000
Hard	>400	>800

D. Grain Size Analysis[22]

This test performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles.

The distribution of different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution, and it is required in classifying the soil.

E. Moisture-Density Relation (Compaction) Test[23]

Purpose: This laboratory test performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort. The compactive effort is the amount of mechanical energy that applied to the soil mass. Several different methods are used to compact soil in the field, and some examples include tamping, kneading, vibration, and static load compaction. This laboratory will employ the tamping or impact compaction method using the type of equipment and methodology developed by R. R. Proctor in 1933, therefore, the test is also known as the Proctor test.

F. Moisture Content Determination[24]

This test performed to determine the water (moisture) content of soils. The water content is the ratio, expressed as a percentage, of the mass of “pore” or “free” water in a given mass of soil to the mass of the dry soil solids.

For many soils, the water content may be an extremely important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine-grained soil largely depends on its water content. The water content can used in expressing the phase relationships of air, water, and solids in a given volume of soil.

G. California Bearing Ratio (CBR) Test[25]

The California bearing ratio (CBR) is a penetration test for evaluation of the mechanical strength of road sub-grades, sub-base and base courses. The California Department of Transportation before World War II developed it. The test performed by measuring the pressure required to penetrate a soil sample with a plunger of standard area mostly 20 cm^2 to (2.5 and 5 mm) depth.

H. Specific Gravity Test[26]

Specific gravity of solids is the ratio of weight in air of a given volume of soil particles at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature. It is the heaviness of soil particles are determined the pycnometer method using a soil sample passing #10(2mm) sieve as per ASTM D854 standards.

Table 2.6 Specific Gravities of Some Soil[27]

Types of Soil	**G_s**
Quartz Sand	2.64 - 2.66
Silt	2.67 - 2.73
Clay	2.70 - 2.90
Chalk	2.60 - 2.75
Loess	2.65 - 2.73
Peat	1.30 - 1.90
Mine tailings	2.80 - 4.50

2.3.3.3 Sample Size and Selection

This study followed on a purposive sampling selection process. For the purpose of sampling and description, pits dug to at least 50 cm below the expected sub-grade level. In the case of a new alignment, the depth from the natural ground surface should be not less than 2 m unless a rock stratum encountered. In borrow pits, the number of samples determined by the heterogeneity of the subsurface and the characteristics of soils. At least one sample should take per test pit or trench. When there is a major change in material property, the number of samples should increase to include as many layers as possible. The quantity of material in each sample must also be sufficient to carry out different types of tests. Soil samples obtained from surface and subsurface investigations for engineering tests are either disturbed or undisturbed[11].

Disturbed Sample: the structure of the natural soil has disturbed by boring or excavation. **Undisturbed Sample:** the term "undisturbed" means a sample where some precautions have taken to minimize disturbance or remolding effects. For laboratory test, the samples is depends on the types of test requirement and standards. The output of the study is to compare the strength of subgrade soils reinforcing with Synthetic fiber from that of soils without reinforcing through laboratory tests. The sample sizes were determined based on standards and specifications.

Here in this study both samples taken, undisturbed samples for unconfined compressive strength test of the natural soil, while, for other tests the disturbed sample is used.

2.4 Synthetic Fiber

Synthetic fibers: Is fibers made by humans through chemical synthesis, as opposed to natural fibers that directly derived from living organisms. They are the result of extensive research by scientists to improve upon naturally occurring animal and plant fibers. In general, synthetic fibers made of extruding fiber-forming materials through spinnerets, forming a fiber and called synthetic or artificial fibers. A process known as polymerization, which involves combining monomers to make a long chain or polymer, creates synthetic fibers. The word polymer comes from a Greek prefix "poly" which means "many" and suffix "mer" which means "single units". (Note: each single unit of a polymer called a monomer). [28]

2.4.1 Classification of Synthetic Fibers

Following are some of the most commonly used synthetic fibers: Know more about Classifications of fibers:-

1. **Rayon**
    - This is a type of synthetic fiber obtained from wood pulp.

- Rayon fabric is soft, absorbent and comfortable.
- It is easy to dye in a wide range of colors.
- Rayon mixed with cotton to make bed sheets.
- Rayon mixed with wool to make carpets.

2. **Nylon**
    - This type of synthetic fiber obtained from coal, water and air.
    - Nylon is very lustrous, easy to wash and elastic.
    - It dries quickly and retains its shape.
    - Nylon finds its application in seat belts of car, sleeping bags, socks, ropes, etc.
    - Nylon also used in ropes for rock climbing, making parachutes and fishing nets.
3. **Polyester**
    - This type of synthetic fiber obtained from coal, water, air and petroleum.
    - Polyester made from repeating units of a chemical known as esters.
    - Polyester is easy to wash, it remains wrinkle-free, and it is quite suitable in making dress material.
    - Polyester retains its shape and remains crisp.
    - Polyester is use in making ropes, nets, raincoats, jackets, etc.

Synthetic Fibers Examples

The modern textile industry is unthinkable today without synthetic fibers. Synthetic fibers like silk have always been greatly valued for its gloss and fineness. Synthetic fibers are smooth. They can distinguish by looking at a cross-section. Some of the synthetic fibers listed as below.

1. **Rayon**
2. **Nylon**
3. **Polyester**

These fibers find its applications in household articles like ropes, bucket, furniture, etc. [28]

2.4.2 Advantages of Synthetic Fibers [28]

- Synthetic fibers are very durable and do not wrinkle easily
- They are elastic and can be easily stretched out
- They are strong and can sustain the heavy load.
- They are soft and hence use in clothing material.

- They are resistant to water damage.

2.4.3 Nylon Synthetic Fiber (NSF)

Nylon is a fabricated fiber, produced by extrusion method. The final structure of this fiber, which determines its textile properties, is as result of several technological operations during production. These include spinning, drawing, antistatic treatment, embracing, molding, nylon sing and water repellency, and heat treatment. Nylon has excellent resilience and inherent stiffness, which resist bending and cause rapid recovery from bending. This quality contributes to the usual resilience of the fabric. Nylon does not absorb much moisture, this thus encourages development of static electricity, and due to the nature of its little moisture absorbency, contributes to less easy stain and less swelling in water and quick dryness. Nylon fabrics are sold with different trade names by different manufacturers, for example, Celon (courtaulds), Antron (Dupont), Enkalon (British Enkalon)[29]. This type of synthetic fiber obtained from coal, water and air. Nylon is very lustrous, easy to wash and elastic. It dries quickly and retains its shape. Nylon finds its application in reinforcement, seat belts of car, sleeping bags, socks, ropes, etc., it also used in ropes for rock climbing, making parachutes and fishing nets. The typical properties of fibers are presented in table 4.1[30]. The decomposition time for nylon synthetic fiber in land is 30 to 40 years[31].

Table 2.7 Typical properties of fibers [30]

Name of Fiber	Tensile Strength (psi)	Young's Modulus ($x10^3$ psi)	Ultimate Elongation (%)	Specific Gravity
Nylon	110-120	0.6	16.2	1.1
Polypropylene	80-110	0.5	25	0.9
A.glass	150-550	10	1.5 - 3.5	2.5

2.5 Soil Stabilization

Soil stabilization is the process of modification on one or more soil properties, by mechanical or chemical stabilization, to create an improved soil material possessing the desired engineering properties. The process may include blending of soils to achieve a desired gradation or mixing with easily accessible additives that can modify the gradation, texture or plasticity, or act as a binder for cementation of the soil[32].

2.5.1 Uses of Stabilization

Pavement structural design is based on believed that the minimum specified pavement structural quality will be full fill for each layer in the pavement system. In the pavement system all layers should resist shearing, avoid extreme deflections that leads to fatigue cracking within the pavement system, and then protect from extreme permanent deflection.

When the quality of pavement layers is increased, the load distribution systems through each layer over the greater area increase so that the required thickness in the pavement system significantly decreased. Commonly, soil improvement achieved from soil stabilization is quality improvement and thickness reduction.

2.5.2 Mechanisms of Stabilization

The stabilization mechanism could vary generally from the formation of new compounds binding the finer soil particles for coating particle surfaces by the additive to decrease the moisture sensitivity. Then, the basic understanding of stabilization mechanisms involved with each additive is required before selecting an effective stabilizer suited for a specific application.

2.5.3 Types of Soil Stabilization

There are number of methods that can use for soil stabilization; however, thus methods are fall into two broad categories. They are; Mechanical stabilization and Chemical stabilization, but some stabilization procedures use a combination of these two methods.

2.5.3.1 Mechanical Stabilization

Mechanical stabilization defined as a process of altering the constancy and shear strength characteristics of the soil without changing the chemical properties of the soil. The main methods of mechanical stabilization can be categorized into compaction, mixing or blending of two or more gradations, applying geo-reinforcement and mechanical remediation[33]. Reinforcing weak sub grade soils by natural and synthetic fiber are methods under mechanical stabilization.

Applying Jute fiber reinforcement reduces the maximum dry density and increases the optimum moisture content of the subgrade soil for each aspect ratio. The effects of aspect ratio (length/diameter ratio) of jute fiber on CBR value of soil have significant change. Test results indicate that CBR value of soil increases with the increase in length of jute fiber. It was also observed that increasing the diameter of jute fiber further increases the CBR value of reinforced soil[5].

Use of fiber with different waste products such as pond ash, rice husk ash, straw ash and bagasse ash, stone dust along with natural soils has found to enhance the CBR strength of the soils. Based on their laboratory investigations conducted on silt sand and pond ash specimens reinforced with polyester fibers, Kumar et al. [34] concluded that the fibers increased the CBR value and ductility of the specimens, and the optimum fiber content for both silt sand and pond ash was approximately 0.3–0.4% of dry unit weight.

Based on full scale field test section, Tingle et al.[35] Found that the fiber-reinforced sand could be a viable alternative material for temporary or low volume roads. The improvement found to be dependent on fire fraction up to a limiting value of 0.8% by dry weight of soil. Significant improvement in CBR value, angle of internal friction and modulus of subgrade reaction was found, when fly ash was reinforced with polypropylene fiber, and 0.5% fiber content was the optimum for fly ash embankments[36].

Based on experimental investigation on the behavior of glass fiber reinforced cohesive Soil for application as pavement sub-grade material, Suchit et al.[37] founded the optimum glass fire content was found as 0.75% irrespective of compacted moisture content under both un soaked and soaked conditions.

Based on improvement of local subgrade soil for road construction by the use of coconut coir fiber , Sign et al.[1]Concluded that, proportion of 1% coir fiber in a soil is the optimum percentage of materials having maximum soaked CBR values. Hence, this proportion may economically use in road pavement and embankments.

2.5.3.2 Chemical Stabilization

Stabilization by chemical additives is the oldest and most common method of ground improvement. Chemical stabilization refers to mixing of soil with one or a combination of admixtures of powder, slurry or liquid to improve or control its stability, strength, swelling, permeability and durability. Soil improvement by means of chemical stabilization can be grouped into three chemical reactions; Cat ion exchange, flocculation-agglomeration pozzolanic reactions[38].

2.5.3.3 Lime Stabilization

Lime is one of the most popular additives agent used to improve fine-grained soils. Lime, alone or combined with other materials, can be used to treat a variety of soil types. When soils treated with lime the construction activity becomes facilitate in three ways. First, a reduction in the liquid limit and an increase in the plastic limit results in a significant reduction in plasticity index.

2.5.3.4 Cement Stabilization

Cement is one of the oldest stabilizing agents, since the invention of soil stabilization technology in 1860’s. It could be considered as first stabilizing agent or hydraulic binder because it can be used alone to bring about the stabilizing action required[39] . The choice of cement depends on type of soil to be stabilized and required final strength.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Study Area

Jimma is located at about 354 Km in Southwest of Addis Ababa[40]. According to the WGS 84 coordinate reference system which is the latest revision of the World Geodetic System, Jimma is geographically located between 7° 38’52” and 7° 43’ 14” N latitude, and between 36° 48’ 00” and 36° 53’ 24” E longitude. The town is found in an area of the altitude of 1718- 2000 m above sea level. It lies in the climatic zone locally known as Woyna Daga which is considered ideal for agriculture as well as human settlement[40]. The Specific geographical locations of the study area were 7°40’22” N latitude & 36°50’4’’E longitude.

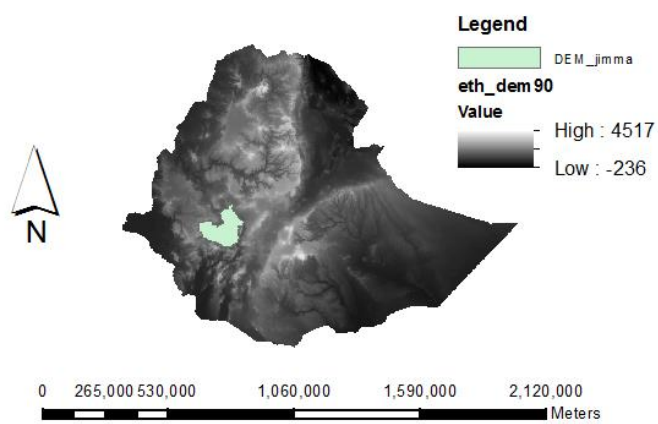


Figure 3.1: Location of Study Area *(Source: Generated from GIS Software)*

3.2 Study Materials and Methods

3.2.1 Weak sub-grade soil

The soil for this study was collected from Jimma town (Merkato near Woma Hotel) specifically 7°40’22” N latitude & 36°50’4’’ E longitude. The disturbed sample was picked along the soil profile at the depth of 2 m to avoid the inclusion of organic matter. Preliminary checks indicated that the soil was grayish-black, highly crack, and plastic in nature as shown in Figure 3.2 below.

Figure 3.2: Photo when samples was taking (Source: The Researcher, 13/10/2020)

3.2.2 Nylon Synthetic Fiber

Fibers used in this study, collected from Tays PLC Synthetic Fiber Company at Addis Ababa, Merkato branch, and then cut the fibers into two different lengths, which were 10 mm and 20 mm. The fiber content used in this study by dry weight percentage was 0.5%, 1%, 1.5%, and 2.5%.

Figure 3.3: Nylon Synthetic Fiber collected from market *(Source: The Researcher, 5/10 /2020)*

Figure 3.4: Nylon Synthetic Fiber after trimmed in to 10 and 20 mm lengths *(Source: The Researcher, 28/11/2020)*

3.3 Study Design

The research design is based on a purposive sampling selection process in terms of which a representative sample of soil materials was surveyed and the research methodology was followed the experimental type which designed to answer the research questions and achieve its objectives based on experimental findings through quantitative, qualitative and comparative analysis approach, the soil samples collected from the site.

After comprehensively, organizing a literature review of different previous published researches, designate the effects of using NSF for the Stabilization of weak subgrade soil. The overall activity and research process in the study include; Problem identification of the study area, Material collection, and preparation of the sample for laboratory test, Trim the fibers, prepare for the test, and Conduct laboratory test for subgrade with different aspect ratios of NSF to select the optimum percent required.

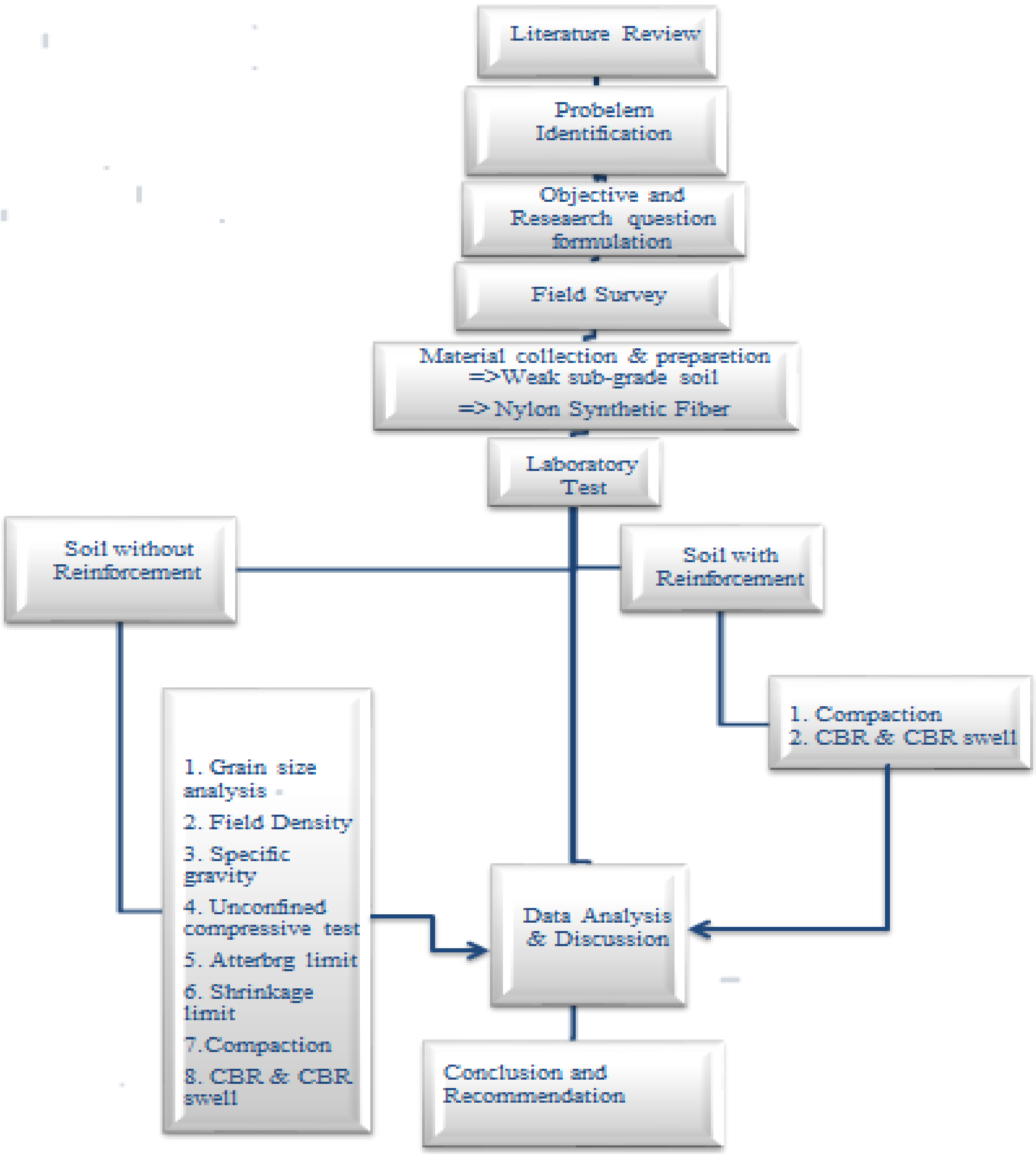


Figure 3.5 Study Design

3.4 Study variables

Two types of variables are taking into consideration: the dependent and independent variables.

1. **Dependent variables**

   Performance Improvement of Weak Sub-Grade Soil by Synthetic Fiber

2. **Independent variables**

- ❖ CBR
- ❖ Aspect ratio
- ❖ Soil Classification
- ❖ Grain size analysis
- ❖ Atterberg's limit
- ❖ Unconfined Compressive Strength
- ❖ Compaction
- ❖ Shrinkage limit
- ❖ Specific Gravity
- ❖ Dosage by dry weight of Synthetic Fiber

3.5 Sample Size and Selection

This study followed a purposive sampling selection process. For sampling and description, pits dug to at least 50 cm below the expected sub-grade level. In the case of a new alignment, the depth from the natural ground surface should be not less than 2 m unless a rock stratum is encountered. In borrow pits, the number of samples determined by the heterogeneity of the subsurface and the characteristics of soils. At least one sample should take per test pit or trench.

In this study, there is no major change in material property. Hence, three (3) representative sample locations were selected for field and laboratory tests from Jimma town, merkato near Woma Hotel.

The quantity of material in each sample must also be sufficient to carry out different types of tests so that about 600 kg (200 kg per each sample location) of disturbed weak subgrade soil brought from the site to Jimma Institute of Technology geotechnical laboratory. For the undisturbed soil sample, the sample taken by using the tubular sampler to minimize the disturbance, after taking the undisturbed sample covered the tip of the tube by plastic material to control the moisture.

Here in this study, both samples are taken, the undisturbed sample is for unconfined compressive strength test and field density test of the natural soil and the disturbed sample was for other tests.

3.6 Sample preparation

Once the required amounts of samples are taken, the next step should be sample preparation. Soil samples were prepared based on the method described in ASTM D 421.

After collecting, the samples from the study area were then air-dried and mixed with stabilizer in their corresponding percentage as shown in table 3.1 below to prepare the sample. The proportion of the mix was by dry weight. The percentage values of NSF were used for the preparation of samples to conduct the entire required laboratory test.

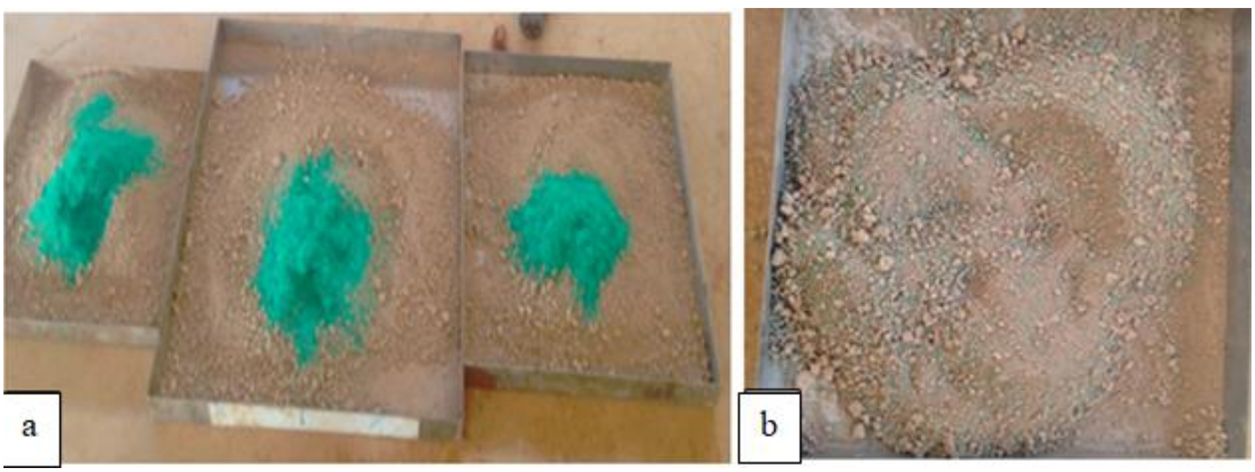


Figure 3.6: Material Preparations; a) Before NSF mix with soil, b) After NSF mix with soil *(Source: The Researcher, 28/11/2020)*

Table 3.1: Percentages of NSF Used in the Study

Diameter of NSF (mm)	Length of NSF (mm)	Aspect Ratio (L/D)	%age of NSF by Dry Weight (%)
0.3	10	33.33	0.5
			1
			1.5
			2.5
	20	66.67	0.5
			1
			1.5
			2.5
0.4	10	25	0.5
			1
			1.5
			2.5
	20	50	0.5
			1
			1.5
			2.5

3.7 Data Collection Process

Both primary and secondary data sources are used. The Primary sources of data for this study were laboratory experimental outputs that done by researcher and Secondary data collected from different standards, journals, book, website, and others.

3.7.1 Field Survey

The Filed Survey was consisting of looking for where weak subgrade soil and Synthetic Fibers are available. The survey helps to get information about the sources of data that the researcher will be performing the laboratory tests.

3.7.2 Experimental investigation/ Laboratory Tests

A. Density Determination

This lab was performed to determine the in-place density of undisturbed soil obtained by pushing or drilling a thin-walled cylinder. The bulk density is the ratio of the mass of moist soil to the volume of the soil sample, and the dry density is the ratio of the mass of the dry soil to the volume of the soil sample.

Standard Reference: ASTM D 2937-00 – Standard Test for Density of Soil in Place by the Drive Cylinder Method

This test is used to determine the in-place density of soils. This test can also use to determine the density of compacted soils used in the construction of structural fills, highway embankments, or earth dams. This method is not recommended for organic or friable soils.

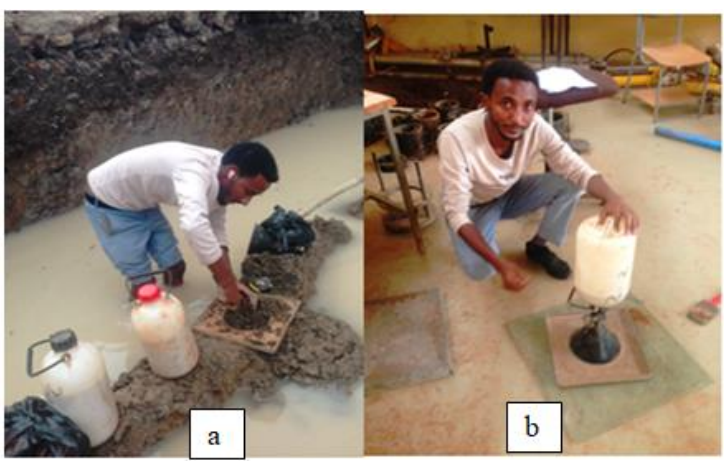


Figure 3.7: Photograph for Field Density Determination a) taking materials at site b) Calibrating the instrument *(Source: Abuye Boja 14/10/2020)*

B. Unconfined Compression Test

The primary purpose of this test is to determine the unconfined compressive strength, which is then used to calculate the unconsolidated undrained shear strength of the clay under unconfined conditions. According to the ASTM standard, the unconfined compressive strength (qu) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. In addition, in this test method, the unconfined compressive strength is taking as the maximum load attained per unit area, or the load per unit area at 15% axial strain, whichever occurs first during the performance of a test.

Standard Reference: ASTM D 2166 Standard Test Method for Unconfined Compressive Strength of Cohesive Soil.

For soils, the undrained shear strength (su) is necessary for the determination of the bearing capacity of foundations, dams, etc. The un-drained shear strength (su) of clays is commonly determined from an unconfined compression test. The un-drained shear strength (su) of cohesive soil is equal to one-half the unconfined compressive strength (qu) when the soil is under the f = 0 condition (f = the angle of internal friction). The most critical condition for the soil usually occurs immediately after construction, which represents un-drained conditions, when the un-drained shear strength is equal to the cohesion (c).

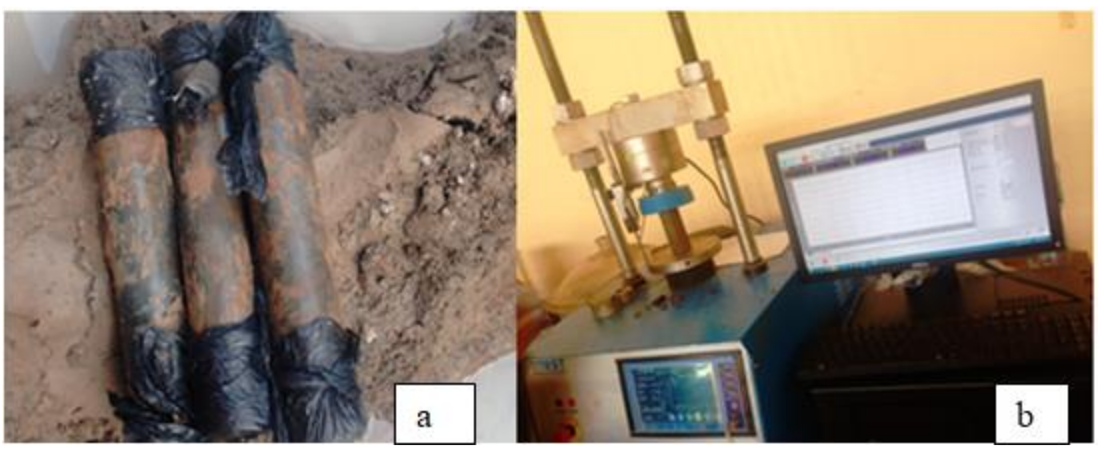


Figure 3.8: Photograph for Unconfined Compression test a) Undisturbed Sample b) Test for undisturbed sample *(Source: The Researcher. 14/10 /2020)*

C. Atterberg limit test

This lab was performed to determine the plastic and liquid limits of fine-grained soil. The liquid limit (LL) is arbitrarily defined as the water content in percent at which a part of the soil in a standard cup, and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2 in.). When subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second. The plastic limit (PL) is the water content, in percent, at which a soil no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without crumbling.

Standard Reference: ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

The Swedish soil scientist Albert Atterberg originally defined seven "limits of consistency" to classify fine-grained soils, but in current engineering practice only two of the limits, the liquid and plastic limits, are commonly used. (A third limit, called the shrinkage limit.) The Atterberg limits are determined based on the moisture content of the soil. The plastic limit is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state. The liquid limit is the moisture content that defines where the soil changes from a plastic to a viscous fluid state. The shrinkage limit is the moisture content that defines where the soil volume will not reduce further if the moisture content is reduced.

Figure 3.9: Photographs taken during LL and PL test *(Source: Abuye B. 22/10/2020)*

D. Grain Size Analysis

This test was performed to determine the percentage of different grain sizes contained within the soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles.

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size Analysis of Soils

The distribution of different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution, and it is required in classifying the soil.

Figure 3.10: Photographs Taken during Wet Sieve Analysis test *(Source: Abuye Boja,24/10/2020)*

E. Moisture-Density (Compaction) Test

This laboratory test was performed to determine the relationship between the moisture content and the dry density of soil for a specified compaction effort. The compaction effort is the amount of mechanical energy that is applied to the soil mass. Several different methods are used to compact the soil in the field, and some examples include tamping, kneading vibration, and static load compaction. This laboratory will employ the tamping or impact compaction method using the type of equipment and methodology developed by R.R. Proctor in 1933, therefore, the test is also known as the Proctor test. Two types of compaction tests are routinely performed: (1) The Standard Proctor Test, and (2) The Modified Proctor Test. Each of these tests can be performed in three different methods as outlined in the attached Table 1. In the Standard Proctor Test, the soil is compacted by a 5.5 lb hammer falling a distance of one foot into a soil-filled mold. The mold filled with three equal layers of soil, and each layer subjected to 25 drops of the hammer. The Modified Proctor Test is identical to the Standard Proctor Test except it employs, a 10 lb hammer falling a distance of 18 inches, and uses five equal layers of soil instead of three. Two types of compaction molds are used for testing. The smaller type is 4 inches in diameter and has a volume of about 1/30 ft3 (944 cm3), and the larger type is 6 inches in diameter and has a volume of about 1/13.333 ft3 (2123 cm3). If the larger mold is used each soil layer must receive 56 blows instead of 25.

Standard Reference: ASTM D 698 - Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbs/ft3 (600 KN-m/m3)). ASTM D 1557 - Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbs/ft3 (2,700 KN-m/m3))

Mechanical compaction is one of the most common and cost-effective means of stabilizing soils. An extremely important task of geotechnical engineers is the performance and analysis of field control tests to assure that compacted fills are meeting the prescribed design specifications. Design specifications usually state the required density (as a percentage of the "maximum" density measured in a standard laboratory test), and the water content. In general, most engineering properties, such as the strength, stiffness, resistance to shrinkage, and imperviousness of the soil, will improve by increasing the soil density. The optimum water content is the water content that results in the greatest density for a specified compaction effort. Compacting at water contents higher than (wet of) the optimum water content results in a relatively dispersed soil structure (parallel particle orientations) that is weaker, more ductile, less previous, softer, more susceptible to shrinking, and less susceptible to swelling than soil compacted dry of optimum to the same density. The soil compacted lower than (dry of) the optimum water content typically results in a flocculated soil structure (random particle orientations) that has the opposite characteristics of the soil compacted wet of the optimum water content to the same density.

Figure 3.11: Photographs Taken during Compaction Test, a) Adding the material in to the mold b) Compacting the materials c) Trimming the top surface by spatula *(Source: Abuye Boja 28/10 /2020)*

F. Moisture Content Determination

This test was performed to determine the water (moisture) content of soils. The water content is the ratio, expressed as a percentage, of the mass of “pore” or “free” water in a given mass of soil to the mass of the dry soil solids.

Standard Reference: ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures.

For many soils, the water content may be an extremely important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine-grained soil largely depends on its water content. The water content can be used in expressing the phase relationships of air, water, and solids in a given volume of soil.

G. CBR Test

The California bearing ratio (CBR) is a penetration test for the evaluation of the mechanical strength of road sub-grades, sub-base, and base courses. It was developed by the California Department of Transportation before World War II**[41]**. The test was performed by measuring the pressure required to penetrate a soil sample with a plunger of the standard area mostly 20 cm² to (2.5 and 5 mm) depth. The measured pressure is then divided by the pressure required to achieve an equal penetration on a standard crushed rock material.

Standard: The CBR test is described in ASTM (American Society for Testing and Materials) Standards D1883-05 (for laboratory-prepared samples) and D4429 (for soils in place in the field), and AASHTO T193.

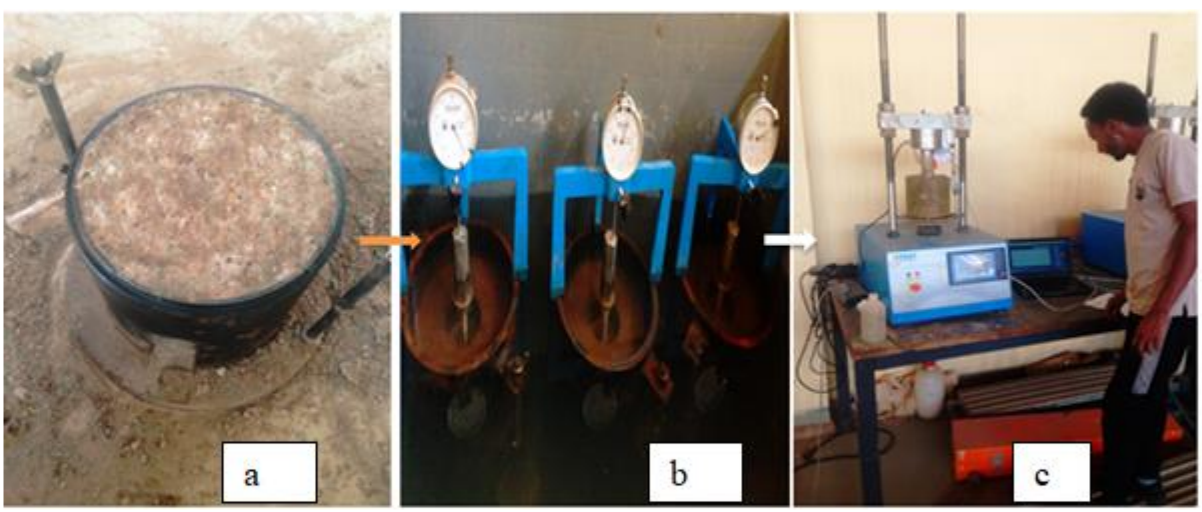


Figure 3.12: Photographs Taken during CBR Test a) After compacting b) During soaking time c) During test *(Source: The researcher.,28/102020 – 1/11/ /2020)*

H. Specific Gravity Test

The specific gravity of solids is the ratio of weight in air of a given volume of soil particles at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature. It is the heaviness of soil particles is determined by the pycnometer method using a soil sample passing #10(2mm) sieve as per ASTM D854 standards.

