JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

Suitability of Ceramic Dust Waste and Plastic Waste Fiber Mix to Improve the Strength of Subgrade Soil

A Research 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 Abraham Amele

July, 2021

Jimma, Ethiopia.

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By Abraham Amele

Advisor: Dr. Ing. Fekadu Fufa

Co-Advisor: Mr. Grima Fikre (Msc.)

July, 2021

Jimma, Ethiopia.

DECLARATION

I, the undersigned, declare that this thesis entitled: ***"Suitability of Ceramic Dust Waste and Plastic Waste Fiber Mix to Improve the Strength of Subgrade Soil "*** is my original work, and has 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 this thesis have to be duly acknowledged.

Abraham Amele	____________	27/07/2021
Candidate	Signature	Date

As Master's Research Advisor, I hereby certify that I have read and evaluated this MSc Thesis prepared under my guidance by Abraham Amele entitled: ***"Suitability of Ceramic Dust Waste and Plastic Waste Fiber Mix to Improve the Strength of Subgrade Soil"***. This thesis has been submitted for examination with my approval as university supervisor.

Dr.Ing. Fekadu Fufa	____________	27/07/2021
Advisor	Signature	Date
Mr. Grima Fikre (MSc.)	____________	27/07/2021
Co-Advisor	Signature	Date

As member of Board of Examiners of the M.Sc. Thesis Open Defense Examination, We certify that we have read, evaluated the thesis prepared by Abraham Amele and examined the candidate. We recommended that the thesis could be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Highway Engineering.

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Internal Examiner	Signature	Date
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External Examiner	Signature	Date
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Chairperson	Signature	Date

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ABSTRACT

Expansive soils mostly cause significant damage to structures such as buildings, pavements and bridges. Therefore, the objective of this study was to quantify the improvements achieved on the weak subgrade soil strength due to mix of plastic waste fiber and ceramic dust waste on expansive clay soils of Jimma town. Demolished and waste ceramics were collected from Jimma town of different construction sites and crushed and powdered manually by means of hand and sieved through 75µm sieve size. Plastic wastes used for this study are Polyethylene Terephthalate (PET) plastic type are collected from JiT campus disposal holes, cleared and cut down to strips to having approximate thickness of 2-4mm and length 7-10 mm.

The percent proportion of ceramic dust waste utilized was 5 to 30% and percentage of plastic fibers 0.5 to 2.5% by dry weight of soil. Firstly, the optimum percentage of ceramic dust waste was determined from laboratory test by mixing varying percentage of ceramic dust waste with clay soil. Then the optimum percentage of ceramic dust waste was used as constant and mixed with the varying amount of plastic fiber and expansive soil. Finally the optimum percentage of plastic waste fiber added was determined. Moisture content, particle size analysis, Atterberg limits, linear shrinkage, free swell, specific gravity, compaction, CBR and UCS tests were conducted. The CBR value of soil increased from 1.03% to optimum value of 5.80%, UCS value also increased from 83.15 kpa to 421.14 kpa (for immediate test) and 464.45 kpa (cured for seven days taste) by increase of ceramic dust waste from 0 to 30%. Laboratory tests revealed that the ideal level of ceramic dust waste as 20%. Clayey soil with 20% (optimum) of ceramic dust waste indicated just minor increment in the quality of soil, repressing its utilization for ground changes. To additionally build the quality of the soil the optimum percentage of ceramic dust waste mixed with various level of plastic fiber. Endeavors have been made with 20% (constant) ceramic dust waste and different rates of plastic fibers. The CBR value increased from 5.80 to 8.30%, UCS value also increased from 421.14 kpa to 744.61 kpa for immediate test and 464.44 kpa to 871.75 kpa for seven days cured test by increase of plastic fiber from 0.5 to 2.5% with optimum value of ceramic dust waste (20%) by weight of dry soil. Laboratory tests revealed that the ideal level of ceramic dust waste as 20% and plastic waste fiber as 1.5% by weight of dry soil.

Ceramic dust waste treatment in clay soil enhances strength but to decrease brittleness in soil specimen, increase ductility behavior and to improve more, expansive soils reinforced with plastic fiber. An optimum content of ceramic dust (20%) with 1.5% (optimum) of plastic fiber by weight of dry soil is recommended for strengthening weak subgrade soil.

***Key word**: Ceramic waste; pavement distress; Plastic waste; Soil stabilization; Weak subgrade.*

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ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CDW	Ceramic Dust Waste
CBR	California Bearing Ratio
CH	Highly Clay
ERA	Ethiopia Road Authority
HDP	High density polyethylene
LDPE	Low density polyethylene
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PC	Poly Carbonate
PET	Polyethylene Terephthalate:
PI	Plastic Index
PL	Plastic Limit
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
PWF	Plastic Waste Fiber
S01	Soil Sample one
S02	Soil Sample Two
WCD	Waste Ceramic Dust
UCS	Unconfined Compression strength
UK	United Kingdom
USCS	Unified Soil Classification System
USDA	United State Department of Agriculture System

CHAPTER ONE

INTRODUCTION

1.1. Background

The existence of expansive soil greatly affects the construction activities in many parts of the southwestern United States, South America, Canada, Africa, Australia, Europe, India and China. Expansive soils are worldwide problems and is also common in our country, Ethiopia which covering nearly 40% of total area of the country and observed in area such as central Ethiopia, the Southern, South-west, south-east and north-east part of Ethiopia. But the capital Addis Ababa area and western Ethiopia has densely expansive soil coverage [1, 2].

Every man-made structure resting on the ground needs safe and stable soil. To attain this safety and stability requirements the Engineering properties of the soil beneath the structure or on the structure must be identified. The foundation is very important for any structure and it has to be strong enough to support the entire structure or loads. For foundation and roadbed to be strong the soil around plays very important role. Expansive soils like black cotton soil always create problems on subgrade of flexible asphalt pavement. The problems are swelling, shrinkage and unequal settlement and this leads pavement failure and distresses [3].

One of the weak sub grade soils that do not favorable for road construction is expansive soils. Those soils are one of the most abundant soils in Ethiopia, which mostly creates problems on built of structure. This damage is due to moisture fluctuation caused by seasonal variation. Properties of the weak sub grade soil vary from place to place due to topography, climate and content of soils etc. These problems need wider application of cost effective and environmentally friendly technology of improving soil properties to be customized or adopted to the current road construction trend in Ethiopia [1].

In general way treatment of weak subgrade soils is accomplished by modification, stabilization, or removal and replacement. Modification refers to a short-term subgrade treatment that is intended to provide a stable working platform during construction. Stabilization refers to a subgrade treatment intended to provide structural stability for improved long-term performance. Removal and replacement, as the name indicates it involves removal of the unsuitable subgrade soil and replacement with a select material (usually granular backfill). Out of these, Stabilization with stabilizing agent is the most effective method [4].

Soil stabilization means the improvement of stability or bearing capacity and compressive strength of the soil by the use of controlled compaction, proportioning and/or the addition of suitable admixture or stabilizers. It can be used to treat a wide range of sub-grade materials from expansive clays to granular materials. The most common improvements achieved through stabilization include better soil gradation, reduction of plasticity index or swelling potential, increases durability, increase the shear strength of a soil and thus improving the load bearing capacity of a sub-grade to support applying loads on pavements and foundations [5].

Recently, utilization of waste materials in soft soil stabilization is given global attention in order to minimize the environmental problems and to achieve sustainability. Spending high cost on stabilization of weak soils using chemicals or other additives were the reason to use waste materials in soil stabilization. Employing waste materials in geotechnical applications have been a great concern of various authors. Meanwhile, bitumen, cement, lime or another chemicals used as soil stabilizer are costly and to overcome it mixing those material with another waste material additives or waste materials only as stabilizer in order to reduce the amount of the costly stabilizers. Stabilization of soft soil using environmental wastes would contribute to reduce the amount of waste and preserve natural resources [6].

This study was focused on ceramic dust waste and plastic waste fiber to improve subgrade strength of both bearing ratio and compressive strength. Ceramic dust is produced as waste from ceramic bricks, roof and floor tiles and stoneware waste industries. In ceramic industry factories around 30% of daily production goes as waste material, which is not recycled. The disposal of which creates soil, water and air pollution [7, 93]. Similarly, Plastics are inexpensive, lightweight and durable materials, which can readily be molded into a variety of products that find use in a wide range of applications. There is also rapid increase in generation of waste plastics all around the world due to economic growth, changing consumption and production patterns. The world's annual consumption of plastic materials has increased from around 5 million tons in the 1950s to nearly 100 million tons. Thus, presently 20 times more plastic is produced as compared to 50 years ago. In Asia, Antarctica and Africa, as well as many other developing regions, plastic consumption has increased much more than the world's average due to rapid urbanization and economic development. Therefore, this is big quantities of plastic wastes need to be disposed off. After food and paper wastes, plastic waste is the third major constitute at municipal and industrial waste in the urban. This situation gets worsened due to the fact that they are not even aware of the ill-effects of plastic waste to the environment [8].

The Biggest challenge in a developing country like Ethiopia is how to construct a road with limited financial source available with a standard quality. Use of local materials can considerably lower down the construction cost. If the stability of local soil is not adequate for supporting wheel loads, the properties are improved by soil stabilization techniques. Therefore, this study focused on how to use locally available waste materials; ceramic dust waste and plastic waste fiber; to improve weak subgrade soil. Subgrade soils are stabilized to improve the performance of such pavements in long run and to minimize the maintenance cost [19]. The stabilization using waste plastic strips and west ceramic dust is an economical method since they are wastes, relatively cheap and easily available in the market or municipal wastes [9].

In Ethiopia expansive soils are known to pose severe problems on road construction activities, which lead to increase in construction and maintenance costs. There is a problematic soil found In Jimma Town that needs treatment [1]. To overcome these problems understanding of their properties and evaluating suitable stabilization methods are very important. This research was conducted to identify and evaluate the engineering properties of expansive soils and they were stabilized with ceramic dust waste and plastic waste fiber admixture. The main objective of the research was to assess the suitability of ceramic dust waste and plastic waste fiber to improve the engineering performance of weak subgrade of bearing capacity and compressive strength. Their performances are also evaluated with laboratory results and compered with standard specifications of ERA, AASHTO or ASTM. The laboratory results as well as the statistical analysis from this study are good news for pavements deterioration due to weak subgrade soil.

1.2. Statements of a Problem

Expansive soils are problematic soils having poor strength and bearing capacity. Engineers face many problems while constructing facilities on such soils. The expansive soils can swell and shrinks depending upon the presence of moisture on it. This behavior causes the volume change of the soil and it results the cracking and failure of structures built on that soil like flexible asphalt pavement [11, 12]. Such a weak soils do not possess sufficient strength to support the loads of the structure coming on them during construction or service life of the structure and having poor strength and bearing capacity. Presence of such treacherous soil poses many challenges to the civil Engineers [13].

Weak soils are spread in most part of Ethiopia and here Jimma town the problem is also common. Such an expansive soils exhibit volume change when subjected to moisture variation and which causes the structures to cracking and failure of structures. One of the difficult challenges in construction of road is constructing a road on weak sub grade/expansive soils. The pavement distresses like longitudinal cracking and failure, traverse cracking, High and low severity alligator cracking and other types are found in study area and it is may be due to expansive soils exist in subgrade layer which make subgrade layer weak [1,3].

There are a number of techniques available to improve the Engineering properties of expansive soils to make it suitable for construction. This study was carried out on the results of the experimental result carried out by stabilization of the expansive soil using a mix of ceramic dust waste and plastic waste fiber; both are locally available waste materials. They are economically feasible and available locally.

Therefore, stabilization of weak subgrade soils with a mix of ceramic dust waste and plastic waste fiber is better way; because they are available locally and cheaper. On other hands plastic waste fiber used for this study were a cut strips with a specified length and thicknesses are good news because they can't burned to recycle for soil stabilization purpose and it can minimize Environmental contamination and air pollution [9]. So, using this ceramic dust waste and plastic waste fiber is better way as a weak soil stabilizer in road construction; is cost effective in relative to cement, bitumen, chemical and lime stabilizer; as well as it is good for environmental clearance other than waste to anywhere.

1.3. Research Questions

The major research questions are:

- What are the engineering properties of the subgrade soils?
- What are the effects on the engineering properties of weak subgrade soil in addition of different mix ratios of the ceramic dust waste and plastic waste fiber?
- What are the optimum mix ratios those to improve the bearing capacity and compressive strength of weak subgrade soil?
- What are the advantages of stabilization of soil using a mix of soil - ceramic dust waste - plastic waste fiber that of using only ceramic dust waste with soil?

1.4. Objective

1.4.1. General Objective

The general objective of this study was to evaluate the suitability of mix of ceramic dust waste and plastic waste fiber to improve the strength of subgrade soil.

1.4.2. Specific Objectives

The specific objectives of the study are:

- to determine the engineering properties of the subgrade soils;
- to investigate the properties of subgrade soil stabilized with different mix ratios of the ceramic dust waste and plastic waste fiber;
- to determine the optimum mix ratios with maximum bearing capacity and compressive strength; and
- to compare the effects of stabilization of soil with only ceramic dust waste that of using mix of ceramic dust waste and plastic waste fiber.

1.5. Significance of the Study

This research will play great role for foundation design on of Highway and may be for others. The results of this research can be utilized by the road contractors who may face a weak subgrade soil during road construction. To construct a road that have a strong subgrade layer with good pavement condition with respect to the stabilizing agent, using locally available and cost effective waste materials as weak soil stabilizer is the better way. On the other hand, this research can be used as a reference for Jimma Institute of Technology students those who wants to carried out further study with respect to stabilizing material type.

1.6. Scope and Limitation of the Study

Two representative expansive soil samples along the road section from different location in Jimma town were collected to conduct this study. This study was supported by different types of literatures and a series of laboratory experiments. The scope of study was to evaluate the suitability of a mix of ceramic dust waste and plastic waste fiber was used for weak subgrade soil stabilizer depending on laboratory test. The relevant laboratory tests conducted were moisture content, specific gravity, grain size analysis, Atterberg limit, free swell, linear shrinkage, compaction, CBR and UCS test. Then the study was compared using ERA, AASHTO and ASTM specification likewise a recommendation was drawn and forwarded. However, the finding of the research was limited on selected expansive soil in Jimma town.

CHAPTER TWO

LITERATURE REVIEW

2.1. General

2.1.1. Soils

Soils are one of Earth's essential natural resources, yet they are often taken for granted. Most people do not realize that soils are a living, breathing and world supporting nearly all terrestrial life. Soils and the functions they can play within an ecosystem are varies greatly from one location to another as a result of many factors including differences in climate, the animal and plant life living on them, the soil's parent material, the position of the soil on the landscape, and the age of the soil. Scientists, engineers, farmers, developers and other professionals consider a soil's physical and chemical characteristics, moisture content and temperature to make decisions. In general, soils are formed by weathering of rocks. The physical properties of soil are dictated primarily by the minerals that constitute particles and the rock from which it is derived [14].

Braja M and kahlad sobhan [15] states that, those soils are used as foundation for many structures like pavement, building, bridge and others must be differentiated and examined for their strength to overcome the failures and distresses.

2.1.2. Soil Texture

The particle size distribution is one of the essential controls of soil structure and functioning. Soil processes, properties and specific features are usually related to these distributions, commonly named soil texture. To express these relationships, the continuous particle size distributions are commonly replaced by their discrete representation with several textural fractions. The fractions are defined as particles within a range of sizes, e.g., gravel, sand, silt, clay, etc. Then the percentages of textural fractions are used as attributes to classify soils and as predictors to the estimate soil properties of parameters.

Different countries have employed different numbers of textural fractions and different ranges of sizes for each of the fractions. Nemes et al. [15] reviewed definitions of textural fractions in 14 European countries and reported the number of ranges varying from three in Italy and France, to eight in the Netherlands and Germany, and nine in Belgium. The authors also observed a large variability in size ranges. For example, while the minimum size of the second smallest fraction was 2 µm in most cases, the maximum size in such a fraction varied from 6 µm in Greece to 60 µm in England and Wales.

Soil texture refers to a mixture of variously sized mineral particles, which determine a soil's textural class. The textural class is defined by the relative amounts of gravel, sand, silt, and clay. Coarser particle fragments (pebbles, cobbles, stones, and boulders) are not considered in the textural class, although they may help define a soil type [74]. Organic matter is also not considered in the determination of soil texture, although it is very important for soil functioning. A soil's textural class; such as clay, clay loam, loam, sandy loam, or sand is perhaps its most fundamental inherent characteristic. It affects many of the important physical, biological, and chemical processes in a soil, but is not easily altered by management, and changes little over time [15].

2.1.3. Clay/Expansive Soils

The term clay can refer to both a size and class of minerals. As a size term, it refers to all constituents of a soil smaller than a particular size usually 0.002 mm in engineering classifications. As a mineral term, it refers to specific clay minerals that are distinguished by small particle size, a net electrical charge, and plastic when mixed with water and high weathering resistance. Clayey soils expand when they are wetted and shrink when dried. These soils are called as expansive soil or swelling soil. Due to swelling nature, those soils are problematic for construction. It swells and shrinks excessively with the change of water content due to presence of fine clay particles in the soil. When they come in contact with water, resulting in alternate swelling and shrinking of soil due to which differential settlement of structure takes place [5].

Expansive soils expand due to the clay content. It has a relatively high percentage of clay minerals and is subject to changes in volume with changing moisture conditions. Based on the seasons change, damage to the structures may appear and disappear on a regular basis. Significant defects occur when the movement is uneven or localized. Expansive soils expand by ten percent or more during a rainfall. When the soils dry out, they shrink back to their original size. Thus, this complete movement against volume change creates cracks deep enough to the foundation and Roadbeds [17].

In construction of any structures, engineering properties of soil are the important factor to be considered. As soils has also a relation with water and thus the stabilization of soil can increase the rate of tolerance of water into the soil thus making it quite ideal for engineering purpose [16].

2.1.4 Origin of Expansive Soils

Parent materials that can be associated with expansive soils are either igneous rocks or sedimentary rocks. The basic igneous rock comprises basalt, dolerite, sills, dykes, and gabbros. The sedimentary rock contains that; Montmorillonite as a constituent which breaks down physically to form expansive soils [77]. The Montmorillonite was probably formed from two separate origins. The product of weathering and erosion of rocks in the highlands were carried to the streams by coastal planes. The fine grained soil eventually accumulating in the ocean basin. The second case in which Montmorillonite is formed could be volcanic eruption sending up clouds of ash fall on the plains and sees and through process thus ashes were altered to Montmorillonite [77].

2.1.5. Mineralogy of Clay and Expansive Soils

Expansiveness of soil is due to the presence of clay minerals. Clay particles have sizes of 0.002mm or less. However, according to Chen. 1988 [77], the grain size alone does not determine clay minerals and the most important property of fine grained soils is their mineralogical composition. Clay minerals are crystalline hydrous alumino-silicates derived from parent rock by weathering or volcanic eruption. The basic building blocks of clay minerals are the silica tetrahedron and the alumina octahedron and combine into tetrahedral and octahedral sheets to form the various types of clays. Clays can be divided into three general groups on the basis of their crystalline arrangement. They are; Kaolinite group, Montmorillonite group (also called the smectite group) and Illite group. Montmorillonite is the clay mineral which causes most of the expansive soil problems. The name Montmorillonite is uses currently as a group name for all clay minerals with high expansiveness potential [77].

2.1.6. Structure of Clay Minerals

Clay minerals are essentially crystalline in nature though some clay minerals do contain material which is non-crystalline (for example allophane). Two fundamental building blocks are involved in the formation of clay mineral structures. They are: Tetrahedral unit and octahedral unit.

The tetrahedral unit consists of four oxygen atoms (or hydroxyls, if needed to balance the structure) placed at the apices of a tetrahedron enclosing a silicon atom which combines together to form a shell-like structure with all the tips pointing in the same direction. The oxygen at the bases of all the units lies in a common plane. Each of the oxygen ions at the base is common to two units [74][75].

Table 2.1: Clay minerals [75]

Name of mineral		Structural formula
Kaolin group	Kaolinite	$Al_4Si_4O_{10}(OH)_8$
	Halloysite	$Al_4Si_4O_6(OH)_{16}$
Montmorillonite group	Montmorillonite	$Al_4Si_8O_{20}(OH)_4nH_2O$
Illite group	Illite	$K_y(Al_4Fe_2.Mg_4.Mg_6)Si_8\_y\ Al_y(OH)_4o_{20}$

i. Kaoiinite Mineral

This is the most common mineral of the kaolin group. The building blocks of gibbsite and silica sheets are arranged to give the structure of the kaolinite layer. The structure is composed of a single tetrahedral sheet and a single alumina octahedral sheet combined in units so that the tips of the silica tetrahedrons and one of the layers of the octahedral sheet form a common layer.

Since hydrogen bonds are comparatively strong, the kaolinite crystals consist of many sheet stacking that are difficult to dislodge. The mineral is, therefore, stable and water cannot enter easily between the sheets to expand the unit cells. Kaolinite is a typical two layered mineral having a tetrahedral and an octahedral sheet joined to from 1 to 1-layer structure held by a relatively strong hydrogen bond. Kaolinite does not absorb water more and hence does not expand more when it comes in contact with water [74][75].

ii. Montmorillonite Mineral

Montmorillonite is the most common mineral of the montmorillonite group. The structural arrangement of this mineral is composed of two silica tetrahedral sheets with a central alumina octahedral sheet. All the tips of the tetrahedra point in the same direction and toward the center of the unit [74].

In stacking of these combined units one above the other, oxygen layers of each unit are adjacent to oxygen of the neighboring units, with a consequence that there is very weak bond (van der walls force bond) and excellent cleavage between them. Water can enter between the sheets causing them to expand significantly and thus the structures can break into pieces. The soils containing a considerable amount of montmorillonite minerals will exhibit high swelling and shrinkage characteristics. Montmorillonite is a three-layer mineral having a single octahedral sheet sandwiched between two tetrahedral sheets [74].

iii. Illite Mineral

The basic structural unit of illite is similar to that of montmorillonite except that some of the silicons are always replaced by aluminum atoms and the resultant charge deficiency is balanced by potassium ions. The potassium ions occur between unit layers. The bonds with them non exchangeable K^+ ions are weaker than the hydrogen bonds, but stronger than the water bond of montmorillonite. Illite, therefore, does not swell as much in the presence of water as does montmorillonite [74].

Summary of Expansion Potential of Types of Clay Minerals

Table 2.2: Expansive soil classification based on free swell ratio [75]

Free swell ratio	Clay type	Potential swell	classification Dominant clay mineral
≤1.0	Non-swelling	Negligible	Kaolinite
1.0–1.5	Mixture of swelling and non-swelling	Low	Kaolinite and montmorillonite
1.5–2.0	Swelling	Moderate	Montmorillonite
2.0–4.0	Swelling	High	Montmorillonite

Table 2.3: Expansion potentials according to atterberg and activity of minerals [74]

Clay mineral type	LL (%)	PL (%)	Activity
Montmorillonite	80- 900	40–100	1.5-7.0
Illite	60–120	35–60	0.5–1.2
Kaolinite	30–110	25–40	0.3-0.5
Hydrated halloysite	50–70	47–60	0.1–0.2
Dehydrated halloysite	33–55	30–45	0.4–0.6
Attapulgite	150–250	100–125	0.4–1.3
Allophane	200–250	120–150	0.4–1.3
Nontronite	37–72	19–27	
Attapulgite	44–47	36–40	
Chlorite	200–250	130–140	

2.1.7. Distribution of Expansive Soils around the World

Expansive soils are found throughout many regions of the world, particularly in arid and semi-arid regions, as well as where wet conditions occur after prolonged periods of drought. Their distribution is dependent on geology (parent material), climate, hydrology, geomorphology and vegetation. The presence of expansive soil greatly affects the construction activities and those soils found in many parts of the world; Burma, China, India, Iran, Israel, Japan and Oman in Asia; Argentina, Canada, Cuba, Mexico, Trinidad, USA and Venezuela in the Americas; Cyprus, Germany, Greece, Norway, Romania, Spain, Sweden, Turkey and UK in Europe; Australia; Ethiopia, Ghana, Kenya, Morocco, South Africa and Zimbabwe in Africa [2].

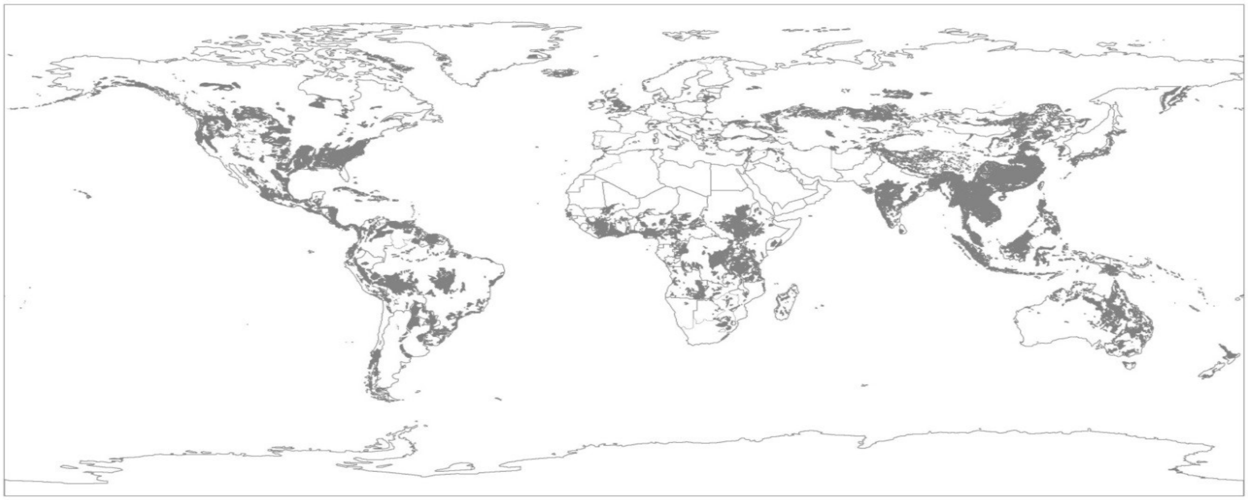


Figure 2.1: Global distribution of shrink–swell (expansive) soils [2]

2.1.8. Distribution of Expansive Soils in Ethiopia

Expansive soil is known to be widely spread in Ethiopia; it covers about nearly 40% of total area of the country. The Southern, South-west, south-east and north-east part has a clay soil distribution but the capital Addis Ababa area and western Ethiopia has densely clay soil coverage. Central part of Ethiopia following the trunk roads like Addis-Ambo, Addis-Woliso, Addis-Debre Berhan, Addis-Gohatsion, Addis- Modjo are some of the areas covered by expansive soils. Areas like some part of Mekelle, Gonder, Bahirdar, Debreberihan and Gambella are also known to be partly covered by expansive soils [1].

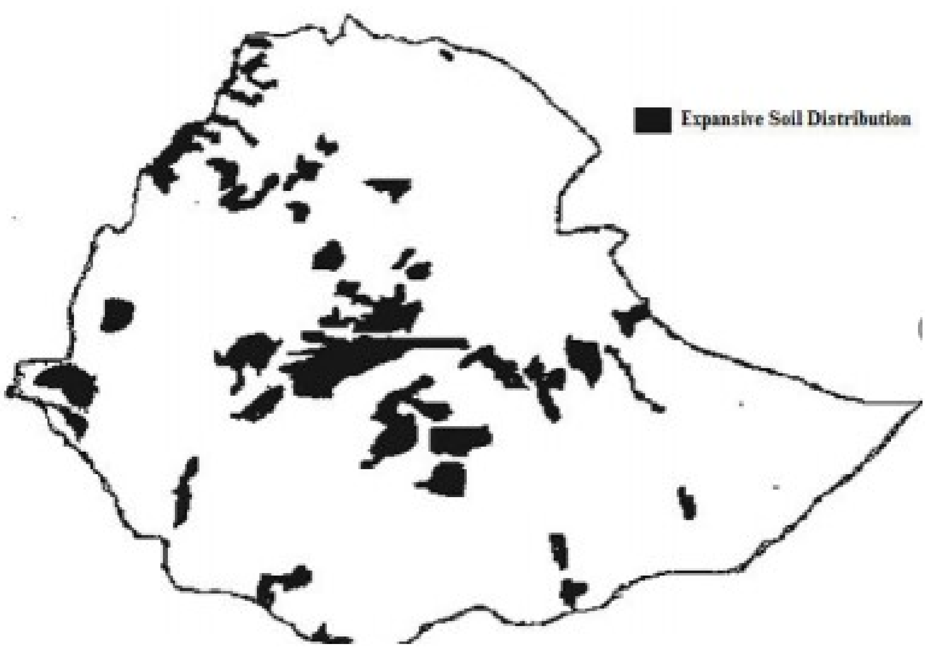


Figure 2.2: Distribution of expansive soils in Ethiopia [1]

2.2. Pavement Failure

The causes of pavement deterioration and failures are too many. Some of them are: Sudden increase in traffic loading especially on new roads where the design is based on lesser traffic, temperature variation, Provision of poor shoulders, Provision of weak subgrade, Poor drainage conditions, temperature of bitumen/bituminous mixed, over heating of bitumen which reduces the binding property of bitumen and etc. [13, 20].

Deterioration of highway pavement is very serious problem that causes unnecessary delay in traffic flow, distorts pavement aesthetics, damages of vehicle and most significantly causes road traffic accident that had resulted into loss of lives and properties. Pavement surface deformation affects the safety and riding quality on the pavement as it may lead to premature failures [13].

Figure 2.3: Pavement deformation due to weak subgrade [13]

2.2.1. Pavement Failure due to Expansive Soil

Expansive soil as road subgrade is considered one of the most common causes of pavement distresses. Longitudinal cracking results from the volumetric change of the expansive subgrade, is one of the most common distresses. Other forms include fatigue (alligator) cracking, edge cracking, rutting in the wheel path, shoving, popouts and maybe others [14, 16]. According to Khdam F. and Budiman J. [21], Expansive subgrades have an adverse effect on the performance of the pavement. When a new route is planned, the location of expansive soils must be known early in planning stage so that they can be avoided or treated if possible.

Figure 2.4: Pavement distresses because of expansive soil as road subgrade [3]

2.2.2. Road Subgrade Strength

The "subgrade" is the in-situ material upon which the pavement structure is placed. Subgrade materials are typically characterized by their resistance to deformation under load. In general, the more resistant to deformation a subgrade is the more loads it can support before reaching a critical deformation value. Although there are other factors involved when evaluating subgrade materials (such as shrink/swell in the case of certain clays and ash), stiffness is the most common characterization [22].

The subgrade of a road pavement, like any foundation, must be capable of supporting the imposed loading without shear failure or excessive deformation. A major input to all methods of design of pavements is a measure of the strength of the soil, i.e. its ability to resist the stress imposed by traffic loading. This input is required for the design of new roads and for the design of the total or partial reconstruction of damaged existing roads [23].

ERA pavement design manual [24] classifies subgrade soil strength based their design CBR value. According to ERA manual, the subgrade strength for design is assigned to one of six strength classes reflecting the sensitivity of thickness design to subgrade strength. The classes are defined in Table 2.4. For subgrades with CBRs less than 3%, special treatment is required.

Table 2.4: ERA sub grade strength class [24]

Subgrade Class	CBR Range in %	Remarks Subgrade quality
S1	<3	Very poor subgrade
S2	3,4	Poor
S3	5,6,7	Poor to fair
S4	8-15	fair
S5	15-30	Fair to Good
S6	>30	Good to Excellent

The strength of the subgrade is the main factor in determining the required thickness of flexible pavements for roads and airfields. The strength of subgrade soil for highways and airports is usually expressed in terms of the California Bearing Ratio (CBR) value. A California Bearing Ratio (CBR) test is run on soils to gauge the strength of the subgrade as compared to a dense graded aggregate. CBR is one of the major factors used in pavement design to determine how thick the pavement should be [25].

During construction it is recommended that all sub grades should be compacted to a relative density of at least 95% of the MDD achieved in Standard /Modified Proctor Density test. Samples of the sub grade soil at the estimated subgrade moisture content can then be compacted in CBR molds to the specified density and penetrated to determine the design CBR value. This value is then used to determine the required pavement thickness from the design chart.

The unconfined compression test is a special type of unconsolidated-undrained test that is commonly used for clay specimens. According to the ASTM and AASHTO standards, 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 this test, the confining pressure is zero. An axial load is rapidly applied to the specimen to cause failure. At failure, the total minor principal stress is zero because the undrained shear strength is independent of the confining pressure as long as the soil is fully saturated and fully undrained. The primary purpose of this test is to determine the unconfined compressive strength of clay soil, which is then used to calculate the unconsolidated undrained shear strength of the clay under unconfined conditions [26].

2.3. Soil Stabilization

Soil stabilization may be defined as the alteration or preservation of one or more soil properties to improve the Engineering characteristics and performance of a soil. Stabilization, in a broad sense, incorporates the various methods employed for modifying the properties of a soil to improve its engineering performance. It refers to the procedure in which a special soil, cementing material or other chemical materials are added to a natural soil to improve one or more of its properties [27].

According to Charles Lucian [28] soil stabilization can improve the properties of expansive soils considerably. Possible materials for the stabilization could include lime, pozzolana, lime-pozzolana mixture, cement, resins or fly ash. When used these stabilizing agents can improve and maintain soil moisture content, increase soil particle cohesion and serve as cementing and water proofing agents [4].

Many researches have been done on the subject of soil stabilization using various additives; the most common methods of soil stabilization of clay soils in pavement work are cement, bitumen and lime stabilization [21]. However, there is justification for seeking cheaper additives which may be used to alter the soil properties. Lime, Cement or bitumen is also oldest traditional chemical stabilizer used for soil stabilization and are costly [29].

2.3.1. Soil Stabilization Techniques for Pavements

2.3.1.1. Mechanical Stabilization

Mechanical stabilization can be defined as a process of improving the stability and shear strength characteristics of the soil without altering 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 [27].

2.3.1.2. Chemical stabilization

Chemical stabilization of soil comprises of changing the physio-synthetic around and within clay particles where by the earth obliges less water to fulfill the static imbalance. Chemical stabilization involves mixing or injecting the soil with chemically active compounds such as Portland cement, lime, fly ash, calcium or sodium chloride or with viscoelastic materials such as bitumen. Calcium chloride being hygroscopic and deliquescent is used as a water retentive additive in mechanically stabilized soil bases and surfacing [27]. The depressing the electric double layer, the salt reduces the water pick up and thus the loss of strength of fine-grained soils. Calcium chloride acts as a soil flocculent and facilitates compaction. Frequent application of calcium chloride may be necessary to make up for the loss of chemical by leaching action. For the salt to be effective, the relative humidity of the atmosphere should be above 30%. Sodium chloride is the other chemical that can be used for this purpose with a stabilizing action similar to that of calcium chloride. Sodium silicate is yet another chemical used for this purpose in combination with other chemicals such as calcium chloride, polymers, chrome lignin, alkyl chlorosilanes, siliconites, amines and quaternary ammonium salts, sodium hexametaphosphate, phosphoric acid combined with a wetting agent [27].

Soil improvement by means of chemical stabilization can be grouped into chemical reactions like; cation exchange, flocculation-agglomeration and pozzolanic reactions.

A) **Cation Exchange**

Soil clay minerals and organic matter tend to be negatively charged, thus attracting positively charged ions (cations) on their surfaces by electrostatic forces. The clay mineral and organic matter components of soil have negatively charged sites on their surfaces which adsorb and hold positively charged ions (cations) by electrostatic force. Soils with a higher clay fraction tend to have a higher CEC. Organic matter has a very high CEC [87].

Cation-exchange capacity (CEC) is a measure of the total negative charges within the soil that absorb cations such as $Ca^{2+,}$ Mg^{2+}, H^{+}, Na^{+}, K^{+}; how many cations can be retained on soil particle surfaces. Negative charges on the surfaces of soil particles bind positively-charged atoms or molecules (cations), but allow these to exchange with other positively charged particles in the surrounding soil water. Cation-exchange capacity arises from various negative charges on soil particle surfaces, especially those of clay minerals and soil organic matter. The CEC of soils varies according to the percentage of clay, type of clay, soil pH and amount of organic matter. Pure sand has a very low CEC, less than 2 meq/100 g, and the CEC of the sand and silt size fractions (2 µm/2 mm) of most soils is negligible. Claying sandy soils for managing water repellence increases the CEC of the surface layers by a small amount depending on type and amount of clay added. Typically CEC is increased by less than 1 meq/100 g [88].

The most commonly occurring clay in western Australian soils, kaolinite, has a CEC of about 10 meq/100 g. Other clays such as illite and smectite have CECs ranging from 25 to 100 meq/100 g. Organic matter has a very high CEC ranging from 250 to 400 meq/100 g . Because a higher CEC usually indicates more clay and organic matter is present in the soil, high CEC soils generally have greater water holding capacity than low CEC soils.

Table 2.5: Relationship between soil texture and CEC [88]

Soil and Soil Components		CEC (meq/100 g)
Clay Type	Kaolinite	3-15
	Illite	15-40
	Montmorillonite	80-100
Soil Texture	Sand	1-5
	Fine Sandy Loam	5-10
	Loam	5-15
	Clay Loam	15-30
	Clay	>30
Organic Matter	Organic	200-400

Clay minerals have the property of absorbing certain anions and cations and retaining them in an exchangeable state. The exchangeable ions are held around the outside of the silica – alumina clay – mineral structural unit and the exchange reaction doesn't affect the structure of the silica – alumina pocket. In clay minerals, the most common exchangeable cations are $Ca^{2+,}$ Mg^{2+} ,H^{+}, $NH^{4+,}$ Na^{+}, frequently in about that order of general relative abundance [74, 87].

The existence of such charges is indicated by the ability of clay to absorb ions from the solution. Cations (positive ions) are more readily absorbed than anions (negative ions); hence, negative charges must be predominant on the clay surface. A cation, such as Na^{+}, is readily attracted from a salt solution and attached to a clay surface. However, the absorbed Na^+ ion is not permanently attached; it can be replaced by K^+ ions if the clay is placed in a solution of potassium chloride (KCl). The process of replacement by excess cation is called cation exchange. Some are more strongly attracted than others, and the cations can be arranged in a series in terms of their affinity for attraction as follows:

$Al^{3+} > H^+ > Ca^{2+} > Mg^{2+} > NH^{4+} = K^+ > Na+ > Li^+$

This series indicates that, for example, Al^{3+} ions can replace Ca^{2+} ions, and Ca^{2+} ions can replace Na^+ ions. The exchangeable cations may be present in the surrounding water or be gained from the stabilizers. H^+ is unique which has small size and high charge density. The process is called cation exchange [74,88].

An example of the cation exchange;

Na-clay + CaCl2 → Ca-Clay + NaCl

$Ca(OH)_2 \rightarrow Ca_2+ + 2(OH)$

Ca^{2+} + Clay Mineral-M^+ → Clay Mineral-Ca^{2+} + M^+

B) Flocculation and Agglomeration

The exchange of cations causes a reduction in the size of the diffused water layer, causing clay particles to approach each other more closely resulting in the development of an edge to face attraction, thereby causing flocculation. The flocculation is also aided by the high concentration of electrolytes in pore fluid and high pH environment. The soil becomes friable and granular, making it easier to work and compact. At this stage, plasticity index of the soil decreases dramatically, as does its tendency to swell and shrink [87].

Flocculated structure occurs in clays. The clay particles have large surface area and, therefore, the electrical forces are important in such soils. The clay particles have a negative charge on the surface and a positive charge on the edges. Inter particle contact develops between the positively charged edges and the negatively charged faces. This results in a flocculated structure. Flocculent structure is formed when there is a net attractive force between particles. When clay particles settle in water, deposits formed have a flocculated structure. The degree if flocculation of a clay deposit depends upon the type and concentration of clay particles, and the presence of salts in water. Clays settling out in a salt water solution have a more flocculent structure than clays settling out in a fresh water solution. Salt water acts as an electrolyte and reduces the repulsive forces between the cation exchange reactions result in the flocculation and agglomeration of the soil particles with consequent reduction in the amount of clay-size materials and hence the soil surface area, which inevitably accounts for the reduction in plasticity. Due to change in texture, a significant reduction in the swelling of the soil occurs. In general, the soils in a flocculated structure have a low compressibility and a high permeability [87].

C) Pozzolanic Reactions

The pozzolanic activity is a measure for the degree of reaction over time or the reaction rate between a pozzolan and Ca^{2+}, $Ca(OH)_2$, $Si(OH)_4$ or H_4SiO_4 in the presence of water. The pozzolanic reaction converts a silica-rich precursor with no cementing properties, to a calcium silicate, with good cementing properties.

A pozzolanic material is by definition capable of binding calcium hydroxide in the presence of water. Therefore, the chemical measurement of this pozzolanic activity represents a way of evaluating pozzolanic materials. This can be done by directly measuring the amount of calcium hydroxide a pozzolan consumes over time.

$Ca^{2+} + 2(OH)^- + SiO_2$ (Clay Silica) → CSH

$Ca^{2+} + 2(OH)^- + Al_2O_3$ (Clay Alumina) →CAH

The calcium silicate gel formed initially coats and binds lumps of clay together. The gel then crystallizes to form an interlocking structure which increases the soil strength

Pozzolanization

pozzolanas are materials possessing alumina (Al_2O_3), silica (SiO_2), and ferrite (Fe_2O_3), with the sum total of their composition by weight equal to or greater than 70%. Cement, fly ash, ground granulated blast furnace slag, bitumen, quicklime, hydrated lime, ceramic powder, calcite, etc., have been in use as conventional binders having fulfilled the above minimum standard requirements, in various civil engineering and earth works. This is because they possess cementitious properties. These materials have been applied to improve the properties of soil in the earth and improve the properties of concrete, asphalt, etc., in other civil engineering areas of responsibility [90].

Clayey soils have the capacity to swelling immediately as they come in contact with moisture. During this state of moisture percolation, the clay minerals become charged with the negative ion on the surface and positive ions on the edge. The adsorbed moisture also dissociates to its dipole forming hydrogen (H^+) and hydroxyl (OH^-) ions. This process is called hydration of the clayey soil where the soil is impregnated with moisture to its optimum content. Due to the problematic properties of the clayey soil as a result of its erratic behavior, it is technically important that such problematic soils are treated with modifiers or binders that trigger processes that will lead to agglomeration of the particles that must have dispersed when moisture was introduced [90, 91]. According to previous research results, ceramic powder is an amorphous material known for its high composition of aluminosilicates (Al-Si-Fe), which satisfies the design standard conditions.

For this reason, they release ionized metals such as Al^{3+}, Si^{2+}, and Fe^{3+}, and research has shown that these metallic compounds trigger pozzolanic reactions. When clayey soil particles disperse due to moisture impregnation, the particles form double diffused layers, which keeps them separated to overcome van der Waals intergranular particles. And during organic or inorganic additive stabilization, hydration reaction, calcination, and carbonation reactions occur. A replacement reaction between these processes occurs between hydrogen ions and calcium, aluminum, and silicon ions. Because these other metallic ions are higher in the electrochemical series ($Li^{+} < Na^{+} < H^{+} < K^{+} < NH^{4+} < Mg^{2+} < Ca^{2+} < Al^{3+} < Fe^{2+}$) than hydrogen, they tend to displace it within the adsorbed moisture to form flocs. Furthermore, the sodium ion attached to octahedral and tetrahedral structures of the clay is replaced under the same principle and this removes its swelling components from the clayey soil. This whole process is called the pozzolanic reaction [91, 92].

The reactive activities in a soil stabilization process and precisely at the phase of pozzolanic reaction where displacement reactions happen depend fundamentally on the arrangement of the metallic oxides in the electrochemical series. This is an arrangement of the metal in the order of their oxidation. Once the elements released during a soil stabilization procedure are identified, it will be possible to identify the outcome of an additive soil stabilization process. the hydrogen ion from the dipolar water molecule of the adsorbed moisture that triggers the hydration reaction is lowest in the series compared to all other metallic elements released during additive soil stabilization. Hence, the replacement of hydrogen ions is very possible within the adsorbed complex or double diffused layer of clay particles. The swelling potential data further provide guiding standards or information on what to expect during chemical additive soil stabilization. The outcome of pozzolanic reactions, which are preceded by hydration, calcination, and carbonation, is the flocculation of dispersed clayey soil particles so as to form a dense and stabilized structure [90].

Inorganic Additive-Induced Pozzolanic Reaction has been of conventional interest to utilize cement, ceramic dust, powderfly ash, metal slag, quicklime, hydrated lime, calcite and others inorganic chemical compounds to trigger pozzolanic reaction in clayey soil stabilization. The utilization of these additives releases calcium ion which displaces hydrogen ions in the adsorbed complex and reacts with the aluminosilica from soil and hydroxyl ion from the dipole adsorbed moisture to form calcium aluminosilicate hydrate (C-A-S-H) in the clayey soil particle double diffused layer forming flocculants. These flocculants settle and strengthening is achieved in the treated soil [92].

The entire effort of clayey soil treatment focusing on the improvement of the expansive and plastic properties and the engineering properties of the soil is to achieve the formation of C-A-S-H. This is the component achieved through a pozzolanic reaction responsible for the alteration of the properties of clayey soils. When clayey soils come in contact with moisture, which they do either during the soil stabilization procedures or during the service life of the foundation structures as they are exposed to moisture by runoff, migration through cracks, or pores or suction as the water table rises in a hydraulically bound condition, they experience volume changes. CaO, which is a major component of both the organic and inorganic chemical additives, goes through a hydration process as soon as it comes in contact with the adsorbed moisture in a soil stabilization procedure. This results in hydrated calcium oxide (Ca(OH)2). This compound undergoes either carbonation to give calcite or pozzolanic reaction in the presence of alumina and silica and further hydration of CaO leading to the formation of the compounds responsible for flocculant formation in clayey soils (C-A-S-H or C-A-H and C-S-H) [92].

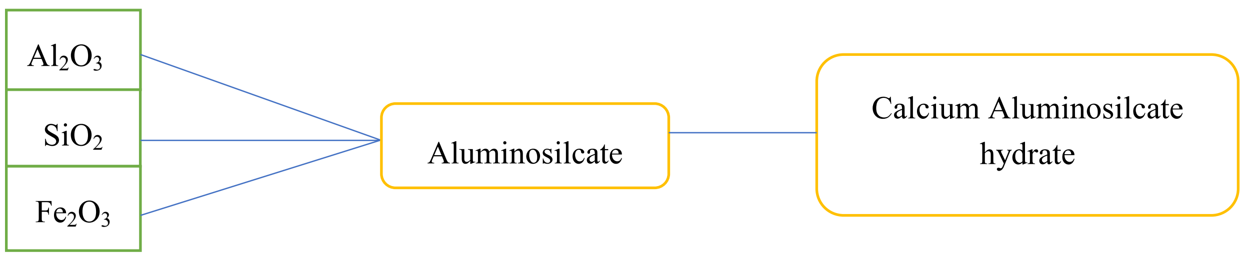


Figure 2.5: Organic reaction part of pozzolanic reaction [92]

2.3.1.3. Stabilization by using Recycled and Waste Products

Cement, Lime, bitumen and Fly ash are popular chemical stabilizer and were commonly used as stabilizer for altering the properties of soils. From the recent studies it is observed that solid waste materials like Rice Husk ash, egg shell powder, coal bottom ash and many other waste product stabilizers are used for soil stabilization purpose with or without lime or cement. Disposal of those waste materials are essential as they can cause hazardous effects on the environment and cost effectives [16].

2.4. Plastic Wastes

2.4.1. General

Plastic is a word that originally meant "pliable and easily shaped." It only recently became a name for a category of materials called polymers. The word polymer means "of many parts," and polymers are made of long chains of molecules. Polymers abound in nature. Cellulose, the material that makes up the cell walls of plants, is a very common natural polymer. Over the last century and a half human have learned how to make synthetic polymers, sometimes using natural substances like cellulose, but more often using the plentiful carbon atoms provided by petroleum and other fossil fuels [8]. Synthetic polymers are made up of long chains of atoms, arranged in repeating units, often much longer than those found in nature. It is the length of these chains, and the patterns in which they are arrayed, that make polymers strong, lightweight, and flexible. In other words, it's what makes them so plastic. These properties make synthetic polymers exceptionally useful, and since we learned how to create and manipulate those, polymers have become an essential part of our lives. Especially over the last 50 years plastics have saturated our world and changed the way that we live [32].

2.4.2. Background

The first synthetic polymer was invented in 1869 by John Wesley Hyatt, who was inspired by a New York firm's offer of $10,000 for anyone who could provide a substitute for ivory. The growing popularity of billiards had put a strain on the supply of natural ivory, obtained through the slaughter of wild elephants. By treating cellulose, derived from cotton fiber, with camphor, Hyatt discovered a plastic that could be crafted into a variety of shapes and made to imitate natural substances like tortoiseshell, horn, linen and ivory. This discovery was revolutionary [33]. Nature only supplied so much wood, metal, stone, bone, tusk, and horn. But now humans could create new materials. This development helped not only people but also the environment. Advertisements praised celluloid as the savior of the elephant and the tortoise. Plastics could protect the natural world from the destructive forces of human need. The creation of new materials also helped free people from the social and economic constraints imposed by the scarcity of natural resources. Inexpensive celluloid made material wealth more widespread and obtainable. And the plastics revolution was only getting started [34].

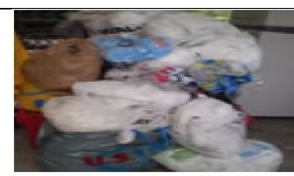
2.4.3. Plastic Problems: Waste and Healthy

Too many plastic products are disposable lasts ever in the environment and it was the plastics industry that offered recycling as a solution. In the 1980s the plastics industry led an influential drive encouraging municipalities to collect and process recyclable materials as part of their waste-management systems. However, recycling is far from perfect and most plastics still end up in landfills or in the environment. Grocery-store plastic bags have become a target for activists looking to ban one-use, disposable plastics and several American cities have already passed bag bans [35].

The ultimate symbol of the problem of plastic waste is the Great Pacific Garbage Patch, which has often been described as a swirl of plastic garbage the size of Texas floating in the Pacific Ocean. The reputation of plastics has suffered further thanks to a growing concern about the potential threat they pose to human health. Some scientists and members of the public are concerned about evidence that these chemicals leach out of plastics and into our food, water and bodies. In very high doses these chemicals can disrupt the endocrine (or hormonal) system. Researchers worry particularly about the effects of these chemicals on children and what continued accumulation means for future generation [9, 36].

2.4.4. Types of Plastic

Table 2.6: Types of plastic, description and general properties [37]

Types of Plastic	Descriptions
A) Polyethylene Terephthalate (PET): Polyethylene Terephthalate sometimes absorb odors and flavors from foods and drinks that are stored in them. Items made from this plastic are commonly recycled. PET plastic is used to make many common household items like beverage bottles, medicine jars, rope, clothing and carpet fiber.	
B) High-Density Polyethylene (HDPE): High-Density Polyethylene products are very safe and are not known to transmit any chemicals into foods or drinks. HDPE products are commonly recycled. Items made from this plastic include containers for milk, motor oil, shampoos and conditioners, soap bottles, detergents, and bleaches. It is NEVER safe to reuse an HDPE bottle as a food or drink container if it didn't originally contain food or drink	
C) Polyvinyl Chloride (PVC): Polyvinyl Chloride is sometimes recycled. PVC is used for all kinds of pipes and tiles, but is most commonly found in plumbing pipes. This kind of plastic should not come in contact with food items as it can be harmful if ingested.	
D) Low-Density Polyethylene (LDPE): Low-Density Polyethylene is sometimes recycled. It is a very healthy plastic that tends to be both durable and flexible. Items such as cling-film, sandwich bags, squeezable bottles, and plastic grocery bags are made from LDPE.	
E) Polypropylene (PP): Polypropylene is occasionally recycled. PP is strong and can usually withstand higher temperatures. It is used to make lunch boxes, margarine containers, yogurt pots, syrup bottles, prescription bottles. Plastic bottle caps are often made from PP.	
F) Polystyrene (PS): Polystyrene is commonly recycled, but is difficult to do. Items such as disposable coffee cups, plastic food boxes, plastic cutlery and packing foam are made from PS.	

G) Others:

Others used to designate miscellaneous types of plastic not defined by the other six codes are like Polycarbonate and Polylactide are included in this category. These types of plastics are difficult to recycle. Polycarbonate (PC) is used in baby bottles, compact discs, and medical storage containers.

2.4.5. Properties of Terephthalate Polyethylene Plastics

Polyethylene (PET) plastics has a different kinds properties like; good gas & moisture barrier, high heat resistance, clear, hard, tough, microwave transparency, solvent resistant and others. Some of physical and mechanical properties of PET plastics are discussed in the Table 2.8.

Table 2.7: PET plastics properties [73]

properties		Common household uses
General properties	◆ Good gas & moisture barrier ◆ High heat resistance ◆ Clear, Hard, Tough ◆ Microwave transparency ◆ Solvent resistant	✓ Mineral Water, fizzy drink and beer bottles ✓ Pre-prepared food trays and roasting bags ✓ Boil in the bag food pouches ✓ Soft drink and water bottles ✓ Fiber for clothing and carpets ✓ Strapping ✓ Some shampoo and mouthwash bottles

		Remarks
Mechanical properties	Coefficient of friction	0.2 – 0.4
	hardness	M 94-101
	Izod impact strength (j/m)	13-35
	Poisons ratio	0.37-0.44 (oriented)
	Young's modules of elasticity (10^9NM^2)	2-2.7
	Tensile modulus (Gpa)	2-4
	Tensile strength (Mpa)	80
Physical properties	Specific gravity	1.28-1.40
	flammability	Self-extinguishing
	Water absorption-equilibrium (%)	<0.7
	Water absorption – over 24 hours (%)	<0.1

2.4.6. Plastic Wastes on Soil Stabilization

Waste plastic is one such which is commonly used for shopping bags, storage and marketing for various purposes due to its most advantage character of less volume and weight. Most of these plastics are specifically made for spot use, having short life span and are being discarded immediately after use. Though, at many places waste plastics are being collected for recycling or reuse, however; the secondary markets for reclaimed plastics have not developed as recycling program. Therefore, the quantity of plastics that is being currently reused or recycled is only a fraction of the total volume produced every year [10].

Plastic is the most common type of solid waste contributing almost 90% of total solid waste and most of it being non-renewable in nature. Various industries use processes such as remolding of plastic and creating new articles out of it. Using these plastics for the stabilization of naturally occurring soil to increase its physical parameters and properties is one of a revolutionary method of reusing the waste plastic and reducing its content from nature. Stabilized soil is the one which has higher CBR and shear strength. Such type of soil is very useful in construction of different types of foundation works. If the foundation of a structure is strong, the structure will be less susceptible to a collapse or distresses. Therefore, the investigation and attempt has been made to demonstrate the potential of reclaimed plastic wastes as soil reinforcement for improving the sub grade soils [38, 39].

The promise that soil stabilization technology can actually improve the mechanical qualities of local road soil so that stronger, more durable roads can be built has prompted national road ministries around the world to conduct extensive testing to verify that this new technology is truly cost-effective [32,40].

2.5. Ceramics

2.5.1. Historical Origins

The term ‘ceramics’ is derived from the Greek ‘keramos’ meaning ‘burned earth’ or ‘pottery’ and is used to describe materials of the pottery industry. Thus, it was used, to refer to a product obtained through the action of fire upon earthen materials. Recent research shows that the processing of clay started around 19000 BC. The oldest findings of pottery in southern Japan are dated between 8000 BC and 9000 BC. As early as 4000 BC fired bricks were used for the construction of temple towers, palaces and fortifications. More than 2000 years ago the Romans spread the technique of brick making into large parts of Europe. In Egypt; glazed ceramic plates were used as wall decorations for the pyramids in 2600 BC and in China, the art of china porcelain making has been known since 1000 BC [41].

2.5.2. General

A ceramic is an inorganic non-metallic solid, made up of either metal or non-metal compounds that have been shaped and then hardened by heating to high temperatures. In general, they are hard, corrosion-resistant and brittle materials. Ceramics can be defined as inorganic, non-metallic materials that are typically produced using clay and other minerals from the earth or chemically processed powders. Ceramics may be crystalline in nature and are compounds of metallic and non-metallic elements such as aluminum and oxygen (alumina), silicone and nitrogen (silicon nitride) and silicon and carbon (silicon carbide) [42, 43].

2.5.3. Ceramic Dust

Ceramic materials are inorganic non-metallic materials made from a mixture of clay, various elements, powders and water. In construction industry, it is most commonly encountered in the form of bricks, tiles, plates, glass and sanitary ware to name a few. Ceramic wastes mainly originate from the construction industry and the construction and demolition waste generated a million tons per year. Ceramic materials represent around 25% of construction and demolition waste, and originate not only from the building process, but also as rejected bricks and tiles from industry [19].

2.5.4. Properties of ceramics

Typical properties of ceramics are; high hardness, high elastic modulus, low ductility, high dimensional stability, good wear resistance, high resistance to corrosion and chemical attack, high weather resistance, high melting point, high working temperature, low thermal expansion, low to medium thermal conductivity, good electrical insulation, low to medium tensile strength, high compressive strength, medium machinability, opacity, brittleness, poor impact strength, low thermal shock resistance and others.

A) Physical Properties of Ceramics

Physical properties can be defined as property that can be observed without changing the identity of the substance. It is important to understand physical properties of the fabricated ceramic bodies because each material has different property profile. Physical properties of ceramics can be defined through several parameters. These parameters are color, melting point, viscosity, density, shrinkage, porosity, electrical, thermal conductivity, etc [40].

Table 2.8: Physical properties of ceramics [40].

Properties	Descriptions
Density	2.00-6.00 g/cm^3
Melting points high	600-4000^{0c}
Thermal conductivities are	low (insulators)
Thermal expansion values	low (1-15 ppm/c)
Color	depends on visible light interaction with “ions” or “pigments” (white, white-grey, Reddish Brown)
Specific Gravity	2.15-3.30

B) Mechanical Properties of Ceramics

Mechanical properties of ceramic bodies usually refer to the properties of the materials, such as strength, toughness or thermal properties. Pottery is expected to resist several continuous mechanical stresses without experiencing fracture, structural damage and losing functionality. Pottery wares are commonly exposed to impact stress subjected to pure compression. The mechanical properties of pottery ceramics that make more sense to be looked at are their facture strength and toughness [45]. In bending test, a material can be exposed until cracks initiate on the surface under tension. The fracture behavior of the brittle material is affected when the initiation of a crack is usually equivalent to the failure due to unstable crack growth. Besides that, toughness becomes as a highly important mechanical properties of a ceramic product as its measure of the intrinsic fracture energy [46]. Generally strength and modulus of ceramics is 30-350 GPa.

C) Chemical Properties of Ceramics

Chemical properties of ceramics are; corrosion properties: very few under normal circumstances; Soluble in certain strong acids (HF) and strong bases; have good chemical resistance to weak acids and weak bases. However, very strong acids or strong bases tend to produce ion exchange reactions and dissolve the structures [89].

Chemical bonds

Underlying many of the properties found in ceramics are the strong primary bonds that hold the atoms together and form the ceramic material. These chemical bonds are of two types: they are either ionic in character, involving a transfer of bonding electrons from electropositive atoms (cations) to electronegative atoms (anions), or they are covalent in character, involving orbital sharing of electrons between the constituent atoms or ions. Covalent bonds are highly directional in nature, often dictating the types of crystal structure possible. Ionic bonds, on the other hand, are entirely non-directional [89].

Most of the primary chemical bonds found in ceramic materials are actually a mixture of ionic and covalent types. The larger the electronegativity difference between anion and cation (that is, the greater the difference in potential to accept or donate electrons), the more nearly ionic is the bonding (that is, the more likely are electrons to be transferred, forming positively charged cations and negatively charged anions). Conversely, small differences in electronegativity lead to a sharing of electrons, as found in covalent bonds.

Secondary bonds also are important in certain ceramics. For example, in diamond, a single-crystal form of carbon, all bonds are primary, but in graphite, a polycrystalline form of carbon, there are primary bonds within sheets of crystal grains and secondary bonds between the sheets [89].

Jijo James and Kasinatha Pandian [86] presented the chemical composition of ceramic dust which was obtained from XRF is shown in Table 2.10. Scanning Electron Microscopy was used to study the structure of particles of the materials adopted.

Table 2.5: Chemical properties of ceramic dust [86]

Constituents (Symbols)	Constituents (Names)	Chemical Composition (% by mass)	Requirement ASTM C-618 (%)
SiO_2	Silicon Oxide	57.14	SiO2 + Al_2O_3 + Fe_2O_3 above 70%
Al_2O_3	Aluminum Oxide	25.24	
Fe_2O_3	Ferric Oxide	6.53	
CaO	Calcium Oxide	1.88	
MgO	Magnesium Oxide	1.11	5 and below
K_2O	Potassium Oxide	3.89	
Na_2O	Sodium Oxide	1.41	1.5 and below
P_2O_5	Phosphorus pentoxide	0.11	
SO_3	Sulfur trioxide	0.01	5 and below
Cl_2	Chlorine	0.043	
MnO	Manganese(II) oxide	0.02	
TiO_2	Titanium dioxide	0.68	
ZrO_2	Zirconium Oxide	1.49	

2.5.5. Ceramic Wastes on Soil Stabilization

A lot of ceramic dust wastage is produced during formation, transportation and placing of ceramic tiles. This wastage or scrap material is inorganic material and hazardous. Hence its disposal is a problem which can be removed with the idea of utilizing it as an admixture to stabilization. An ideal solution lies for reducing project cost, increasing longevity and reduce accumulation of waste shall be through utilization of industrial waste combined with weak soil for pavement construction. Few types of waste materials namely crusher dust, fly ash and ceramic dust waste are popular as admixtures in improving weak soils [46, 48].

From the available literature it is found that limited research has been done to study the effects of ceramic dust waste on different geotechnical properties of expansive soil. The previous study had undertaken to investigate the effects of dust waste on index properties, compaction properties, CBR and swelling pressure of an expansive soil. The economy of stabilization has also been studied by strengthening the expansive soil subgrade of a flexible pavement. Thus, use of Ceramic dust waste not only improves the soil properties but problem of their disposal can also be solved. The previous study shows that the Ceramic waste materials have been used to improve the properties of clayey soils and effect of ceramic dust on various soil properties have been evaluated [49,50].

2.6. Studies on Soil Stabilization

2.6.1. Previous Studies on Plastic Waste Fiber

There are many researches had conducted on suitability of plastic waste fiber to improve weak subgrade soil. Some of them are as follow.

Choudhary et al [51] studies to demonstrate the potential of reclaimed high-density polyethylene strips (HDPE) as soil reinforcement for improving engineering performance of subgrade soil. A series of California Bearing Ratio (CBR) tests were carried out on randomly reinforced soil by varying percentage of HDPE strips (i.e. 0.25%, 0.50%, 1%, 2%, 4%) with different lengths and proportions. It increases the CBR value and Secant Modulus which is maximum when strip content is 4% and aspect ratio 3. The maximum CBR value of reinforced system is 3 times that of unreinforced system.

Akshat Malhotra and Hadi Ghasemain et al. [52] studied the effect of HDPE plastic waste on the UCS of soil. In a proportion of 1.5%, 3%, 4.5% and 6% of the weight of dry soil, HDPE plastic (40 micron) waste was added. They concluded that the UCS of black cotton soil increased on addition of plastic waste. When 4.5 % plastic waste mixed with soil strength obtained was 287.32KN/m2 which is aximum because for natural soil it was 71.35KN/m2.

Achmad Fauzi et.al.[53] used two soil samples R2 and R24 collected from various sites of Kuantan. Waste cutting HDPE and crushed waste glass were used as additives. The variations of additive contents were 4%, 8 %, 12 % by dry total weight of soil sample respectively. They evaluated engineering properties like sieve analysis, Atterberg limit, Specific gravity, Standard Compaction, soaked California bearing ratio and tri-axial test of the soil sample before stabilization and after stabilization. The result shown that on addition of waste HDPE and glass there was an increasing PI, about 10% for R24 and 2% for R2 samples respectively.