The specific gravity Gs, of a soil calculated as follows:

$$\mathrm{Gs} = \frac{Ws}{Ws + Wfw - Wfws}$$

Where: -

W_s = Weight Dry sample, W_{fw} = Weight Flask filled with water only, W_{fws} = Weight of flask filled with water and sample, and K = correction factor based on the density of water at 20 ^{0}C. Specific gravity at a standard temperature of 20 ^{o}C.

$$\mathrm{Gs20} = \mathrm{k} * \mathrm{Gs} = \frac{K * Ws}{Ws + Wfw - Wfws}$$

$$\mathrm{K} = \frac{\text{Relative Density of water @T}^0\text{c}}{\text{Relative Density of water @20}^0\text{c}}$$

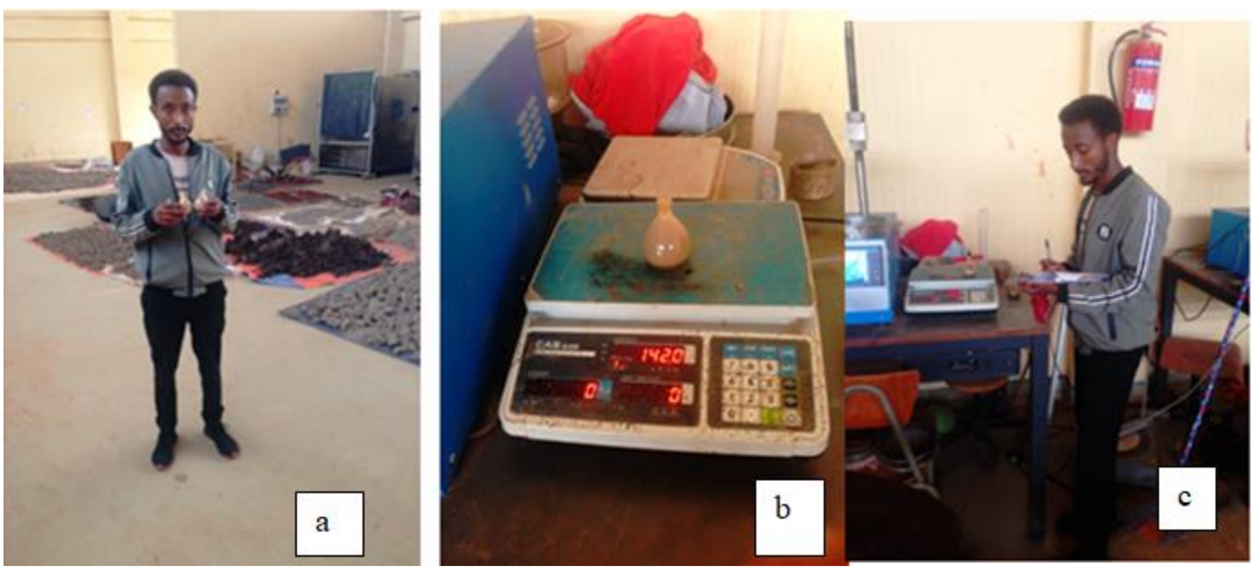


Figure 3.13: Photographs Taken Specific Gravity Test a) Pycnometer preparation b) weighting the pycnometer c) Recording the weight *(Source: Abuye Boja,30/10 /2020)*

3.8 Data Processing and Analysis

The research is conducted first by identification of the use of Synthetic Fiber in pavement construction materials/ improvement of weak subgrade soil through literature review and then from the laboratory test findings, it is developed and interpreted. In this study, NSF is used as a reinforcing material, in weak subgrade soil. The main parameter in the analysis of subgrade is the evaluation of the California Bearing Ratio. A soil reinforced with NSF was analyzed to study the improvement in CBR values by changing the dry weight percentages and aspect ratios of fiber. laboratory results were analyzed by Excel and the results obtained were compared.

CHAPTER FOUR

4. RESULT AND DISCUSSIONS

4.1 Introduction

This chapter presents test results, discussion, and analysis of all experimental work that was performed on untreated and treated soil samples with Nylon synthetic Fiber. Primarily, properties of materials (untreated soil) were examined, and then the effect of stabilizers on moisture-density relation, CBR, and CBR swell values were investigated by varying percentage of stabilizers from 0.5% to 2.5% and compared with untreated soils.

4.2 Laboratory Test Result of untreated soil

To determine the quality of the materials, laboratory tests were carried out on Jimma town around Merkato near Woma Hotel soil samples. The summary results of the laboratory tests conducted for identification and determination of the engineering properties of the soil before mixing with NSF presented in table 4.1. The details are presented in the next sections as outlined in the summary table.

Table 4.1: Summary of Physical and Engineering Properties of untreated Soil

S. No.	Properties	Values/ laboratory Result
1	Percentage of passing sieve No. 200	89.48
2	Natural Moisture Content, %	39.27
3	Field Dry Density, (g/cm3)	1.23
4	Liquid limit, %	43
5	Plastic Limit, %	21
6	Plastic Index, %	22
7	Linear Shrinkage Limit, %	6.77
8	AASHTO classification system	A-7-6(21) very poor sub-grade
9	Unified Soil Classification System (USCS)	CL

10	Specific Gravity	2.63
11	Optimum moisture content, (%)	17.02
12	Maximum dry density, (g/cm3)	1.51
13	Unconfined Compressive Strength(qu), KPa	61.4
14	Soaked CBR value, (%)	1.81
15	CBR-swell, (%)	8.95
16	Color	Gray

4.2.1 Grain size analysis

The gradation of the soil sample was conducted in both mechanical (sieve) and hydrometer tests. The gradation analysis was done through a mechanical sieve for the material retained on sieve No. 200 and hydrometer analysis for material passing sieve No. 200. The hydrometer test was conducted by taking 50 gm of soil sample which passing No. 200 sieves and soaked for 24 hours in a chemical solution (Sodium hexa-meta phosphate) to disintegrate the particles.

The lab result for the mechanical wet sieve analysis test shows that the sample subgrade soil is fine-grained, it contains 89.48% fine-grained soil (about 5.37% is clay particles and 84.11% is silt particles) and 10.52% Coarse-grained soil (about 10.4% is coarse-grained soil and 0.12 is sandy soil) out of the 1 kilograms of soil. The experimental data is shown in appendix A and the particle size distribution curve as given in Figure 4.1. The percent passing of each test is not only used to categorize soils as coarse-grained and fine-grained but it also helps to determine the soil classifications together with the Atterberg limits.

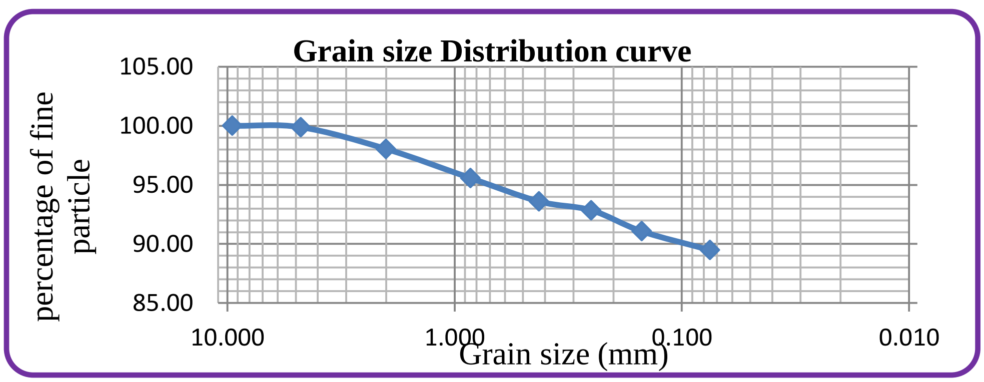


Figure 4.1 Grain Size Distribution Curve Result from Sieve Analysis

The lab result for the hydrometer test shows that the sample soil contains 94% of silt particles and 6% of clay particles out of the 50 grams of soil, (i.e. $\frac{89.48\%*94}{100} = 84.11\%$ silt particles and $\frac{89.48\%*6}{100} = 5.37\%$ clay particles). Hence, these values are useful for soil classification. The experimental data is shown in appendix A and the particle size distribution curve as given in Figure 4.2.

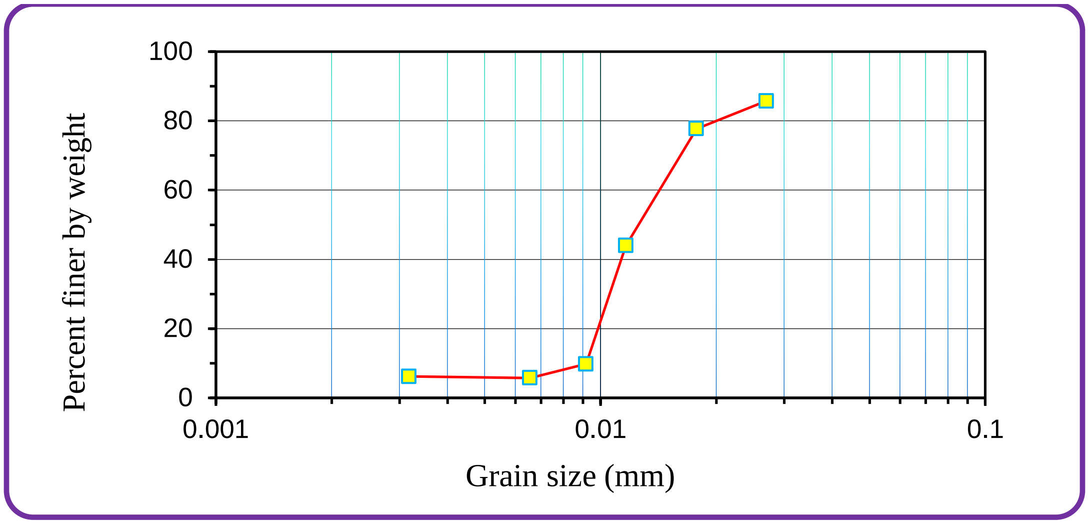


Figure 4.2 Grain Size Distribution Curve result from Hydrometer Analysis

4.2.2 Natural Moisture Content

The natural moisture content is the ratio of the weight of water to the weight of solids in a given mass of soil. This ratio is expressed in percentage, the detailed calculations, and its values shown in table 4.2 below.

Table 4.2 Natural water content of the soil

Sample collected in (Red lid)			
Moisture content determination			
Specimen Number	1	2	3
Moisture can and lid number	2E	P65	G3T2
Mc=Mass of empty, clean can + lid(gram)	33	37.7	34.7
Mcms=Mass of can, lid, and moist soil(gram)	147.3	150.1	140.6
Mcds=Mass of can, lid, and dry soil	114.2	117.5	109.9

Ms= Mass of soil solids (grams)	81.2	79.8	75.2
Mw=Mass of pore water (grams)	33.1	32.6	30.7
w= Water content, w%	40.76	40.85	40.82
Average Water Content,w %	**40.813**		
Sample collection (black lid)			
Moisture content determination			
Specimen Number	1	2	3
Moisture can and lid number	G3T3	69	A18/22-2
Mc=Mass of empty, clean can + lid(gram)	38.3	25.3	28.7
Mcms=Mass of can, lid, and moist soil(gram)	167.7	152.3	153.4
Mcds=Mass of can, lid, and dry soil	132	117.3	119.7
Ms= Mass of soil solids (grams)	93.7	92	91
Mw=Mass of pore water (grams)	35.7	35	33.7
w= Water content, w%	38.10	38.04	37.03
Average Water Content,w %	**37.73**		
Overall Average Natural water content	**39.27**		

4.2.3 Field Density Determination

These test methods cover the determination of the in-place density and unit weight of soil and rock using a pouring device and calibrated sand to determine the volume of a test pit. The dry density is an important factor in determining the magnitude of volume change. The swell or swelling pressure of an expansive soil increases with increasing dry density for constant moisture content.

Table 4.3 Field Density Determination by Sand Replacement Method

Determination of Dry density of soil using sand replacement method			
	1. Calibration Bulk Density of Sand		
S/N	**Observation and calculation**	**T1**	**T2**
1	Volume of calibrating container, V cm^3	1000	1000
2	weight of cylinder + sand (before pouring),w_1 g	5421.5	5325.5
3	Mean weight of cylinder + sand (after pouring), w_2 g	2156.1	2059.1
4	Mean weight of sand in cone(of pouring cylnider) @glass, w_3 g	1802.4	1803.6
5	weight of sand to fill calibrating container w_4=(w1-w2-w3)	1463	1462.8
6	bulk density of sand = w_4/v	1.463	1.4628
7	Average bulk density of sand	1.4629	
8	Water Content ,w	40.8133817	37.725588
	2. Dry density of soil		
S/N	**Observation and calculation**	**T1**	**T2**
1	Weight of wet soil from hole, Ww,g	3266.2	3370.6
2	weight of cylinder + sand (before pouring),w_1 g	6671.7	6817.5
3	weight of cylinder + sand (after pouring),w_5 g	2156.1	2059.1
4	Weight of sand in hole, Wh =(W_1-W_5-w_3)	2713.2	2954.8
5	Volume of hole Vh=Wh/gama of sand, cm^3	1854.55	2019.96
6	Bulk density of soil, gama bulk=(weight of wet soil in hole/weight of sand in hole)*bulk density sand	1.76	1.67
7	the dry density of soil= bulk density of soil/(1+ water content)	1.25	1.21
8	**Average dry density**	**1.23**	

4.2.4 Atterberg's Limits of the Untreated Soil

Drop cone methods were used for the determination of the liquid limit of soil while the plastic limit was determined by making threads 1/8" (3 mm) thickness as per ASTM requirements. The liquid limit, plastic limit, and Plasticity Index of the expansive clay soil were determined as 43%, 21%, and 22% respectively see Appendix A. The purpose of conducting Atterberg limit test is to know the plasticity property of a soil passing the No. 40 (425 μm) sieve with varying degrees of moisture content.

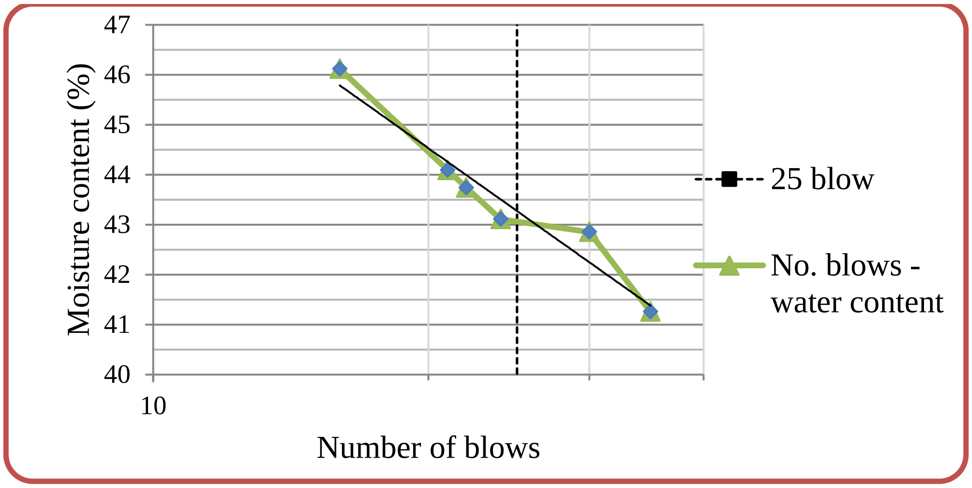


Figure 4.3 Liquid Limit

4.2.5 Soil classification

Based on gradation and Atterberg limit of the sample soil was classified **CL** as per USCS system in Figure 4.4 and **A-7-6(21) as** per AASHTO classification system. This indicated that the sub-grade soil was clay, a highly expansive material; Week sub-grade and it required treatment to use as a sub-grade material.

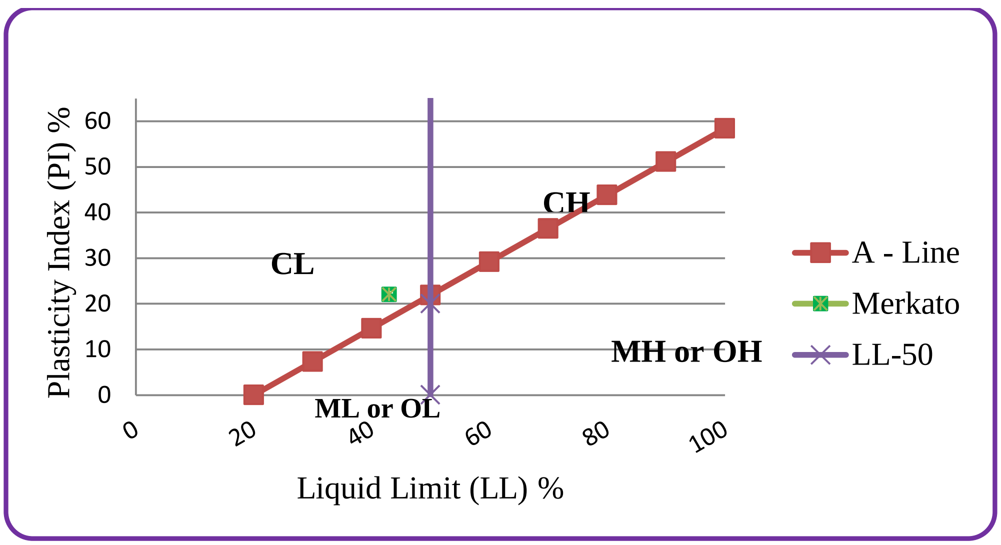


Figure 4.4 Plasticity Chart (USC)

From the AASHTO Classification system, results are shown in table 4.3 it can conclude that the soil samples in this study fall under A-7-6, which were clayey soils with a group index of 21. The group index results indicate that generally, the soils of the study area were very poor for subgrade material. The smaller the value of the group index, the better is the soil in that category. A group index of zero indicates a good subgrade, whereas a group of 20 or greater shows a very poor subgrade[13]. In the study, the value of the group index is 21, so that, the soil is categorized under very poor subgrade.

Table 4.4 Classification of soils based on AASHTO classification system

Sample	Sieve Analysis Percentage of Passing Soil Particle in sieve No.			LL (%)	PI (%)	LL (%)	Group Index(GI)	Soil Group	Material Type
	10 (2 mm)	40 (0.425 mm)	200 (0.075 mm)						
Merkato near Woma Hotel	98.48	93.6	89.48	43	22	13	21	A-7-6	clayey soil

4.2.6 Specific Gravity G_s of Soil

The specific gravity of the soil (CL) in this study was determined as per ASTM D 854 standard. Specific gravity determined was 2.63 as shown in table 4.3 below and this value indicates that the soil is classified as chalks, see section 2.3.3.2.

Table 4.5 Specific gravity of untreated soil

The specific gravity of soil at test Temperature, G_s at Tx ^{o}c (ASTM D-854)			
Location:	Merkato near toWoma Hotell		
Trial No.	1	2	3
Mass of clean, dry pycnometer, g	26.7	26.6	27.4
Mass of clean, dry pycnometer + dry soil, g	51.7	51.4	52.4
Mass of clean, dry pycnometer + dry soil + water at temperature Tx^o c,g	139.3	137.3	142.2
Test temperature(Tx), ^{o}c	26	26	26
Density of water at Tx, g/ml	0.99681	0.9968	0.99681
Mass of clean, dry pycnometer + water at temperature Ti ^{o}c(23^{o}c), g	123.8	121.9	126.7
Density of water at Ti, g/ml at23^{0}c	0.99757	0.99757	0.99757
Correction factor, k	0.999238	0.99924	0.999238
Specific gravity G at 26^{o}c	2.6296	2.6383	2.63158
Average specific gravity at 26^{o}c	2.63		

4.2.7 Unconfined Compressive Strength of untreated soil

According to the ASTM D 2166 standard, the unconfined compressive strength (q_u) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. The unconfined compressive strength of the expansive clay soil was determined as 61.4 kpa. If the value of unconfined compressive strength lies in the range from 50 - 100 kpa, then the soil categorized as a medium concerning its consistency refer to section 2.3.3.2, see Appendix A for detailed calculations and values.

4.2.8 Compaction Characteristics of Soil

Modified proctor compaction test conducted for the soils under consideration to determine the optimum moisture content and maximum dry density of the soils. The optimum moisture content is the moisture content corresponding to the maximum dry density of soils obtained from the compaction curve. The moisture added to soil prepared for CBR is the OMC from the compaction test, the optimum moisture content obtained from this compaction test is used as input data to prepare the CBR specimen to test the soaked condition CBR determination.

The Dry density and Optimum moisture content determined from the modified proctor test as per ASTM D1557 and material preparation Method C, MDD, and OMC for the sample of natural soil were 1.51 g/cm^3 and 17.02% as shown in figure 4.4 below.

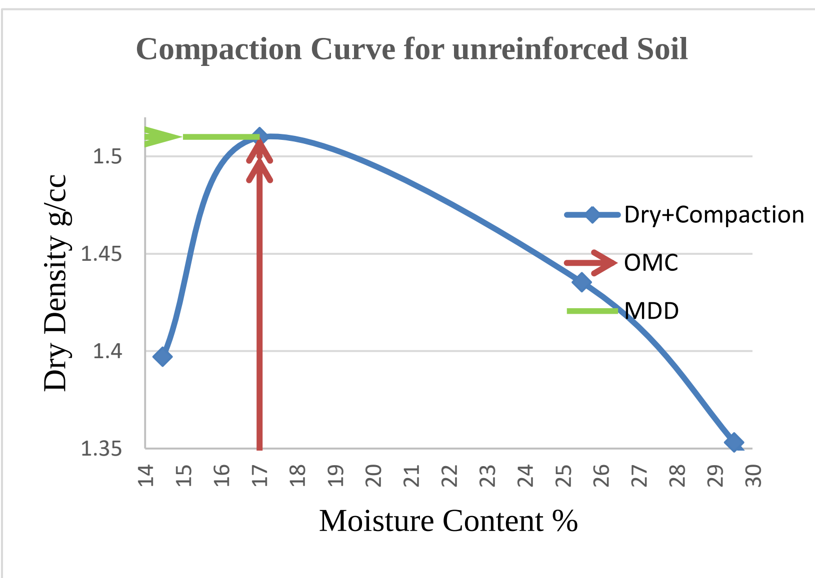


Figure 4.5 Compaction Curve for natural Soil

4.2.9 California Bearing Ratio (CBR) And CBR Swell of natural soil

Samples were soaked for 96 hours, CBR and CBR swell were determined as per ASTM standard. The sample had CBR and CBR swell were 1.80% and 8.95% respectively. Based on CBR value, the material is classified as poor sub-grade materials.

The result shows that the soil had weak strength and high plasticity index, which not satisfied the standard requirement of subgrade for highway construction. Therefore, the soil requires initial treatment and stabilization to improve its engineering property.

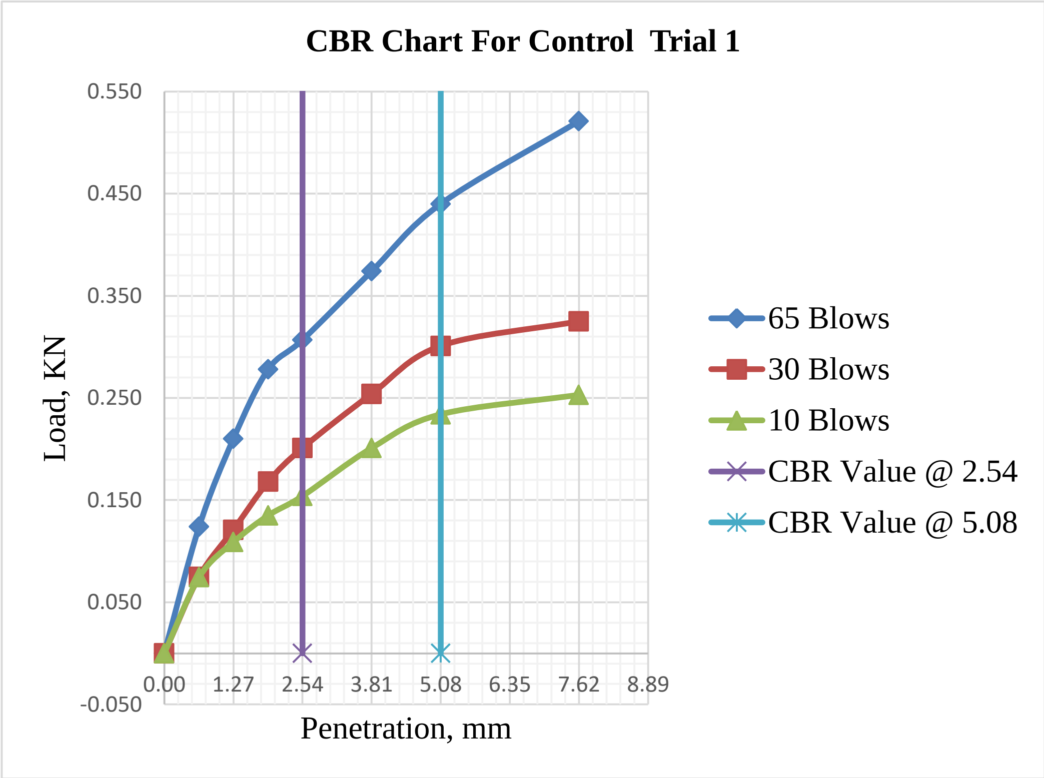


Figure 4.6 Load versus Penetration Graph for CBR determination of natural soil -Trial 1

Table 4.6 CBR Values of Natural Soil for trail - 1

CBR Penetration Determination								
Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**					
65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen. mm**	**Load, KN**	**CBR %**	**Pen. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.124		0.64	0.075		0.64	0.075	
1.27	0.210		1.27	0.121		1.27	0.109	
1.91	0.278		1.91	0.168		1.91	0.135	
2.54	0.307	2.30	2.54	0.201	1.51	2.54	0.154	1.15
3.81	0.374		3.81	0.254		3.81	0.201	
5.08	0.440	2.20	5.08	0.301	1.51	5.08	0.234	1.17
7.62	0.521		7.62	0.325		7.62	0.253	
Modified Max.Dry Density g/cc		**1.510**			**OMC %**		**17.0**	

Swell Determination							
Date		**65 Blows**		**30 Blows**		**10 Blows**	
		Gauge rdg mm	**Swell in %**	**Gauge rdg mm**	**Swell in %**	**Gauge rdg mm**	**Swell in %**
20/10/2020	Initial	0.00	9.04	0.1	7.75	0.10	4.56
24/10/2020	Final	10.52		9.12		5.41	

No.of blows	**MCBS %**	**DDBS g/cm3**	**Correcrt CBR %**	**% OF Compaction**	
10	17.3	1.31	1.17	87	
30	17.3	1.46	1.51	97	
65	17.0	1.55	2.31	102	
CBR at MDD, %			**2.0**	**Swell at MDD, %**	**9.00**

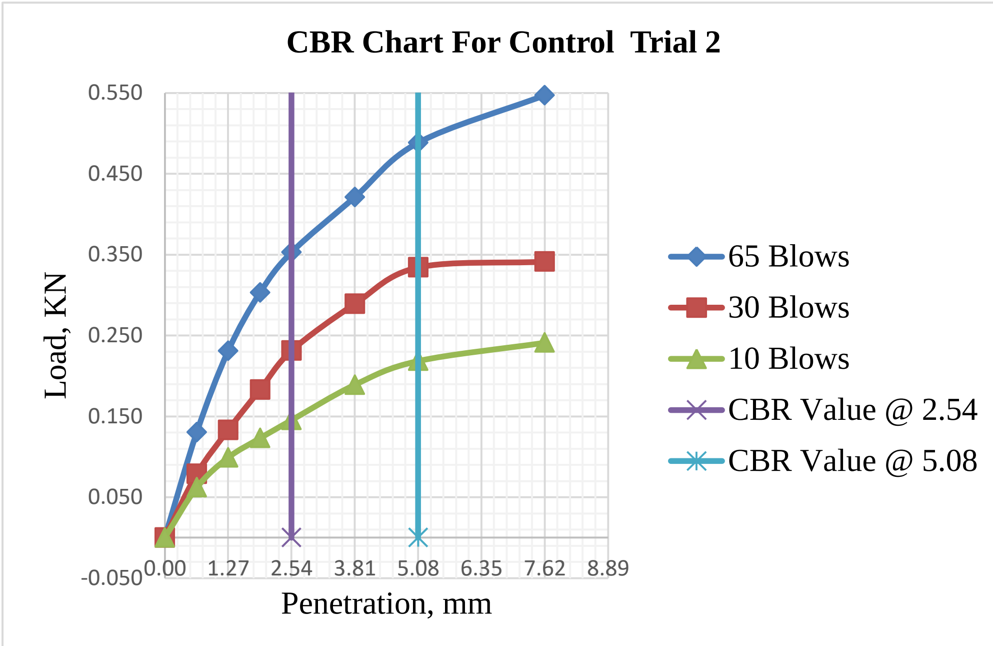


Figure 4.7 Load versus Penetration Graph for CBR determination of natural soil - Trial 2

Table 4.7 CBR Values of Natural Soil for trail - 2

CBR Penetration Determination								
Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**					
65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen. mm**	**Load, KN**	**CBR %**	**Pen. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.130		0.64	0.079		0.64	0.062	
1.27	0.231		1.27	0.133		1.27	0.099	
1.91	0.303		1.91	0.183		1.91	0.123	
2.54	0.353	2.65	2.54	0.231	1.73	2.54	0.145	1.09
3.81	0.421		3.81	0.289		3.81	0.189	
5.08	0.488	2.44	5.08	0.334	1.67	5.08	0.218	1.09
7.62	0.547		7.62	0.341		7.62	0.241	
Modified Max.Dry Density g/cc		**1.511**			**OMC %**		**17.0**	
Swell Determination								
Date		**65 Blows**		**30 Blows**		**10 Blows**		
		Gauge rdg	**Swell in %**	**Gauge rdg**	**Swell in %**	**Gauge rdg**	**Swell in %**	

		mm		**mm**		**mm**	
20/10/2020	Initial	0.00	9.46	0.4	7.26	0.00	4.40
24/10/2020	Final	11.01		8.85		5.12	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.4	1.38	1.09	92	
30	17.2	1.58	1.74	104	
65	17.4	1.68	2.65	111	
CBR at MDD, %			**1.6**	**Swell at MDD, %**	**8.90**
Average CBR, %			**1.8**	**Average Swell, %**	**8.95**

4.3 Effect of NSF on the Performance of Weak Soil

4.3.1 Effect of Nylon Synthetics Fiber on moisture density relation

The moisture density relations are determined based on ASTM D1557 method A. Tests were conducted with different percentages (0.5%, 1%, 1.5% & 2.5%) of Nylon Fiber added to the sub-grade soil. the moisture content versus dry density graph is plotted to determine the values of MDD and OMC as shown in Figure 4.8 below. As shown in the figure, the optimum moisture content almost remains constant with the increase in nylon synthetic fiber (NSF) content, and the maximum dry density increases with the increase in NSF content. The variation in OMC with fiber content and fiber length is very small. This might be due to the reason that the water absorption capacity of fiber is zero. For MDD it may be due to the increase the interfacial bonding area between the fiber and the soil. The details of test results are attached in Appendix B (Specifically on Appendix B1).

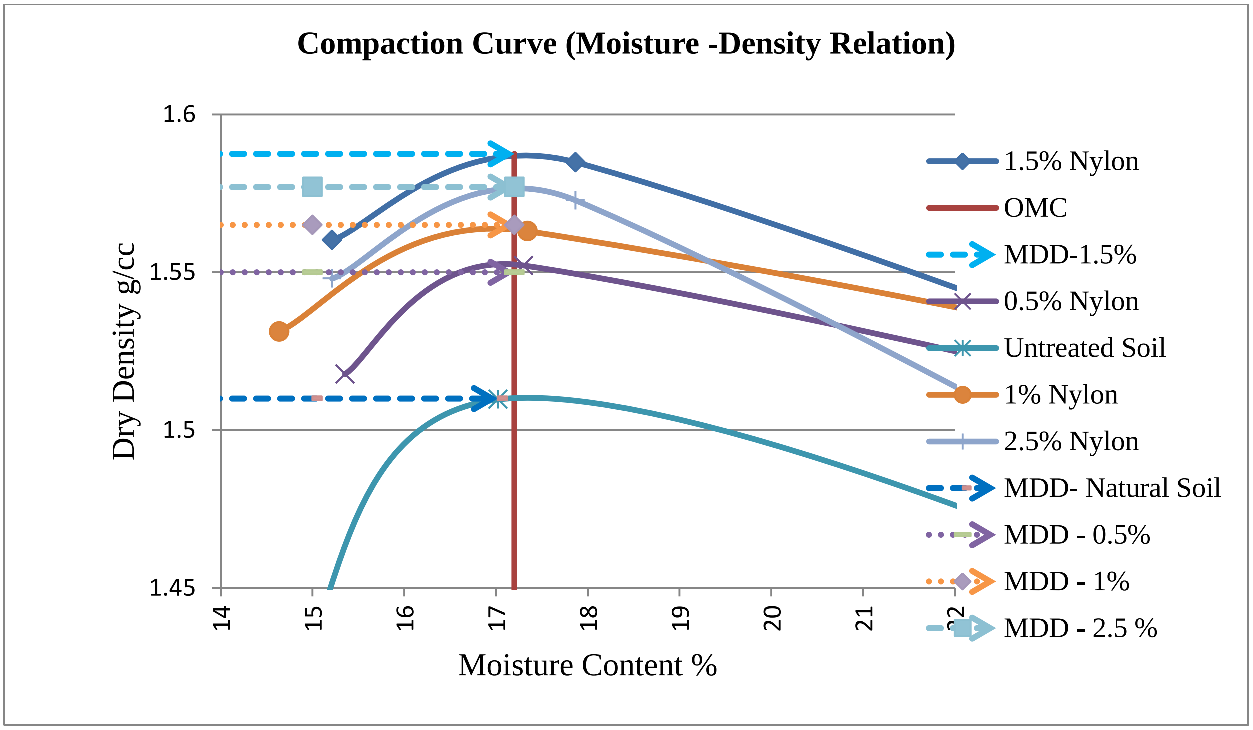


Figure 4.8 Effects of Nylon Synthetic Fibers on Moisture and Density

4.3.2 Effect of Nylon Synthetic Fiber on CBR and CBR swell

CBR test for this study was conducted by taking air-dried sample its preparation was based on ASTM 1557 standard Modified Proctor Method A. Sample pass through sieve No. 4 (4.75 mm) for natural soil mixed with different percent of NSF (0.5%, 1%, 1.5% & 2.5%) and applied modified compaction. The value was determined by the three-point CBR method through modified compaction with 5 layers each layer receives 65, 30, and 10 blows and is soaked for 96 hours for all samples. Soaked CBR swells also conducted with different percent of NSF threads added to the soil.

The effects of NSF were determined by changing its percentages and aspect ratios. The summary of the results is shown below in Table 4.9 and Figure 4.9 and its detailed calculations shown as in Appendices B (B2).

From CBR test results, the CBR value of soil increases with the increase in nylon synthetic fiber (NSF) content and contact area.This is due to the increase the interfacial bonding area between the fiber and the soil. It was also observed that increasing the diameter of NSF further increases the CBR value of reinforced soil, and this increase is substantial at a fiber content of 1.5% for aspect ratio of 50 (length = 20 mm, diameter = 0.4 mm). Swelling of the soil decreases as increasing the percentage of fibers in the soil. This might be due to the reason that the water absorption capacity of nylon fiber is zero.as shown in table 4.4.

Table 4.8 Effect of Nylon Synthetic Fiber on CBR

Weak Sub-grade Soil + Nylon Synthetic Fiber Thread						
S. No	Fiber Diameter, D (mm)	Fiber Length, L (mm)	Aspect Ratio (AR) = L/D	% Wt. of fibers	CBR Value (%)	Soaked CBR Swell (%)
1	0.3	10	33.33	0.5	5.03	8.22
				1	5.83	7.09
				1.5	6.575	5.84
				2.5	6.52	3.87
		20	66.67	0.5	5.45	8
				1	6.2	6.13
				1.5	7.38	4.23
				2.5	7.3	3.87
2	0.4	10	25.00	0.5	5.21	6.19
				1	6.39	6.03
				1.5	6.89	5.06
				2.5	6.81	4.11
		20	50.00	0.5	6.01	6.07
				1	6.87	5.66
				1.5	7.96	5.65
				2.5	8.02	5.5

Table 4.9 Percentage increase in CBR values due to reinforcement of fibers

Fiber Length, L (mm)	Percentage of Fiber by Dry Weight of Soil	Fiber Diameter = 0.3 mm			Fiber Diameter = 0.4 mm		
		CBR Value (%)	% Increase in CBR Value	Soaked CBR Swell (%)	CBR Value (%)	% Increase in CBR Value	Soaked CBR Swell (%)
	0	**1.80**	-		**1.80**	-	
10	0.5	5.03	171.9	8.22	5.21	181.6	6.19
	1	5.83	215.1	7.09	6.39	245.4	6.03
	1.5	6.575	255.4	5.84	6.89	272.4	5.06
	2.5	6.52	252.4	3.87	6.81	268.1	4.11
	0	**1.80**	-	8.95	**1.80**	-	8.95
20	0.5	5.45	194.6	8	6.01	224.9	6.07
	1	6.2	235.1	6.13	6.87	271.4	5.66
	1.5	7.38	298.9	4.23	7.96	330.3	5.65
	2.5	7.3	294.6	3.87	8.02	333.5	5.5

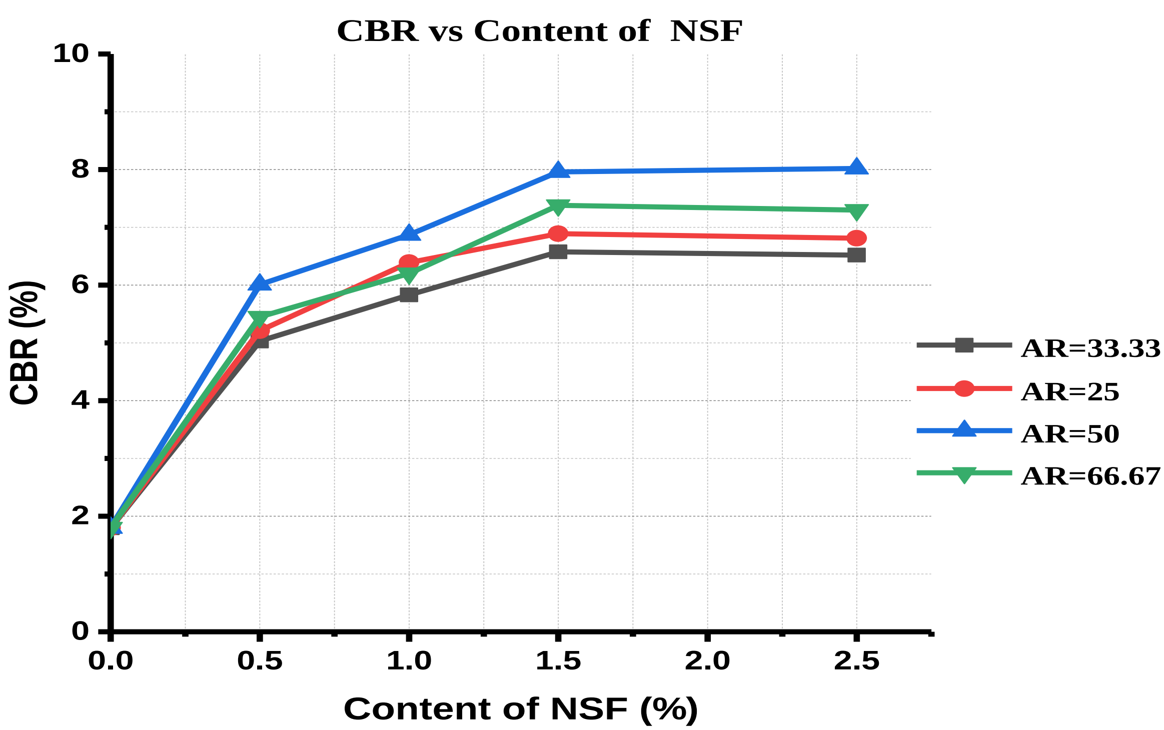


Figure 4.9 Summary of CBR Test Result for Different Aspect Ratios (AR)

As shown in figure 4.10 below, swelling of the soil decreases as increasing the percentage of fibers but the degree of minimizing the swell is not sufficient.

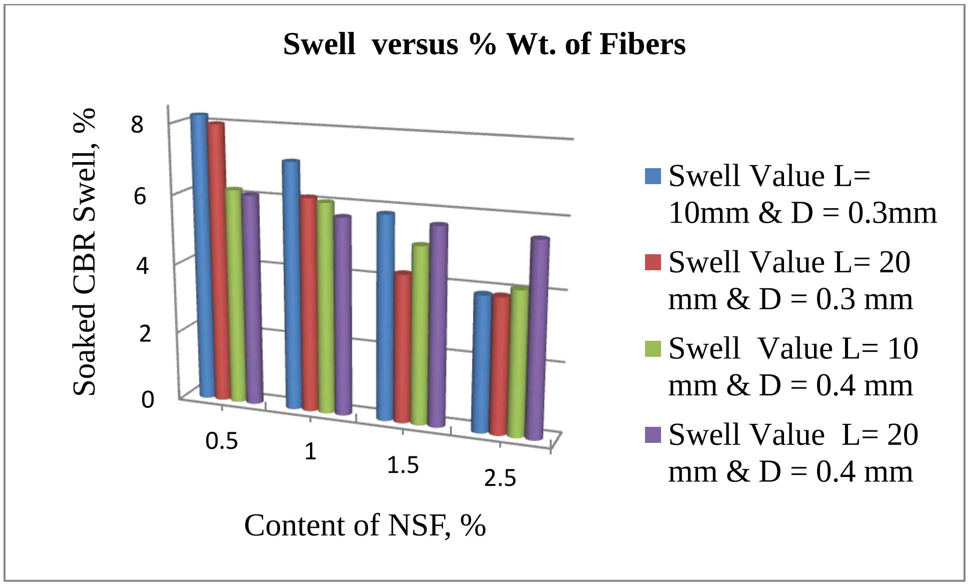


Figure 4.10 Effects of Nylon Synthetic Fibers on CBR Swell

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the detailed laboratory investigations on Weak sub-grade soil with NSF threads as reinforcing material, graphs plotted between various soil properties and various physical parameters (Aspect ratio, percentage weight of fibers) of reinforcing material. The following conclusions are drawn:

1. The contents and the aspect ratios of NS fiber affect the performance of weak subgrade soil, the CBR Values increase, with the increase in the diameter and length of NS fiber which indicates that the interfacial bonding is higher as the contact area increases. Increasing the content of NS fiber further increases the CBR values of reinforced soil, and this increase is substantial at a fiber content of 1.5%. The optimum moisture content almost remains constant with the increase in NS fiber content and the maximum dry density increases with the increase in NS fiber content.
2. The aspect ratio of 50 (length = 20 mm, diameter = 0.4 mm) is the critical value that gives the largest CBR value out of other aspect ratios.
3. Hence, reinforcing weak sub-grade soil with NSF can solve the problems of existing subgrade in the road construction industry.

5.2 Recommendation

Based on the findings of this research, the following recommendations forwarded:

- In the study NSF can use as a stabilizer of weak sub grade soil and it has the potential to improve the CBR values. Therefore, concerned bodies like those that Construction Industries, Fiber Industries, Higher Education Sectors and Government Entities made aware about this potential soil stabilizing material and promote its standardized production and usage.
- The potential of NSF in minimizing the soaked CBR Swelling values are not much enough. Therefore, the researcher recommends using small amount of cement/lime mixing with NSF may improve the soaked CBR swelling as well as CBR Values.
- The following topics are recommended for future studies
  - This study conducted by taking limited parameters. The researcher recommends that, adding other parameters like, unconfined compressive strength and durability test with different aspect ratio (AR).
  - In this study four aspect ratios (i.e. two different diameters and two different lengths) by varying the percentages of the fiber to 0.5, 1, 1.5 and 2.5 % were used; further studies with different aspect ratios and percentages are recommended for future study to implement in construction industries in Ethiopia

REFERENCE

[1] R. R. Singh and E. S. Mitta, “Improvement of local subgrade soil for road construction by the use of coconut coir fiber,” *IJRET Int. J. Res. Eng. Technol.*, vol. 03, no. 05, May 2014, [Online]. Available: http://www.ijret.org

[2] D. Nebro, “Stabilization of Potentially Expansive Subgrade Soil Using Lime and Con-Aid,” *MScThesis Addis Ababa Univ.*, 2002.

[3] D. H. Gray and H. Ohashi, “Mechanics of fiber reinforcement in sand,” *J. Geotech. Eng.*, 1983.

[4] P. Aggarwal and B. Sharma, “Application of jute fiber in the improvement of subgrade characteristics,” *Proc Proc Int Conf Adva Civ Eng*, 2010.

[5] H. Akhtar, H. Shakhawat, and H. Kamrul, “Application of Jute Fiber for the Improvement of Subgrade Characteristics,” *Am. J. Civ. Eng.*, Feb. 2018, doi: 10.11648/j.ajce.20150302.11.

[6] H. Singh and O. Yachang, “Use of fly ash reinforced with Jute geotextile as a pavement subgrade,” *Int. J. Earth Sci. Eng.*, vol. 5, no. 4, 2012.

[7] S. G. Somal and G. W. Singh, “Effects of Cement and Corn Cob Ash on UCS and direct shear test of clayey soil,” *Int. J. Adv. Res. Dev.*, vol. 2, no. 5, 2017.

[8] EL MINO, “The Pan-American Health organization OPS –part of WHO-, through their ‘Chronicle of Disasters’ series, carried out an analysis in the health sector in regards to the phenomena,” *EL NIÑO South Oscil.*, 1998 1997.

[9] U. U. Bantayehu, “Performance, Problems and Remedial Measures for Roads Constructed on Expansive Soil in Ethiopia – A Review,” *Civ. Environ. Res.*, vol. 9, 2017.

[10] V. N. S. Murthy, *Geotechnical Engineering: Principles and Practices of Soil Mechanics and Foundation*. New York: Marcel Dekker, Inc.

[11] *Site Investigation Manual*. Ethiopia: Ethiopia Road Authority, 2013.

[12] *Flexible Pavement Design Manual*. Ethiopia: Ethiopian Road Authority, 2013.

[13] Dr. K. R. Arora, *Soil Mechanics and Foundation Engineering*, 7th ed. Delhi: Delhi: Standard Publisher Distributors, 2004.

[14] D. Nelson and J. Miller, “Expansive Soils Problems and Practices in Foundation and Pavement Engineering,” *N. Y.*, 1992.

[15] F. H. Chen, “Foundation on expansive soils,” *Elsevier*, 1988.

[16] D. Teklu, “Examining the Swelling Pressure of Addis Ababa Expansive Soil.” MSc. Thesis, Addis Ababa University, Addis Ababa, 2003.

[17] “ASTM D 2937-00 – Standard Test for Density of Soil in Place by the Drive Cylinder Method”.

[18] “ASTM D 4914 Standard Test Methods for Density of Soil and Rock in Place by the Sand Replacement Method in a Test Pit.”.

[19] “ASTM D 4318 Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.”.

[20] “ASTM D 2166 Standard Test Method for Unconfined Compressive Strength of Cohesive Soil.”.

[21] p Anjen, “Geo-technical Investigations and Improvement of Ground Conditions,” 2019.

[22] “ASTM D 422 – 63, ‘Standard Test Method for Particle-Size Analysis of Soils,’ 1998.”.

[23] “ASTM D 1557 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft3 (2,700 kN-m/m3))”.

[24] "ASTM D 2216 Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass."

[25] "ASTM D 1883 Standard Test Method for CBR (California Bearing Ratio) of Laboratory- Compacted Soils.".

[26] "ASTM D 854 Standard Test Method for Specific Gravity of Soils.".

[27] M. D. Braja, "Principles of Foundation Engineering," Ninth Edition.,

[28] "https://en.wikipedia.org/wiki/Synthetic_fiber," *google*.

[29] A. Giwa, M. T. Isa, and U. A. Idris, "Analysis of Some Physical and Mechanical Properties of Selected Fibers," *Int. J. Text. Sci.*, vol. 2, no. 3, 2013, doi: 10.5923/j.textile.20130203.02.

[30] H. Ahsan, B. Razia, and M. A. Mohammad, "Mechanical Properties of Synthetic Fibers Reinforced Mortars," *Int. J. Sci. Eng. Res.*, vol. 4, no. 4, Apr. 2013.

[31] L. Rick, "https://www.thebalancesmb.com/how-long-does-it-take-garbage-to-decompose-2878033".

[32] J. P. Guyer, "Introduction to Soil Stabilization in Pavements," New York, 2011.

[33] G. P. Makusa, "Soil Stabilization Methods and Materials in Engineering Practice," *Dep. Civ. Environ. Nat. Resour. Eng. Luleå Univ. Technol. LuleaSweden*, 2012.

[34] R. Kumar, V. Kanaujia, and D. Chandra, "Engineering behaviour of fire-reinforced pond ash and silty sand.," *Geosynth In*, vol. 6, no. 6, 1999, doi: 10.1680/gein.6.0162.

[35] J. Tingle, R. Santoni, and S. Webster, "Full-scale fild tests on discrete fire reinforced sand.," *J Transp Eng*, vol. 1, no. 128, 2002, doi: 10.1061/(ASCE)0733-947X.

[36] P. Kumar, H. Mehndiratta, S. Chandranarayana, and S. Singh, "Effect of randomly distributed fires on flash embankments," *J Inst Eng India Part CV Civ. Eng Div Board*, vol. 3, no. 86, 2005.

[37] K. P. Suchit and B. Singh, "Experimental Investigation on the Behaviour of Glass FibreReinforced Cohesive Soil for Application as Pavement Subgrade Material," *2017*, 21 April, doi: 10.1007/s40891-017-0090-x.

[38] J. k Mitchell and K. Soga, "Fundamentals of Soil Behavior," *2005*.

[39] P. Sherwood, "Soil stabilization with cement and lime," *State Art Rev.*, 1993.

[40] GSE, "Geology, Geochemistry and Gravity Survey of Jimma area.," 2012.

[41] "http://en.wikipedia.org/wiki/California_bearing_ratio."

APPENDIX

Appendix A: - Laboratory Analysis Data for Untreated Soil

A.1 Field Density Determination Data

Determination of Dry density of soil using sand replacement method			
Apparatus	Sand Pouring Cylinder		
	Cylinderical calibrating container		
	Metal tray with hole		
	Excavating tool		
	balance		
	Glass plate		
	Metal tray		
	clean uniform sand (passing 1mm:retained on 600micro is sieve		
	Water Content Determination Apparatus		
1. Calibration Bulk Density of Sand			
S/N	**Observation and calculation**	**T1**	
1	Volume of calibrating container, V cm3	1000	1000
2	weight of cylinder + sand (before pouring),w1 g	5421.5	5325.5
3	Mean weight of cylinder + sand (after pouring), w2 g	2156.1	2059.1
4	Mean weight of sand in cone(of pouring cylnider) @glass, w3 g	1802.4	1803.6
5	weight of sand to fill calibrating container w4=(w1-w2-w3)	1463	1462.8
6	bulk density of sand = w4/v	1.463	1.4628
7	Average bulk density of sand	1.4629	
8	Water Content ,w	40.8133817	37.72559
2. Dry density of soil			
S/N	**Observation and calculation**	**T1**	**T2**
1	Weight of wet soil from hole, Ww,g	3266.2	3370.6
2	weight of cylinder + sand (before pouring),w1 g	6671.7	6817.5
3	weight of cylinder + sand (after pouring),w5 g	2156.1	2059.1
4	Weight of sand in hole, Wh =(W1-W5-w3)	2713.2	2954.8
5	Volume of hole Vh=Wh/gama of sand, cm3	1854.54545	2019.962
6	Bulk density of soil, gama bulk=(weight of wet soil in hole/weight of sand in hole)*bulk density sand	1.76106589	1.66876
7	dry density of soil= bulk density of soil/(1+water content)	1.25063816	1.211655
8	**Average dry density**	**1.231146792**	

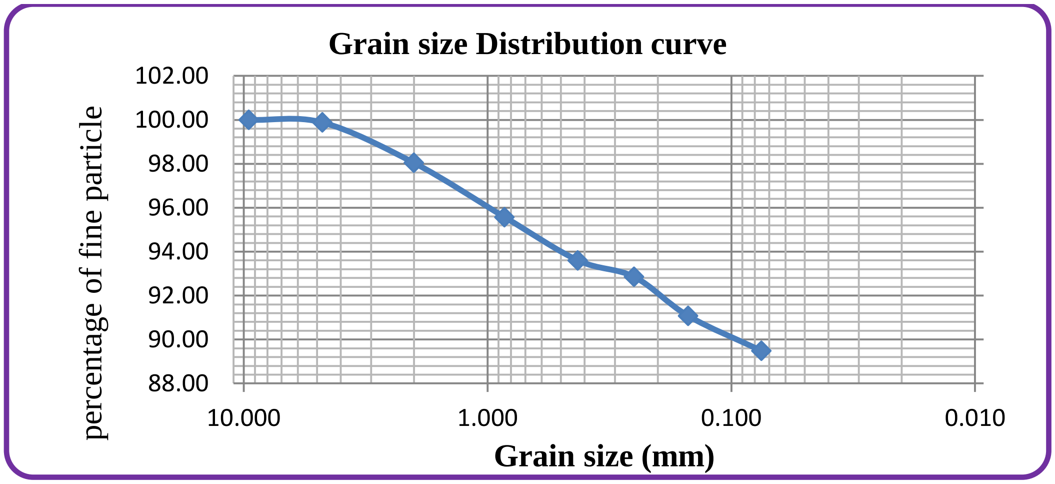
A.2 Natural Water Content Determination

Sample 1 (Red lid)			
Moisture content determination			
Specimen Number	1	2	3
Moisture can and lid number	2E	P65	G3T2
Mc=Mass of empty, clean can + lid(gram)	33	37.7	34.7
Mcms=Mass of can, lid, and moist soil(gram)	147.3	150.1	140.6
Mcds=Mass of can, lid and dry soil	114.2	117.5	109.9
Ms= Mass of soil solids (grams)	81.2	79.8	75.2
Mw=Mass of pore water (grams)	33.1	32.6	30.7
w= Water content, w%	40.7635	40.8521	40.8245
Average Water Content, %	**40.8134**		
Sample 2 (black lid)			
Moisture content determination			
Specimen Number	1	2	3
Moisture can and lid number	G3T3	69	A18/22-2
Mc=Mass of empty, clean can + lid(gram)	38.3	25.3	28.7
Mcms=Mass of can, lid, and moist soil(gram)	167.7	152.3	153.4
Mcds=Mass of can, lid and dry soil	132	117.3	119.7
Ms= Mass of soil solids (grams)	93.7	92	91
Mw=Mass of pore water (grams)	35.7	35	33.7
w= Water content, w%	38.1003	38.0435	37.033
Average Water Content,w %	**37.7256**		
Overall Average Natural Water Content	**39.2695**		

A.3 Gradation data for Mechanical Sieve

Method of Testing:	Grain Size Analysis (ASTM D-421)			
Method of Testing:	Wet Sieve Analysis			
Wt. of Sample: (g)	1 Kg			
Sample Location:	Merkato			
Depth (m)	2 m			
Location:	Merkato near to Wema Hotel			
Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle
9.500	0.000	0.00	0.00	100.00
4.750	1.200	0.12	0.12	99.88
2.000	18.400	1.84	1.96	98.04
0.850	24.700	2.47	4.43	95.57
0.425	19.700	1.97	6.40	93.60
0.250	7.500	0.75	7.15	92.85
0.150	17.800	1.78	8.93	91.07
0.075	15.900	1.59	10.52	89.48
pan	894.800	89.48	100.00	0.00
sum	1000.000	100.00		
AASHTO CLASSIFICATION		%pass 0.075mm=89.48, Silty clay, clayey soil, **A-7-6(21)**		
UNIFIDE CLASSIFICATION SYSTEM		**CL**		

Grain Size Distribution Curve Result from Sieve Analysis

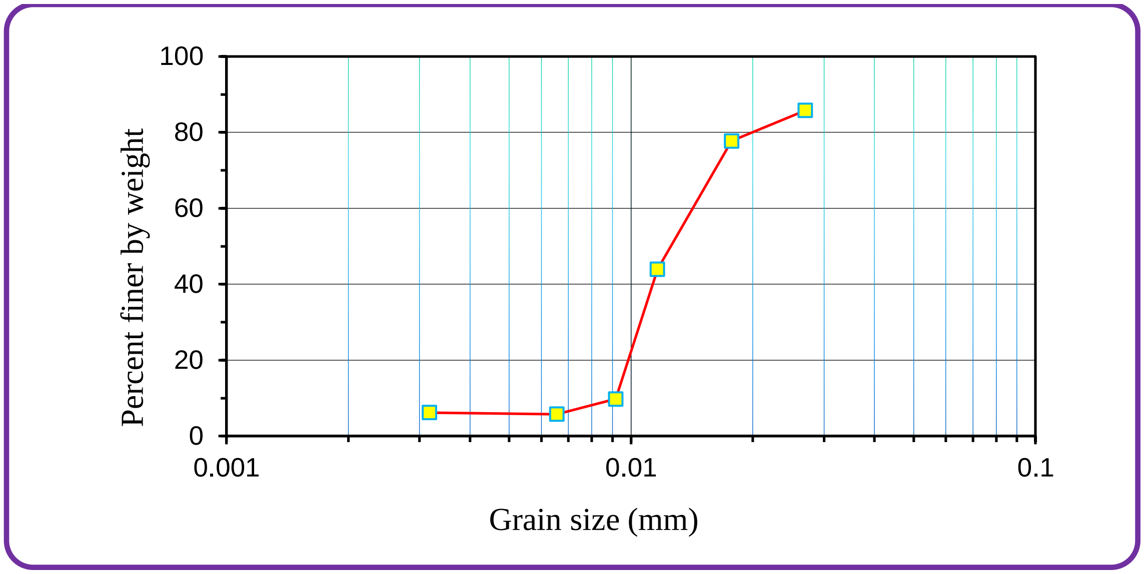


A.4 Hydrometer Analysis Data

Sample description:			Values	SI Unit	
Gravity =			981	g/sec2	
Mass in suspension =			50.00	g	
Specific unit weight =			2.63		
Dispersing agent correction =			4.00	g/L	
Mencius correction =			0.50	g/L	
Cylinder diameter =			5.95	cm	
Hydrometer number =			1		
Time (min)	Hydrometer reading (g/L)	Temperature (^{o}C)	Corrected distance of fall (cm)	Grain size (mm)	Percent finer by weight
t	Rt	Te	HR	D	p
2	46.0	21.0	7.87	0.0270	85.8
5	42.0	21.0	8.51	0.0177	77.7
15	25.0	22.0	11.23	0.0116	44.0
30	8.0	22.0	13.95	0.0092	9.8
60	6.0	22.0	14.27	0.0066	5.8
250	6.0	23.0	14.27	0.0032	6.2

1440	6.0	22.0	14.27	0.0013	5.8
Clay fraction (%) =6.0			Silt fraction (%) = 94		

Grain Size Distribution Curve result from Hydrometer Analysis

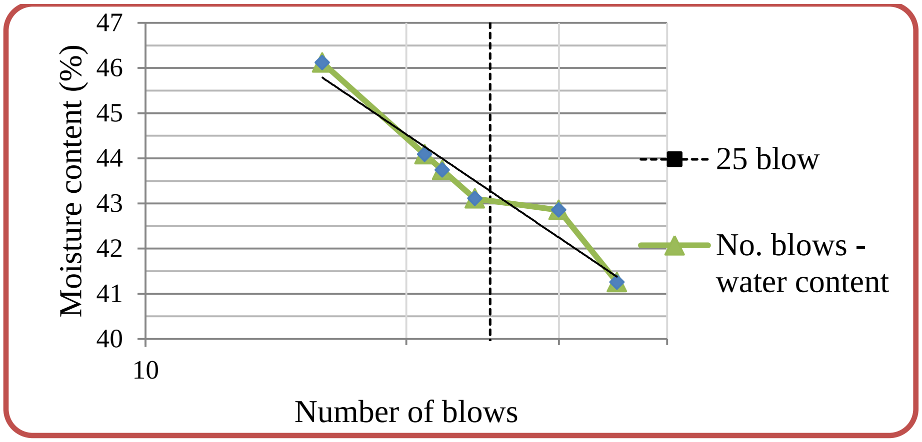


A.5 Atterberg's Limit

a) Liquid Limit Data and Determinations

Material location:	Merkato near to Woma Hotel					
Determination	Liquid Limit (D-4318)					
Number of blows	35	30	24	22	21	16
Test No	01	02	03	01	02	03
Wt. of Container, (g)	5.76	18.78	16.61	16.30	5.79	6.49
Wt. of container + wet soil, (g)	26.54	41.41	34.59	36.69	27.90	24.93
Wt. of container + dry soil, (g)	20.47	34.62	29.17	30.48	21.14	19.11
Wt. of water, (g)	6.07	6.79	5.42	6.21	6.76	5.82
Wt. of dry soil, (g)	14.71	15.84	12.57	14.19	15.34	12.62
Moisture content, (%)	41.26	42.85	43.31	43.74	44.09	46.12
Moisture Content at 25 blow, %	43.20					

Liquid Limit determination chart



b) Data for Plastic Limit Determination

Material location:	Merkato near to Woma Hotel		
	Plastic Limit (ASTM D-4318)		
Test No	01	02	3
Wt. of Container, (g)	18.48	17.84	17.3
Wt. of container + wet soil, (g)	30.90	30.09	27.355
Wt. of container + dry soil, (g)	28.70	27.96	25.574
Wt. of water, (g)	2.20	2.13	1.78
Wt. of dry soil, (g)	10.22	10.12	8.27
Moisture container, (%)	21.52	21.06	21.53
Average moisture content, %	21.37		

A.6 Specific Gravity Data and Determination

Specific gravity of soil at test Temperature, G_s at Tx ^oc (ASTM D-854)			
Location:	Merkato near toWoma Hotell		
Trial No.	1	2	3
Mass of clean, dry pycnometer, g	26.7	26.6	27.4
Mass of clean, dry pycnometer + dry soil, g	51.7	51.4	52.4
Mass of clean, dry pcnometer + dry soil + water at temperature Tx ^oc,g	139.3	137.3	142.2
Test temperature(Tx), ^oc	26	26	26
Density of water at Tx, g/ml	0.99681	0.9968	0.99681
Mass of clean, dry pycnometer + water at temperature Ti $^oc(23^oc)$, g	123.8	121.9	126.7
Density of water at Ti, g/ml at23^0c	0.99757	0.99757	0.99757
Correction factor, k	0.999238	0.99924	0.999238
Specific gravity G at 26^oc	2.6296	2.6383	2.63158
Average specific gravity at 26^oc	2.63		

A.7 Shrinkage Limit Data and determination

LINEAR SHRINKAGE (BS1377:Part 2:1990)				
Trial 1	1	2	3	4
Initial Length L0	140.00	140.00	140.00	140.00
Oven dried Length LD	130.74	130.41	130.53	130.40
Linear shrinkage,Ls	0.0661	0.0685	0.0676	0.0686
Percentage of Linear Shrinkage (%)	6.61	6.85	6.76	6.86
Average Percentage of Linear Shrinkage (%)	6.77			

A.8 Unconfined Compressive Strength (q_u)

a) Unconfined Compressive Strength Data and Determinations

Trial 1				Trial 4			
Shrinkage	Area	F	σ1−σ3	Shrinkage	Area	F	σ1−σ3
%	mm^2	Newton	kPa	%	mm^2	Newton	kPa
0	1123.9698	0	0	0	1134.0815	-1	-0.8817708
0.0123846	1124.0964	5	4.4480172	0	1134.0815	0	0
0.0247692	1124.2356	8	7.1159461	0.0044944	1134.1325	1	0.8817312
0.0517901	1124.5396	11	9.7817813	0.011236	1134.2089	2	1.7633435
0.0686782	1124.7296	10	8.8910259	0.0460674	1134.6042	3	2.6440939
0.0990768	1125.0718	12	10.665986	0.0764045	1134.9487	4	3.5243885
0.1564963	1125.7189	14	12.436498	0.1179775	1135.421	5	4.4036528
0.1891466	1126.0871	15	13.320462	0.1426966	1135.7021	6	5.2830755
0.2319297	1126.57	16	14.202402	0.147191	1135.7532	8	7.0437836
0.3501464	1127.9065	17	15.072172	0.1606742	1135.9066	7	6.1624785
0.3760414	1128.1997	18	15.954623	0.547191	1140.3212	9	7.8925128
0.5100203	1129.7189	19	16.818342	0.8157303	1143.4086	10	8.7457797
0.6102229	1130.8579	21	18.569972	0.8235955	1143.4993	11	9.6195948
0.6552578	1131.3705	20	17.677674	0.8393258	1143.6807	12	10.492439
0.7520829	1132.4743	22	19.426489	0.8539326	1143.8492	13	11.365134
0.7959919	1132.9755	23	20.300526	0.8842697	1144.1993	15	13.109604
0.9063274	1134.2371	24	21.159598	0.9303371	1144.7314	17	14.850646
1.0076559	1135.3981	25	22.018709	0.9359551	1144.7963	18	15.723322
1.0999775	1136.4579	26	22.878102	0.9629213	1145.108	19	16.592322
1.1776627	1137.3513	27	23.739367	0.9752809	1145.2509	20	17.463422
1.2328304	1137.9866	28	24.604859	1.0044944	1145.5889	21	18.331184
1.3240261	1139.0383	29	25.460074	1.0325843	1145.914	22	19.198648
1.3915785	1139.8186	30	26.319977	1.0539326	1146.1613	23	20.066984
1.5064175	1141.1476	31	27.165636	1.0662921	1146.3045	24	20.936846
1.6009908	1142.2444	32	28.015021	1.0898876	1146.5779	25	21.804013
1.6752984	1143.1076	34	29.743481	1.105618	1146.7603	26	22.672567
1.7687458	1144.1951	35	30.58919	1.1134831	1146.8515	27	23.542717
1.8408016	1145.035	36	31.440088	1.1516854	1147.2947	28	24.405237
1.9297456	1146.0735	37	32.284144	1.1966292	1147.8166	30	26.136579
1.9815357	1146.679	38	33.139178	1.2449438	1148.3782	32	27.865385
2.0682279	1147.6941	39	33.981181	1.2921348	1148.9272	34	29.592824
2.1965773	1149.2002	40	34.806815	1.3067416	1149.0972	33	28.718196
2.2337311	1149.637	41	35.663433	1.3337079	1149.4113	35	30.450371
2.3125422	1150.5644	42	36.503822	1.352809	1149.6339	36	31.314318
2.4904301	1152.6634	43	37.304905	1.3921348	1150.0923	37	32.17133

2.5377167	1153.2227	44	38.15395	1.4157303	1150.3676	38	33.032919
2.5816258	1153.7425	45	39.003505	1.4370787	1150.6168	39	33.894865
2.6840802	1154.9571	47	40.694151	1.4561798	1150.8398	40	34.757227
2.7088494	1155.2512	46	39.818181	1.4910112	1151.2467	41	35.613565
2.7966674	1156.2949	48	41.511902	1.5404494	1151.8248	42	36.46388
2.9340239	1157.9311	49	42.316852	1.5573034	1152.022	43	37.325677
2.985814	1158.5493	50	43.157422	1.6044944	1152.5745	45	39.04303
3.1569466	1160.5966	51	43.942918	1.6752809	1153.4043	46	39.88194
3.2706598	1161.9609	53	45.612549	1.6955056	1153.6416	47	40.740557
3.312317	1162.4616	52	44.732662	1.7	1153.6943	48	41.605475
3.3607296	1163.0439	54	46.429889	1.7404494	1154.1692	49	42.454779
3.4339113	1163.9253	55	47.253891	1.8134831	1155.0277	51	44.154784
3.5870299	1165.7738	56	48.036763	1.8224719	1155.1335	50	43.285041
3.7784283	1168.0927	57	48.797497	1.8707865	1155.7022	53	45.859564
3.9687007	1170.4071	58	49.555406	1.9011236	1156.0596	52	44.980379
4.0756586	1171.7121	59	50.353665	1.9561798	1156.7088	54	46.684178
4.1814907	1173.0063	60	51.15062	1.9786517	1156.974	55	47.537802
4.2771898	1174.179	61	51.951192	1.9853933	1157.0536	56	48.398797
4.5541545	1177.5862	62	52.650071	2.0516854	1157.8367	57	49.229742
4.6599865	1178.8934	63	53.439945	2.1044944	1158.4613	58	50.066413
4.885161	1181.6843	64	54.15998	2.1483146	1158.98	59	50.90683
5.3366359	1187.3201	66	55.587368	2.1921348	1159.4993	60	51.746474
5.4402162	1188.6207	65	54.685234	2.2741573	1160.4725	61	52.564797
9.2434136	1238.4304	33	26.646633	2.3404494	1161.2602	62	53.390273
10.802747	1260.0805	13	10.316802	2.8258427	1167.0608	63	53.981763
11.090971	1264.1654	9	7.1193218	3.605618	1176.5017	64	54.398564
11.213691	1265.9127	7	5.5296073	3.8426966	1179.4024	66	55.960546
11.287998	1266.973	6	4.7356966	3.8831461	1179.8987	65	55.089476
11.45125	1269.3089	4	3.1513212	4.0662921	1182.1512	67	56.676336
11.551452	1270.7469	3	2.3608164	4.2359551	1184.2456	68	57.420521
11.7102	1273.0317	2	1.5710528	4.4842697	1187.3243	69	58.11386
				4.5089888	1187.6317	70	58.940833
				7.4955056	1225.9745	44	35.889817

Trial 2				**Trial 3**			
`	Area	F	σ1−σ3	Shrinkage	Area	F	σ1−σ3
%	mm^2	Newton	kPa	%	mm^2	Newton	kPa
0	1134.0815	-2	-1.7635417	0	1122.1752	1	0.8911264
0.00573	1134.1465	1	0.8817203	0.0343376	1122.5607	2	1.7816409
0.01719	1134.2765	4	3.5264771	0.0587062	1122.8344	-1	-0.8906033
0.0573	1134.7317	5	4.4063279	0.0786442	1123.0584	0	0

0.069906	1134.8748	7	6.168081	0.3311918	1125.9041	3	2.6645253
0.098556	1135.2003	8	7.0472144	0.5748782	1128.6637	4	3.5440142
0.1363741	1135.6302	9	7.925115	0.6158618	1129.1291	5	4.4281916
0.1547101	1135.8388	10	8.8040665	0.6468764	1129.4816	6	5.3121717
0.1810681	1136.1387	11	9.6819166	0.6856447	1129.9225	7	6.1951153
0.2452441	1136.8696	12	10.5553	0.707798	1130.1746	8	7.0785525
0.3369241	1137.9154	14	12.303199	0.7576429	1130.7422	9	7.9593739
0.4068302	1138.7141	15	13.172753	0.8185645	1131.4368	10	8.8383199
0.4480862	1139.186	16	14.045116	0.889455	1132.246	11	9.7152029
0.5260142	1140.0785	18	15.788387	0.9105007	1132.4865	12	10.596153
0.6142562	1141.0907	19	16.650736	0.9824989	1133.31	13	11.470825
0.6417603	1141.4066	20	17.52224	1.0068675	1133.589	14	12.350156
0.6921843	1141.9861	21	18.389015	1.0655738	1134.2616	15	13.224462
0.7345863	1142.474	22	19.256456	1.1420027	1135.1385	17	14.976146
0.7552143	1142.7114	23	20.127566	1.1730173	1135.4948	16	14.090774
0.8411643	1143.7019	25	21.858843	1.3059371	1137.024	18	15.8308
0.8709603	1144.0457	24	20.978183	1.3413824	1137.4325	19	16.704287
0.9420124	1144.8663	26	22.710076	1.4399646	1138.5702	20	17.565891
0.9523264	1144.9855	27	23.581085	1.4698715	1138.9158	21	18.438588
1.0279624	1145.8605	28	24.435784	1.5241471	1139.5435	22	19.305976
1.0760944	1146.418	29	25.296183	1.5485157	1139.8256	23	20.178526
1.1952785	1147.8009	30	26.136937	1.6670359	1141.1994	24	21.030505
1.2571625	1148.5203	31	26.991252	1.7678334	1142.3704	25	21.88432
1.3201925	1149.2539	32	27.844153	1.802171	1142.7699	26	22.751737
1.3832226	1149.9884	33	28.695942	1.832078	1143.118	27	23.619608
1.4061426	1150.2557	34	29.558644	1.8675233	1143.5309	28	24.485564
1.4164566	1150.3761	35	30.424833	1.9162605	1144.0991	29	25.347454
1.5127206	1151.5005	36	31.263556	1.9882588	1144.9396	30	26.202256
1.5665826	1152.1306	37	32.114415	2.1156402	1146.4295	31	27.040476
1.5986706	1152.5063	38	32.971621	2.1610545	1146.9617	32	27.899799
1.6823287	1153.4869	39	33.810526	2.1732388	1147.1045	33	28.768084
1.7063947	1153.7694	40	34.668974	2.265175	1148.1836	34	29.611989
1.7751547	1154.577	41	35.51084	2.3128046	1148.7434	35	30.468075
1.8129727	1155.0217	42	36.362952	2.3770492	1149.4994	36	31.317981
1.8416227	1155.3589	43	37.217874	2.4368631	1150.2041	37	32.168203
1.9206968	1156.2903	44	38.052727	2.5077537	1151.0405	38	33.013609
2.0330048	1157.6159	45	38.872998	2.5852902	1151.9566	39	33.855441
2.0559248	1157.8868	46	39.727546	2.6207355	1152.3759	40	34.710895
2.1246848	1158.7002	47	40.562692	2.6739034	1153.0055	41	35.559242
2.1579189	1159.0938	48	41.411661	2.7093487	1153.4255	42	36.413274
2.1762549	1159.3111	49	42.266482	2.7636243	1154.0694	43	37.259459