A.I.Dhatrak et.al. [54] Calculated the engineering properties by mixing waste plastic. It was observed that for construction of flexible pavement to improve the sub grade soil of pavement using waste plastic bottles chips is an alternative method. In a proportion of 0.5%, 1%, 1.5%, 2%, and 2.5% of the weight of dry soil, plastic waste was added to calculate CBR value. He concluded that using plastic waste strips will improve the soil strength and can be used as sub grade. It is economical and eco-friendly method to dispose waste plastic.

Anas Ashraf et.al. [55] studied on the possible use of plastic bottles for soil stabilization. The analysis was done by conducting plate load tests on soil reinforced with layers of plastic bottles filled with sand. The bottles cut to halves placed at middle and one third position of tank. The test results shown that cut bottles placed at middle position were the most efficient in increasing strength of soil.

Jasmin Varghese Kalliyath et.al. [56] studied then effect of plastic fibers. Various tests such as Standard Proctor, UCC were carried out with different samples of silty clay. Authors observed that the replacement of 0.5 % waste plastic fiber to the expansive clayey soil reduce its OMC and increased maximum dry density but UCS of the soil was found to be increased. The test results also shown that with 1% replacement, MDD and UCS were less than the 0.5 % replacement but greater than the untreated soil. Further increase in the plastic replacement shown decrease in the MDD and the UCS.

Subhash, K. et.al. [57] Conducted experimental study on soil stabilization using glass and plastic granules mixed with varying percentage. Modified Proctor tests were carried out to study OMC and CBR. They concluded that there is a decrease in MDD on addition of glass and plastic in varying percentages. The MDD of 1.53 g/cc was obtained at 6% of glass and plastic. The maximum OMC was obtained as 22.6% at 6% mixing of additive. Further, an increase in the OMC was observed, maximum value of OMC was obtained as 22.6% at 6 % glass and plastic additive with the soil. An increase in the UCS from 0.609 Kg/cm2 to 3.023 Kg/cm2 which is about 5 times as that of virgin soil. Maximum CBR value was 7.14 %, which is 2 times of CBR of virgin soil.

2.6.2. Previous Studies on Ceramic Dust Waste

Many researchers had conducted several findings and outcomes on ceramic dust waste as soil stabilizer; to improve the weak Road subgrade soil with other materials and alone. Some of them are as follows.

Koyuncu, et.al. [58] added ceramic tile dust wastes up to 40% to find out its impact on swelling pressure and swelling potential of Na-bentonite, and observed that swelling pressure and swelling potential reduced by 86% and 57% respectively at 40% addition of ceramic tile dust waste. According to the results of these experiments, a remarkable decrease of zinc (Zn) was noted in the content of CMW from ceramic refinery plant and it was reused as a construction material.

Rajamannan [59] investigated the effect of addition of ceramic waste to clay materials, and concluded from chemical, mineralogical and morphological analyses, that ceramic waste can be added to the clay material with no detrimental effect on the properties of the sintered fire-clay products. The test results also indicate that the ceramic waste may be used as filler in ceramic bricks, thus enhancing the possibility of its reuse in a safe and sustainable way.

Akshay Kumar Sabat [60] explored the impact of ceramic dust waste on index properties, compaction qualities, unconfined compressive strength, California bearing ratio, shear strength parameters and swelling pressure of an expansive soil. The expansive soil collected locally was mixed with clay dust from 0 to 30% at an augmentation of 5%. From the examination of test results, it was found that liquid limit, plastic limit, plasticity index, OMC, cohesion and swelling pressure decreased while MDD, UCS, CBR and angle of internal friction increased with an increment in ceramic dust contents.

T.G. Rani,Ch. Shivanarayana, D.S.V. Prasad and G.V.R. Prasada Raju [61] carried out studies on an expansive soil mixed with tile waste from 0 to 30% at an increment of 10%. From the analysis of test results, it was found that index properties, OMC, and swelling pressure decreased, MDD and CBR increased with an increase in tile waste.

Chen, James A. & Idusuyi, Felix [62] The MDD goes on increasing and OMC goes on decreasing with increase in percentage of addition of ceramic dust. The soaked CBR goes on increasing with increase in percentage of addition of ceramic dust. There is 150% increase in soaked CBR value as compared to untreated soil, when 30% ceramic dust was added.

2.6.3. Previous Studies on Mix of Ceramic Dust Waste with Plastic Waste Fiber

There was no research conducted with mixing ceramic dust waste and plastic waste fiber to improve road subgrade soil strength and in this study the effects of adding various amount of ceramic dust waste and plastic waste fiber was presented with a series of laboratory evidences.

2.7. Identification of Expansive Soils

Investigation of expansive soils generally consists of two important phases. The first is the visual identification and recognition of the soil as expansive and the second is sampling and measurement of material properties to be used as the basis for design. The theme of this topic is to discuss different ways that are commonly used to identify expansive soils.

Field Identification

Soils that can exhibit high swelling potential can be identified by field observations, mainly during reconnaissance and preliminary investigation stages. Important observations include; they have usually black or grey color, 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 [18].

Laboratory Identification

Laboratory identification of expansive soils can be categorized into mineralogical, indirect and direct methods.

I. Mineralogical Identification

Clay mineralogy is a fundamental factor controlling expansive soil behavior. Clay minerals can be identified using a variety of techniques. The techniques that can be used are: X-ray diffraction, Differential thermal analysis, Dye absorption, Chemical analysis and Electron microscope resolution [18].

II. Direct Methods

These methods offer the most useful data by direct measurement; and tests are simple to perform and do not require complicated equipment. Testing should be performed on a number of samples to avoid erroneous conclusions. Direct measurement of expansive soils can be achieved by the use of conventional one-dimensional consolidometer.

III. Indirect Methods

In this method simple soil property tests can be used for the evaluation of engineering properties of soils. Such tests are easy to perform and should be included as routine tests in the investigation of expansive soils. Such tests may include: Atterberg limits, free swell test and others [18]. Some of Those tests are discussed below.

i. Particle Size Determination

Soil classification commonly based on grain size and soil consistency. Several classification systems exist: Unified Soil Classification System (USCS) (ASTM D-2487), American Association of State Highway and Transportation Officials (AASHTO), (ASTM D-3282), U.S. Department of Agriculture (USDA), Burmister Soil Identification System, Massachusetts Institute of Technology (MIT) and may be others.

Table 2.6: Soil grain sizes

Soil grain sizes					
Soil type	USCS Symbol	Grain Size Range (mm)			
		USCS	AASHTO	USDA	MIT
Gravel	G	76.2 to 4.75	76.2 to 2	>2	<2
Sand	S	4.75 to 0.075	2 to 0.075	2 to 0.05	2 to 0.06
Silt	M	0.075 to 0.002	0.075 to 0.002	0.05 to 0.002	0.06 to 0.002
clay	C	< 0.002	< 0.002	< 0.002	< 0.002

Particle sizes are determined by means of Mechanical Analysis (i.e. Sieve) and Hydrometer Analysis (ASTM D-422) Standard Test Method.

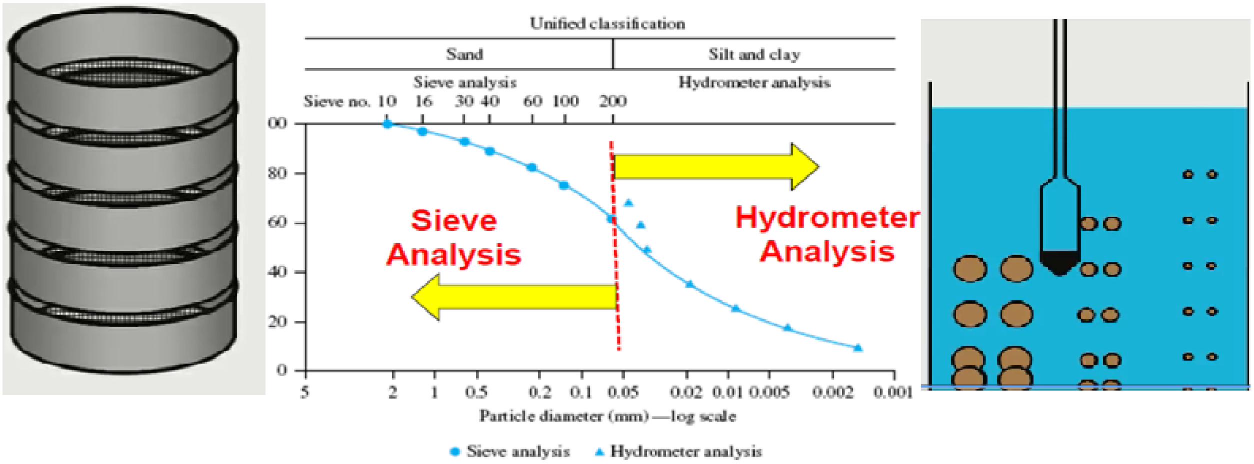


Figure 2.6: Particle size distribution curve (sieve analysis and hydrometer analysis) [14] [74]

Wet Sieve Analysis

The sieve analysis determine the grain size distribution curve of soil samples by passing them through a stack of sieves of decreasing mush opening sizes and by measuring the weight retained on each sieve. The sieve analysis is generally applied to the soil fraction larger than 75µm. The coarse grained soil (particles greater than 75µm) can be further sub divided in-to gravel fraction and sand fraction. For wet sieve analysis the samples are washed on 75µm sieve and the retaining samples are oven dried and sieved on mechanical sieves sized 9.5mm to 75µm.

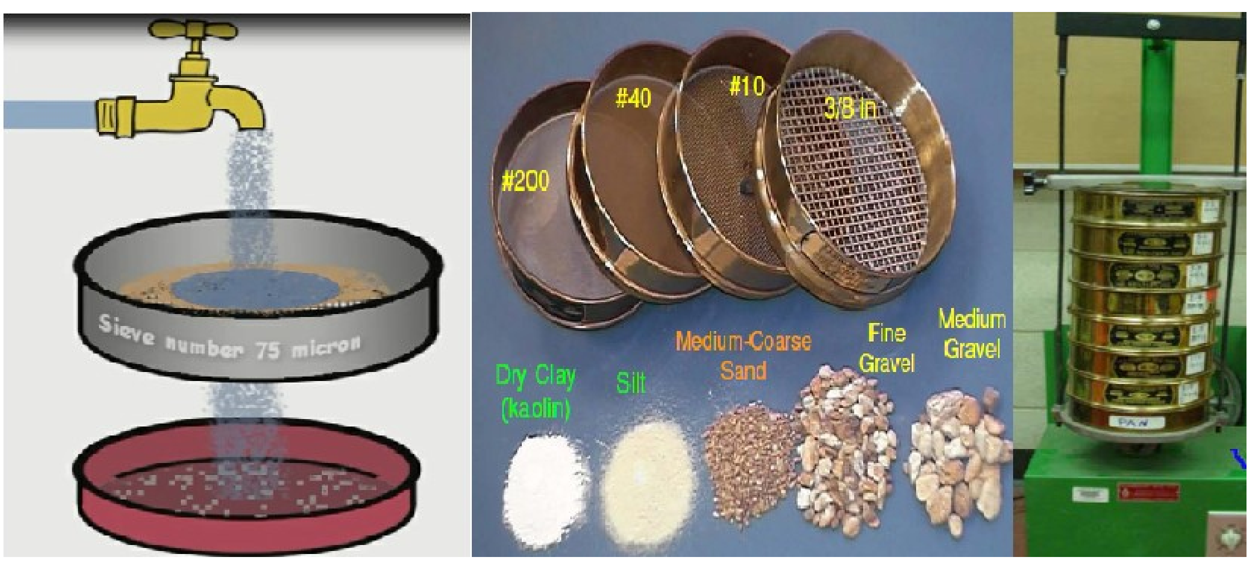


Figure 2.7: Particle sizes (Wet sieve analysis) [74]

Hydrometer Analysis

Hydrometer analysis (ASTM D-442 & AASHTO T-88) Based on the principle of sedimentation of soil grains in water; basically the behaviors of fine-grained soils are influenced by the shape and arrangement of particles.

Hydrometer analysis is a method used to determine the grain size distribution of fine grained soil having particles sizes smaller than 75µm using Hydrometer. It is based on the Stokes law, which says that the larger the grain-size, the greater it's setting velocity in a fluid. Stoke's equation was developed using a sphere, whereas most silt and practically clay particles are platy shaped. Stoke's equation was developed using only a single sphere ,which in soil sample many particles are present and they affect the settlement (fall) of each other.

ii. Moisture (Water) Content

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 is also used in expressing the phase relationships of air, water, and solids in a given volume of soil. This method describes the procedures for determining the moisture content of soils and aggregates using a field laboratory oven [72]. 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. ASTM D-2216 standard test method is conducted for laboratory determination of water (moisture) content of soil, rock, and soil-aggregate mixtures. The moisture (water) content is one of the most commonly determined properties in characterizing the engineering behavior of soil.

According to the definition, the pore water comprises the capillary and hygroscopic water contained in the voids between the solid particles (Head, 1992). The accurate determination of the moisture content is important since the moisture content strongly influences the mechanical behavior of soil. The moisture content is determined as the reduction in the mass of the test specimen after oven drying, usually at $110^{o}\pm5^{o}C$, expressed as a percentage of its oven dried mass. The equilibrium oven dried mass is usually recorded after between 16 hours and 24 hours oven drying [71].

Table 2.7: Typical values of water content in a saturated state [71]

Soil or sample types	Natural Water Content in a Saturated State (%)
Loose uniform sand	25-30
Dense uniform sand	12-16
Loose angular-grained silty sand	25
Dense angular-grained silty sand	15
Stiff clay	20
Soft clay or clay	30-50
Soft organic clay	80-130
Glacial till	10

iii. Atterberg Limits Test

Atterberg limits are commonly used index to classify soils and are used to identify expansiveness. It is common to use two indices on the basis of Atterberg limits which are called plasticity index (PI) and the liquidity limits (LL). The more expansive soils directly relate with higher plasticity, high swelling soil will manifest high index property.

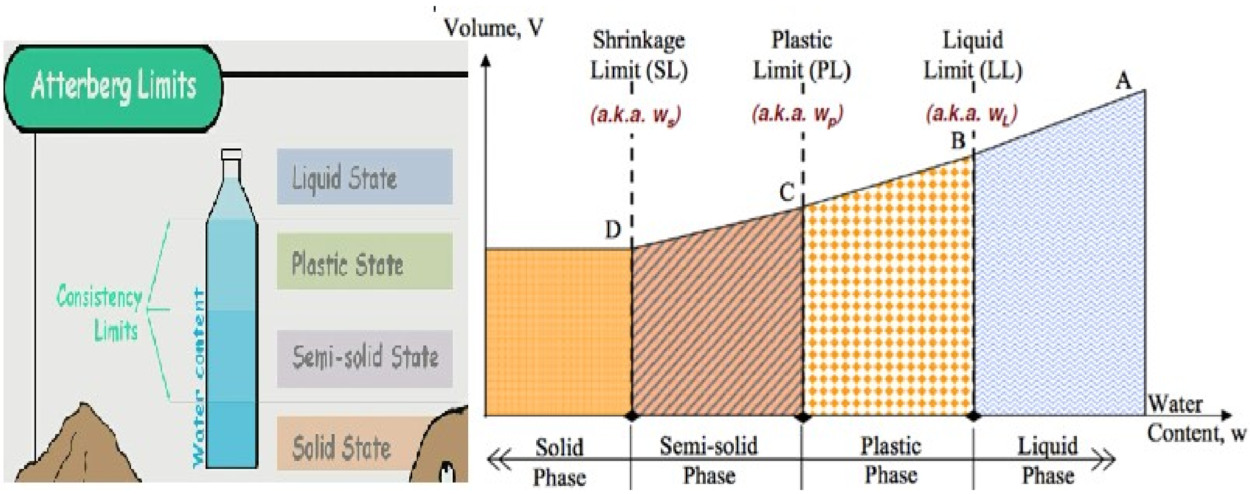


Figure 2.8: Atterberg limits [65]

In this method, measurements of the Atterberg limits of the soil are conducted for identification of all soils and provide a wide acceptable means of rating. Liquid limit less than 35% indicates low plasticity, between 35% and 50% intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity [65].

Atterberg limits are based on the moisture content of the soil. The liquid limit and plastic limit test conducted using Casagrande's liquid limit apparatus as per the procedures laid down in AASHTO or ASTM standards. This lab is performed to determine the plastic and liquid limits of a fine grained soil. The liquid limit (LL) is arbitrarily defined as the water content, in percent, at which a part of 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 13.2 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 can no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without crumbling [25].

The methods described herein are performed only on that portion of a soil that passes the 425-µm (No. 40) sieve. Therefore, the relative contribution of this portion of the soil to the properties of the sample as a whole must be considered when using these tests to evaluate properties of a soil.

Table 2.8: Swelling potential of soil [64]

Swelling Potential	LL	PI
Low	<35	0-15
Medium	35-50	10-35
High	50-70	20-55
Very high	>70	> 35

iv. Free Swell Test

Free swell ratio is defined as the ratio of sediments at which the volume of 10 cc oven dried soil passing through 425µm sieve in distilled water to that of Kerosene. The free swell test may be considered as a measurement of volume change in clay upon saturation and is one of the most commonly used simple tests to estimate the swelling potential of expansive clay [64].

This test has not yet been standardized by AASHTO and ASTM. The method was suggested by Holtz and Gibbs (1956) and Indian standard IS 2720 (part XL (40)) to measure the expansive potential of cohesive soils. The free swell test gives a fair approximation of the degree of expansiveness of the soil sample without being loaded. Free Swell is the percentage heave, $(\Delta h/h) * 100$, of soil following absorption of water at the seating pressure.

Table 2.9: Degree of expansion and differential free swell index [64]

Degree of expansion	Free Swell index (%)
Low	Less than 20
Moderate	20 to 35
High	35 to 50
Very high	Greater than 50

v. Specific Gravity Test

Specific gravity is defined as the ratio of the mass of a given volume of a material to the mass of an equal volume of water. In effect, it tells us how much the material is heavier than (or lighter) than water. The specific gravity of soil is defined as the ratio of the unit mass of solids (mass of solids divided by volume of solids) in the soil to the unit mass of water. ASTM, AASHTO and other standards are clearly described about the determination, test procedures and significance of determination of specific gravity. The specific gravity of soil solids is determined by either density bottle (specific gravity flask) or pycnometer. The density bottle is suitable for all types of soil and it is the accurate method, whereas the specific gravity flask or pycnometer methods are only suitable for coarse grained soils.

vi. Linear Shrinkage Test

Linear Shrinkage limit of a soil is the water content, expressed as a percentage of the weight of the oven-dried soil, at which further loss in moisture will not cause a decrease in its volume. This test followed a British standard (BS1377: Part 2:1990), the swell potential is presumed to be related to the opposite property of linear shrinkage measured in a very simple test. The linear shrinkage value is the way of quantifying the amount of shrinkage likely to be experienced by clayey material. Theoretically it appears that the shrinkage characteristics of the clay should be a consistent and reliable index to the swelling potential. Altmeyer in 1955 [67] suggests a relationship between linear shrinkage, shrinkage limit and the potential of expansiveness as shown in the Table 2.15.

Table 2.10: Shrinkage limit, linear shrinkage and degree of expansion relationship [64, 67]

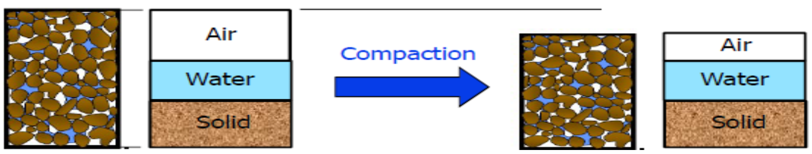
Shrinkage limit (%)	Linear shrinkage	Probable swell (%)	(%) Degree of expansion
< 10	> 8	>1.5	Critical
10-12	5-8	0.5-1.5	Marginal
> 12	0-5	<0.5	Non-critical

vii. Compaction (Moisture-Density) Test

Compaction is densification of soil by reducing air voids by application of mechanical energy. It is used in construction of highway embankments, airports, earth dams and many other engineering structures; loose soils must be compacted to improve their strength by increasing their unit weight. The degree of compaction is measured in terms of its dry unit weight. This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort [25].

The compactive effort is the amount of mechanical energy that is 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. This test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort [72].

Preparation of soil sample for proctor's compaction test is conducted as per AASHTO or ASTM standards. The optimum water content is the water content that results in the greatest density for a specified compactive effort. Purpose of Compaction are it can increases shear strength of soils, increases the bearing capacity of foundations or embankment, decreases the undesirable settlement of structures reduction in hydraulic conductivity, increasing the stability of slopes on embankments and others.



Two types of compaction tests are usually performed: The Standard Proctor Test, and Modified Proctor Test. Each of these tests can be performed in three different methods as outlined in the attached Table 2.16. 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 is filled with three equal layers of soil, and each layer is 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. There are two types of compaction molds 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 (2124 cm3). If the larger mold is used each soil layer must receive 56 blows instead of 25 [72].

Table 2.11: Alternative proctor test methods [72]

	Standard Proctor (ASTM 698)			Modified Proctor (ASTM 1557)		
	Method A	Method B	Method C	Method A	Method B	Method C
Material	≤ 20% Retained on No.4 Sieve	>20% Retained on No.4 ≤ 20% Retained on 3/8" Sieve	>20% Retained on No.3/8" <30% Retained on 3/4" Sieve	≤ 20% Retained on No.4 Sieve	>20% Retained on No.4 ≤ 20% Retained on 3/8" Sieve	>20% Retained on No.3/8" <30% Retained on 3/4" Sieve
soil passing	Sieve No.4	3/8" Sieve	¾" Sieve	Sieve No.4	3/8" Sieve	¾" Sieve
Mold	4" DIA	4" DIA	6" DIA	4" DIA	4" DIA	6" DIA
No.of Layers	3	3	3	5	5	5
No. of blows	25/layer	25/layer	56/layer	25/layer	25/layer	56/layer

viii. California Bearing Ratio Test

In road constructions, the most widely used laboratory test for evaluating the potential strength of subgrade, sub base, and base course materials is the California Bearing Ratio test.

The California Bearing Ratio (CBR) is a very commonly used laboratory test for predicting the strength of a subgrade layer. This test method was first introduced into the California State Highway Department in the 1920s. The US Army Corps of Engineers then adapted the method in the 1940"s for military airfields. After the Second World War, the CBR was also used in the UK and its use spread to European countries. CBR test was standardized by American Society Of Testing Materials ASTM D-1883 for laboratory prepared samples and by American Association of State Highway and Transportation officials AASHTO T-193; and by British Standard as BS 1377 part 4 [25][30]. Soaked CBR test is used to simulate the worst scenario that would likely happen to the sample due to wet weathers. Hence, before performing the tests, soaking the remolded samples for four days (96 hours) is mandatory.

Subgrade strength for pavement structural design is evaluated in terms of California Bearing Ratio (CBR). Strength indicators other than CBR may be used provided they are adequately correlated on CBR values. Design CBR of the subgrade class under study below 3% is S1 according to ERA pavement design manual and cannot preferable for road construction and support structures constructed on it unless special treatment is made.

The CBR swell of the soil is measured by placing the tripod with the dial indicator on the top of soaked CBR mold. The compacted soil samples of the CBR mold are soaked for 96 hours in a water bath to get the CBR swell of the soil. The initial dial reading of the soil of the dial indicator on the soaked CBR of mold is taken just after soaking the sample.

ix. Unconfined Compression Strength Test

The unconfined compression strength of soil is a load per unit area at which an unconfined cylindrical specimen of soil will fail in simple compression test. It is used to calculate the unconsolidated undrained shear strength of the soil under unconfined conditions. To measure the resistance of the soil by compressibility or shearing deformation, UCS test gives the shear strength of the soil that is useful parameters for computing safe bearing capacity of soil as well as strength of soil. The undrained shear strength is necessary for the determination of the bearing capacity of foundations, dams, etc. It measures the strength of cohesive soil, but it is lengthy and need experienced engineer to conduct. [18].

Determination of the Unconfined Compressive Strength (UCS) of undisturbed soil specimen and the test is a special case of a triaxial compression test, especially for cohesive soils only which can stand alone without confinement. A simple compression axial load is applied quickly in the soil specimen in which the all-round pressure (confined pressure) is equal to zero (i.e., σ3 =0). The test is an undrained test and is based on the assumption that there is no moisture loss during the test. The soil specimen is sheared by applying an axial load of major principal stress (σ1) and failure is reached. The Deviator stress (σ1-σ3) is equal to the major principal stress and minor principal stress (σ3) is equal to zero. Axial stress on the specimen is gradually increased until the specimen fails [14].

Table 2.12: Relationship of consistency and unconfined compression strength. [68]

Consistency	qu (kn/m^2)	Remarks
Very Soft	0-25	Squishes between finger when squeezed
Soft	25-50	Very easily deformed by squeezing
Medium stiff (firm)	50-100	Thumb makes impression to deform
Stiff	100-200	Hard to deform by hand squeezing (cannot be indented by thumb pressure)
Very stiff	200-400	Very hard to deform by hand (Can be indented by thumb nail)
Hard	>400	Nearly impossible to deform by hand or difficult to indent by thumb nail

x. Sensitivity

This is a measure of the loss of strength that occurs when the soil is disturbed or remolded. For many naturally deposited clay soils, the unconfined compression strength is much less when the soils are tested after remolding without any change in the moisture content. This property of clay soil is called sensitivity. Sensitivity is defined as the ratio of the undisturbed strength to the remolded strength as outlined in Table 2.18 [74].

Table 2.13 Sensitivity of soil [85]

Descriptive Term	Shear Strength Ratio: $\frac{\text{undisturbed}}{\text{remolded}}$
Insensitive, normal	< 2
Moderately sensitive	2 – 4
Sensitive	4 – 8
Extra sensitive	8 – 16
Quick	> 16

2.8. Engineering Soil Classification

There are a number of systems and methods used to classify soils. The most common of these systems are the American Association of State Highway and Transportation Officials (AASHTO) soil classification system, the Unified Soil Classification System (USCS) and the United States Department of Agriculture (USDA) soil classification system.

2.8.1. Textural Soil Classification System

U.S. Department of Agriculture System (USDA):

Its classification is based on determining the percentages of gravel, sand, silt and clay-size materials in a given sample by mechanical analysis. This method of classification does not reveal any properties of the soil other than grain-size distribution. Because of its simplicity, it is widely used by workers in the field of agriculture. One significant disadvantage of this method is that the textural name as derived from the chart does not always correctly express the physical characteristics of the soil [14, 20].

2.8.2. AASHTO System

This system was originally developed by Hogentogler and Terzaghi in 1929 as the Public Roads Classification System. Afterwards, there are several revisions. The present AASHTO (1978) system is primarily based on the version in 1945 comprised of 8 Major Groups: A1 through A7 (with or without subgroups and A8: organics). The AASHTO system uses both grain-size distribution and Atterberg limits data to assign a group classification and a group index to the soil. The group classification ranges from A-1 (best soils) to A-8 (worst soils). For qualitative evaluation of the desirability of a soil as a highway subgrade material, a number referred to as the group index (GI) has also been developed. Group index values near 0 indicate good soils have higher performance, while values of 20 or more indicate very poor soils have the weaker subgrade performance [14, 20 and 74]. It is standardized in ASTM D-3282.

Table 2.14: AASHTO system soil grouping

A1 to A3	A4 to A7
Granular Materials (Less than or equal to 35% passes #200 Sieve) #Using LL and PI separates silty materials from clayey materials (only for A2 group)	Silt-Clay Materials (≥ 36% passes #200 Sieve) #Using LL and PI separates silty materials from clayey materials

Generally**,** A-1 materials are well graded stone fragments gravel and sands, A-2 materials are silty or clayey gravel and sand; A-3 soils are clean poorly graded sands; A4 & A5 are generally silts, A6 & A7 are generally clays.

The system is based on the Particle-size distribution, Liquid Limit and Plasticity Index. A Group Index is introduced to further differentiate soils containing appreciable fine-grained materials.

Table 2.19: Classification of soils and soil-aggregate mixture (AASHTO classification)

General classification	Granular Material (35% or less of total samples passing No.200)							silt-clay Materials (more than 35% of total sample passing No. 200)			
group classification	A1		A3	A-2				A-4	A-5	A-6	A-7
sieve analysis percent passing	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
No 10	50 Max										
No 40	30 Max	50 max	51 Min								
No 200	15 Max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Liquid Limits				40 max	41max	40 max	41max	40 max	41 min	40 max	41 min
Plastic Limit	6 max		N.P	10 max	10 max	11 min	11 max	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 and sand				silty soils		clayey soils	
General rating as subgrade	Excellent to Good					Fair to poor					

2.8.3. Unified Soil Classification System

The Unified Soil Classification System was originally proposed by A. Casagrande in 1942 and was later revised and adopted by the United States Bureau of Reclamation and the U.S. Army Corps of Engineers. The system is currently used in practically all geotechnical work.

The Unified Soil Classification System is based on the recognition of the type and predominance of the constituents considering grain-size, gradation, plasticity and compressibility and it is standardized in ASTM D-2487. It is divided into two broad categories: the first one is Coarse Grained Soils: Gravels (G) and Sands (S) < 50% passing through #200 sieve (i.e. >50% retained on #200 sieve). The second type, Fine Grained Soils: Silts (M) and Clays (C) ≥ 50% passing through #200 sieve and the third soil type is highly organic (peaty) soils.

In the field, identification is accomplished by visual examination for the coarse-grained soils and a few simple hand tests for the fine-grained soils. In the laboratory, the grain-size curve and the Atterberg limits can be used. The peaty soils are readily identified by color, odor, spongy feel and fibrous texture. In the Unified System, the following symbols are used for identification:

Table 2.15. USCS symbol and their description

Symbol	G	S	M	C	O	Pt	H	L	W	P
Descriptions	Gravel	Sand	Silt	Clay	Organic silts and clay	Peat and highly organic soils	High plasticity	Low plasticity	Well graded	Poor graded

Low plasticity LL<35%; Intermediate plasticity LL=35-50%; High plasticity LL 50-70% (Fat for Clay, Elastic for Silt, e.g. high-quality pottery clay) [14, 20].

Secondary descriptions of (coarse grained) are: - **M** = Silty > 12% fines, PI<4 or plots below “A” Line; **C** = Clayey> 12% fines, PI>7 and plots on or above “A” line; **P** = Poorly Graded < 5% fines, Cu < 6 and/or 1>Cc>3; **W** = Well Graded: < 5% fines, Cu $\geq$ 6 and 1$\leq$ C_c $\leq$ 3.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Sampling Area

The samples; clay soil, ceramic dust waste and plastic waste fibers were collected from Jimma town. The town is located at southwestern part of Ethiopia which is 335km far from Addis Ababa. Its geographical coordinates are between 7°13'- 8°56'N latitude and 35°49'-38°38'E longitude. The town has a temperature of 20-30$°_C$ with an average annual rainfall 800-2500mm. The town is found in an area of the altitude of 1718-2000m above sea level. It is lies in the climatic zone locally known as Woina-Dega which is considered ideal for agriculture as well as human settlement.

The main geological formation of Jimma town is the Cenozoic tertiary volcanic rock of Nazareth series and Jimma volcanic that were formed by lava and debris ejected from fissure eruptions. Basalts, Trachyte, Rhyolite, and Ignimbrite are the major rock types that belong to the trap series formation. It is mostly covered with black, gray and red colored plastic clay soils. Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA), this Zone has a total population of 120,960, of whom 60,824 are men and 60,136 women with an area of 50.52 km^2. Jimma town has a population density of 2,394.30 all are urban inhabitants [80, 81, 82].

Site visiting was the first and foremost for investigation of soil natures. Site visit was made to the sampling places to get information about the texture of soils around the vicinity area. After consideration of the soil textures and other factors two sampling area were selected. Expansive soils were collected from two pits in Jimma town; pit one was sampled from Bosa Addis ketema Kebele, which is located latitude of 7^0 41’41’’ and longitude of $36^0$49’21’’ and pit two was from seto semero kebele which is located latitude of 7^0 40’33’’ and longitude of $36^0$52’07’’. Plastic waste fiber collected from Jimma University, Jimma institute of technology compound and ceramic demolished wastes were from different construction sites in Jimma town.

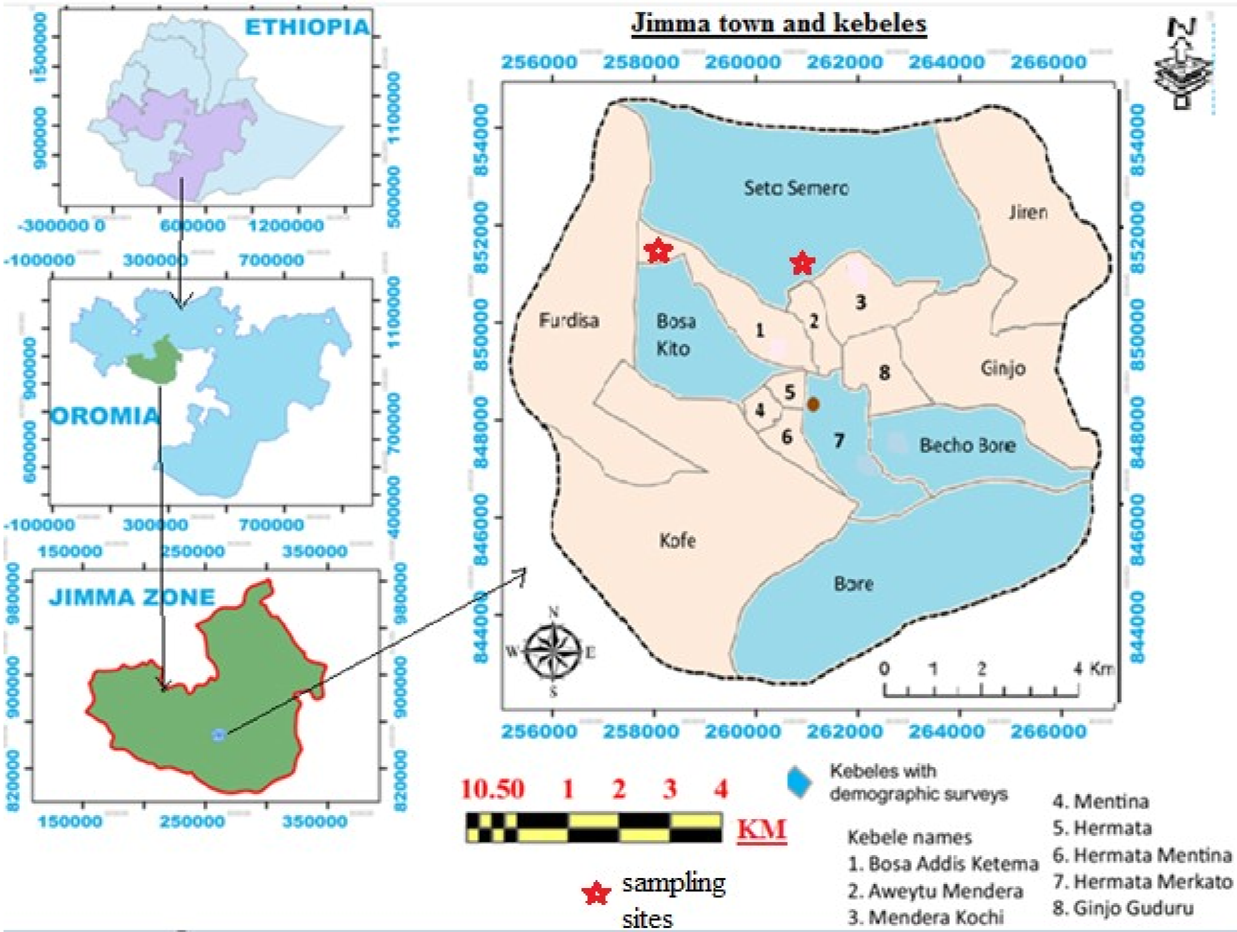


Figure 3.1: Study area description map [83]

3.2. Study Variables

There are two type of study variable which are dependent and independent.

3.2.1. Dependent Variable

The dependent variables are more related with general objective of the study. Dependent variable was improvement of weak subgrade soil with ceramic dust waste and plastic waste fiber.

3.2.2. Independent Variable

The independent variable of this research was engineering properties of untreated and treated weak subgrade Soil (Moister content, LL, PL, PI, Linear shrinkage, free swell, OMC, MDD, CBR, and UCS), dosage of ceramic dust waste and plastic waste fiber.

3.4. Study Design

To meet the objectives of this study, generally the study designs were organized based on literature review of different previous published researches. This research was designed to answer the research questions and meet its objectives based on experimental findings. it would followed the experimental type of study which was begin with collecting samples and procedures including: taking samples, preparation of samples for each laboratory tests, laboratory tests on engineering properties of ceramic dust waste and native soils, mixing expansive soil with ceramic dust waste and plastic waste fiber. The expansive soil was replaced by mix of ceramic dust waste and plastic waste fiber with optimums ratios and compared for the strength with ERA and AASHTO or ASTM standard specification. The research study was conducted by using both experimental and analytical methods. Qualitative and quantitative study would be employed in this study area. Qualitative study gives impression of the findings where a quantitative study was used to describe the numerical aspects of the research finding.

The laboratory test data was analyzed and interpreted so that the effects of expansive soil and its performances on additives requirement was presented in Figure 3.2.

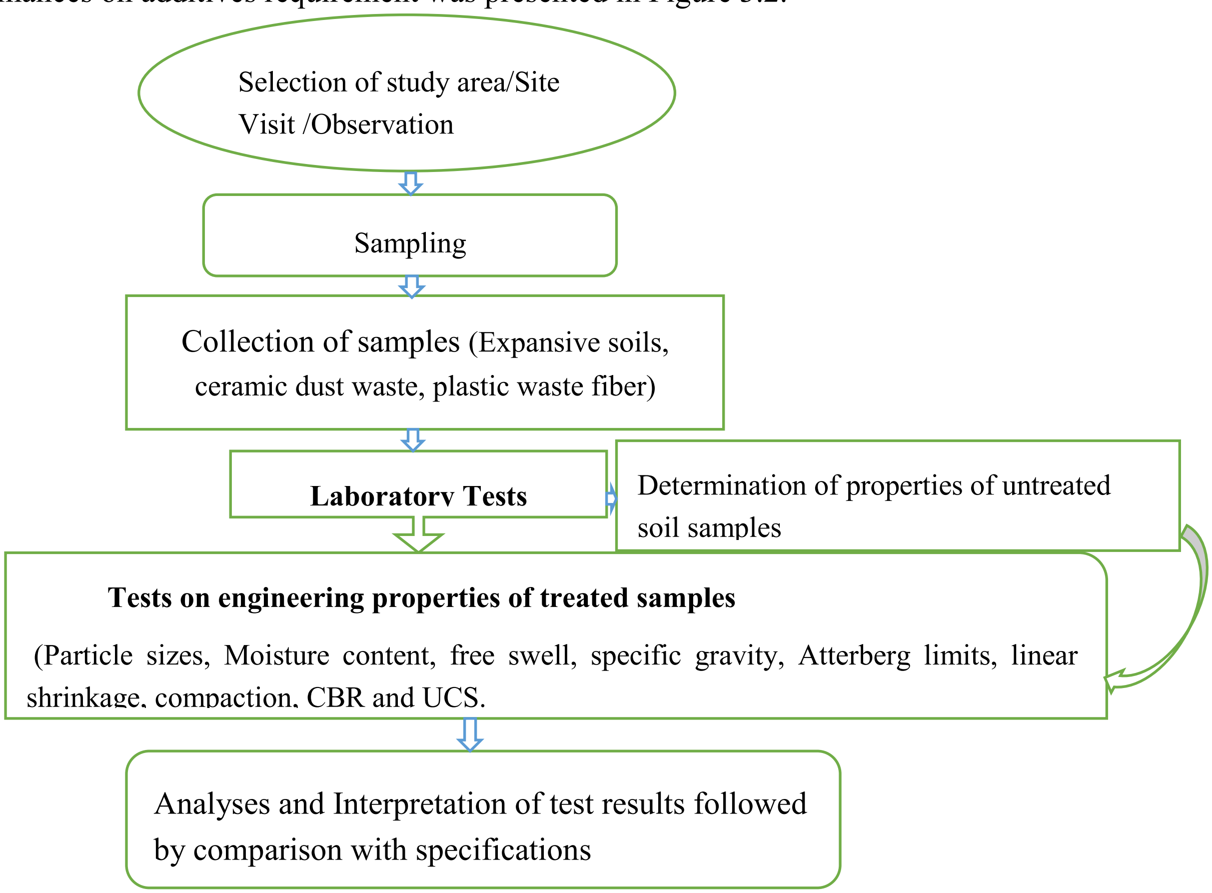


Figure 3.2: Flow chart of study method

3.5. Sample Size and Sampling Technique

For this study two soil sampling sites along flexible pavement Road segment in Jimma town were selected for sampling and other ceramic dust waste and plastic wastes were also collected from different construction sites and waste disposal sites in Jimma town. The samples were obtained by inspection of the study area and the required data were selected. Site visiting was the first and foremost for investigation of soil natures to get information about the texture of soils around the vicinity area. The Expansive soil sample one was collected from Jimma town, Bosa Addis Ketema kebele and sample two was collected from seto semero kebele. The soil sample one was black grey and sample two was black in color, both are highly plastic clay. Additive samples were also collected from different disposal sites. Plastic waste fiber was collected from JIT, Jimma university compound and ceramic demolish also collected from different construction sites in Jimma town.

The sampling technique used was purposive sampling which is non – probability method. This sampling technique is conducted based on goal of the researcher to be achieved and based on the information that to determine the strength of the expansive soil. This technique is characterized as there is no idea of population, no probability of selecting any individual, has free distribution, not used for generalization purpose and no risk for drawing conclusions. Among the technics Purposive sampling technique was selected.

The weak subgrade soil were mixed with the crushed ceramic dust and PET plastic fiber by percentage of the weight of dry soil taken for each tests starting from 5% to 30% within 5% difference for CDW and from 0.5% to 2.5% within 0.5% difference for PWF.

Figure 3.3: Sample collection (natural soil, ceramic waste and plastic waste)

3.6 Experimental Procedure

Based on laboratory results, first the engineering properties of subgrade soil, ceramic dust waste and plastic waste fiber was determined. Then, by adding varying percentages of ceramic dust waste to soil sample, the optimum percentage of ceramic dust waste added on soil were determined. Afterward, the engineering properties of soil was studied by using optimum percentage of ceramic dust waste and varying percentages of waste plastic fiber and optimum plastic fiber content for strengthening clay soil more was determined. Then, the effects of stabilization with only ceramic dust waste and stabilization using waste ceramic dust - waste plastic fiber mix was discussed and the laboratory test results were compared with a standard specification.

The soil sample was collected from the site and air dried. Air dried soil sample was sieved by depending on test type. Ceramic waste collected from building construction sites and crushed and powdered manually by means of hand. Plastic waste also collected from waste disposal holes and cut down with in small sizes. The formed dry mixes were blended together with water in order to get homogeneous blends.

The test procedures utilized throughout the conduct of this research study were the continuous reviewed related literatures on methods of stabilization, types of stabilizers and properties of ceramic dust and plastic fiber includes articles, reference books, research papers and standard specifications like ERA, AASHTO and ASTM. Necessary data collection, organization, comparison and analysis were obtained, and then subsequently compared the results with preexisting literature and standard specifications. A conclusion and recommendation were drawn based on the results.

3.7. Laboratory Tests and Methods

A) Test Methods

The tests were performed on weak subgrade soils before and after mix with waste ceramic dust and plastic waste fiber; the tests conducted are as follow:

a. Untreated weak subgrade soil test: This test was covered a laboratory tests like; particle size determination, moisture content test, Atterberg limit test, linear shrinkage, specific gravity, free swell, compaction test, CBR test and UCS test; to determine the engineering properties before mixing.

***b. Treated weak subgrade soil with the mix of waste ceramic dust and plastic waste fiber*: This** test was conducted on a mix of ceramic dust waste of various percentages (5%, 10%, 15%, 20%, 25% and 30% by weight of dry soil) with a weak soil and optimum percentage of CDW was determined. The determined optimum percentage of CDW was also mixed with various percentages of (0.5%, 1%, 1.5%, 2% and 2.5% by weight of dry soil) PWF reinforcement and clay soil; and the optimum percentage PWFR to improve more was also determined. Then the optimum amount mix ratio of soil-CDW-PWF also determined. Plastic waste strips used for this study were Polyethylene Terephthalate (PET) plastic type having approximate thickness of 2-4mm and length 7-10 mm. Laboratory tests were conducted are Atterberg limit tests, compaction test, free swell test, linear shrinkage, CBR test, and UCS test (for immediate and 7 days curing).

B) Laboratory Tests

i. Moisture Content:

Natural moisture content test was conducted for natural subgrade soil according to the standard test procedure of ASTM D-2216. This test is one of the most significant index properties used in establishing a correlation between soil behavior and its index properties. The water content of a material is used in expressing the phase relation of air, water, and solids in a given volume of material. Moisture content was determined by the ratio of mass of water to mass of soil.

For this study the moisture or water content of natural soil sample was determined by oven-drying method. The disturbed sample from site was placed in the moisture can and secured with lid. After the samples were brought from site to laboratory testing room, the soil sample was weighed and the secured lid was removed and the sample was placed in the oven to dry for 24 hours. The sample was then reweighed and the weight of dry soil divided the difference in weight was given moisture content of the soil. Moisture content was determined for the soil samples under investigation using oven temperature of 105°c±5 for 24 hours.

Figure 3.4: Sampling and test for natural moisture content

ii. Atterberg Limits test

This test procedure adopted for the determination of Liquid limit, Plastic Limit and Plasticity Index are in accordance with ASTM D-4318. The liquid limit (LL) is arbitrarily defined as the water content in percent at which a part of 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 can no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without crumbling. And plastic index is the difference of liquid limit to plastic limit.

This lab was performed to determine the plastic and liquid limits of a fine grained soil. An Atterberg limits device was used to determine the liquid limit of each soil using the material passing through a 425µm (No. 40) sieve. The liquid limit of each soil had been determined by using Casagrande apparatus. The plasticity index was then computed for each soil based on the liquid and plastic limit obtained [72].

Figure 3.5: Atterberg limits test

iii. Particle Size Distribution

The objective of grain size analysis is to determine the percentage of soils passing different sieve opening sizes. This test was performed to determine the percentage of different grain sizes enclosed within a soil. The determination of grain size analysis can be performed by two ways one is by mechanical sieve analysis and the other is by sedimentation (hydrometer analysis). 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. For this study both wet sieve analysis and hydrometer analysis was done according to ASTM D-422.

For mechanical sieve analysis, 1000 gm of air dried natural soil sample was put in a tray and soaked in water. After 24 hours the samples were washed on the75-μm sieve and dried it in an oven. Oven dried samples were sieved on mechanical sieve by using sieve shaker on sieve sizes 9.50 mm, 4.75 mm, 2.00 mm, 0.85 mm, 0.425 mm, 0.30 mm, 0.15 mm, 0.075 mm . The retaining samples were weighted. But this method is only useful to differentiate only gravel and sandy soil of coarse grained soils.

For fine grained soils that mean to differentiate silt and clay soil particles sedimentation (hydrometer) analysis was used. For the materials passing 75 microns, hydrometer method was used. For this means materials passing on 75-μm sieve were collected for hydrometer analysis then performed to measure the amount of silt and clay size particles. About 50 gram of soil was taken and 125 ml solution of sodium hexametaphosphate as dispersing agent was added to soil, distilled water was added and treated for 24 hours. Then the soaked soil was transferred to dispersion cup and stirred for 15 minutes. The soil mixture was poured into the standard measuring flask and made total volume of oil suspension exactly by 1000cc. Finally, the percentage of, silt and clay-sized particles in the specimens were determined from hydrometer readings.

Figure 3.6: Particle size distribution test (for sieve and hydrometer test)

iv. Soil Classification

Soil classification is the arrangement of soils into different group in order that the soils in a particular group would have similar behavior. The most widely used soil classification systems for engineering purposes are American Association of State High Way and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS). The AASHTO system of soil classification comprises seven groups of inorganic soils from A-1 to A-7 with 12 subgroups in all. The system is based on particle-size distribution, liquid limit and plasticity index. On the other hand, the unified soil classification system is based on the recognition of the type and predominance of the constituents considering grain size, gradation, plasticity and compressibility. It divides soil in to three major divisions: coarse grained soils, fine grained soils and highly organic soils. On this research each soil was classified using the AASHTO and USCS soil classification system using particle size distribution and Atterberg limits.

v. Free Swell Test

This test has not yet been standardized by AASHTO and ASTM. The method was suggested by Holtz and Gibbs (1956) and Indian standard IS 2720 (part XL) to measure the expansive potential of cohesive soils. The free swell test gives a fair approximation of the degree of expansiveness of the soil sample without being loaded.

The procedure consists of pouring very slowly of 10 cm^3 of that part of the dry soil passing No. 40 (0.425 mm) sieve in to a 100 cm^3 graduated measuring cylinder and letting the content stand for approximately 24 hours until all the soil completely settles on the bottom of the graduating cylinder. The test was performed by taken two samples of oven dried soil. One was put in a 100 cm^3 graduated glass cylinder containing kerosene and the other sample was put in a similar cylinder containing distilled water. Both the samples were left undisturbed on quiet area for 24 hours and then their volumes were noted. The test was conducted for the determination of the free swell (%) of the natural soil and soil-ceramic dust waste mixture. The free swell test gives a fair approximation of the degree of expansiveness of the samples.

Figure 3.7: Free swell test

vi. Linear Shrinkage

The linear shrinkage is defined as the decrease in one dimension of a soil mass, expressed as a percentage of the original dimension, when the water content is reduced from a given value to the shrinkage limit. The linear shrinkage ratio characterizes the change in length induced by drying a cylindrical sample of soil initially about its liquid limit LS is where LO is Original length sample at about the liquid limit (140mm for standard mold) and LD is Length of the sample after dried.

Linear shrinkage test followed a British standard (BS1377: Part 2:1990), and covered the determination of total linear shrinkage from linear measurement on a standard bar of length 140 mm with a semicircular Section of diameter 25 mm. The grove filled by a soil of the fraction passing 0.425 mm sieve size, originally having the moisture content of the liquid limit.

Figure 3.8: Linear shrinkage test

vii. Specific Gravity

Specific gravity, which is the measure of the heaviness of the soil particles are determined by the method of Pycnometer or density bottle method using a soil sample passing No. 10 sieve and oven dried at 105^0c $\pm$ 5. This lab was performed to determine the specific gravity of soil by using a density bottle. Specific gravity is defined as the ratio of the mass of a given volume of a material to the mass of an equal volume of water. This test was performed the determination of the specific gravity for the natural soil and ceramic dust. It was conducted in accordance with ASTM D-854 standard. The importance of determining the specific gravity in this study was to determine particle sizes in hydrometer analysis. In effect, it tells us how much the material is heavier than (or lighter).

Figure 3.9: Specific gravity test

viii. Compaction Test

Soil compaction reduces the air void in the soil, increases the stiffness and thus, reduces future settlement and permeability. This laboratory test was conducted to determine optimum water content and maximum dry density of soil through compaction test. There are two types of compaction tests: Standard Proctor compaction and Modified Proctor compaction test. In this particular study it was performed modified proctor compaction test. In general, most engineering properties, such as the strength, stiffness, resistance to shrinkage, and imperviousness of the soil can be improved by increasing the soil density. The maximum water content is the water content that results in the highest density for a stated compactive effort. The compactive effort is the amount of mechanical energy that is applied to the soil. Various methods are used to compact soil in the field, and some examples include vibration, kneading, tamping and static load compaction. This laboratory was conducted the impact or tamping compaction method using optimum water content and maximum dry density.

The laboratory test was conducted with accordance of ASTM D-1557 using modified effort of hammer 4.89 kg for 457 mm height. The test was performed on disturbed samples of soil passing sieve sizes 19 mm mixed with water to form samples at various moisture contents ranging from the dry state to wet state. These samples were compacted in 5 layers at 56 blows per layer in accordance with the specified nominal compaction energy of modified proctor test. Dry density was determined based on the moisture content and the unit weight of compacted soil. It was done to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the material. The test was done on the natural soil and then various percentages of ceramic dust waste and plastic waste fiber added on the Expansive clay soil and MDD and OMC were determined.

Figure 3.10: Compaction test

ix. CBR and CBR Swell Test

The California bearing ratio (CBR) test is commonly used to obtain an indication of the strength of subgrade soil, sub base course material and base course materials for use in road and airfield pavements. The test is used primarily to determine empirically required thicknesses of flexible pavements for highway and airfield pavements. In this case the test was conducted to determine the strength of subgrade soil. It is expressed by the force exerted by the plunger and the depth of its penetration into the specimen. It is designed to determining the relationship between force and penetration. The CBR and CBR-swell tests were conducted in accordance with ASTM D-1883 for the natural soil, soil stabilized with ceramic dust waste and soil- ceramic dust waste-plastic waste fiber. CBR tests were conducted on the compacted specimens at the optimum moisture content using a modified compaction test. A three point CBR tests at 10, 30 and 65 blows were conducted according to ASTM specification. The samples passing 19 mm sieve size were compacted in CBR molds at optimum moisture content and gauged for swelling characteristics before and after soaking for four days to evaluate the percentage of swell. The CBR swell of the soil was measured by placing the tripod with the dial indicator on the top of the soaked CBR mold. The initial dial reading of the dial indicator on the soaked CBR mold was taken just after soaking the sample. At the end of 96 hours the final dial reading of the dial indicator was taken.

Figure 3.11: CBR and CBR-swell test

x. *Unconfined Compression Strength Test*

According to ASTM D-2166 material testing manual, the main aim of performing unconfined compressive strength test is to determine the approximate compressive strength of soils with sufficient cohesion to permit testing in the unconfined state. The unconfined compressive strength (qu) is defined as the compressive stress at which an unconfined cylindrical sample of soil is fail in a simple compression test and shear strength is half of the value of unconfined compressive strength.

It provides measures of the undrained compressive strength and the stress-strain characteristics of the soil. Unconfined compression test is popular method of measuring soil shear strength, since it is one of the fastest and cheapest methods of measuring shear strength. The specimens were prepared based on the maximum dry unit weight and optimum water content.

The study was conducted for both uncured and seven day cured UCS testes. The strength has tested for natural and stabilized samples. For natural soil undisturbed soil sample was brought from sampling pits for test and sensitivity also checked. Disturbed samples were remolded by using previously determined maximum dry density and optimum moisture contents for natural soil samples, stabilized with ceramic dust waste and plastic waste fiber and the strength was tested for both immediate cure and seven days cured. Ceramic dust waste passing number 200 sieve standard (75µm) and plastic waste fiber strip (Polyethylene Terephthalate (PET) plastic type) with a thick of 2-4mm and length 7-10 mm was used. Samples were cured by a means of packed or enfold with low-density Polyethylene plastic bag and put in the desiccator to fix the loss of moisture with the water was added until pores of desiccator and left for seven days.

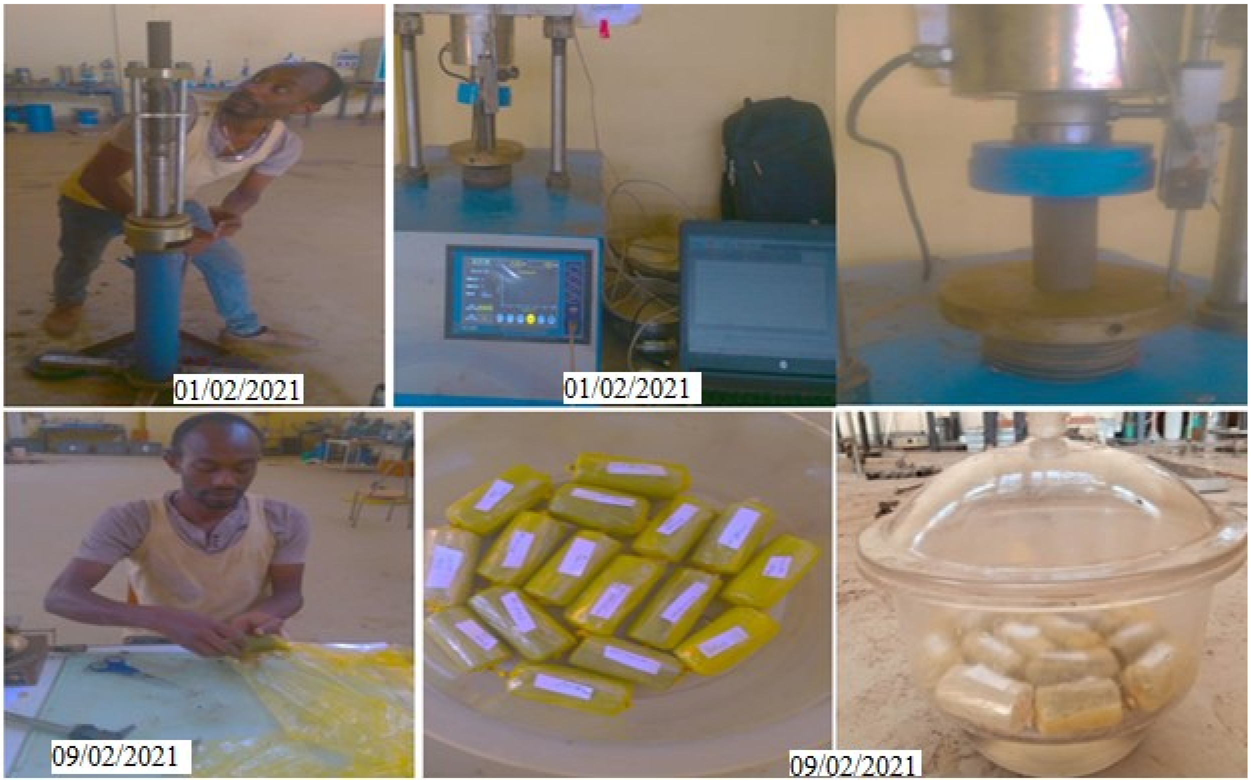


Figure 3.12: UCS (Unconfined compression strength) test

3.9. Sample Preparations

A) Soil sample preparations

For this research, Soil samples were excavated from two pits from Jimma town was collected in large sacks and transported for laboratory tests. The laboratory was conducted in Jimma University, Jimma institute of Technology, in the soil laboratory testing room. The soil samples were air dried and sieved with different sieve size as required for the type of laboratories were conducted.

B) Ceramic dust waste preparations

Ceramic wastes which are demolished, broken and wastes from construction sites in Jimma town were collected and pulverized into a powder by hand and sieved in 75µm sieve size to use.

Figure 3.13: Ceramic waste sample preparation for laboratory test

C) Plastic waste fiber preparations

Plastics wastes were collected from disposal sites from JiT campus screened and washed to use. Washed and air dried plastic samples were ready to cut into small piece using sharp successor. Plastic waste strips used for this study are Polyethylene Terephthalate (PET) plastics type which was cut with a thick of 2-4mm and length of 7-10 mm.

Figure 3.14: Plastic waste fiber preparation

3.10. Data Processing and Analysis

After data were collected it was organized and interpreted using Microsoft word and Microsoft excels, in form of Figure, Table and diagram form according to set objectives. The result obtained from laboratory would be analyzed both qualitatively and quantitatively.

3.11. Data Quality Assurance

The qualities of data were strictly followed during sample collection and preparation according to ERA, AASHTO and ASTM manual. To check the accuracy and validity of data field study again and again, verification was checked and attention given during data collecting, testing and recording. Laboratory test and field work manuals were prepared in order to avoid error of data. Laboratory equipment was calibrated before any measurement or analysis. The calibration results were compared against the standards or protocols.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the result of laboratory tests on engineering properties of natural soil samples as well as CDW and PWF stabilized soil and discussion to the result of the laboratory tests. Laboratory tests are included natural moisture content, particle size analysis, Atterberg's limits tests, free swell, linear shrinkage, specific gravity, compaction, CBR, UCS tests on sample.

4.1. Properties of Untreated Soil Samples

4.1.1. Particle Sizes

The soil sample 01 was black-grey in color and almost 93.41% of the soil was passed through No.200 sieve and 6.59% retained. Fine grained soils; silt and clay contains more percent 28.8% and 65.13% respectively. As the result indicated the soil contains mostly clay. The tabular experimental results are presented in Appendix A-2 and the particle size distribution curves were shown in Figures 4.1and 4.2.

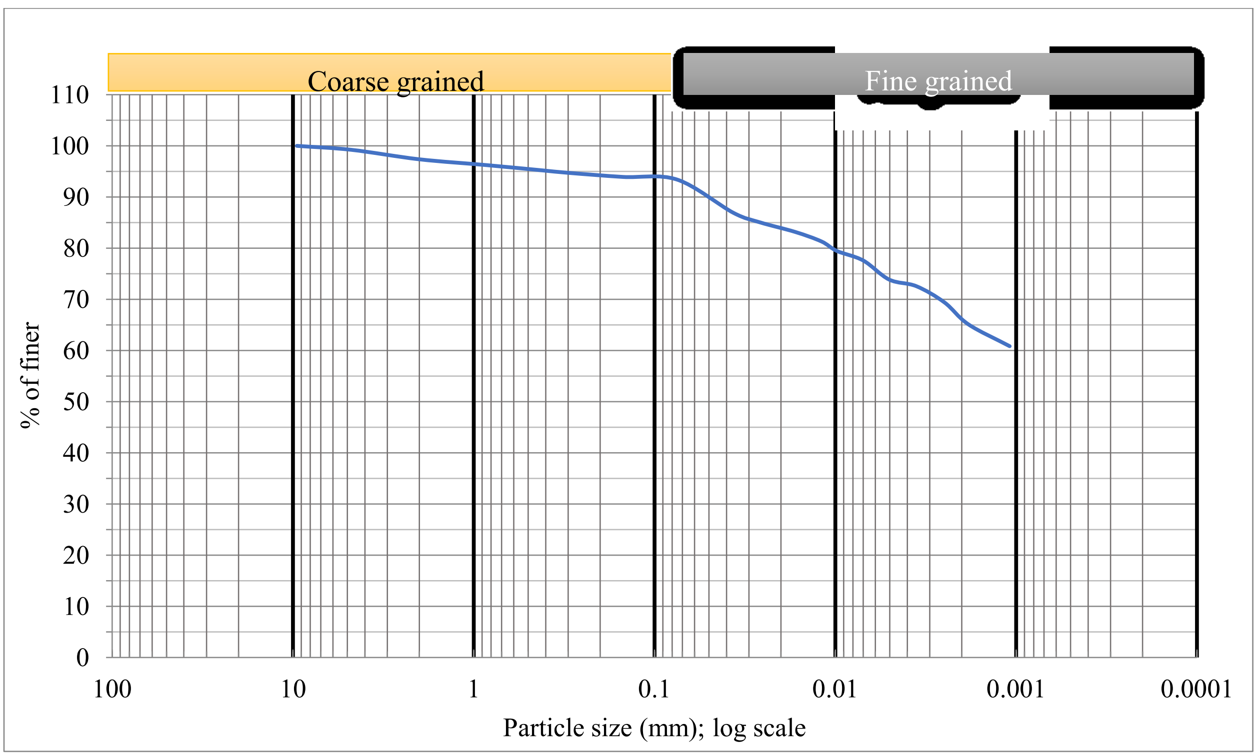


Figure 4.1: Particle size of S01

The soil sample 02 was black in color and 90.18% of the soil was passing through No.200 sieve (75μm) and 9.82% retains. Samples passed through No.200 sieve (75μm) are fine grained soils and retained on this sieve are coarse grained soils. Fine grained soils; silt and clay contained more percent 30.72% and 59.46% respectively; this indicates that almost the given soil sample was also clay soil.