2.2610589	1160.3169	50	43.091674	2.8101462	1154.6218	44	38.107717
2.3733669	1161.6518	51	43.903002	2.9031901	1155.7282	45	38.93649
2.411185	1162.1019	52	44.746505	2.9774036	1156.6122	46	39.771324
2.428375	1162.3067	53	45.598981	2.9906956	1156.7707	47	40.630351
2.478799	1162.9076	54	46.43533	3.0527249	1157.5108	48	41.468294
2.550997	1163.7692	55	47.260229	3.1435534	1158.5963	49	42.292557
2.624341	1164.6458	56	48.083289	3.2609659	1160.0025	50	43.103355
2.7171671	1165.7571	57	48.895264	3.2997342	1160.4676	51	43.947803
2.7813431	1166.5266	58	49.720255	3.3628711	1161.2257	52	44.780268
2.8363511	1167.187	59	50.548883	3.4525919	1162.3049	54	46.459412
2.8936512	1167.8758	60	51.375328	3.4614533	1162.4115	53	45.594867
2.9532432	1168.5929	61	52.19953	3.6165264	1164.2818	55	47.239424
2.9830392	1168.9518	62	53.038971	3.7461232	1165.8494	56	48.03365
3.0930552	1170.2789	63	53.833323	3.8081524	1166.6012	57	48.859886
3.1537933	1171.0128	65	55.507505	3.9067346	1167.798	58	49.666124
3.1744213	1171.2623	64	54.641902	4.0418697	1169.4426	59	50.451388
3.2787073	1172.5252	66	56.28877	4.103899	1170.199	60	51.27333
3.3577813	1173.4845	67	57.094915	4.2789101	1172.3385	61	52.032752
3.4059134	1174.0693	68	57.918217	4.335401	1173.0308	62	52.854537
3.4872794	1175.0591	69	58.720451	4.4727514	1174.7174	63	53.62992
3.6076094	1176.526	70	59.4972	4.5259194	1175.3716	64	54.450865
3.7646115	1178.4454	71	60.248867	4.6953921	1177.4617	66	56.052781
3.8413935	1179.3864	73	61.896594	4.7707133	1178.393	65	55.159868
3.8883796	1179.9629	72	61.018866	4.8648649	1179.5592	67	56.800881
4.0705936	1182.2042	74	62.594938	5.0321223	1181.6366	68	57.547303
4.0980976	1182.5433	75	63.422626	5.1384581	1182.9612	69	58.328203
4.3158377	1185.2343	76	64.122343	5.2835623	1184.7735	70	59.083025
4.4281458	1186.6271	77	64.889805	5.3311918	1185.3695	71	59.896933
4.5576438	1188.2371	78	65.643464	5.5704475	1188.3729	73	61.42853
4.7811139	1191.0258	79	66.329378	5.5970315	1188.7076	72	60.569986
4.8017419	1191.2839	80	67.154439	5.7487816	1190.6214	74	62.152417
4.8613339	1192.0301	81	67.951306	6.0821887	1194.8481	75	62.769483
5.1741921	1195.9629	82	68.563999				
5.2853541	1197.3666	83	69.318789				
5.5764382	1201.0577	84	69.938353				
5.8446023	1204.4785	85	70.569962				
5.9523264	1205.8581	86	71.318507				

b) Stress calculation

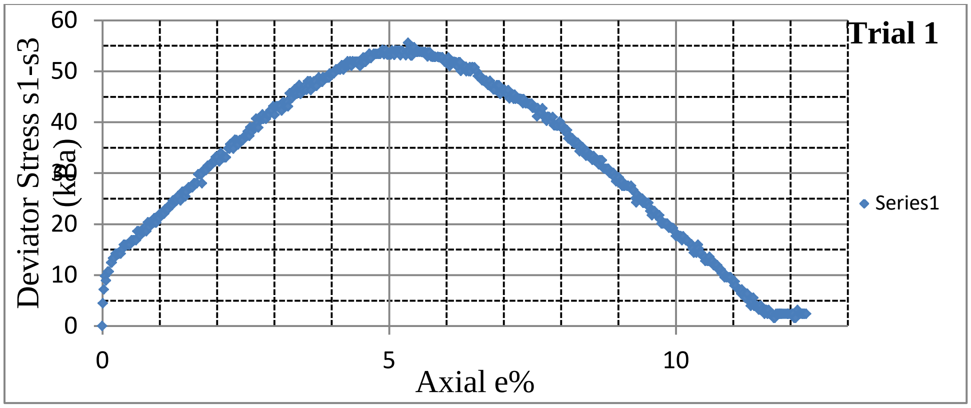
Trial 1					
Depth, m			1.5		
Sample Type			Undisturbed		
Sample Shape			Cylindrical		
Sample Heigth mm			88.8		
Sample Diameter mm			37.8		
Area, mm2			1124		
Volume cm33			99.8		
F	e	A	σ1–σ3	(σ1–σ3)$_{memb}$	(σ1–σ3)
Newton		cm^2	kPa	kPa	kPa
66	0.0534	1187	55.2	0.7	54.5

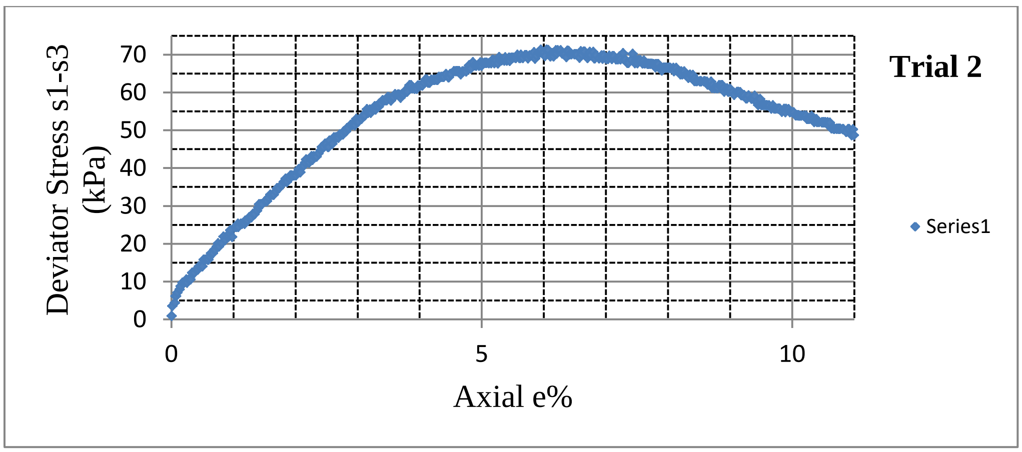
Trial 2					
Depth, m			1.5		
Sample Type			Undisturbed		
Sample Shape			Cylindrical		
Sample Height mm			87.3		
Sample Diameter mm			38		
Area mm2 2			1134.1		
Volume cm33			99		
F	e	A	σ1–σ3	(σ1–σ3)$_{memb}$	(σ1–σ3)
Newton		cm^2	kPa	kPa	kPa
86	0.0595	1206	71.4	0.8	70.6

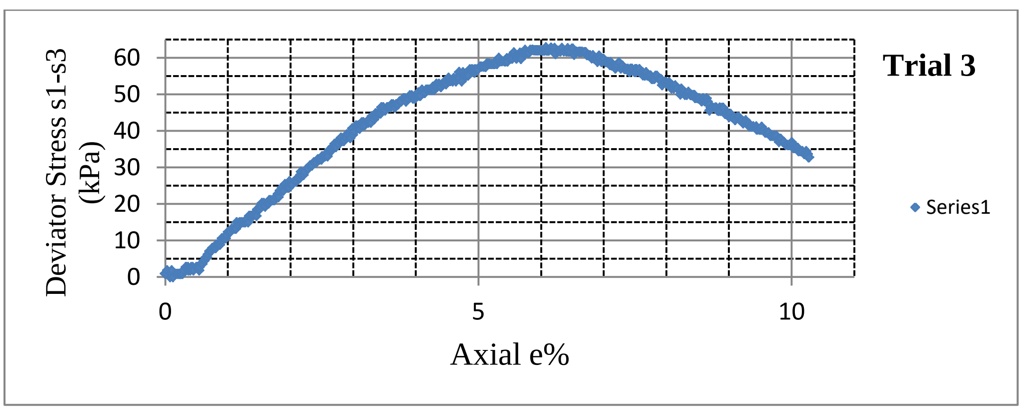
Trial 3					
Depth, m			1.5		
Sample Type			Undisturbed		
Sample Shape			Cylindrical		
Sample Heigth, mm			90.3		
Sample Diameter, mm			37.8		
Area, mm2			1122.2		
Volume, cm3			101.3		
F	e	A	σ1–σ3	(σ1–σ3)$_{memb}$	(σ1–σ3)
Newton		cm^2	kPa	kPa	kPa
75	0.0643	1199	62.7	0.8	61.9

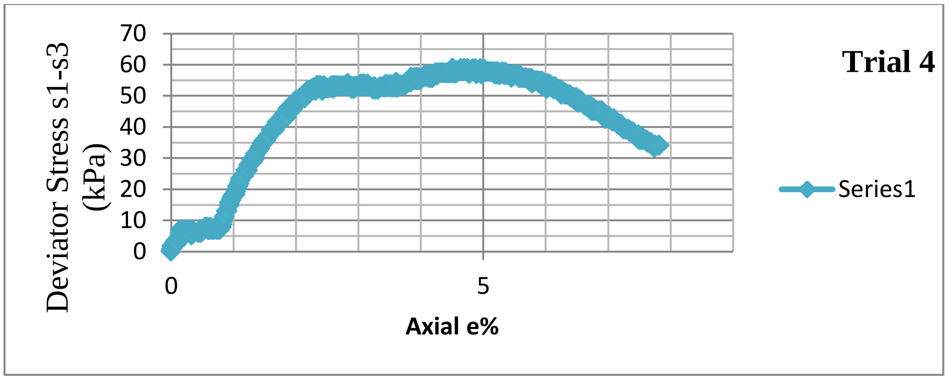
Trail 4					
Depth, m			1.5 m		
Sample Type			Undisturbed		
Sample Shape			cylindrical		
Sample Height, mm			89		
Sample Diameter, mm			38		
Area, mm2			1134.1		
Volume, cm3			100.9		
F	e	A	σ1–σ3	(σ1–σ3)$_{memb}$	(σ1–σ3)
Newton		cm^2	kPa	kPa	kPa
70	0.0469	1190	59.1	0.6	58.6

c) Stress - strain curves drawn from the data









A.9 Compaction Data for Determination of MDD and OMC

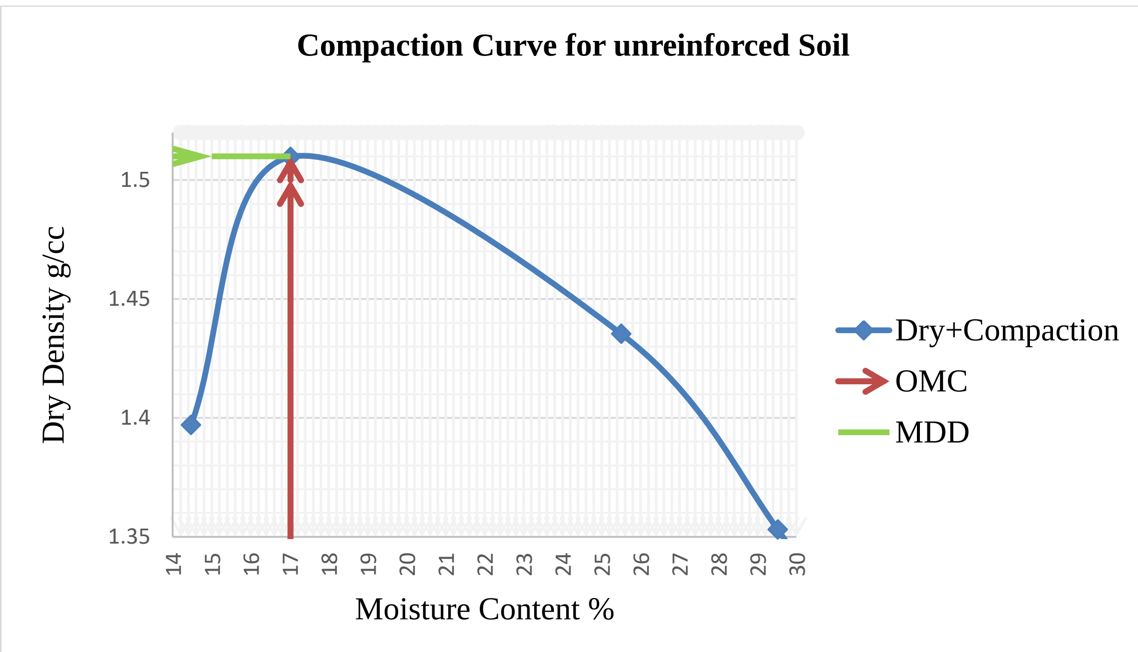
a) Moisture Content Determination for Compacted Natural Soil

Moisture Content Determination						
Compacted Soil Sample No.	**1 (400ml)**			**2 (600ml)**		
Container Code.	P3	P15	J41	G190	SB	A
Mass of Wet soil + Container(gm)(F)	141.1	184.5	204.9	141.6	119.8	131.6
Mass of dry soil + container(gm)(G)	127.9	164	183.4	125.7	106.4	117.7
Mass of container(gm)(H)	35.9	25.4	32.8	34.1	25.1	37
Mass of moisture(gm)F-G=(I)	13.2	20.5	21.5	15.9	13.4	13.9
Mass of Dry soil(gm)G-H=(J)	92	138.6	150.6	91.6	81.3	80.7
Moisture content % (I/J)*100=w	14.35	14.79	14.28	17.36	16.48	17.22
Actual Average water content			**14.47**			**17.02**
Compacted Soil Sample No.	**3 (1000ml)**			**4 (1300ml)**		
Container Code.	12	T3	02-2	2	P67	F
Mass of Wet soil +Container(gm)(F)	142.6	154.3	113.1	160.5	229.1	212.2
Mass of dry soil + container(gm)(G)	122.3	130.6	95.7	129.9	181.5	168.9
Mass of container(gm)(H)	41.2	37.6	28.8	34.5	35.5	36.5
Mass of moisture(gm)F-G=(I)	20.3	23.7	17.4	30.6	47.6	43.3
Mass of Dry soil(gm)G-H=(J)	81.1	93	66.9	95.4	146	132.4
Moisture content % (I/J)*100=w	25.03	25.48	26.01	32.08	32.60	32.70
Actual Average water content			**25.51**			**32.46**
Compacted Soil Sample No.	**5 (1150ml)**					
Container Code.	G19	E	D			
Mass of Wet soil + Container(gm)(F)	154.7	177	191.9			
Mass of dry soil + container(gm)(G)	127.6	145.7	154.5			
Mass of container(gm)(H)	36	37.9	29.6			
Mass of moisture(gm)F-G=(I)	27.1	31.3	37.4			
Mass of Dry soil(gm)G-H=(J)	91.6	107.8	124.9			

Moisture content % (I/J)*100=w	29.59	29.04	29.94			
Actual Average water content			**29.52**			

b) Dry Density Determination for compacted Natural Soil

Density Determination					
Test No.	1	2	3	4	5
Actual Average Water Content (w)	**14.47**	**17.02**	**25.51**	**32.46**	**29.52**
Mass of sample (gm)	500	500	500	500	500
Water Added(cc)	400	600	1000	1150	1300
Mass of Mold+Wet soil(gm)(A)	10265	10647.9	10727.2	10471.9	10615.4
Mass of Mold(gm)(B)	6611	6611	6611	6611	6611
Mass of Wet Soil(gm)A-B=C	3654	4036.9	4116.2	3860.9	4004.4
Volume of Mold cm^3(D)	2285.00	2285.00	2285.00	2285.00	2285.00
Bulk Density gm/cm^3 C/D=(E)	**1.60**	**1.77**	**1.80**	**1.69**	**1.75**
Dry Density gm/cm^3 E/(100+w)*100	1.3969619	1.5097189	1.435288617	1.275602203	1.353036589
Summary of Moisture Content and Dry Density					
Water Content, w%	14.47	17.02	25.51	29.52	32.46
Dry Density (g/cm3	**1.3969619**	**1.509718887**	**1.435288617**	**1.353036589**	**1.275602203**



A.9 California Bearing Ratio (CBR) and CBR Swell of Natural soil Data

Trial -1

COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		N9	N9	TN	TN	N6	N6
Mass of soil + Mould	g	13508.5	14024.5	13475.5	14046	12923.5	13616.5
Mass Mould	g	9376	9376	9560	9560	9408	9408
Mass of Soil	g	4132.5	4648.5	3915.5	4486	3515.5	4208.5
Volume of Mould	g	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.809	2.034	1.714	1.963	1.539	1.842
Dry density of soil	g/cc	1.545	1.573	1.461	1.506	1.311	1.385

Moisture Determination

MOISTURE CONTENT DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.		B	Z	F	T	D	B
Mass of wet soil + Container	g	232.42	173.04	230.84	180.40	222.84	201.50
Mass of dry soil + Container	g	203.16	137.99	202.27	142.40	194.31	155.89
Mass of container	g	31.49	18.46	36.76	17.10	29.78	17.69
Mass of water	g	29.26	35.05	28.56	38.00	28.53	45.61
Mass of drysoil	g	171.66	119.52	165.52	125.29	164.53	138.21
Moisture content	%	17.05	29.33	17.26	30.33	17.34	33.00

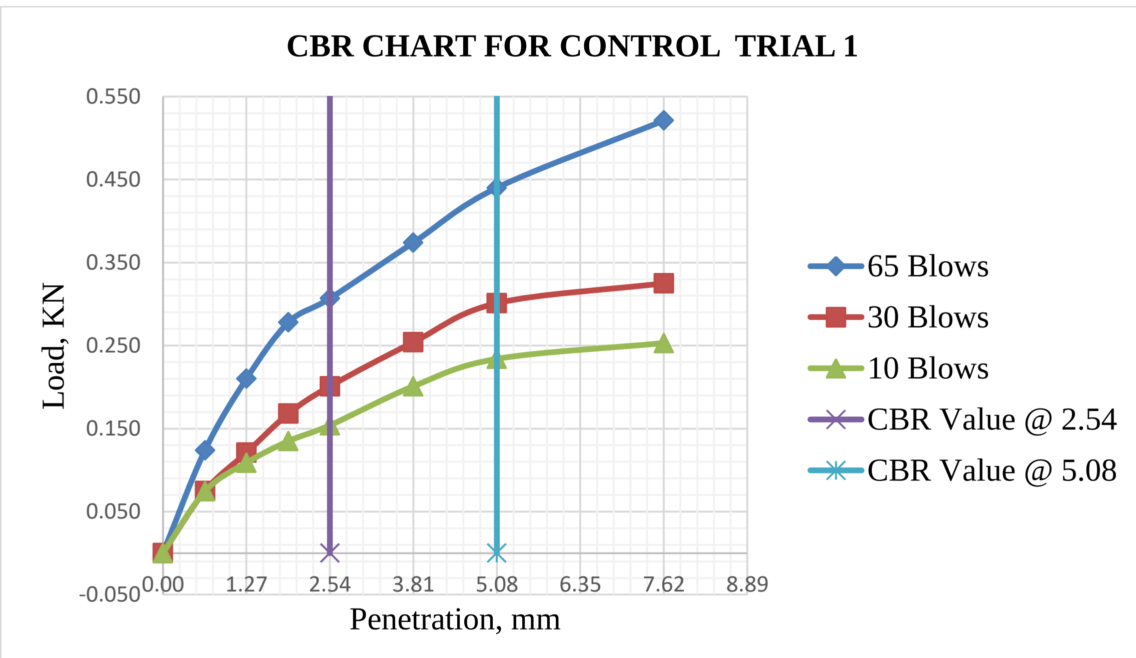
CBR Penetration Determination

Penetration after 96 hrs Soaking Period	**Surcharge Weight:-4.55 KG**

65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen. mm**	**Load, KN**	**CBR %**	**Pen. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.124		0.64	0.075		0.64	0.075	
1.27	0.210		1.27	0.121		1.27	0.109	
1.91	0.278		1.91	0.168		1.91	0.135	
2.54	0.307	2.30	2.54	0.201	1.51	2.54	0.154	1.15
3.81	0.374		3.81	0.254		3.81	0.201	
5.08	0.440	2.20	5.08	0.301	1.51	5.08	0.234	1.17
7.62	0.521		7.62	0.325		7.62	0.253	

Modified Max.Dry Density g/cc			1.510		OMC %		17.0	
Swell Determination								
Date		65 Blows		30 Blows		10 Blows		
		Gauge rdg	Swell in %	Gauge rdg	Swell in %	Gauge rdg	Swell in %	
		mm		mm		mm		
20/10/2020	Initial	0.00	9.04	0.1	7.75	0.10	4.56	
24/10/2020	Final	10.52		9.12		5.41		

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.3	1.31	1.17	87	
30	17.3	1.46	1.51	97	
65	17.0	1.55	2.31	102	
CBR at MDD, %			2.0	Swell at MDD, %	9.00



Trial -2

COMPACTION DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		N2	N2	N30	N30	N7	N7
Mass of soil + Mould	g	13487.5	14024	13324.5	13940	12780.5	13517
Mass Mould	g	9293.5	9293.5	9395.5	9395.5	9331.5	9331.5
Mass of Soil	g	4194	4730.5	3929	4544.5	3449	4185.5
Volume of Mould	g	2124	2124	2124	2124	2124	2124
Wet density of soil	g/cc	1.975	2.227	1.850	2.140	1.624	1.971
Dry density of soil	g/cc	1.682	1.670	1.578	1.580	1.384	1.437

Moisture Determination

MOISTURE CONTENT DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		2B	J41	A	1A	C10	NB
Mass of wet soil + Container	g	156.20	301.00	131.99	183.00	217.63	194.00
Mass of dry soil + Container	g	137.15	233.90	115.21	139.75	190.73	146.21
Mass of container	g	27.85	32.78	17.69	17.70	35.83	17.61
Mass of water	g	19.05	67.11	16.78	43.25	26.90	47.79
Mass of drysoil	g	109.30	201.12	97.52	122.05	154.90	128.60
Moisture content	%	17.43	33.37	17.21	35.43	17.37	37.16

CBR Penetration Determination

Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.130		0.64	0.079		0.64	0.062	
1.27	0.231		1.27	0.133		1.27	0.099	
1.91	0.303		1.91	0.183		1.91	0.123	
2.54	0.353	2.65	2.54	0.231	1.73	2.54	0.145	1.09
3.81	0.421		3.81	0.289		3.81	0.189	
5.08	0.488	2.44	5.08	0.334	1.67	5.08	0.218	1.09
7.62	0.547		7.62	0.341		7.62	0.241	

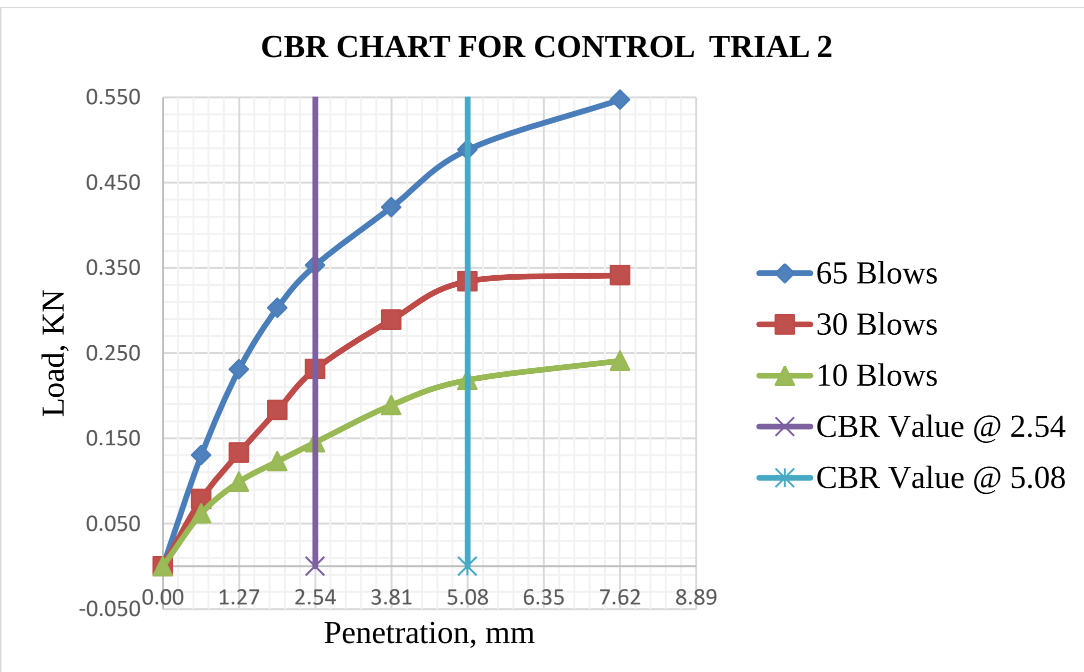
Modified Max.Dry Density g/cc	1.511	OMC %	17.0

Swell Determination

Date		65 Blows	30 Blows	10 Blows

		Gauge rdg	Swell in %	Gauge rdg	Swell in %	Gauge rdg	Swell in %
		mm		mm		mm	
20/10/2020	Initial	0.00	9.46	0.4	7.26	0.00	4.40
24/10/2020	Final	11.01		8.85		5.12	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.4	1.38	1.09	92	
30	17.2	1.58	1.74	104	
65	17.4	1.68	2.65	111	
CBR at MDD, %			1.6	Swell at MDD, %	8.90
Average CBR, %			1.8	Average Swell, %	8.95



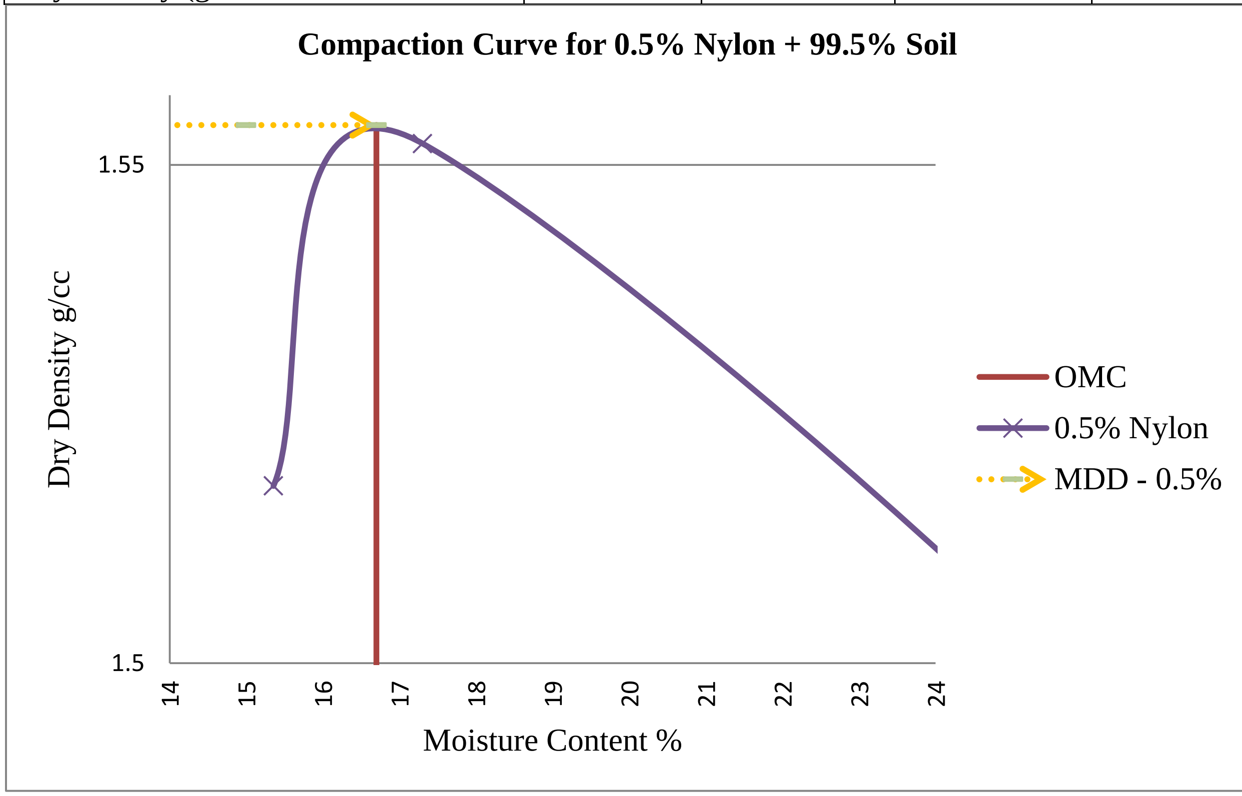
Appendix B: - Laboratory Data Analysis for Reinforced Soil

B1. Data Analysis for Density Moisture Relation

i. Compaction Data for 0.5% Nylon Synthetic Fiber Reinforced with Soil

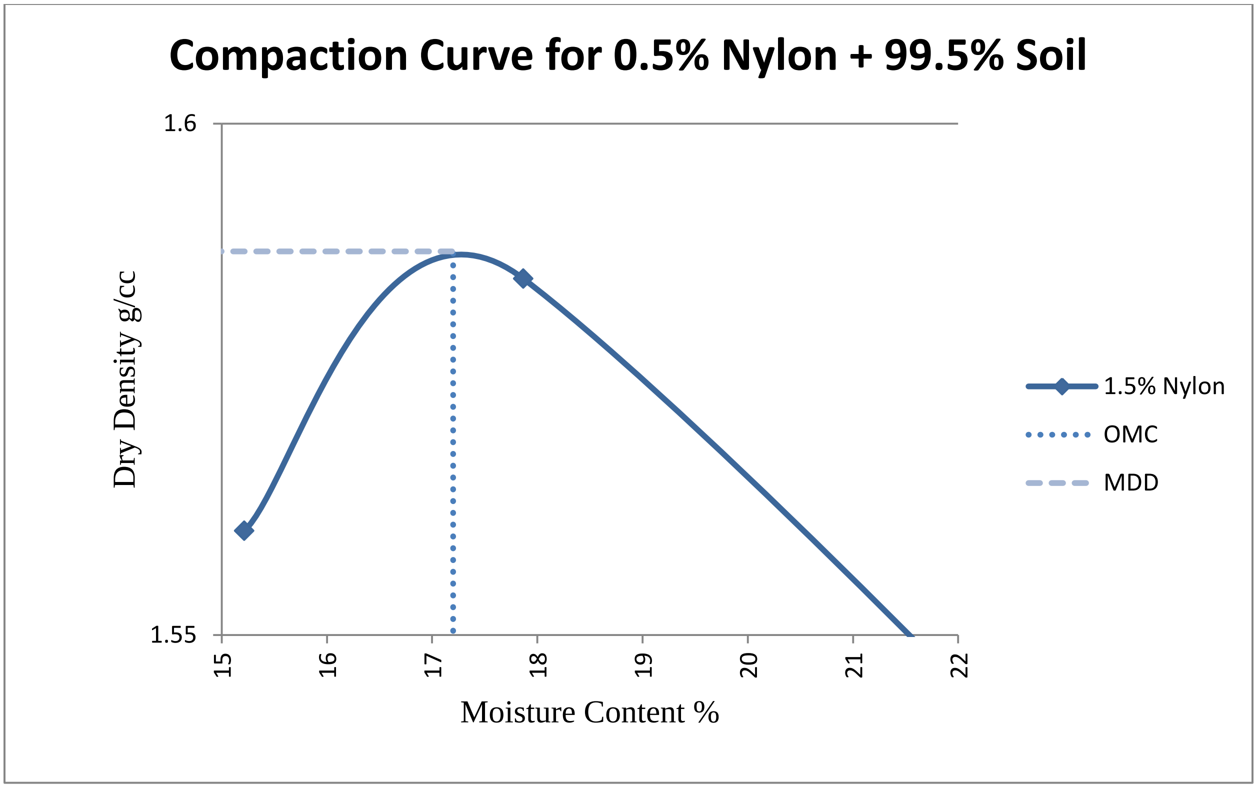
Moisture Content Determination (0.5% Nylon Fiber)				
Compacted Soil Sample No.	**1(500ml)**		**2(600ml)**	
Container Code .	1B	1A	2C	2B
Mass of Wet soil+Container(gm)(F)	153	133.1	172.4	169.5
Mass of dry soil+container(gm)(G)	135.5	117.2	152.1	147.55
Mass of container(gm)(H)	16.7	17.7	27.5	27.7
Mass of moisture(gm)F-G=(I)	17.5	15.9	20.3	21.95
Mass of Dry soil(gm)G-H=(J)	118.8	99.5	124.6	119.85
Moisture content % (I/J)*100=w	14.73	15.98	16.29	18.31
Actual Average water content	**15.36**		**17.30**	
Compacted Soil Sample No.	**3(1150ml)**		**4(1400ml)**	
Container Code .	4C	3B	4A	4B
Mass of Wet soil+Container(gm)(F)	180.5	204.1	252	251.2
Mass of dry soil+container(gm)(G)	141.2	160.4	192.5	192.7
Mass of container(gm)(H)	18.5	18.2	17.4	26.4
Mass of moisture(gm)F-G=(I)	39.3	43.7	59.5	58.5
Mass of Dry soil(gm)G-H=(J)	122.7	142.2	175.1	166.3
Moisture content % (I/J)*100=w	32.03	30.73	33.98	35.18
Actual Average water content	**31.38**		**34.58**	
Density Determination				
Compacted Soil Sample No.	1	2	3	4
Actual Average Water Content (w)	**15.36**	**17.30**	**31.38**	**34.58**
Mass of sample (gm)	5000	5000	5000	5000
Water Added(cc)	500	600	1150	1400
Mass of Mold+Wet soil(gm)(A)	10593.5	10728.3	10945.7	10736.0
Mass of Mold(gm)(B)	6592.8	6568	6595.4	6620.1
Mass of Wet Soil(gm)A-B=C	4000.6655	4160.3069	4350.319783	4115.931593
Volume of Mold cm^3(D)	2285.00	2285.00	2285.00	2285.00
Bulk Density g/cm^3 C/D=(E)	**1.75**	**1.82**	**1.90**	**1.80**
Dry Density g/cm^3 E/(100+w)*100	1.5177792	1.5521324	1.449120688	1.338457824
Summary of Moisture Content and Dry Density				
Water Content, w%	15.36	17.30	31.38	34.58

Dry Density (g/cm3	1.517779	1.5521324	1.4491207	1.3384578



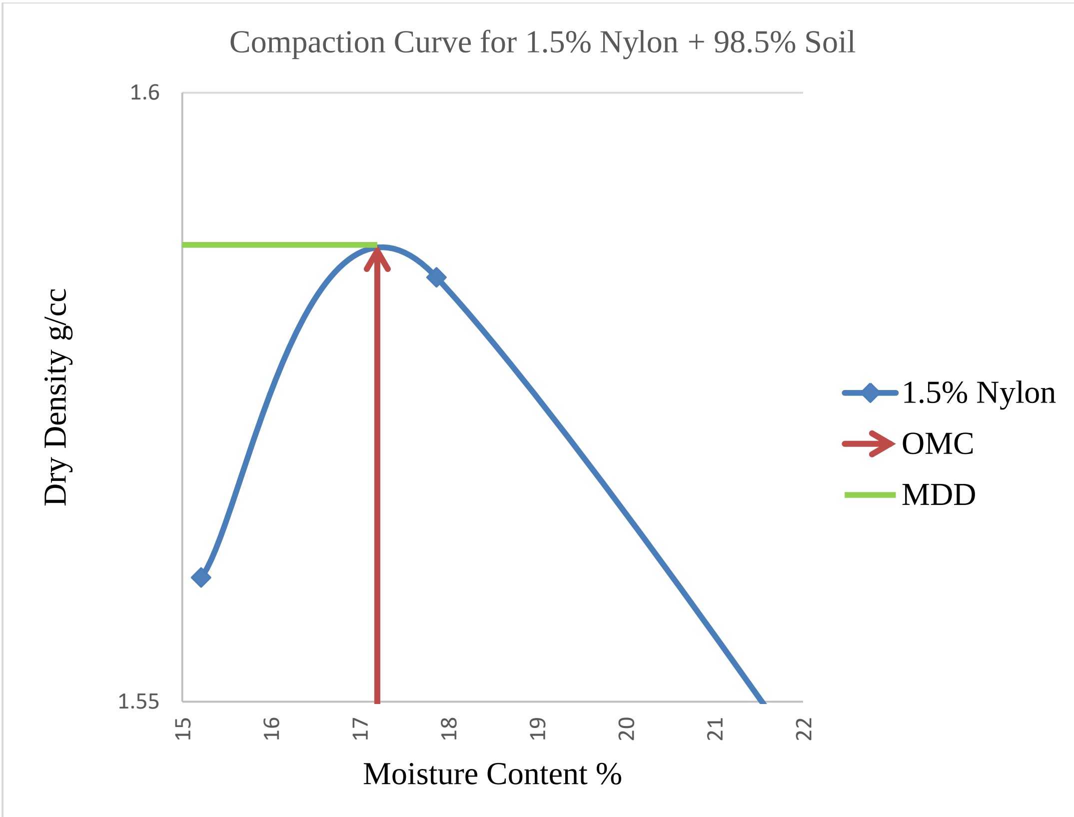
ii. Compaction Data for 1% Nylon Synthetic Fiber Reinforced with Soil

Moisture Content Determination (1% Nylon Fiber)				
Compacted Soil Sample No.	**1(500ml)**		**2(600ml)**	
Container Code .	1A	1B	2A	2B
Mass of Wet soil+Container(gm)(F)	153.1	132.5	171.9	168.4
Mass of dry soil+container(gm)(G)	136.2	117.4	151.2	147
Mass of container(gm)(H)	16.6	17.7	27.6	27.7
Mass of moisture(gm)F-G=(I)	16.9	15.1	20.7	21.4
Mass of Dry soil(gm)G-H=(J)	119.6	99.7	123.6	119.3
Moisture content % (I/J)*100=w	14.13	15.15	16.75	17.94
Actual Average water content	**14.64**		**17.34**	
Compacted Soil Sample No.	**3(1150ml)**		**4(1400ml)**	
Container Code .	3A	3B	4A	4B
Mass of Wet soil+Container(gm)(F)	179.6	203.7	249.2	252.9
Mass of dry soil+container(gm)(G)	139.7	159	191.8	194.1
Mass of container(gm)(H)	18.3	18.2	17.4	26.4
Mass of moisture(gm)F-G=(I)	39.9	44.7	57.4	58.8
Mass of Dry soil(gm)G-H=(J)	121.4	140.8	174.4	167.7
Moisture content % (I/J)*100=w	32.87	31.75	32.91	35.06
Actual Average water content	**32.31**		**33.99**	
Density Determination				
Compacted Soil Sample No.	1	2	3	4
Actual Average Water Content (w)	**14.64**	**17.34**	**32.31**	**33.99**
Mass of sample (gm)	5000	5000	5000	5000
Water Added(cc)	500	600	1150	1400
Mass of Mold+Wet soil(gm)(A)	10603.9	10758.9	10989.8	10532.3
Mass of Mold(gm)(B)	6592.8	6568	6595.4	6620.1
Mass of Wet Soil(gm)A-B=C	4011.0982	4190.872	4394.4208	3912.2103
Volume of Mold cm^3(D)	2285.00	2285.00	2285.00	2285.00
Bulk Density g/cm^3 C/D=(E)	**1.76**	**1.83**	**1.92**	**1.71**
Dry Density g/cm^3 E/(100+w)*100	1.53125928	1.56301	1.4535604	1.2778238
Summary of Moisture Content and Dry Density				
Water Content, w%	14.64	17.34	32.31	33.99
Dry Density (g/cm3	1.53125928	1.56301	1.4535604	1.2778238


Compaction Curve for 0.5% Nylon + 99.5% Soil
1.6
1.55
Dry Density g/cc
15
16
17
18
19
20
21
22
Moisture Content %
1.5% Nylon
OMC
MDD

iii. Compaction Data for 1.5% Nylon Synthetic Fiber Reinforced with Soil

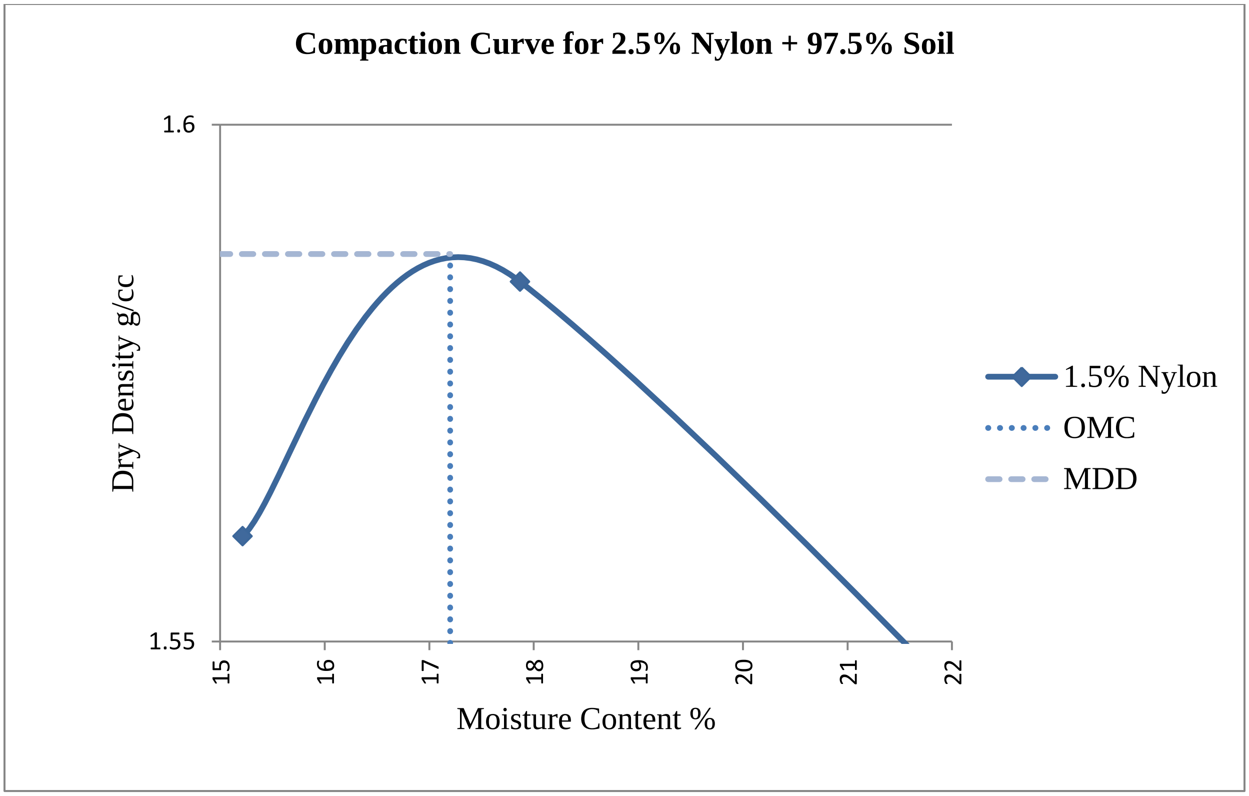
Moisture Content Determination (1.5% Nylon Fiber)				
Compacted Soil Sample No.	**1(500ml)**		**2(600ml)**	
Container Code .	1A	1B	2A	2B
Mass of Wet soil+Container(gm)(F)	152	131.3	173.2	168.4
Mass of dry soil+container(gm)(G)	134.6	115.9	151.2	147
Mass of container(gm)(H)	16.6	17.7	27.6	27.7
Mass of moisture(gm)F-G=(I)	17.4	15.4	22	21.4
Mass of Dry soil(gm)G-H=(J)	118	98.2	123.6	119.3
Moisture content % (I/J)*100=w	14.75	15.68	17.80	17.94
Actual Average water content	**15.21**		**17.87**	
Compacted Soil Sample No.	**3(1150ml)**		**4(1400ml)**	
Container Code .	3A	3B	4A	4B
Mass of Wet soil+Container(gm)(F)	179.6	203.7	249.2	252.9
Mass of dry soil+container(gm)(G)	140.2	159.5	192.3	194.6
Mass of container(gm)(H)	18.3	18.2	17.4	26.4
Mass of moisture(gm)F-G=(I)	39.4	44.2	56.9	58.3
Mass of Dry soil(gm)G-H=(J)	121.9	141.3	174.9	168.2
Moisture content % (I/J)*100=w	32.32	31.28	32.53	34.66
Actual Average water content	**31.80**		**33.60**	
Density Determination				
Compacted Soil Sample No.	1	2	3	4
Actual Average Water Content (w)	**15.21**	**17.87**	**31.80**	**33.60**
Mass of sample (gm)	5000	5000	5000	5000
Water Added(cc)	500	600	1150	1400
Mass of Mold+Wet soil(gm)(A)	10700.2	10836.4	10902.6	10736.3
Mass of Mold(gm)(B)	6592.8	6568	6595.4	6620.1
Mass of Wet Soil(gm)A-B=C	4107.4	4268.4	4307.2	4116.2
Volume of Mold cm^3(D)	2285.00	2285.00	2285.00	2285.00
Bulk Density g/cm^3 C/D=(E)	**1.80**	**1.87**	**1.88**	**1.80**
Dry Density g/cm^3 E/(100+w)*100	1.5601827	1.584822	1.4301752	1.3483839
Summary of Moisture Content and Dry Density				
Water Content, w%	15.21	17.87	31.80	33.60
Dry Density (g/cm3	1.5601827	1.584822	1.4301752	1.3483839


Compaction Curve for 1.5% Nylon + 98.5% Soil
Dry Density g/cc
1.6
1.55
15
16
17
18
19
20
21
22
Moisture Content %
1.5% Nylon
OMC
MDD

iv. Compaction Data for 2.5% Nylon Synthetic Fiber Reinforced with Soil

Moisture Content Determination (2.5% Nylon Fiber)				
Compacted Soil Sample No.	**1(500ml)**		**2(600ml)**	
Container Code .	1A	1B	2A	2B
Mass of Wet soil+Container(gm)(F)	152	131.3	173.2	168.4
Mass of dry soil+container(gm)(G)	134.6	115.9	151.2	147
Mass of container(gm)(H)	16.6	17.7	27.6	27.7
Mass of moisture(gm)F-G=(I)	17.4	15.4	22	21.4
Mass of Dry soil(gm)G-H=(J)	118	98.2	123.6	119.3
Moisture content % (I/J)*100=w	14.75	15.68	17.80	17.94
Actual Average water content	**15.21**		**17.87**	
Compacted Soil Sample No.	**3(1150ml)**		**4(1400ml)**	
Container Code .	3A	3B	4A	4B
Mass of Wet soil+Container(gm)(F)	179.6	203.7	249.2	252.9
Mass of dry soil+container(gm)(G)	140.2	159.5	192.3	194.6
Mass of container(gm)(H)	18.3	18.2	17.4	26.4
Mass of moisture(gm)F-G=(I)	39.4	44.2	56.9	58.3
Mass of Dry soil(gm)G-H=(J)	121.9	141.3	174.9	168.2
Moisture content % (I/J)*100=w	32.32	31.28	32.53	34.66
Actual Average water content	**31.80**		**33.60**	
Density Determination				
Compacted Soil Sample No.	1	2	3	4
Actual Average Water Content (w)	**15.21**	**17.87**	**31.80**	**33.60**
Mass of sample (gm)	5000	5000	5000	5000
Water Added(cc)	500	600	1150	1400
Mass of Mold+Wet soil(gm)(A)	10668.099	10803.891	10651.8402	10382.0021
Mass of Mold(gm)(B)	6592.8	6568	6595.4	6620.1
Mass of Wet Soil(gm)A-B=C	4075.2994	4235.8908	4056.4402	3761.9021
Volume of Mold cm^3(D)	2285.00	2285.00	2285.00	2285.00
Bulk Density g/cm^3 C/D=(E)	**1.78**	**1.85**	**1.78**	**1.65**
Dry Density g/cm^3 E/(100+w)*100	1.5479894	1.5727518	1.346912187	1.232323099
Summary of Moisture Content and Dry Density				
Water Content, w%	15.21	17.87	31.80	33.60

Dry Density (g/cm3	1.547989 4	1.5727518	1.346912187	1.232323099


Compaction Curve for 2.5% Nylon + 97.5% Soil
1.6
1.55
Dry Density g/cc
15
16
17
18
19
20
21
22
Moisture Content %
1.5% Nylon
OMC
MDD

B 2. Laboratory Data Analysis on CBR values in Different Aspect Ratio (Length/Diameter)

B 2.1 CBR Laboratory Data Analysis of 0.5% for 0.3mm diameter and 10 mm Length

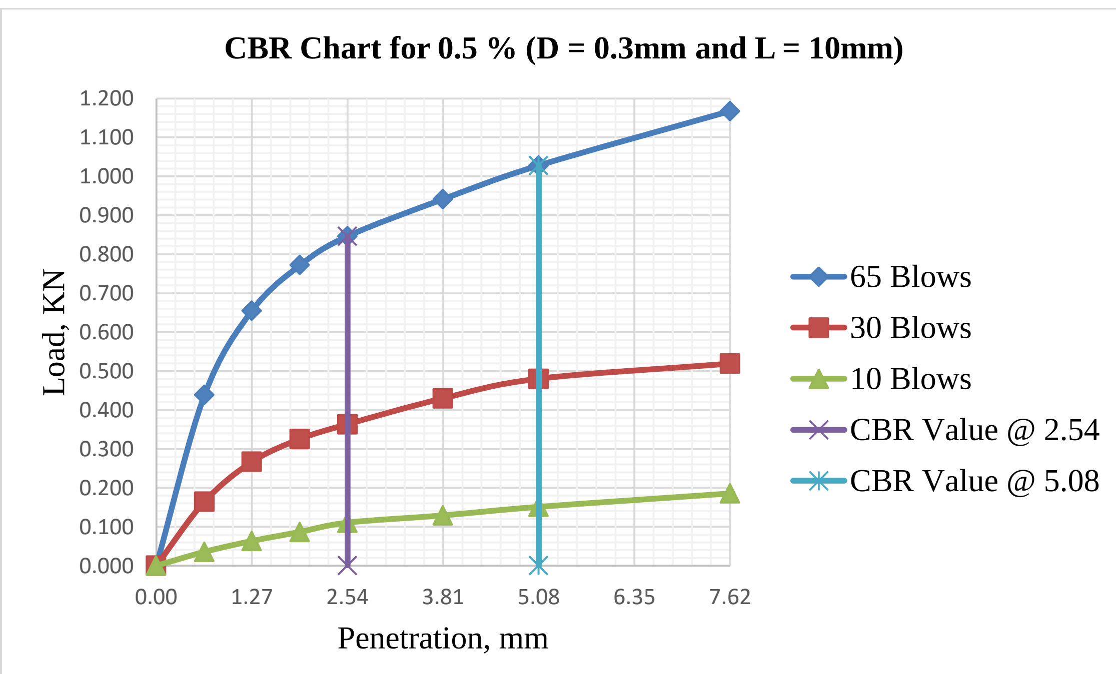
Fiber Content= 0.5%		**Fiber length =10mm**			**Fiber Diameter = 0.3mm**	
CBR Data						
COMPACTION DATA	**65 Blows**		**30 Blows**		**10 Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.	N9	N9	TN	TN	N6	N6
Mass of soil + Mould g	13557.5	14109	13446.5	14033	12972.5	13674
Mass Mould g	9365.5	9365.5	9432	9432	9392.5	9392.5
Mass of Soil g	4192	4743.5	4014.5	4601	3580	4281.5
Volume of Mould g	2285	2285	2285	2285	2285	2285
Wet density of soil g/cc	1.835	2.076	1.757	2.014	1.567	1.874
Dry density of soil g/cc	1.563	1.603	1.500	1.532	1.337	1.349

Moisture Determination						
MOISTURE CONTENT DATA	**65 Blows**		**30 Blows**		**10 Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.	F	K4	B	DH	A14	HC
Mass of wet soil + Container g	226.10	156.10	229.50	155.88	222.90	181.32
Mass of dry soil + Container g	198.00	124.61	200.50	122.71	194.50	135.51
Mass of container g	36.50	17.91	31.00	17.06	29.00	17.73
Mass of water g	28.10	31.49	29.00	33.17	28.40	45.80
Mass of drysoil g	161.50	106.70	169.50	105.65	165.50	117.78
Moisture content %	17.40	29.51	17.11	31.40	17.16	38.89

CBR Penetration Determination								
Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**					
65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen. mm**	**Load, KN**	**CBR %**	**Pen. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.438		0.64	0.165		0.64	0.036	
1.27	0.655		1.27	0.267		1.27	0.064	
1.91	0.772		1.91	0.326		1.91	0.087	
2.54	0.846	6.41	2.54	0.364	2.75	2.54	0.111	0.84
3.81	0.942		3.81	0.430		3.81	0.129	
5.08	1.028	5.14	5.08	0.480	2.40	5.08	0.151	0.76

7.62	1.168		7.62	0.519		7.62	0.186
Modified Max.Dry Density g/cc		**1.503**		**OMC %**		**17.2**	
Swell Determination							
Date		**65 Blows**		**30 Blows**		**10 Blows**	
		Gauge Rdg mm	**Swell in %**	**Gauge Rdg mm**	**Swell in %**	**Gauge Rdg mm**	**Swell in %**
17/12/2020	Initial	0.13	8.57	0.14	7.16	0.12	3.29
21/12/2020	Final	10.10		8.48		3.95	

No.of blows	**MCBS %**	**DDBS g/cm3**	**Correcrt CBR %**	**% OF Compaction**	
10	17.2	1.337	0.84	89	
30	17.1	1.500	2.73	100	
65	17.4	1.563	6.36	104	
CBR % at MDD			**5.03**	**Swell %**	**8.22**



B 2.2 CBR Laboratory Data Analysis of 1% for 0.3mm diameter and 10 mm Length

Fiber Content = 1%	Fiber Length = 10 mm	Fiber Diameter = 0.3 mm

Trial 1 (AR = 33.33)

COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		A1	A1	B1	B1	C1	C1
Mass of soil + Mould	g	13510	14084.5	13186.5	13796	12764.1	13483.5
Mass Mould	g	9366.9	9366.9	9278.9	9278.9	9285.8	9285.8
Mass of Soil	g	4143.1	4717.6	3907.6	4517.1	3478.3	4197.7
Volume of Mould	g	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.813	2.065	1.710	1.977	1.522	1.837
Dry density of soil	g/cc	1.546	1.588	1.460	1.509	1.300	1.333

Moisture Determination

MOISTURE CONTENT DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.		O	PS	SS	I3	3A	A1
Mass of wet soil + Container	g	153.80	142.97	143.30	142.94	124.50	143.97
Mass of dry soil + Container	g	135.20	113.96	125.00	113.24	109.00	109.06
Mass of container	g	27.50	17.31	18.10	17.46	18.30	16.81
Mass of water	g	18.60	29.01	18.30	29.70	15.50	34.91
Mass of drysoil	g	107.70	96.65	106.90	95.79	90.70	92.25
Moisture content	%	17.27	30.02	17.12	31.00	17.09	37.84

CBR Penetration Determination

Penetration after 96 hrs Soaking Period — **Surcharge Weight:-4.55 KG**

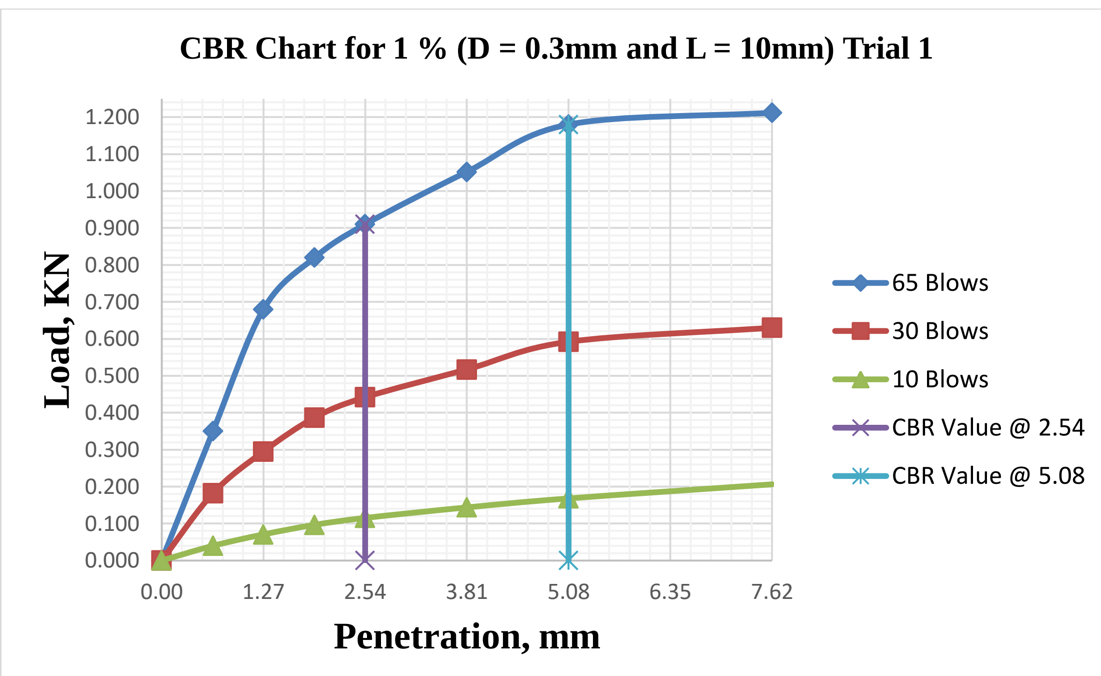
65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.350		0.64	0.182		0.64	0.040	
1.27	0.680		1.27	0.295		1.27	0.071	
1.91	0.820		1.91	0.387		1.91	0.097	
2.54	0.910	6.89	2.54	0.442	3.35	2.54	0.115	0.87
3.81	1.052		3.81	0.517		3.81	0.144	
5.08	1.180	5.90	5.08	0.592	2.96	5.08	0.168	0.84
7.62	1.212		7.62	0.630		7.62	0.206	

Modified Max.Dry Density g/cc	**1.504**	**OMC %**	**17.0**

Swell Determination

Date		**65 Blows**	**30 Blows**	**10 Blows**

		Gauge rdg	**Swell in %**	**Gauge rdg**	**Swell in %**	**Gauge rdg**	**Swell in %**
		mm		mm		mm	
13/01/2021	Initial	0.00	7.30	1	5.58	0.00	5.49
17/01/2021	Final	8.50		7.49		6.39	
No. of blows	**MCBS %**	**DDBS g/cm3**	**Correct CBR %**	**% of Compaction**			
10	17.089	1.3001	0.87	86.44			
30	17.119	1.4601	3.32	97.08			
65	17.270	1.546	6.84	102.80			
CBR % at MDD			**5.9**	**Swell %**	**6.85**		



Fiber Content = 1%	Fiber Length = 10 mm	Fiber Diameter = 0.3 mm

Trial 2 (AR = 33.33)

COMPACTION DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		N2	N2	N30	N30	N7	N7
Mass of soil + Mould	g	13537.1	14093	13324.5	13955.5	12954.7	13680.9
Mass Mould	g	9390.9	9390.9	9450.6	9450.6	9376.4	9376.4
Mass of Soil	g	4146.2	4702.1	3873.9	4504.9	3578.3	4304.5
Volume of Mould	g	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.815	2.058	1.695	1.972	1.566	1.884
Dry density of soil	g/cc	1.553	1.607	1.454	1.506	1.348	1.372

Moisture Determination

MOISTURE CONTENT DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		P4	Z	HC11	K4	G3T3	I3
Mass of wet soil + Container	g	134.40	130.19	138.20	187.47	149.30	157.19
Mass of dry soil + Container	g	117.50	105.75	121.00	147.43	131.00	119.45
Mass of container	g	17.10	18.50	17.60	17.90	17.90	18.39
Mass of water	g	16.90	24.45	17.20	40.04	18.30	37.74
Mass of drysoil	g	100.40	87.25	103.40	129.54	113.10	101.07
Moisture content	%	16.83	28.02	16.63	30.91	16.18	37.34

CBR Penetration Determination

Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.462		0.64	0.181		0.64	0.064	
1.27	0.689		1.27	0.293		1.27	0.104	
1.91	0.813		1.91	0.358		1.91	0.126	
2.54	0.891	6.75	2.54	0.400	3.03	2.54	0.141	1.07
3.81	0.991		3.81	0.473		3.81	0.167	
5.08	1.082	5.41	5.08	0.528	2.64	5.08	0.186	0.93
7.62	1.229		7.62	0.570		7.62	0.202	

Modified Max.Dry Density g/cc	1.504	OMC %	40.2

Swell Determination

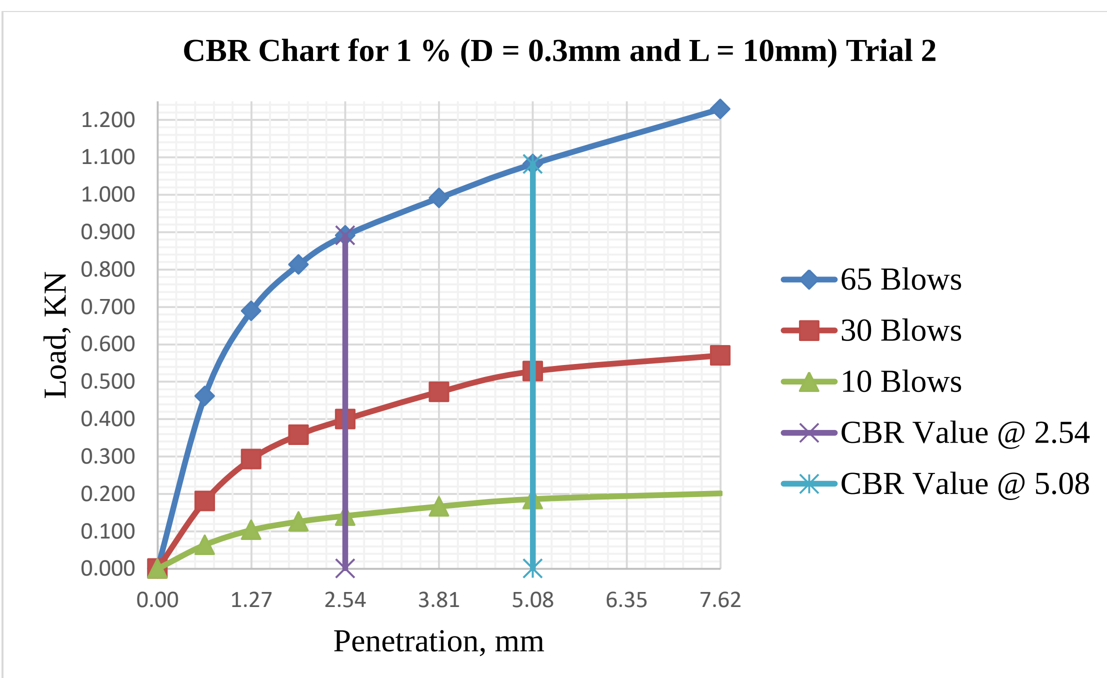
Date		65 Blows	30 Blows	10 Blows

		Gauge rdg	Swell in %	Gauge rdg	Swell in %	Gauge rdg	Swell in %
		mm		mm		mm	
13/01/2021	Initial	0.20	7.73	1.01	6.18	1.20	5.45
17/01/2021	Final	9.20		8.20		7.54	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction
10	16.18	1.35	1.07	89.62
30	16.63	1.45	3.00	96.65
65	16.83	1.55	6.70	103.26

CBR % at MDD	**5.7**	**Swell %**	**7.33**

Average CBR (%)	**5.83**
Average Swell (%)	**7.09**



CBR Chart for 1 % (D = 0.3mm and L = 10mm) Trial 2

B 2.3 CBR Laboratory Data Analysis of 1.5% for 0.3 mm diameter and 10 mm Length

Fiber Content = 1.5%		Fiber Length = 10 mm		Fiber Diameter = 0.3 mm		
Trial 1 (AR = 33.33)						
COMPACTION DATA	**65 Blows**		**30 Blows**		**10 Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.	N9	N9	TN	TN	N6	N6
Mass of soil + Mould g	13460.9	14047.5	13170.6	13788	12975	13702.5
Mass Mould g	9361.8	9361.8	9320.9	9320.9	9410.1	9410.1
Mass of Soil g	4099.1	4685.7	3849.7	4467.1	3564.9	4292.4
Volume of Mould cc	2285	2285	2285	2285	2285	2285
Wet density of soil g/cc	1.794	2.051	1.685	1.955	1.560	1.879
Dry density of soil g/cc	1.530	1.582	1.436	1.474	1.330	1.359

Moisture Determination						
MOISTURE CONTENT DATA	**65 Blows**		**30 Blows**		**10 Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.	Z9	D	MK	A3	T1C1	C10
Mass of wet soil + Container g	146.50	254.88	146.30	248.87	131.60	281.07
Mass of dry soil + Container g	127.50	203.48	127.30	195.79	114.80	213.15
Mass of container g	17.40	29.80	17.40	33.06	17.50	35.65
Mass of water g	19.00	51.40	19.00	53.08	16.80	67.92
Mass of drysoil g	110.10	173.68	109.90	162.73	97.30	177.50
Moisture content %	17.26	29.59	17.29	32.62	17.27	38.26

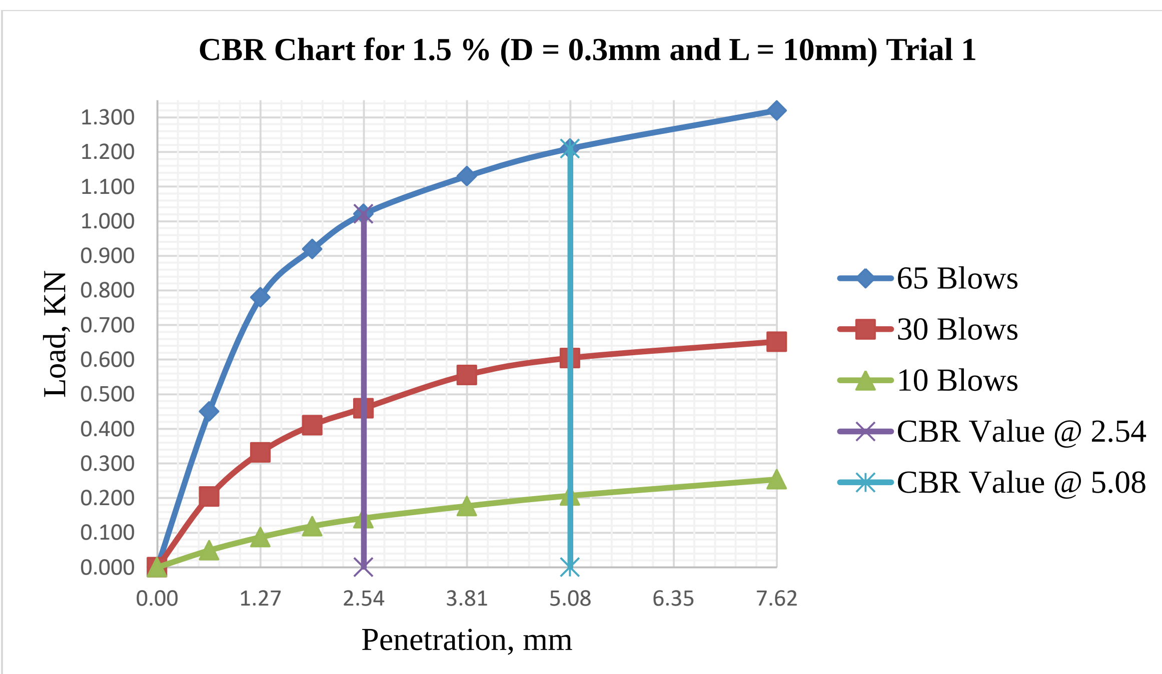
CBR Penetration Determination

Penetration after 96 hrs Soaking Period — **Surcharge Weight:-4.55 KG**

65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen. mm**	**Load, KN**	**CBR %**	**Pen. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.450		0.64	0.205		0.64	0.049	
1.27	0.780		1.27	0.332		1.27	0.087	
1.91	0.920		1.91	0.411		1.91	0.119	
2.54	1.021	7.73	2.54	0.460	3.48	2.54	0.142	1.10
3.81	1.130		3.81	0.556		3.81	0.177	
5.08	1.210	6.05	5.08	0.605	3.03	5.08	0.207	1.00
7.62	1.320		7.62	0.652		7.62	0.254	

Modified Max. Dry Density g/cc		1.506			OMC %		17.0	
Swell Determination								
Date		65 Blows		30 Blows			10 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm		Swell in %	Gauge rdg mm	Swell in %
13/01/2021	Initial	1.00	6.21	0.1		5.38	0.00	4.01
17/01/2021	Final	8.23		6.36			4.67	

No. of blows	MCBS %	DDBS g/cc	Correct CBR %		% of Compaction
10	17.266	1.330	1.1		88.341
30	17.288	1.436	3.459		95.381
65	17.257	1.530	7.677		101.587
CBR % at MDD		**6.6**	**Swell %**		**6**



Fiber Content = 1.5%		Fiber Length = 10 mm		Fiber Diameter = 0.3 mm	
Trial 2 (AR = 33.33)					

Compaction Data		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		N2	N2	N30	N30	N7	N7
Mass of soil + Mould	g	13607.2	14118.5	13287.1	13876.7	13012.1	13755.4
Mass Mould	g	9357.5	9357.5	9293.2	9293.2	9349.2	9349.2
Mass of Soil	g	4249.7	4761	3993.9	4583.5	3662.9	4406.2
Volume of Mould	cc	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.860	2.084	1.748	2.006	1.603	1.928
Dry density of soil	g/cc	1.586	1.570	1.493	1.513	1.366	1.413

Moisture Determination

MOISTURE CONTENT DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		3B	B	I0	F	B3	OZ-ZZ
Mass of wet soil + Container	g	126.00	226.12	142.20	280.3	170.00	254.5
Mass of dry soil + Container	g	110.10	178.19	125.50	220.54	148.90	194.29
Mass of container	g	18.10	31.5	27.90	37.12	27.10	29.03
Mass of water	g	15.90	47.93	16.70	59.76	21.10	60.21
Mass of drysoil	g	92.00	146.690	97.60	183.420	121.80	165.260
Moisture content	%	17.28	32.674	17.11	32.581	17.32	36.433

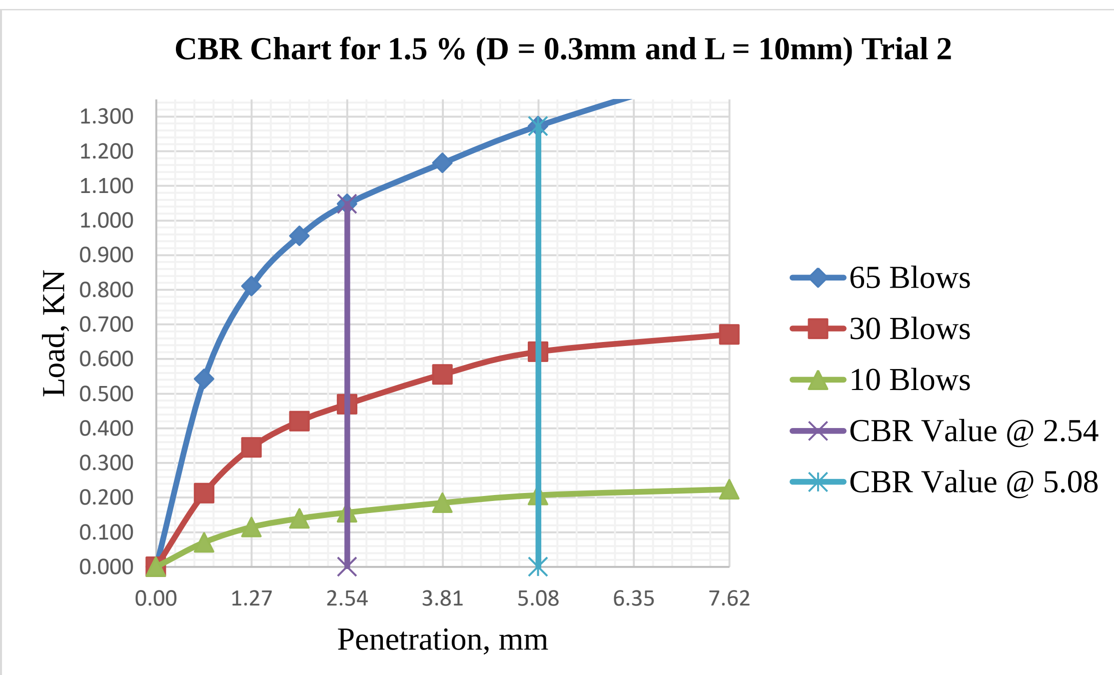
CBR Penetration Determination

Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen. mm	Load, KN	CBR %	Pen. mm	Load, KN	CBR %
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.543		0.64	0.213		0.64	0.071	
1.27	0.811		1.27	0.345		1.27	0.115	
1.91	0.956		1.91	0.421		1.91	0.140	
2.54	1.048	7.94	2.54	0.470	3.56	2.54	0.157	1.19
3.81	1.166		3.81	0.556		3.81	0.185	
5.08	1.273	6.37	5.08	0.621	3.11	5.08	0.207	1.04
7.62	1.446		7.62	0.671		7.62	0.224	