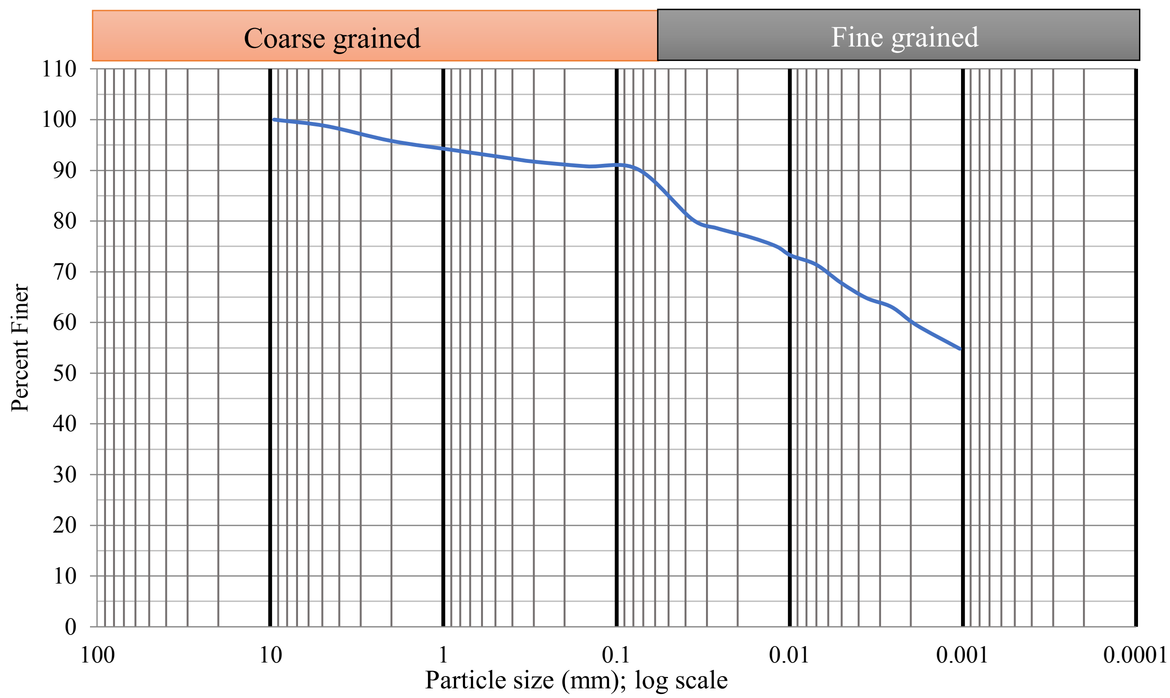


Figure 4.2: Particle size of S02

4.1.2. Atterberg Limits

The value of LL was 83.55%, PL 36.04% and PI was 47.53% for S01. For S02; LL was 80.21% PL 31.35% and PI was 48.85%. For S01 almost 93.41% of the soil passed through No. 200 sieve and for S02 soil almost 90.18% of the soil passed through No. 200 sieve. The result indicates, for both of the samples have very high swelling potential and those were failed to use for subgrade. The laboratory test data were shown in the Table 4.1 and detail tabular test results of atterberg limits shown in Appendix A-6.

Table 4.1: Atterberg limits and soil classifications of S01 and S02

Samples	Atterberg Limits			Soil classification		Swelling potential	Color	Performance
	LL	PL	PI	AASHTO	USCS			
S01	83.55	36.01	47.53	A-7-5 (54)	CH	Very high	black-grey	Very weak soil
S02	80.21	34.35	45.86	A-7-5 (49)	CH	Very high	black	Very weak soil

LL less than 35% indicates low plasticity, between 35-50% intermediate plasticity, between 50-70% high plasticity and greater than 70% is very high plasticity [64]. Hence, LL value indicates that the soils were highly plastic clay. Accordingly, the soils fall under the A-7-5 soil class based on AASHTO soil classification system, the group index values were also more than 20 and CH (inorganic clay of high plasticity) soil class based on USCS soil classification system. Soils under this class are generally classified as a material of poor engineering property to be used as a sub-grade material. These values indicate both soil samples are very high plastic clay; the sub grade shrink and swell easily and does not resist internal and external loads. Finally the structure make crack and easily demolish. To protect this failure stabilization using different additives should be required. Therefore; the soil requires initial modification and/or stabilization to improve its engineering property.

4.1.3. Moisture Contents

The natural moisture content of S01 was 44.0% and S02 was 39.47%. Those soils have high moisture content. The laboratory test data were shown in the Table 4.2 and tabular experimental results were presented in Appendix A-1.

Table 4.2: Moisture content of S01 and 02

Samples name	Natural moisture content (%)	Remarks
S01	44.04	Clay or soft clay
S02	39.47	Clay or soft clay

4.1.4. Free Swells

Free swell of sample one was 90% and sample two was 85%. Soils are called having very high degree of expansion when the free swell index exceeds 50%, High when the degree of expansion is 35-50%, moderate when it is in 20-35% and low degree of expansion when it is less than 20%. This result indicates that the soils are highly expansive. Both of the soil samples have very high degree of expansion and such soils undergo volumetric changes leading to pavement distress, cracking and general unevenness due to seasonal wetting and drying. A result of the free swell tests of the soil was given in Table 4.3 and Appendix A-4.

Table 4.3: Free swell of S01 and 02

Sample pits	Initial reading	Final reading	% free swell	Remarks
Sample 01	10	19	90	Very High
Sample 02	10	18.5	85	Very High

4.1.5. Specific Gravity

Specific gravity which is the measuring of the heaviness of soil particle was determined by using the soil sample passed 2mm sieve size and it was oven dried and density bottle having a capacity of 100 ml used to determine the two pits of soil samples. An average specific gravity of sample one was 2.67 and samples two was 2.70. The specific gravity of solid particles most soils vary from 2.5-2.9. For the most of calculation the specific gravity can be assumed as 2.65 for cohesion less soils and 2.70 for clay soils. Therefore the results indicate both soil samples are grouped under clay soil. The summary of the test results were tabulated while the laboratory test analyses were given in Appendix A-3.

4.1.6. Linear Shrinkages

When the degree of expansion is less than 5% it is called non-critical, 5-8 % marginal and greater than 8% is called critical degree of expansion. Based on this; both of the samples have the value of linear shrinkage were greater than 8% and so it was set aside that they had critical (very high) degree of expansion hence stabilization of soil was required. Results of the linear shrinkage test of the untreated soil sample were given in Table 4.4 and Appendix A-5.

Table 4.4: Linear shrinkage of S01 and S02

Sample names	Length of mold (cm)	Length of dry specimen (cm)	Linear Shrinkage (%)	Degree of expansion
S01	140	108.50	22.50	Very high (Critical)
S02	140	112.70	19.50	Very high (Critical)

4.1.7. Moisture-density (Compactions)

Modified proctor test was applied to determine the MDD and OMC of natural soils according to ASTM D-1557. The OMC of soil sample one was 22.50% and MDD 1.622 g/cc. In another hand OMC and MDD of sample one was 22.00% and 1.625 g/cc respectively. The laboratory test results were shown on Figure 4.3 and the summary of test results also tabulated and attached in Appendix A-7.

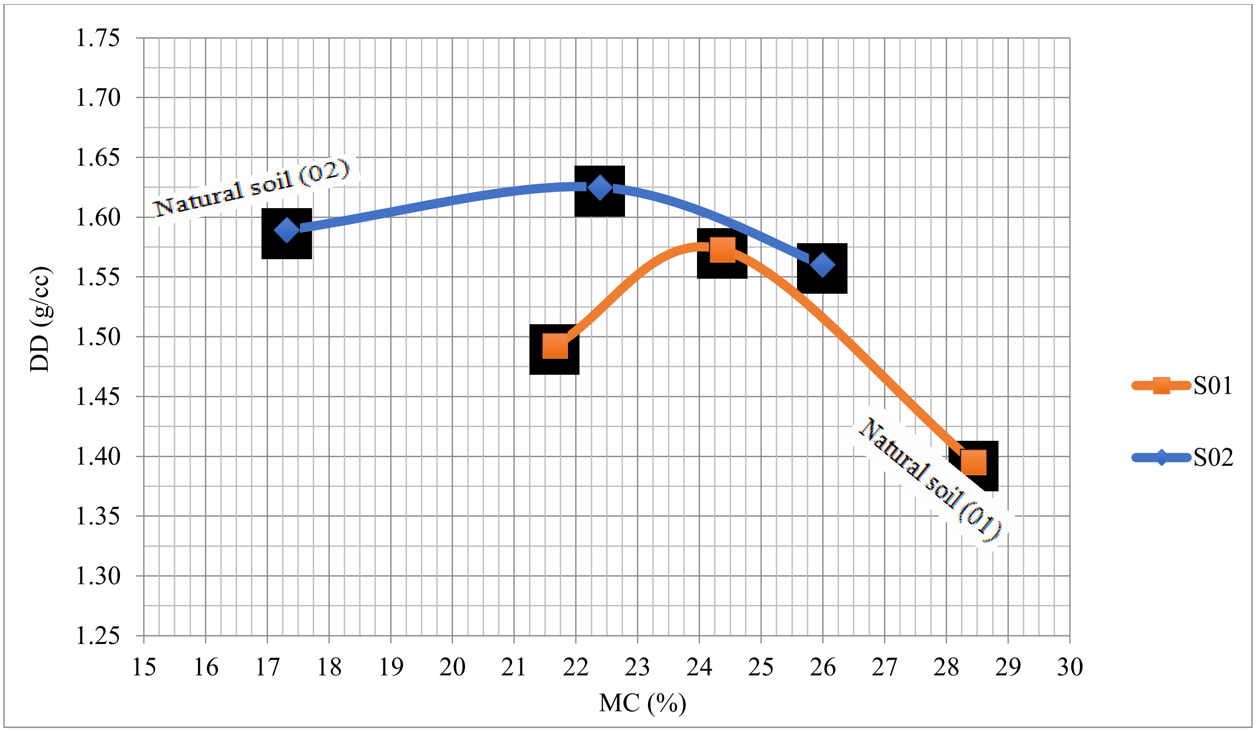


Figure 4.3: OMC and MDD of S01 and S02

4.1.8. CBR and CBR swell

As indicated in Table 4.5, the CBR value at 95% MDD compaction of S01 was 1.03% and CBR swell was 8.34%. On another hand CBR of S02 and CBR swell was 1.56% and 7.40% respectively.

CBR values of natural sub grade soils of the two samples were not fulfilled the requirement of sub-grade soils as per ERA standard. According to ERA manual 2013 specification it is not allowed to use CBR values less than 3%, because from both a technical and economic perspective. It would normally be inappropriate to lay a pavement on soils of such bearing capacity. Based on the suitability of sub-grade soil, both of the soil samples were classified under poor and not allowed to use for sub-grade materials. The CBR swell value also indicated that they had critical (very high) degree of expansion. Therefore the soils need to be treated before use. The test results were shown in Appendix A-8.

Table 4.5: CBR and CBR swell of SO1 and SO2

Samples	CBR (%) at 95 (%) MDD	CBR swell (%)	ERA (2013) requirement for subgrade (CBR value)	Remarks
S01	1.03	8.34	Minimum 3%	Failed for subgrade
S02	1.56	7.40	Minimum 3%	Failed for subgrade

4.1.9. Unconfined Compression Strengths

4.3.9.1. Undisturbed and Remolded Natural Soil Sample

Undisturbed soil samples were taken directly from site and disturbed samples were remolded at MDD and OMC were determined from compaction test. For undisturbed site samples the stress value was taken a minimum value because every design from site must be designed and considered for minimum strength. But for remolded samples the average value was considered because the value difference may be happened from at the time of remolding, from materials and other factors.

Sensitivity terms the effect of soil disturbance on shear strength. Sensitivity of soil is an indication of the reduction in shear strength of soil when it is subjected to any disturbance (in this case when it was remolded and subjected to cyclic loading). Sensitivity of sample one was 0.90 and sample two was 0.84. Both of the results indicate that insensitive or normal sensitivity; where the values were less than one.

As it is described in previous section the strength (consistency) of soils from 0-25 kpa is said very soft soil, 25- 50 kpa is called soft soil, and 50-100 kpa is medium stiff or firm soil and so forth. Depending on those grouping the strength (consistency) of both samples were firm soils which means thumb makes impression to deform or intended only by strong finger pressure.

Table 4.6 shows the laboratory test results of UCS of undisturbed and remolded natural soil samples of two pits and the additional tabular test data were included in Appendix A-9.

Table 4.6: Unconfined compression strength of S01 and S02

Sample	Sample type (Immediate)	Avg. UCS (kpa)	Shear strength (kpa)	Remarks	Strength (Consistency)	Sensi tivity
S01	Undisturbed	74.86	37.43	The minimum value was considered	Firm soil	0.90
	Remolded	83.20	41.58	The average value was taken	Firm soil	
S02	Undisturbed	82.53	41.27	The minimum value was considered	Firm soil	0.84
	Remolded	97.92	48.96	The average value was taken	Firm soil	

4.2. Soil Sample Used for Stabilization

From two pits of soil samples, weaker soil sample was selected for stabilization; because this study focused on additive materials on expansive soils whether they are suitable or not rather than investigating different and more soil samples. From two samples, S01 was weaker soil and the stabilization was done with S01.

Table 4.7: Factors identified to select weaker soil

Comparison factors	Soil sample (S01)	Soil sample (S02)	Weaker soil
Particle sizes	Clay= 65.13%	Clay= 59.46%	S01
Soil classifications	A-7-5 (54)	A-7-5 (49)	S01
Natural moisture contents	44.01%	39.47%	S01
Atterberg limits	LL= 83.35% & PI = 47.53%	LL= 80.21% & PI = 45.86%	S01
Free swells	90.00%	85.00%	S01
Linear shrinkages	22.50%	19.50%	S01
CBR	1.03%	1.56%	S01
UCS	Undisturbed = 74.85 kpa & Remolded =83.15 kpa	Undisturbed = 82.53 kpa & Remolded =97.91 kpa	S01

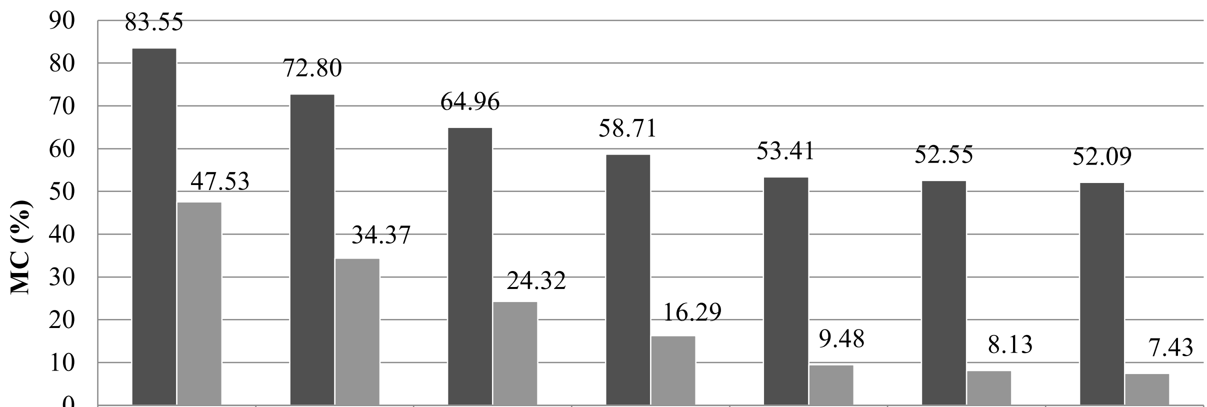
4.3. Effects of Addition of CDW on Engineering Properties of the Soil

4.3.1. Effects of Addition of CDW on Atterberg Limits

The effect of CDW addition in varying proportion with natural expansive soil was studied and the variation in Atterberg limits for various additive mix-ratios was presented in Table 4.8 and Figure 4.4. From the results it was observed that addition of CDW decreased LL and PI values. PI value reduced from 47.53% (untreated soil) to 7.43% (30% stabilized with CDW) which decreased 84.37%, hence CDW had decreased PI. Up to 20% of CDW added, there was a considerable decrease in LL and PI, and then the values seem almost constant. Blending expansive soil with CDW was satisfied ERA (2013) standard specification for sub-grade construction. The Detailed tabular results of the Atterberg limits were shown in Appendix C-3.

Table 4.8: Effects of CDW on Atterberg limits

Ratios	LL (%)	PI (%)	ERA (2013) Requirement	Remarks	Reduction in PI (%)
S01	83.55	47.53	$PI \leq 30\%$	Not satisfied	-
S01 + 5% CDW	72.80	34.37		Not satisfied	27.69
S01 + 10% CDW	64.96	24.32		Satisfied	48.83
S01 + 15% CDW	58.71	16.29		Satisfied	65.73
S01 + 20% CDW	53.41	9.48		Satisfied	80.01
S01 + 25% CDW	52.55	8.13		Satisfied	82.90
S01 + 30% CDW	52.09	7.43		Satisfied	84.37



	S01	S01 + 5% CDW	S01 + 10% CDW	S01 + 15% CDW	S01 + 20% CDW	S01 + 25% CDW	S01 + 30% CDW
LL	83.55	72.80	64.96	58.71	53.41	52.55	52.09
PI	47.53	34.37	24.32	16.29	9.48	8.13	7.43

Figure 4.4: LL and PI of soil stabilized with CDW

4.3.2. Effects of Addition of CDW on Free Swell Index

Soils are called highly expansive when the free swell index exceeds 50%, and such soils undergo volumetric changes leading to pavement distortion, cracking and general unevenness due to seasonal wetting and drying. As shown in Table 4.9, the free swell of the samples were decreased with increase CDW in ratios. The slight reduction was observed for mix ratio of 5 and 10% of CDW, they had very high degree of expansion and others 15 - 30% additives were in the range they had high to low degree of expansion. Up to 20% of CDW added, there was a substantial decrease in FSI and after that the values got almost constant.

The FSI soil stabilized with CDW was given in Table 4.9 and the tabular data were presented in Appendix C-2.

Table 4.9: Free swell test result of expansive soil stabilized with CDW

FSI					
Ratios	FS (%)	Reduction (%)	IS 2720 (part XL) requirement	Degree of expansion	Result comparison
S01	90	-	FSI < 50%	Very high	control
S01 + 5% CDW	80	11.11		Very high	Slight reduction
S01 + 10% CDW	60	33.33		Very high	Slight reduction
S01 + 15% CDW	35	61.11		High	In the Range
S01+ 20% CDW	18	80.00		Low	In the Range
S01 + 25% CDW	16	82.22		Low	In the Range
S01 + 30% CDW	15	83.33		Low	In the Range

4.3.3. The Effects of Addition of CDW on Linear Shrinkage

According to Altmeyer (1955), soils having linear shrinkage value above 8% is grouped to critical, between 5% and 8% is marginal, and less than 5% possess non-critical degree of expansion. The LS of the soil after stabilization using different ratios of CDW was given in Table 4.10. In increment of additive content percentages the LS value had reduced. So the additive contents were effective to reduce the volume change when exposed to variable humidity and whether condition. The linear shrinkage for native soil was under critical degree of expansion with 22.50%. For 5 and 10% replacement, there were critical degree of expansion with 17.57 and 10.86% of linear shrinkage value was observed respectively. When 15% of CDW replaced, it had 6.14% liner shrinkage and it was grouped marginal degree of expansion. For last three replacements, which means for 20, 25 and 30% the linear shrinkage values were 2.93, 2.36 and 2.07% respectively and the degree of expansions were non-critical. For 5- 20% replacements a considerable improvement was shown, but for other replacements the values were shown very slight decrement and it seems the same.

Table 4.10: The effects of addition of CDW on linear shrinkages

Ratios	LO (cm)	LD (cm)	LS %	Reduction (%)	Degree of expansion
S01	140	108.50	22.50	-	Critical
S01+ 5% CDW	140	115.40	17.57	21.91	Critical
S01+ 10% CDW	140	124.80	10.86	51.73	Critical
S01 + 15% CDW	140	131.40	6.14	72.71	Marginal
S01 + 20% CDW	140	135.90	2.93	86.98	Non-critical
S01 + 25% CDW	140	136.70	2.36	89.51	Non-critical
S01+ 30% CDW	140	137.10	2.07	90.80	Non-critical

4.3.4. Effects of Addition of CDW on Compaction

Proctor compaction test was conducted for soil stabilized with CDW under consideration to determine the MDD and OMC of the soils. The purpose of drawing the compaction curves shown in Figure 4.5 was to show the peak moisture-density relationship and to extract MDD and OMC values from the curve. The soil samples were subjected to the determination of MDD and OMC in the laboratory and which are used to determine the strength of soil.

The laboratory test result revealed that the range of MDD of the soil samples were in the range of 1.622 g/cc to 1.481 g/cc (decreasing performance) and OMC were ranges between 22.5% to 29.4% (increasing result). The OMC and MDD of stabilized soils were presented in Figure 4.5 and the value of laboratory data analysis was attached in Appendix (C-4).

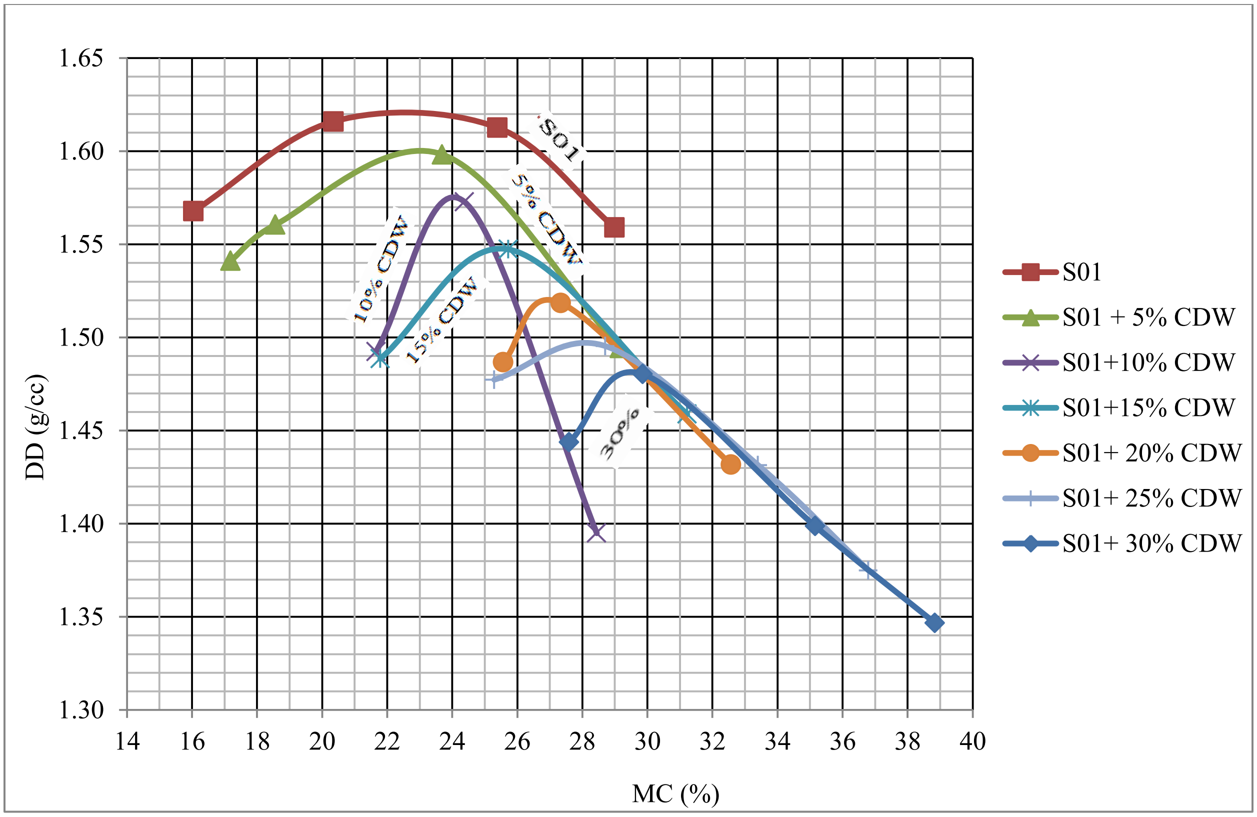


Figure 4.5: MC and DD of Soil stabilized with CDW

A) Effects of Ceramic Dust Waste on Optimum Moisture Content

Figure 4.6 shows the variation of OMC with different percentage of CDW. OMC is the water content at which the dry density becomes its maximum value. As shown on Figure 4.6, with increase in percentage of CDW, the OMC of soil was increased. The OMC increased from 22.5 to 29.4% when CDW was increased from 0 to 30%. The increase is due to the addition of CDW (%), which decreases the quantity of free silt and clay fraction and coarser materials with larger surface areas were formed (these processes need water to take place). This implies that more water is needed in order to compact the soil-CDW mixture or CDW additive has higher attraction of water molecules.

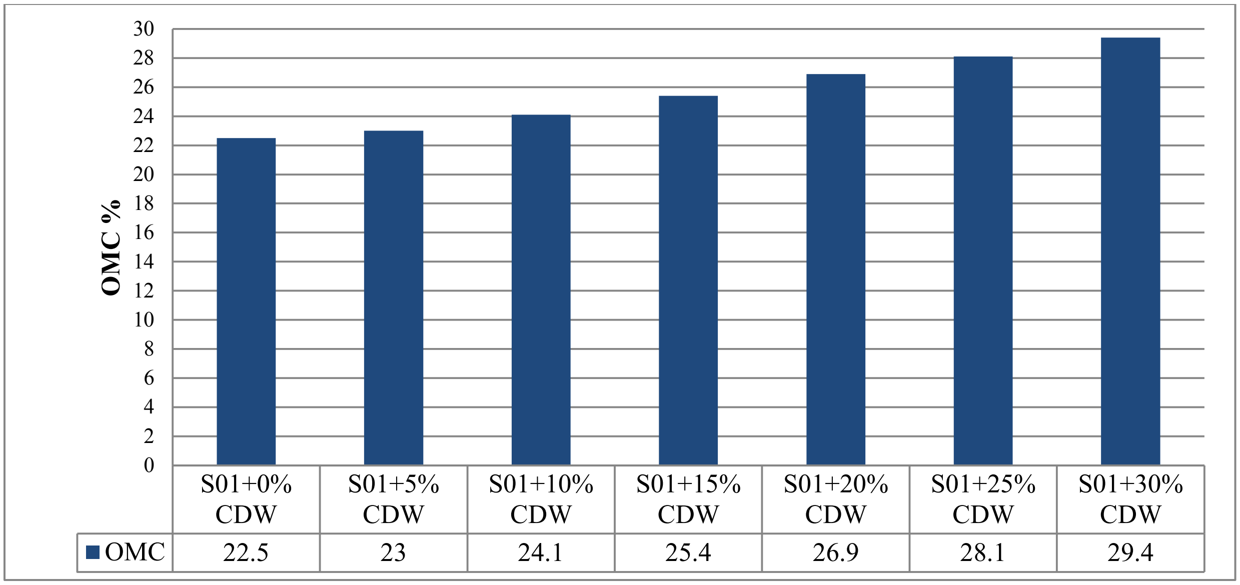


Figure 4.6: OMC of soil stabilized CDW

B) Effects of Ceramic Dust Waste on Maximum Dry Densities

Figure 4.7 shows the variation of MDD with a different mix ratio of CDW. From the Figure it is clear that within increase the percentage of ceramic dust, the MDD of soil shown declining. The MDD decreased from 1.622 g/cc to1.481 g/cc when ceramic dust was increased from 0 to 30%. The reason of such behavior is due to replacement of CDW particles having lower specific gravity which was 2.51 with soil particles having higher specific gravity (2.67). The specific gravity laboratory result tabular data of CDW was included in Appendix B-1.

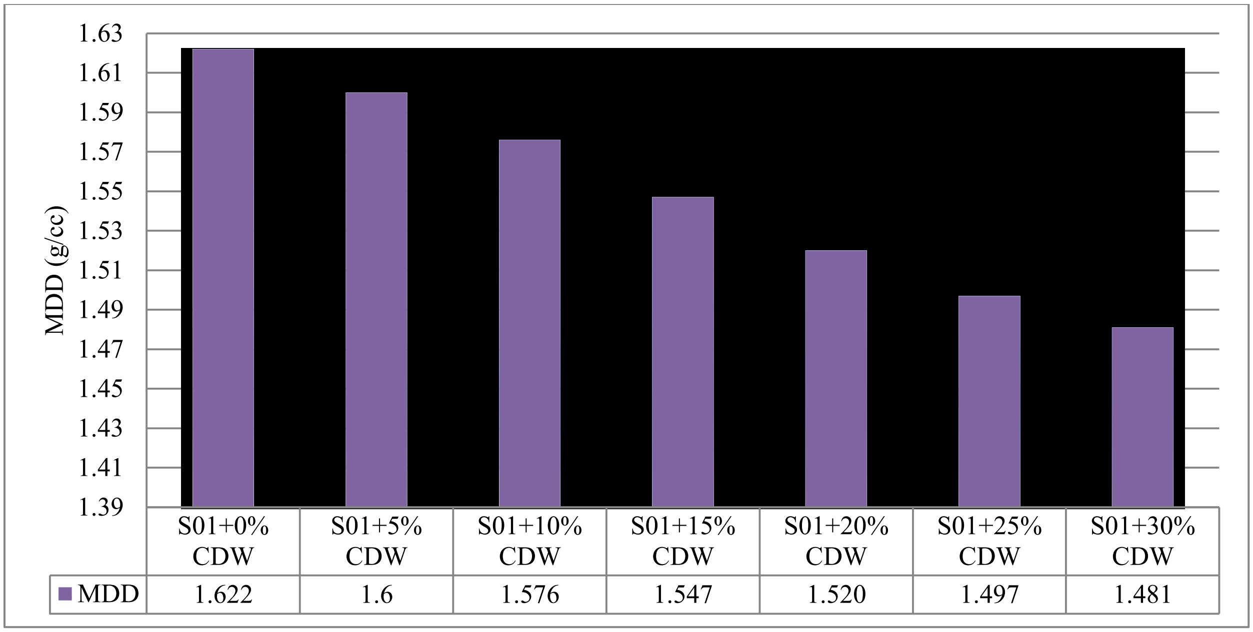


Figure 4.7: MDD of soil stabilized with CDW

4.3.5. Effect of CDW on CBR and CBR Swell

According to ERA manual standard specification it is not allowed to use CBR values less than 3%, because from both a technical and economic perspective it would normally be inappropriate to lay a pavement on soils of such bearing capacity, there should be special treatment needed. Therefore improvement of soil using CDW was needed to be acceptable as subgrade soils. The soil stabilized with CDW had shown an improvement on strength. The test result of stabilized and natural soil was presented in Table 4.11 and tabular test data was included in Appendix D.

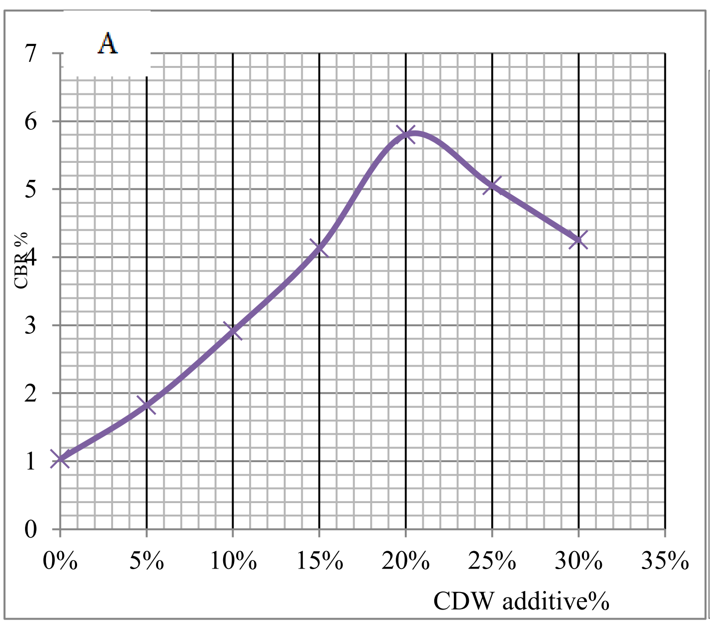
From Table 4.11 the observations seen for natural and stabilized soils that the CBR values of natural soil was 1.03%, natural soil stabilized with 5 and 10% of CDW were 1.82 and 2.91% respectively. They are not acceptable as subgrade soil because their CBR values were less than 3% but it has shown a slight improvement when the percentage of stabilizer increased. For soil sample stabilized with 15, 20, 25 and 30% of CDW the CBR values ware 4.13, 5.80, 5.05 and 4.25% respectively and all are acceptable as subgrade. As it is shown in the Table 4.11 and Figure 4.8 for soil replaced with 20% CDW was a peak value and the next two replacements 25 and 30% shown a decrement.

The CBR swell test was also performed for varying combination of soil- CDW mixtures. The CBR swell of untreated soil was founded 8.74%, which shows high swelling behavior and other stabilized values were also mentioned in the Table 4.11 and Figure 4.8, those were decreasing logically. The soil sample mixed with CDW compacted in CBR molds at OMC and soaked for 96 hours to evaluate the percent of swelling characteristics after soaking.

The results shown decrease in the CBR swell from 8.74% for natural soil to 1.03% replaced with 30% of CDW by weight of dry soil. So the minimum CBR swell values were obtained at 30% CDW. ERA Manual recommend that sub-grade soil should have CBR swell less than two percent is preferable for subgrade soil; so that stabilized soil satisfied for 20, 25 and 30% replacement of soil with CDW by weight of dry soil and it is possible to use as sub-grade material in road construction.

Table 4.11: Effect of ceramic dust waste on CBR value

Ratio	CBR (%)	% of increment	Swell (%)	Subgrade Strength Classes	ERA (2013) requirement	Remarks
S01	1.03		8.74	S1	CBR ≥ 3% and CBR swell < 2%	Not Acceptable (control)
S01 + 5% CDW	1.82	76.70	6.14	S1		Not Acceptable (slight improvement)
S01 + 10% CDW	2.91	182.52	4.34	S1		Not Acceptable (slight improvement)
S01 + 15% CDW	4.13	300.97	3.24	S2		Acceptable (slight improvement)
S01 + 20% CDW	5.80	463.11	1.85	S3		Acceptable (the maximum value)
S01 + 25% CDW	5.05	390.21	1.30	S3		Acceptable (decline from maximum)
S01 + 30% CDW	`4.25	312.62	1.03	S2		Acceptable (decline from maximum)



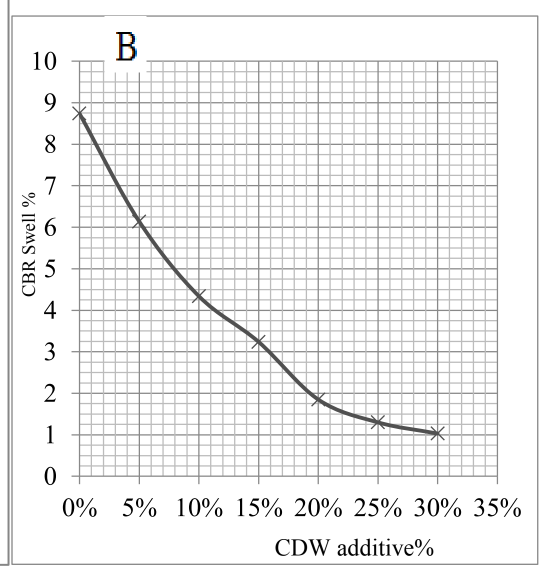


Figure 4.8: (A) CBR values (B) CBR swell values of soil stabilized with CDW

4.3.6. Effect of Ceramic Dust Waste on Unconfined Compression Strength

The remolded un-stabilized and stabilized samples with different percentage of CDW were compacted at the OMC and MDD and subjected to unconfined compression tests to determine their strength at different curing times. The samples were tested for immediate and seven day cured. They were mixed with 5, 10, 15, 20, 25 and 30% of CDW by weight of dry soil. Samples were extruded from the compaction mold by Shelby tube or cylindrical soil sampler. The extruded samples were sealed with impermeable plastic bag to be cured at room temperature for seven days. Both immediate and seven day cured UCS test were conducted for treatment of sample one with different mix ratio.

The summarized UCS test results were shown as Table 4.12 and Table 4.13 and detailed UCS laboratory results also included in Appendix C8 and C10.

A) Remolded Samples of Immediate Test for UCS (Axial Stress and Cohesion)

Table 4.12: Summary of laboratory test results of UCS for S01 stabilized with different mix ratios of CDW (immediate curing duration)

Ratios	Test type (Immediate)	Avg. UCS (qu) (kpa)	Shear strength (su) (kpa)	Strength (Consistency)
S01	Remolded	83.15	41.58	Firm soil
S01+ 5% CDW	Remolded	154.37	77.19	Stiff soil
S01+ 10% CDW	Remolded	247.53	123.77	Very stiff soil
S01+ 15% CDW	Remolded	346.48	173.24	Very stiff soil
S01+ 20% CDW	Remolded	421.14	210.57	Hard soil
S01+ 25% CDW	Remolded	365.04	182.52	Very stiff soil
S01+ 30% CDW	Remolded	306.11	153.06	Very stiff soil

B) Remolded Sample of Cured for 7 Days Test (UCS: Axial Stress and Cohesion)

Table 4.13: Summary of laboratory test results of UCS for S01 stabilized with different mix ratios of CDW (seven day curing duration)

Ratios	Test type (cured for 7 days)	Avg. UCS (qu) (kpa)	Shear strength(su) (kpa)	Strength (Consistency)
S01+ 5% CDW	Remolded	188.23	94.12	Stiff soil
S01+10% CDW	Remolded	274.12	137.06	Very stiff soil
S01+15% CDW	Remolded	401.12	200.56	Hard soil
S01+20% CDW	Remolded	464.46	232.23	Hard soil
S01+25% CDW	Remolded	404.96	202.48	Hard soil
S01+30% CDW	Remolded	355.68	177.84	Very stiff soil

As discussed in the Table 4.12, 4.13 and on Figure 4.9, it had shown some enhancement for cured samples than uncured (immediate test). From previous discussion, the strength (consistency) of soil from 0-25 kpa is said very soft soil, 25- 50 kpa is called soft soil, 50- 100 kpa is medium stiff or firm soil, 100-200Kpa is stiff soil, 200-400 kpa is very stiff soil and 400-1000 kpa is hard soil. As discussed above UCS of the soil without an addition of CDW was 83.15 kpa, and cohesion was 41.58 kpa, it had a medium stiff or firm consistency.

For immediate tests, soil stabilized with 5% of CDW had shown stiff soil strength; 10, 15, 25% and 30% were very stiff soil and at 20% hard soil consistency was observed. Until 20% of stabilization the increasing values had observed and for next two replacements it had declined.

Cured for seven day tests; soil stabilized with 5% of CDW, the consistency division was stiff soil, 10 and 30% of CDW it were presented very stiff soil strength and 15, 20 and 25% the hard soil consistency were presented. Similarly, until 20% of stabilization the increasing values had observed and for next two replacements the values shown declined.

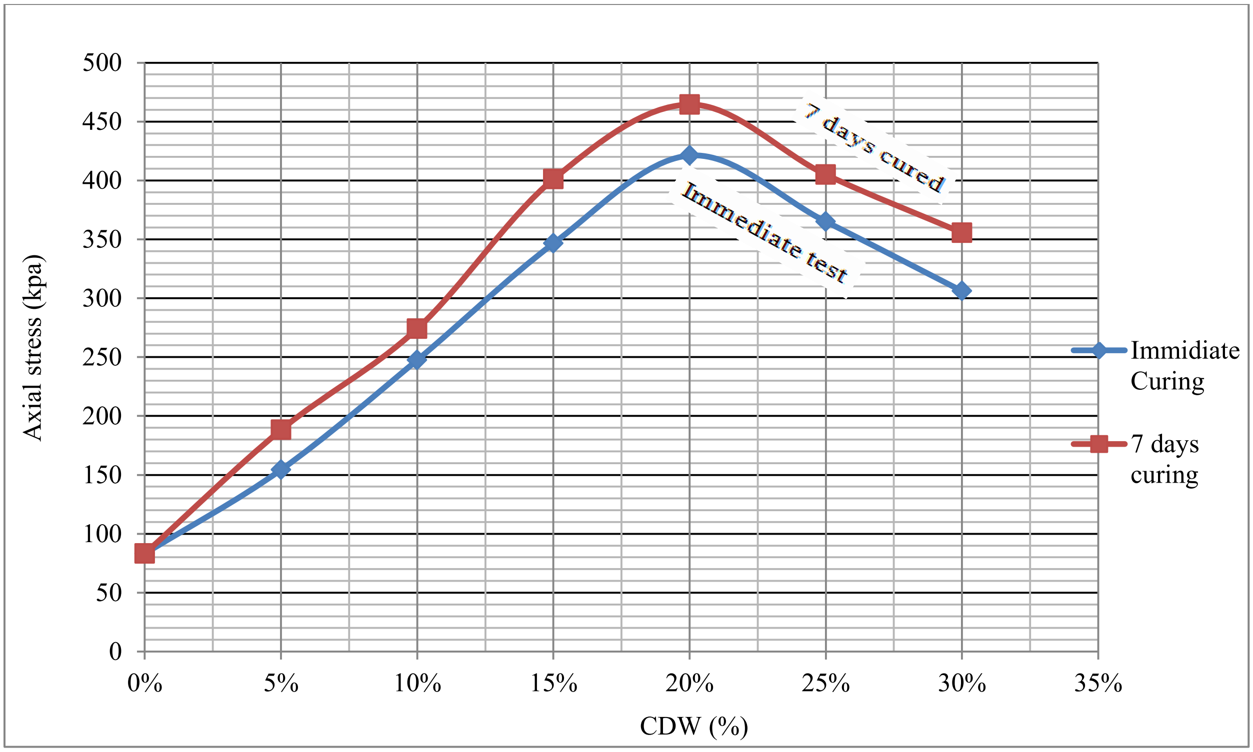


Figure 4.9: Comparison of UCS values of immediate and seven day cured duration for S01 mixed with different ratios of CDW

4.4. Soil stabilized with Ceramic Dust Waste and Plastic Waste Fiber

Clay soil is poor in bearing capacity and shear strength which shows high swelling & shrinkage characteristics due to clay minerals. To utilize soil as subgrade material, soil was blended with CDW and plastic fibers. In the last investigation the level of CDW utilized was 5 to 30% by dry weight of soil and 20% were used as optimum. It was presented that with increase in percentage of CDW the CBR and UCS values were increased, later increments there was a slight decrease in graph at 25 and 30% replacement of CDW. Therefore 20% selected as optimum percentage. Endeavors have been made with 20% CDW and different mix ratios of plastic fibers.

Some of the researchers had confused that by mixing different types of materials or additives by similar time at once or by only changing the mix ratio of materials with different mix ratio and they were confused that; which material is improving better and which one is less improver, which material was got optimum and which one is still increasing. It is a headache to decide that which material is suitable at what ratio of mixture. Studying a lonely for materials is such useful to know that the stabilizing or improving capacity of additive materials for each of them specifically. In another way, it is also good to use only one material if there is a scarcity of one of two materials in the application area and continue with only one material without conducting another study.

From the analysis it was obtained that 20% of CDW shown considerable improvement in properties of clay soil, repressing its utilization for ground changes. CDW treatment in clay soil enhances strength but it may impart brittleness in soil specimen. To additionally build the quality of the weak soil, the soil was reinforced with plastic fiber with varying amount (0.5, 1, 1.5, 2 and 2.5%) and mixed with optimum percentage (20%) of CDW was used and checked for the extra improvement on strength. Adding plastic strip fiber is useful to decrease brittleness and to add ductility of soil.

4.4.1. Effects of Addition of CDW and PWF on Compaction

On Figure 4.10, it was presented that the OMC decreased from 26.90 to 26.10% with the varying percentage of plastic strips on native soil stabilized with optimum amount (%) of CDW. Similarly, the MDD decreased from 1.520 to 1.455 g/cc with the varying percentage of plastic fiber on natural soil stabilized with optimum amount of CDW in a weight of dry soil. The OMC and MDD of soil stabilized with optimum amount of CDW and different mix ratio of PWF were presented in Figure 4.10 and the value of laboratory data analysis were attached in Appendix (C-5).

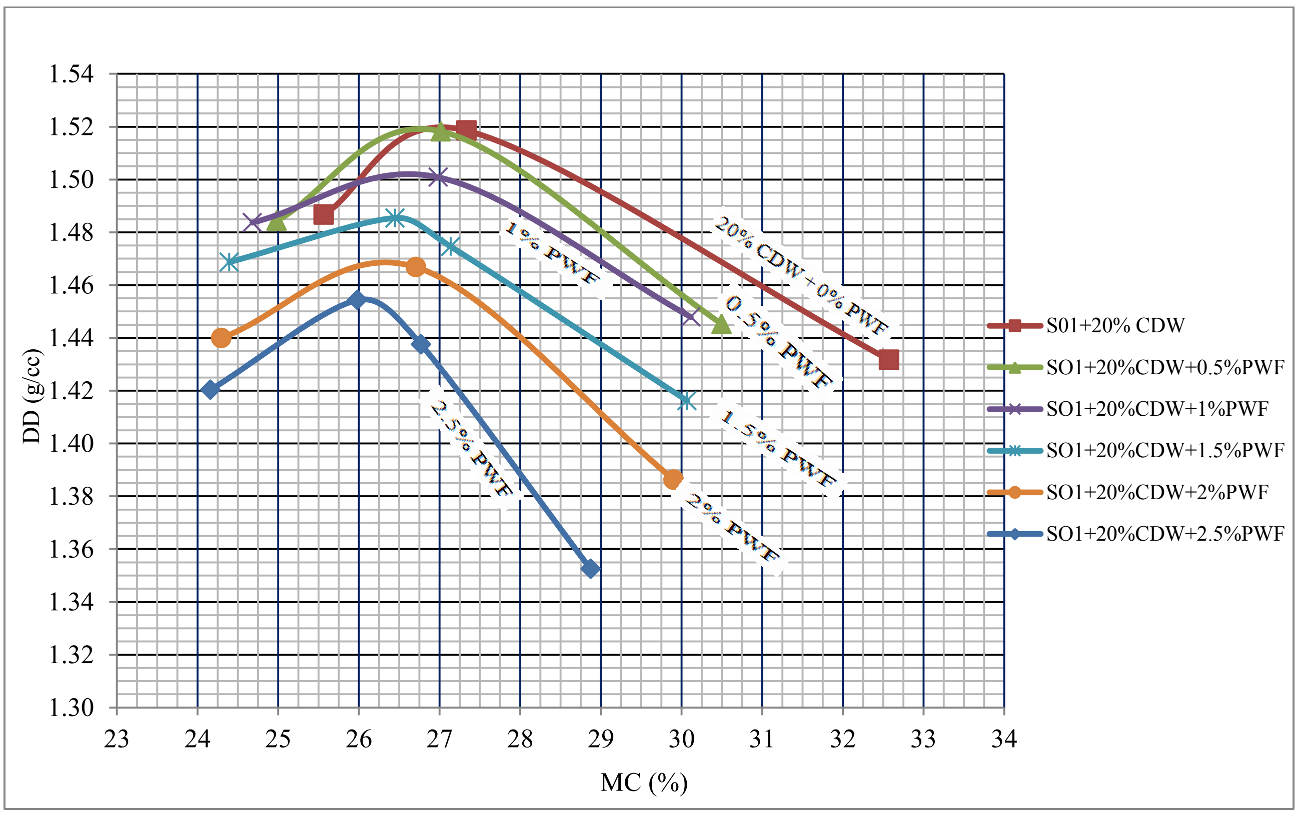


Figure 4.10: Moisture content and dry density of Soil+ 20% CDW + PWF with different mix ratios

A) Effects of Optimum Percentage of CDW and Varying Mix Ratio of PWF on OMC

From Figure 4.11 it was observed that an increased percentage of PWF with optimum percentage of CDW, the OMC of soil was declined. This is because plastic waste fiber is non-water observant.

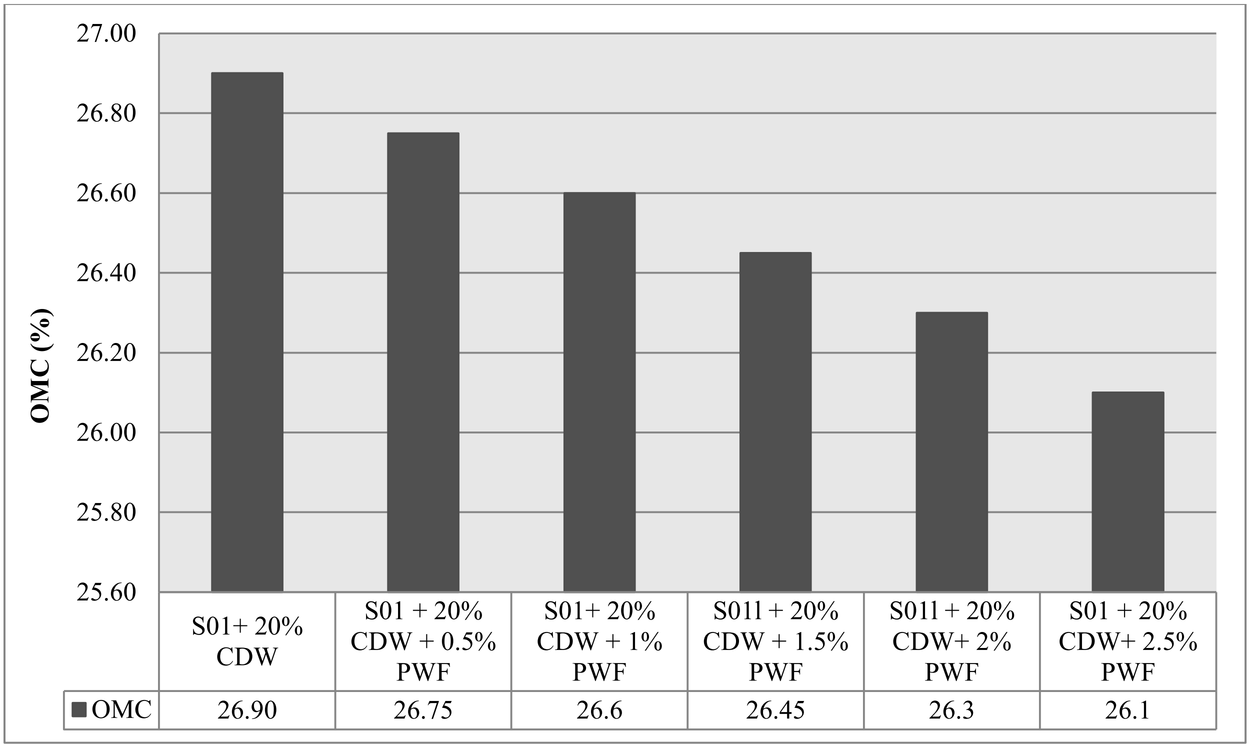


Figure 4.11: Variation of MDD with optimum percentage of CDW and varying amount PWF

B) MDD of Soil Stabilized with CDW and PWF

As shown in the Figure 4.13, the MDD decreased by increasing the content of PWF. This decrement was because the specific gravity or weight of plastic fiber and CDW were less dense than that of soil sample. Where the specific gravity of PWF is 1.28-1.40 [83], CDW was 2.51 and soil was 2.67.

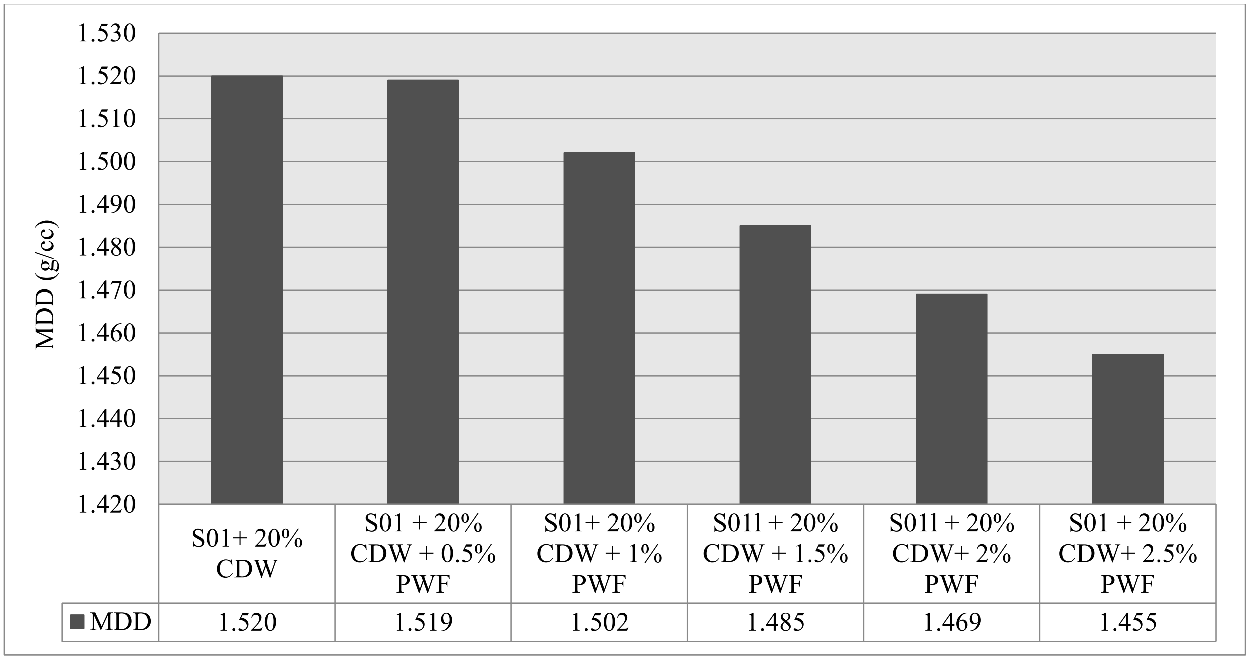


Figure 4.13: MDD of soil stabilized with CDW and PWF

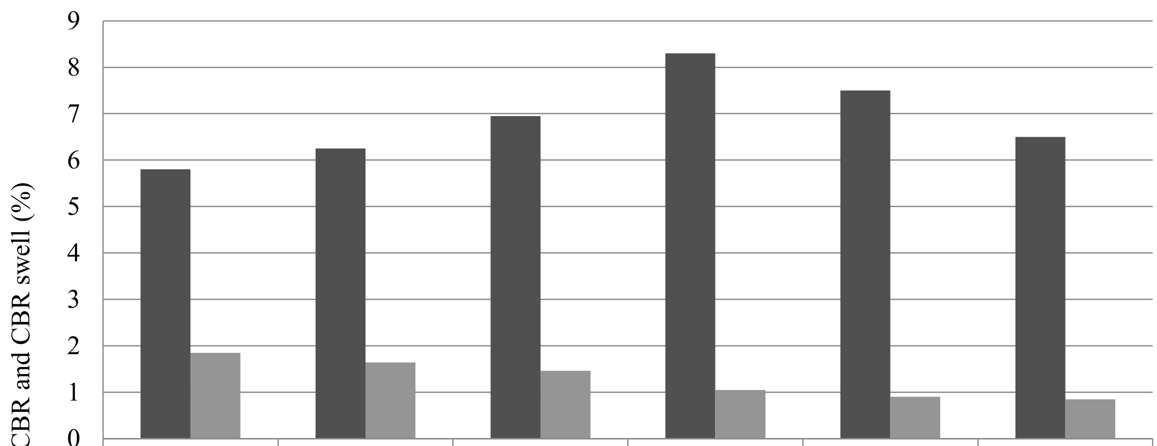
4.4.2 Effects of Addition of CDW and PWF on CBR and CBR Swell

CBR and CBR-swell tests were conducted in accordance with ASTM D-1883 procedure and conducted to determine the CBR value of the soil samples replaced with optimum amount of CDW and varying percentage of PWF in weight of dry soil. Three point CBR and CBR swell tests were conducted for each of the combination and the results of the soaked CBR test for was shown in Table 4.14 and Figure 4.14. Detail of laboratory test result was included in Appendix C-7.

Table 4.14: Effect of optimum percentage of CDW and varying mix ratio of PWF on CBR and CBR swell

Ratios	CBR (%)	Remarks	Subgrade strength classes	Swell (%)
S01 +20% CDW	5.80	optimum for S01+CDW	S3	1.85
S01 +20% CDW+0.5%PWF	6.25	7.76% increment from optimum for S01+CDW and 506.80% from untreated soil	S3	1.64
S01 +20% CDW+1%PWF	6.95	19.82% increment from optimum for S01+CDW and 574.76% from untreated soil	S3	1.46
S01 +20% CDW+1.5%PWF	8.30	43.10% increment from optimum for S01+CDW and 705.82% from untreated soil (optimum for S01+CDW+PWF)	S4	1.05
S01 +20% CDW+2%PWF	7.50	29.31% increment from optimum for S01+CDW and 628.16% from untreated soil	S3	0.90
S01 +20% CDW+2.5%PWF	6.50	12.10% increment from optimum for S01+CDW and 5.31% from untreated soil	S3	0.85

From laboratory outcomes it was summarized that, the CBR values were increased from 5.80% that means the optimum amount of CDW added to soil replacement; to 8.30 which was also the optimum percentage for soil stabilized with CDW and PWF. Adding PWF of 0.5% up to 1.5% there were considerable increments on CBR values and further addition of PWF 2 and 2.5%, the CBR values were decreased. Subgrade strength classes for soil stabilized with CDW (optimum) was S3 and later after stabilized with CDW and PWF it was improved to S4. CBR swell test was also performed for varying combination of soil-CDW (opt) - PWF mixtures and shown a reduction from 1.85 to 0.85%, but it was reduced slightly.



	S01 +20% CDW	S01 +20% CDW+0.5%PWF	S01 +20% CDW+ 1%PWF	S01 +20% CDW+1.5%PWF	S01 +20% CDW+2%PWF	S01 +20% CDW+2.5%PWF
CBR %	5.80	6.25	6.95	8.30	7.50	6.50
Swell %	1.85	1.64	1.46	1.05	0.90	0.85

Figure 4.14: CBR Test and CBR Swell of optimum percentage of Ceramic Dust Waste and varying mix ratio of plastic waste fiber

4.4.3. Effects of Addition of CDW and PWF on UCS

The samples were mixed and compacted at MDD and at OMC and the tests were performed on remolded specimens treated with different concentrations of CDW and PWF contents. The soil sample was mixed with optimum amount of CDW and varying percentage of plastic waste fiber by mass of dry soil. The samples were tested for immediate and seven day cured. Samples were extruded from the compaction mold by Shelby tube or cylindrical soil sampler. For cured samples, the specimen was extruded and sealed with impermeable plastic bag to be cured at room temperature for seven days. Both immediate and seven day cured UCS tests were conducted for samples of soil mixed with optimum (20%) of CDW with varying amount of PWF. The summarized UCS test results were shown in Table 4.15 and detailed UCS laboratory results were attached in Appendix C9 and C11.

A) Remolded Sample of Immediate Test (Soil Stabilized with Optimum Amount of CDW and Different Amount of PWF)

Table 4.15: UCS of CDW and PWF (immediate test)

Ratios	Sample type: Immediate	Avg. UCS (qu) (kpa)	Shear strength (su) (kpa)	Consistency
S01+ 20% CDW	Remolded	421.14	210.57	Hard
S01+ 20% CDW+0.5%	Remolded	510.68	255.34	Hard
S01+ 20% CDW+1%	Remolded	585.01	292.51	Hard
S01+ 20% CDW+1.5%	Remolded	744.61	372.30	Hard
S01+ 20% CDW+2%	Remolded	663.05	331.53	Hard
S01+ 20% CDW+2.5%	Remolded	557.11	278.56	Hard

B) Remolded Sample of Seven Days Cured Test (Soil Stabilized with Optimum Amount of CDW and Different Amount of PWF)

Table 4.16: UCS of CDW and PWF (seven day cured)

Ratios	Sample type: cured for 7 days	Avg. UCS (qu) (kpa)	Shear strength (su) (kpa)	Consistency
S01+ 20% CDW	Remolded	464.45	232.22	Hard
S01+ 20% CDW+0.5%	Remolded	578.85	289.42	Hard
S01+ 20% CDW+1%	Remolded	630.45	315.22	Hard
S01+ 20% CDW+1.5%	Remolded	871.75	435.87	Hard
S01+ 20% CDW+2%	Remolded	782.01	391.00	Hard
S01+ 20% CDW+2.5%	Remolded	628.66	314.33	Hard

The UCS of soil samples with different percentage of fibers were calculated from the loads at failure and shown in Table 4.15, Table 4.16 and Figure 4.15. From Figure and Tables it was presented that the improvement in UCS values for immediate and cured sample specimen that was stabilized with soil-CDW-PWF and without plastic fiber. As it was discussed, the strength of soils from 0-25 kpa is said very soft soil, 25- 50 kpa is called soft soil, 50- 100 kpa is medium stiff or firm soil, 100-200 kpa is stiff soil, 200-400 kpa is very stiff soil and 400-1000 kpa is hard soil. Therefore the consistencies of samples, both immediate and cured for seven days were hard.

The optimum UCS value of soil stabilized with CDW for immediate and cured for seven days were 421.14 kpa and 464.45 kpa respectively. Comparatively, the optimum UCS value of soil stabilized with optimum amount of CDW and varying amount of PWF for both immediate and seven days cured were 744.61kpa and 871.75 kpa respectively. Those were shown improvements that of soil-CDW stabilization compared to soil-CDW-PWF stabilized.

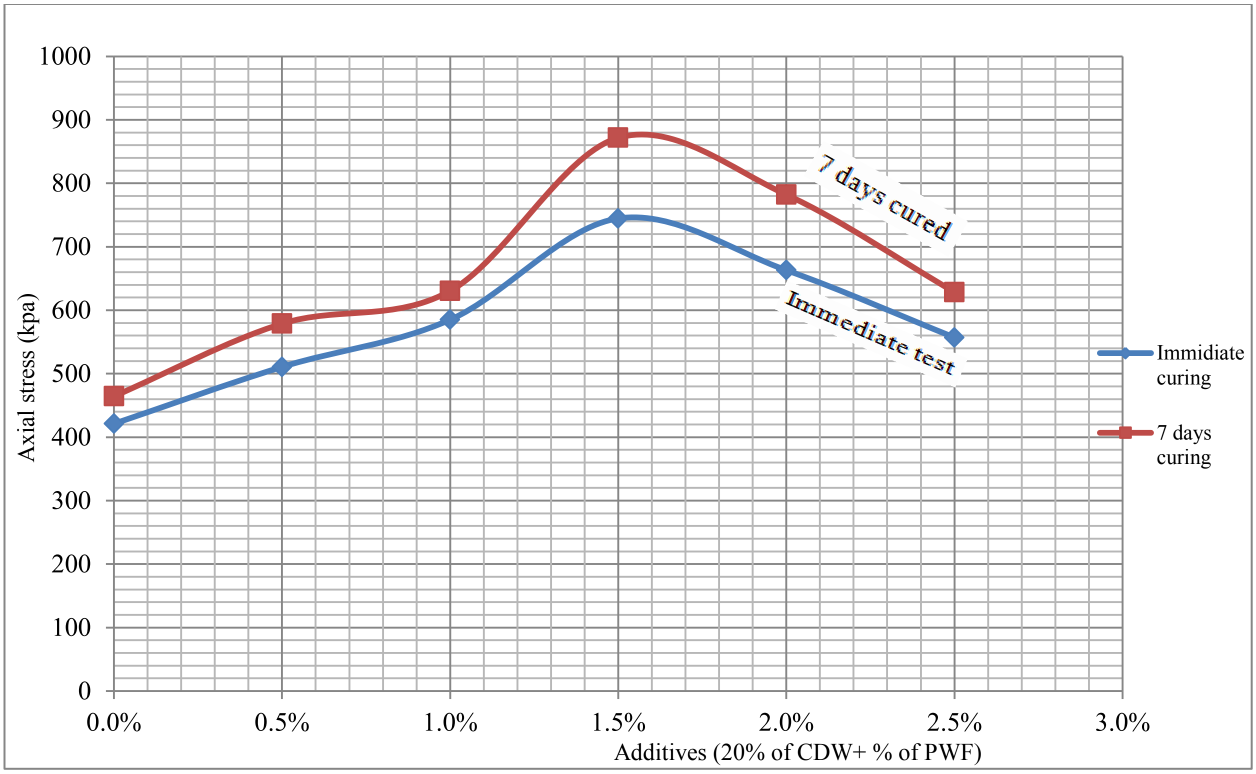


Figure 4.15: Comparison of immediate and cured tests (S01+CDW (opt) +PWF (vary)

4.5. Comparison of the Effects of Stabilization of Expansive Soil with only CDW and with soil-CDW- PWF Reinforced on Soil Strength

Table 4.17: Comparison of the effects of stabilization of expansive soil with only CDW and with soil-CDW – PWF reinforced on soil strength

R. No	Comparison Items		Optimum Values of Soil-CDW stabilized	Optimum Values of Soil-CDW-PWF stabilized	% of improvement or reduction
1	CBR and CBR swell	CBR values	5.80% (463.10% increased from natural soil)	8.30% (705.82% increased from natural soil)	43.10% increment from optimum for S01+CDW to S01+CDW-PWF
		CBR Swell	1.85% (at optimum)	1.05% (at optimum)	76.19% reduction
2	UCS	Immediate test	421.14 kpa	744.60 kpa	On UCS = 323.46 kpa enhancement
		Cured for seven days test	464.45 kpa	871.75 kpa	On UCS = 407.30 kpa enhancement
3	Shear strength	Immediate test	210.57 kpa	372.30 kpa	On cohesion= 161.73 kpa enhancement
		Cured for seven days test	232.23 kpa	435.87 kpa	On cohesion= 203.64 kpa enhancement

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study was conducted on stabilization of the weak subgrade soil in Jimma town with locally available ceramic dusts waste and plastic waste fiber with the support of series of laboratory investigations in specific arrived at the following conclusions.