Modified Max.Dry Density g/cc	1.506	OMC %	17.0

Swell Determination							
Date		65 Blows		30 Blows		10 Blows	
		Gauge rdg	Swell in %	Gauge rdg	Swell in %	Gauge rdg	Swell in %
		mm		mm		mm	
13/01/2021	Initial	8.90	6.10	5.08	5.09	5.49	4.00
17/01/2021	Final	16.00		11.01		10.15	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction		
10	17.324	1.366	1.189	90.725	**Average CBR (%)**	**6.58**
30	17.111	1.493	3.534	99.104	**Average Swell (%)**	**5.92**
65	17.283	1.586	7.880	105.296		
CBR % at MDD			**6.55**	**Swell %**	**5.84**	



B 2.4 CBR Laboratory Data Analysis of 2.5 % for 0.3 mm diameter and 10 mm Length

Fiber Content = 2.5%	Fiber Length = 10 mm	Fiber Diameter = 0.3 mm

Trial 1

COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		N9	N9	TN	TN	N6	N6
Mass of soil + Mould	g	13423.4	14030.5	13155.3	13776.2	12967	13692.1
Mass Mould	g	9366.5	9366.5	9325	9325	9401.3	9401.3
Mass of Soil	g	4056.9	4664	3830.3	4451.2	3565.7	4290.8
Volume of Mould	cc	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.775	2.041	1.676	1.948	1.560	1.878
Dry density of soil	g/cc	1.514	1.575	1.429	1.469	1.331	1.358

Moisture Determination

MOISTURE CONTENT DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.		Z9	D	MK	A3	T1C1	C10
Mass of wet soil + Container	g	149.00	257.38	148.80	251.37	134.10	283.57
Mass of dry soil + Container	g	130.00	205.98	129.80	198.29	117.30	215.65
Mass of container	g	19.90	32.30	19.90	35.56	20.00	38.15
Mass of water	g	19.00	51.40	19.00	53.08	16.80	67.92
Mass of drysoil	g	110.10	173.68	109.90	162.73	97.30	177.50
Moisture content	%	17.26	29.59	17.29	32.62	17.27	38.26

CBR Penetration Determination

Penetration after 96 hrs Soaking Period — **Surcharge Weight:-4.55 KG**

65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.401		0.64	0.182		0.64	0.044	
1.27	0.694		1.27	0.295		1.27	0.077	
1.91	0.819		1.91	0.366		1.91	0.106	
2.54	0.909	6.88	2.54	0.409	3.10	2.54	0.126	1.10
3.81	1.006		3.81	0.495		3.81	0.158	
5.08	1.077	5.38	5.08	0.538	2.69	5.08	0.184	1.00
7.62	1.175		7.62	0.580		7.62	0.226	

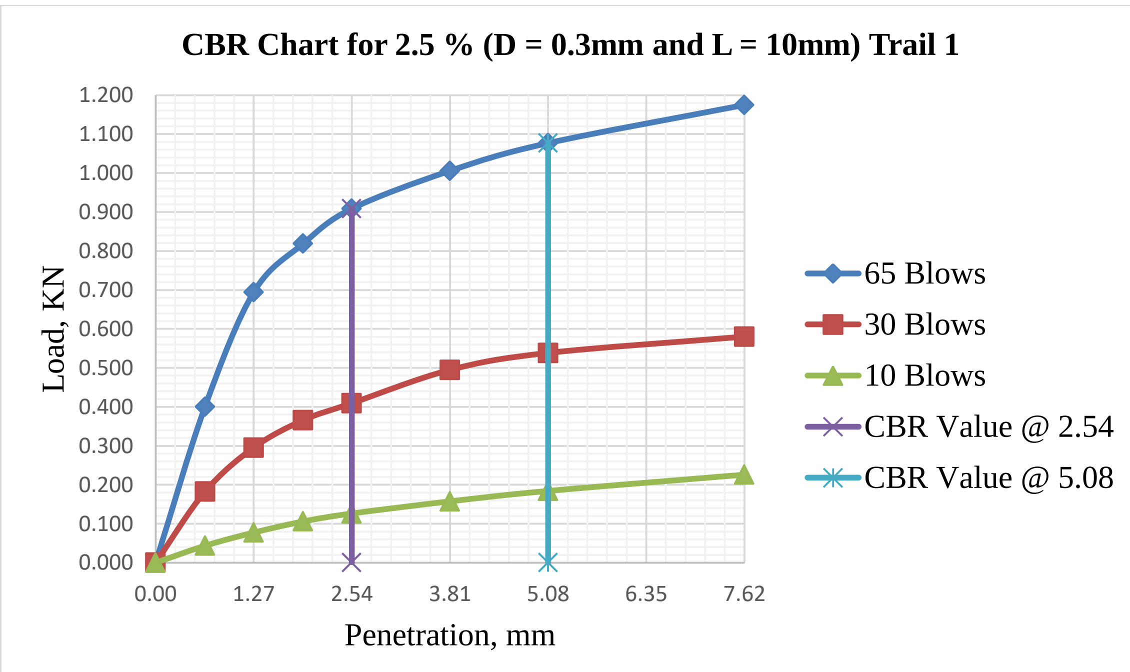
Modified Max.Dry Density g/cc	**1.506**	**OMC %**	**17.0**

Swell Determination

Date		**65 Blows**		**30 Blows**		**10 Blows**	
		Gauge rdg	**Swell in %**	**Gauge rdg**	**Swell in %**	**Gauge rdg**	**Swell in %**

		mm		**mm**		**mm**	
4/11/2020	Initial	0.90	5.67	0	5.00	0.00	3.62
8/11/2020	Final	7.50		5.82		4.21	

No.of blows	MCBS %	DDBS g/cm3	**Correcrt CBR %**	% OF Compaction	
10	17.27	1.331	**1.10**	88	
30	17.29	1.429	**3.08**	95	
65	17.26	1.514	**6.83**	101	
CBR at MDD, %			**6.50**	**Swell at MDD, %**	**5.50**



Fiber Content = 2.5%	Fiber Length = 10 mm	Fiber Diameter = 0.3 mm
Trial 2		

COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		N2	N2	N30	N30	N7	N7
Mass of soil + Mould	g	13592.6	14102.4	13272.4	13863.7	13001.2	13744.5
Mass Mould	g	9351.1	9351.1	9291.2	9291.2	9342.8	9342.8
Mass of Soil	g	4241.5	4751.3	3981.2	4572.5	3658.4	4401.7
Volume of Mould	cc	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.856	2.079	1.742	2.001	1.601	1.926
Dry density of soil	g/cc	1.583	1.567	1.488	1.509	1.365	1.412

Moisture Determination

MOISTURE CONTENT DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.		3B	B	I0	F	B3	OZ-ZZ
Mass of wet soil + Container	g	128.60	228.72	144.80	282.90	172.60	257.10
Mass of dry soil + Container	g	112.70	180.79	128.10	223.14	151.50	196.89
Mass of container	g	20.70	34.10	30.50	39.72	29.70	31.63
Mass of water	g	15.90	47.93	16.70	59.76	21.10	60.21
Mass of drysoil	g	92.00	146.690	97.60	183.420	121.80	165.260
Moisture content	%	17.28	32.674	17.11	32.581	17.32	36.433

CBR Penetration Determination

Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**					
65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.483		0.64	0.190		0.64	0.063	
1.27	0.722		1.27	0.307		1.27	0.102	
1.91	0.851		1.91	0.375		1.91	0.125	
2.54	0.933	7.07	2.54	0.418	3.17	2.54	0.140	1.06
3.81	1.038		3.81	0.495		3.81	0.165	
5.08	1.133	5.66	5.08	0.553	2.76	5.08	0.184	0.92
7.62	1.287		7.62	0.597		7.62	0.199	

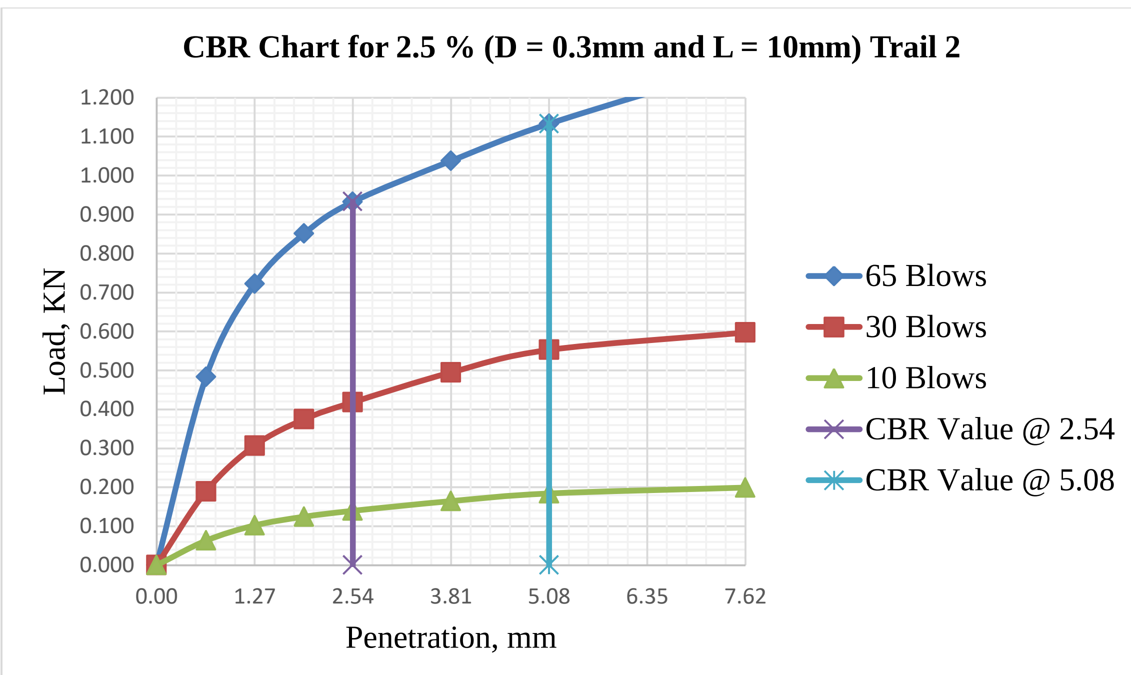
Modified Max.Dry Density g/cc	**1.506**	**OMC %**	**17.0**

Swell Determination

Date		**65 Blows**	**30 Blows**	**10 Blows**

		Gauge rdg	Swell in %	Gauge rdg	Swell in %	Gauge rdg	Swell in %
		mm		mm		mm	
4/11/2020	Initial	9.10	5.50	5.2	4.30	6.59	3.96
8/11/2020	Final	15.50		10.20		11.20	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.32	1.365	1.06	91	
30	17.11	1.488	3.15	99	
65	17.28	1.583	7.01	105	
CBR at MDD, %			6.54	**Swell at MDD, %**	**5.12**
Average CBR, %			**6.52**	**Average Swell, %**	**5.31**



B 2.5 CBR Laboratory Data Analysis of 0.5 % for 0.3 mm diameter and 20 mm Length

Fiber Content = 0.5%	Fiber Length = 20 mm	Fiber Diameter = 0.3 mm
Trial 1		

COMPACTION DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		N9	N9	TN	TN	N6	N6
Mass of soil + Mould	g	13294.5	13903	13354.5	13981.5	12889.5	13603.5
Mass Mould	g	9278.5	9278.5	9463	9463	9390	9390
Mass of Soil	g	4016	4624.5	3891.5	4518.5	3499.5	4213.5
Volume of Mould	g	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.758	2.024	1.703	1.977	1.532	1.844
Dry density of soil	g/cc	1.498	1.538	1.455	1.453	1.309	1.338

Moisture Determination

MOISTURE CONTENT DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		A3	D	D	F	C10	C10
Mass of wet soil + Container	g	222.10	270.50	229.00	265.33	206.50	244.35
Mass of dry soil + Container	g	194.20	212.71	200.00	204.76	181.60	187.18
Mass of container	g	33.00	29.80	29.70	36.78	35.50	35.81
Mass of water	g	27.90	57.79	29.00	60.57	24.90	57.17
Mass of drysoil	g	161.20	182.91	170.30	167.98	146.10	151.37
Moisture content	%	17.31	31.59	17.03	36.06	17.04	37.77

CBR Penetration Determination

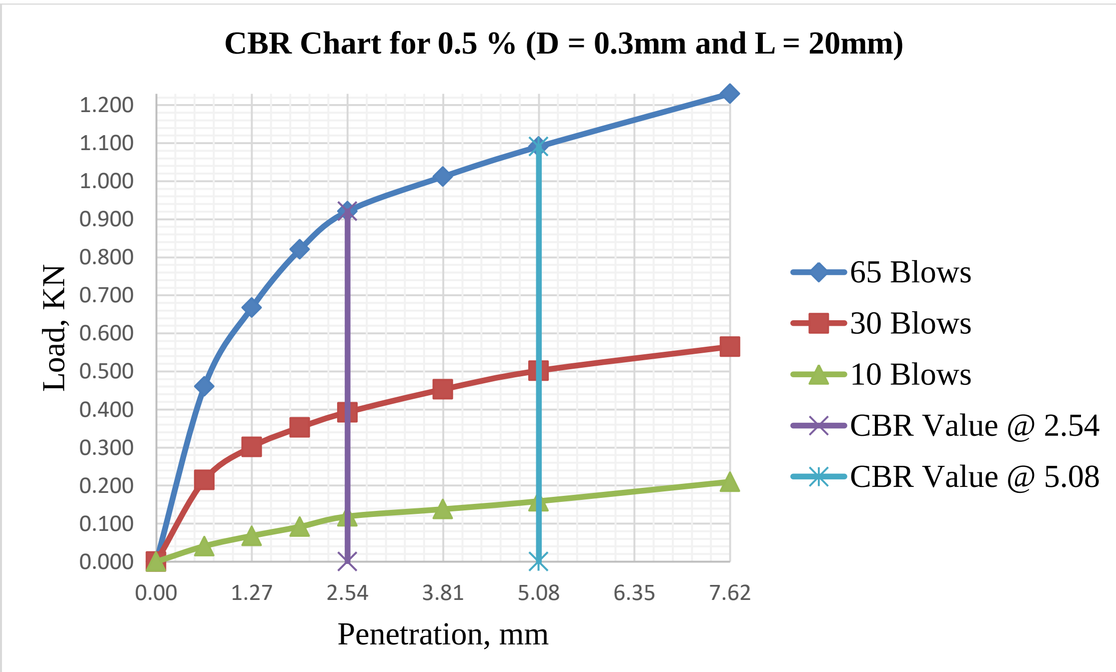
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.461		0.64	0.215		0.64	0.041	
1.27	0.668		1.27	0.302		1.27	0.068	
1.91	0.821		1.91	0.353		1.91	0.092	
2.54	0.921	6.98	2.54	0.393	2.98	2.54	0.119	0.90
3.81	1.012		3.81	0.453		3.81	0.138	
5.08	1.091	5.46	5.08	0.502	2.51	5.08	0.159	0.80
7.62	1.230		7.62	0.565		7.62	0.210	

Modified Max.Dry Density g/cc	1.502	OMC %	17.0

Swell Determination

Date		65 Blows		30 Blows		10 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
9/11/2020	Initial	0.22	8.02	0.25	7.90	0.64	5.32
13/11/2020	Final	9.56		9.45		6.83	

No.of blows	MCBS %	DDBS g/cm3	=	96.88761089	
10	17.04	1.309	6.92	100	
30	17.03	1.455	0.00	0	
65	17.31	1.498	5.45	0	
CBR at MDD, %			5.45	**Swell at MDD, %**	**8.00**
Average CBR, %			**5.45**	**Average Swell, %**	**8.00**



B 2.6 CBR Laboratory Data Analysis of 1 % for 0.3 mm diameter and 20 mm Length

Fiber Content = 1%	Fiber Length = 20 mm	Fiber Diameter = 0.3 mm
Trial 1		

COMPACTION DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		N9	N9	TN	TN	N6	N6
Mass of soil + Mould	g	13486.5	14023.5	13357.5	13994	12821.6	13584
Mass Mould	g	9309.7	9309.7	9383.5	9383.5	9340.5	9340.5
Mass of Soil	g	4176.8	4713.8	3974	4610.5	3481.1	4243.5
Volume of Mould	g	2124	2124	2124	2124	2124	2124
Wet density of soil	g/cc	1.966	2.219	1.871	2.171	1.639	1.998
Dry density of soil	g/cc	1.679	1.704	1.597	1.640	1.399	1.449

Moisture Determination

MOISTURE CONTENT DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		EB	13-14	B	T4C22	MK	P5
Mass of wet soil + Container	g	171.12	154.61	149.50	151.10	147.20	190.88
Mass of dry soil + Container	g	150.11	122.74	130.16	118.69	128.19	143.19
Mass of container	g	27.60	17.39	17.50	18.50	17.50	17.20
Mass of water	g	21.01	31.87	19.34	32.41	19.02	47.69
Mass of drysoil	g	122.51	105.35	112.66	100.19	110.69	125.99
Moisture content	%	17.15	30.25	17.16	32.35	17.18	37.85

CBR Penetration Determination

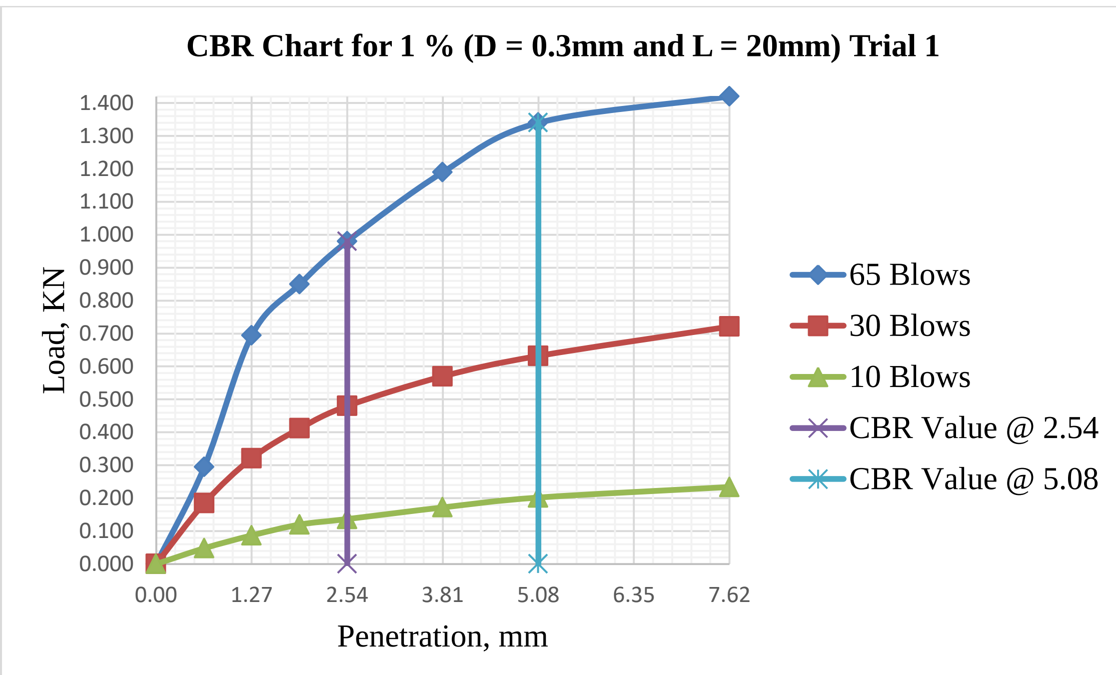
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.295		0.64	0.185		0.64	0.048	
1.27	0.694		1.27	0.321		1.27	0.087	
1.91	0.850		1.91	0.412		1.91	0.120	
2.54	0.980	7.42	2.54	0.480	3.64	2.54	0.137	1.04
3.81	1.190		3.81	0.570		3.81	0.172	
5.08	1.340	6.70	5.08	0.632	3.16	5.08	0.202	1.01
7.62	1.420		7.62	0.721		7.62	0.234	

Modified Max.Dry Density g/cc	1.520	OMC %	17.0

Swell Determination

Date		65 Blows		30 Blows		10 Blows	
		Gauge rdg	Swell in %	Gauge rdg	Swell in %	Gauge rdg	Swell in %
		mm		mm		mm	
9/11/2020	Initial	0.14	5.91	0	5.79	0.00	5.27
13/11/2020	Final	7.02		6.74		6.13	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.2	1.399	1.04	92	
30	17.2	1.597	3.61	105	
65	17.1	1.679	7.37	110	
CBR at MDD, %			**6.10**	**Swell at MDD, %**	**5.88**



Fiber Content = 1%	Fiber Length = 20 mm			Fiber Diameter = 0.3 mm	
Trial 2					

COMPACTION DATA	65 Blows		30 Blows		10 Blows	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.	N2	N2	N30	N30	N7	N7
Mass of soil + Mould g	13625.3	14180	13134.8	13798	12855.2	13616.5
Mass Mould g	9502.7	9502.7	9329.5	9329.5	9430.5	9430.5
Mass of Soil g	4122.6	4677.3	3805.3	4468.5	3424.7	4186
Volume of Mould g	2285	2285	2285	2285	2285	2285
Wet density of soil g/cc	1.804	2.047	1.665	1.956	1.499	1.832
Dry density of soil g/cc	1.541	1.575	1.422	1.464	1.280	1.319

Moisture Determination

MOISTURE CONTENT DATA	65 Blows		30 Blows		10 Blows	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.	DH	K4	B	T45	C10	13
Mass of wet soil + Container g	143.70	151.22	223.70	185.71	247.40	178.5
Mass of dry soil + Container g	125.15	120.48	195.59	143.21	216.52	133.58
Mass of container g	16.60	17.88	31.40	16.79	35.50	18.21
Mass of water g	18.55	30.74	28.12	42.5	30.88	44.92
Mass of drysoil g	108.55	102.600	164.19	126.420	181.02	115.370
Moisture content %	17.09	29.961	17.12	33.618	17.06	38.936

CBR Penetration Determination

Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.540		0.64	0.208		0.64	0.074	
1.27	0.781		1.27	0.344		1.27	0.118	
1.91	0.881		1.91	0.431		1.91	0.141	
2.54	0.985	7.46	2.54	0.478	4.10	2.54	0.157	0.50
3.81	1.156		3.81	0.561		3.81	0.181	
5.08	1.234	6.17	5.08	0.624	3.80	5.08	0.198	0.50
7.62	1.345		7.62	0.701		7.62	0.210	

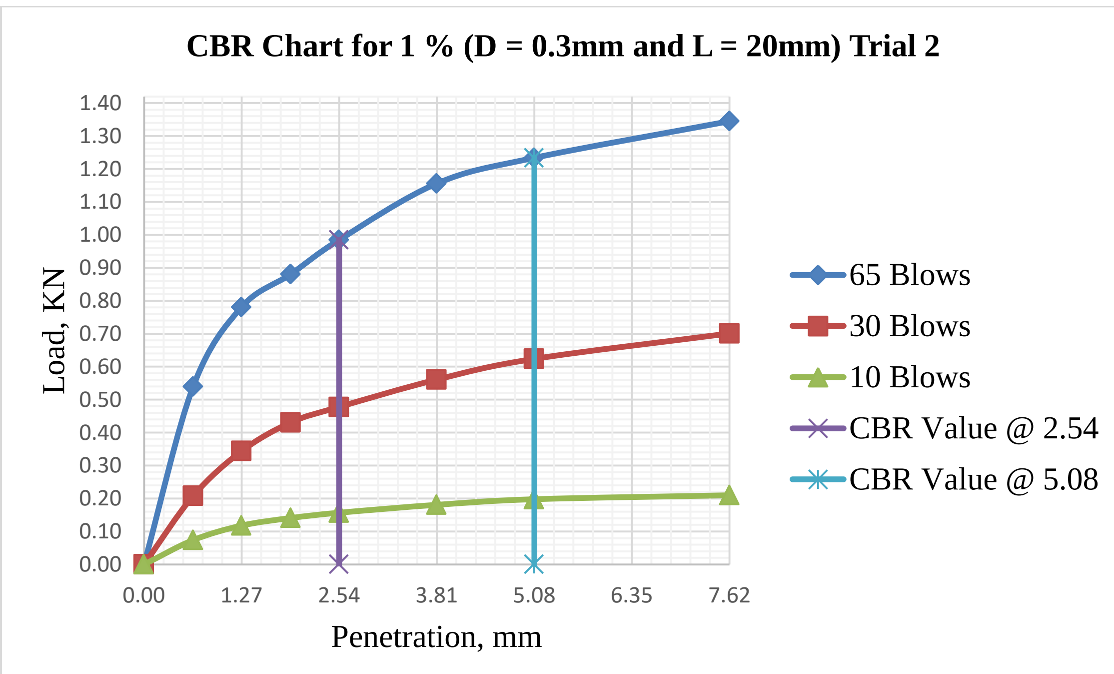
Modified Max.Dry Density g/cc	1.520	OMC %	17.0

Swell Determination

Date		65	30 Blows	10 Blows

		Blows					
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
9/11/2020	Initial	0.00	6.86	0	4.94	1.40	2.59
13/11/2020	Final	7.99		5.75		4.41	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.1	1.28	0.50	84	
30	17.1	1.42	3.59	94	
65	17.1	1.54	7.41	101	
CBR at MDD, %			0.00	**Swell at MDD, %**	**0.00**
Average CBR, %			**6.2**	**Average Swell, %**	**6.125**



B 2.7 CBR Laboratory Data Analysis of 1.5 % for 0.3 mm diameter and 20 mm Length

Fiber Content = 1.5%	Fiber Length = 20 mm	Fiber Diameter = 0.3 mm
Trial 1		

COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		N9	N9	TN	TN	N6	N6
Mass of soil + Mould	g	13440.5	13964	13465	14038	12826.5	13536
Mass Mould	g	9351.1	9351.1	9556.5	9556.5	9316.8	9316.8
Mass of Soil	g	4089.4	4612.9	3908.5	4481.5	3509.7	4219.2
Volume of Mould	g	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.790	2.019	1.711	1.961	1.536	1.846
Dry density of soil	g/cc	1.528	1.565	1.458	1.505	1.311	1.360

Moisture Determination

MOISTURE CONTENT DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.		4A	B	SS	F	3B	2
Mass of wet soil + Container	g	152.50	293.16	148.50	319.20	147.80	285.17
Mass of dry soil + Container	g	132.80	234.36	129.23	253.43	128.82	217.65
Mass of container	g	17.50	31.49	18.20	36.53	18.20	28.84
Mass of water	g	19.71	58.80	19.27	65.77	18.98	67.52
Mass of drysoil	g	115.30	202.87	111.03	216.90	110.62	188.81
Moisture content	%	17.09	28.98	17.35	30.32	17.15	35.76

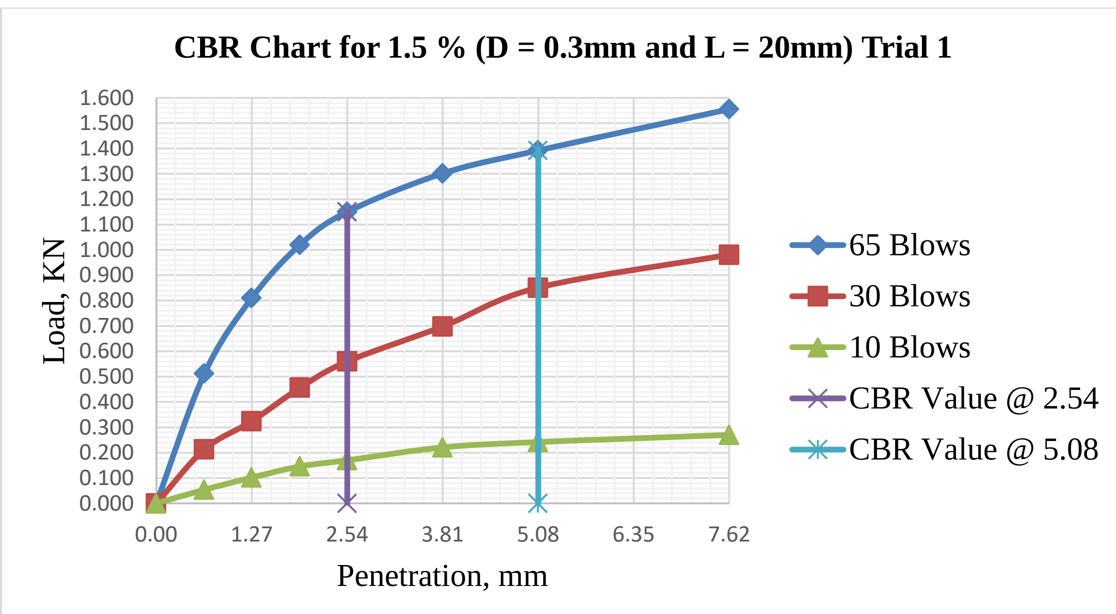
CBR Penetration Determination

Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**					
65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen. mm**	**Load, KN**	**CBR %**	**Pen. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.512		0.64	0.213		0.64	0.054	
1.27	0.810		1.27	0.324		1.27	0.102	
1.91	1.020		1.91	0.456		1.91	0.146	
2.54	1.150	8.71	2.54	0.560	4.24	2.54	0.170	1.29

3.81	1.302		3.81	0.698		3.81	0.221	
5.08	1.392	6.96	5.08	0.851	4.26	5.08	0.242	1.21
7.62	1.555		7.62	0.981		7.62	0.270	
Modified Max.Dry Density g/cc		**1.540**		**OMC %**			**17.0**	

Swell Determination							
Date		**65 Blows**		**30 Blows**		**10 Blows**	
		Gauge rdg mm	**Swell in %**	**Gauge rdg mm**	**Swell in %**	**Gauge rdg mm**	**Swell in %**
9/11/2020	Initial	5.00	4.52	0	3.52	0.00	2.50
13/11/2020	Final	10.26		4.10		2.91	

No.of blows	**MCBS %**	**DDBS g/cm3**	**Correcrt CBR %**	**% OF Compaction**	
10	17.2	1.31	1.29	85	
30	17.4	1.46	4.26	95	
65	17.1	1.53	8.65	99	
CBR at MDD, %			**7.35**	**Swell at MDD, %**	**4.27**



Fiber Content = 1.5%	Fiber Length = 20 mm	Fiber Diameter = 0.3 mm
Trial 2		

COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		N2	N2	N30	N30	N7	N7
Mass of soil + Mould	g	13688.6	14190.5	13316.4	13904	12856	13580
Mass Mould	g	9464.5	9464.5	9427.6	9427.6	9383.3	9383.3
Mass of Soil	g	4224.1	4726	3888.8	4476.4	3472.7	4196.7
Volume of Mould	g	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.849	2.068	1.702	1.959	1.520	1.837
Dry density of soil	g/cc	1.578	1.576	1.452	1.467	1.296	1.342

Moisture Determination

MOISTURE CONTENT DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.		A3	A3	A14	D	D	C10
Mass of wet soil + Container	g	170.50	279.41	169.50	296.02	229.6	289.53
Mass of dry soil + Container	g	150.28	220.81	148.80	229.15	201.20	221.176
Mass of container	g	32.50	33.1	28.60	29.68	36.40	35.57
Mass of water	g	20.22	58.6	20.70	66.87	28.40	68.354
Mass of drysoil	g	117.78	187.710	120.20	199.470	164.80	185.606
Moisture content	%	17.17	31.218	17.22	33.524	17.23	36.827

CBR Penetration Determination

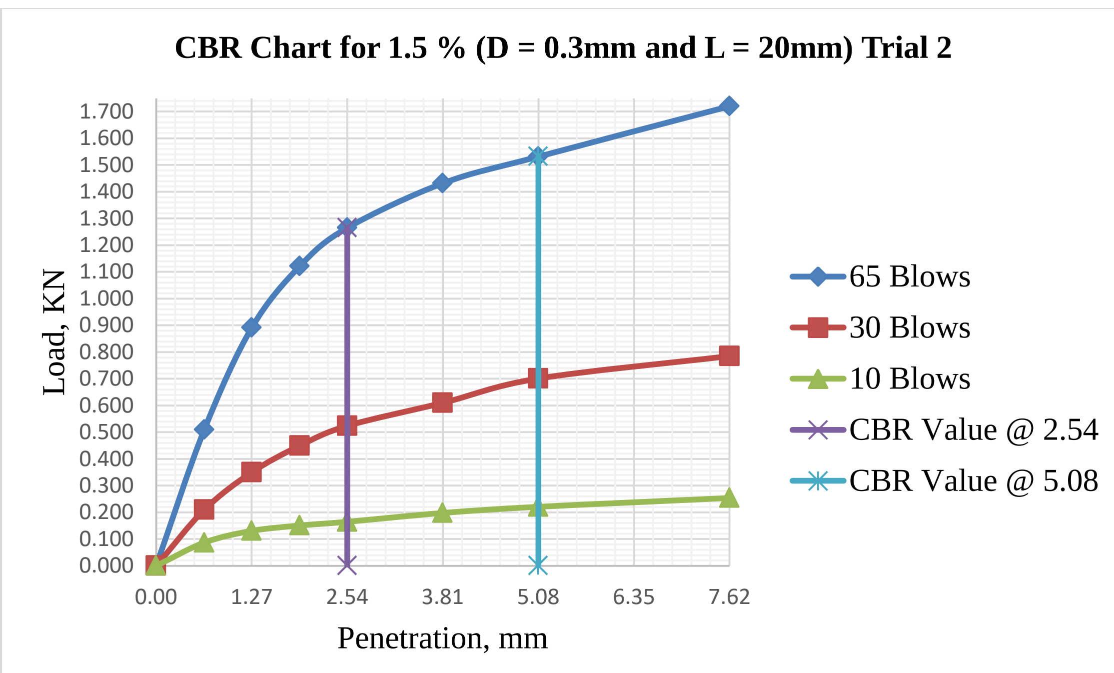
Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**					
65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.510		0.64	0.210		0.64	0.087	
1.27	0.891		1.27	0.350		1.27	0.131	
1.91	1.122		1.91	0.450		1.91	0.151	
2.54	1.265	9.58	2.54	0.524	3.97	2.54	0.165	1.25
3.81	1.432		3.81	0.610		3.81	0.198	
5.08	1.532	7.66	5.08	0.701	3.51	5.08	0.221	1.11
7.62	1.720		7.62	0.785		7.62	0.254	

Modified Max.Dry Density g/cc	**1.540**	**OMC %**	**17.0**

Swell Determination

Date		65 Blows		30 Blows		10 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
9/11/2020	Initial	0.20	4.24	0	3.99	0.00	1.83
13/11/2020	Final	5.13		4.64		2.13	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.2	1.296	1.25	84	
30	17.2	1.452	3.94	94	
65	17.2	1.578	9.51	102	
CBR at MDD, %			7.41	Swell at MDD, %	4.19
Average CBR, %			7.38	Average Swell, %	4.23



B 2.8 CBR Laboratory Data Analysis of 2.5 % for 0.3 mm diameter and 20 mm Length

Fiber Content = 2.5%	Fiber Length = 20 mm	Fiber Diameter = 0.3 mm

Trial 1

COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		N9	N9	TN	TN	N6	N6
Mass of soil + Mould	g	13422.1	13932.4	13440.2	14013	12813.4	13523.1
Mass Mould	g	9320.5	9320.5	9529.5	9529.5	9312.1	9312.1
Mass of Soil	g	4101.6	4611.9	3910.7	4483.5	3501.3	4211
Volume of Mould	g	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.795	2.018	1.711	1.962	1.532	1.843
Dry density of soil	g/cc	1.533	1.565	1.458	1.506	1.308	1.357

Moisture Determination

MOISTURE CONTENT DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.		A1	C1	A2	C2	A3	C3
Mass of wet soil + Container	g	153.70	294.36	149.70	320.40	149.00	286.37
Mass of dry soil + Container	g	134.00	235.56	130.43	254.63	130.02	218.85
Mass of container	g	18.70	32.69	19.40	37.73	19.40	30.04
Mass of water	g	19.71	58.80	19.27	65.77	18.98	67.52
Mass of drysoil	g	115.30	202.87	111.03	216.90	110.62	188.81
Moisture content	%	17.09	28.98	17.35	30.32	17.15	35.76