The test results shown that the subgrade soils considered for this study was A-7-5 (54) for soil sample one and A-7-5(49) for sample two as per AASHTO soil classification system and CH as USCS for both of the samples. Particle size determination test represented as 6.59% (0.77% gravel and 5.82% sandy: USCS) of soil sample one was coarse grained soil and 93.41% (28.28% silty and 65.13% clay) was fine grained soil. Similarly, 9.82% (1.27% gravel and 8.55% sandy soil: USCS) of soil sample two was coarse grained and 90.18% (30.72% silty and 59.46% clay) was fine grained soil.

Consistency characteristic test indicted that; the natural moisture content was 44.01% (clay or soft clay), liquid limit 83.65% (very high), plastic index 47.53% (very high), free swell index 90% (very high), linear shrinkage 22.50% (critical) and specific gravity was 2.69 for soil sample one. For soil sample two; the natural moisture content was 39.47% (clay or soft clay), liquid limit 80.21% (very high), plastic index 45.86% (very high), free swell index 85% (very high), linear shrinkage 19.50% (critical) and specific gravity was 2.70. The moisture -density test indicates that the MDD and OMC of soil sample one was 1.622 g/cc and 22.50% respectively and also MDD was 1.625 g/cc and OMC 22.00% for sample two.

Strength test conducted for both of soil samples shown that, CBR and CBR swell of sample one was 1.03% and 8.34% respectively and 1.56% and 7.40% for sample two. Unconfined compression strength test indicated that; stress for undisturbed soil sample one was 74.85 kpa, for disturbed soil was 83.15 kpa and sensitivity was 0.900. Shear strength of soil sample one for undisturbed soil was 37.43 kpa and 41.58 kpa for disturbed soil. For soil sample two; the stress value was 82.53 Kpa, for disturbed soil was 97.91 kpa and sensitivity was 0.843. Shear strength of soil sample two for undisturbed soil was 41.27 kpa and 48.96 kpa for disturbed soil. From the laboratory results the soil consistency was founded as firm soil and they are failed to accept as subgrade soil for pavement construction.

From both of samples weaker soil was selected based on laboratory test results and specified for stabilization. From those samples, sample one was weaker soil and stabilization with ceramic dust waste and plastic waste fiber was done with soil sample one.

A series of tests were performed to study the effects of randomly distributed plastic waste fiber reinforcement on the strength of stabilized soil with ceramic dust waste. First, the effect of addition of ceramic dust waste with clay soil was evaluated and next the effect of addition of optimum amount of ceramic dust waste with different ratio of plastic waste fiber was determined. The following conclusions were drawn on the basis of the result obtained and discussions made in this study.

The liquid limit has reduced from 83.55% to 52.09%; plastic index value reduced from 47.53% to 7.43% with addition of 30% ceramic dust waste to the expansive soil. The free swell index for clay soil was obtained as 90% which has high degree of expansion and its value was decreased to 15% has low degree of expansion for soil blended with 30% of ceramic dust waste. The Percentage of reduction was reported as 75%. Linear shrinkage value was reduced from 22.50% (having Degree of expansion) to 2.12% (non-critical) with the addition of 30% of ceramic dust waste to expansive soil which was shown 26.82% reduction from native soil.

Specific Gravity of ceramic dust waste was reported as 2.51. The maximum dry density values decreased from 1.622 g/cc to 1.481 g/cc and optimum moisture contents increased from 22.5% to 29.40% for a soil blended with 30% ceramic dust waste. A significant positive change has been noticed on the strength of the expansive soil after adding ceramic dust waste and plastic waste fiber on native soil. CBR value for expansive soil was 1.03%. After adding ceramic dust waste to soil, the CBR values increased from 1.82 to 5.80% for 5 to 20% ceramic dust waste. But from 25 and 30% ceramic dust waste content added to the expansive soil the CBR values got decreased to 5.05 and 4.25% respectively. CBR swell also decreased from 8.74% (native soil) to 1.85% (optimum value of soil-CDW stabilized). Unconfined compressive strength of native soil was 83.15 kpa and after stabilization it was increased to 421.14 kpa for uncured and 464.45 kpa for cured sample in addition of 20% of ceramic dust waste. For next mixtures 25 and 30% of CDW, the values of UCS shown failing.

From the analysis it was obtained that 20% of ceramic dust waste given considerable improvement in properties of clay soil and then for next additions it seems the same or getting failed. So 20% selected as optimum percentage.

Laboratory tests revealed that the ideal level of ceramic dust waste as 20%. Clayey soil with 20% ceramic dust waste indicates just minor enhancement in the strength of soil, repressing its utilization for subgrade acceptability. To further build the strength of the soil plastic fiber mix added with optimum level of 20% of ceramic dust. It is reported that strength properties of optimum combination of soil-ceramic dust waste specimens fortified with plastic fibers was better than soil- ceramic dust waste alone to treat expansive soil. Ceramic dust waste treatment in expansive soil enhances strength but to improve more, minimize brittleness and increase ductility, expansive soil treated with 20% (optimum) of ceramic dust waste and reinforced with plastic fiber. An optimum fiber content of 1.5% (by weight of dry soil) was recommended for strengthening expansive soil.

The CBR value increased from 5.80% (optimum value of soil-CDW stabilized) to 8.30% (optimum value of soil-CDW-PWF mixture) with the addition of 1.5% PWF on soil-CDW (optimum) mixtures. But for further addition of 2.0 and 2.5% PWF the negative effects (7.50 and 6.50% respectively) on CBR value was presented. The CBR swell was decreased from 1.85% (optimum value of soil-CDW stabilized) to 1.05% (optimum value of soil-CDW- PWF stabilized).

The unconfined compressive strength (UCS) of the soil- ceramic dust wastes (optimum) and reinforced with waste plastic fibers used for the improvement of the engineering properties of the soil. PWF was used from 0.5 to 2.5% with optimum percentage of ceramic dust waste. UCS of soil stabilized with optimum percentage of CDW and varying percentage of PWF; until 1.5% PWF by weight of dry soil shown positive effects which increased from 421.14 kpa (optimum value of soil-CDW stabilized) to 744.61 kpa (optimum value of soil-CDW- PWF stabilized) for immediate test and 464.45 Kpa (optimum value of soil-CDW stabilized) to 871.75 Kpa (optimum value of soil-CDW- PWF stabilized) for seven days cured test and 1.5% of PWF stabilization was considered as an optimum percentage.

Generally; in the light of above observations it was concluded that ceramic dust waste along with plastic waste fiber used in combination with clay soil can be used as expansive or clay soil stabilizer. Expansive soil treated with 20% of ceramic dust and reinforced with 1.5% of plastic fiber by weight of dry soil is recommended for strengthening weak subgrade soil. The use of waste ceramics or plastics will also results in increasing the solution against the disposal of wastes and Environmental aesthetics.

5.2. Recommendations

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

- ✓ Ceramic dust waste and plastic waste fiber combinations have significant potential to be used in place of conventional material for various road constructions as weak subgrade stabilizer and should be projected for future construction.
- ✓ It is highly recommended to use ceramic dust waste and plastic waste fiber as soil stabilizer at the indicated percentages for the effective construction and cost minimization of the highway or any road construction project whom facing weak subgrade at the time of construction.
- ✓ Further studies should be carried out in order to identify the long term effects that Ceramic dust waste and plastic waste fibers have on the durability of the road pavement structures.
- ✓ Ceramic dust waste investigated in this research work can be used as a stabilizer of expansive sub grade soil in combination with plastic waste fibers. Therefore, concerned bodies like Ethiopian Road Authority, Highway Engineers, higher education sectors, government entities and other stakeholders should be made aware about this potential soil stabilizing materials and promote its standardized production and usage.
- ✓ The ceramic and plastic factories in collaboration with higher education should work together to do more research for further study of ceramic dust waste and plastic waste fibers as a soil stabilizing material and to preserve the environmental impact and suitable waste treatment.
- ✓ Powdered ceramic west directly from factories were sieved in 75 µm sieve to used but for demolished ceramic wastes collected from different building construction sites, grinding machine complex must be set up as; well as plastic cutting machine also needed.
- ✓ This study was conducted by taking limited parameter such as natural moisture contents, atterberg limits, free swell index, linear shrinkage, moisture density relation, CBR and CBR swell potential and UCS tests on expansive soil sample using ceramic dust waste and plastic waste fiber. Additional test parameters like PH value test, volumetric shrinkage and mineralogical tests should also be performed to have more accurate test results.
- ✓ This study was done for specific area, specific number of sample pits and specific stabilizers; it is recommended as more investigation shall be performed on different parts of the country by mixing with other various waste materials as soil stabilizers from more soil sampling pits.
- ✓ Curing time for this study was conducted for seven days on UCS test. Additional curing time should be performed to check the effects on the strength.

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APPENDIX

Appendix A: Laboratory Test Results of Natural Soil Samples

Appendix A-1: Natural Moisture (Water) Content According to ASTM D-2216

NATURAL MOISTURE CONTENT DETERMINATION						
ASTM D 2216 - Standard Test Method for Laboratory Determination of						
Water (Moisture) Content of natural Soil						
samples	Sample 01			Sample 02		
can code	G3	B3	T3	C8	B22	A29
Wt. of Container +lid (g)	54.19	45.65	55.27	69.04	57.37	54.73
Wt. of container + wet soil (g)	168.29	154.62	162.88	192.24	173.21	170.51
Wt. of container + dry soil (g)	133.32	122.35	129.05	157.20	139.41	138.96
Wt. of water (g)	34.97	32.27	33.83	35.04	33.80	31.55
Wt. of dry soil (g)	79.13	76.70	73.78	88.16	82.04	84.23
Moisture container (%)	44.19	42.07	45.85	39.75	41.20	37.46
Average	44.04			39.47		

Appendix A-2: Particle Size Analysis (According to ASTM D-422)

A) Soil sample 01: wet sieve and hydrometer analysis

Particle size (mm)	Mass of retain on each sieve (g)	%ge of mass of retained Soil	%age of cumulative mass retained soil	%age of passing
9.50	0	0	0	100.00
4.75 (#4)	7.724	0.7724	0.7724	99.23
2.00 (#10)	18.525	1.8525	2.6249	97.38
0.85(#20)	11.361	1.1361	3.761	96.24
0.425(#40)	10.011	1.0011	4.7621	95.24
0.30(#50)	5.088	0.5088	5.2709	94.73
0.15 (#100)	7.991	0.7991	6.07	93.93
0.075(#200)	5.203	0.5203	6.5903	93.41
pan	934.097	93.4097	100	0.00

% of course grained soil	6.59			% of fine grained soil	93.41
	AASHTO	*USCS*			
Gravel (%)	*2.62*	0.77		*Silt (%)*	*28.28*
Sandy soil (%)	*3.97*	5.82		*Clay (%)*	*65.13*

Dispersing agent	Sodium Hexametaphosphate	weight of soil sample used (g)	50.00
Date (test started)	12-Feb-21	zero correction (+)	6.00
Date (test Ended)	13-Feb-21	meniscus correction (+)	1.00
Type of Hydrometer used	152H	F#200	93.41
Specific gravity of soil	2.67 g/cc		

Date of taste	Time	Elapsed Time (min)	Temperature 0c	Act Hydro Rdng	Hyd. Corr for Meniscus	Eff. hydro depth (L)	K	Equivalent particle diameter **(D)**	Temp.Correction Factors: **(CT)**	Correction Factors **(a)** for Unit Weight of Solids	corrected hydrometer reading (Rc)	percentage of Finer (P)	percentage of Adjusted Finer (PA)
12/2/2021	2:40	1'	23	52	53	7.8	0.01309	0.036558	0.70	0.996	46.70	93.0264	86.90
12/2/2021	2:41	2'	23	51	52	7.9	0.01309	0.0260158	0.70	0.996	45.70	91.0344	85.04
12/2/2021	2:45	5'	23	50	51	8.1	0.01309	0.016666	0.70	0.996	44.70	89.0424	83.17
12/2/2021	2:50	10'	23	49	50	8.3	0.01309	0.01192557	0.70	0.996	43.70	87.0504	81.31
12/2/2021	2:55	15'	23	48	49	8.4	0.01309	0.00979566	0.70	0.996	42.70	85.0584	79.45
12/2/2021	3:10	30'	23	47	48	8.6	0.01309	0.00700855	0.70	0.996	41.70	83.0664	77.59
12/2/2021	3:40	60'	23	45	46	8.9	0.01309	0.0050415	0.70	0.996	39.70	79.0824	73.87
12/2/2021	4:40	120'	24	44	45	9.1	0.012934	0.0035617	1.00	0.996	39.00	77.6880	72.57
12/2/2021	6:40	240'	25	42	43	9.4	0.012594	0.0024924	1.30	0.996	37.30	74.3016	69.41
12/2/2021	10:40	480'	24	40	41	9.7	0.012934	0.0018386	1.00	0.996	35.00	69.7200	65.13
13/2/2021	2:40	1440'	23	38	39	9.9	0.01309	0.00108536	0.70	0.996	32.70	65.1384	60.85

B) Soil sample 02: wet sieve and hydrometer analysis

Sieve size (mm)	Mass of retain on each sieve (g)	%ge ofmass of retained soil	%age of cumulative mass retained soil	%age of passing
9.50	0	0	0	100
4.75 (#4)	12.711	1.2711	1.2711	98.7289
2.00 (#10)	29.27	2.927	4.1981	95.8019
0.85(#20)	18.734	1.8734	6.0715	93.9285
0.425(#40)	14.927	1.4927	7.5642	92.4358
0.30(#50)	7.236	0.7236	8.2878	91.7122
0.15 (#100)	9.194	0.9194	9.2072	90.7928
0.075(#200)	6.128	0.6128	9.82	90.18
pan	901.8	90.18	100	0

% of course grained soil	9.82		% of fine grained	90.18
	AASHTO	USCS		
Gravel (%)	*4.20*	1.27	*Silt (%)*	*30.72*
Sandy soil (%)	*5.62*	8.55	*Clay (%)*	*59.46*

Dispersing agent	Sodium Hexametaphosphate	weight of soil sample used (g)	50.00
Date (test started)	10-Feb-21	zero correction (+)	6.00
Date (test Ended)	11-Feb-21	meniscus correction (+)	1.00
Type of Hydrometer used	152H	F#200	90.18
Specific gravity of soil	2.70 g/cc		

Date of taste	Time	Elapsed Time (min)	Temperature 0c	Act Hydro Rdng	Hyd. Corr for Meniscus	Eff. Hydro Depth (L)	K	Equivalent Particle Diameter **(D)**	Temp. Correction Factors: **(CT)**	Correction Factors **(a)** for Unit Weight of Solids	Corrected Hydrometer Reading (Rc)	Percentage of Finer (P)	Percentage of Adjusted Finer (PA)
10/2/2021	3:25	1'	24	50	51	7.9	0.01301	0.036567	1.00	0.99	45.00	89.1000	80.35
10/2/2021	3:26	2'	24	49	50	8.1	0.01301	0.026182	1.00	0.99	44.00	87.1200	78.56
10/2/2021	3:30	5'	24	48	49	8.3	0.01301	0.016762	1.00	0.99	43.00	85.1400	76.78
10/2/2021	3:35	10'	24	47	48	8.4	0.01301	0.011923	1.00	0.99	42.00	83.1600	74.99
10/2/2021	3:40	15'	24	46	47	8.6	0.01301	0.009851	1.00	0.99	41.00	81.1800	73.21
10/2/2021	3:55	30'	24	45	46	8.8	0.01301	0.0070462	1.00	0.99	40.00	79.2000	71.42
10/2/2021	4:25	60'	24	43	44	9.1	0.01301	0.0050666	1.00	0.99	38.00	75.2400	67.85
10/2/2021	5:25	120'	25	41	42	9.4	0.01286	0.00359926	1.30	0.99	36.30	71.8740	64.82
10/2/2021	7:25	240'	25	40	41	9.6	0.01286	0.0025720	1.30	0.99	35.30	69.8940	63.03
10/2/2021	11:25	480'	25	38	39	9.9	0.01286	0.0018468	1.30	0.99	33.30	65.9340	59.46
11/2/2021	3:25	1440'	23	36	37	10.2	0.01317	0.0010420	0.70	0.99	30.70	60.7860	54.82

C) Combined result of wet sieve analysis and hydrometer analysis

Sample 01			Sample 02	
Particle size (mm)	Percent finer (%)		Particle size (mm)	Percent finer (%)
9.50	100		9.50	100
4.75 (#4)	99.23		4.75 (#4)	98.7289
2.00 (#10)	97.38		2.00 (#10)	95.8019
0.85(#20)	96.24		0.85(#20)	93.9285
0.425(#40)	95.24		0.425(#40)	92.4358
0.30(#50)	94.73		0.30(#50)	91.7122
0.15 (#100)	93.93		0.15 (#100)	90.7928
0.075(#200)	93.41		0.075(#200)	90.18
0.036558	86.90		0.0365670	80.35
0.0260158	85.04		0.0261820	78.56
0.016666	83.17		0.0167620	76.78
0.01192557	81.31		0.0119230	74.99
0.00979566	79.45		0.0098510	73.21
0.00700855	77.59		0.0070462	71.42
0.0050415	73.87		0.0050666	67.85
0.0035617	72.57		0.0035993	64.82
0.0024924	69.41		0.0025720	63.03
0.0018386	65.13		0.0018468	59.46
0.00108536	60.85		0.0010420	54.82

Appendix A-3: Specific Gravity Test Analysis (According to ASTM D-854)

Specific gravity test data for natural soil (01)

Determination Code	3	11	5
Mass of dry, clean Calibrated pycnometer, Mp, in g	31.37	27.025	31.288
Mass of oven dry sample(gm)	25	25	25
Mass of Pycnometer + water(gm)	125.763	133.22	128.061
Mass of Pycnometer + water + sample(gm)	141.359	148.861	143.721
Mass of Pycnometer + sample(gm)	56.37	52.025	56.288
Observed temperature of water,Ti	21	22	22

Water Temperature(^{O}C)

^{o}C	18	19	20	21	22	23	24	25	26	27	28
k	1.0016	1.0014	1.0012	1.0009	1.0007	1.00 05	1.0003	1.000	0.99 97	0.998 3	0.998

Temperature of contents of pycnometer when Mpsw was taken, Tx, in oc		23	23	22
K for Tx		1.0005	1.0005	1.0007
Specific gravity at 20oc, Gs	Gs=A*k/(A+B-C)	2.66	2.67	2.68
Average Specific gravity at 20oc, Gs		2.67		

Specific gravity test data of soil sample 02

Determination Code	2	7	12
Mass of dry, clean Calibrated pycnometer, Mp, in g	29.452	30.571	31.67
Mass of oven dry sample(gm) (A)	25	25	25
Mass of Pycnometer + water(gm) B	121.642	125.483	130.213
Mass of Pycnometer + water + sample(gm) C	137.348	141.263	145.934
Mass of Pycnometer + sample(gm) D	54.452	55.571	56.67
Observed temperature of water,Ti	23	23	23

Water Temperature(^{O}C)

^{o}C	18	19	20	21	22	23	24	25	26	27	28
k	1.0016	1.0014	1.0012	1.0009	1.0007	1.000 5	1.0003	1.000	0.999 7	0.998 3	0.998

Temperature of contents of pycnometer when Mpsw was taken, Tx, in oc		22	23	22
K for Tx		1.0007	1.0005	1.0007
Specific gravity at 20oc, Gs	Gs=A*k/(A+B-C)	2.69	2.71	2.69
Average Specific gravity at 20oc, Gs		2.700		

Specific gravity test data of CDW									
Determination Code					11		5		3
Mass of dry, clean Calibrated pycnometer, Mp, in g					27.025		31.288		31.37
Mass of oven dry sample(gm) A					25		25		25
Mass of Pycnometer + water(gm) B					133.002		128.034		125.77
Mass of Pycnometer + water + sample(gm) C					148.051		143.112		140.802
Mass of Pycnometer + sample(gm) D					52.025		56.288		56.37
Observed temperature of water,Ti					23		23		24
Water Temperature (OC)									
^oC	18	19	20	21	22	23	24	25	26
k	1.0016	1.0014	1.0012	1.0009	1.007	1.0005	1.0003	1.000	0.9997
Temperature of contents of pycnometer when Mpsw was taken, Tx, in oc					23		24	23	
K for Tx					1.0005		1.0003	1.0005	
Specific gravity at 20oc, Gs			Gs=A*k/(A+B-C)		2.51357		2.52041	2.50928	
Average Specific gravity at 20oc, Gs					2.51				

Appendix A-4: Free Swell Index of Natural Soil

Samples	Initial reading	Final reading	% free swelling
sample 01	10	19.00	90.00
sample 02	10	18.50	85.00

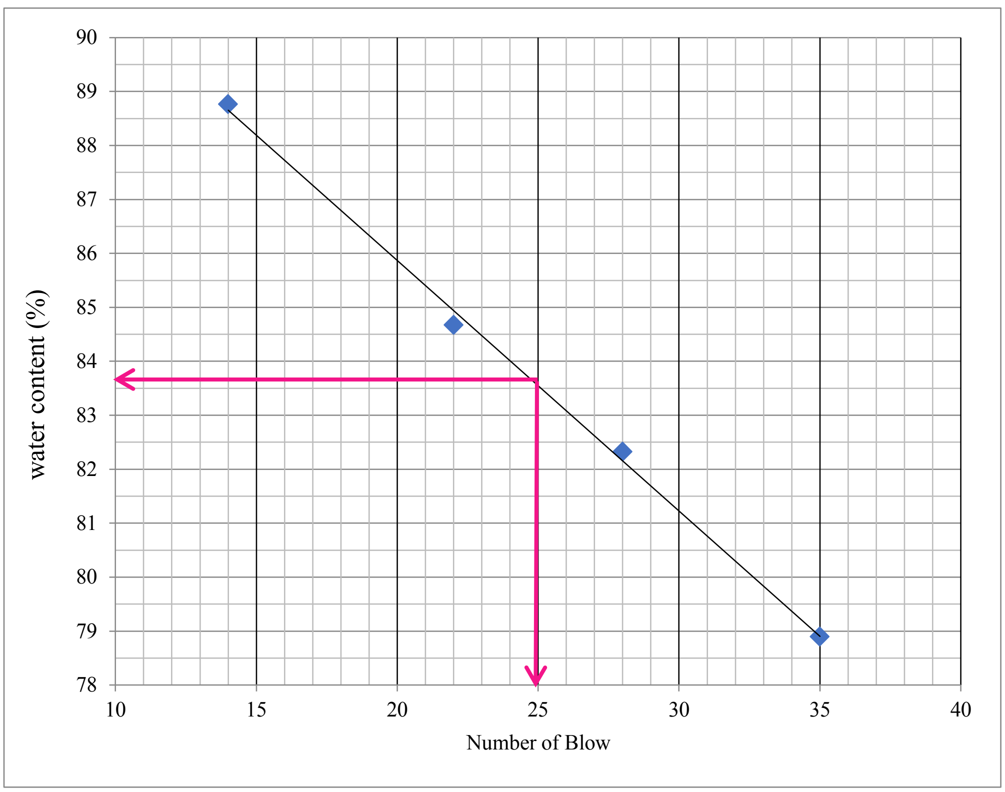
Appendix A-5: Linear Shrinkage Index of Natural Soil

Sample pits	length of mold (cm)	length of dry specimen (cm)	liner shrinkage %
sample 01	140	108.50	29.03
sample 02	140	112.70	24.22

Appendix A-6: Atterberg Limits Data Analysis of Natural Soil (According to ASTM D-4318)

Natural soil sample 01

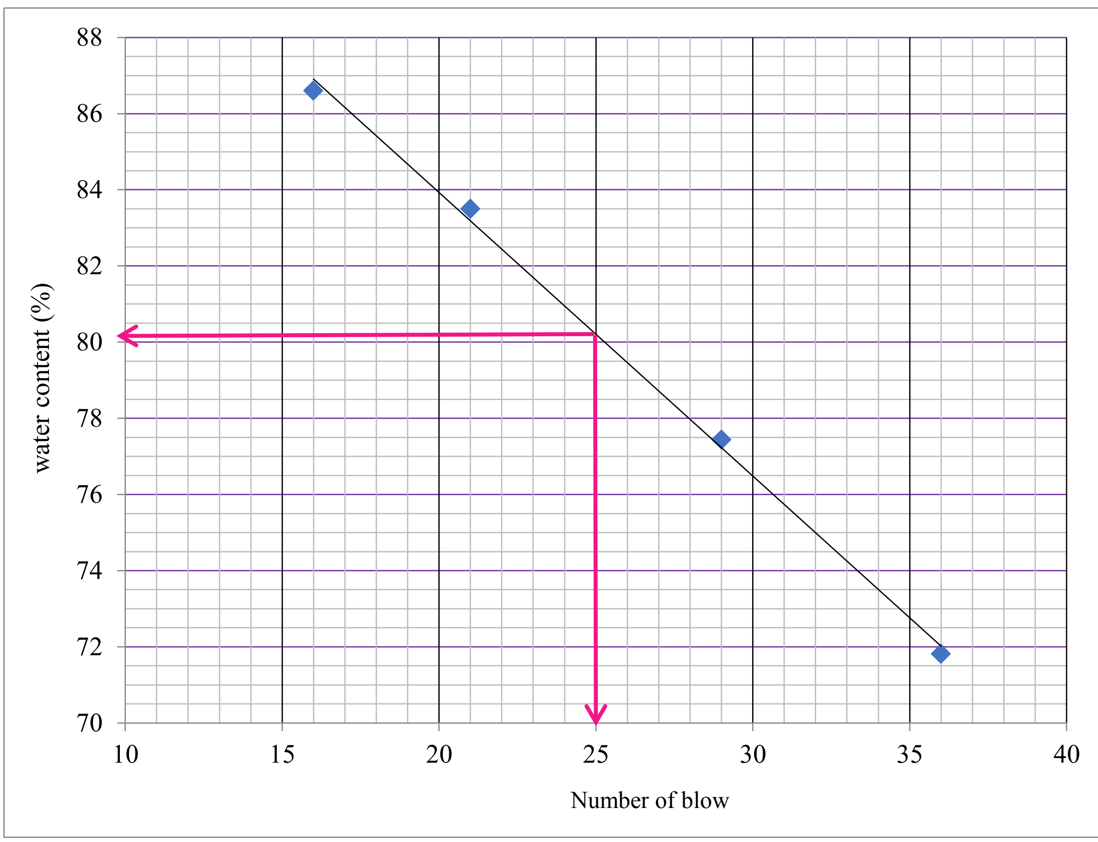
DETERMINATION OF LIQUID LIMIT & PLASTIC LIMIT OF SOIL						
TEST METHOD : ASTM D 4318						
Liquid limit and plastic limit test : natural soil (Sample 01)						
Determinations	Liquid Limit				Plastic Limit	
Number of blows	35	28	22	14		
Test No	1	2	3	4	1	2
Container Code	1B	T2D	3E	T3	NC41	B11
Wt. of container + wet soil (g)	40.28	41.94	38.93	42.30	24.32	25.08
Wt. of container + dry soil (g)	30.41	30.95	29.65	30.45	22.51	22.93
Wt. of container (g)	17.90	17.60	18.69	17.10	17.45	17.00
Wt. of water (g)	9.87	10.99	9.28	11.85	1.81	2.15
Wt. of dry soil (g)	12.51	13.35	10.96	13.35	5.06	5.93
Moisture content (%)	78.90	82.32	84.67	88.76	35.77	36.26
LL	83.55				Average	36.01



LL	**83.55**
PL	**36.01**
PI = LL-PL	**47.53**

Natural soil sample 02

DETERMINATION OF LIQUID LIMIT & PLASTIC LIMIT OF SOIL						
TEST METHOD : ASTM D-4318						
Liquid limit and plastic limit test : natural soil (Sample 02)						
Determinations	Liquid Limit				Plastic Limit	
Number of blows	36	29	21	16		
Test No	1	2	3	4	1	2
Container Code	B8	TO	NO	C14	113C	B3
Wt. of container + wet soil (g)	68.34	39.29	56.41	42.21	15.80	13.38
Wt. of container + dry soil (g)	61.31	29.99	47.91	32.00	13.42	11.39
Wt. of container (g)	51.52	17.98	37.73	20.21	6.50	5.59
Wt. of water (g)	7.03	9.30	8.50	10.21	2.38	1.99
Wt. of dry soil (g)	9.79	12.01	10.18	11.79	6.92	5.80
Moisture content (%)	71.81	77.44	83.50	86.60	34.39	34.31
LL	80.21				PI :Average	34.35

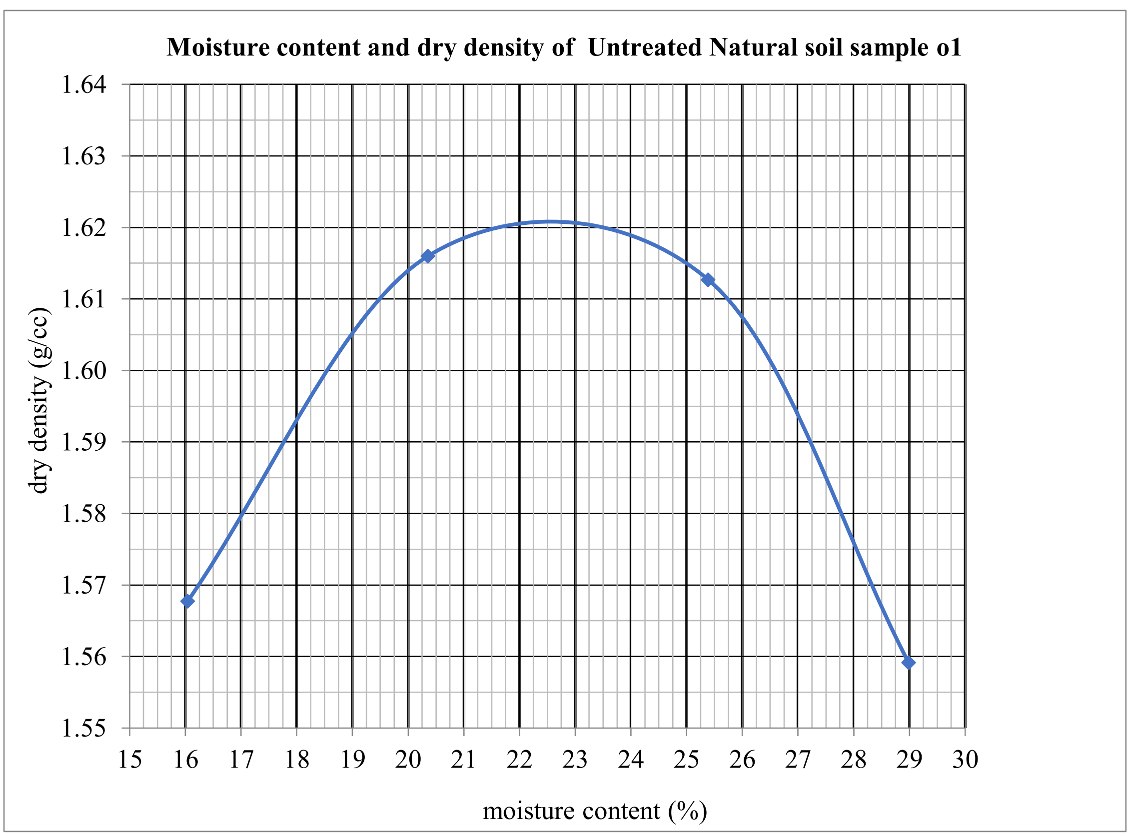


LL	**80.21**
PL	**34.35**
PI	**45.86**

Appendix A-7: Compaction Test Data Analysis of Natural Soil (According to ASTM D-1557)

Untreated Natural Soil (Sample 01)	
Mass of sample (g)	5000
Mass of Mold (g)	6527
Volume of Mold (cm^3)	2124

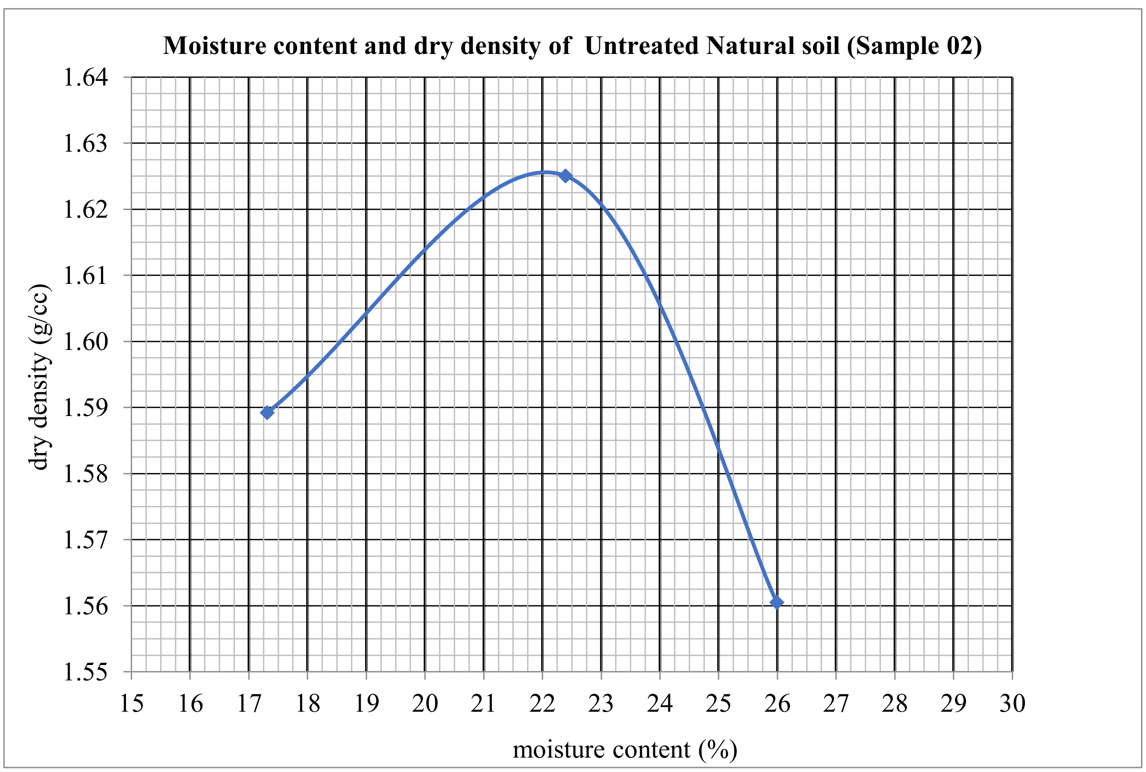
Test No.	1		2		3		4	
Mass of Mold + Wet soil (g) (A)	10391		10658		10822		10798.5	
Mass of Wet Soil (g) A-B=C	3864		4131		4295		4271.5	
Bulk Density g/cm^3 C/D=(E)	1.82		1.94		2.02		2.01	
moisture determination								
Container code	C14	H	T	4A	C8	A2	B12	3T2
Mass of wet soil + container(g) (F)	73.30	109.12	102.30	95.6	71.8	67	85.4	86.6
Mass of dry soil + container (g) (G)	66.28	96.14	87.70	82.6	58.0	55.0	70.5	71.10
Mass of container (g) (H)	20.50	18.64	17.20	17.6	5.80	5.70	19.5	17.20
Mass of moisture (g) F-G=(I)	7.02	12.98	14.60	13.0	13.80	12.00	14.9	15.50
Mass of dry soil (g) G-H=(J)	45.78	77.5	70.50	65.00	52.2	49.3	51.00	53.90
Moisture content (%) (I/J)*100=K	15.33	16.75	20.71	20.00	26.44	24.34	29.22	28.76
Avg. moisture content % (L)	16.04		20.35		25.39		28.99	
Dry density g/cm^3 E/(100+L)*100	1.57		1.62		1.61		1.56	



OMC	**22.5**
MDD	**1.622**

Untreated Natural Soil (Sample 02)	
Mass of sample (g)	5000
Mass of Mold (g)	6755
Volume of Mold (cm^3)	2124

Test No.	1		2		3	
Mass of Mold + Wet soil (g) (A)	10715		10979.5		10931	
Mass of Wet Soil (g) A-B=C	3960		4224.5		4176	
Bulk Density g/cm^3 C/D=(E)	1.86		1.99		1.97	
moisture determination						
Container code	A12	G7	N53	S2	5HD	G10
Mass of wet soil + container(g) (F)	183.34	117.12	117.15	100.11	95.03	106.38
Mass of dry soil + container (g) (G)	163.17	102.74	99.13	84.63	79.1	88.0
Mass of container (g) (H)	49.73	17.40	18.05	16.01	18.25	17.20
Mass of moisture (g) F-G=(I)	20.17	14.38	18.02	15.5	15.89	18.34
Mass of dry soil (g) G-H=(J)	113.44	85.34	81.08	68.62	60.89	70.84
Moisture content (%) (I/J)*100=K	17.78	16.85	22.22	22.56	26.10	25.89
Avg. moisture content % (L)	17.32		22.39		25.99	
Dry density g/cm^3 E/(100+L)*100	1.59		1.63		1.56	



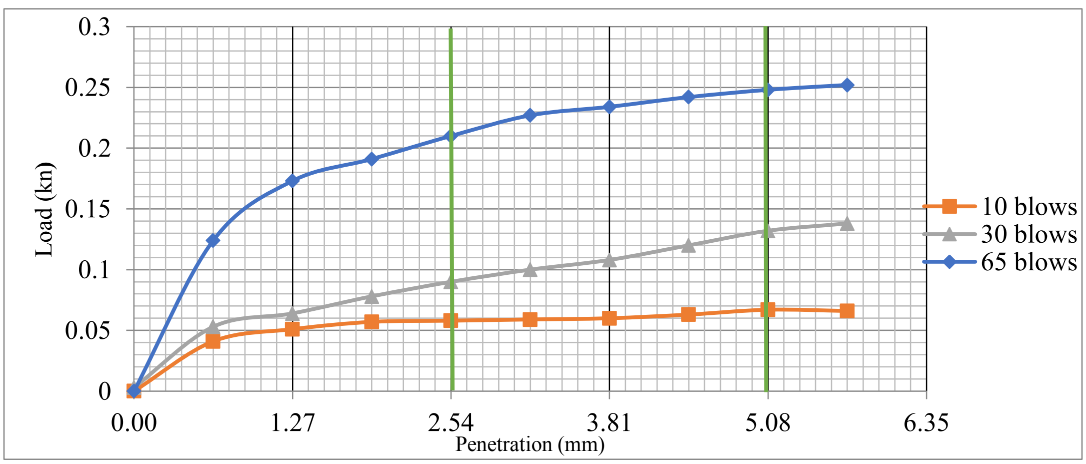
OMC	**22.00**
MDD	**1.625**

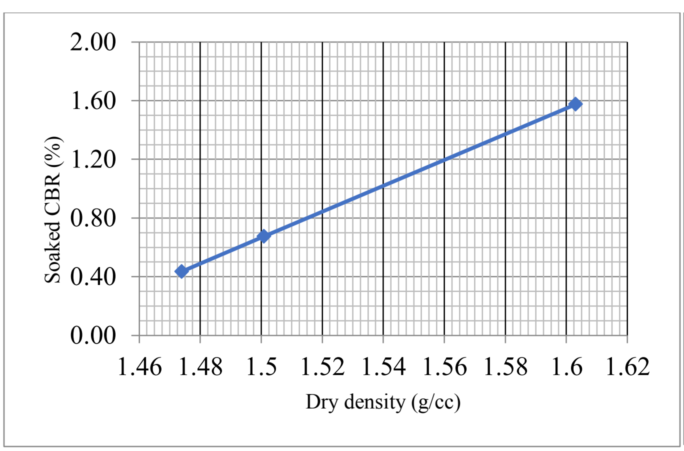
Appendix A-8: California Bearing Ratio Test Data Analysis (ASTM D-1883)

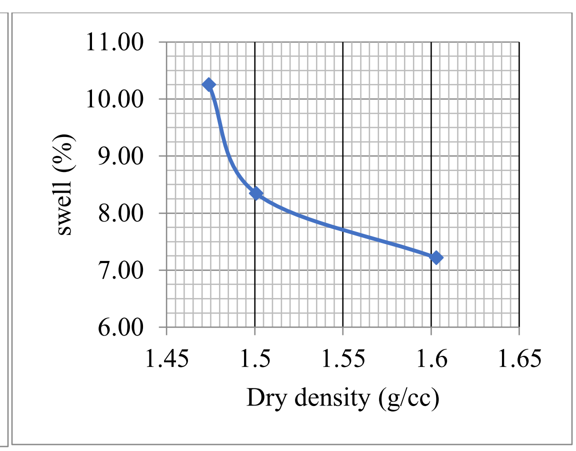
CBR result summary of natural soil sample 01

Penetration and load determination of untreated soil sample 01						
Penetration and load data after 96-hours soaking						
	Number of Blows					
	10 blows		30 blows		65 blows	
Penetration (mm)	Load (kn)	CBR %	Load (kn)	CBR %	Load (kn)	CBR %
@2.54	0.058	0.43	0.09	0.67	0.21	1.57
@5.08	0.067	0.34	0.13	0.66	0.25	1.24

MMDD (g/cc)	1.622		
Dry Density at 95% of MDD	1.541		
No of Blows	10	30	65
CBR Values (%)	0.43	0.67	1.57
CBR swell (%)	10.25	8.34	7.22
DDBS (g/cc)	1.474	1.501	1.603
CBR (%) at 95% MDD and CBR swell (%)	1.03 and 8.34 respectively		



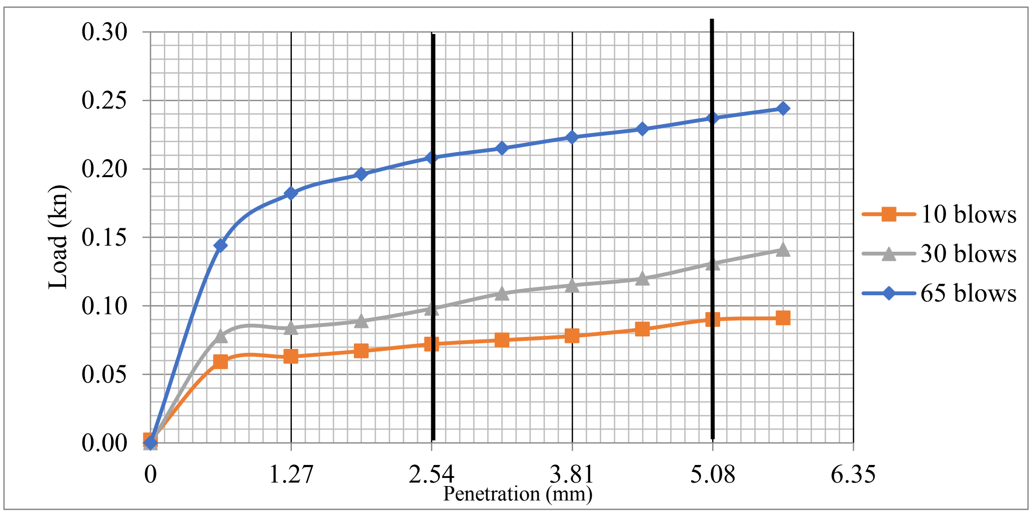


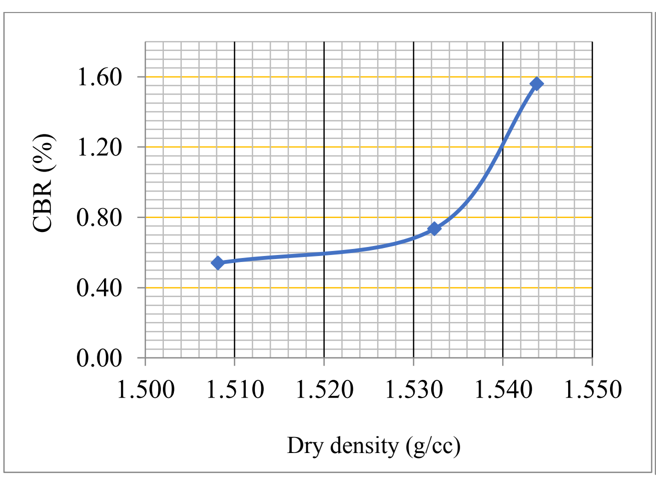


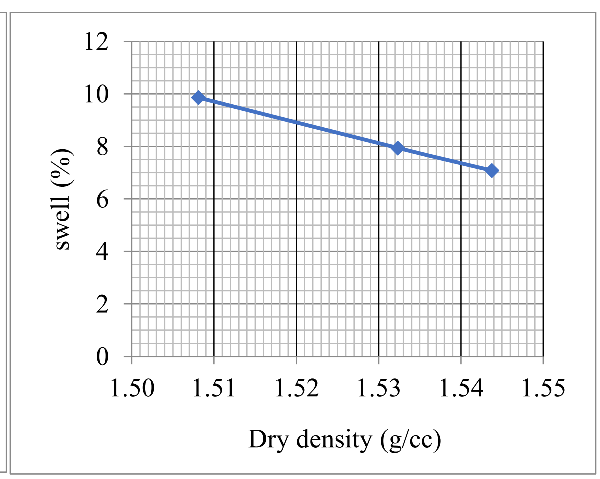
Penetration and load determination of untreated soil sample 02						
Penetration and Load Data After 96-hours Soaking						
	Number of Blows					
	10 blows		30 blows		65 blows	
Penetration (mm)	Load (kn)	CBR %	Load (kn)	CBR %	Load (kn)	CBR %
@2.54	0.07	0.54	0.1	0.73	0.21	1.56
@5.08	0.09	0.45	0.13	0.66	0.24	1.19

CBR result summary of natural soil sample 01

MMDD (g/cc)	1.625		
Dry Density at 95% of MDD	1.544		
No of Blows	10	30	65
CBR Values (%)	0.54	0.73	1.56
CBR swell (%)	9.85	7.94	7.08
DDBS (g/cc)	1.508	1.532	1.544
CBR (%) at 95% MDD and CBR swell (%)	1.56 and 7.94 respectively		

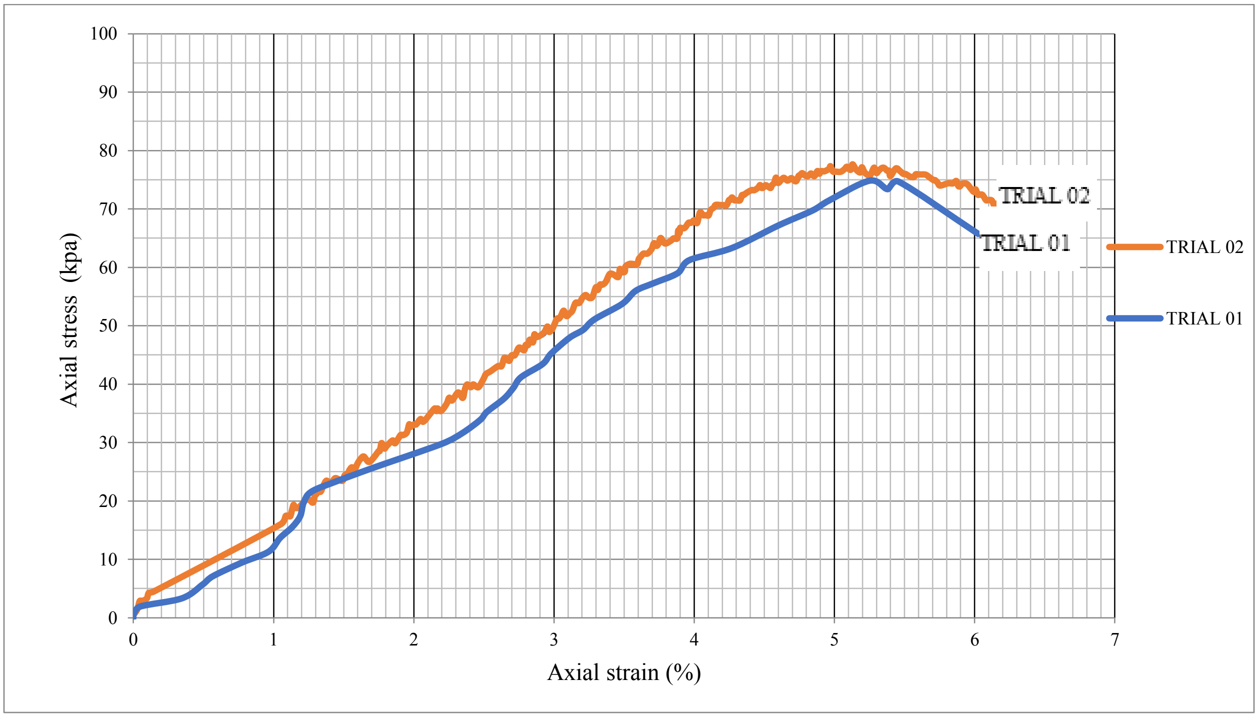






Appendix A-9: Unconfined Compression Strength Test Data Analysis According to ASTM D-2166

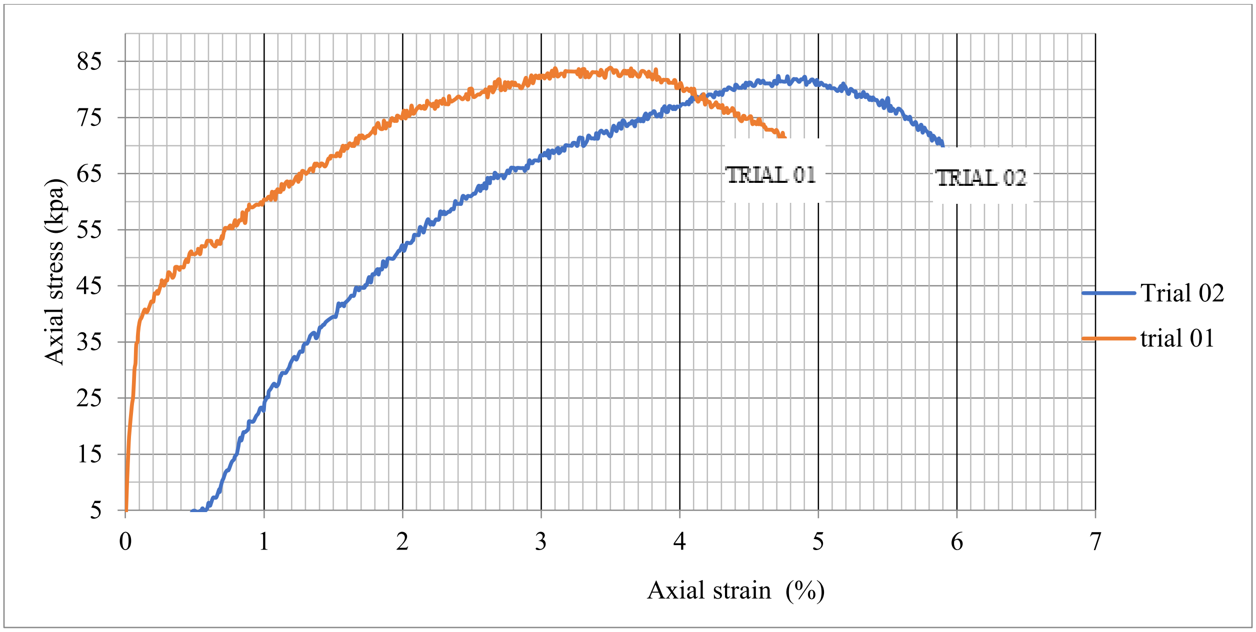
A) Undisturbed natural soil sample (sample 01)



Sample information	Trial number: 01	Trial number:02
	Sample type	
	Undisturbed (natural soil 01)	Undisturbed (natural soil 01)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	76	76
Sample Diameter (mm)	38	38
Area (mm^2)	1134.12	1134.12
Volume (cm^3)	86.20	86.20
Axial stress (qu) (kpa)	74.85	77.65
Shear stress (Su) or Cohesion (C) (kpa)	37.43	38.83
Corrected Area at peak qu (mm^2)	1196.93	1195.40
Load at peak qu, (N)	89.58	92.82

Trial 01					Trial 02			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Axial Stress (kpa)**		**Axial strain (%)**	**Ac (mm^2)**	**F (N)**	**Axial Stress (kpa)**
7.73352E-39	1134.0815	5.877E-36	5.183E-36		8.163E-39	1134.0815	0.5396754	0.47587
7.73352E-39	1134.0815	0.5396605	0.4758569		0.0956641	1135.1674	3.7776679	3.3278508
0.345739565	1138.0161	3.777653	3.3195076		1.2958103	1148.97	24.284944	21.136274
0.565825011	1140.5349	8.0949962	7.0975434		1.5409787	1151.831	29.141933	25.300529
0.964109521	1145.1217	12.95197	11.310562		1.8488566	1155.444	35.078257	30.359115
1.045593462	1146.0647	15.650302	13.655688		2.0168622	1157.4252	38.31625	33.104732
1.132410451	1147.0711	17.808974	15.525607		2.0482063	1157.7955	39.395586	34.026375
1.189525504	1147.7341	19.967616	17.397423		2.1318118	1158.7846	41.014582	35.394483
1.214657332	1148.0261	22.665948	19.743408		2.2363133	1160.0233	42.633578	36.752348
1.458348726	1150.8651	26.983261	23.446067		2.5474019	1163.7263	49.109563	42.20027
1.716510873	1153.8881	29.681593	25.723112		2.6808421	1165.3219	51.26822	43.994898
2.200089003	1159.5936	34.538597	29.785088		2.6969168	1165.5145	52.347541	44.913678
2.344781474	1161.3117	36.697239	31.599818		2.8496424	1167.3467	55.045873	47.154691
2.473482333	1162.8442	39.395571	33.878631		2.9533386	1168.594	58.283865	49.875203
2.52145968	1163.4166	41.014582	35.253565		3.1108962	1170.4944	60.982198	52.099523
2.643306632	1164.8727	43.712914	37.525916		3.2684538	1172.4009	64.22019	54.776648
2.70955939	1165.6659	45.871556	39.352232		3.3279313	1173.1222	66.918507	57.043083
2.764390644	1166.3232	48.030227	41.180889		3.5039796	1175.2625	69.616839	59.235143
2.917460391	1168.1622	50.728559	43.425956		3.5096063	1175.331	70.696175	60.150014
2.979905982	1168.914	52.887201	45.244731		3.538545	1175.6836	71.235836	60.590992
3.110893149	1170.4943	56.125194	47.949992		3.8311428	1179.2607	76.092824	64.525874
3.206845334	1171.6547	57.744205	49.284322		3.8954523	1180.0498	77.711821	65.854697
3.287568845	1172.6326	59.902877	51.084096		3.905095	1180.1682	78.791156	66.762651
3.485569201	1175.0383	63.140869	53.73516		4.139826	1183.058	83.108462	70.248846
3.582286835	1176.217	65.839171	55.975363		4.270045	1184.6673	85.267134	71.975594
3.708701385	1177.7611	67.458183	57.276624		4.3263117	1185.364	84.727474	71.478019
3.881569913	1179.8793	69.616854	59.003367		4.4557359	1186.9697	87.425806	73.654621
3.965340163	1180.9085	72.315156	61.236882		4.6655443	1189.582	89.044787	74.853847
4.269956288	1184.6662	75.013489	63.320357		4.7700352	1190.8872	90.663798	76.131304
4.60122761	1188.78	79.870492	67.186943		4.8568514	1191.9739	90.124138	75.609154
4.843395635	1191.8053	83.108485	69.733271		5.0706757	1194.6588	91.743119	76.794413
4.962195848	1193.2951	85.267127	71.455186		**5.129359**	**1195.398**	**92.82244**	**77.64984**
5.250820361	**1196.9302**	**89.58447**	**74.845194**		5.4685805	1199.6874	91.743119	76.472522
5.380281649	1198.5678	87.965459	73.392141		5.6791941	1202.3662	90.663798	75.404479
5.7998908	1203.9068	84.727466	70.377099		5.9444639	1205.7573	89.584447	74.297246
6.025306802	1206.7946	79.330832	65.736815		6.2041071	1209.0951	85.267134	70.521448

B) Remolded soil sample (sample 01)

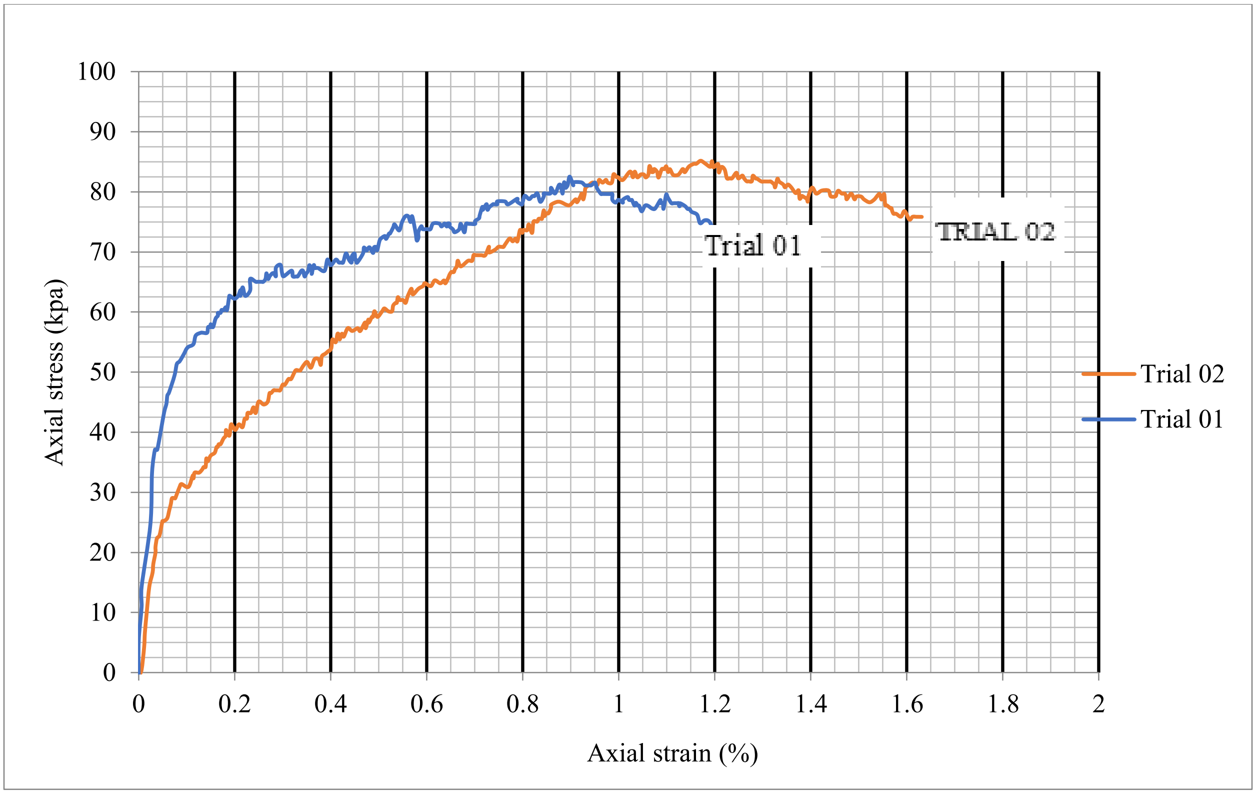


	Trial number: 01	Trial number:02
Sample information	Sample type	
	Remolded (natural soil 01)	Remolded (natural soil 01)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	77	80
Sample Diameter (mm)	38	38
Area (mm^2)	1134.12	1134.12
Volume (cm^3)	87.30	90.73
Axial stress (qu) (kpa)	83.89	82.41
Shear stress (Su) or Cohesion (C) (kpa)	41.95	41.21
Corrected Area at peak qu (mm^2)	1175.21	1159.03
Load at peak qu, (N)	98.59	95.52

Trial 01			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**
7.633E-39	1134.0815	1.0894239	0.9606222
0.0247931	1134.3627	19.609958	17.287202
0.056351	1134.7209	28.870225	25.442577
0.0691228	1134.866	34.862161	30.719188
0.0781394	1134.9684	39.219946	34.555982
0.1540246	1135.831	45.756608	40.284699
0.2223969	1136.6093	49.569666	43.611879
0.3012892	1137.5087	52.293271	45.971755
0.3576403	1138.152	54.472148	47.860171
0.5387145	1140.2241	57.74048	50.639591
0.5492322	1140.3446	59.37466	52.067295
0.6964968	1142.0357	61.553538	53.898084
0.8339919	1143.6192	64.821869	56.681341
0.9038677	1144.4256	67.545474	59.021289
1.0308451	1145.8939	69.724351	60.847127
1.2014017	1147.8721	72.447956	63.115009
1.3216167	1149.2705	75.17159	65.408094
1.4778955	1151.0935	77.895194	67.670608
1.6003671	1152.5261	80.074072	69.477011
1.8362887	1155.2961	84.431857	73.082441
1.8655901	1155.641	86.066008	74.47469
2.0466643	1157.7773	87.155461	75.27826
2.2683131	1160.4031	90.423793	77.924468
2.4050576	1162.029	91.513216	78.752956
2.4816934	1162.9422	93.147397	80.096328
2.9610522	1168.6869	96.415728	82.499193
3.1849552	1171.3897	97.505152	83.238865
3.3126831	1172.9372	98.049879	83.593461
3.4997692	**1175.2112**	**98.594606**	**83.895225**
3.6447773	1176.9798	97.505152	82.843523
3.945316	1180.6624	95.871001	81.201031
3.985888	1181.1613	95.326275	80.705554
4.2901844	1184.9166	90.968519	76.772086
4.3209893	1185.2981	89.879066	75.828237
4.5869654	1188.6023	87.700188	73.784301
4.7154464	1190.205	85.521281	71.854246
4.749256	1190.6274	84.431857	70.91375