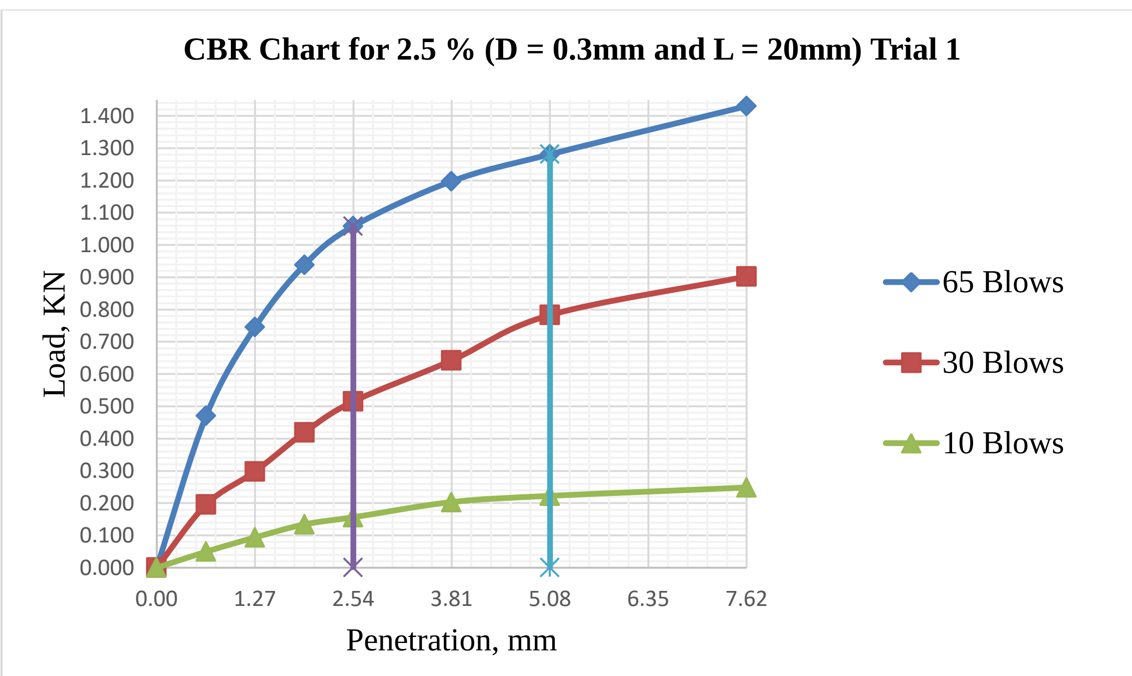
CBR Penetration Determination

Penetration after 96 hrs Soaking Period — **Surcharge Weight:-4.55 KG**

65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**	**Pen. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.471		0.64	0.196		0.64	0.050	
1.27	0.745		1.27	0.298		1.27	0.094	
1.91	0.938		1.91	0.420		1.91	0.134	
2.54	1.058	8.02	2.54	0.515	3.90	2.54	0.156	1.18
3.81	1.197		3.81	0.642		3.81	0.203	
5.08	1.281	6.40	5.08	0.783	3.91	5.08	0.223	1.11
7.62	1.430		7.62	0.903		7.62	0.248	

Modified Max.Dry Density g/cc		1.512			OMC %		17.0	
Swell Determination								
Date		65 Blows		30 Blows			10 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %		Gauge rdg mm	Swell in %
20/11/2020	Initial	5.20	4.30	0	2.32		0.00	2.41
24/11/2020	Final	10.20		2.70			2.80	

No.of blows		MCBS %		DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10		17.2		1.3079	**1.18**	87	
30		17.4		1.4584	**3.91**	96	
65		17.1		1.5330	**7.95**	101	
CBR at MDD, %					**7.2**	**Swell at MDD, %**	**3.78**



Fiber Content = 2.5%	Fiber Length = 20 mm	Fiber Diameter = 0.3 mm
Trial 2		

COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		N2	N2	N30	N30	N7	N7
Mass of soil + Mould	g	13674.2	14182.1	13301.5	13891.2	12848	13565
Mass Mould	g	9476.2	9476.2	9456.2	9456.2	9385	9385
Mass of Soil	g	4198	4705.9	3845.3	4435	3463	4180
Volume of Mould	g	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.837	2.059	1.683	1.941	1.516	1.829
Dry density of soil	g/cc	1.568	1.570	1.436	1.454	1.293	1.337

Moisture Determination

MOISTURE CONTENT DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.		A3	A3	A14	D	D	C10
Mass of wet soil + Container	g	170.50	279.41	169.50	296.02	229.6	289.53
Mass of dry soil + Container	g	150.28	220.81	148.80	229.15	201.20	221.176
Mass of container	g	32.50	33.1	28.60	29.68	36.40	35.57
Mass of water	g	20.22	58.6	20.70	66.87	28.40	68.354
Mass of drysoil	g	117.78	187.710	120.20	199.470	164.80	185.606
Moisture content	%	17.17	31.218	17.22	33.524	17.23	36.827

CBR Penetration Determination

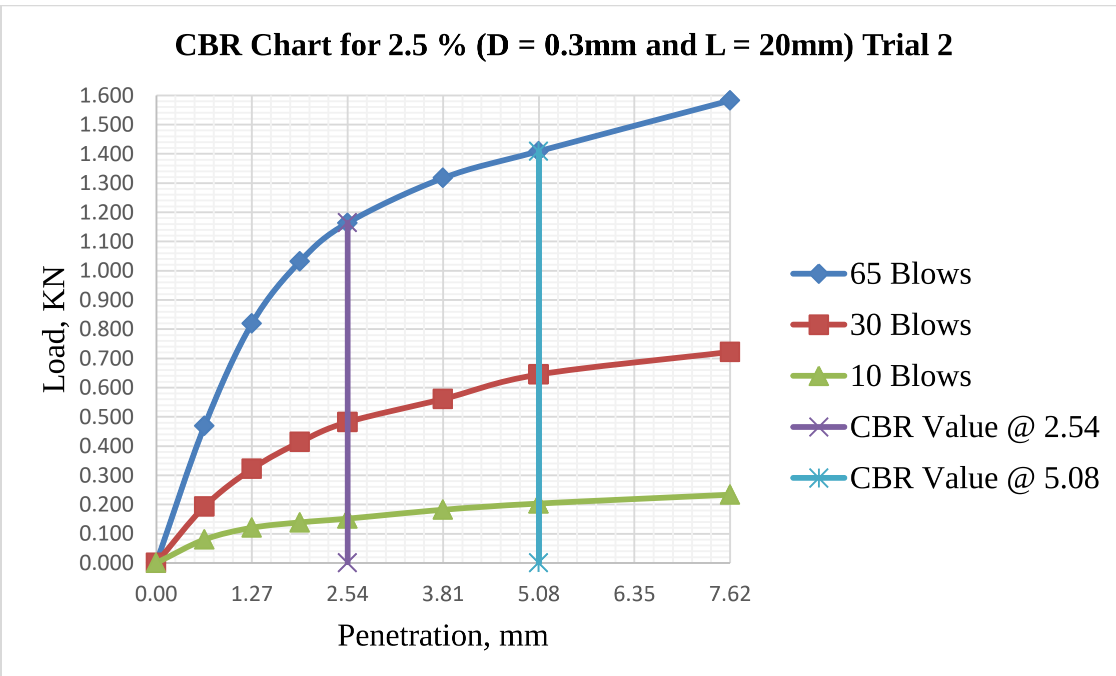
Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**					
65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.469		0.64	0.193		0.64	0.080	
1.27	0.820		1.27	0.322		1.27	0.121	
1.91	1.032		1.91	0.414		1.91	0.139	
2.54	1.164	8.82	2.54	0.482	3.65	2.54	0.152	1.15
3.81	1.317		3.81	0.561		3.81	0.182	
5.08	1.409	7.05	5.08	0.645	3.22	5.08	0.203	1.02
7.62	1.582		7.62	0.722		7.62	0.234	

Modified Max.Dry Density g/cc	**1.512**	**OMC %**	**17.0**

Swell Determination

Date		65 Blows		30 Blows		10 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
20/11/2020	Initial	0.00	4.12	0	3.44	0.00	2.10
24/11/2020	Final	4.80		4.00		2.45	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.2	1.29	1.15	85	
30	17.2	1.44	3.62	95	
65	17.2	1.57	8.75	104	
CBR at MDD, %			**7.3**	**Swell at MDD, %**	**4.0**
Average CBR, %			**7.3**	**Average Swell, %**	**3.9**



B 2.9 CBR Laboratory Data Analysis of 0.5% for 0.4 mm diameter and 10 mm Length

Fiber Content = 0.5%	Fiber Length = 10 mm	Fiber Diameter = 0.4 mm
Trial 1		

COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		N9	N9	TN	TN	N6	N6
Mass of soil + Mould	g	13479	14023	13391	13957.5	12968.5	13666.5
Mass Mould	g	9344	9344	9337.5	9337.5	9443	9443
Mass of Soil	g	4135	4679	4053.5	4620	3525.5	4223.5
Volume of Mould	cc	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.810	2.048	1.774	2.022	1.543	1.848
Dry density of soil	g/cc	1.545	1.571	1.515	1.538	1.317	1.371

Moisture Determination

MOISTURE CONTENT DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.		13-4	14	SS	13	1A	B3
Mass of wet soil + Container	g	135.20	153.67	137.50	173.00	135.30	136.23
Mass of dry soil + Container	g	118.00	121.96	120.00	135.77	118.00	105.55
Mass of container	g	17.50	17.56	17.50	17.44	17.00	17.44
Mass of water	g	17.20	31.71	17.50	37.24	17.30	30.68
Mass of drysoil	g	100.50	104.40	102.50	118.33	101.00	88.11
Moisture content	%	17.11	30.38	17.07	31.47	17.13	34.82

CBR Penetration Determination

Penetration after 96 hrs Soaking Period — **Surcharge Weight:-4.55 KG**

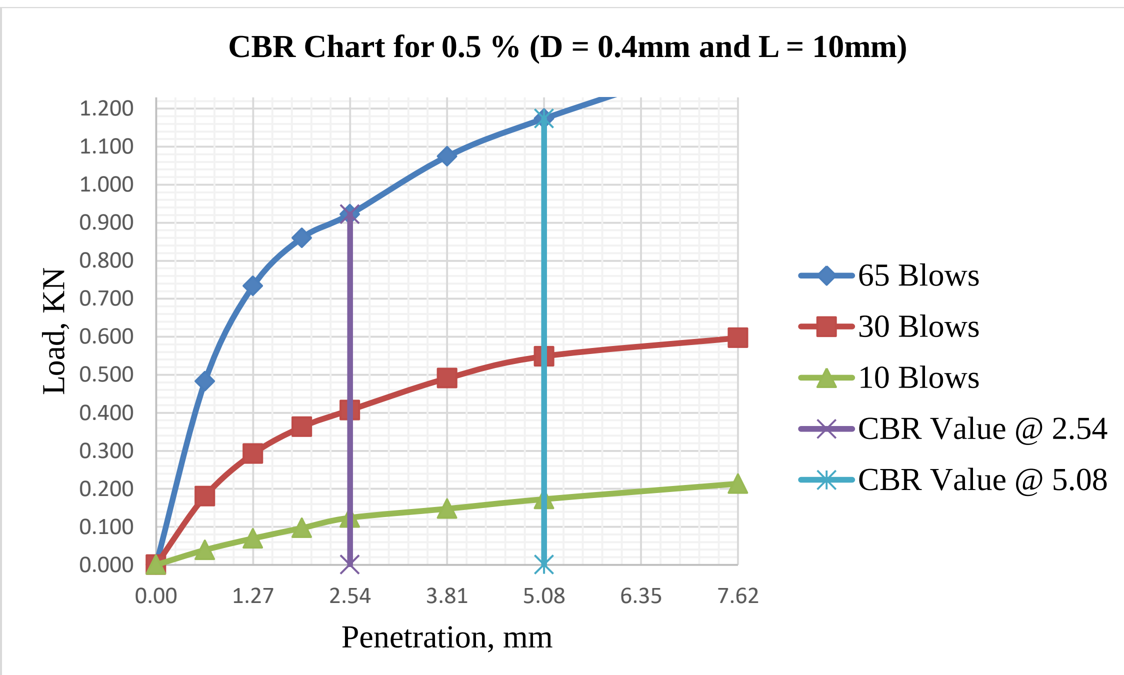
65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.482		0.64	0.180		0.64	0.039	
1.27	0.733		1.27	0.292		1.27	0.070	
1.91	0.860		1.91	0.363		1.91	0.097	
2.54	0.922	6.99	2.54	0.407	3.08	2.54	0.124	0.94
3.81	1.074		3.81	0.491		3.81	0.148	
5.08	1.174	5.87	5.08	0.549	2.74	5.08	0.173	0.86
7.62	1.343		7.62	0.597		7.62	0.213	

Modified Max.Dry Density g/cc	**1.500**	**OMC %**	**17.1**

Swell Determination

Date		65 Blows		30 Blows		10 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
13/11/2020	Initial	0.61	6.51	4.5	5.24	6.05	3.65
17/11/2020	Final	8.19		10.60		10.30	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.13	1.317	0.94	87.8	
30	17.07	1.515	3.06	101.0	
65	17.11	1.545	6.94	103.0	
CBR at MDD, %			5.21	**Swell at MDD, %**	**6.19**
Average CBR, %			**5.21**	**Average Swell, %**	**6.19**



B 2.10 CBR Laboratory Data Analysis of 1% for 0.4 mm diameter and 10 mm Length

Fiber Content = 1%	Fiber Length = 10 mm	Fiber Diameter = 0.4 mm
Trial 1		

COMPACTION DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		A1	A1	B1	B1	C1	C1
Mass of soil + Mould	g	13688.7	14262.6	13271.2	13883.9	12906.9	13658.1
Mass Mould	g	9506.9	9506.9	9333.3	9333.3	9346.6	9346.6
Mass of Soil	g	4181.8	4755.7	3937.9	4550.6	3560.3	4311.5
Volume of Mould	cc	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.830	2.081	1.723	1.992	1.558	1.887
Dry density of soil	g/cc	1.563	1.599	1.473	1.508	1.331	1.377

Moisture Determination

MOISTURE CONTENT DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		4B	B3	1B	B4	F	A5
Mass of wet soil + Container	g	166.50	246.48	133.70	194.10	216.80	162.44
Mass of dry soil + Container	g	146.00	195.85	116.80	149.32	190.50	122.88
Mass of container	g	26.30	27.87	17.50	9.73	36.40	15.99
Mass of water	g	20.50	50.63	16.90	44.78	26.30	39.56
Mass of drysoil	g	119.70	167.98	99.30	139.59	154.10	106.89
Moisture content	%	17.13	30.14	17.02	32.08	17.07	37.02

CBR Penetration Determination

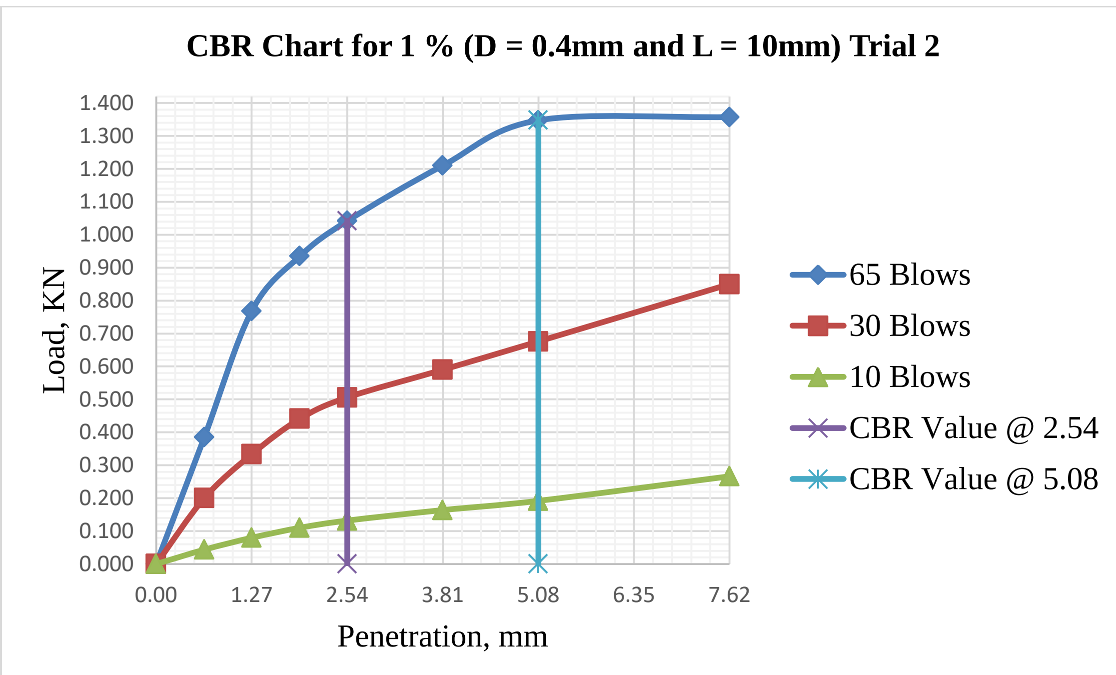
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.385		0.64	0.200		0.64	0.044	
1.27	0.768		1.27	0.333		1.27	0.080	
1.91	0.935		1.91	0.441		1.91	0.110	
2.54	1.042	7.89	2.54	0.506	3.83	2.54	0.132	1.00
3.81	1.210		3.81	0.590		3.81	0.164	
5.08	1.348	6.74	5.08	0.676	3.38	5.08	0.192	0.96
7.62	1.357		7.62	0.850		7.62	0.266	

Modified Max.Dry Density g/cc	1.501	OMC %	17.3

Swell Determination

Date		65 Blows		30 Blows		10 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
20/11/2020	Initial	0.08	6.51	8.11	4.80	7.52	3.42
24/11/2020	Final	7.66		13.70		11.50	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.1	1.331	1.00	89	
30	17.0	1.473	3.81	98	
65	17.1	1.563	7.83	104	
CBR at MDD, %			6.31	Swell at MDD, %	6.07



Fiber Content = 1%	Fiber Length = 10 mm	Fiber Diameter = 0.4 mm
Trial 2		

COMPACTION DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		N2	N2	N30	N30	N7	N7
Mass of soil + Mould	g	13503.4	14051.9	13318.6	13954.5	12858.6	13601.8
Mass Mould	g	9331.8	9331.8	9309.4	9309.4	9309.5	9309.5
Mass of Soil	g	4171.6	4720.1	4009.2	4645.1	3549.1	4292.3
Volume of Mould	cc	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.826	2.066	1.755	2.033	1.553	1.878
Dry density of soil	g/cc	1.560	1.594	1.498	1.509	1.326	1.370

Moisture Determination

MOISTURE CONTENT DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		D	TG	MK	A1	P15	A
Mass of wet soil + Container	g	255.90	169.30	159.90	193.20	129.90	202.70
Mass of dry soil + Container	g	222.90	134.70	139.10	148.19	113.60	152.78
Mass of container	g	29.50	17.90	17.60	18.40	18.50	18.20
Mass of water	g	33.00	34.60	20.80	45.01	16.30	49.92
Mass of drysoil	g	193.40	116.80	121.50	129.79	95.10	134.58
Moisture content	%	17.06	29.62	17.12	34.68	17.14	37.10

CBR Penetration Determination

Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.458		0.64	0.204		0.64	0.059	
1.27	0.781		1.27	0.335		1.27	0.099	
1.91	0.935		1.91	0.426		1.91	0.128	
2.54	1.033	7.83	2.54	0.483	3.66	2.54	0.147	1.12
3.81	1.175		3.81	0.567		3.81	0.178	
5.08	1.296	6.48	5.08	0.642	3.21	5.08	0.203	1.50
7.62	1.385		7.62	0.753		7.62	0.249	

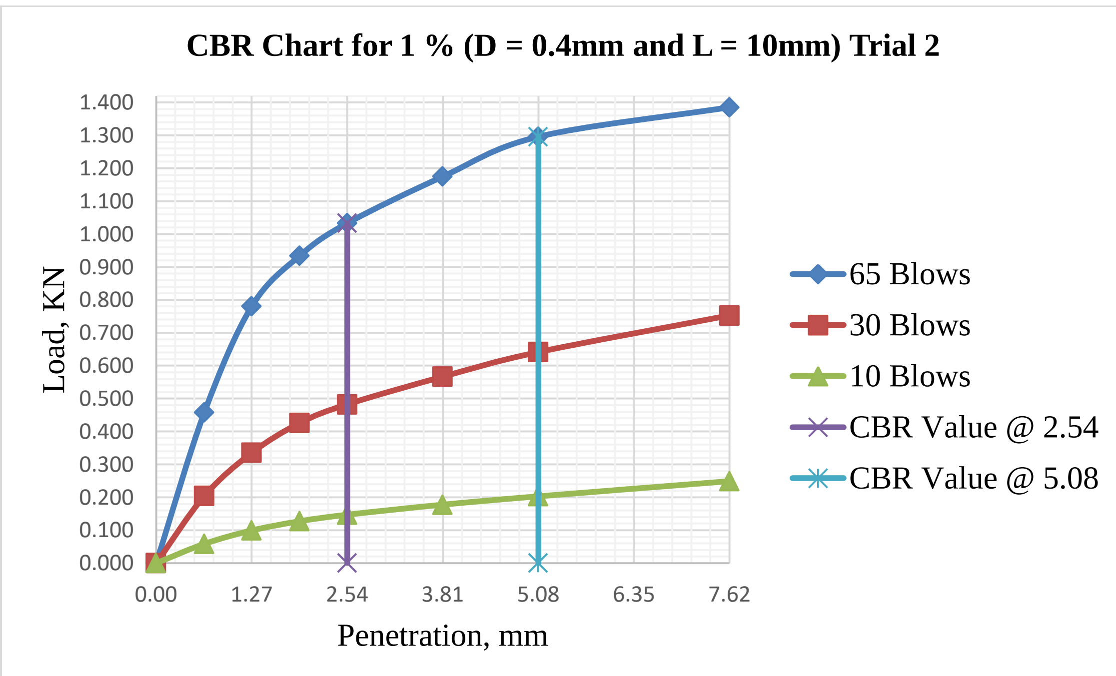
Modified Max.Dry Density g/cc	1.501	OMC %	17.3

Swell Determination

Date		65 Blows	30 Blows	10 Blows

		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
20/11/2020	Initial	4.75	6.11	8.07	5.58	4.65	5.03
24/11/2020	Final	11.86		14.56		10.51	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.1	1.33	1.50	88	
30	17.1	1.50	3.63	100	
65	17.1	1.56	7.77	104	
CBR at MDD, %			6.46	**Swell at MDD, %**	**5.98**
Average CBR, %			**6.4**	**Average Swell, %**	**6.025**



B 2.11 CBR Laboratory Data Analysis of 1.5% for 0.4 mm diameter and 10 mm Length

Fiber Content = 1.5%	Fiber Length = 10 mm	Fiber Diameter = 0.4 mm
Trial 1		

COMPACTION DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		N9	N9	TN	TN	N6	N6
Mass of soil + Mould	g	13611.1	14130.2	13265	13833.1	12897.9	13628.6
Mass Mould	g	9362.2	9362.2	9373.9	9373.9	9319.6	9319.6
Mass of Soil	g	4248.9	4768	3891.1	4459.2	3578.3	4309
Volume of Mould	cc	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.859	2.087	1.703	1.952	1.566	1.886
Dry density of soil	g/cc	1.584	1.583	1.455	1.413	1.338	1.302

Moisture Determination

MOISTURE CONTENT DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		N.M	A-14	2A	3A	3A	H
Mass of wet soil + Container	g	123.90	224.90	197.70	151.17	135.60	230.09
Mass of dry soil + Container	g	108.00	177.60	173.00	118.50	118.50	170.60
Mass of container	g	16.70	28.83	27.70	32.68	18.10	37.87
Mass of water	g	15.90	47.30	24.70	32.67	17.10	59.49
Mass of drysoil	g	91.30	148.77	145.30	85.82	100.40	132.73
Moisture content	%	17.42	31.79	17.00	38.07	17.03	44.82

CBR Penetration Determination

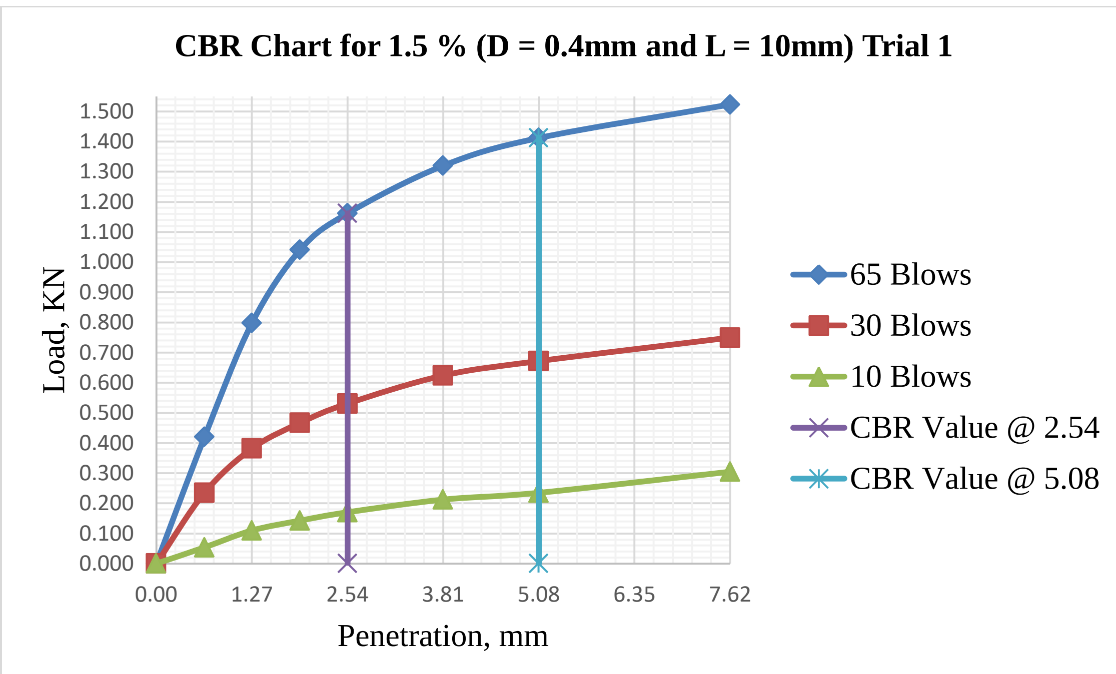
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.420		0.64	0.235		0.64	0.054	
1.27	0.798		1.27	0.382		1.27	0.110	
1.91	1.041		1.91	0.467		1.91	0.143	
2.54	1.162	8.80	2.54	0.531	4.02	2.54	0.170	1.29
3.81	1.320		3.81	0.624		3.81	0.212	
5.08	1.412	7.06	5.08	0.672	3.36	5.08	0.235	1.18
7.62	1.523		7.62	0.750		7.62	0.305	

Modified Max.Dry Density g/cc	1.512	OMC %	17.2

Swell Determination

Date		65 Blows		30 Blows		10 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
20/11/2020	Initial	1.00	5.24	1	3.32	7.24	2.54
24/11/2020	Final	7.10		4.87		10.20	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.0	1.338	1.29	88	
30	17.0	1.455	3.99	96	
65	17.4	1.584	8.74	105	
CBR at MDD, %			6.81	Swell at MDD, %	5.16



Fiber Content = 1.5%	Fiber Length = 10 mm	Fiber Diameter = 0.4 mm
Trial 2		

COMPACTION DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		N2	N2	N30	N30	N7	N7
Mass of soil + Mould	g	13607.2	14118.5	13287.1	13876.7	13012.1	13755.4
Mass Mould	g	9357.5	9357.5	9293.2	9293.2	9349.2	9349.2
Mass of Soil	g	4249.7	4761	3993.9	4583.5	3662.9	4406.2
Volume of Mould	g	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.860	2.084	1.748	2.006	1.603	1.928
Dry density of soil	g/cc	1.584	1.584	1.491	1.514	1.368	1.381

Moisture Determination

MOISTURE CONTENT DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		A	F	B	D	C	A3
Mass of wet soil + Container	g	170.10	203.6	129.30	248.1	142.90	235.2
Mass of dry soil + Container	g	149.00	163.5	113.00	194.4	124.50	177.6
Mass of container	g	27.70	36.3	18.20	29.3	17.30	32.37
Mass of water	g	21.10	40.1	16.30	53.7	18.40	57.6
Mass of drysoil	g	121.30	127.200	94.80	165.100	107.20	145.230
Moisture content	%	17.39	31.525	17.19	32.526	17.16	39.661

CBR Penetration Determination

Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.482		0.64	0.389		0.64	0.063	
1.27	0.805		1.27	0.596		1.27	0.113	
1.91	0.999		1.91	0.712		1.91	0.141	
2.54	1.105	8.37	2.54	0.790	5.98	2.54	0.164	1.24
3.81	1.243		3.81	0.895		3.81	0.199	
5.08	1.343	6.71	5.08	0.973	4.86	5.08	0.221	1.11
7.62	1.485		7.62	1.098		7.62	0.264	

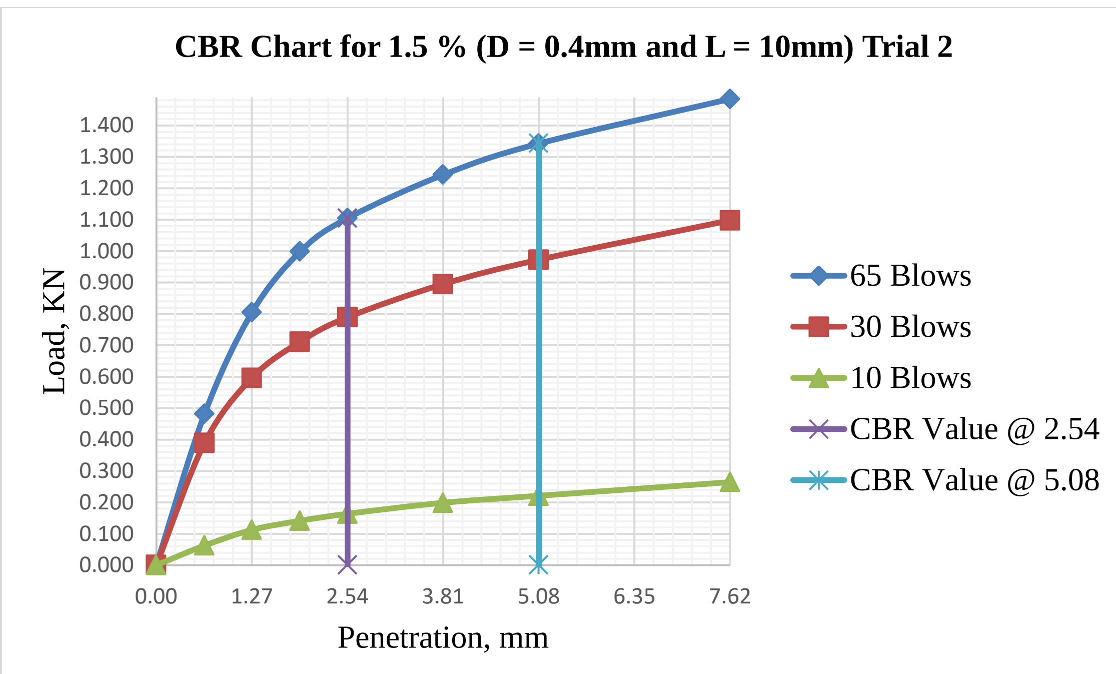
Modified Max.Dry Density g/cc	1.515	OMC %	17.2

Swell Determination

Date		65 Blows	30 Blows	10 Blows

		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
20/11/2020	Initial	8.90	5.41	6.01	3.63	5.20	2.23
24/11/2020	Final	15.20		10.24		7.80	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.2	1.37	1.24	90	
30	17.2	1.49	5.94	98	
65	17.4	1.58	8.31	105	
CBR at MDD, %			6.97	**Swell at MDD, %**	**4.95**
Average CBR, %			**6.89**	**Average Swell, %**	**5.055**



B 2.12 CBR Laboratory Data Analysis of 2.5% for 0.4 mm diameter and 10 mm Length

Fiber Content = 2.5%	Fiber Length = 10 mm	Fiber Diameter = 0.4 mm
Trial 1		

COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		N9	N9	TN	TN	N6	N6
Mass of soil + Mould	g	13605.1	14115.2	13272	13829.5	12882.1	13629.2
Mass Mould	g	9382.2	9382.2	9376.2	9376.2	9320.4	9320.4
Mass of Soil	g	4222.9	4733	3895.8	4453.3	3561.7	4308.8
Volume of Mould	CC	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.848	2.071	1.705	1.949	1.559	1.886
Dry density of soil	g/cc	1.574	1.572	1.457	1.412	1.332	1.302

Moisture Determination

MOISTURE CONTENT DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.		AS	BD	MK	DE	H	4A
Mass of wet soil + Container	g	126.30	227.30	200.10	153.57	137.40	231.89
Mass of dry soil + Container	g	110.40	180.00	175.40	120.90	120.30	172.40
Mass of container	g	19.10	31.23	30.10	35.08	19.90	39.67
Mass of water	g	15.90	47.30	24.70	32.67	17.10	59.49
Mass of drysoil	g	91.30	148.77	145.30	85.82	100.40	132.73
Moisture content	%	17.42	31.79	17.00	38.07	17.03	44.82

CBR Penetration Determination

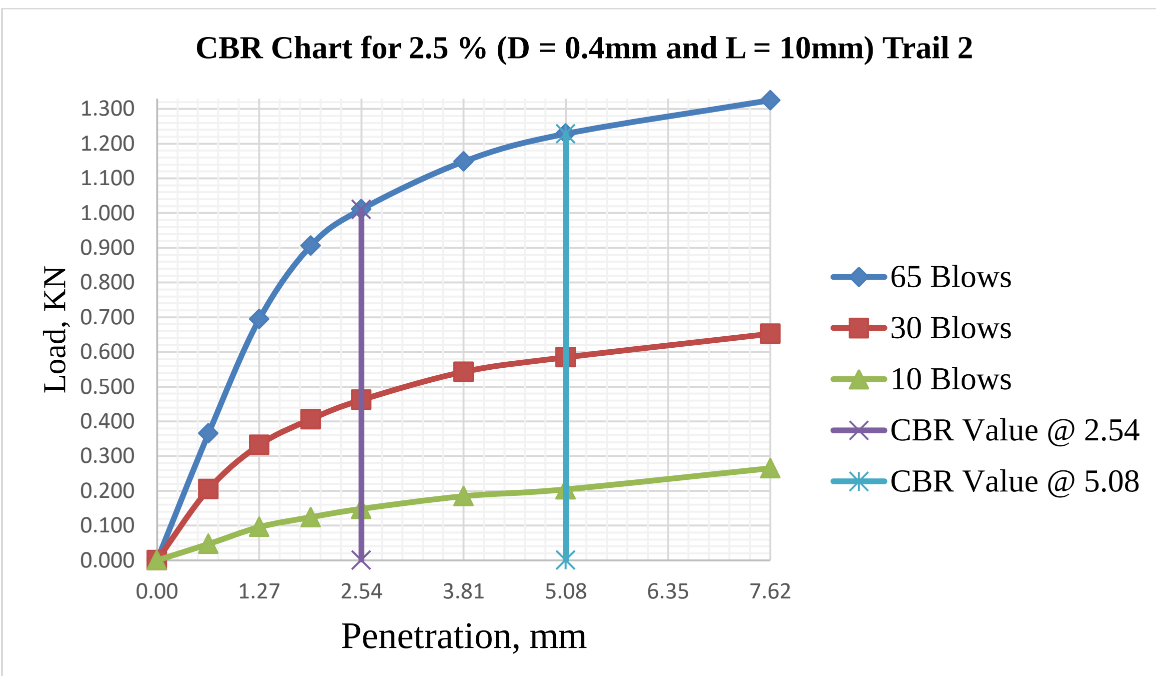
Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**					
65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.365		0.64	0.205		0.64	0.047	
1.27	0.694		1.27	0.332		1.27	0.096	
1.91	0.906		1.91	0.406		1.91	0.124	
2.54	1.011	7.66	2.54	0.462	3.50	2.54	0.148	1.12
3.81	1.148		3.81	0.543		3.81	0.185	
5.08	1.228	6.14	5.08	0.585	2.92	5.08	0.204	1.02
7.62	1.325		7.62	0.652		7.62	0.265	

Modified Max.Dry Density g/cc	**1.530**	**OMC %**	**17.1**

Swell Determination

Date		65 Blows		30 Blows		10 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
25/11/2020	Initial	1.00	4.47	1.5	3.07	6.81	2.23
29/11/2020	Final	6.20		5.07		9.41	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.0	1.332	1.12	87	
30	17.0	1.457	3.47	95	
65	17.4	1.574	7.60	103	
CBR at MDD, %			**6.74**	**Swell at MDD, %**	**4.11**