Trial 02			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**
0.4608464	1109.5469	4.3173283	3.8910733
0.4745936	1109.7002	4.8569888	4.3768479
0.5997515	1111.0974	7.0156604	6.3141722
0.6352019	1111.4938	8.0949813	7.2829746
0.7835126	1113.1553	15.650302	14.059406
0.8290887	1113.6669	19.967631	17.929626
0.9976578	1115.5631	25.36428	22.73675
1.0880899	1116.583	30.221269	27.06585
1.1683941	1117.4903	33.459261	29.941434
1.3275552	1119.2928	39.935246	35.678998
1.4975691	1121.2247	44.252574	39.468069
1.5641284	1121.9828	46.950892	41.846354
1.7587399	1124.2054	52.347556	46.564048
1.9330955	1126.2042	56.125209	49.83573
2.0597005	1127.66	59.363201	52.642818
2.1624327	1128.8441	62.601194	55.456014
2.3064017	1130.5076	65.299526	57.761242
2.3982811	1131.5719	67.458183	59.614581
2.5798702	1133.6811	70.696175	62.359843
2.8981972	1137.3976	75.553164	66.426343
2.9039812	1137.4654	75.013503	65.947945
3.1940937	1140.8742	79.870477	70.008138
3.3590436	1142.8215	81.489474	71.305515
3.5420728	1144.99	83.10847	72.584452
3.675921	1146.581	84.187806	73.425083
3.7446427	1147.3996	86.346462	75.254045
3.9674783	1150.0621	87.965459	76.487576
4.2170644	1153.0588	91.203451	79.096963
4.4377255	1155.7213	92.822447	80.315596
4.6128011	1157.8426	93.901783	81.100649
4.6887708	1158.7654	94.441444	81.501777
4.7104669	**1159.0293**	**95.520779**	**82.414466**
4.829123	1160.4743	94.981119	81.846808
4.9962354	1162.5156	94.441444	81.238861
5.269711	1165.8717	92.822447	79.616351
5.4100633	1167.6016	91.203451	78.111792
5.9345746	1174.1122	80.949813	68.945554

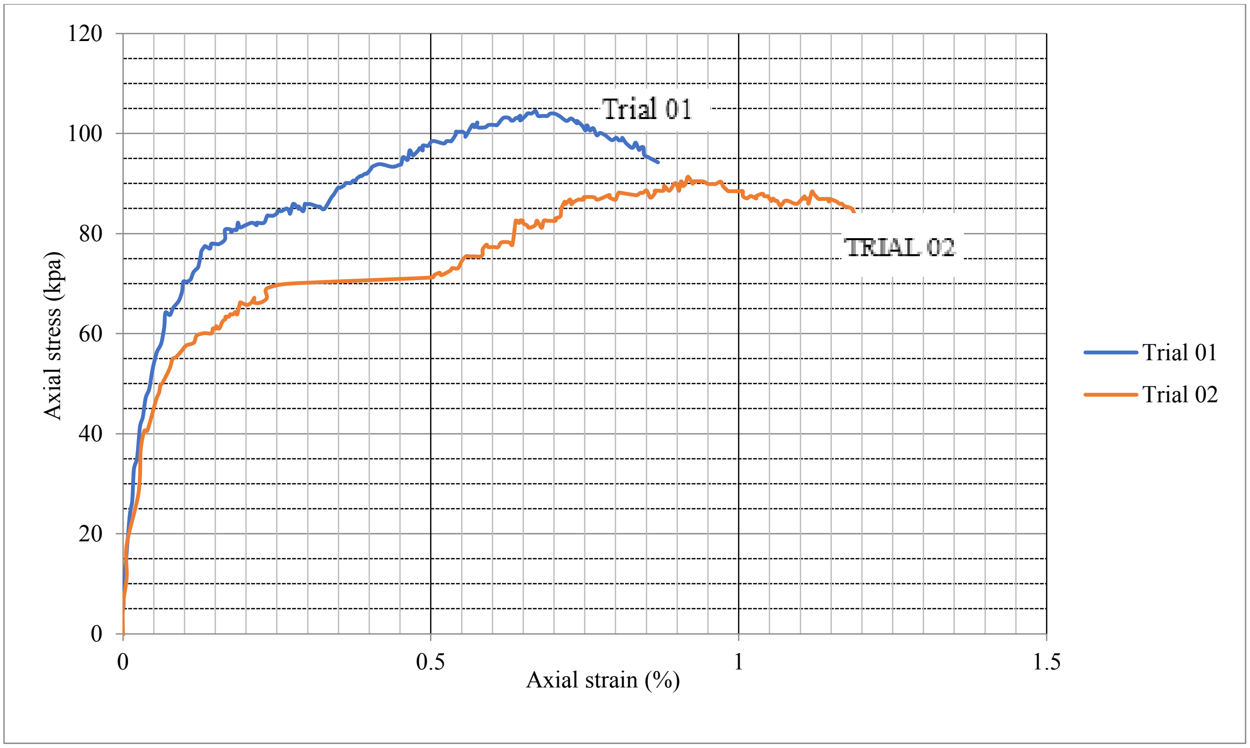
C) Undisturbed natural soil sample (sample 02)



Sample information	Trial number: 01	Trial number:02
	Sample type	
	Undisturbed (Natural soil 02)	Undisturbed (Natural soil 02)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	85	76
Sample Diameter (mm)	38	38
Area (mm^2)	1134.12	1134.12
Volume (cm^3)	96.40	86.20
Axial stress (qu) (kpa)	82.53	85.12
Shear stress (Su) or Cohesion (C) (kpa)	41.27	42.56
Corrected Area at peak qu (mm^2)	1144.35	1147.49
Load at peak qu, (N)	94.44	97.68

Trial 01					Trial 02			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**		**Axial strain (%)**	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**
6.915E-39	1134.0815	-1.0793209	-0.9517137		7.734E-39	1134.0815	1.0793209	-0.9517137
6.915E-39	1134.0815	5.9363246	5.2344779		0.0060935	1134.1506	0.5396605	0.4758279
0.0061125	1134.1508	16.189963	14.274964		0.0289415	1134.4098	18.888295	16.650327
0.033953	1134.4667	42.093903	37.104574		0.0380767	1134.5135	25.36428	22.356966
0.0597572	1134.7596	52.347541	46.130952		0.0639664	1134.8074	30.760944	27.106753
0.07945	1134.9832	58.283865	51.352181		0.0746275	1134.9285	32.919586	29.005868
0.1032179	1135.2533	61.521858	54.192187		0.0891033	1135.0929	35.617918	31.378857
0.1337747	1135.6006	64.22019	56.551738		0.1584003	1135.8807	41.554242	36.583279
0.1500724	1135.786	65.839201	57.967963		0.1766807	1136.0887	44.252574	38.951688
0.1840255	1136.1723	68.537503	60.323158		0.1926723	1136.2708	46.950907	41.320174
0.2118672	1136.4893	72.315186	63.630325		0.2337907	1136.7391	49.109548	43.202129
0.2220524	1136.6054	71.235836	62.674203		0.2688257	1137.1384	51.26822	45.085294
0.2478566	1136.8994	73.934168	65.031408		0.3175635	1137.6944	55.585533	48.858053
0.3313816	1137.8521	75.013489	65.925516		0.3663013	1138.2509	59.363186	52.152987
0.3388506	1137.9374	76.092839	66.86909		0.3960057	1138.5904	60.982198	53.559382
0.3490369	1138.0537	75.553179	66.38806		0.4142761	1138.7993	64.22019	56.392897
0.3646559	1138.2321	77.17216	67.800019		0.4858619	1139.6185	67.458183	59.193655
0.416943	1138.8298	77.711821	68.238311		0.5353626	1140.1856	70.156515	61.530783
0.4671938	1139.4047	77.17216	69.730244		0.5825846	1140.7272	72.854847	63.86702
0.4692302	1139.428	77.17216	70.728858		0.6389317	1141.3741	73.934168	64.776455
0.5303461	1140.1281	78.791171	74.107296		0.658738	1141.6017	76.6325	67.127179
0.5486802	1140.3383	80.949813	74.987541		0.7425007	1142.5651	80.410153	70.37687
0.5615829	1140.4863	82.029164	75.924727		0.7889597	1143.1001	82.029134	71.760237
0.5792382	1140.6888	82.029164	71.911957		0.8125606	1143.3721	85.267127	74.575134
0.6478231	1141.4762	85.267156	74.699019		0.8331299	1143.6093	86.346477	75.503479
0.6783811	1141.8274	83.648145	73.258132		0.8788159	1144.1364	89.58447	78.298771
0.7245569	1142.3585	89.044809	77.948215		0.9222231	1144.6376	91.203451	79.678887
0.7985743	1143.2109	89.044809	77.890099		0.9595469	1145.069	93.901783	82.005351
0.8440713	1143.7354	90.663791	79.269897		0.9663933	1145.1481	93.362123	81.528424
0.8827782	1144.1821	91.203451	79.710609		1.0615901	1146.25	94.981104	82.86247
0.8977172	**1144.3546**	**94.441444**	**82.528131**		1.0722512	1146.3735	95.520794	83.324322
0.9377816	1144.8174	92.822462	81.080584		1.0950992	1146.6383	96.060455	83.775723
0.9547581	1145.0136	92.282802	80.595375		1.1461158	1147.2301	96.600115	84.202913
1.008404	1145.6341	89.58447	78.196405		1.1613545	1147.407	97.139776	84.660264
1.0267381	1145.8463	90.12413	78.652894		**1.1689638**	**1147.4953**	**97.679436**	**85.12404**
1.0477896	1146.0901	87.965459	76.752655		1.2314144	1148.2209	94.441444	82.250242
1.0695188	1146.3418	88.505149	77.206594		1.3593473	1149.7101	92.822462	80.73554
1.1272397	1147.0111	89.044809	77.63204		1.4141785	1150.3495	91.743112	79.752381

D) Remolded soil sample (sample 02)



Sample information	Trial number: 01	Trial number:02
	Sample Type	
	Remolded (Natural soil 02)	Remolded (Natural soil 02)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	88	85
Sample Diameter (mm)	38	38
Area (mm^2)	1134.12	1134.12
Volume (cm^3)	99.80	96.40
Axial stress (qu) (kpa)	104.46	91.35
Shear stress (Su) or Cohesion (C) (kpa)	52.23	45.68
Corrected Area at peak qu (mm^2)	1141.73	1144.62
Load at peak qu, (N)	119.26	104.57

Trial 01					Trial 02			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**		**Axial strain (%)**	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**
6.679E-39	1134.0815	5.877E-36	5.183E-36		6.915E-39	1134.115	-0.5793209	-0.5108132
0.0059193	1134.1486	18.348634	16.178333		6.915E-39	1134.115	6.4363246	5.6751957
0.0111797	1134.2083	26.983291	23.790419		0.0061125	1134.1843	12.91231	11.384666
0.0177578	1134.2829	37.236929	32.828608		0.0061125	1134.1843	20.189963	17.801306
0.0322255	1134.4471	49.109548	43.289413		0.0254466	1134.4037	32.062612	28.263847
0.0427485	1134.5665	55.585533	48.99275		0.0288417	1134.4422	41.776589	36.825666
0.054587	1134.7009	63.68053	56.120983		0.0397068	1134.5655	46.093903	40.626921
0.0670845	1134.8428	69.616854	61.344932		0.0539671	1134.7274	53.109548	46.803796
0.0690569	1134.8652	72.854847	64.196917		0.0587209	1134.7814	54.728559	48.228286
0.0815543	1135.0071	73.934168	65.139826		0.0607572	1134.8045	56.347541	49.653964
0.096022	1135.1715	77.711821	68.458219		0.0756974	1134.9741	60.125224	52.974972
0.0979965	1135.194	79.870492	70.358455		0.08045	1135.0281	62.283865	54.874292
0.1229871	1135.478	83.648145	73.667782		0.0865614	1135.0976	62.823526	55.346367
0.134169	1135.6051	87.965459	77.461308		0.1150819	1135.4217	66.061518	58.182366
0.1657378	1135.9642	89.58447	78.862052		0.1198357	1135.4757	67.68053	59.605441
0.1900738	1136.2412	92.282802	81.217617		0.1563262	1135.8907	69.299511	61.008961
0.2170389	1136.5483	93.362123	82.145323		0.1855255	1136.223	72.537503	63.840905
0.2551837	1136.9829	96.060455	84.487159		0.1902793	1136.2771	75.235836	66.212578
0.2985933	1137.4779	97.679436	85.873698		0.505362	1139.8755	81.711821	71.684864
0.3196391	1137.7181	97.139776	85.381235		0.5345624	1140.2101	83.330832	73.083749
0.3492355	1138.056	101.45709	89.14947		0.5569715	1140.4671	86.029164	75.433273
0.3735694	1138.334	103.0761	90.549965		0.592961	1140.88	88.187806	77.298057
0.385408	1138.4693	104.15542	91.48725		0.6432117	1141.457	93.727466	82.112132
0.4505201	1139.2139	106.85375	93.796042		0.7022902	1142.1361	94.806817	83.008335
0.4570961	1139.2891	108.47276	95.210917		0.7321682	1142.4799	98.630149	86.329879
0.5564083	1140.4269	113.32974	99.374835		0.789888	1143.1446	99.70947	87.22385
0.6077095	1141.0156	116.02807	101.68842		0.8048281	1143.3167	100.78879	88.154741
0.6537481	1141.5443	118.18674	103.53233		0.9041358	1144.4625	102.4078	89.481134
0.6701903	**1141.7333**	**119.26606**	**104.46053**		0.9061732	1144.486	103.48712	90.422356
0.7510857	1142.6639	114.94875	100.59717		**0.9177172**	**1144.6194**	**104.56644**	**91.354774**
0.8109353	1143.3534	113.32974	99.120484		0.9706831	1145.2316	103.48712	90.363491
0.83264	1143.6036	112.25042	98.155005		1.0019199	1145.5929	101.32845	88.450661
0.8451353	1143.7477	111.17107	97.198941		1.0066737	1145.6479	100.24913	87.504308
0.8379026	1143.6643	110.63141	96.734161		1.0555658	1146.214	99.70947	86.990271
0.846451	1143.7629	110.63141	95.725822		1.1132866	1146.8831	98.630149	85.998433
0.8530292	1143.8388	110.09175	95.247608		1.1716852	1147.5608	98.090459	85.477352
0.8688125	1144.0209	110.09175	94.232286		1.1913405	1147.7891	95.931817	83.579657

Appendix B: Laboratory Test Results of Specific Gravity of CDW

<table>
<tr><th colspan="10">Specific gravity test data of CDW</th></tr>
<tr><td colspan="5">Determination code</td><td colspan="2">11</td><td>5</td><td colspan="2">3</td></tr>
<tr><td colspan="5">Mass of dry, clean calibrated pycnometer (g)</td><td colspan="2">27.025</td><td>31.288</td><td colspan="2">31.37</td></tr>
<tr><td colspan="5">Mass of oven dry sample(g) A</td><td colspan="2">25</td><td>25</td><td colspan="2">25</td></tr>
<tr><td colspan="5">Mass of Pycnometer + water(g) B</td><td colspan="2">133.002</td><td>128.034</td><td colspan="2">125.77</td></tr>
<tr><td colspan="5">Mass of Pycnometer + water + sample(g) C</td><td colspan="2">148.051</td><td>143.112</td><td colspan="2">140.802</td></tr>
<tr><td colspan="5">Mass of Pycnometer + sample (g) D</td><td colspan="2">52.025</td><td>56.288</td><td colspan="2">56.37</td></tr>
<tr><td colspan="5">Observed Temperature of water, Ti</td><td colspan="2">23</td><td>23</td><td colspan="2">24</td></tr>
<tr><td colspan="10">Water Temperature (^OC)</td></tr>
<tr><td>^oC</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td></tr>
<tr><td>k</td><td>1.0016</td><td>1.0014</td><td>1.0012</td><td>1.0009</td><td>1.007</td><td>1.0005</td><td>1.0003</td><td>1.000</td><td>0.9997</td></tr>
<tr><td colspan="5">Temperature of contents of Pycnometer when Mpsw was taken, Tx, in ^oc</td><td colspan="2">23</td><td>24</td><td colspan="2">23</td></tr>
<tr><td colspan="5">K for Tx</td><td colspan="2">1.0005</td><td>1.0003</td><td colspan="2">1.0005</td></tr>
<tr><td colspan="3">Specific gravity at 20^oc, (Gs)</td><td colspan="2">Gs=A*k/(A+B-C)</td><td colspan="2">2.5136</td><td>2.5204</td><td colspan="2">2.50928</td></tr>
<tr><td colspan="5">Average specific gravity at 20oc, (Gs)</td><td colspan="5">2.51</td></tr>
</table>

Appendix C: Laboratory Test Results of S01 Stabilized with CDW and PWF

Appendix C-1: Linear Shrinkage Tabular Data of S01 Stabilized with CDW

Sample pits	length of mold (cm)	length of dry specimen (cm)	Linear shrinkage (%)
Sample 01 + 0% Additive	140	108.50	29.03
Soil + 5% CDW	140	115.40	21.32
Soil + 10% CDW	140	124.80	12.18
Soil + 15% CDW	140	131.40	6.54
Soil + 20% CDW	140	135.90	3.02
Soil + 25% CDW	140	136.70	2.41
Soil + 30% CDW	140	137.10	2.12

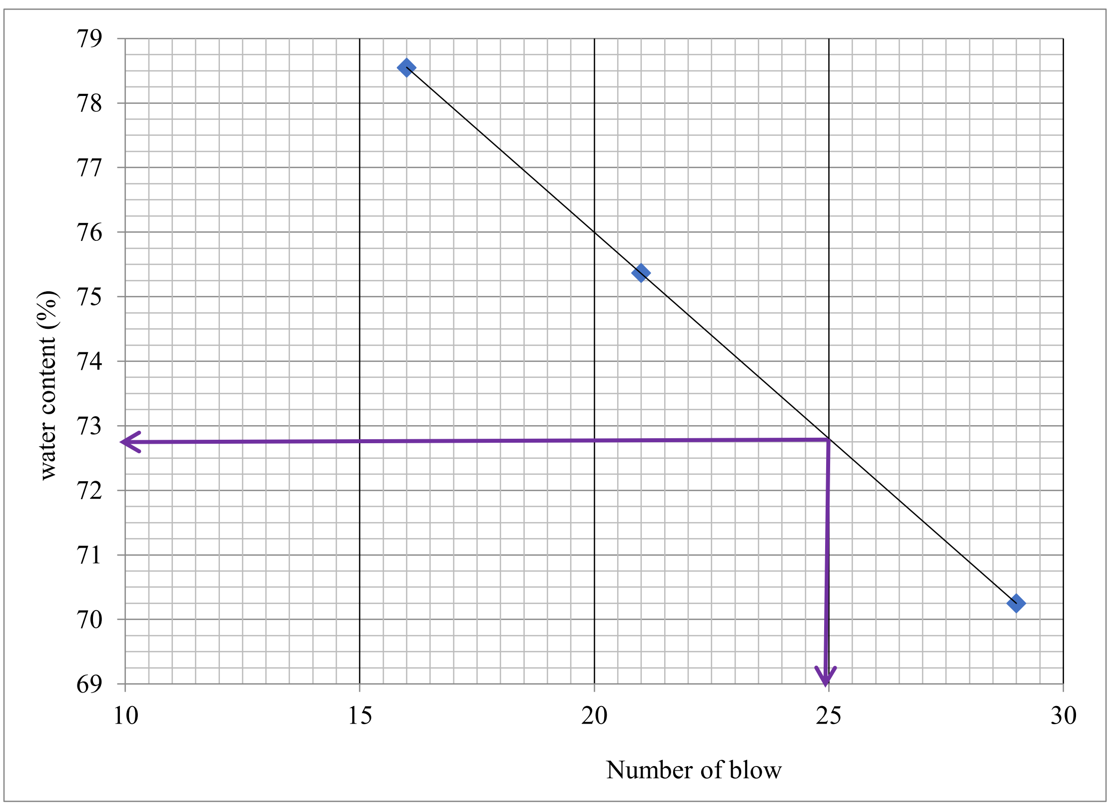
Appendix C-2: Free Swells Index Test Analysis of S01 with CDW

	Free swell test with sample 01`		
Ratios	Initial reading	Final reading	% free swelling
soil sample 01 + 0% of additives	10	19	90
soil sample 01 + 5% CDW	10	18	80
soil sample 01 + 10% CDW	10	16	60
soil sample 01 + 15% CDW	10	13.5	35
soil sample 01 + 20% CDW	10	11.8	18
soil sample 01 + 25% CDW	10	11.6	16
soil sample 01 + 30% CDW	10	11.5	15

Appendix C-3: Atterberg Limits Data Analysis of Soil Stabilized with CDW (According to ASTM D-4318)

A) Atterberg Limits Data of Soil +5% CDW

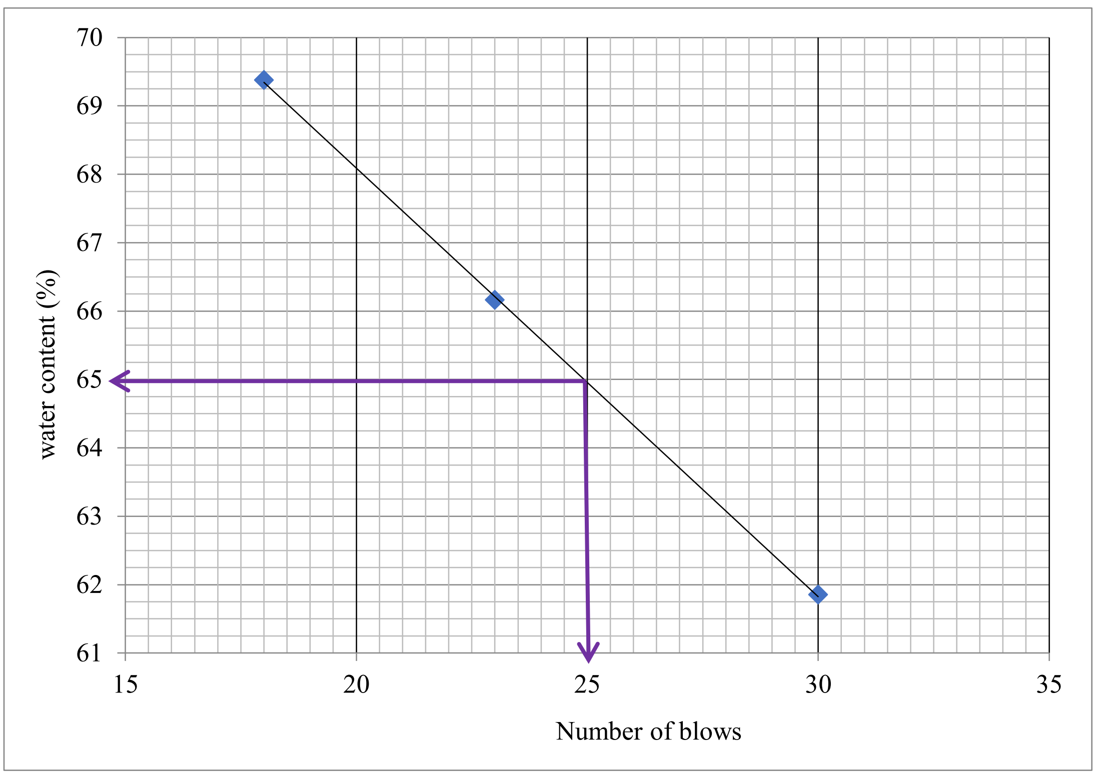
DETERMINATION OF LIQUID LIMIT & PLASTIC LIMIT OF SOIL					
TEST METHOD : ASTM D-4318					
Liquid limit and plastic limit test : Soil + 5% CDW					
Determination	Liquid Limit			Plastic Limit	
Number of blows	29	21	16		
Test No	1	2	3	1	2
Container code	B33	N53	G2T3	A2	T6
Wt. of container + wet soil (g)	48.66	43.25	38.19	26.02	16.98
Wt. of container + dry soil (g)	39.31	32.42	28.89	23.25	14.13
Wt. of container (g)	26.00	18.05	17.05	16.01	6.75
Wt. of water (g)	9.35	10.83	9.30	2.77	2.85
Wt. of dry soil (g)	13.31	14.37	11.84	7.24	7.38
Moisture content (%)	70.25	75.37	78.55	38.26	38.62
LL (%)	72.80			PI: Average (%)	38.44



LL (%)	**72.80**
PL (%)	**38.44**
PI (%)	**34.37**

B) Atterberg Limits Data of Soil + 10% CDW

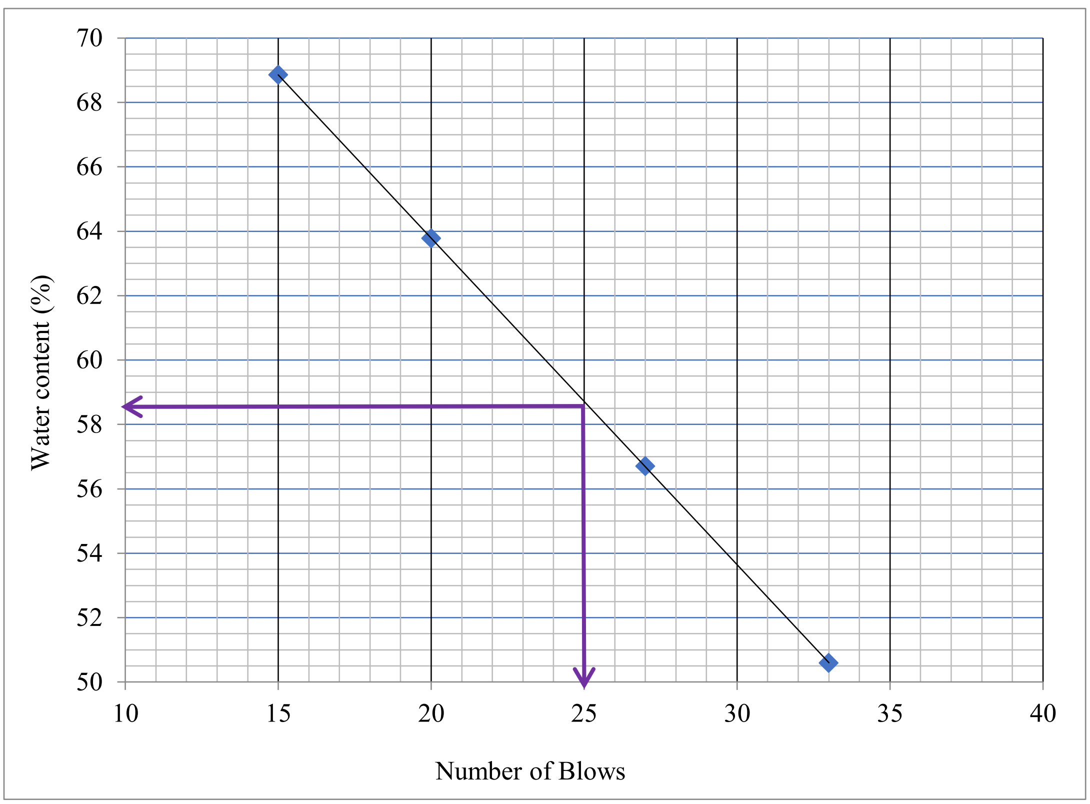
DETERMINATION OF LIQUID LIMIT & PLASTIC LIMIT OF SOIL					
TEST METHOD : ASTM D-4318					
Liquid limit and plastic limit test : Soil+ 10% CDW					
Determination	Liquid Limit			Plastic Limit	
Number of blows	30	23	18		
Test No	1	2	3	1	2
Container code	A1	TP3	P66	4C	G3
Wt. of container + wet soil (g)	77.97	38.24	60.76	37.18	24.46
Wt. of container + dry soil (g)	68.94	30.01	51.2	34.58	22.13
Wt. of container (g)	54.34	17.57	37.42	28.11	16.46
Wt. of water (g)	9.03	8.23	9.56	2.60	2.33
Wt. of dry soil (g)	14.60	12.44	13.78	6.47	5.67
Moisture content (%)	61.8	66.2	69.4	40.19	41.1
LL (%)	64.96			PI: Average (%)	40.64



LL (%)	**64.96**
PL (%)	**40.64**
PI (%)	**24.32**

C) Atterberg Limits Data of Soil + 15% CDW

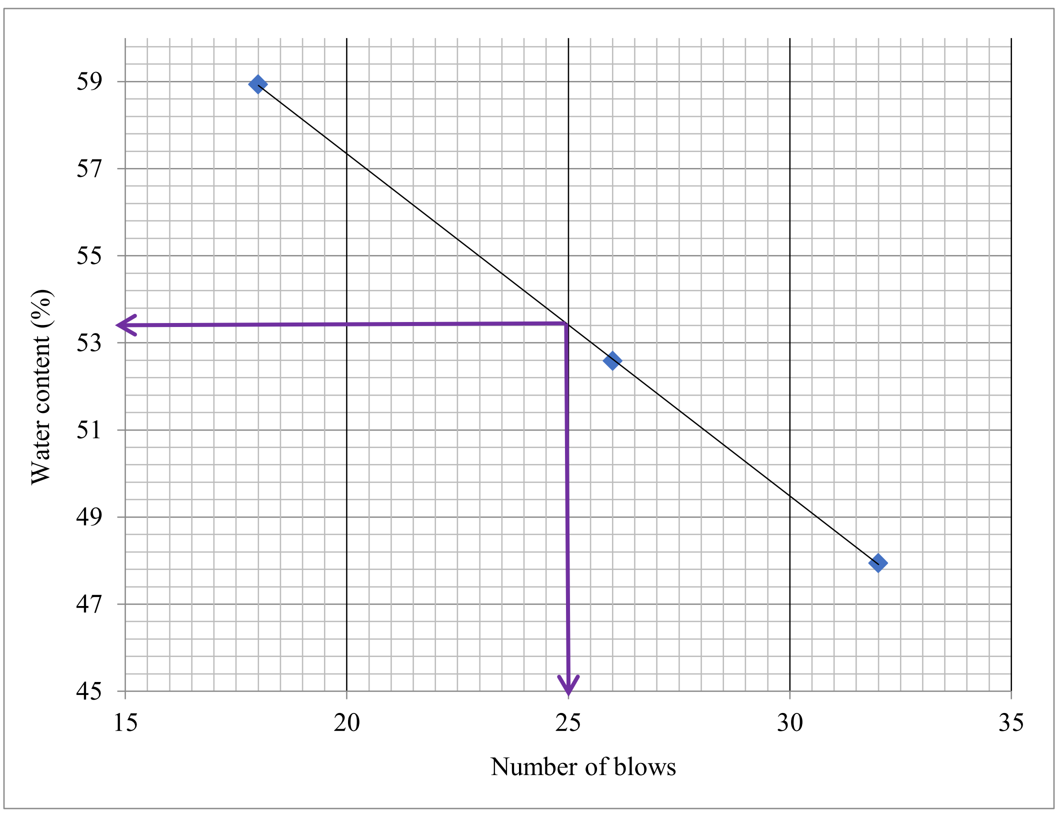
DETERMINATION OF LIQUID LIMIT & PLASTIC LIMIT OF SOIL						
TEST METHOD : ASTM D-4318						
Liquid limit and plastic limit test : soil+ 15% CDW						
Determination	Liquid Limit				Plastic Limit	
Number of blows	33	27	20	15		
Test No	1	2	3	4	G10	B14
Container Code	4F	4D	4C	C14	NC41	B11
Wt. of container + wet soil (g)	46.97	44.39	49.63	37.50	28.52	29.68
Wt. of container + dry soil (g)	40.51	37.62	41.25	30.45	25.17	26.02
Wt. of container (g)	27.74	25.68	28.11	20.21	17.22	17.45
Wt. of water (g)	6.46	6.77	8.38	7.05	3.35	3.66
Wt. of dry soil (g)	12.77	11.94	13.14	10.24	7.95	8.57
Moisture content (%)	50.59	56.70	63.77	68.85	42.14	42.71
LL (%)	58.71				PI: Average (%)	42.42



LL (%)	58.71
PL (%)	42.42
PI (%)	16.29

D) Atterberg Limits Data of Soil + 20% CDW

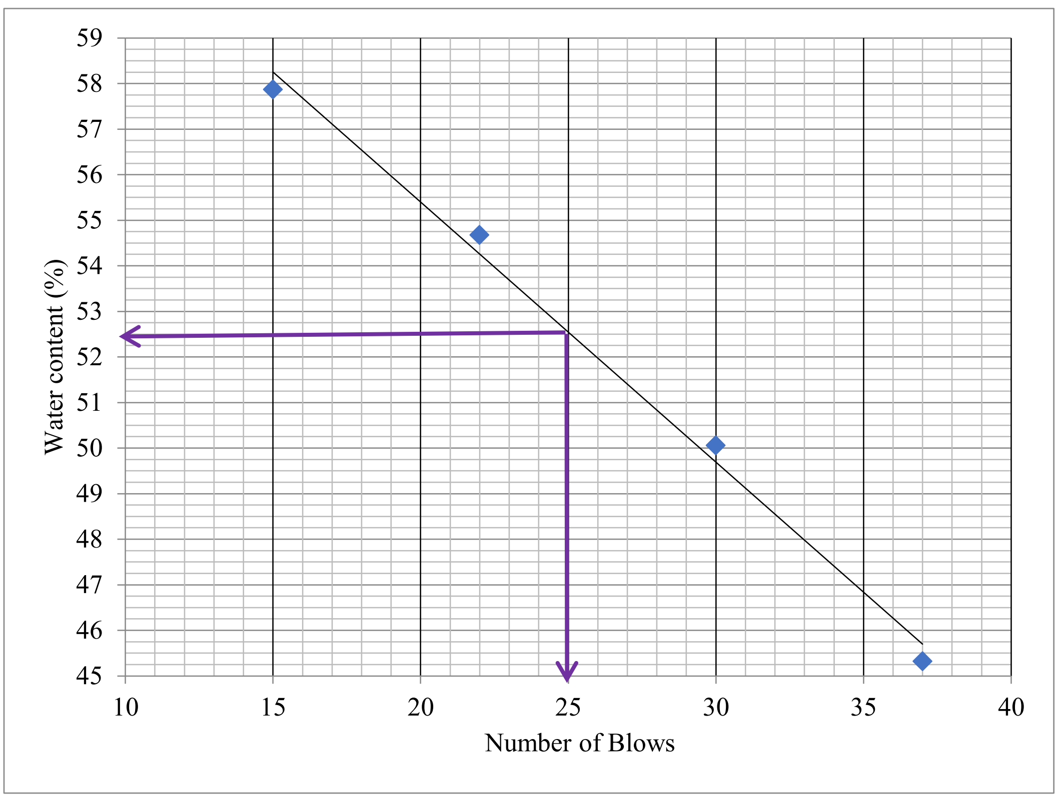
DETERMINATION OF LIQUID LIMIT & PLASTIC LIMIT OF SOIL					
TEST METHOD : ASTM D-4318					
Liquid limit and plastic limit test : soil + 20% CDW					
Determination	Liquid Limit			Plastic Limit	
Number of blows	32	26	18		
Test No	1	2	3	1	2
Container Code	A1	A4	4A	G1	B14
Wt. of container + wet soil (g)	77.72	37.51	35.59	15.80	28.42
Wt. of container + dry soil (g)	70.16	30.58	28.89	12.97	25.08
Wt. of container (g)	54.39	17.40	17.52	6.55	17.45
Wt. of water (g)	7.56	6.93	6.70	2.83	3.34
Wt. of dry soil (g)	15.77	13.18	11.37	6.42	7.63
Moisture content (%)	47.94	52.58	58.93	44.08	43.77
LL (%)	53.41			PI: Average (%)	43.93



LL (%)	53.41
PL (%)	43.93
PI (%)	9.48

E) Atterberg Limits Data of Soil + 25% CDW

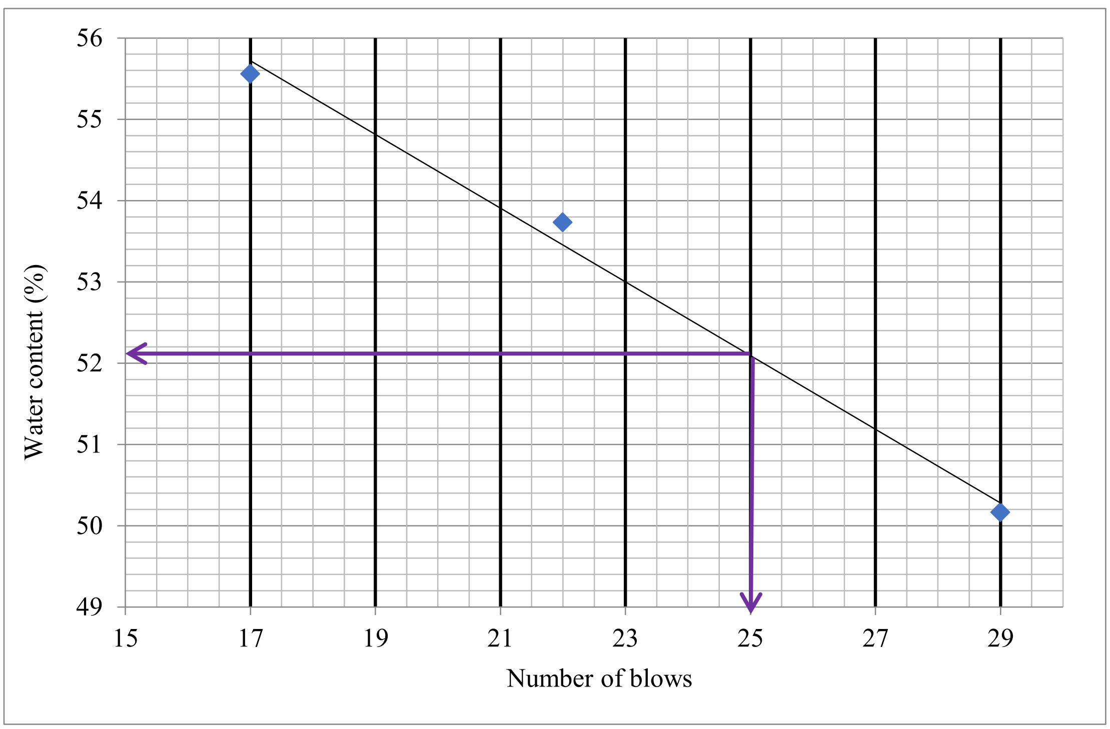
DETERMINATION OF LIQUID LIMIT & PLASTIC LIMIT OF SOIL						
TEST METHOD : ASTM D-4318						
Liquid limit and plastic limit test : soil + 25% CDW						
Determination	Liquid Limit				Plastic Limit	
Number of blows	37	30	22	15		
Test No	1	2	3	4	1	2
Container Code	5HY	5CH	TO	B33	A23	P13
Wt. of container + wet soil (g)	51.95	54.55	37.37	50.51	15.04	17.07
Wt. of container + dry soil (g)	44.40	45.67	30.52	41.53	12.14	13.81
Wt. of container (g)	27.74	27.93	17.99	26.01	5.54	6.55
Wt. of water (g)	7.55	8.88	6.85	8.98	2.90	3.26
Wt. of dry soil (g)	16.66	17.74	12.53	15.52	6.60	7.26
Moisture content (%)	45.32	50.06	54.67	57.86	43.94	44.90
LL (%)	52.55				PI: Average (%)	44.42



LL (%)	52.55
PL (%)	44.42
PI (%)	8.13

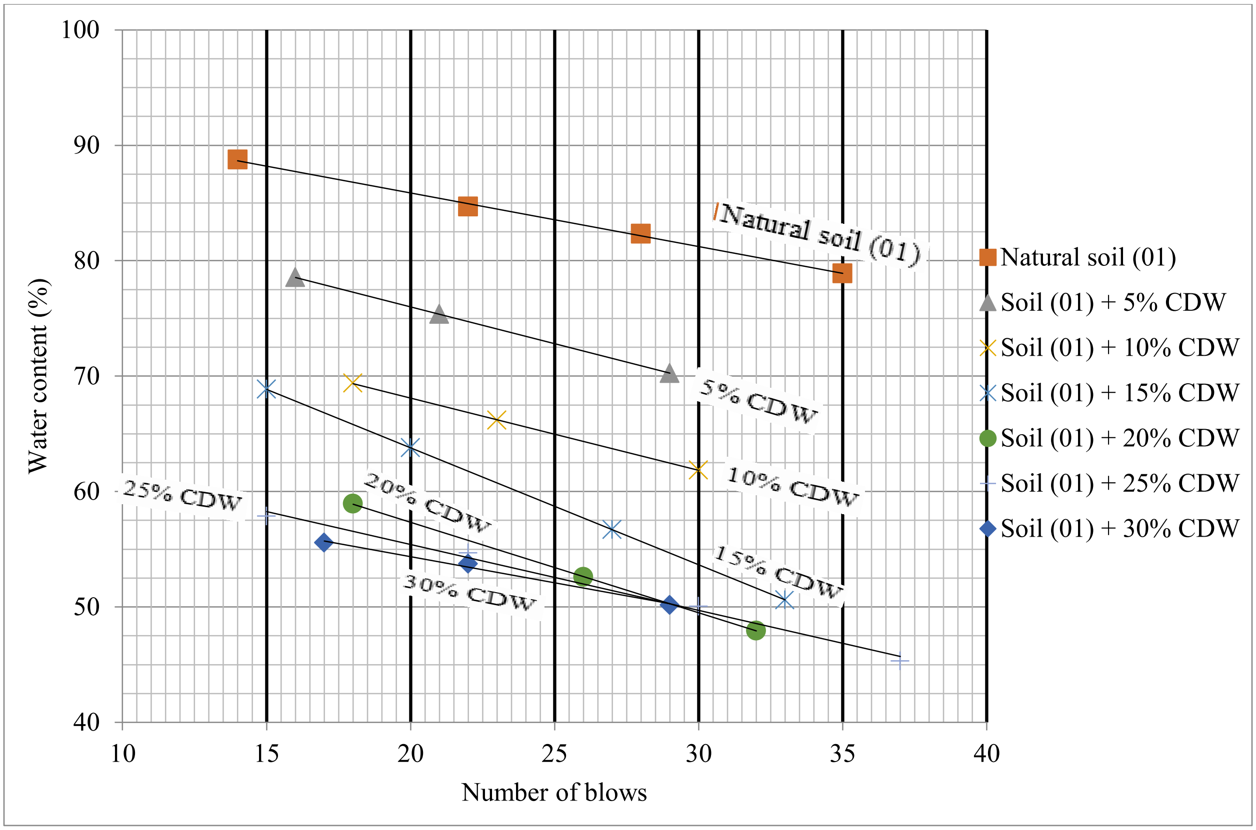
F) Atterberg Limits Data of Soil + 30% CDW

DETERMINATION OF LIQUID LIMIT & PLASTIC LIMIT OF SOIL					
TEST METHOD : ASTM D-4318					
Liquid limit and plastic limit test : soil + 30% CDW					
Determination	Liquid Limit			Plastic Limit	
Number of blows	29	22	17		
Test No	1	2	3	1	2
Container Code	NO	G3	1B	HC12	4E
Wt. of container + wet soil (g)	65.45	40.58	35.41	30.01	41.10
Wt. of container + dry soil (g)	56.19	32.15	29.16	26.36	37.03
Wt. of container (g)	37.73	16.46	17.91	18.14	27.97
Wt. of water (g)	9.26	8.43	6.25	3.65	4.07
Wt. of dry soil (g)	18.46	15.69	11.25	8.22	9.06
Moisture content (%)	50.16	53.73	55.56	44.40	44.92
LL (%)	52.09			PI: Average (%)	44.66



LL (%)	52.09
PL (%)	44.66
PI (%)	7.43

G) Summary of Liquid Limits Test

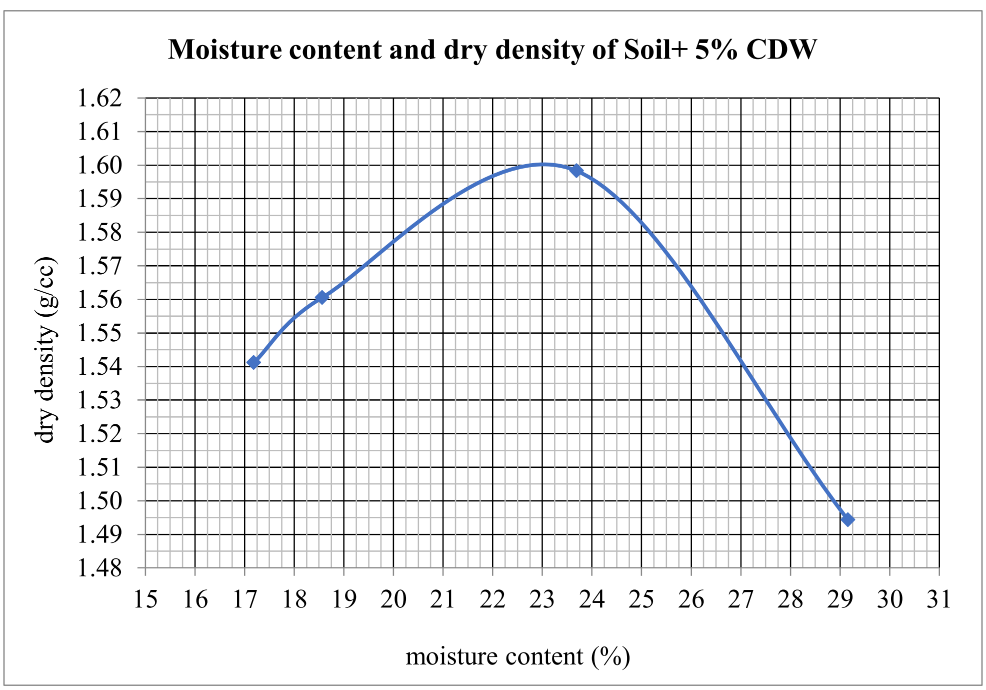


Appendix C-4: Compaction Test Data Analysis of Soil Stabilized with CDW (According to ASTM D-1557)

A) Compaction Test data analysis of Soil + 5% CDW

Soil + 5% CDW	
Mass of sample (g)	5000
Mass of Mold (g)	6674
Volume of Mold (cm^3)	2124

Test No.	1		2		3		4	
Mass of Mold + Wet soil (g)(A)	10510		10604		10873		10773.5	
Mass of Wet Soil (g)A-B=C	3836		3930		4199		4099.5	
Bulk Density g/cm^3 C/D=(E)	1.81		1.85		1.98		1.93	
moisture determination								
Container code	A2	B11	A49	21L	Da	QP1	NM	119D
Mass of wet soil+ container(g) (F)	124.2	137.32	128.5	83.54	111.03	96.58	141.54	90.32
Mass of dry soil+ container(g) (G)	108.27	120.54	112.82	71.21	92.95	81.48	112.81	74.33
Mass of container (g)(H)	17.70	20.50	26.50	6.20	17.50	17.0	16.5	18.2
Mass of moisture (g) F-G=(I)	15.94	16.78	15.68	12.33	18.08	15.1	28.73	15.99
Mass of dry soil (g) G-H=(J)	90.57	100.04	86.32	65.01	75.45	64.48	96.31	56.13
Moisture content % (I/J)*100=K	17.60	16.77	18.16	18.97	23.96	23.42	29.83	28.49
Avg. Moisture Content % (L)	17.19		18.57		23.69		29.16	
Dry density (g/cm^3) E/(100+L)*100	1.54		1.56		1.60		1.49	

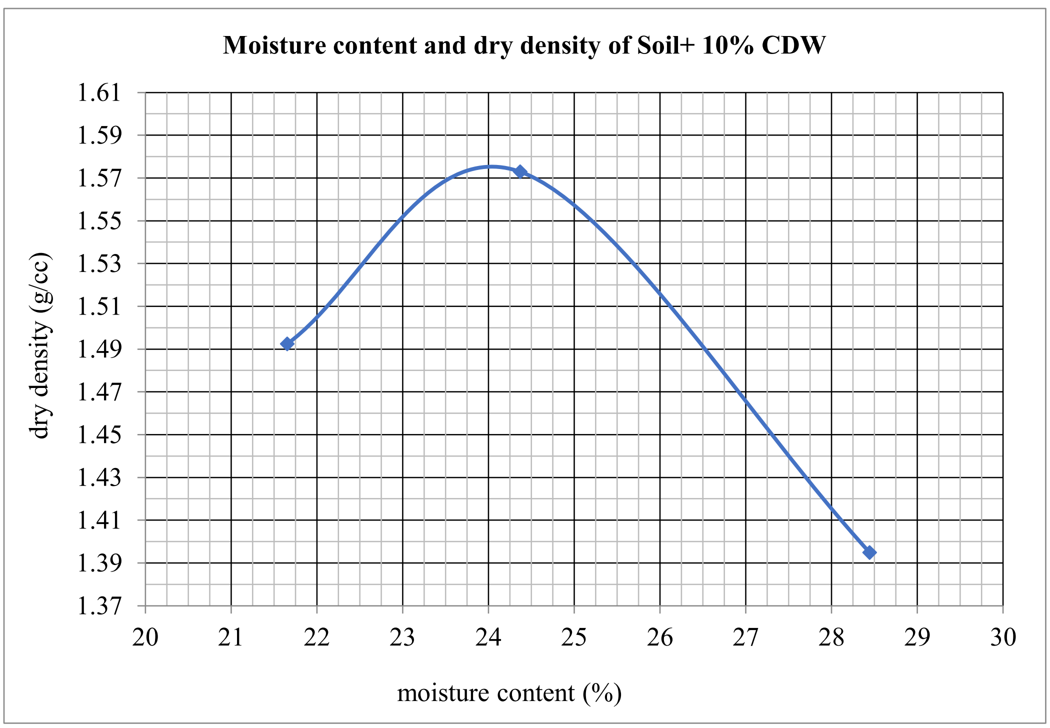


OMC (%)	23.00
MDD (gm./cm^3)	1.600

B) Compaction Test Data Analysis of Soil + 10% CDW

Soil + 10% CDW	
Mass of sample (g)	**5000**
Mass of Mold (g)	**6675**
Volume of Mold (cm^3)	**2124**

Test No.	1		2		3	
Mass of mold + wet soil (g) (A)	10531.5		10830		10480.5	
Mass of wet soil (g) A-B=C	3856.5		4155		3805.5	
Bulk Density g/cm^3 C/D=(E)	1.82		1.96		1.79	
	Moisture determination					
Container code	1	B11	G3T3	DH	E29	P4
Mass of wet soil + container (g) (F)	46.31	59.24	145.49	134.90	153.00	127.00
Mass of dry soil + container (g) (G)	39.28	51.60	120.00	112.27	122.59	102.97
Mass of container (g) (H)	6.16	17.01	17.93	17.08	17.50	17.00
Mass of moisture (g) F-G=(I)	7.03	7.64	25.49	22.63	30.41	24.03
Mass of dry soil (g) G-H=(J)	33.12	34.59	102.07	95.19	105.09	85.97
Moisture content % (I/J)*100=K	21.23	22.09	24.97	23.77	28.94	27.95
Avg. moisture content % (L)	21.66		24.37		28.44	
Dry density g/cm^3 E/(100+L)*100	1.49		1.57		1.39	

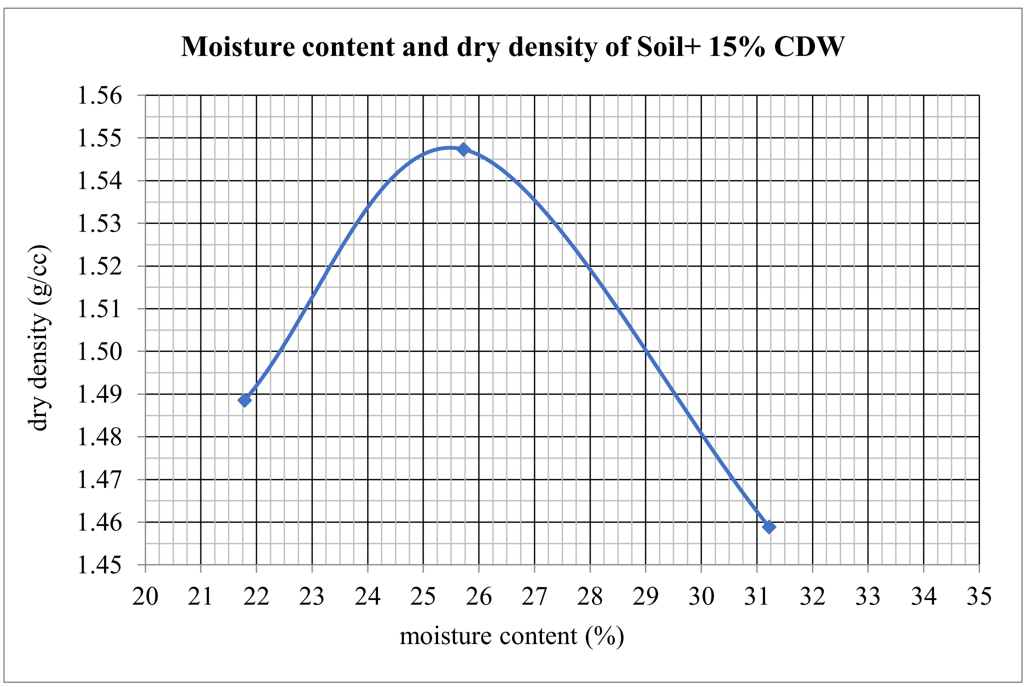


OMC (%)	**24.1**
MDD (gm./cm^3)	**1.576**

C) Compaction Test data Analysis of Soil + 15% CDW

Soil + 15% CDW	
Mass of sample (g)	5000
Mass of Mold (g)	6640
Volume of Mold (cm^3)	2124

Test No.	1		2		3	
Mass of mold + wet soil (g) (A)	10490.5		10772		10706	
Mass of wet soil (g) A-B=C	3850.5		4132		4066	
Bulk Density g/cm^3 C/D=(E)	1.81		1.95		1.91	
Moisture determination						
Container code	Q11	B4	C6	T	P4	H23
Mass of wet soil + container (g) (F)	87.20	104.5	91.03	119.74	140	118.32
Mass of dry soil + container (g) (G)	72.81	90.21	78.04	98.91	109.89	95.29
Mass of container (g) (H)	6.16	25.20	28.00	17.2	17	18.6
Mass of moisture (g) F-G=(I)	14.39	14.29	12.99	20.83	30.11	23.03
Mass of dry soil (g) G-H=(J)	66.65	65.01	50.04	81.71	92.89	76.69
Moisture content % (I/J)*100=K	21.59	21.98	25.96	25.49	32.41	30.03
Avg. moisture content % (L)	21.79		25.73		31.22	
Dry density g/cm^3 E/(100+L)*100	1.49		1.55		1.46	

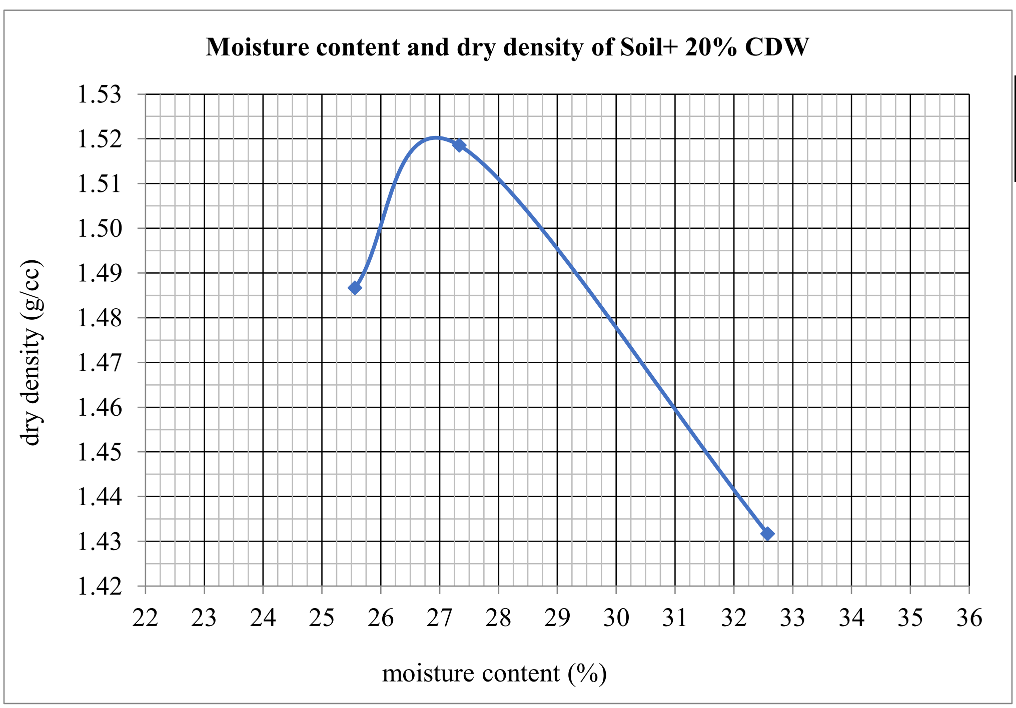


OMC (%)	25.4
MDD (gm./cm^3)	1.547

D) Compaction Test Data Analysis of Soil + 20% CDW

Soil + 20% CDW	
Mass of sample (g)	**5000**
Mass of Mold (g)	**6529**
Volume of Mold (cm^3)	**2124**

Test No.	1		2		3	
Mass of mold + wet soil (g) (A)	10494		10636		10560.5	
Mass of wet soil (g) A-B=C	3965		4107		4031.5	
Bulk Density g/cm^3 C/D=(E)	1.87		1.93		1.90	
	Moisture determination					
Container code	H23	W113	T	H12	T1C1	B4
Mass of wet soil + container (g) (F)	157.88	272	105.96	133.56	165.16	124.18
Mass of dry soil + container (g) (G)	129.55	224.56	86.94	108.82	129.3	99.59
Mass of container (g) (H)	17.50	41.00	17.13	18.60	17.56	25.20
Mass of moisture (g) F-G=(I)	28.33	47.44	19.02	24.74	35.86	24.59
Mass of dry soil (g) G-H=(J)	112.05	183.56	69.81	90.22	111.74	74.39
Moisture content % (I/J)*100=K	25.28	25.84	27.25	27.42	32.09	33.06
Avg. moisture content % (L)	25.56		27.33		32.57	
Dry density g/cm^3 E/(100+L)*100	1.49		1.52		1.43	

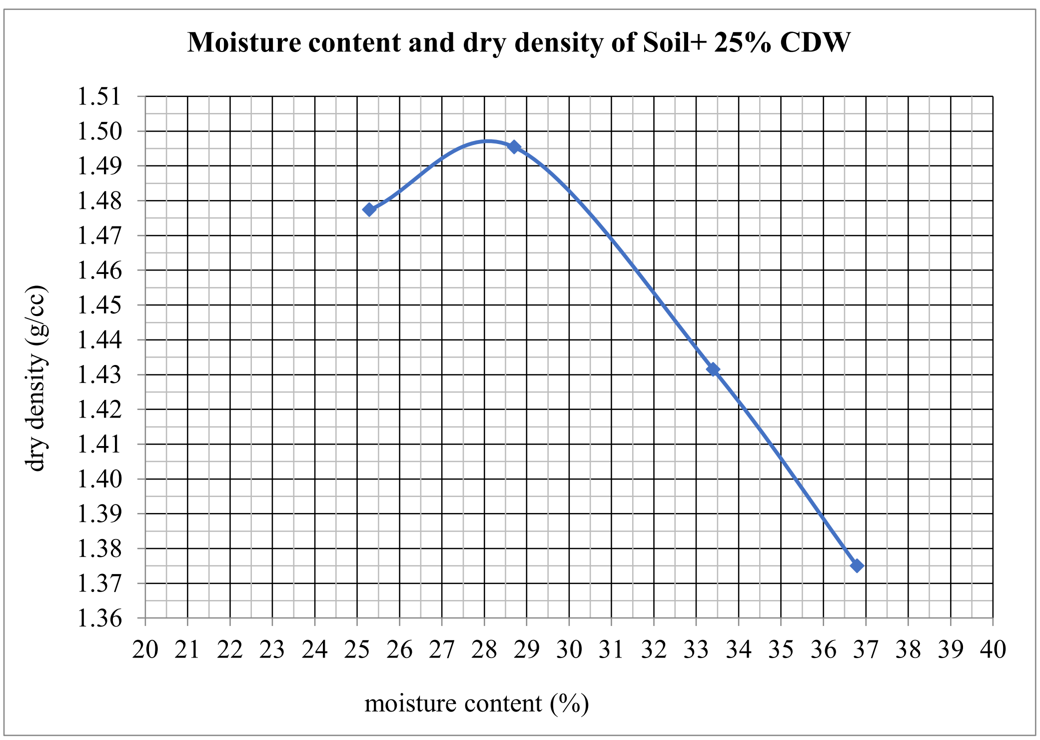


OMC (%)	**26.9**
MDD (gm./cm^3)	**1.520**

E) Compaction Test Data Analysis of Soil + 25% CDW

Soil + 25% CDW	
Mass of sample (g)	**5000**
Mass of Mold (g)	**6602**
Volume of Mold (cm^3)	**2124**

Test No.	1		2		3		4	
Mass of mold + wet soil (g) (A)	10533.5		10690		10658		10597	
Mass of wet soil (g) A-B=C	3931.5		4088		4056		3995	
Bulk Density g/cm^3 C/D=(E)	1.85		1.92		1.91		1.88	
Moisture determination								
Container code	T1C1	H23	HC11	G3T3	3C	B8	11D	S1
Mass of wet soil + container (g) (F)	128.87	118.32	131.76	93.26	148.72	113	129.7	149.21
Mass of dry soil + container (g) (G)	106.42	97.94	106.22	76.54	116.44	89.02	99.22	116.65
Mass of container (g) (H)	17.50	17.50	17.70	18.00	20.50	16.70	17.00	27.50
Mass of moisture (g) F-G=(I)	22.45	20.38	25.54	16.72	32.28	23.98	30.48	32.56
Mass of dry soil (g) G-H=(J)	88.92	80.44	88.52	58.54	95.94	72.32	82.22	89.15
Moisture content % (I/J)*100=K	25.25	25.34	28.85	28.56	33.65	33.16	37.07	36.52
Avg. moisture content % (L)	25.29		28.71		33.40		36.80	
Dry density g/cm^3 E/(100+L)*100	1.48		1.50		1.43		1.37	

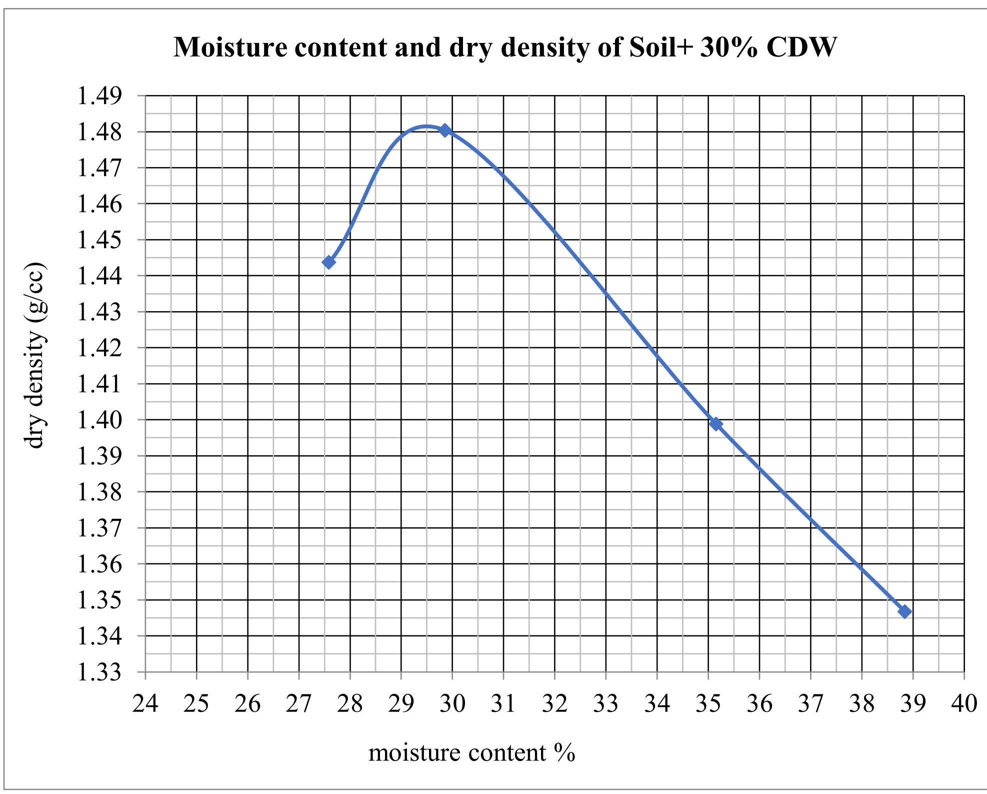


OMC (%)	**28.1**
MDD (gm./cm^3)	**1.497**

F) Compaction Test Data Analysis of Soil + 30% CDW

SOIL+ 30% CDW	
Mass of sample (g)	**5000**
Mass of Mold (g)	**6528**
Volume of Mold (cm^3)	**2124**

Test No.	1		2		3		4	
Mass of mold + wet soil (g) (A)	10440.5		10611		10543.5		10499.5	
Mass of wet soil (g) A-B=C	3912.5		4083		4015.5		3971.5	
Bulk Density g/cm^3 C/D=(E)	1.84		1.92		1.89		1.87	
Moisture determination								
Container code	CD	BG	OW	29B	2A	A	C6	B11
Mass of wet soil + container (g) (F)	89.11	129.55	129.71	135.5	152.5	113	179.47	83.24
Mass of dry soil + container (g) (G)	73.9	106.18	106.1	108.5	120.5	88	137	64.75
Mass of container (g) (H)	20.5	18.64	27.5	17.5	28	18	28	17
Mass of moisture (g) F-G=(I)	15.21	23.37	23.61	27.00	32.00	25.0	42.47	18.49
Mass of dry soil (g) G-H=(J)	53.4	87.54	78.6	91	92.5	70	109	47.75
Moisture content % (I/J)*100=K	28.48	26.70	30.04	29.67	34.59	35.71	38.96	38.72
Avg. moisture content % (L)	27.59		29.85		35.15		38.84	
Dry density g/cm^3 E/(100+L)*100	1.44		1.48		1.40		1.35	



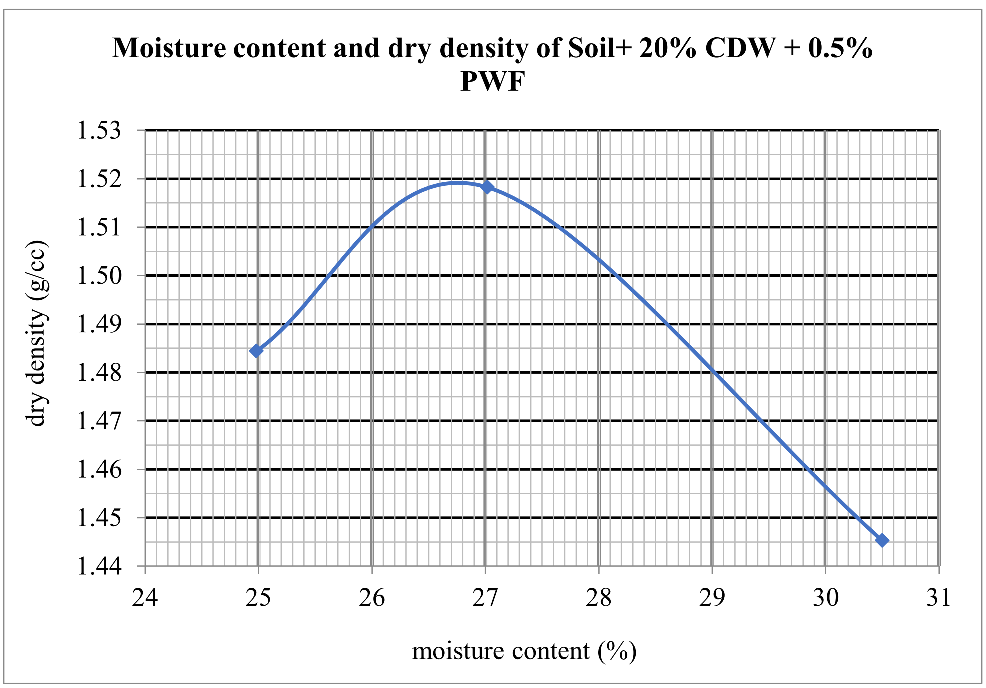
OMC (%)	**29.4**
MDD (gm./cm^3)	**1.481**

Appendix C-5: Compaction Test Data Analysis of Soil Stabilized with CDW and PWF (According to ASTM D-1557)

A) Compaction Test Data Analysis of Soil + 20% CDW +0.5% PWF

Soil + 20% CDW + 0.5% PWF	
Mass of sample (g)	**5000**
Mass of Mold (g)	**6614**
Volume of Mold (cm^3)	**2124**

Test No.	1		2		3	
Mass of mold + wet soil (g) (A)	10554.5		10710		10620	
Mass of wet soil (g) A-B=C	3940.5		4096		4006	
Bulk Density g/cm^3 C/D=(E)	1.86		1.93		1.89	
	Moisture content Determination					
Container code	C14	11F	4C	1B	A1	B33
Mass of wet soil + container (g) (F)	94.57	97.84	136.03	131.46	163.08	123.95
Mass of dry soil + container (g) (G)	79.74	82.11	113.06	107.32	137.69	99.1
Mass of container (g) (H)	20.21	19.32	28.11	17.91	54.39	17.67
Mass of moisture (g) F-G=(I)	14.83	15.73	22.97	24.14	25.39	24.85
Mass of dry soil (g) G-H=(J)	59.53	62.79	84.95	89.41	83.3	81.43
Moisture content % (I/J)*100=K	24.91	25.05	27.04	27.00	30.48	30.52
Avg. moisture content % (L)	**24.98**		**27.02**		**30.50**	
Dry density g/cm^3 E/(100+L)*100	**1.48**		**1.52**		**1.45**	



OMC (%)	**26.75**
MDD (gm./cm^3)	**1.519**

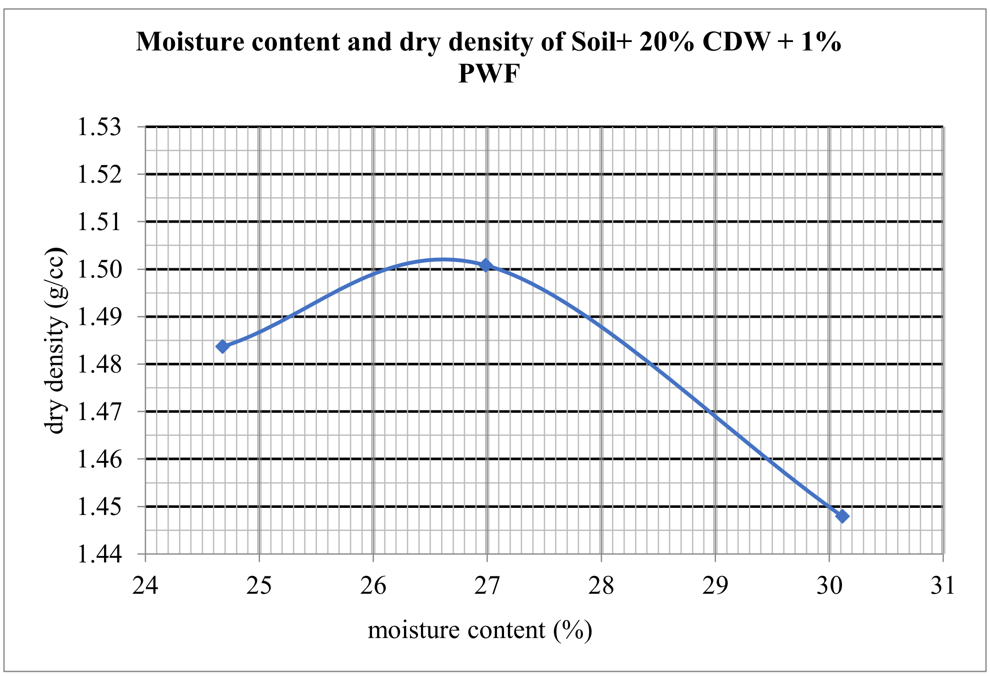
B) Compaction Test Data Analysis of Soil + 20% CDW +1% PWF

Soil+20% CDW +1% PWF	
Mass of sample used (g)	5000
Volume of Mold (cm^3)	2124
Mass of Mold(g)	6755

Test No.	1	2	3
Mass of mold + wet soil (g) (A)	10684	10803	10756.5
Mass of wet soil (g) A-B=C	3929	4048	4001.5
Bulk Density (g/cm^3) C/D=(E)	1.85	1.91	1.88

Moisture content Determination

Container code	H12	B14	A12	G10	P13	12K
Mass of wet soil + container (g) (F)	101.97	106.98	195.02	121.94	81.25	126.51
Mass of dry soil + container (g) (G)	85.32	89.32	165.24	98.91	63.98	101.74
Mass of container (g) (H)	18.14	17.45	49.73	17.22	6.53	19.64
Mass of moisture (g) F-G=(I)	16.65	17.66	29.78	23.03	17.27	24.77
Mass of dry soil (g) G-H=(J)	67.18	71.87	115.51	81.69	57.45	82.1
Moisture content % (I/J)*100=K	24.78	24.57	25.78	28.19	30.06	30.17
Avg. moisture content % (L)	24.68		26.99		30.12	
Dry density g/cm^3 E/(100+L)*100	1.48		1.50		1.45	

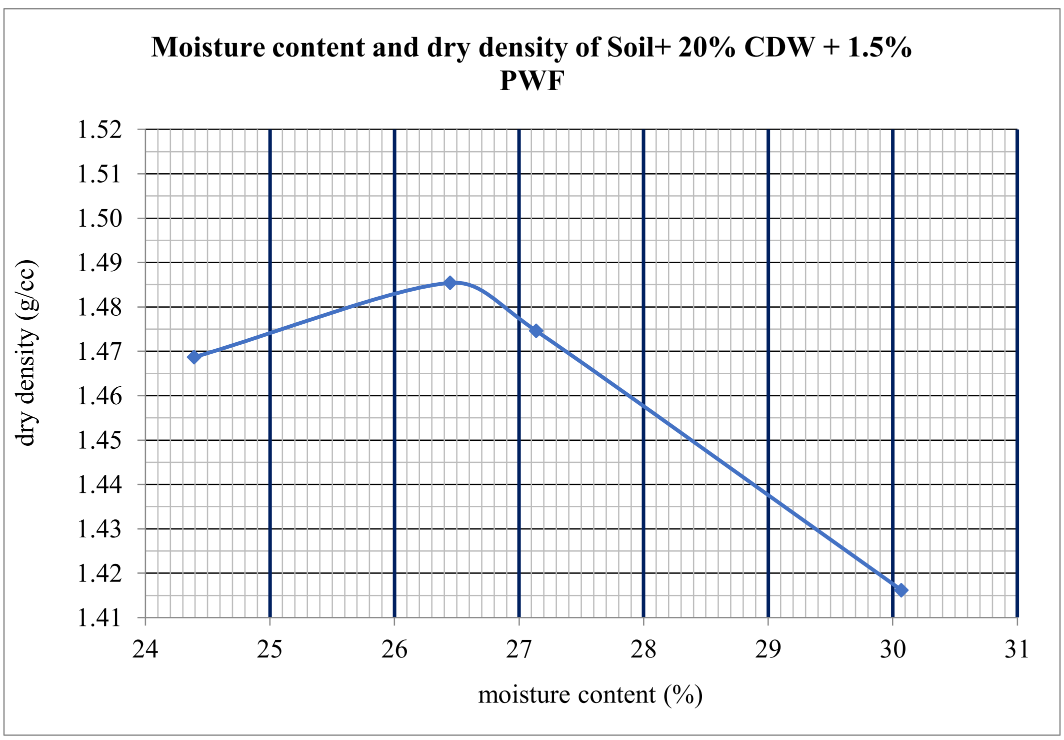


OMC (%)	**26.60**
MDD (gm./cm^3)	**1.502**

C) Compaction Test Data Analysis of Soil + 20% CDW +1.5% PWF

Soil+20% CDW + 1.5% PWF	
Volume of Mold (cm^3)	2124
Mass of sample (g)	5000
Mass of Mold (g)	6545

Test No.	1		2		3		4	
Mass of mold + wet soil (g) (A)	10425.5		10534.5		10527		10457.5	
Mass of wet soil (g) A-B=C	3880.5		3989.5		3982		3912.5	
Bulk Density (g/cm^3) C/D=(E)	1.83		1.88		1.87		1.84	
moisture determination								
Container code	B8	TO	NO	C14	B12	T2D	4D	5CH
Mass of wet soil + container (g) (F)	198.83	138.41	154.64	98.94	129.12	112.74	180.61	196.84
Mass of dry soil + container (g) (G)	169.32	115.31	130.58	82.21	105.19	92.37	144.41	158.21
Mass of container (g) (H)	51.52	17.99	37.73	20.21	16.59	17.67	25.68	27.93
Mass of moisture (g) F-G=(I)	29.51	23.10	24.06	16.73	23.93	20.37	36.20	38.63
Mass of dry soil (g) G-H=(J)	117.8	97.32	92.85	62.00	88.60	74.70	118.73	130.28
Moisture content % (I/J)*100=K	25.05	23.74	25.91	26.98	27.01	27.27	30.49	29.65
Avg. moisture content % (L)	24.39		26.45		27.14		30.07	
Dry density g/cm^3 E/(100+L)*100	1.47		1.49		1.47		1.42	

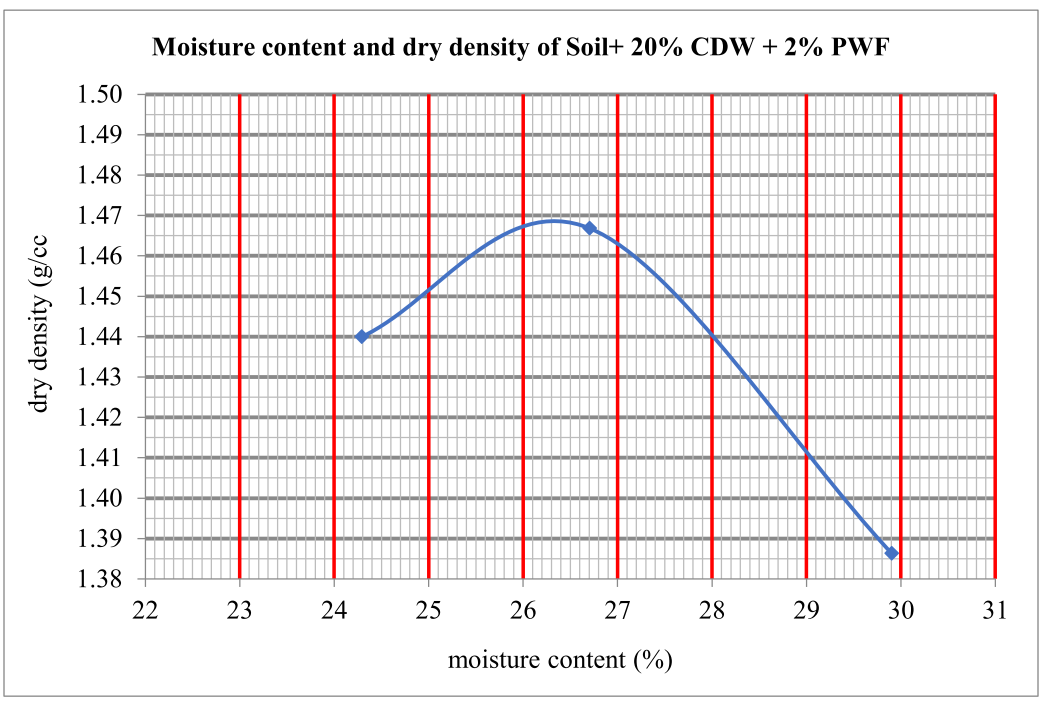


OMC (%)	**26.45**
MDD (gm./cm^3)	**1.485**

D) Compaction Test Data Analysis of Soil + 20% CDW +2% PWF

Soil+20% CDW + 2% PWF	
Mass of sample used (g)	5000
Volume of Mold (cm^3)	2124
Mass of Mold(g)	6611

Test No.	1		2		3	
Mass of mold + wet soil (g) (A)	10412.5		10558.5		10436	
Mass of wet soil (g) A-B=C	3801.5		3947.5		3825	
Bulk Density (g/cm^3) C/D=(E)	1.79		1.86		1.80	
	Moisture determination					
Container code	C14	2E	B12	G13	4F	NC41
Mass of wet soil + container (g) (F)	149.69	156.04	137.33	128.7	195.21	150.08
Mass of dry soil + container (g) (G)	124.38	129.32	111.67	105.24	157.08	119.22
Mass of container (g) (H)	20.21	19.32	16.59	16.46	27.74	17.46
Mass of moisture (g) F-G=(I)	25.31	26.72	25.66	23.46	38.13	30.86
Mass of dry soil (g) G-H=(J)	104.17	110	95.08	88.78	129.34	101.76
Moisture content % (I/J)*100=K	24.30	24.29	26.99	26.42	29.48	30.33
Avg. moisture content % (L)	24.29		26.71		29.90	
Dry density g/cm^3 E/(100+L)*100	1.44		1.47		1.39	



OMC (%)	**26.30**
MDD (gm./cm^3)	**1.469**

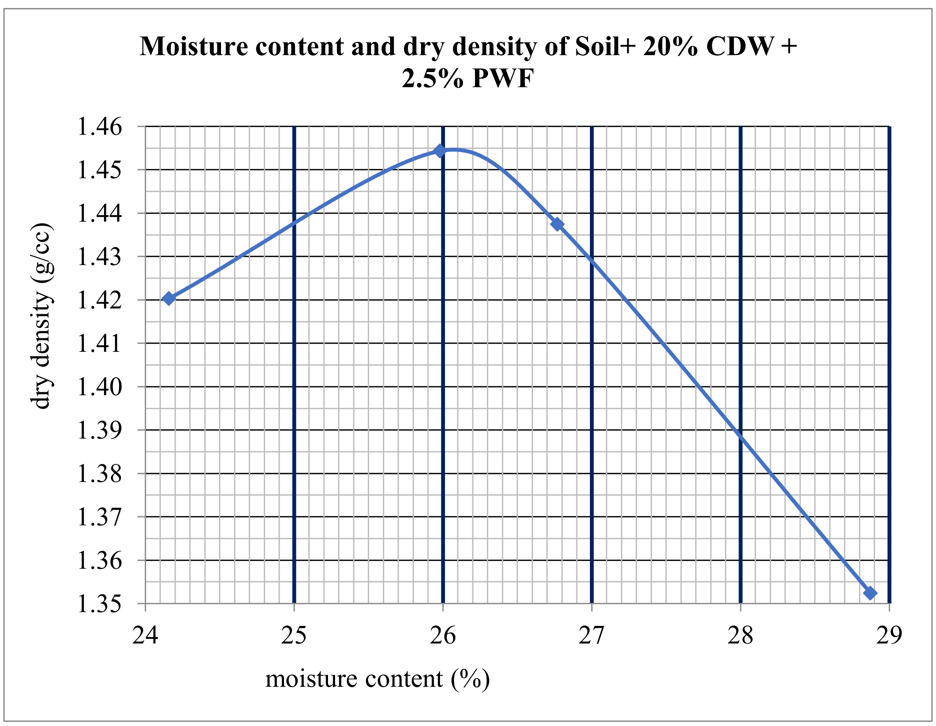
E) Compaction Test data analysis of Soil + 20% CDW +2.5% PWF

Soil+20% CDW + 2.5% PWF	
Mass of sample used (g)	5000
Volume of Mold (cm^3)	2124
Mass of Mold (g)	6679

Test No.	1	2	3	4
Mass of mold + wet soil (g) (A)	10424.5	10570.5	10549.5	10381
Mass of wet soil (g) A-B=C	3745.5	3891.5	3870.5	3702
Bulk Density (g/cm^3) C/D=(E)	1.76	1.83	1.82	1.74

moisture determination

Container code	TP3	A1	4T	N53	B33	C14	A17	5HY
Mass of wet soil + container (g) (F)	116.17	233.25	145.74	118.97	154.17	116.54	103.91	182.24
Mass of dry soil + container (g) (G)	97.10	198.24	119.32	98.14	127.17	96.15	85.32	147.12
Mass of container (g) (H)	17.57	54.39	17.52	18.05	26.01	20.21	19.65	27.82
Mass of moisture (g) F-G=(I)	19.07	35.01	26.42	20.83	27	20.39	18.59	35.12
Mass of dry soil (g) G-H=(J)	79.53	143.85	101.8	80.09	101.16	75.94	65.67	119.3
Moisture content % (I/J)*100=K	23.98	24.34	25.95	26.01	26.69	26.85	28.31	29.44
Avg. moisture content % (L)	24.16		25.98		26.77		28.87	
Dry density g/cm^3 E/(100+L)*100	1.42		1.45		1.44		1.35	



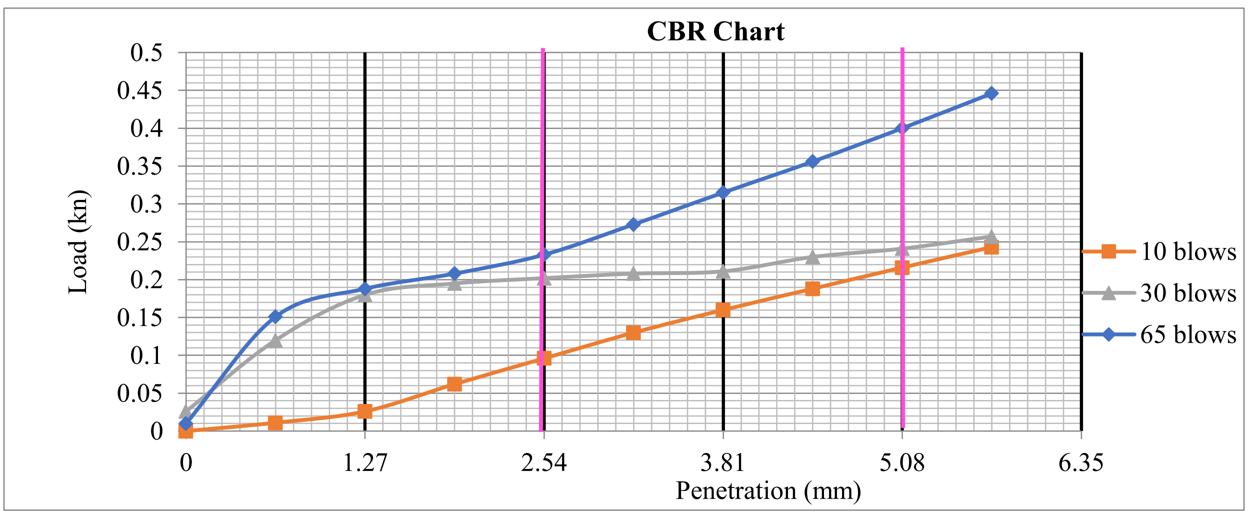
OMC (%)	**26.10**
MDD (g/cc)	**1.455**

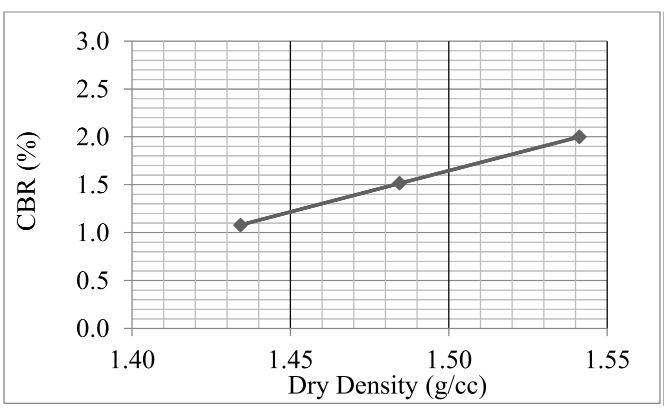
Appendix C-6: California Bearing Ratio Test Data Analysis (S01+CDW): (ASTM D-1883)

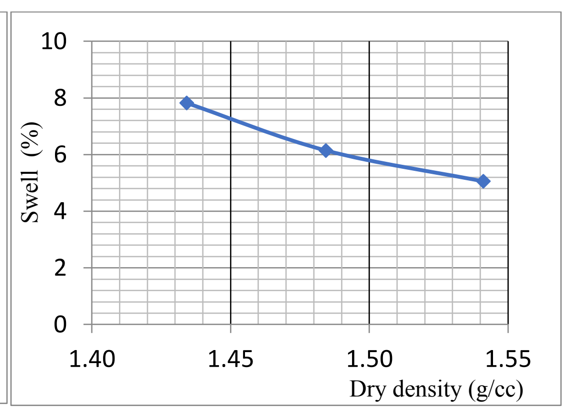
A) CBR test result summary of Soil + 5% CDW

Penetration and load determination of soil + 5% CDW						
Penetration and load data after 96-hours soaking						
	Number of Blows					
	10 blows		30 blows		65 blows	
Penetration (mm)	Load (kn)	CBR %	Load (kn)	CBR %	Load (kn)	CBR %
@2.54	0.096	0.72	0.202	1.51	0.233	1.75
@5.08	0.216	1.08	0.241	1.21	0.40	2.00

MMDD (g/cc)	1.600		
Dry Density at 95% of MDD	1.520		
No of Blows	10	30	65
CBR values (%)	1.08	1.51	2.00
CBR swell (%)	7.82	6.14	5.05
DDBS (g/cc)	1.434	1.484	1.541
CBR (%) at 95% MDD and CBR swell (%)	1.82 and 6.14 respectively		



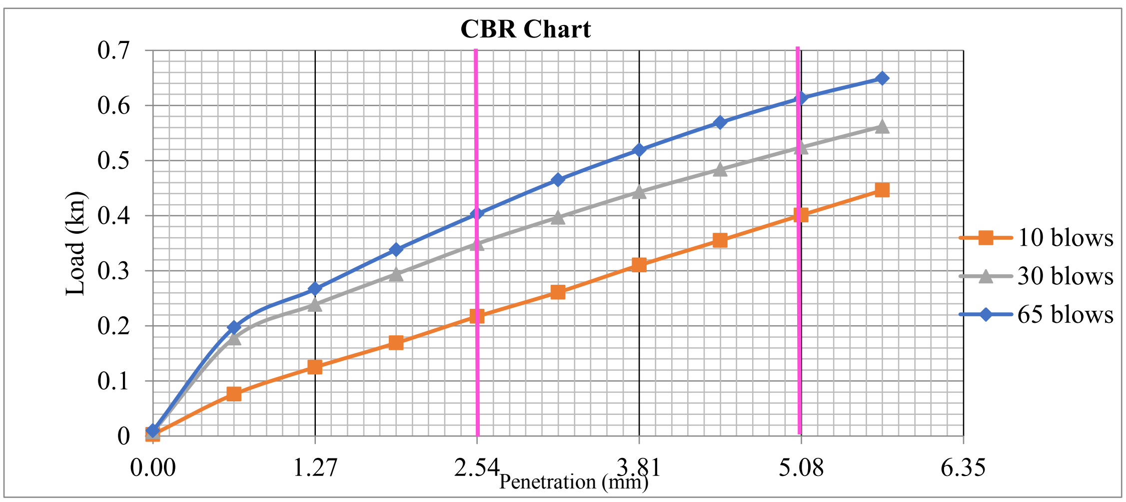


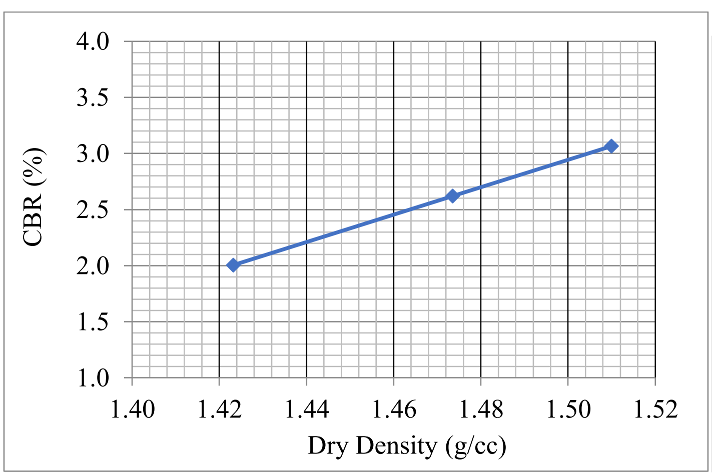


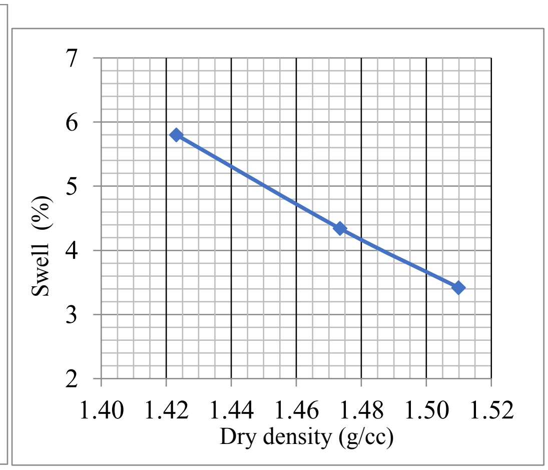
B) CBR test result summary of Soil + 10% CDW

Penetration and load determination of soil + 10% CDW						
Penetration and load data after 96-hours soaking						
	Number of Blows					
	10 blows		30 blows		65 blows	
Penetration (mm)	Load (kn)	CBR %	Load (kn)	CBR %	Load (kn)	CBR %
@2.54	0.217	1.63	0.349	2.62	0.403	3.02
@5.08	0.401	2.01	0.524	2.62	0.613	3.07

MMDD (g/cc)	1.576		
Dry Density at 95% of MDD	1.1.497		
No of Blows	10	30	65
CBR values (%)	2.01	2.62	3.07
CBR swell (%)	5.80	4.34	3.42
DDBS (g/cc)	1.423	1.474	1.510
CBR (%) at 95% MDD and CBR swell (%)	2.90 and 4.34 respectively		



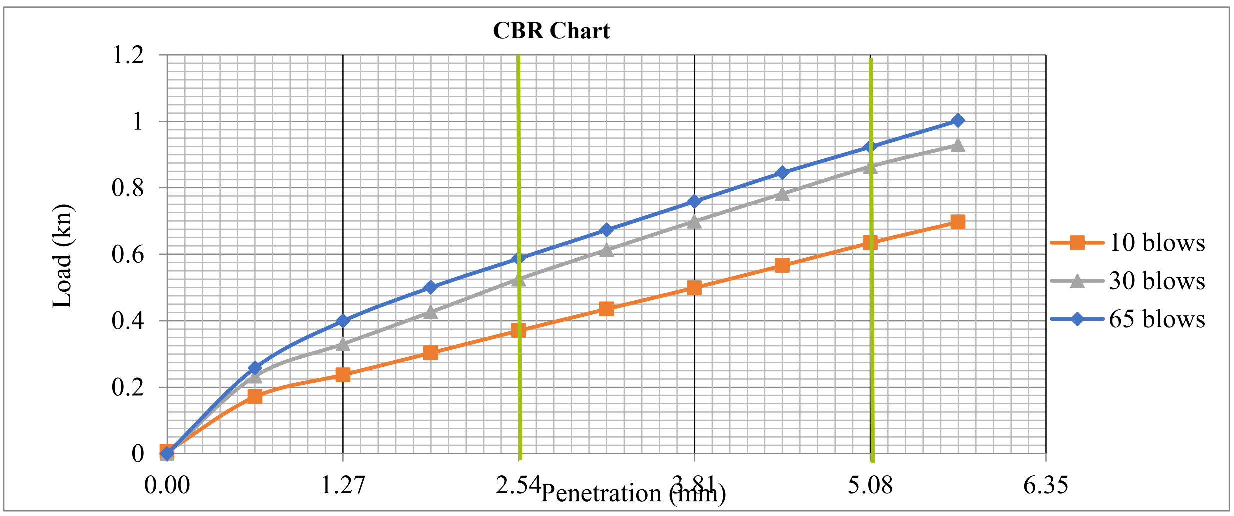


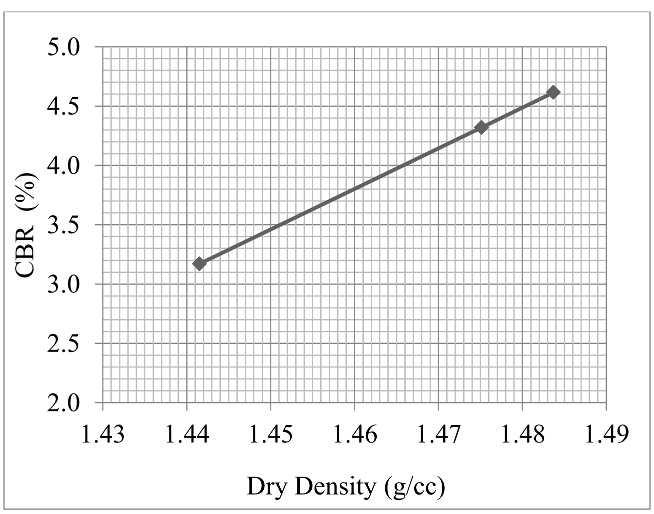


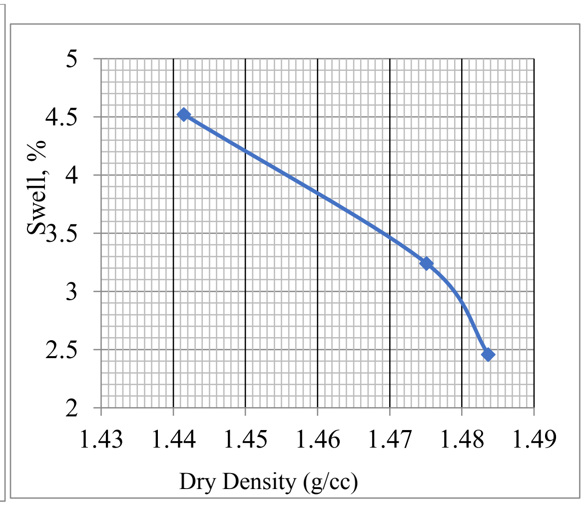
C) CBR test result summary of soil + 15% CDW

Penetration and load determination of soil + 15% CDW						
Penetration and load data after 96-hours soaking						
	Number of Blows					
	10 blows		30 blows		65 blows	
Penetration (mm)	Load (kn)	CBR %	Load (kn)	CBR %	Load (kn)	CBR %
@2.54	0.37	2.77	0.525	3.94	0.587	4.40
@5.08	0.634	3.17	0.864	4.32	0.923	4.62

MMDD (g/cc)	1.547		
Dry Density at 95% of MDD	1.470		
No of Blows	10	30	65
CBR values (%)	3.17	4.32	4.62
CBR swell (%)	4.52	3.24	2.46
DDBS (g/cc)	1.442	1.475	1.484
CBR (%) at 95% MDD and CBR swell (%)	4.13 and 3.24 respectively		



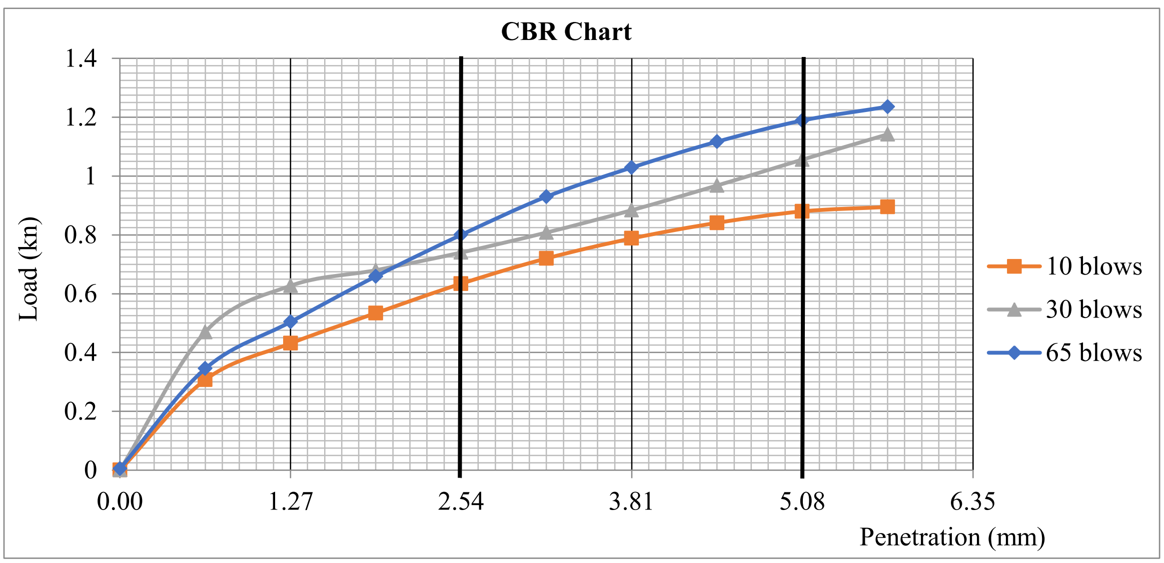


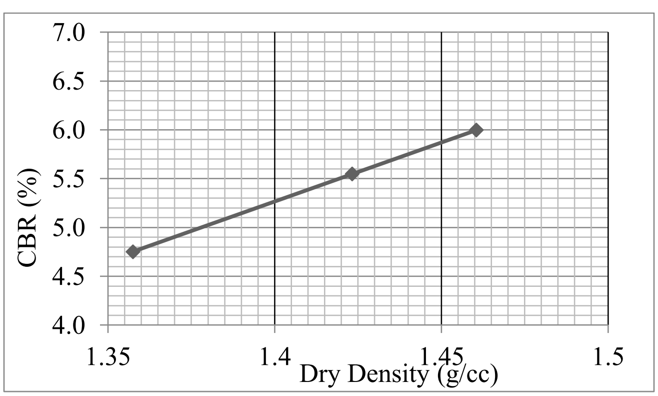


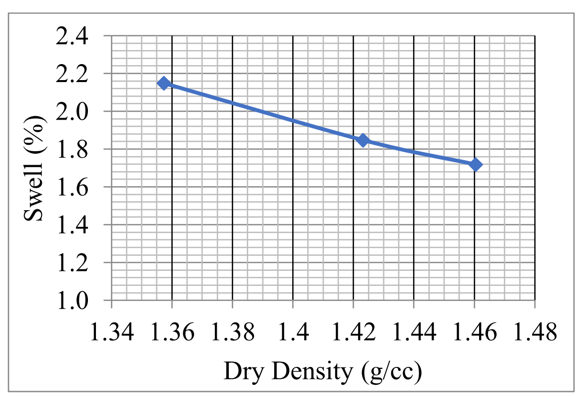
D) CBR test result summary of soil + 20% CDW

Penetration and load determination of Soil + 20 % CDW						
Penetration and load data after 96-hours soaking						
	Number of Blows					
	10 blows		30 blows		65 blows	
Penetration (mm)	Load (kn)	CBR %	Load (kn)	CBR %	Load (kn)	CBR %
@2.54	0.634	4.75	0.74	5.55	0.80	6.00
@5.08	0.88	4.40	1.056	5.28	1.189	5.95

MMDD (g/cc)	1.520		
Dry Density at 95% of MDD	1.444		
No of Blows	10	30	65
CBR values (%)	4.75	5.55	6.00
CBR swell (%)	2.148	1.847	1.718
DDBS (g/cc)	1.442	1.475	1.484
CBR (%) at 95% MDD and CBR swell (%)	5.80 and 1.847 respectively		



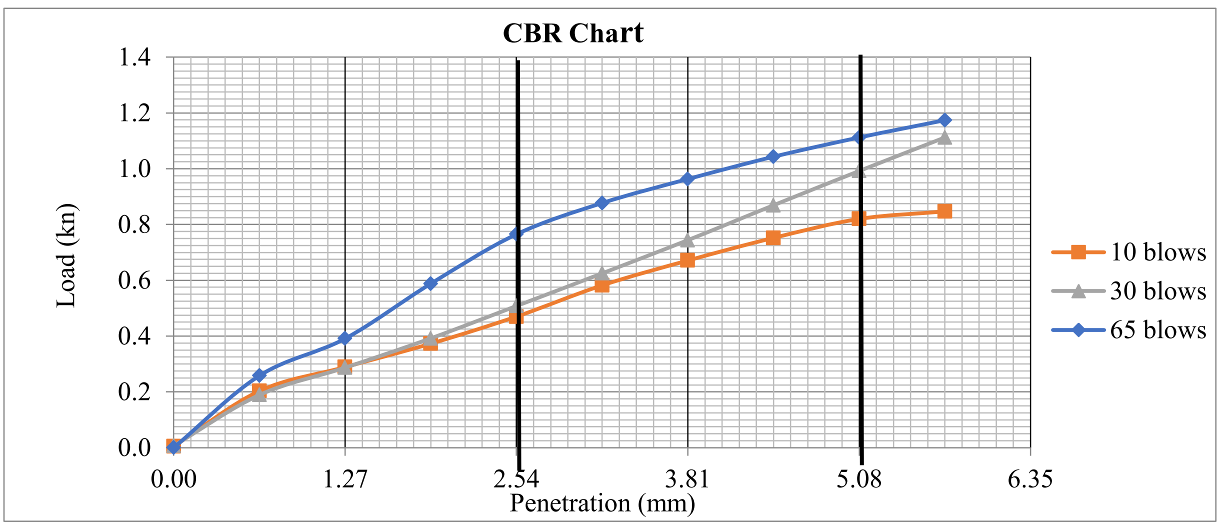


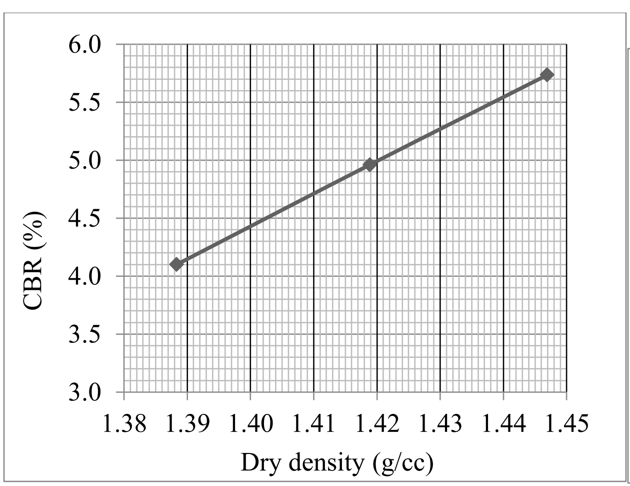


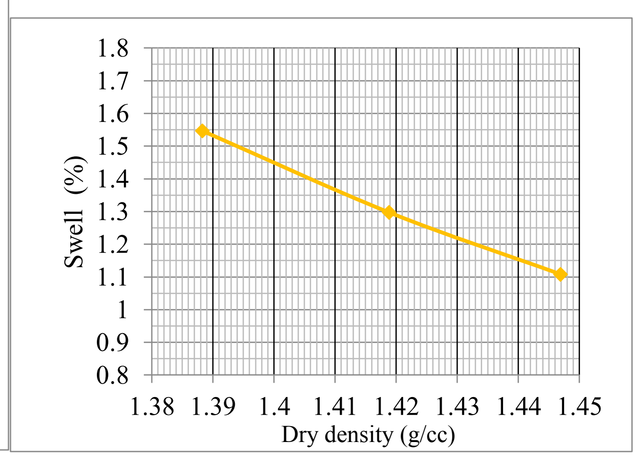
E) CBR test result summary of soil + 25% CDW

Penetration and load determination of soil + 25 % CDW						
Penetration and load data after 96-hours soaking						
	Number of Blows					
	10 blows		30blows		65 blows	
Penetration (mm)	Load (kn)	CBR %	Load (kn)	CBR %	Load (kn)	CBR %
@2.54	0.47	3.52	0.508	3.81	0.765	5.73
@5.08	0.82	4.10	0.992	4.96	1.112	5.56

MMDD (g/cc)	1.497		
Dry Density at 95% of MDD	1.422		
No of Blows	10	30	65
CBR values (%)	4.10	4.96	5.73
CBR swell (%)	1.55	1.30	1.11
DDBS (g/cc)	1.388	1.419	1.447
CBR (%) at 95% MDD and CBR swell (%)	5.05 and 1.30 respectively		



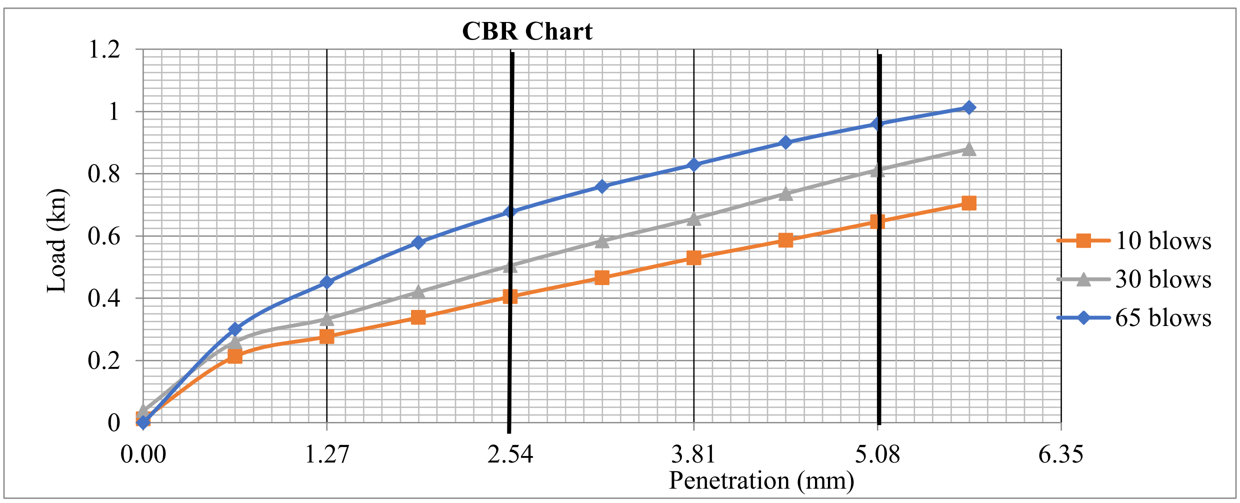


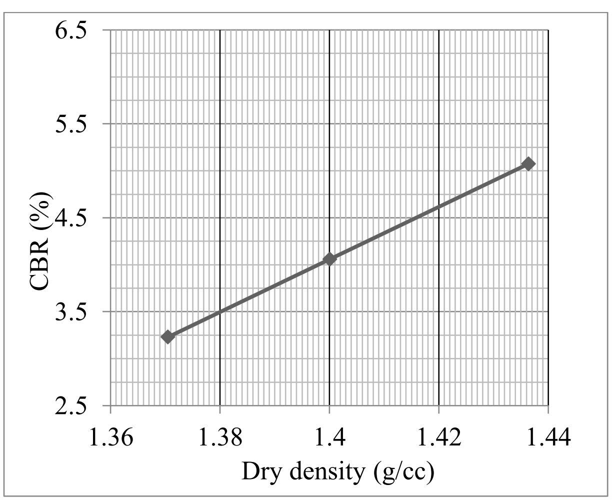


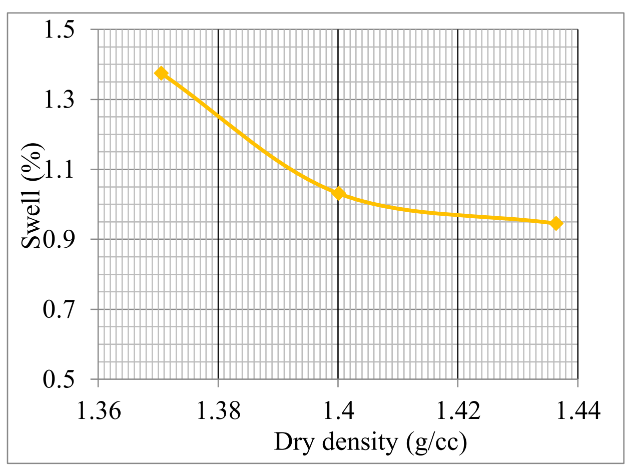
F) CBR test result summary of soil + 30% CDW

Penetration and load determination of Soil + 30 % CDW						
Penetration and load data after 96-hours soaking						
	Number of Blows					
	10 blows		30blows		65 blows	
Penetration (mm)	Load (kn)	CBR %	Load (kn)	CBR %	Load (kn)	CBR %
@2.54	0.405	3.04	0.505	3.79	0.677	5.07
@5.08	0.646	3.23	0.812	4.06	0.960	4.80

MMDD (g/cc)	1.481		
Dry Density at 95% of MDD	1.407		
No of Blows	10	30	65
CBR values (%)	3.23	4.06	5.07
CBR swell (%)	1.37	1.03	0.95
DDBS (g/cc)	1.37	1.400	1.436
CBR (%) at 95% MDD and CBR swell (%)	4.25 and 1.03 respectively		





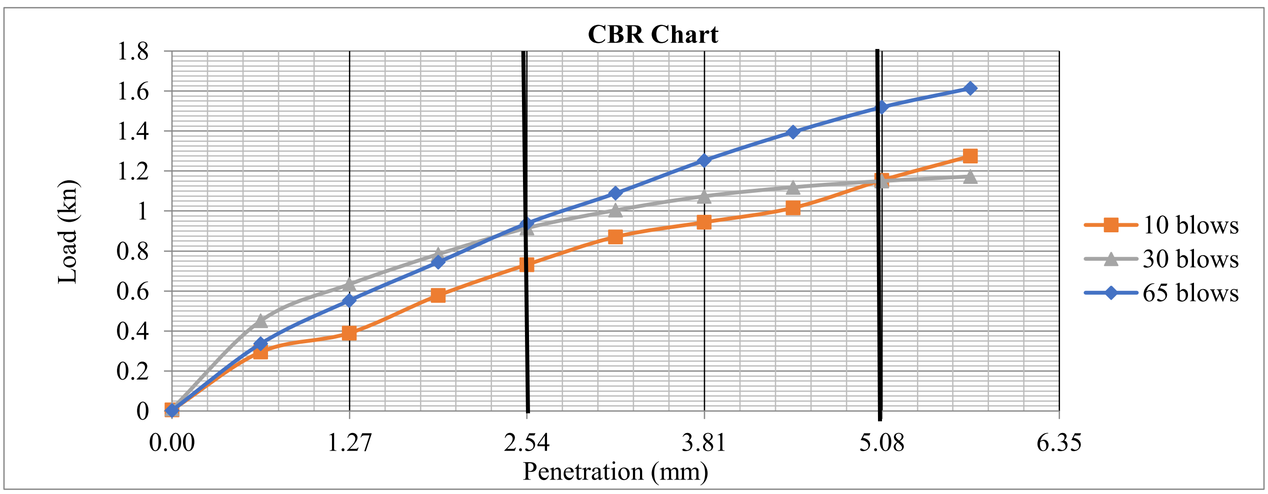


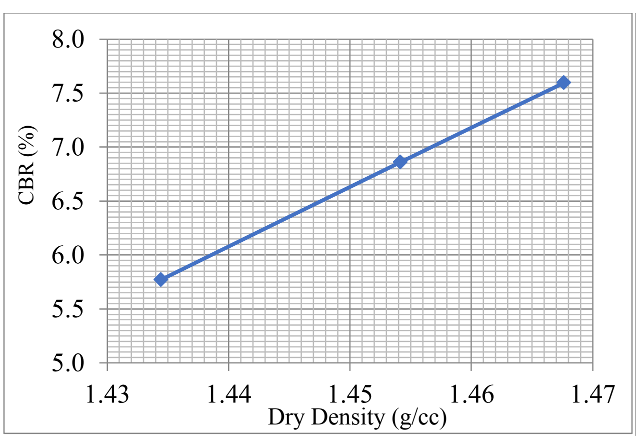
Appendix C-7: California Bearing Ratio Test Data Analysis (S01+CDW+PWF): (ASTM D-1883)

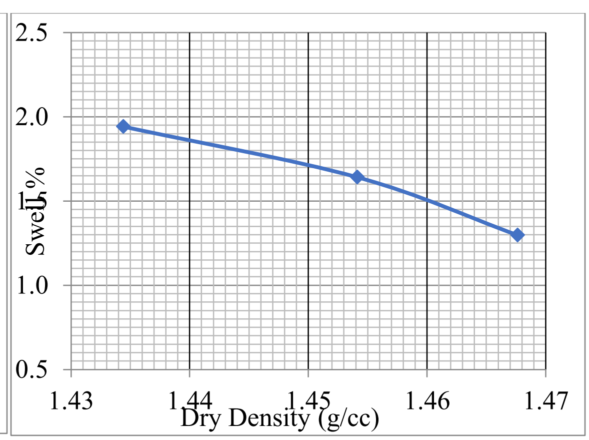
A) CBR test result summary of soil + 20% CDW + 0.5 % PWF

Penetration and load determination of Soil + 20% CDW + 0.5 % PWF						
Penetration and load data after 96-hours soaking						
	Number of Blows					
	10 blows		30 blows		65 blows	
Penetration (mm)	Load (kn)	CBR %	Load (kn)	CBR (%)	Load (kn)	CBR (%)
@2.54	0.732	5.49	0.915	6.86	0.938	7.03
@5.08	1.154	5.77	1.15	5.75	1.519	7.60

MMDD (g/cc)	1.519		
Dry Density at 95% of MDD	1.443		
No of Blows	10	30	65
CBR values (%)	5.77	6.86	7.60
CBR swell (%)	1.942	1.641	1.297
DDBS (g/cc)	1.434	1.454	1.468
CBR (%) at 95% MDD and CBR swell (%)	6.25 and 1.64 respectively		



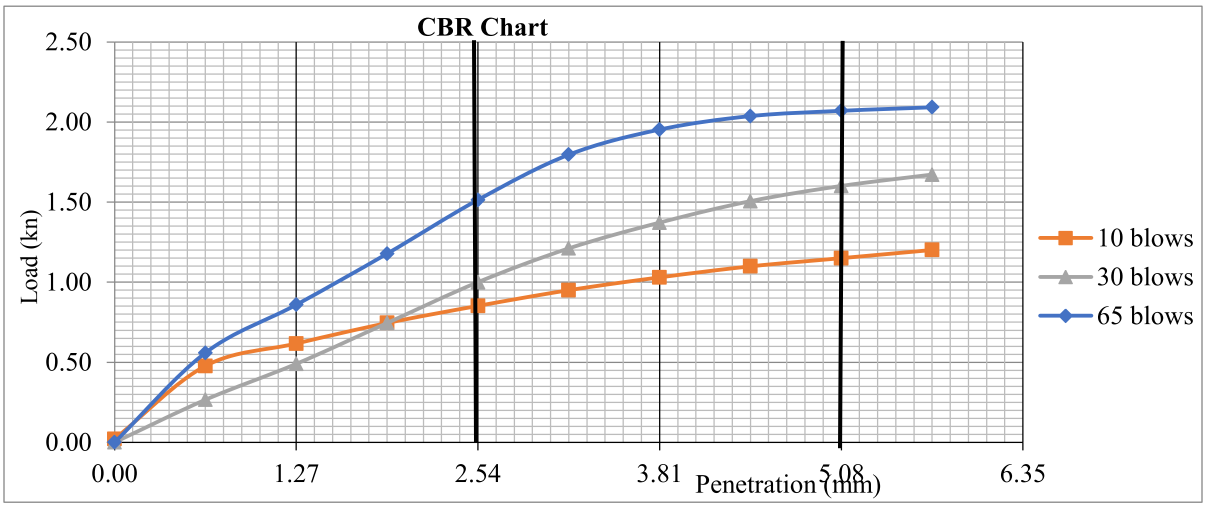


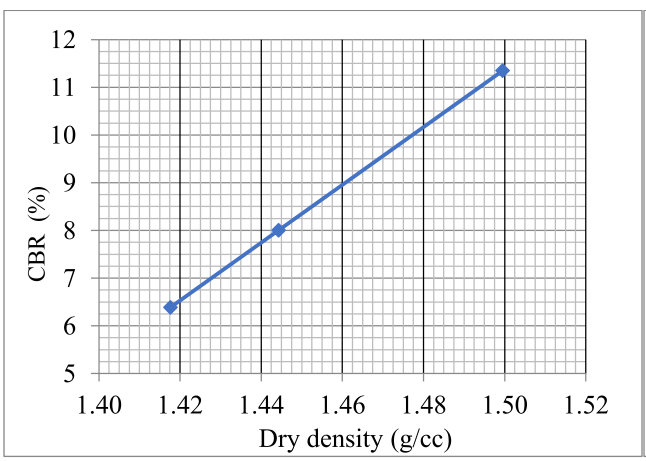


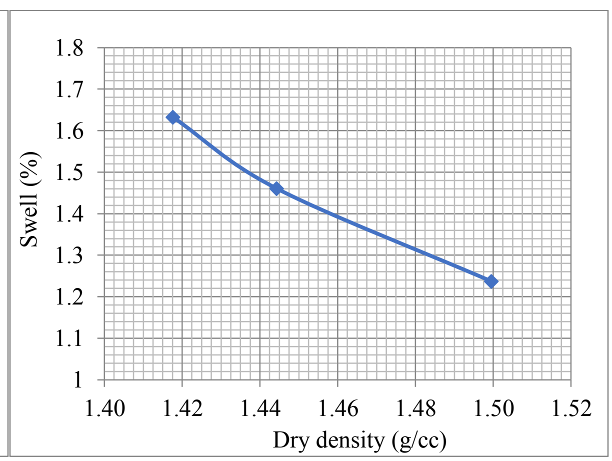
B) CBR test result summary of soil + 20% CDW + 1 % PWF

Penetration and load determination of Soil + 20% CDW + 1 % PWF						
Penetration and load data after 96-hours soaking						
	Number of Blows					
	10 blows		30 blows		65 blows	
Penetration (mm)	Load (kn)	CBR %	Load (kn)	CBR (%)	Load (kn)	CBR (%)
@2.54	0.852	6.39	1.00	7.50	1.514	11.35
@5.08	1.15	5.75	1.601	8.01	2.07	10.35

MMDD (g/cc)	1.502		
Dry Density at 95% of MDD	1.427		
No of Blows	10	30	65
CBR values (%)	6.39	8.01	11.35
CBR swell (%)	1.632	1.460	1.237
DDBS (g/cc)	1.418	1.444	1.500
CBR (%) at 95% MDD and CBR swell (%)	6.95 and 1.46 respectively		



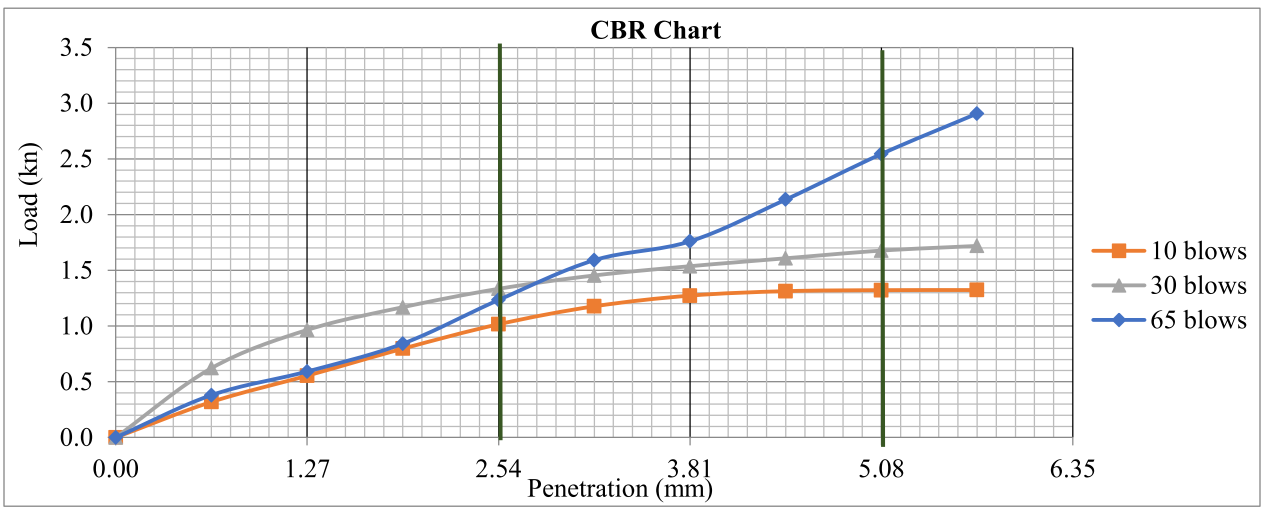


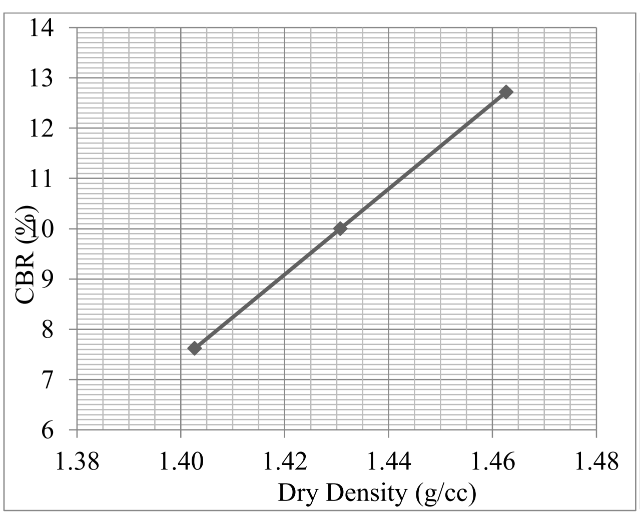


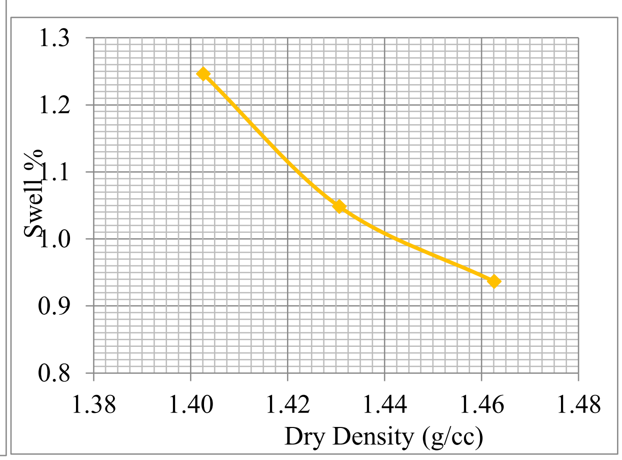
C) CBR test result summary of soil + 20% CDW + 1.5 % PWF

Penetration and load determination of soil + 20% CDW + 1.5 % PWF						
Penetration and load data after 96-hours soaking						
	Number of Blows					
	10 blows		30 blows		65 blows	
Penetration (mm)	Load (kn)	CBR (%)	Load (kn)	CBR (%)	Load (kn)	CBR (%)
@2.54	1.016	7.62	1.334	10.00	1.234	9.25
@5.08	1.322	6.61	1.677	8.39	2.544	12.72

MMDD (g/cc)	1.485		
Dry Density at 95% of MDD	1.411		
No of Blows	10	30	65
CBR values (%)	7.62	10.00	12.72
CBR swell (%)	1.246	1.048	0.936
DDBS (g/cc)	1.403	1.431	1.463
CBR (%) at 95% MDD and CBR swell (%)	8.30 and 1.05 respectively		