Fiber Content = 2.5%	Fiber Length = 10 mm	Fiber Diameter = 0.4 mm
Trial 2		

COMPACTION DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		N2	N2	N30	N30	N7	N7
Mass of soil + Mould	g	13545.2	14108.5	13272.1	13864.3	13012.1	13748.2
Mass Mould	g	9379.6	9379.6	9301.1	9301.1	9349.2	9349.2
Mass of Soil	g	4165.6	4728.9	3971	4563.2	3662.9	4399
Volume of Mould	CC	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.823	2.070	1.738	1.997	1.603	1.925
Dry density of soil	g/cc	1.553	1.573	1.483	1.507	1.368	1.378

Moisture Determination

MOISTURE CONTENT DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		E	G	C	D	B	A4
Mass of wet soil + Container	g	170.10	203.6	129.30	248.1	142.90	235.2
Mass of dry soil + Container	g	149.00	163.5	113.00	194.4	124.50	177.6
Mass of container	g	27.70	36.3	18.20	29.3	17.30	32.37
Mass of water	g	21.10	40.1	16.30	53.7	18.40	57.6
Mass of drysoil	g	121.30	127.200	94.80	165.100	107.20	145.230
Moisture content	%	17.39	31.525	17.19	32.526	17.16	39.661

CBR Penetration Determination

Penetration after 96 hrs Soaking Period — **Surcharge Weight:-4.55 KG**

65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.419		0.64	0.338		0.64	0.054	
1.27	0.700		1.27	0.519		1.27	0.098	
1.91	0.869		1.91	0.619		1.91	0.123	
2.54	0.950	7.20	2.54	0.687	5.20	2.54	0.142	1.08
3.81	1.081		3.81	0.779		3.81	0.173	
5.08	1.170	5.85	5.08	0.846	4.23	5.08	0.192	0.96
7.62	1.292		7.62	0.955		7.62	0.230	

Modified Max.Dry Density g/cc	1.530	OMC %	17.1

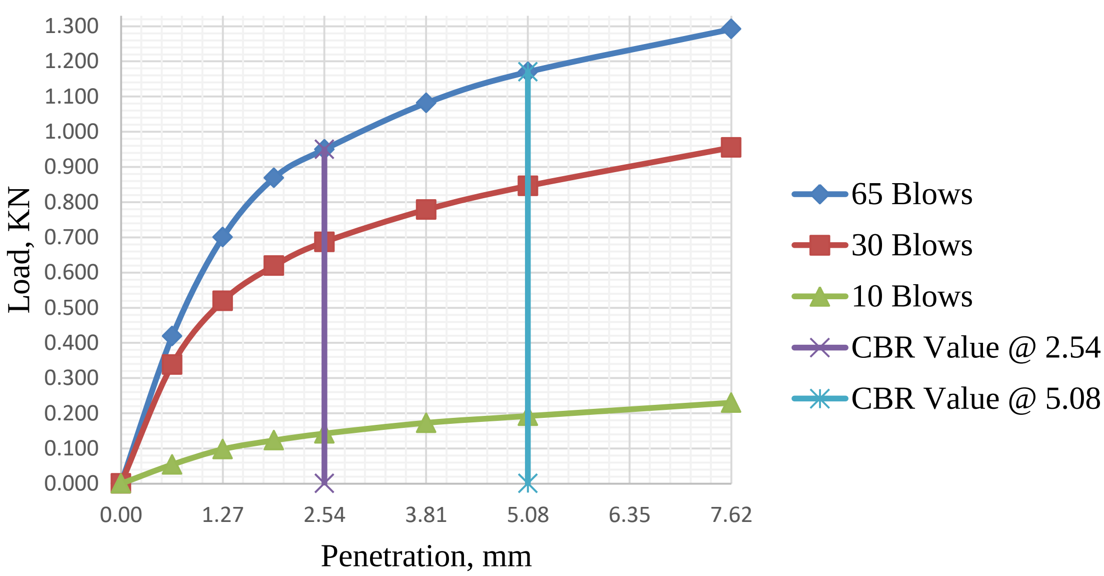
Swell Determination

Date		65 Blows	30 Blows	10 Blows

		Gauge rdg	Swell in %	Gauge rdg	Swell in %	Gauge rdg	Swell in %
		mm		mm		mm	
25/11/2020	Initial	5.50	4.30	6.12	3.51	4.56	2.28
29/11/2020	Final	10.51		10.20		7.21	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.2	1.37	1.08	89	
30	17.2	1.48	5.16	97	
65	17.4	1.55	7.14	101	
CBR at MDD, %			6.87	**Swell at MDD, %**	**4.10**
Average CBR, %			**6.81**	**Average Swell, %**	**4.105**

CBR Chart for 2.5 % (D = 0.4mm and L = 10mm) Trail 2



B 2.13 CBR Laboratory Data Analysis of 0.5% for 0.4 mm diameter and 20 mm Length

Fiber Content = 0.5%	Fiber Length = 20 mm	Fiber Diameter = 0.4 mm
Trial 1		

COMPACTION DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		N9	N9	TN	TN	N6	N6
Mass of soil + Mould	g	13534	14047	13403	13950.5	13121	13809.5
Mass Mould	g	9360.5	9360.5	9413	9413	9602.5	9602.5
Mass of Soil	g	4173.5	4686.5	3990	4537.5	3518.5	4207
Volume of Mould	cc	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.826	2.051	1.746	1.986	1.540	1.841
Dry density of soil	g/cc	1.559	1.600	1.491	1.521	1.315	1.360

Moisture Determination

MOISTURE CONTENT DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		2	1A	K4	4	B	2B
Mass of wet soil + Container	g	149.72	169.18	161.50	204.73	155.50	228.07
Mass of dry soil + Container	g	130.50	135.67	140.50	163.34	135.50	175.71
Mass of container	g	18.50	16.82	18.00	27.91	18.50	27.89
Mass of water	g	19.22	33.51	21.00	41.39	20.00	52.36
Mass of drysoil	g	112.00	118.85	122.50	135.43	117.00	147.82
Moisture content	%	17.16	28.19	17.14	30.56	17.09	35.42

CBR Penetration Determination

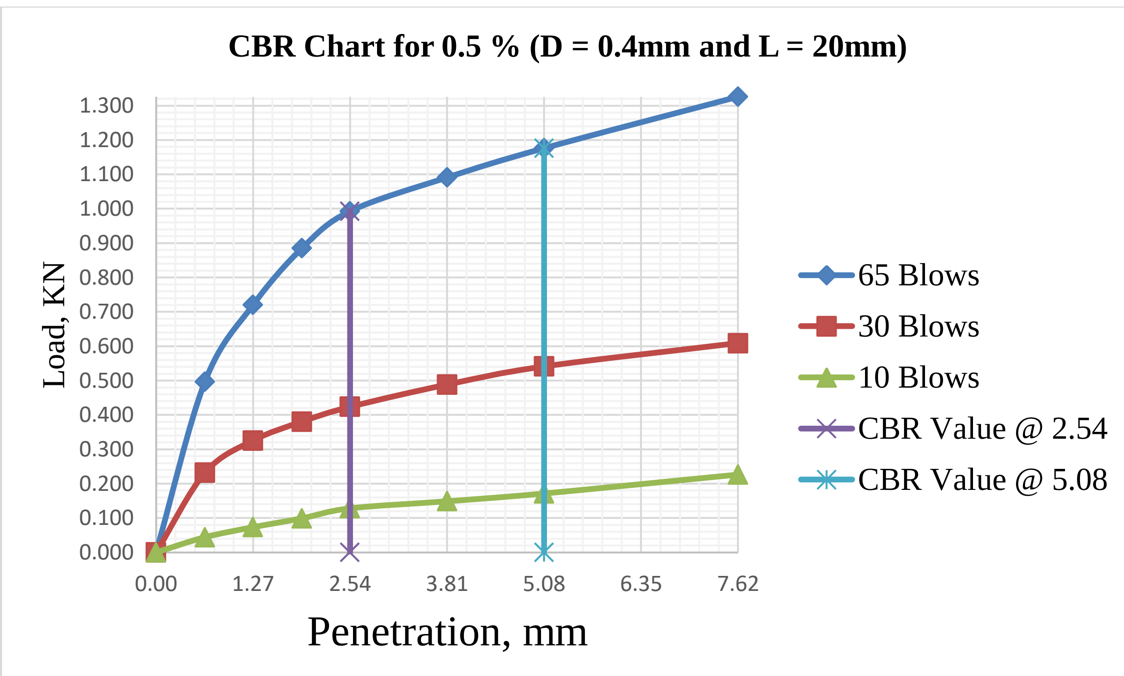
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.497		0.64	0.232		0.64	0.044	
1.27	0.720		1.27	0.326		1.27	0.073	
1.91	0.885		1.91	0.381		1.91	0.099	
2.54	0.993	7.52	2.54	0.424	3.21	2.54	0.128	0.97
3.81	1.091		3.81	0.488		3.81	0.149	
5.08	1.176	5.88	5.08	0.541	2.71	5.08	0.171	0.86
7.62	1.326		7.62	0.609		7.62	0.226	

Modified Max.Dry Density g/cc	1.530	OMC %	17.1

Swell Determination

Date		65 Blows		30 Blows		10 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
30/11/2020	Initial	0.39	6.32	0.37	5.32	0.37	3.39
4/12/2020	Final	7.75		6.56		4.32	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.09	1.315	0.97	85.9	
30	17.14	1.491	3.19	97.4	
65	17.16	1.559	7.46	101.9	
CBR at MDD, %			6.01	**Swell at MDD, %**	**6.07**
Average CBR, %			**6.01**	**Average Swell, %**	**6.07**



B 2.14 CBR Laboratory Data Analysis of 1% for 0.4 mm diameter and 20 mm Length

Fiber Content = 1%	Fiber Length = 20 mm	Fiber Diameter = 0.4 mm
Trial 1		

COMPACTION DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		N9	N9	TN	TN	N6	N6
Mass of soil + Mould	g	13680	14117.2	13402	13883.1	12956.9	13611.7
Mass Mould	g	9399.1	9399.1	9473.6	9473.6	9412.1	9412.1
Mass of Soil	g	4280.9	4718.1	3928.4	4409.5	3544.8	4199.6
Volume of Mould	cc	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.873	2.065	1.719	1.930	1.551	1.838
Dry density of soil	g/cc	1.600	1.584	1.469	1.448	1.325	1.359

Moisture Determination

MOISTURE CONTENT DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		3A	TG	C	A	DH	B4
Mass of wet soil + Container	g	137.60	204.27	163.90	212.26	132.80	225.52
Mass of dry soil + Container	g	120.20	160.85	144.10	163.90	115.90	169.32
Mass of container	g	18.20	17.99	27.60	18.43	17.00	9.86
Mass of water	g	17.40	43.42	19.80	48.36	16.90	56.20
Mass of drysoil	g	102.00	142.86	116.50	145.47	98.90	159.46
Moisture content	%	17.06	30.39	17.00	33.24	17.09	35.24

CBR Penetration Determination

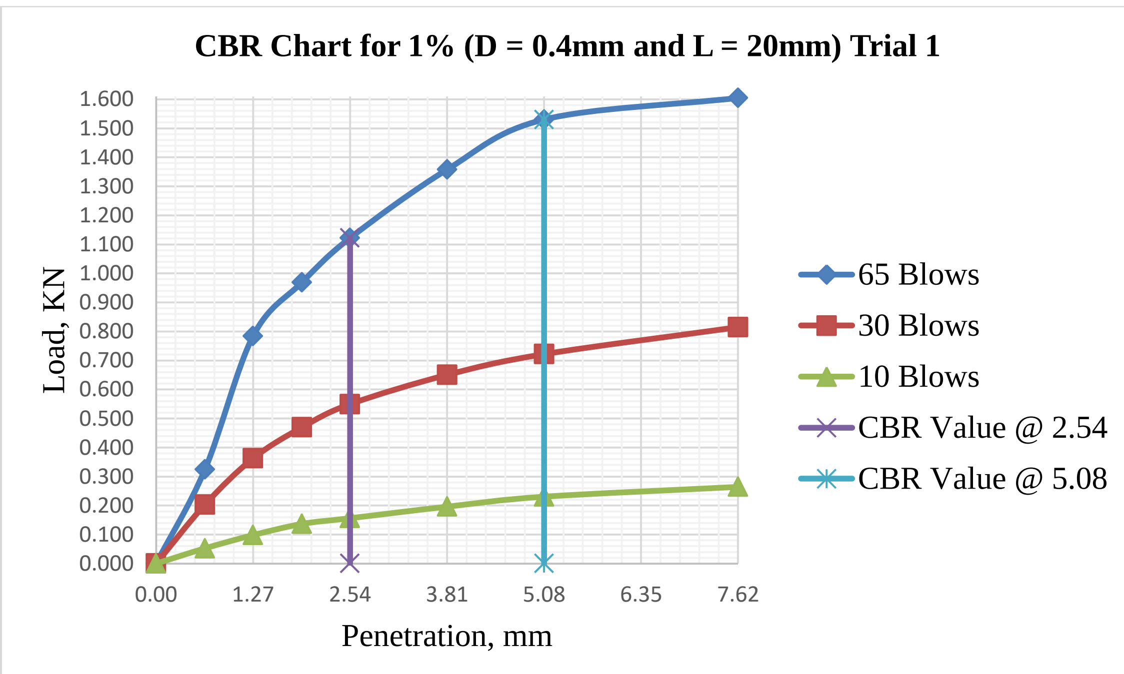
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.325		0.64	0.204		0.64	0.053	
1.27	0.784		1.27	0.363		1.27	0.098	
1.91	0.969		1.91	0.470		1.91	0.137	
2.54	1.122	8.50	2.54	0.550	4.16	2.54	0.157	1.19
3.81	1.358		3.81	0.650		3.81	0.196	
5.08	1.530	7.65	5.08	0.722	3.61	5.08	0.231	1.15
7.62	1.605		7.62	0.815		7.62	0.264	

Modified Max.Dry Density g/cc	1.540	OMC %	17.3

Swell Determination

Date		65 Blows		30 Blows		10 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
4/12/2020	Initial	3.89	6.04	3.36	4.95	1.29	3.13
8/12/2020	Final	10.92		9.12		4.93	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.1	1.325	1.19	86	
30	17.0	1.469	4.13	95	
65	17.1	1.600	8.44	104	
CBR at MDD, %			**6.82**	**Swell at MDD, %**	**5.77**



Fiber Content = 1%	Fiber Length = 20 mm	Fiber Diameter = 0.4 mm
Trial 2		

COMPACTION DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		N2	N2	N30	N30	N7	N7
Mass of soil + Mould	g	13585.6	14086.6	13414.5	14004	12940.7	13696.7
Mass Mould	g	9368.1	9368.1	9429.5	9429.5	9425.6	9425.6
Mass of Soil	g	4217.5	4718.5	3985	4574.5	3515.1	4271.1
Volume of Mould	cc	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.846	2.065	1.744	2.002	1.538	1.869
Dry density of soil	g/cc	1.576	1.568	1.489	1.505	1.313	1.356

Moisture Determination

MOISTURE CONTENT DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		TG	C	A	B3	A1	2A
Mass of wet soil + Container	g	115.00	200.31	146.67	251.54	124.10	255.11
Mass of dry soil + Container	g	100.80	158.844	127.90	196.07	108.60	192.711
Mass of container	g	17.70	27.91	18.20	27.93	18.20	27.83
Mass of water	g	14.20	41.466	18.77	55.47	15.50	62.399
Mass of drysoil	g	83.10	130.934	109.70	168.140	90.40	164.881
Moisture content	%	17.09	31.669	17.11	32.990	17.15	37.845

CBR Penetration Determination

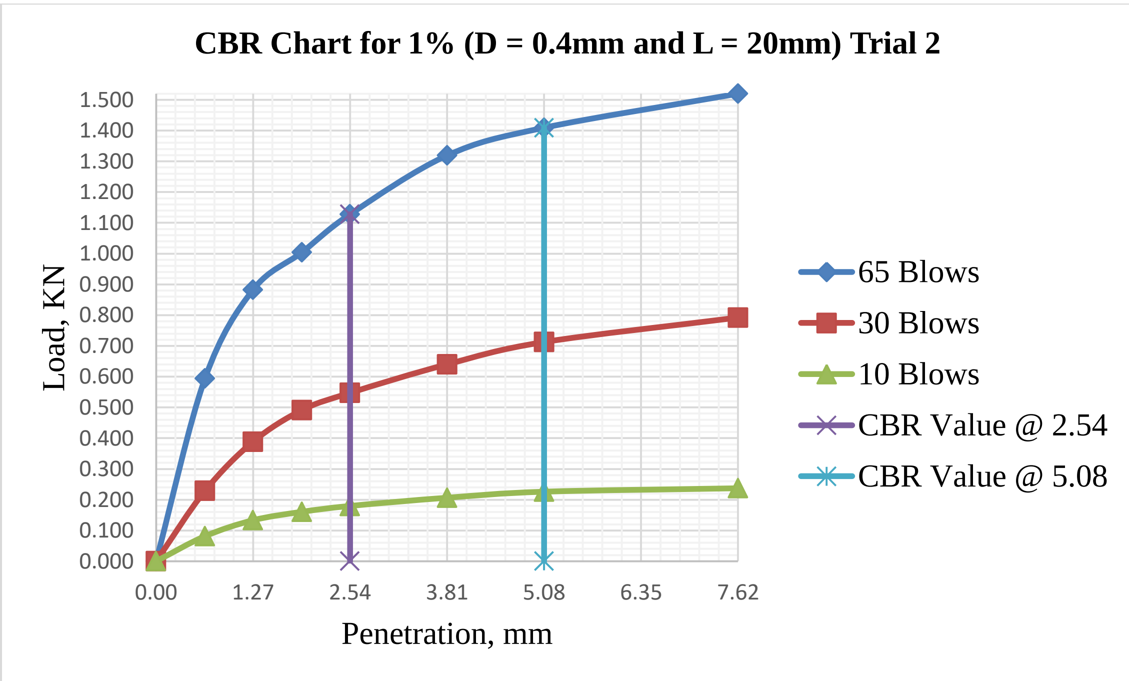
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.594		0.64	0.229		0.64	0.081	
1.27	0.883		1.27	0.389		1.27	0.133	
1.91	1.004		1.91	0.491		1.91	0.161	
2.54	1.128	8.54	2.54	0.547	4.15	2.54	0.180	1.36
3.81	1.319		3.81	0.640		3.81	0.207	
5.08	1.409	7.05	5.08	0.713	3.56	5.08	0.226	1.13
7.62	1.520		7.62	0.792		7.62	0.237	

Modified Max.Dry Density g/cc	1.540	OMC %	17.3

Swell Determination

Date		65 Blows		30 Blows		10 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
4/12/2020	Initial	0.54	5.73	0.08	5.02	0.71	3.63
8/12/2020	Final	7.21		5.92		4.93	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.1	1.31	1.36	85	
30	17.1	1.49	4.12	97	
65	17.1	1.58	8.48	102	
CBR at MDD, %			6.91	**Swell at MDD, %**	**5.55**
Average CBR, %			**6.9**	**Average Swell, %**	**5.66**



B 2.15 CBR Laboratory Data Analysis of 1.5% for 0.4 mm diameter and 20 mm Length

Fiber Content = 1.5%	Fiber Length = 20 mm	Fiber Diameter = 0.4 mm
Trial 1		

COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		N9	N9	TN	TN	N6	N6
Mass of soil + Mould	g	13713.8	14282.6	13369.3	13951.7	12850.5	13589.5
Mass Mould	g	9360.1	9360.1	9421.9	9421.9	9340.8	9340.8
Mass of Soil	g	4353.7	4922.5	3947.4	4529.8	3509.7	4248.7
Volume of Mould	cc	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.905	2.154	1.728	1.982	1.536	1.859
Dry density of soil	g/cc	1.627	1.637	1.475	1.501	1.311	1.355

Moisture Determination

MOISTURE CONTENT DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.		2A	C	1B	B3	10	H
Mass of wet soil + Container	g	176.00	224.66	122.40	217.70	170.10	224.46
Mass of dry soil + Container	g	154.30	177.39	107.10	171.65	149.20	168.56
Mass of container	g	27.50	27.78	17.80	27.96	27.50	18.47
Mass of water	g	21.70	47.27	15.30	46.05	20.90	55.90
Mass of drysoil	g	126.80	149.61	89.30	143.69	121.70	150.09
Moisture content	%	17.11	31.60	17.13	32.05	17.17	37.24

CBR Penetration Determination

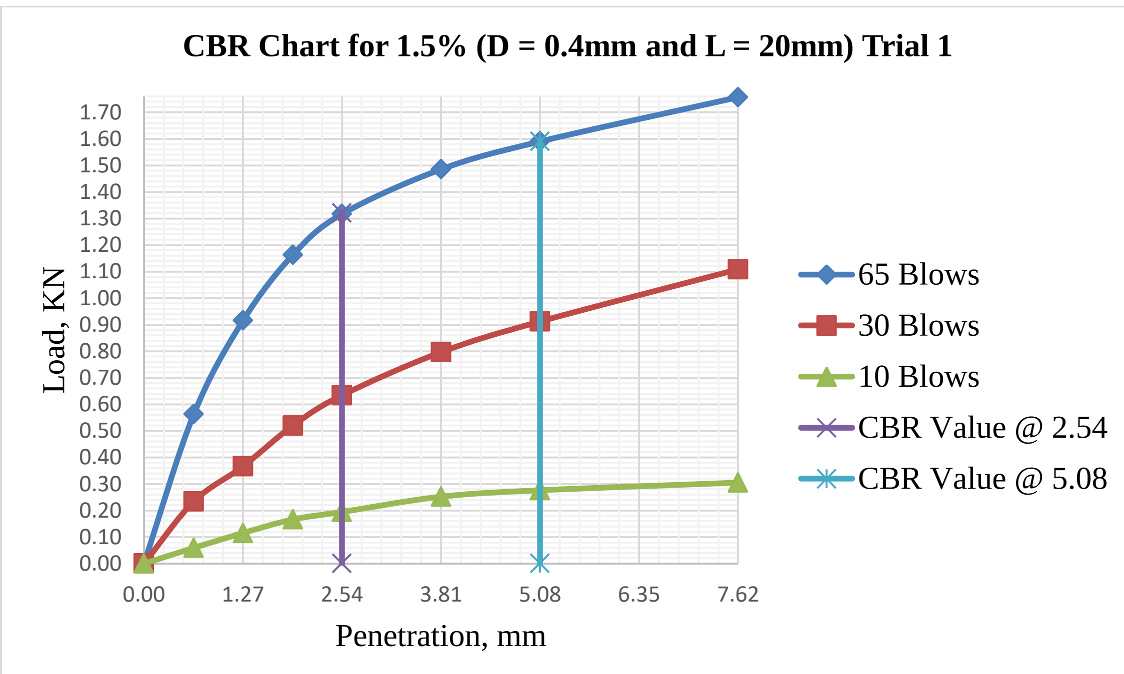
Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**					
65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.563		0.64	0.234		0.64	0.059	
1.27	0.915		1.27	0.366		1.27	0.115	
1.91	1.163		1.91	0.520		1.91	0.166	
2.54	1.317	9.98	2.54	0.634	4.80	2.54	0.195	1.47
3.81	1.485		3.81	0.796		3.81	0.252	
5.08	1.590	7.95	5.08	0.912	4.56	5.08	0.276	1.38
7.62	1.757		7.62	1.109		7.62	0.305	

Modified Max.Dry Density g/cc	**1.541**	**OMC %**	**17.4**

Swell Determination

Date		65 Blows		30 Blows		10 Blows	
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
4/12/2020	Initial	9.40	5.98	4.03	5.11	10.17	3.20
8/12/2020	Final	16.36		9.98		13.89	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.2	1.311	1.47	85	
30	17.1	1.475	4.77	96	
65	17.1	1.627	9.90	106	
CBR at MDD, %			**7.82**	**Swell at MDD, %**	**5.76**



Fiber Content = 1.5%	Fiber Length = 20 mm	Fiber Diameter = 0.4 mm
Trial 2		

COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		N2	N2	N30	N30	N7	N7
Mass of soil + Mould	g	13661.4	14244.5	13214.7	13819.5	12773.1	13544.5
Mass Mould	g	9338.8	9338.8	9271.2	9271.2	9290.3	9290.3
Mass of Soil	g	4322.6	4905.7	3943.5	4548.3	3482.8	4254.2
Volume of Mould	cc	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.892	2.147	1.726	1.991	1.524	1.862
Dry density of soil	g/cc	1.614	1.661	1.473	1.509	1.301	1.342

Moisture Determination

MOISTURE CONTENT DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.		2B	1B	3B	2A	4B	2B
Mass of wet soil + Container	g	145.80	176.04	140.50	216.8	160.89	274.06
Mass of dry soil + Container	g	128.50	140.22	122.60	171.12	141.20	205.27
Mass of container	g	27.80	17.907	18.10	27.79	26.30	27.775
Mass of water	g	17.30	35.82	17.90	45.68	19.69	68.79
Mass of drysoil	g	100.70	122.313	104.50	143.330	114.90	177.495
Moisture content	%	17.18	29.286	17.13	31.871	17.14	38.756

CBR Penetration Determination

Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**					
65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.561		0.64	0.231		0.64	0.096	
1.27	1.007		1.27	0.396		1.27	0.148	
1.91	1.279		1.91	0.513		1.91	0.172	
2.54	1.448	10.97	2.54	0.600	4.55	2.54	0.189	1.43
3.81	1.634		3.81	0.696		3.81	0.226	
5.08	1.749	8.75	5.08	0.801	4.00	5.08	0.252	1.26
7.62	1.944		7.62	0.887		7.62	0.287	

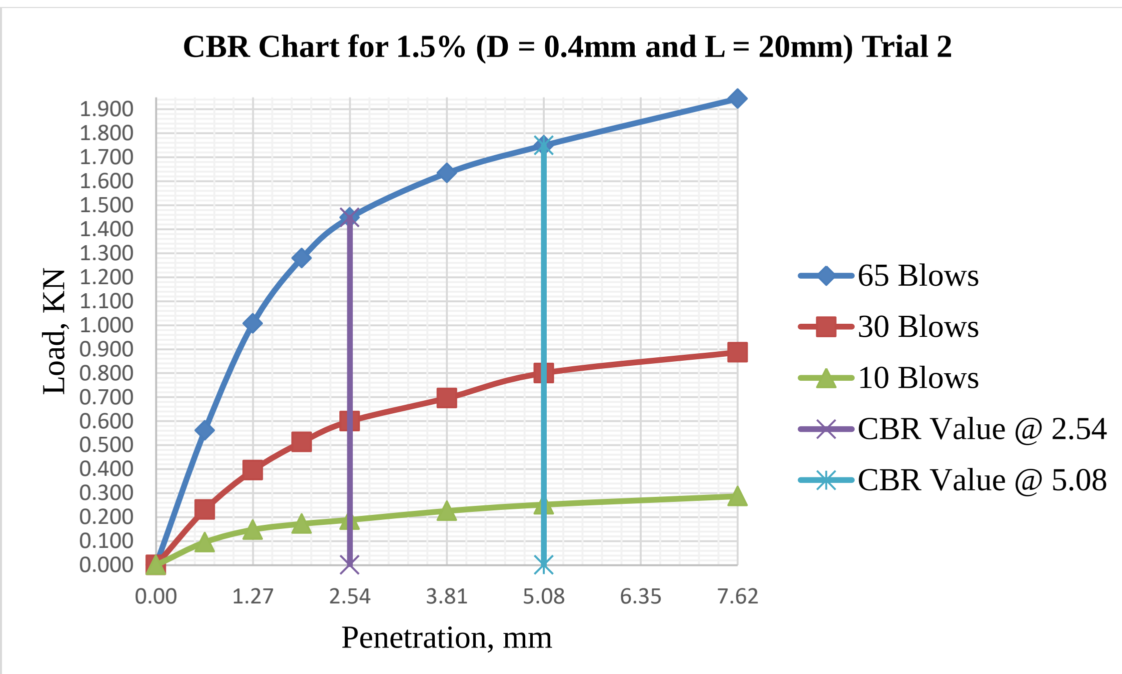
Modified Max.Dry Density g/cc	**1.541**	**OMC %**	**17.4**

Swell Determination

Date		**65 Blows**	**30 Blows**	**10 Blows**

		Gauge rdg mm	**Swell in %**	**Gauge rdg mm**	**Swell in %**	**Gauge rdg mm**	**Swell in %**
4/12/2020	Initial	5.46	5.77	2.55	4.81	8.85	3.52
8/12/2020	Final	12.18		8.15		12.95	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.1	1.30	1.43	84	
30	17.1	1.47	4.51	96	
65	17.2	1.61	10.89	105	
CBR at MDD, %			8.10	**Swell at MDD, %**	**5.53**
Average CBR, %			**7.96**	**Average Swell, %**	**5.645**



B 2.16 CBR Laboratory Data Analysis of 2.5% for 0.4 mm diameter and 20 mm Length

Fiber Content = 2.5%	Fiber Length = 20 mm	Fiber Diameter = 0.4 mm
Trial 1		

COMPACTION DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		N9	N9	TN	TN	N6	N6
Mass of soil + Mould	g	13680.2	14275.4	13340.2	13911.2	12820.1	13531.2
Mass Mould	g	9369.2	9369.2	9421.9	9421.9	9340.8	9340.8
Mass of Soil	g	4311	4906.2	3918.3	4489.3	3479.3	4190.4
Volume of Mould	cc	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.887	2.147	1.715	1.965	1.523	1.834
Dry density of soil	g/cc	1.611	1.632	1.464	1.490	1.301	1.328

Moisture Determination

MOISTURE CONTENT DATA		**65 Blows**		**30 Blows**		**10 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.		BK	D	B3	A1	A10	F
Mass of wet soil + Container	g	179.00	228.66	125.40	219.80	172.20	228.60
Mass of dry soil + Container	g	157.30	181.39	110.10	173.75	151.40	170.60
Mass of container	g	30.50	31.78	20.80	29.06	29.40	18.47
Mass of water	g	21.70	47.27	15.30	46.05	20.80	58.00
Mass of drysoil	g	126.80	149.61	89.30	144.69	122.00	152.13
Moisture content	%	17.11	31.60	17.13	31.83	17.05	38.12

CBR Penetration Determination

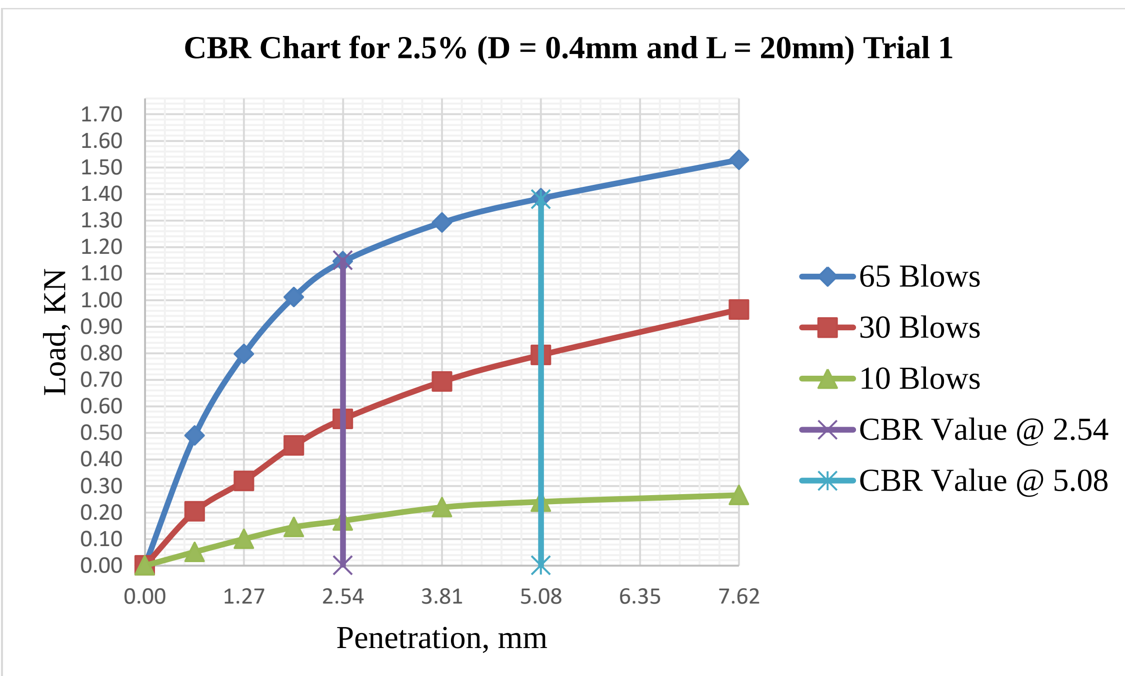
Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**					
65 Blows			**30 Blows**			**10 Blows**		
Pen.mm	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**	**Pen.mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.490		0.64	0.204		0.64	0.052	
1.27	0.796		1.27	0.319		1.27	0.100	
1.91	1.012		1.91	0.452		1.91	0.145	
2.54	1.146	8.68	2.54	0.552	4.18	2.54	0.169	1.28
3.81	1.292		3.81	0.693		3.81	0.219	
5.08	1.383	6.92	5.08	0.793	3.97	5.08	0.240	1.20
7.62	1.528		7.62	0.964		7.62	0.265	

Modified Max.Dry Density g/cc	**1.550**	**OMC %**	**17.1**

Swell Determination

Date		**65 Blows**		**30 Blows**		**10 Blows**	
		Gauge rdg mm	**Swell in %**	**Gauge rdg mm**	**Swell in %**	**Gauge rdg mm**	**Swell in %**
25/12/2020	Initial	0.00	5.58	0.02	5.12	1.12	3.54
29/12/2020	Final	6.50		5.98		5.24	

No.of blows	MCBS %	DDBS g/cm3	**Correcrt CBR %**	% OF Compaction	
10	17.0	1.301	1.28	84	
30	17.1	1.464	4.15	94	
65	17.1	1.611	8.61	104	
CBR at MDD, %			**7.82**	**Swell at MDD, %**	**5.47**



Fiber Content = 2.5%	Fiber Length = 20 mm	Fiber Diameter = 0.4 mm
Trial 2		

COMPACTION DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		N2	N2	N30	N30	N7	N7
Mass of soil + Mould	g	13625.3	14223.4	13201.5	13800.8	12745.2	13501.2
Mass Mould	g	9335.2	9335.2	9265.6	9265.6	9285.3	9285.3
Mass of Soil	g	4290.1	4888.2	3935.9	4535.2	3459.9	4215.9
Volume of Mould	cc	2285	2285	2285	2285	2285	2285
Wet density of soil	g/cc	1.878	2.139	1.722	1.985	1.514	1.845
Dry density of soil	g/cc	1.594	1.655	1.471	1.505	1.293	1.330

Moisture Determination

MOISTURE CONTENT DATA		65 Blows		30 Blows		10 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		1B	A1	2B	A2	3B	A3
Mass of wet soil + Container	g	142.90	177.54	143.50	221.80	162.99	274.06
Mass of dry soil + Container	g	125.50	141.72	125.60	176.12	143.30	205.27
Mass of container	g	27.80	19.407	21.10	32.79	28.40	27.775
Mass of water	g	17.40	35.82	17.90	45.68	19.69	68.79
Mass of drysoil	g	97.70	122.313	104.50	143.330	114.90	177.495
Moisture content	%	17.81	29.286	17.13	31.871	17.14	38.756

CBR Penetration Determination

Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.488		0.64	0.201		0.64	0.083	
1.27	0.876		1.27	0.344		1.27	0.129	
1.91	1.113		1.91	0.446		1.91	0.150	
2.54	1.260	9.55	2.54	0.522	3.95	2.54	0.164	1.25
3.81	1.421		3.81	0.606		3.81	0.197	
5.08	1.522	7.61	5.08	0.696	3.48	5.08	0.220	1.10
7.62	1.691		7.62	0.772		7.62	0.250	

Modified Max.Dry Density g/cc	1.550	OMC %	17.1

Swell Determination

Date		65 Blows	30 Blows	10 Blows

		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
25/12/2020	Initial	3.21	5.70	1.01	4.97	7.00	3.64
29/12/2020	Final	9.85		6.80		11.24	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction	
10	17.1	1.29	1.25	83	
30	17.1	1.47	3.92	95	
65	17.8	1.59	9.47	103	
CBR at MDD, %			8.21	**Swell at MDD, %**	**5.52**
Average CBR, %			**8.02**	**Average Swell, %**	**5.495**