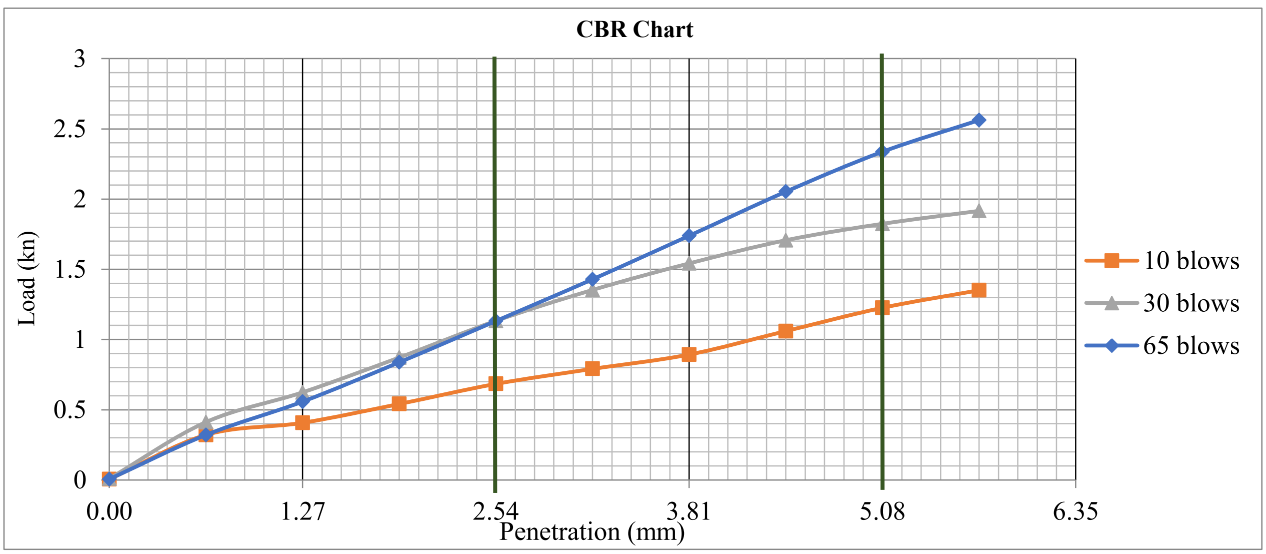


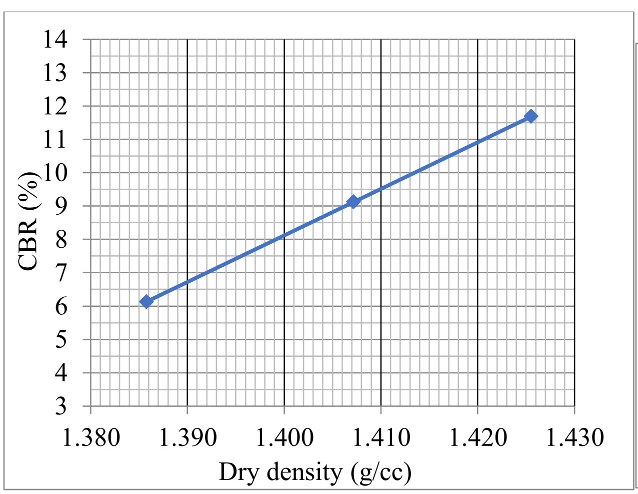


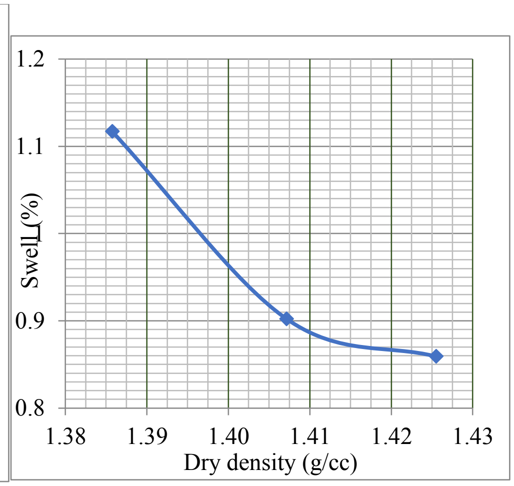
D) CBR test result summary of soil + 20% CDW + 2 % PWF

Penetration and load determination of soil + 20% CDW + 2 % PWF						
Penetration and load data after 96-hours soaking						
	Number of Blows					
	10 blows		30 blows		65 blows	
Penetration (mm)	Load (kn)	CBR %	Load (kn)	CBR (%)	Load (kn)	CBR (%)
@2.54	0.684	5.13	1.133	8.49	1.132	8.49
@5.08	1.226	6.13	1.824	9.12	2.337	11.69

MMDD (g/cc)	1.469		
Dry Density at 95% of MDD	1.396		
No of Blows	10	30	65
CBR values (%)	6.13	9.12	11.69
CBR swell (%)	1.12	0.90	0.86
DDBS (g/cc)	1.386	1.407	1.426
CBR (%) at 95% MDD and CBR swell (%)	7.50 and 0.90 respectively		



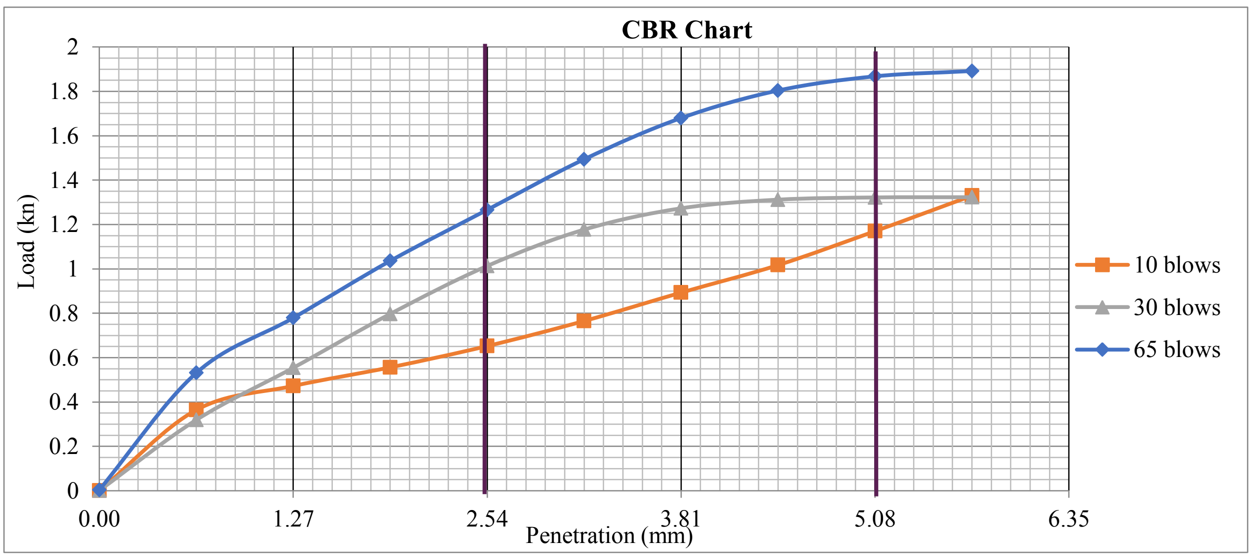


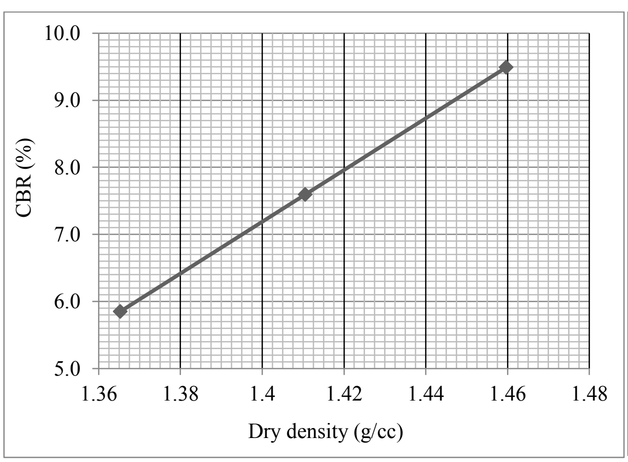


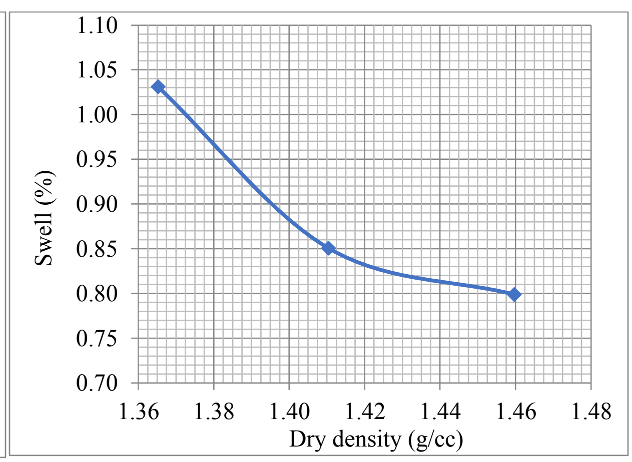
E) CBR test result summary of soil + 20% CDW + 2.5 % PWF

penetration and load determination of soil + 20% CDW + 2.5 % PWF						
Penetration and load data after 96-hours soaking						
	Number of Blows					
	10 blows		30 blows		65 blows	
Penetration (mm)	Load (kn)	CBR %	Load (kn)	CBR (%)	Load (kn)	CBR (%)
@2.54	0.652	4.89	1.013	7.59	1.266	9.49
@5.08	1.17	5.85	1.322	6.61	1.868	9.34

MMDD (g/cc)	1.455		
Dry Density at 95% of MDD	1.382		
No of Blows	10	30	65
CBR values (%)	5.85	7.59	9.49
CBR swell (%)	1.03	0.85	0.80
DDBS (g/cc)	1.365	1.411	1.460
CBR (%) at 95% MDD and CBR swell (%)	6.50 and 0.85 respectively		

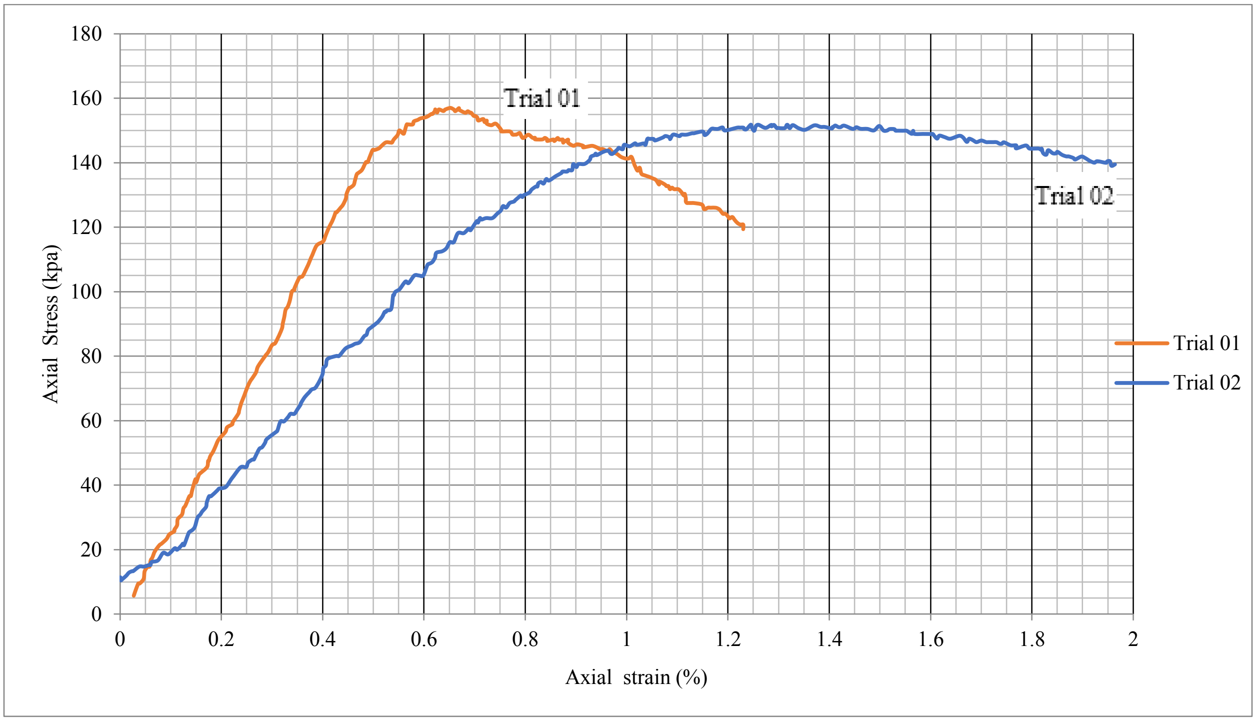






Appendix C-8: Unconfined Compression strength Test Data Analysis According to ASTM D-2166 (Immediate): Soil Sample One Stabilized with CDW

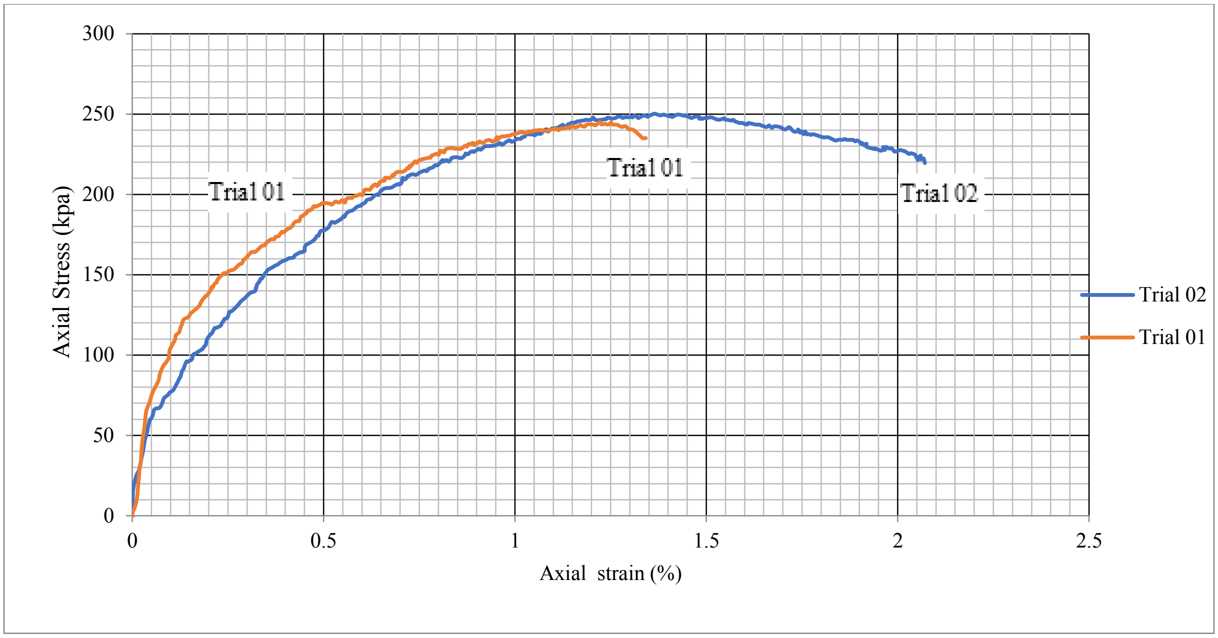
A) UCS test result summary data of Soil Sample 01+ 5% CDW (immediate test)



Sample information	Trial number: 01	Trial number:02
	Sample Type	
	Remolded (Immediate) (soil sample 01 + 5% CDW)	**Remolded** (Immediate) (soil sample 01 + 5% CDW)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	83	76
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	94.132	86.20
Axial stress (qu) (kpa)	156.96	151.79
Shear stress (Su) or Cohesion (C) (kpa)	78.48	75.90
Corrected Area at peak qu (mm^2)	1141.504	1148.380
Load at peak qu, (N)	179.17	174.312

Trial 01					Trial 02			
Axial strain %	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**		**Axial strain %**	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**
0.0271223	1134.3892	6.4759851	5.708786		0.0007629	1134.0902	12.951978	11.420589
0.0312943	1134.4365	8.6346492	7.6113992		0.0015158	1134.0987	11.872657	10.468804
0.0361626	1134.4918	10.793291	9.5137677		0.0380767	1134.5135	16.729631	14.746083
0.0486799	1134.6338	15.110634	13.317631		0.1218394	1135.4649	24.284936	21.387659
0.0549385	1134.7049	16.729616	14.743583		0.1759077	1136.08	41.55425	36.576871
0.0820597	1135.0129	24.824612	21.871656		0.265774	1137.1036	55.04588	48.408851
0.0973598	1135.1867	28.062604	24.720695		0.2863332	1137.3381	60.442545	53.143868
0.1140491	1135.3764	33.459269	29.469759		0.3571561	1138.1465	74.473836	65.434316
0.1397799	1135.6689	41.554235	36.590096		0.392954	1138.5555	82.029141	72.046678
0.1502117	1135.7876	46.411239	40.862604		0.427216	1138.9473	91.203459	80.076981
0.1557752	1135.8509	49.109541	43.235905		0.4820472	1139.5748	98.219104	86.189257
0.1752463	1136.0724	53.966545	47.502733		0.5178452	1139.9849	105.23478	92.312436
0.1835915	1136.1674	57.204537	50.348687		0.542972	1140.2729	113.86941	99.861542
0.2218396	1136.6029	66.918515	58.875895		0.5901939	1140.8145	119.80573	105.01771
0.2350531	1136.7535	71.775489	63.140769		0.6358799	1141.339	128.44038	112.53482
0.2510473	1136.9357	79.870485	70.250658		0.6907112	1141.9692	135.99569	119.08875
0.260784	1137.0467	83.108477	73.091523		0.7516359	1142.6702	143.01133	125.15539
0.2872099	1137.3481	91.203444	80.189562		0.7942802	1143.1614	147.86834	129.35036
0.3198945	1137.721	100.91742	88.701378		0.8239846	1143.5038	151.64599	132.6152
0.3310215	1137.848	108.47276	95.331499		0.8711965	1144.0484	156.50296	136.7975
0.3442339	1137.9989	114.94874	101.00954		0.8856723	1144.2155	157.58231	137.72083
0.3769197	1138.3722	125.74205	110.45776		0.9214602	1144.6288	160.28064	140.02849
0.3908272	1138.5312	130.59905	114.70837		0.9633416	1145.1128	164.59796	143.73951
0.412386	1138.7777	136.53535	119.8964		0.9922831	1145.4476	165.13762	144.16864
0.5605112	1140.474	169.99462	149.05612		1.0204616	1145.7737	166.75663	145.54064
0.5674649	1140.5537	173.23261	151.88466		1.0532078	1146.1529	168.91527	147.37587
0.6224035	1141.1843	178.62925	156.52972		1.1331659	1147.0798	171.07394	149.13866
0.6502197	**1141.5038**	**179.16894**	**156.95869**		**1.2451172**	**1148.3802**	**174.31194**	151.7894
0.6592613	1141.6077	178.62925	156.47166		1.4492035	1150.7583	173.23261	150.53779
0.7009862	1142.0874	176.47061	154.51586		1.5657224	1152.1205	172.69292	149.89137
0.7524467	1142.6796	171.6136	150.18524		1.6045621	1152.5753	171.6136	148.89579
0.85537	1143.8658	168.37561	147.19875		1.6715803	1153.3609	168.91527	146.45483
0.9596836	1145.0706	164.59796	143.74482		1.7302162	1154.049	168.91527	146.3675
1.0215759	1145.7866	157.58231	137.53199		1.7880891	1154.7291	167.83595	145.3466
1.1022453	1146.7212	151.10633	131.77251		1.8284547	1155.2039	164.59796	142.4839
1.1829135	1147.6573	144.09068	125.55201		1.8680573	1155.6701	164.0583	141.95946
1.2135127	1148.0128	140.31303	122.22253		1.9152691	1156.2263	162.43929	140.49091

B) UCS test result summary data of soil sample 01 + 10% CDW (immediate test)

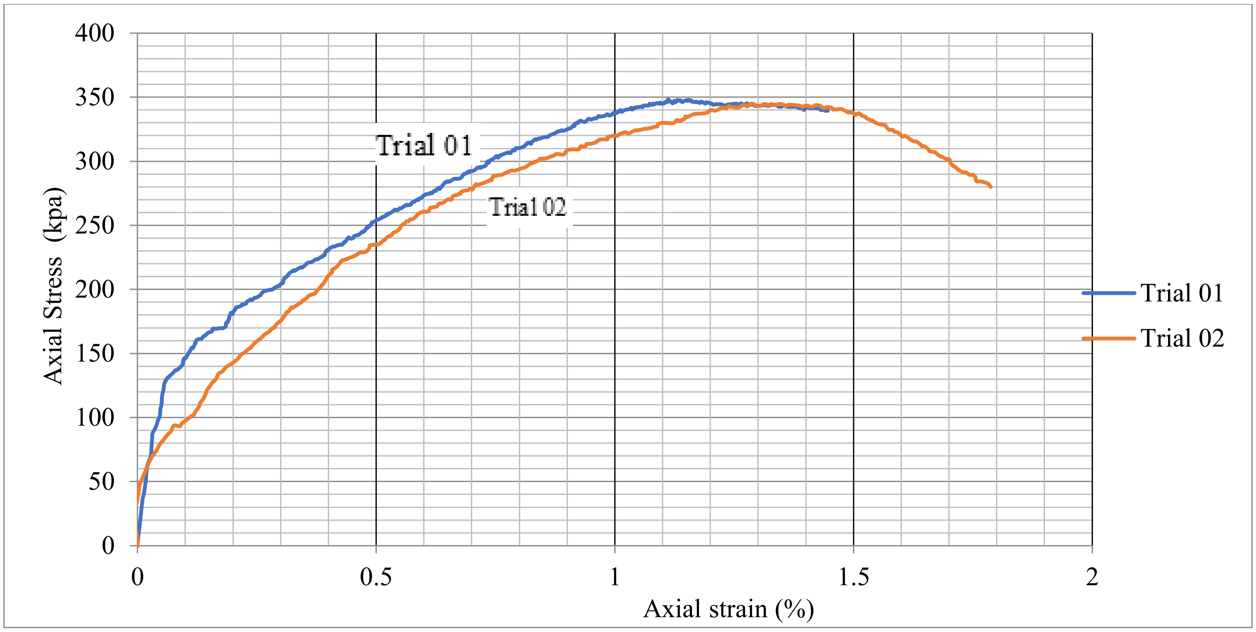


Sample information	Trial number: 01	Trial number:02
	Sample type	
	Remolded (Immediate) (soil sample 01 + 10% CDW)	**Remolded** (Immediate) (soil sample 01 +10 % CDW)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	81	78
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	91.863	88.461
Axial stress (qu) (kpa)	244.896	250.171
Shear stress (Su) (kpa)	122.448	125.086
Corrected Area at peak qu (mm^2)	1148.101	1149.780
Load at peak qu, (N)	281.165	287.641

Trial 01			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**
7.256E-39	1134.0815	-0.5396605	-0.4758569
0.0128664	1134.2274	13.491631	11.894996
0.0221535	1134.3328	37.776589	33.302916
0.0350104	1134.4787	71.235836	62.791691
0.0521625	1134.6734	86.346477	76.098091
0.0914585	1135.1197	109.55212	96.511512
0.1271848	1135.5257	133.83701	117.86348
0.1643428	1135.9483	145.70966	128.27138
0.2022166	1136.3794	158.66163	139.62029
0.2250766	1136.6398	167.83592	147.65972
0.2393746	1136.8027	171.6136	150.96164
0.3201143	1137.7235	186.72422	164.12091
0.3708451	1138.3028	195.89856	172.09705
0.3915669	1138.5396	201.29523	176.80125
0.4265773	1138.94	208.31087	182.89891
0.4494467	1139.2016	213.70754	187.59413
0.5073171	1139.8642	221.8025	194.58677
0.5380419	1140.2163	222.34216	194.99998
0.564481	1140.5195	225.58013	197.78717
0.6080722	1141.0197	231.51645	202.90311
0.6638044	1141.6599	240.15114	210.35261
0.6966673	1142.0377	244.46842	214.06335
0.7302555	1142.4241	249.32542	218.24244
0.8009922	1143.2388	256.88073	224.69561
0.8074254	1143.3129	259.57909	227.04116
0.8874493	1144.236	264.9757	231.57434
0.9424657	1144.8715	266.59474	232.85996
0.9567638	1145.0368	268.75338	234.71157
0.9703365	1145.1937	270.37236	236.09312
1.0517921	1146.1365	274.6897	239.66579
1.1332477	1147.0808	276.84835	241.35035
1.148968	1147.2632	278.46733	242.72314
1.1982765	1147.8357	279.54671	243.54243
1.2211364	**1148.1014**	**281.16569**	**244.89622**
1.2568627	1148.5168	279.54671	243.39802
1.2975905	1148.9907	276.30869	240.47948
1.3183123	1149.232	276.30869	238.42899

Trial 01			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**
7.535E-39	1134.0815	-1.0793209	-0.9517137
0.0007422	1134.0899	8.6346567	7.613732
0.0274548	1134.3929	44.792235	39.485643
0.0430364	1134.5698	64.759851	57.078773
0.0972039	1135.1849	86.886138	76.539191
0.1298525	1135.556	101.99675	89.820973
0.1832779	1136.1638	117.64705	103.54761
0.2151844	1136.5271	132.75769	116.80996
0.2515426	1136.9414	141.93201	124.8367
0.3116449	1137.6269	158.12197	138.99283
0.3442948	1137.9996	170.53425	149.85441
0.4251737	1138.9239	184.56554	162.05257
0.4830519	1139.5863	198.59689	174.27105
0.558737	1140.4536	214.24717	187.86136
0.6151285	1141.1007	224.50078	196.74054
0.6967508	1142.0387	235.83376	206.50243
0.7687263	1142.867	245.00811	214.38024
0.8058267	1143.2945	251.4841	219.96441
0.8614772	1143.9363	254.72206	222.67155
0.8837394	1144.1932	259.0394	226.39481
0.9126773	1144.5273	261.19804	228.21477
0.9980092	1145.5138	267.13437	233.20047
1.0180437	1145.7457	269.83267	235.50834
1.067757	1146.3214	272.53103	237.74399
1.0863072	1146.5364	274.15001	239.11148
1.1093103	1146.8031	276.84838	241.40881
1.1842544	1147.6729	282.78464	246.3983
1.2629081	1148.5871	284.40368	247.61177
1.2873931	1148.872	284.94334	248.02009
1.3497243	1149.5979	286.02266	248.80235
1.3653058	**1149.7795**	**287.64164**	**250.17114**
1.3794031	1149.9439	286.56232	249.19679
1.4113096	1150.316	285.483	248.17789
1.5745542	1152.2239	282.78464	245.42508
1.6643365	1153.2759	280.08634	242.86152
1.8743258	1155.7439	270.37239	233.93798
1.9121696	1156.1898	266.59471	230.5804

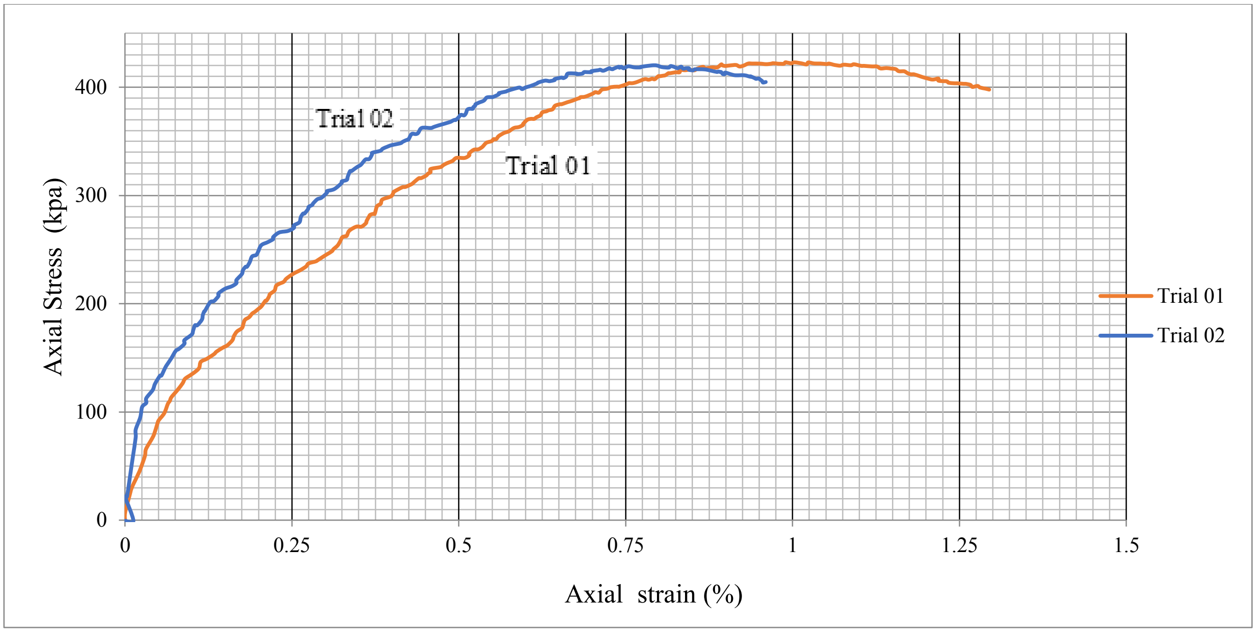
C) UCS test result summary data of soil sample 01+ 15% CDW (immediate test)



Sample information	Trial number: 01	Trial number:02
	Sample Type	
	Remolded (Immediate) (soil sample 01 + 15% CDW)	**Remolded** (Immediate) (soil sample 01 +15 % CDW)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	83	76
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	94.13	86.20
Axial stress (qu) (kpa)	348.16	344.800
Shear stress (Su) or Cohesion (C) (kpa)	174.08	172.40
Corrected Area at peak qu (mm^2)	1146.83	1148.82
Load at peak qu, (N)	399.28	396.114

Trial 01					Trial 02			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**		**Axial strain (%)**	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**
7.081E-39	1134.0815	-2.1789074	-1.921297		7.734E-39	1134.0815	-1.0793209	-0.9517137
7.081E-39	1134.0815	0.544697	0.480298		7.734E-39	1134.0815	4.8570037	4.2827642
0.0055732	1134.1447	21.788865	19.211715		-0.0053305	1134.0211	32.379925	28.553196
0.017416	1134.279	57.74048	50.905004		0.0038072	1134.1247	52.887231	46.632643
0.0278651	1134.3976	79.529345	70.107117		0.0388371	1134.5221	83.648145	73.72985
0.0383147	1134.5162	105.13127	92.666169		0.0883378	1135.0842	105.77443	93.186419
0.0508538	1134.6585	128.55431	113.2978		0.1203236	1135.4477	118.18674	104.08823
0.0592134	1134.7534	145.98539	128.64944		0.138599	1135.6555	130.59902	114.9988
0.0940449	1135.1491	160.14814	141.08116		0.1599237	1135.8981	145.70966	128.27706
0.1191237	1135.4341	177.57925	156.39768		0.2056147	1136.4181	164.0583	144.36438
0.1469888	1135.7509	188.47367	165.94631		0.2376004	1136.7825	175.93095	154.76219
0.1853035	1136.1869	196.64451	173.07409		0.2779609	1137.2426	191.04156	167.98664
0.1992358	1136.3455	205.36008	180.71976		0.3221311	1137.7465	211.54884	185.9367
0.2291909	1136.6867	216.2545	190.24988		0.3891468	1138.512	232.59577	204.29804
0.2870112	1137.3458	228.7831	201.15527		0.4317936	1138.9996	253.64277	222.68907
0.3148763	1137.6637	240.22225	211.154		0.5132776	1139.9325	270.91202	237.65619
0.3601574	1138.1807	251.66139	221.10846		0.5711555	1140.5961	290.33998	254.55109
0.4131013	1138.7858	265.82417	233.42771		0.6275077	1141.2429	302.21263	264.81008
0.4430558	1139.1285	273.99501	240.53039		0.6922396	1141.9868	316.78358	277.39689
0.4994829	1139.7745	289.24718	253.7758		0.7417403	1142.5563	325.95792	285.28828
0.5517299	1140.3733	300.1416	263.19593		0.8308411	1143.5829	342.14786	299.18939
0.5872583	1140.7808	308.31245	270.2644		0.865871	1143.987	347.54452	303.80112
0.6269662	1141.2367	317.57274	278.27071		0.9024244	1144.4089	353.48085	308.87634
0.6638872	1141.6608	326.83298	286.27852		0.9344101	1144.7784	356.71881	311.60511
0.7182242	1142.2857	336.638	294.70562		0.9633491	1145.1129	361.57581	315.75559
0.7426061	1142.5663	344.26406	301.30774		1.0516869	1146.1353	371.82948	324.42024
0.7830109	1143.0316	351.34545	307.38036		1.1049948	1146.7531	378.30546	329.8927
0.8255051	1143.5213	360.06102	314.8704		1.1461183	1147.2301	382.08309	333.04834
0.9160668	1144.5665	375.31319	327.9086		1.1979028	1147.8314	389.63845	339.45617
0.9564716	1145.0334	381.84986	333.48359		1.223795	1148.1323	392.33676	341.71738
1.0951002	1146.6383	396.55736	345.84345		1.2382633	1148.3005	393.95574	343.07722
1.1118194	**1146.8322**	**399.281**	**348.15991**		**1.2831939**	**1148.8231**	**396.11444**	**344.8002**
1.137595	1147.1312	398.73627	347.5943		1.3372647	1149.4527	395.03506	343.6723
1.1689433	1147.4951	397.64681	346.53466		1.4895715	1151.2299	389.09873	337.98526
1.2622914	1148.5799	395.46791	344.31031		1.5550639	1151.9958	378.84513	328.85982
1.3103589	1149.1393	394.92318	343.66866		1.6038041	1152.5664	368.0518	319.3324
1.3779318	1149.9267	394.37845	342.95964		1.6365503	1152.9501	362.11547	314.07731

D) **UCS test result summary data of soil sample 01+ 20% CDW (immediate test)**

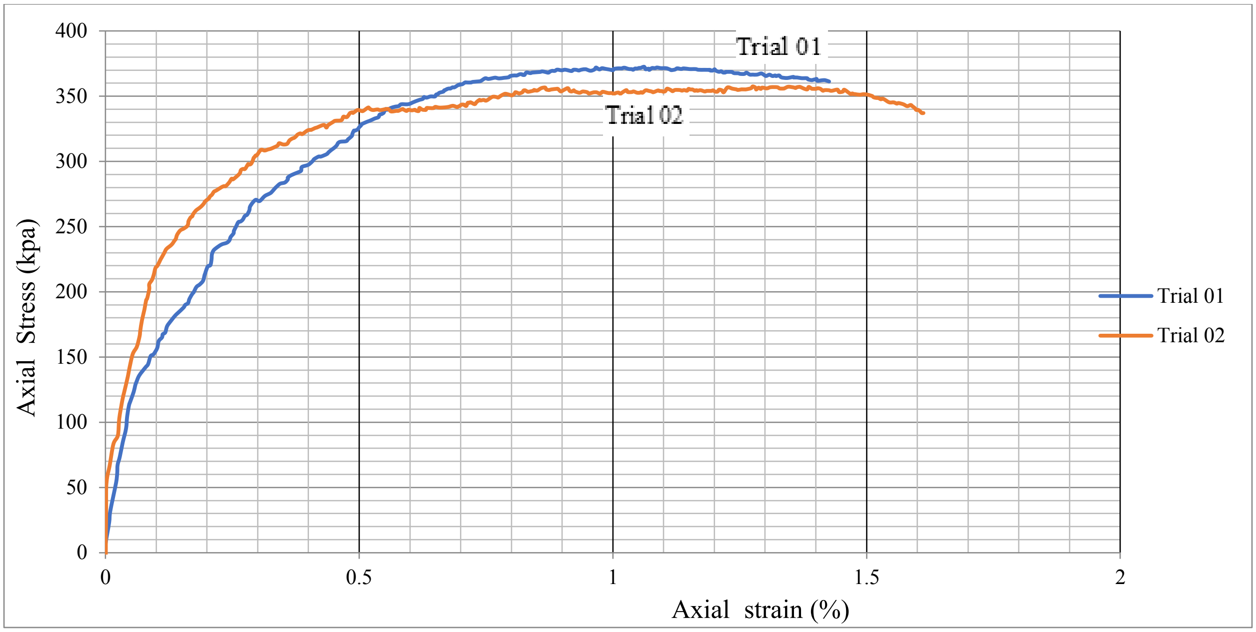


Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (Immediate) (soil sample 01 + 20% CDW)	**Remolded** (Immediate) (soil sample 01 +20 % CDW)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	76	84
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	86.20	95.265
Axial stress (qu) (kpa)	423.096	420.18
Shear stress (Su) or Cohesion (C) (kpa)	211.548	210.088
Corrected Area at peak qu (mm^2)	1145.41	1143.10
Load at peak qu, (N)	484.62	480.30

Trial 01			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**
7.734E-39	1134.0815	-1.0793507	-0.95174
0.0068539	1134.1592	26.443601	23.315598
0.0296994	1134.4184	67.458153	59.464966
0.0502611	1134.6518	104.69505	92.270645
0.0670157	1134.842	125.20239	110.32583
0.1073762	1135.3005	157.04259	138.32689
0.1370756	1135.6382	177.01027	155.86854
0.1774386	1136.0974	206.69183	181.93144
0.2101848	1136.4702	230.43713	202.76566
0.2376004	1136.7825	250.40475	220.27498
0.2749142	1137.2078	269.8327	237.2765
0.3122305	1137.6335	284.94331	250.47021
0.328985	1137.8248	298.43494	262.2855
0.3670617	1138.2596	321.10092	282.09814
0.3830533	1138.4423	332.97357	292.48172
0.4203696	1138.869	350.78248	308.00952
0.4759613	1139.5051	373.44846	327.72864
0.536886	1140.2031	394.4954	345.98696
0.5757231	1140.6485	410.14567	359.57236
0.6160862	1141.1117	424.71668	372.19553
0.6541629	1141.5491	438.74797	384.34438
0.6777713	1141.8204	444.6843	389.45204
0.7006168	1142.0831	450.08096	394.08774
0.7371702	1142.5037	457.63627	400.55561
0.7897176	1143.1088	466.27089	407.8972
0.8095164	1143.337	470.04858	411.11989
0.8308386	1143.5828	473.28654	413.86293
0.9001406	1144.3826	480.30218	419.70422
0.9267932	1144.6904	480.84185	420.06279
0.9511621	1144.972	483.00055	421.84484
0.9892413	**1145.4124**	**484.61953**	**423.09611**
1.0090401	1145.6415	484.07987	422.54045
1.0646318	1146.2852	481.92117	420.41994
1.16668	1147.4688	475.9849	414.81294
1.1940956	1147.7872	470.04858	409.5259
1.2466406	1148.3979	463.57259	403.66897
1.2694861	1148.6636	459.79491	400.28682

Trial 01			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**
6.997E-39	1134.0815	-1.6190112	-1.4275968
0.0124068	1134.2222	-0.5396605	-0.4757978
6.997E-39	1134.0815	24.824589	21.889599
0.0227429	1134.3395	107.93307	95.150593
0.0413441	1134.5506	136.53532	120.34309
0.0544321	1134.6991	151.64599	133.64423
0.0689007	1134.8634	169.4549	149.31744
0.0888824	1135.0904	188.88286	166.40336
0.1150676	1135.388	210.46951	185.37233
0.1192002	1135.4349	219.10414	192.96935
0.149518	1135.7797	242.84944	213.81738
0.1763934	1136.0855	262.27739	230.86062
0.2135958	1136.509	291.95896	256.89101
0.2611433	1137.0508	313.00589	275.27872
0.2818062	1137.2864	332.97357	292.77898
0.3321057	1137.8604	357.79813	314.44818
0.3603527	1138.183	379.38479	333.32495
0.412723	1138.7815	396.65404	348.31444
0.423059	1138.8997	400.43172	351.59524
0.4444122	1139.144	412.84403	362.41602
0.4692168	1139.4279	415.54233	364.69384
0.4995346	1139.7751	424.17702	372.15854
0.5126317	1139.9251	432.27199	379.21086
0.5243392	1140.0593	436.58927	382.95313
0.5298524	1140.1225	439.82729	385.77197
0.5560375	1140.4227	447.3826	392.29542
0.5705061	1140.5886	451.69994	396.02354
0.6042662	1140.976	457.09661	400.61894
0.6607691	1141.625	467.88988	409.8455
0.6945292	1142.0131	472.74688	413.95924
0.7537842	1142.695	479.22286	419.37952
0.7889248	**1143.0997**	**480.30218**	**420.17524**
0.8144197	1143.3935	478.14354	418.17934
0.8447284	1143.743	475.9849	416.1642
0.9129479	1144.5305	470.58824	411.1627
0.9501503	1144.9603	466.81055	407.70893
0.9556634	1145.0241	463.03293	404.38707

E) **UCS test result summary data of soil sample 01+ 25% CDW (immediate test)**

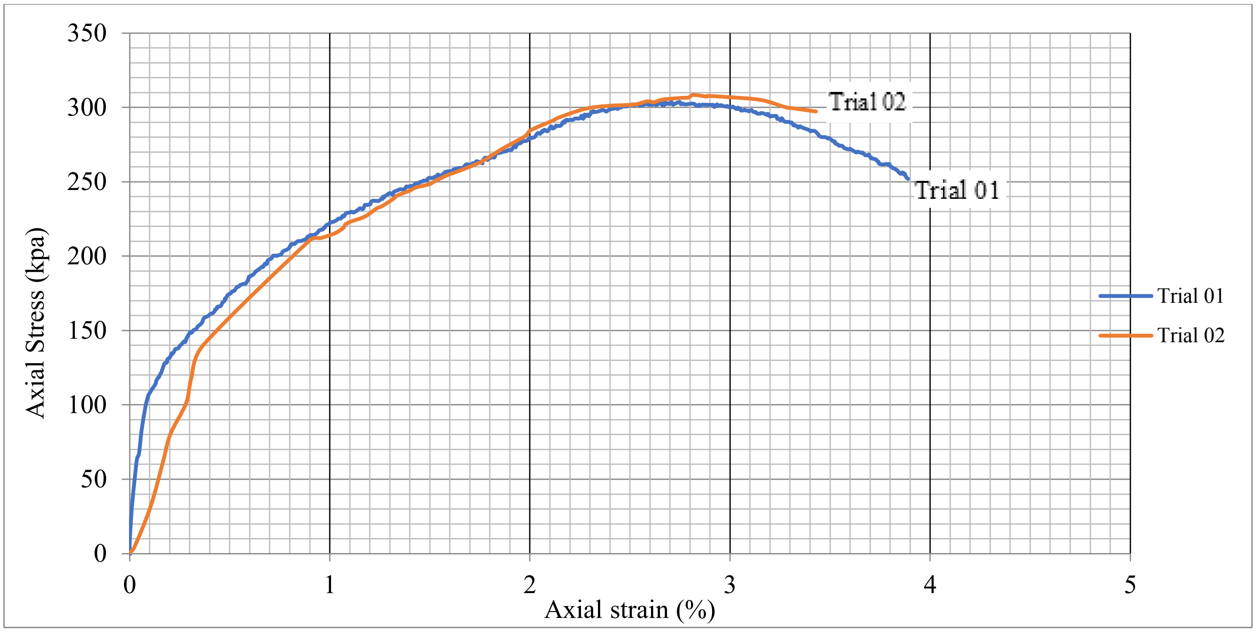


Sample information	Trial number: 01	Trial number:02
	Sample Type	
	Remolded (Immediate) (soil sample 01 + 25% CDW)	**Remolded** (Immediate) (soil sample 01 + 25 % CDW)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	80	85
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	90.73	96.40
Axial stress (qu) (kpa)	372.573	357.51
Shear stress (Su) or Cohesion (C) (kpa)	186.28	178.755
Corrected Area at peak qu (mm^2)	1146.25	1148.74
Load at peak qu, (N)	427.06	410.686

Trial 01			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**
7.347E-39	1134.0815	-1.0894537	-0.9606485
0.0209737	1134.3194	61.008841	53.784534
0.0282049	1134.4015	83.342403	73.468174
0.0426674	1134.5656	118.20459	104.18489
0.0607467	1134.7708	148.1643	130.5676
0.0947356	1135.1569	172.67677	152.1171
0.1113677	1135.3459	187.38428	165.04598
0.1424646	1135.6995	208.62839	183.70035
0.1721144	1136.0368	226.05947	198.98957
0.1981497	1136.3331	245.66945	216.19492
0.2444315	1136.8603	272.36083	239.57281
0.2791452	1137.2561	294.69445	259.12761
0.353632	1138.1062	323.01995	283.82233
0.4020834	1138.6599	339.36158	298.03595
0.4555988	1139.272	355.70326	312.21979
0.496819	1139.744	369.86604	324.51678
0.5315304	1140.1417	379.67101	333.00335
0.5517793	1140.3738	387.84185	340.10062
0.6002331	1140.9297	392.74433	344.23183
0.6551933	1141.5609	401.45984	351.67623
0.6877351	1141.935	407.45184	356.80826
0.7202792	1142.3093	411.80959	360.5062
0.7853627	1143.0587	416.16735	364.08223
0.797658	1143.2003	417.80153	365.46659
0.8056116	1143.292	418.34626	365.91375
0.8605742	1143.9258	422.15928	369.04428
0.8800983	1144.1512	422.70401	369.4477
0.9220433	1144.6355	423.79346	370.24315
0.9422922	1144.8695	424.33819	370.64328
0.9784508	1145.2876	425.42765	371.45923
1.0543823	1146.1665	425.97237	371.64965
1.0616136	**1146.2502**	**427.06177**	**372.57289**
1.115129	1146.8706	424.33819	369.99658
1.2214351	1148.1049	422.70401	368.17544
1.2510848	1148.4496	421.61456	367.1163
1.3320804	1149.3923	418.89098	364.4456
1.41886	1150.4041	416.71208	362.23103

Trial 01			
Axial strain %	**Ac (mm^2)**	**F (N)**	**Axial stress (kpa)**
0.0006788	1134.0892	-1.0793209	-0.9517072
0.0013576	1134.0969	36.157548	31.882239
0.0081489	1134.1739	75.553119	66.615109
0.0244466	1134.3588	101.99678	89.915799
0.0441394	1134.5823	153.26494	135.0849
0.0672273	1134.8444	188.34323	165.96392
0.0767338	1134.9524	211.54881	186.39443
0.0862402	1135.0604	229.35778	202.06659
0.1079705	1135.3073	254.72206	224.36398
0.136491	1135.6315	271.99137	239.50671
0.1609376	1135.9096	284.40368	250.37528
0.1677278	1135.9869	291.95899	257.00912
0.1942107	1136.2883	304.3713	267.8645
0.2186573	1136.5667	315.70423	277.77009
0.2485354	1136.9071	325.95789	286.70583
0.2899585	1137.3794	341.60817	300.34671
0.3503945	1138.0692	356.17918	312.96794
0.3762122	1138.3642	363.73448	319.52384
0.4054911	1138.6988	369.13115	324.16925
0.4388551	1139.0804	373.44843	327.85081
0.468134	1139.4155	380.46408	333.91162
0.4824335	1139.5792	384.24176	337.17863
0.5879739	1140.789	387.47972	339.6594
0.6397225	1141.3832	389.09876	340.90108
0.6635542	1141.657	389.63842	341.29202
0.7078137	1142.1659	391.79707	343.02991
0.7193891	1142.2991	394.49543	345.35214
1.0128593	1145.6857	403.66971	352.33897
1.2089606	1147.9599	407.4474	354.93174
1.255262	1148.4982	407.98706	355.23527
1.2722846	1148.6962	409.06638	356.11364
1.2756897	**1148.7358**	**410.68536**	**357.51072**
1.3934865	1150.1081	409.06638	355.67646
1.4248085	1150.4735	407.98706	354.62533
1.4459161	1150.7199	406.36802	353.14241
1.4949417	1151.2927	404.74904	351.56051
1.5194545	1151.5792	401.51107	348.66127

F) **UCS test result summary data of soil sample 01 + 30% CDW (immediate test)**

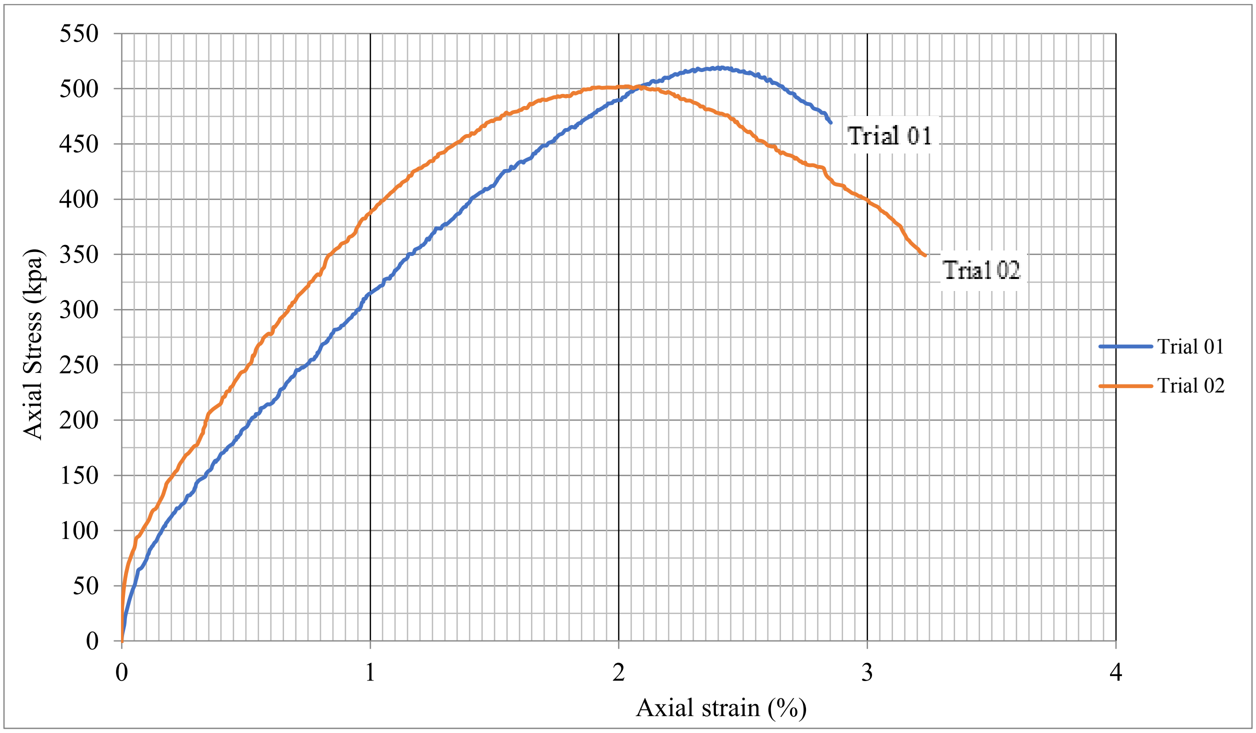


Sample information	Trial number: 01	Trial number:02
	Sample Type	
	Remolded (Immediate) (soil sample 01 + 30% CDW)	**Remolded** (Immediate) (soil sample 01 + 30 % CDW)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	84	76
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	95.27	86.20
stress (Peak, qu) (kpa)	303.76	308.46
Cohesion (kpa)	151.88	154.23
Corrected Area at peak qu (mm^2)	1165.63	1166.945
Load at peak qu, F, (N)	354.07	359.96

Trial 01					Trial 02			
Axial strain %	**Ac (mm²)**	**F (N)**	**Axial stress (kpa)**		**Axial strain %**	**Ac (mm²)**	**F (N)**	**Axial stress (kpa)**
0.0006869	1134.0893	-1.6341507	-1.4409366		7.734E-39	1134.0815	0.5396605	0.4758569
0.0144175	1134.245	40.854126	36.018784		0.0236085	1134.3493	4.8570037	4.2817531
0.0521773	1134.6735	83.342433	73.450583		0.1050924	1135.2746	36.157608	31.849218
0.0803255	1134.9932	113.30208	99.826222		0.167538	1135.9847	70.696175	62.233386
0.1132806	1135.3677	125.83068	110.82814		0.2033309	1136.3921	91.203481	80.25705
0.1434882	1135.7111	134.54625	118.46873		0.2817706	1137.286	114.94875	101.07286
0.1750696	1136.0704	145.44067	128.02082		0.3091862	1137.5988	134.91637	118.59749
0.2100831	1136.469	153.06678	134.68628		0.3685851	1138.277	159.74098	140.33577
0.2567689	1137.001	159.60345	140.37231		0.9009035	1144.3914	241.23046	210.79367
0.3309159	1137.8468	171.58732	150.80002		1.0227479	1145.8001	246.62709	215.24442
0.3645568	1138.231	178.12398	156.49194		1.0669181	1146.3117	250.94444	218.91466
0.4249732	1138.9216	185.7501	163.09296		1.1011877	1146.7089	255.80144	223.07443
0.4723458	1139.4637	193.37621	169.70809		1.1758177	1147.5749	260.11872	226.66819
0.5046129	1139.8332	199.36815	174.90993		1.2344561	1148.2562	266.59471	232.17354
0.5464928	1140.3132	204.81536	179.61324		1.3174659	1149.2221	274.15001	238.55268
0.6014165	1140.9433	212.44147	186.1981		1.3380277	1149.4616	276.84838	240.85048
0.6432965	1141.4242	217.88868	190.89194		1.3974265	1150.1541	280.626	243.98992
0.6879216	1141.9371	223.88062	196.05337		1.4979488	1151.3278	286.02266	248.42852
0.7565771	1142.7271	229.87255	201.16137		1.5223202	1151.6127	288.18136	250.24156
0.9790182	1145.2941	252.20612	220.21078		1.6296964	1152.8698	295.73667	256.52218
1.0826872	1146.4944	262.55587	229.00753		1.7309816	1154.058	302.21266	261.86955
1.2145054	1148.0243	272.36083	237.24309		1.7660116	1154.4696	304.91096	264.11347
1.4015606	1150.2023	284.3447	247.21278		1.8573962	1155.5445	314.0853	271.80718
1.7652126	1154.4602	305.04414	264.23098		1.9769593	1156.954	324.87857	280.80509
2.1130233	1158.5622	331.19079	285.86363		2.114035	1158.5742	337.29088	291.12585
2.3217088	1161.0374	344.80885	296.98341		2.1467836	1158.9619	339.98924	293.3567
2.5717202	1164.0168	351.34545	301.83883		2.2739586	1160.4701	347.00489	299.02096
2.6578108	1165.0462	352.4349	302.50723		2.6196982	1164.5902	353.48088	303.52382
2.7067116	**1165.6318**	**354.06908**	**303.75723**		2.6600612	1165.0732	355.63952	305.2508
2.9236623	1168.2368	351.89018	301.21477		2.7918063	1166.6522	357.79816	306.68795
3.0903362	1170.246	348.62188	297.90477		**2.8161777**	**1166.9447**	**359.95686**	**308.46093**
3.1888247	1171.4366	345.35351	294.81197		2.8831909	1167.75	358.87748	307.32391
3.2666524	1172.379	341.54049	291.32258		2.9867624	1168.9967	358.87748	306.99616
3.3176184	1172.9971	337.72746	287.91842		3.152777	1171.0005	357.2585	305.08825
3.4402132	1174.4863	331.19079	281.98778		3.2791941	1172.5311	351.86183	300.08743
3.526993	1175.5428	324.10941	275.71042		3.3111773	1172.9189	351.32217	299.5281
3.5696949	1176.0634	320.84104	272.80932		3.4292171	1174.3526	349.16353	297.32427

Appendix C-9: Unconfined Compression Strength Test Data Analysis According to ASTM D-2166 (Immediate): Soil Sample One Stabilized with CDW and PWF

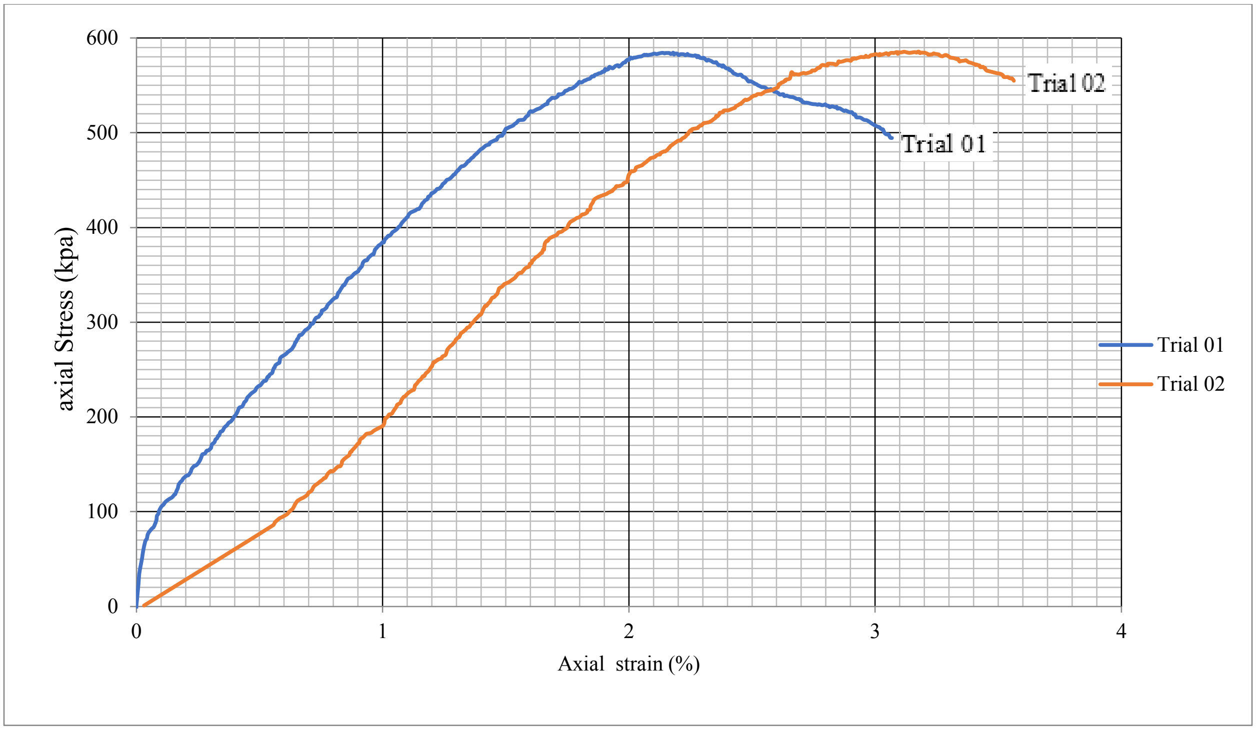
A) **UCS test result summary of soil sample 01 + 20% CDW + 0.5% PWF (immediate test)**



Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (Immediate) (soil sample 01+ 20% CDW+ 0.5% PWF)	**Remolded** (Immediate) (soil sample 01+ 20% CDW+ 0.5% PWF)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	79	84
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	89.60	95.27
stress (Peak, qu) (kpa)	519.24	502.121
Cohesion (kpa)	259.62	251.065
Corrected Area at peak qu (mm^2)	1161.97	1157.53
Load at peak qu, F, (N)	603.35	581.22

Trial 01					Trial 01			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**		**Axial strain (%)**	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**
7.44E-39	1134.0815	-3.2379925	-2.8551674		-0.0006891	1134.0737	-2.1586418	-1.9034405
0.002931	1134.1147	7.555306	6.6618532		0.0034446	1134.1206	38.85591	34.260829
0.0337021	1134.4638	44.252574	39.007479		0.0275601	1134.3941	79.870492	70.408061
0.0674018	1134.8464	72.854817	64.197954		0.0716573	1134.8947	108.47276	95.579582
0.1157543	1135.3958	94.441444	83.179316		0.1384917	1135.6543	136.53535	120.22615
0.1611782	1135.9123	113.32974	99.769792		0.1529603	1135.8189	143.55102	126.38549
0.2117278	1136.4878	131.67834	115.86429		0.1991238	1136.3442	167.83595	147.69816
0.2593487	1137.0304	145.70966	128.14932		0.2576907	1137.0115	191.04156	168.02078
0.2996421	1137.4899	161.8996	142.33058		0.3286589	1137.821	218.02482	191.61609
0.3619158	1138.2008	178.08959	156.46588		0.3892921	1138.5136	242.84944	213.30393
0.4212585	1138.8791	196.97788	172.95767		0.5091803	1139.8856	284.40365	249.50193
0.4622858	1139.3485	210.46951	184.72794		0.5656787	1140.5333	309.76793	271.59921
0.5106383	1139.9023	223.96114	196.47399		0.6380251	1141.3637	332.97357	291.7331
0.5963555	1140.8852	244.46842	214.27959		0.7151944	1142.2508	358.33785	313.71205
0.6850013	1141.9036	273.07066	239.13636		0.8109672	1143.3537	385.86077	337.48154
0.7780437	1142.9743	294.11766	257.32656		1.1499621	1147.2747	479.76258	418.17585
0.8234676	1143.4978	309.22827	270.42314		1.2732949	1148.7079	506.20615	440.67438
0.9546063	1145.0119	343.22718	299.75862		1.3311727	1149.3818	515.3805	448.39802
0.9919686	1145.4439	359.41717	313.7798		1.4000734	1150.1849	526.17383	457.46889
1.0535107	1146.1564	371.28982	323.94342		1.4765535	1151.0778	540.74478	469.77258
1.2842854	1148.8358	429.03396	373.45107		1.5378759	1151.7947	548.30003	476.03973
1.3985742	1150.1674	456.55695	396.94824		1.6081549	1152.6174	554.23641	480.8503
1.4689071	1150.9885	470.58824	408.85574		1.6198681	1152.7546	556.39505	482.66565
1.5209222	1151.5964	484.07987	420.35549		1.678435	1153.4413	564.49008	489.39647
1.9011534	1156.06	552.61731	478.01786		1.7879872	1154.7279	569.34702	493.05731
2.0769819	1158.1358	579.60069	500.46006		1.8251941	1155.1655	572.58499	495.67355
2.1634307	1159.1591	588.23526	507.46723		1.8672239	1155.6603	576.90227	499.19712
2.2139827	1159.7583	593.09232	511.39302		1.8927177	1155.9606	579.06103	500.93493
2.2337636	1159.993	594.7113	512.68525		2.0029602	1157.261	580.68001	501.77101
2.3172813	1160.9848	601.72689	518.29007		**2.0256973**	**1157.5295**	**581.21967**	**502.12081**
2.4000675	**1161.9696**	**603.34587**	**519.24413**		2.0904643	1158.2952	579.06103	499.92524
2.4403608	1162.4495	602.80621	518.56552		2.2482486	1160.1649	569.34702	490.74664
2.4667354	1162.7638	600.64757	516.56886		2.3068144	1160.8604	565.5694	487.19846
2.4828537	1162.956	599.56825	515.5554		2.4025872	1161.9996	555.31573	477.89668
2.526812	1163.4805	597.94927	513.93151		2.4528844	1162.5987	549.37935	472.54426
2.6176549	1164.5658	588.23526	505.11122		2.488025	1163.0177	541.8241	465.87779
2.7744366	1166.4437	565.56928	484.86632		2.5272982	1163.4863	536.42738	461.05175

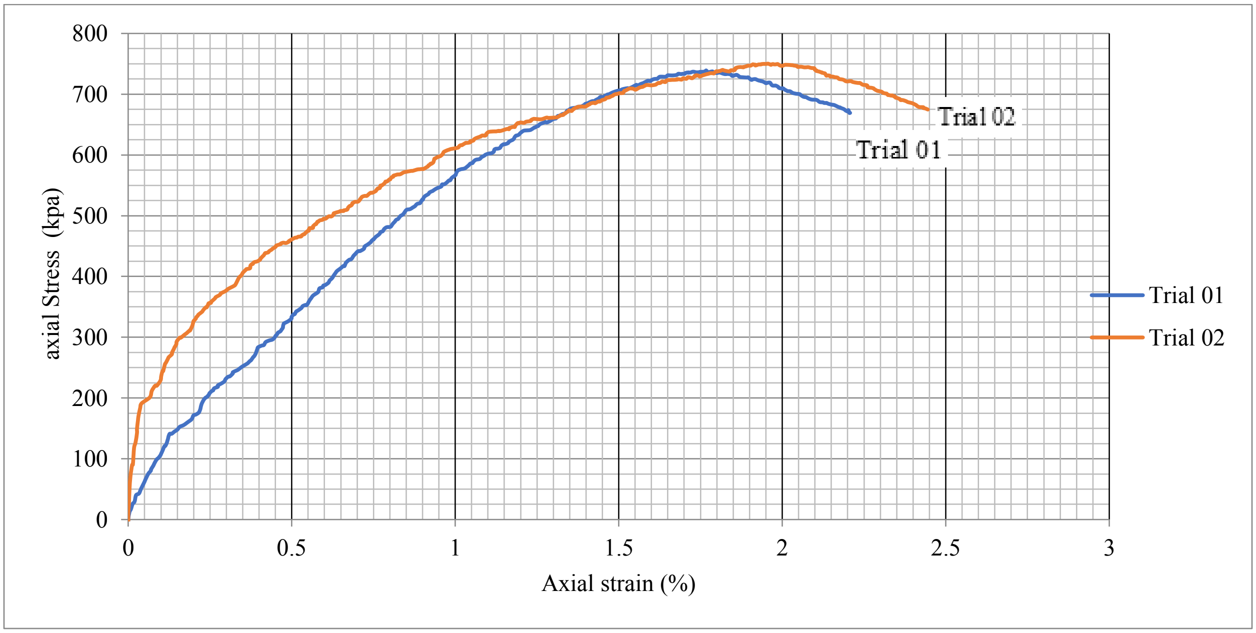
B) **UCS test result summary of soil sample 01 + 20% CDW + 1% PWF (immediate test)**



Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (Immediate) (soil sample 01+ 20% CDW+ 1% PWF)	**Remolded** (Immediate) (soil sample 01+ 20% CDW+ 1% PWF)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	83	80
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	94.13	90.73
stress (Peak, qu) (kpa)	585.53	584.49
Cohesion (kpa)	292.765	292.245
Corrected Area at peak qu (mm^2)	1171.25	1159.36
Load at peak qu, F, (N)	685.805	677.634

Trial 01					Trial 01			
Axial strain %	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**		**Axial strain %**	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**
0.0313678	1134.4373	1.0894388	0.960334		7.347E-39	1134.0815	0.5447268	0.4803243
0.5541422	1140.4009	97.505182	85.50079		0.0086498	1134.1796	26.691347	23.533616
0.6308153	1141.2809	116.57044	102.14001		0.0173008	1134.2777	48.480213	42.741042
0.6991237	1142.066	137.26985	120.19433		0.0821793	1135.0142	104.58654	92.145576
0.7897389	1143.1091	163.4165	142.95793		0.1038063	1135.26	120.38347	106.04044
0.8761693	1144.1058	188.4737	164.7345		0.1578712	1135.8747	134.54625	118.45166
0.9646933	1145.1285	212.44144	185.51756		0.1737309	1136.0552	147.07485	129.46101
1.037184	1145.9673	233.14086	203.4446		0.2602363	1137.0405	176.48983	155.2186
1.1013123	1146.7104	257.65336	224.68913		0.321511	1137.7395	200.45757	176.18935
1.1549823	1147.333	275.08444	239.75989		0.3618801	1138.2004	216.2545	189.99686
1.2100473	1147.9725	295.78385	257.65761		0.397203	1138.6041	228.23837	200.45456
1.2811454	1148.7993	317.02802	275.96467		0.5183101	1139.9902	271.27138	237.9594
1.3522435	1149.6273	339.36161	295.19273		0.5745387	1140.6349	292.51555	256.44976
1.429613	1150.5296	368.23183	320.0542		0.6451845	1141.4459	318.11747	278.69692
1.536259	1151.7758	399.28097	346.66554		0.7302475	1142.424	348.07715	304.68297
1.6443	1153.041	430.3301	373.21319		0.9119081	1144.5185	409.63069	357.90658
1.7509437	1154.2925	461.92396	400.17929		1.0012972	1145.5519	440.67982	384.68779
1.8394677	1155.3335	483.71285	418.67812		1.0784304	1146.4451	464.10283	404.81906
1.9342629	1156.4503	508.22532	439.4701		1.1923289	1147.7667	497.33087	433.30312
2.0883078	1158.2697	547.98996	473.11084		1.3509226	1149.6119	540.36391	470.0403
2.168467	1159.2188	563.2422	485.88084		1.44611	1150.7222	564.87632	490.88852
2.2542011	1160.2355	582.30746	501.88728		1.7418873	1154.1861	628.06404	544.16183
2.4960713	1163.1136	624.79573	537.17514		1.7643058	1154.4495	630.78773	546.39698
2.5971401	1164.3205	636.77961	546.91091		1.7845535	1154.6875	634.60076	549.58658
2.7184245	1165.7721	655.84487	562.5841		1.9212329	1156.2967	658.5685	569.54978
2.7755806	1166.4575	663.47098	568.79141		1.9855952	1157.0559	664.56044	574.35463
2.7804616	1166.516	665.64989	570.63073		1.9942737	1157.1584	667.8288	577.12824
2.9017437	1167.9731	672.73128	575.98183		2.0383871	1157.6795	671.64183	580.16215
2.9623859	1168.703	679.26794	581.2152		2.1027493	1158.4406	675.99964	583.54277
3.1505837	1170.974	684.71515	584.73983		**2.1801281**	**1159.357**	**677.63376**	**584.49104**
3.1735868	**1171.2522**	**685.80455**	**585.53106**		2.2148407	1159.7685	675.99964	582.87462
3.1826479	1171.3618	684.17042	584.08121		2.2712481	1160.4379	674.91019	581.59956
3.2572298	1172.2649	683.08097	582.70191		2.3724914	1161.6413	663.47098	571.1496
3.3241456	1173.0763	678.72322	578.58405		2.4708426	1162.8128	649.3082	558.39445
3.4105761	1174.126	671.64183	572.03558		2.6133072	1164.5138	629.15349	540.27138
3.4586734	1174.7109	664.01571	565.25882		2.6653755	1165.1368	626.42992	537.64496
3.5444076	1175.7551	655.84487	557.8074		2.6964724	1165.5091	622.61689	534.20164

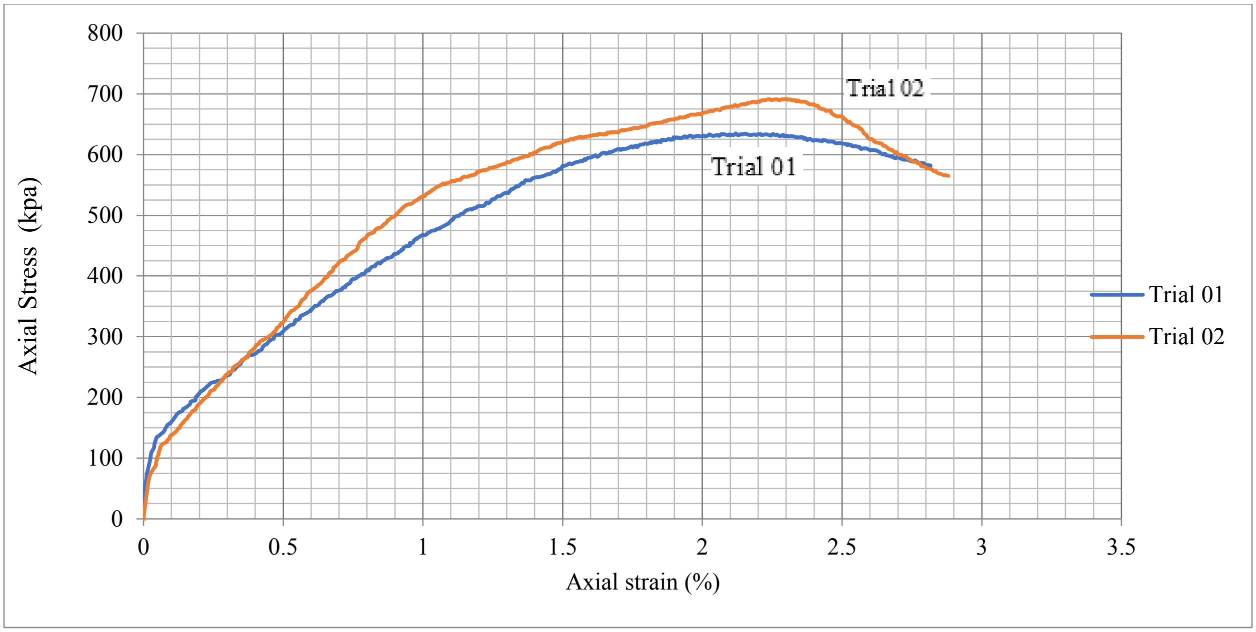
C) **UCS test result summary of soil sample 01 + 20% CDW + 1.5% PWF (immediate test)**



Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (Immediate) (soil sample 01+ 20% CDW+ 1.5% PWF)	**Remolded** (Immediate) (soil sample 01+ 20% CDW+ 1.5% PWF)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	78	78
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	88.461	88.461
stress (Peak, qu) (kpa)	739.04	750.17
Cohesion (kpa)	369.52	375.085
Corrected Area at peak qu (mm^2)	1154.49	1156.72
Load at peak qu, F, (N)	853.211	867.742

Trial 01					Trial 01			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**		**Axial strain (%)**	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**
0.0415533	1134.5529	60.442537	53.27432		7.535E-39	1134.0815	6.5366626	5.7638385
0.0986882	1135.2018	120.34541	106.01235		0.0140844	1134.2413	102.40769	90.2874
0.1417258	1135.6911	164.59796	144.93198		0.0296513	1134.4179	185.20534	163.26025
0.2233481	1136.6201	214.24717	188.49496		0.0659741	1134.8302	228.2384	201.12119
0.2849334	1137.3221	254.72206	223.96651		0.1119339	1135.3523	289.79194	255.24406
0.3658148	1138.2454	293.03831	257.4474		0.1571521	1135.8665	339.90633	299.24848
0.3969779	1138.6015	322.71993	283.43537		0.2001463	1136.3559	371.50019	326.9224
0.4652439	1139.3824	352.94122	309.76537		0.246106	1136.8794	404.72817	355.99921
0.5090224	1139.8838	385.32114	338.03547		0.3246821	1137.7757	437.95621	384.92317
0.5617044	1140.4877	417.70101	366.24772		0.3721243	1138.3175	470.63953	413.45191
0.6240356	1141.203	454.39827	398.17479		0.431427	1138.9954	503.32284	441.90067
0.6641021	1141.6633	480.30221	420.70391		0.5151926	1139.9545	528.92476	463.98763
0.7227213	1142.3374	513.2218	449.27339		0.5544803	1140.4048	546.90057	479.56705
0.7687275	1142.867	537.50676	470.31434		0.5974751	1140.8981	564.87638	495.11555
0.8340249	1143.6196	572.04533	500.20596		0.6834641	1141.8859	591.02303	517.58502
0.9037727	1144.4245	606.58395	530.03405		0.7234934	1142.3463	608.45405	532.63537
0.9920732	1145.4452	645.43986	563.48387		0.8317214	1143.593	649.85293	568.25543
1.0173015	1145.7371	660.55048	576.52883		0.9154858	1144.5598	664.5605	580.62541
1.0736955	1146.3902	679.97843	593.14743		0.9555156	1145.0224	685.25988	598.46855
1.117474	1146.8978	694.00972	605.11907		1.0363151	1145.9572	710.31713	619.84611
1.1746089	1147.5609	716.67564	624.52082		1.0948768	1146.6357	726.11403	633.25606
1.2250656	1148.1471	735.56399	640.65312		1.1645574	1147.4441	737.00833	642.30432
1.2591973	1148.5439	747.43664	650.76887		1.3184272	1149.2333	763.15498	664.05575
1.3400787	1149.4855	771.72148	671.36251		1.362789	1149.7502	776.77321	675.60174
1.3860825	1150.0217	781.97515	679.96553		1.3768373	1149.9139	781.13079	679.295
1.3979545	1150.1602	786.83221	684.10662		1.4160236	1150.371	788.2123	685.18094
1.4395078	1150.6451	797.62542	693.19845		1.5121405	1151.4937	808.36701	702.01601
1.5708434	1152.1805	826.76739	717.56762		1.5712891	1152.1857	820.35089	711.99539
1.7014381	1153.7112	846.19528	733.45504		1.7709164	1154.5272	846.49754	733.19843
1.7526382	1154.3124	850.51268	736.81325		1.9180487	1156.2591	863.92856	747.17557
1.7674764	**1154.4868**	**853.21099**	**739.0392**		1.9350547	1156.4596	866.10746	748.93013
1.7726727	1154.5479	849.43324	735.72805		**1.957235**	**1156.7213**	**867.74158**	**750.17346**
1.8698766	1155.6915	841.878	728.46256		2.0570492	1157.9001	862.83922	745.17589
1.9099431	1156.1636	837.56071	724.43099		2.0829268	1158.2061	861.74965	744.03827
1.9900811	1157.1089	821.91038	710.31376		2.0984534	1158.3898	860.11553	742.5096
2.0115999	1157.363	817.5931	706.42753		2.1213733	1158.661	852.48947	735.75399
2.0316344	1157.5997	812.73615	702.0874		2.145033	1158.9412	846.49754	730.40596

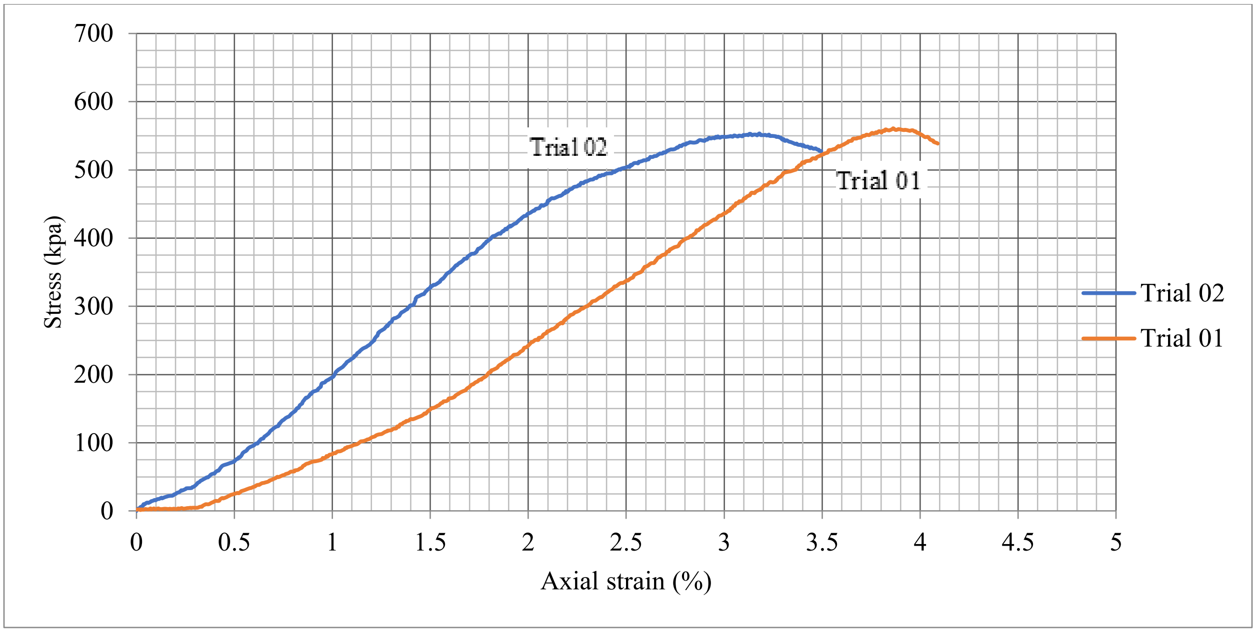
D) **UCS test result summary of soil sample 01 + 20% CDW + 2% PWF (immediate test)**



Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (Immediate) (soil sample 01+ 20% CDW+ 2% PWF)	**Remolded** (Immediate) (soil sample 01+ 20% CDW+ 2% PWF)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	76	85
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	86.192	96.40
stress (Peak, qu) (kpa)	634.85	691.25
Cohesion (Kpa)	317.425	345.625
Corrected Area at peak qu (mm^2)	1158.65	1160.75
Load at peak qu, F, (N)	735.57	802.375

Trial 01					Trial 02			
Axial strain (%)	**Ac (mm²)**	**F (N)**	**Stress (kpa)**		**Axial strain (%)**	**Ac (mm²)**	**F (N)**	**Stress (kpa)**
7.734E-39	1134.0815	0.5396605	0.4758569		0.0013604	1134.0969	8.71557	7.6850309
0.0106611	1134.2024	75.013518	66.137682		0.0244887	1134.3593	83.342433	73.470931
0.0396026	1134.5308	140.31303	123.67494		0.0687038	1134.8612	139.99349	123.35737
0.1104254	1135.3352	188.88289	166.36751		0.1312856	1135.5723	173.2215	152.54114
0.18429	1136.1754	221.26281	194.74354		0.1857051	1136.1915	203.7259	179.30596
0.230749	1136.7044	249.32539	219.34057		0.226519	1136.6562	228.7831	201.2773
0.3084183	1137.59	270.37239	237.6712		0.3020253	1137.5171	271.8161	238.95562
0.3746735	1138.3466	305.99028	268.80239		0.378892	1138.3948	312.12553	274.1804
0.4660657	1139.3918	338.3702	296.9744		0.4632417	1139.3595	347.53242	305.02438
0.553633	1140.3951	374.52781	328.41934		0.5101782	1139.897	377.4921	331.16334
0.6412105	1141.4003	409.06638	358.38994		0.578882	1140.6847	415.62262	364.3624
0.7089916	1142.1795	431.19264	377.51742		0.65915	1141.6064	455.38732	398.90047
0.7630599	1142.8018	453.85861	397.14553		0.7332959	1142.4591	496.24148	434.36258
0.7980949	1143.2054	467.8899	409.27896		0.8523374	1143.8308	550.16887	480.98799
0.8963334	1144.3386	498.65079	435.75459		0.9727394	1145.2215	599.7386	523.68785
0.9534434	1144.9984	515.3805	450.1146		1.0475658	1146.0875	625.88525	546.10598
1.016657	1145.7296	538.58602	470.08125		1.1305545	1147.0495	640.59269	558.46996
1.0928104	1146.6118	558.01404	486.66344		1.2026596	1147.8867	657.47905	572.77348
1.1453528	1147.2212	577.98171	503.81016		1.2958521	1148.9705	672.73128	585.5079
1.235982	1148.274	597.40961	520.26749		1.3584339	1149.6994	684.71515	595.56015
1.4362636	1150.6073	650.83641	565.64602		1.4053704	1150.2467	694.52012	603.80099
1.4751033	1151.0608	657.85211	571.51811		1.5461798	1151.8918	721.21143	626.11039
1.5459261	1151.8889	676.20069	587.0364		1.6883491	1153.5576	734.82955	637.01159
1.5999945	1152.5218	685.9147	595.1425		1.8073907	1154.9561	749.53699	648.97446
1.7028005	1153.7272	701.56497	608.08568		1.8794957	1155.8048	759.34196	656.98114
1.7675299	1154.4874	706.96157	612.35971		2.002619	1157.2569	774.04952	668.86574
1.9365913	1156.4777	728.54823	629.97168		2.0713228	1158.0688	783.3097	676.39303
2.0508314	1157.8266	731.78619	632.03437		2.1488695	1158.9866	791.48054	682.90741
2.0812888	1158.1867	733.40517	633.2357		2.2039694	1159.6396	796.38302	686.75045
2.1201284	**1158.6463**	**735.56393**	**634.8477**		**2.2978424**	**1160.7538**	**802.37496**	**691.25336**
2.2457826	1160.1356	732.32585	631.24159		2.3196097	1161.0125	801.28551	690.16099
2.3493516	1161.3661	729.62755	628.24941		2.3495405	1161.3683	798.01726	687.13538
2.4209374	1162.2181	724.23095	623.14549		2.4121217	1162.1131	790.93587	680.60147
2.4894714	1163.0349	719.91354	618.99564		2.4427324	1162.4777	781.13091	671.95345
2.5427768	1163.6711	713.97728	613.55593		2.4733431	1162.8426	772.96007	664.71599
2.6372106	1164.7997	702.10463	602.76854		2.5697074	1163.9927	746.81342	641.5963
2.7324074	1165.9397	689.69232	591.53343		2.5846341	1164.1711	737.00845	633.07574

E) **UCS test result summary of soil sample 01 + 20% CDW + 2.5% PWF (immediate test)**

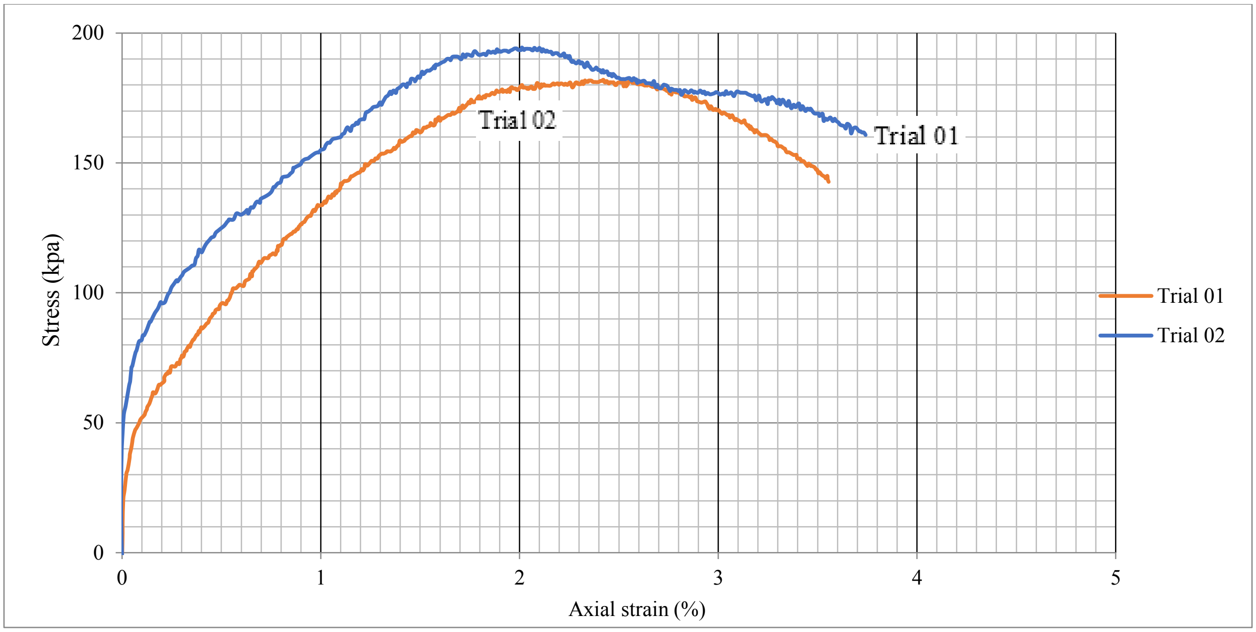


Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (Immediate) (soil sample 01+ 20% CDW+ 2.5% PWF)	**Remolded** (Immediate) (soil sample 01+ 20% CDW+ 2.5% PWF)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	83	88
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	94.13	99.81
stress (Peak, qu) (Kpa)	560.87	553.34
Cohesion (Kpa)	280.435	276.67
Corrected Area at peak qu (mm^2)	1179.6529	1171.322
Load at peak qu, F, (N)	661.6298	648.14

Trial 01					Trial 01			
Axial strain %	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**		**Axial strain %**	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**
0.0216162	1134.3267	1.6189814	1.427262		6.679E-39	1134.0815	5.877E-36	5.183E-36
0.6052684	1140.9875	41.014582	35.946564		6.679E-39	1134.0815	1.0793209	0.9517137
0.7747156	1142.936	63.140869	55.244448		0.5227013	1140.0405	89.58444	78.58005
1.0724688	1146.376	105.77443	92.268532		0.7323086	1142.4477	146.24932	128.01402
1.2593488	1148.5457	131.13871	114.17805		0.8437043	1143.7312	179.70857	157.12483
1.5675625	1152.142	185.10523	160.66182		0.9610317	1145.0861	215.86615	188.5152
1.7774536	1154.6041	226.65948	196.30927		1.0777002	1146.4367	250.94441	218.89077
1.8436983	1155.3833	243.3891	210.65659		1.2049149	1147.9129	284.40365	247.75718
1.9727018	1156.9038	272.53103	235.56932		1.2899442	1148.9017	315.70426	274.78788
2.0828776	1158.2055	300.59361	259.53392		1.3973848	1150.1536	346.4652	301.23386
2.1756195	1159.3035	318.94225	275.11539		1.5028477	1151.3851	379.38479	329.50296
2.2781246	1160.5196	344.30653	296.68308		1.595787	1152.4725	403.13002	349.79578
2.3443705	1161.3068	358.33782	308.56429		1.7328891	1154.0804	437.66865	379.23583
2.6107443	1164.4832	418.78039	359.62768		1.8172589	1155.0722	464.65191	402.2709
2.7446287	1166.0862	450.62059	386.43848		1.9635894	1156.7962	495.95252	428.72937
2.8115709	1166.8894	466.81058	400.04697		2.0374136	1157.668	512.14242	442.39145
2.9301138	1168.3144	495.41283	424.04066		2.1013498	1158.424	527.25303	455.14683
3.0061205	1169.23	510.5235	436.63224		2.191653	1159.4936	543.44308	468.69003
3.0542362	1169.8103	523.47547	447.4875		2.2806374	1160.5494	557.47437	480.35384
3.0814309	1170.1385	531.03077	453.81873		2.3922676	1161.8767	573.66431	493.7394
3.1595299	1171.0822	547.76037	467.73862		2.4631061	1162.7205	582.29899	500.80735
3.1867257	1171.4112	553.15703	472.21424		2.5890399	1164.2237	598.48893	514.06694
3.2341429	1171.9852	565.02968	482.11333		2.6244592	1164.6472	604.42519	518.97707
3.2941117	1172.7119	576.90233	491.93865		2.6782442	1165.2908	610.36158	523.78476
3.3415289	1173.2872	584.45764	498.13688		2.6900503	1165.4322	612.52022	525.57344
3.5472364	1175.7895	622.23423	529.20545		2.7976193	1166.7219	627.09117	537.48125
3.5827993	1176.2232	629.24987	534.97488		2.9255222	1168.2592	638.42416	546.47476
3.6302176	1176.802	635.72586	540.21481		3.0055431	1169.223	641.12246	548.33206
3.6936725	1177.5774	644.36048	547.19164		3.1170482	1170.5687	645.43986	551.38999
3.7083166	1177.7564	647.59851	549.85775		**3.1793589**	**1171.322**	**648.13817**	**553.339**
3.8115191	1179.0201	657.31245	557.50743		3.2633158	1172.3386	643.82076	549.17645
3.8631198	**1179.6529**	**661.6298**	**560.8682**		3.3551427	1173.4525	632.48789	538.99744
3.9063534	1180.1836	659.47115	558.7869		3.3872827	1173.8429	629.78947	536.5194
3.9182077	1180.3293	658.93143	558.2607		3.4122071	1174.1458	627.09117	534.08289
3.9746905	1181.0235	657.31245	556.56169		3.4430347	1174.5207	626.01185	532.99348
3.9844524	1181.1436	654.61415	554.22063		3.4732065	1174.8878	622.77389	530.07095
4.0053724	1181.401	651.91579	551.81584		3.4817333	1174.9916	622.23423	529.56484

Appendix C-10: Unconfined Compression strength Test Data Analysis According to ASTM D-2166 (Cured for 7 days): Soil Sample One Stabilized with CDW

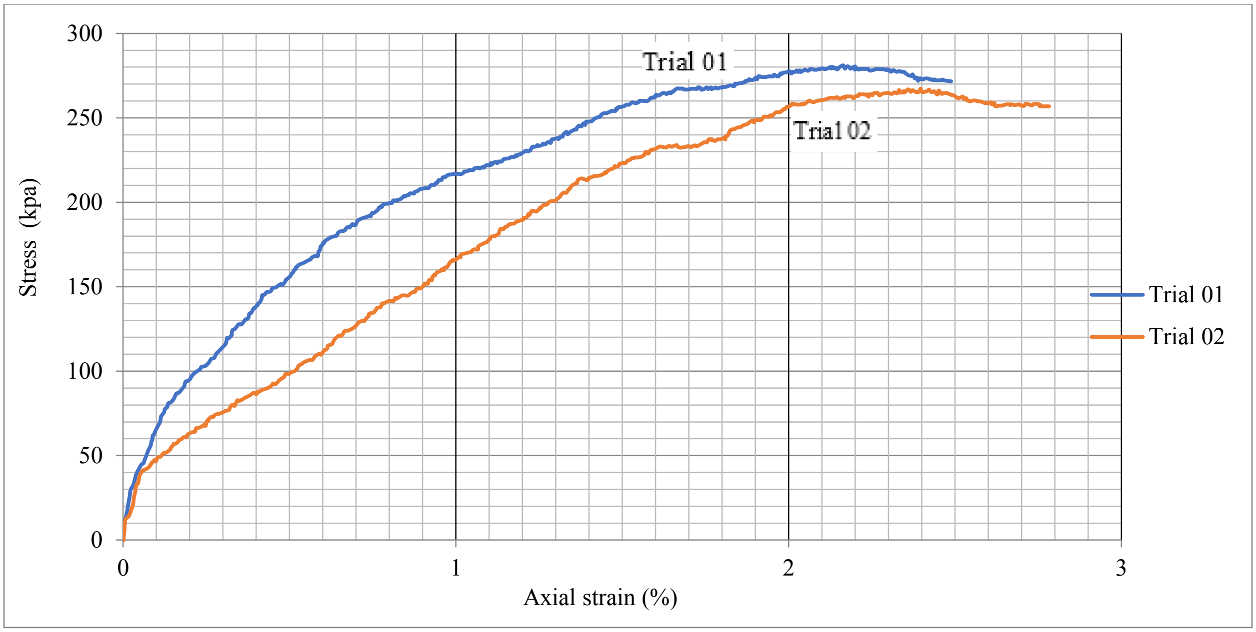
A) **UCS test result summary of soil sample 01 + 5% CDW (cured for 7 days)**



Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (cured for 7 days) (soil sample 01+ 5%CDW)	**Remolded** (cured for 7 days) (soil sample 01+ 5% CDW)
Sample shape	cylindrical	cylindrical
Sample height (mm)	85	82
Sample diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	96.40	93.00
stress (Peak, qu) (kpa)	182.012	194.44
Cohesion (kpa)	91.006	97.22
Corrected Area at peak qu (mm^2)	1162.23	1157.37
Load at peak qu, F, (N)	211.55	225.04

Trial 01					Trial 01			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**		**Axial strain (%)**	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**
6.915E-39	1134.0815	5.877E-36	5.183E-36		7.168E-39	1134.0815	-1.6190112	-1.4275968
0.0374469	1134.5063	41.014552	36.151893		7.168E-39	1134.0815	-1.0793507	-0.95174
0.0728562	1134.9084	54.506212	48.026973		-0.0049405	1134.0255	17.269284	15.228303
0.1382267	1135.6513	65.299511	57.499615		-0.0007048	1134.0735	46.950877	41.400206
0.198822	1136.3408	73.934168	65.063375		0.0183524	1134.2897	64.22019	56.617099
0.2880231	1137.3574	82.568794	72.597055		0.0472906	1134.6181	80.949813	71.345429
0.3479453	1138.0413	91.743112	80.614926		0.073405	1134.9146	88.505119	77.983947
0.4248855	1138.9206	100.37777	88.134122		0.1108123	1135.3396	94.981104	83.658761
0.5222545	1140.0354	109.0124	95.62194		0.1496338	1135.781	101.99675	89.803183
0.5549352	1140.41	114.94872	100.79596		0.180691	1136.1344	106.85375	94.050276
0.646856	1141.4651	122.50406	107.32177		0.2251555	1136.6407	111.71073	98.281477
0.7347017	1142.4753	129.5197	113.36762		0.2484484	1136.9061	116.02804	102.05596
0.7980257	1143.2046	135.456	118.48798		0.3126796	1137.6387	123.04372	108.15712
0.9035627	1144.4221	144.63031	126.37847		0.3522036	1138.0899	125.74202	110.48514
1.0016138	1145.5555	153.26497	133.79095		0.386787	1138.485	132.75769	116.60908
1.0928524	1146.6123	160.28062	139.78624		0.4496039	1139.2034	138.15433	121.27275
1.285553	1148.8506	174.31191	151.72722		0.5152493	1139.9551	143.55099	125.92688
1.3059818	1149.0884	176.47058	153.57442		0.5978282	1140.9021	148.40797	130.07949
1.6974954	1153.6649	197.51754	171.20876		0.6479403	1141.4776	151.64596	132.85058
1.7866965	1154.7127	201.83486	174.79227		0.757343	1142.7359	159.74095	139.78816
1.8745333	1155.7463	203.99353	176.50372		0.7834597	1143.0367	162.43929	142.11204
1.9378572	1156.4927	205.61251	177.78972		0.8307503	1143.5818	165.67728	144.87576
2.0113956	1157.3606	208.31084	179.98785		1.0453131	1146.0614	180.78792	157.74715
2.0958306	1158.3587	208.8505	180.29864		1.2132994	1148.0103	191.58119	166.88107
2.2946526	1160.7159	209.39016	180.39743		1.3777593	1149.9247	203.45384	176.92797
2.347089	1161.3392	211.00917	181.6947		1.6226722	1152.7875	218.02479	189.12835
2.4219827	**1162.2305**	**211.54884**	**182.01969**		1.7433748	1154.2036	221.26281	191.70172
2.4349258	1162.3847	210.46951	181.067		1.855592	1155.5233	222.34213	192.41683
2.5833579	1164.1558	210.46951	180.79153		1.95229	1156.6629	223.42145	193.16039
2.6705125	1165.1983	209.39016	179.70346		**2.012283**	**1157.3711**	**225.04044**	**194.44104**
2.7569939	1166.2345	206.69183	177.23008		2.0546355	1157.8715	224.50078	193.89092
2.8611666	1167.4852	204.53319	175.19125		2.4195438	1162.2015	215.86615	185.73901
3.023906	1169.4444	198.0572	169.36009		2.4654226	1162.7482	213.16785	183.33106
3.1737025	1171.2536	190.50187	162.64784		2.7576284	1166.2421	207.23152	177.69168
3.2840145	1172.5895	185.64489	158.32045		3.2517061	1172.1979	205.07282	174.94726
3.4624077	1174.7564	175.39126	149.30011		3.4239257	1174.2883	201.83486	171.87846
3.47194	1174.8724	174.8516	148.82604		3.6928433	1177.5672	192.66057	163.60898

B) **UCS test result summary of soil sample 01 + 10% CDW (cured for 7 days)**

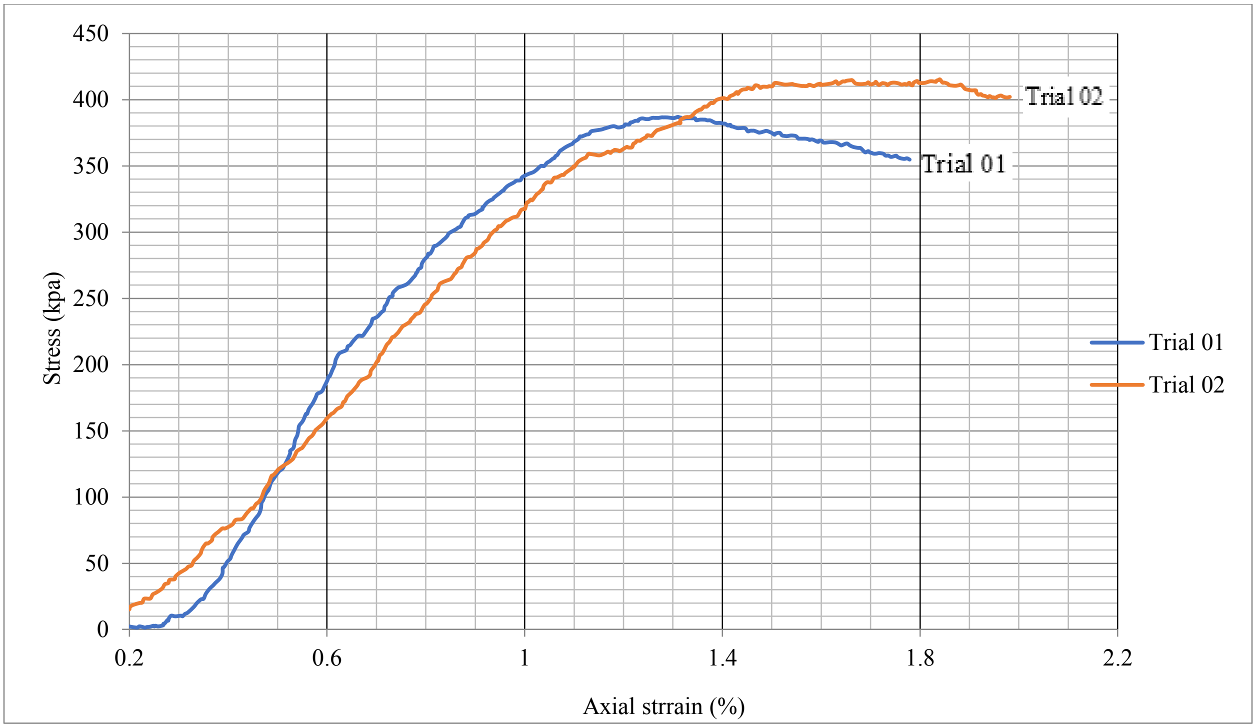


Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (cured for 7 days) (soil sample 01+ 10%CDW)	**Remolded** (cured for 7 days) (soil sample 01+ 10% CDW)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	85	77
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	96.40	87.327
stress (Peak, qu) (kpa)	281.014	267.22
Cohesion (kpa)	140.507	133.61
Corrected Area at peak qu (mm^2)	1159.171	1161.93
Load at peak qu, F, (N)	325.74	310.49

Trial 01			
Axial strain %	**Ac (mm^2)**	**F (N)**	**Stress (KPA)**
6.915E-39	1134.0815	-0.5447268	-0.4803243
6.915E-39	1134.0815	-1.6341507	-1.4409465
6.915E-39	1134.0815	2.1788776	1.9212707
0.0170158	1134.2745	26.14665	23.051431
0.074869	1134.9312	59.919387	52.795611
0.1061787	1135.2869	77.350467	68.132967
0.1320424	1135.5809	89.334369	78.668429
0.2014665	1136.3709	108.39963	95.391064
0.2885875	1137.3638	127.46486	112.07044
0.3478028	1138.0396	145.4407	127.79933
0.4151849	1138.8097	162.32705	142.54098
0.490054	1139.6665	175.9451	154.38298
0.5635621	1140.509	189.56316	166.20926
0.6016776	1140.9463	201.0023	176.17157
0.6928825	1141.9942	212.98617	186.50373
0.7561807	1142.7225	221.70174	194.01187
0.8473856	1143.7737	232.59616	203.35855
0.9181707	1144.5908	238.58809	208.44838
0.9590093	1145.0628	245.12476	214.07102
1.0713128	1146.3626	252.20615	220.00556
1.2966021	1148.9792	272.90559	237.52004
1.3633032	1149.7562	280.53164	243.99229
1.4306865	1150.5422	288.15776	250.45389
1.5089585	1151.4565	296.3286	257.35111
1.5981214	1152.4998	302.32054	262.31721
1.7675983	1154.4882	308.31248	267.05554
1.8458714	1155.4089	312.1255	270.1429
1.9186985	1156.2668	317.02799	274.18239
1.9765517	1156.9492	319.75162	276.37481
2.0800086	1158.1716	322.47525	278.43479
2.1535167	1159.0417	324.6541	280.10564
2.1644065	**1159.1707**	**325.74356**	**281.01432**
2.210009	1159.7112	323.56465	279.0045
2.28692	1160.624	323.56465	278.78506
2.3332024	1161.174	322.47525	277.71483
2.3788048	1161.7165	317.57271	273.36508
2.4625228	1162.7136	317.02799	272.66215

Trial 01			
Axial strain %	**Ac (mm^2)**	**F (N)**	**Stress (KPA)**
8.278E-39	1134.0815	-1.0894537	-0.9606485
8.278E-39	1134.0815	-2.1788776	-1.9212707
0.0065199	1134.1554	13.618022	12.007192
0.0366694	1134.4975	32.683283	28.808598
0.0774115	1134.9601	49.02494	43.195298
0.1523757	1135.8122	64.821869	57.070939
0.2509722	1136.9349	79.529345	69.950659
0.3397901	1137.9481	92.60267	81.376881
0.4261635	1138.9352	101.86294	89.436989
0.5174234	1139.98	114.39154	100.34521
0.6135753	1141.0829	129.64374	113.61465
0.7040239	1142.1223	145.98539	127.81941
0.8091376	1143.3326	161.78232	141.50066
0.9264745	1144.6867	175.9451	153.7059
0.9851429	1145.365	189.01843	165.02899
1.0927012	1146.6105	202.09172	176.25141
1.2214473	1148.105	221.15698	192.62784
1.3143378	1149.1857	234.23031	203.82286
1.4145623	1150.354	247.84836	215.454
1.4601936	1150.8867	252.20612	219.1407
1.5164174	1151.5437	258.74278	224.6921
1.5767165	1152.2492	264.18999	229.28199
1.756797	1154.3613	272.90556	236.4126
1.8105762	1154.9935	276.17386	239.1129
1.8366505	1155.3003	281.0764	243.29293
1.9376916	1156.4907	289.79191	250.57867
2.0680656	1158.0303	300.68633	259.65324
2.1006571	1158.4158	301.77578	260.5073
2.2603666	1160.3087	307.22299	264.77694
2.345926	1161.3253	308.85717	265.95233
2.3964466	**1161.9264**	**310.49135**	**267.22118**
2.4763	1162.8778	307.76772	264.6604
2.51867	1163.3833	305.04414	262.20434
2.5952675	1164.2982	301.23106	258.7233
2.6392681	1164.8243	299.59694	257.20353
2.7305308	1165.9172	300.14166	257.42965
2.77779	1166.484	299.59694	256.83759

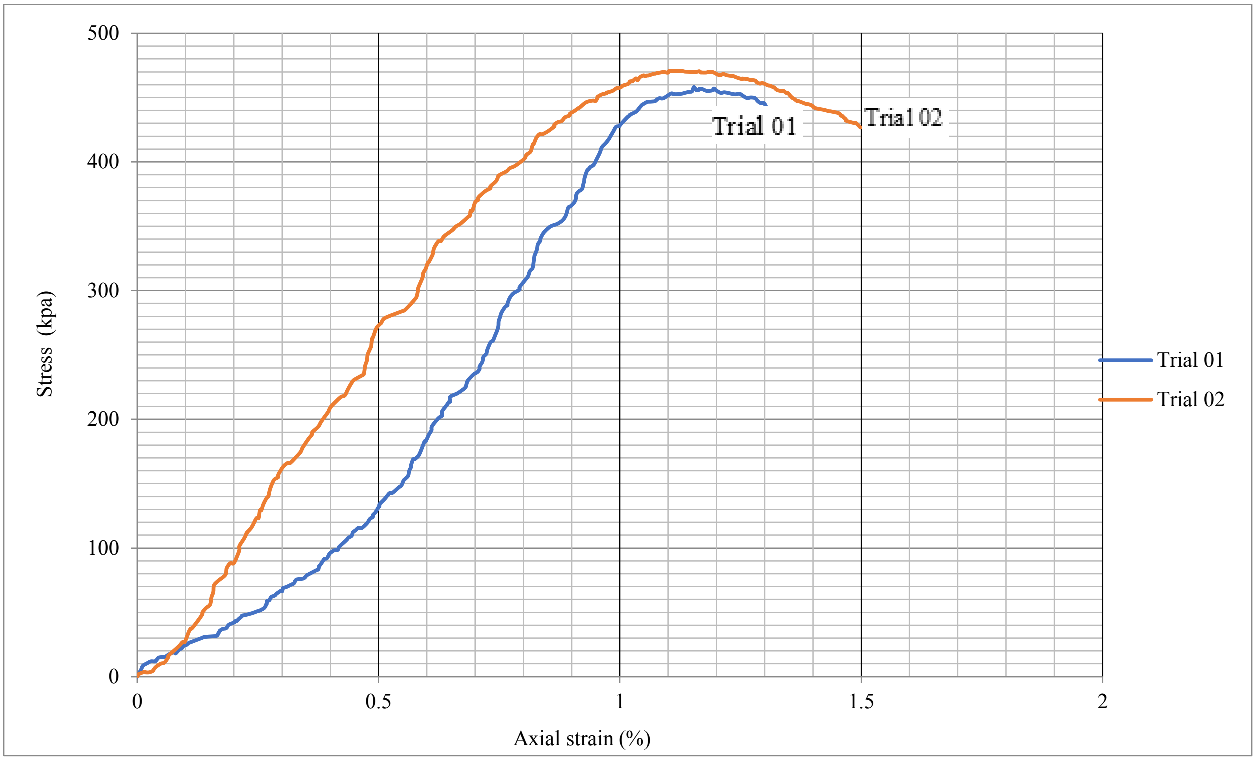
C) **UCS test result summary of soil sample 01 + 15% CDW (cured for 7 days)**



Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (cured for 7 days) (soil sample 01+ 15%CDW)	**Remolded** (cured for 7 days) (soil sample 01+ 15% CDW)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	76	79
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	86.192	89.595
stress (Peak, qu) (kpa)	415.26	386.97
Cohesion (kpa)	207.63	193.485
Corrected Area at peak qu (mm^2)	1155.34	1149.13
Load at peak qu, F, (N)	479.76	444.68

Trial 01				Trial 02			
Axial strain %	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**	**Axial strain %**	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**
0.0007328	1134.0898	-0.5396605	-0.4758534	7.734E-39	1134.0815	5.877E-36	5.183E-36
0.0175838	1134.2809	-1.0793209	-0.9515464	0.0220826	1134.332	1.0793209	0.9515035
0.1567804	1135.8623	12.41231	10.927653	0.1012852	1135.2313	1.6190112	1.4261509
0.2930484	1137.4147	45.331895	39.855205	0.3503072	1138.0682	26.44363	23.23554
0.3589835	1138.1673	73.934168	64.958961	0.3883839	1138.5033	48.030227	42.187167
0.465946	1139.3904	112.25042	98.517956	0.4066618	1138.7122	63.68053	55.923287
0.521626	1140.0282	143.55102	125.91884	0.4287469	1138.9648	79.330832	69.651699
0.6359149	1141.3394	196.43822	172.11201	0.4553996	1139.2697	95.520794	83.84388
0.7150372	1142.249	240.6908	210.71657	0.525462	1140.0721	151.64599	133.01438
0.8066153	1143.3036	283.86399	248.28401	0.5437399	1140.2817	175.39126	153.81398
0.874016	1144.081	315.1646	275.47404	0.571916	1140.6048	195.35887	171.27657
0.9890375	1145.41	359.95683	314.26024	0.600855	1140.9369	214.78683	188.25479
1.0154121	1145.7152	371.28982	324.06815	0.61837	1141.138	233.13546	204.30086
1.0652301	1146.2921	391.25744	341.32436	0.6419784	1141.4091	243.92876	213.70844
1.0820811	1146.4874	395.03506	344.56118	0.7021402	1142.1006	269.8327	236.26
1.1091884	1146.8017	405.28873	353.40786	0.7265091	1142.381	286.56235	250.84657
1.173658	1147.5498	412.84403	359.76132	0.7661092	1142.8369	299.51432	262.07968
1.1824499	1147.6519	415.54239	362.08051	0.7920014	1143.1351	315.70426	276.17404
1.2366645	1148.2819	424.71668	369.87144	0.8049463	1143.2843	324.33894	283.69054
1.2454552	1148.3841	426.87532	371.71824	0.8468327	1143.7673	342.14786	299.14114
1.2571769	1148.5204	427.95464	372.61387	0.8795788	1144.1452	355.09983	310.36257
1.260108	1148.5545	429.57368	374.01244	0.9663933	1145.1481	383.70213	335.06768
1.2894123	1148.8955	436.04967	379.53815	0.9915251	1145.4388	388.55907	339.2229
1.2996698	1149.0149	437.66865	380.90773	1.0242713	1145.8178	397.73342	347.11751
1.3150541	1149.194	439.28763	382.25715	1.050924	1146.1264	405.28873	353.61608
1.3333695	1149.4073	444.6843	386.88138	1.0722487	1146.3735	414.46301	361.54275
1.3883168	1150.0478	459.79491	399.80504	1.1651566	1147.4511	434.43069	378.60497
1.4015041	1150.2016	461.41395	401.15919	1.2283626	1148.1854	440.90667	384.00304
1.53191	1151.7249	473.82626	411.40577	1.2580646	1148.5308	443.60498	386.23691
1.8322848	1155.249	477.60388	413.42075	**1.3098491**	**1149.1334**	**444.6843**	**386.9736**
1.840344	**1155.3438**	**479.76252**	**415.2552**	1.3448791	1149.5414	443.60498	385.89733
1.8784402	1155.7924	474.90558	410.89178	1.3959031	1150.1363	439.82729	382.4132
1.9128727	1156.1981	470.58824	407.0135	1.4172253	1150.385	437.12899	379.98494
1.918002	1156.2586	466.81055	403.72506	1.5276482	1151.675	429.03402	372.53045
1.9407127	1156.5264	465.73123	402.69833	1.5939035	1152.4504	424.17702	368.0653
1.9458409	1156.5868	464.65191	401.74408	1.6578725	1153.2001	421.47872	365.4862
1.9531673	1156.6733	464.11225	401.2475	1.7302187	1154.0491	412.84403	357.73525

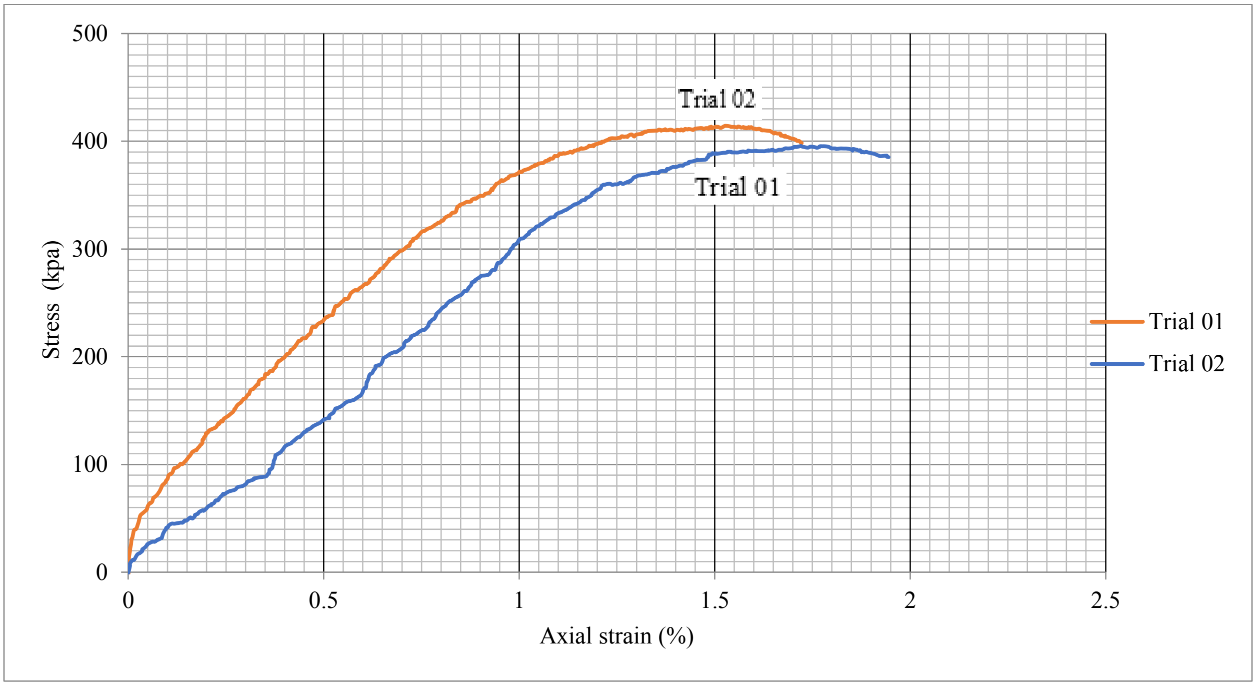
D) **UCS test result summary of soil sample 01 + 20% CDW (cured for 7 days)**



Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (cured for 7 days) (soil sample 01+ 20%CDW)	**Remolded** (cured for 7 days) (soil sample 01+ 20% CDW)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	79	79
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	89.595	89.595
stress (Peak, qu) (kpa)	458.14	470.75
Cohesion (kpa)	229.07	235.375
Corrected Area at peak qu (mm^2)	1147.31	1146.72
Load at peak qu, F, (N)	525.63	539.82

Trial 01					Trial 02			
Axial strain %	**Ac (mm^2)**	**F (N)**	**Stress (KPA)**		**Axial strain %**	**Ac (mm^2)**	**F (N)**	**Stress (KPA)**
7.44E-39	1134.0815	5.877E-36	5.183E-36		0.0007328	1134.0898	0.5447268	0.4803207
7.44E-39	1134.0815	1.0793209	0.9517137		0.0051257	1134.1396	2.7236193	2.401485
0.0395618	1134.5303	14.570981	12.843183		0.0153783	1134.2559	4.357785	3.8419768
0.096705	1135.1793	27.522951	24.245467		0.0856822	1135.054	26.691362	23.515499
0.1919469	1136.2625	46.411216	40.845505		0.1347481	1135.6117	56.651056	49.885938
0.3699725	1138.2929	93.901783	82.493518		0.1589147	1135.8866	80.618829	70.974364
0.443968	1139.1389	124.6627	109.4359		0.1926012	1136.27	100.22879	88.208603
0.5516632	1140.3725	173.77228	152.38203		0.2211619	1136.5952	122.01765	107.35366
0.6036783	1140.9693	214.24717	187.77645		0.2467928	1136.8873	139.99349	123.13753
0.6483682	1141.4825	248.24607	217.4769		0.274622	1137.2045	165.05069	145.13721
0.6967207	1142.0383	268.21369	234.85525		0.3376019	1137.9232	198.2787	174.24612
0.7370164	1142.5019	298.43497	261.21179		0.3808082	1138.4167	225.51477	198.0951
0.7487382	1142.6369	315.70429	276.29451		0.4694202	1139.4302	268.00308	235.20798
0.762657	1142.7971	328.65626	287.58933		0.4774758	1139.5224	285.43416	250.48577
0.7670535	1142.8478	329.73558	288.521		0.4950511	1139.7237	308.31245	270.51507
0.7795068	1142.9912	340.52885	297.92779		0.577072	1140.664	335.54855	294.1695
0.8036843	1143.2698	352.40149	308.24002		0.5924503	1140.8404	357.88217	313.70047
0.8703522	1144.0387	402.59039	351.90279		0.6122227	1141.0674	374.76853	328.43681
0.9260322	1144.6816	440.90664	385.17841		0.700102	1142.0772	421.06983	368.68771
0.9318943	1144.7494	450.08093	393.16985		0.7491679	1142.6418	445.03763	389.48132
0.9590004	1145.0627	466.81058	407.67253		0.8062894	1143.2998	463.55817	405.45635
0.9795129	1145.2999	480.30221	419.36809		0.8333858	1143.6122	482.0787	421.54036
1.0014932	1145.5541	491.6352	429.16802		0.8963645	1144.3389	500.59927	437.45716
1.0154121	1145.7152	498.11119	434.76003		0.9132083	1144.5335	505.50175	441.6662
1.034459	1145.9357	503.50779	439.38572		0.9300522	1144.7281	510.9489	446.34958
1.0417866	1146.0206	507.28548	442.64953		0.9974262	1145.5071	524.02222	457.45873
1.0901391	1146.5808	515.38044	449.49334		1.0062133	1145.6088	526.20113	459.3201
1.1113855	1146.8272	519.15812	452.69081		1.0252542	1145.8292	530.01416	462.55949
1.1494818	1147.2691	521.85643	454.86835		1.0413653	1146.0157	533.82719	465.8114
1.1531444	**1147.3117**	**525.63411**	**458.14414**		1.0728558	1146.3805	537.09555	468.5142
1.1568069	1147.3542	524.01513	456.7161		**1.1021481**	**1146.7201**	**539.81912**	**470.75057**
1.2088244	1147.9583	520.77711	453.65507		1.1673251	1147.4763	538.72979	469.491
1.2410586	1148.333	519.69779	452.56715		1.2346992	1148.259	536.00609	466.79893
1.260108	1148.5545	516.99948	450.13055		1.2691184	1148.6593	532.73785	463.79099
1.2857485	1148.8529	513.76146	447.19518		1.3401539	1149.4864	522.93277	454.92733
1.2916106	1148.9211	512.14248	445.75949		1.4683108	1150.9815	498.42033	433.0394
1.3025984	1149.049	509.44412	443.36153		1.4895475	1151.2296	495.15203	430.1071

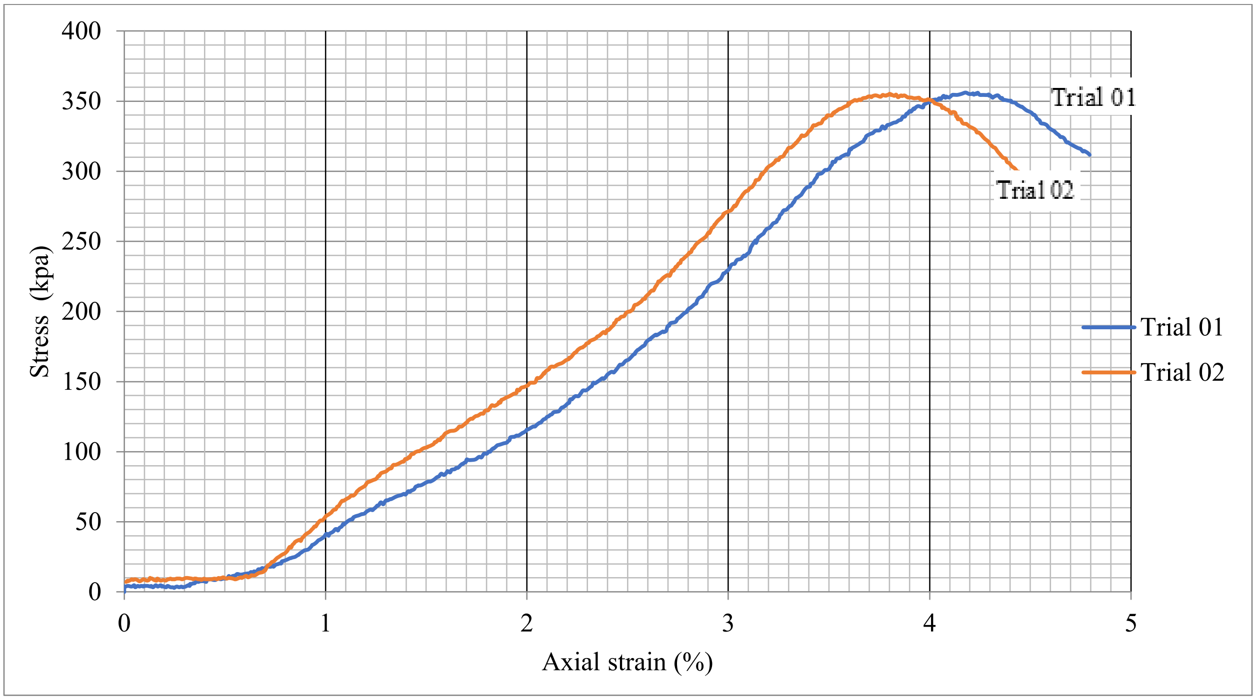
E) **UCS test result summary of soil sample 01 + 25% CDW (cured for 7 days)**



Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (cured for 7 days) (soil sample 01+ 25%CDW)	**Remolded** (cured for 7 days) (soil sample 01+ 25% CDW)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	82	81
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	92.997	91.863
stress (Peak, qu) (kpa)	414.33	395.58
Cohesion (kpa)	207.165	197.79
Corrected Area at peak qu (mm^2)	1151.68	1153.94
Load at peak qu, F, (N)	477.18	456.48

Trial 01					Trial 02			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**		**Axial strain (%)**	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**
0.0007048	1134.0895	-1.0894388	-0.9606286		7.256E-39	1134.0815	0.5447268	0.4803243
0.0049364	1134.1375	25.057197	22.093615		0.0357122	1134.4866	22.333592	19.686078
0.0444232	1134.5855	64.821869	57.132643		0.1028508	1135.2491	49.024954	43.184314
0.0951918	1135.1621	94.781578	83.496074		0.1785608	1136.1101	62.098265	54.658666
0.1544226	1135.8355	121.47292	106.94588		0.2799835	1137.2657	89.879066	79.030845
0.1981404	1136.333	144.35124	127.03252		0.3771205	1138.3745	123.65183	108.6214
0.2517293	1136.9435	163.96123	144.21229		0.5142542	1139.9437	162.87178	142.87704
0.3194216	1137.7156	193.37618	169.96882		0.6092484	1141.0332	199.36812	174.72595
0.3835876	1138.4484	222.24644	195.21871		0.7020997	1142.1002	238.04337	208.426
0.4576259	1139.2952	249.48254	218.97972		0.7578108	1142.7413	257.10863	224.99285
0.5267283	1140.0867	277.80807	243.67277		0.7978086	1143.2021	277.80804	243.00869
0.6169837	1141.122	307.76772	269.70623		0.8428056	1143.7208	292.51555	255.75782
0.6649326	1141.6729	329.01189	288.18403		0.9028023	1144.4133	314.84914	275.11839
0.7008936	1142.0863	340.99576	298.57267		0.9556558	1145.024	331.19076	289.24352
0.7290986	1142.4108	351.89018	308.0242		0.9977965	1145.5114	352.43493	307.66603
0.7763421	1142.9547	366.05296	320.26899		1.0585067	1146.2143	370.41074	323.16012
0.8771745	1144.1174	393.83379	344.22498		1.1063611	1146.7689	382.93934	333.92895
0.9314694	1144.7444	405.81766	354.50502		1.1734998	1147.548	398.73624	347.46803
0.9427513	1144.8748	412.89905	360.64995		1.2084984	1147.9545	409.08599	356.3608
1.0055071	1145.6006	425.42765	371.35774		1.2584945	1148.5358	415.07792	361.39748
1.1289038	1147.0304	447.21648	389.89071		1.3777733	1149.9249	430.3301	374.22454
1.2106983	1147.9801	457.56623	398.58377		1.4506258	1150.7749	439.59039	381.99511
1.22057	1148.0948	459.74508	400.44174		1.4556261	1150.8333	440.13512	382.44906
1.2480701	1148.4145	462.46871	402.7019		1.4749103	1151.0586	440.67985	382.84745
1.2586466	1148.5375	463.01344	403.13305		1.4784813	1151.1003	441.22458	383.3068
1.2755696	1148.7344	464.64756	404.4865		1.4813388	1151.1337	443.40342	385.18847
1.3235185	1149.2926	469.5501	408.55575		1.5906181	1152.412	450.48481	390.90605
1.4144793	1150.353	472.8184	411.02027		1.6277584	1152.8471	450.48481	390.75852
1.4934534	1151.2753	474.45258	412.11047		1.6377579	1152.9643	451.57427	391.66371
1.5082609	1151.4483	476.08677	413.46776		1.6484708	1153.0898	452.11899	392.09346
1.5280043	**1151.6792**	**477.17616**	**414.33079**		**1.7206098**	**1153.9362**	**456.47675**	**395.5823**
1.5646708	1152.1082	476.08677	413.23095		1.7234673	1153.9698	455.93202	395.09875
1.5794783	1152.2815	475.54204	412.69605		1.808462	1154.9687	454.2979	393.34219
1.6034528	1152.5623	474.45258	411.65028		1.846317	1155.4141	453.75317	392.71909
1.6676188	1153.3144	469.5501	407.13105		1.8834573	1155.8515	450.48481	389.74282
1.6704391	1153.3475	467.91592	405.70248		1.9398819	1156.5166	447.21651	386.6927
1.7049906	1153.7529	463.55817	401.78289		1.9398819	1156.5166	446.12706	385.75069

F) **UCS test result summary of soil sample 01 + 30% CDW (Cured for 7 days)**

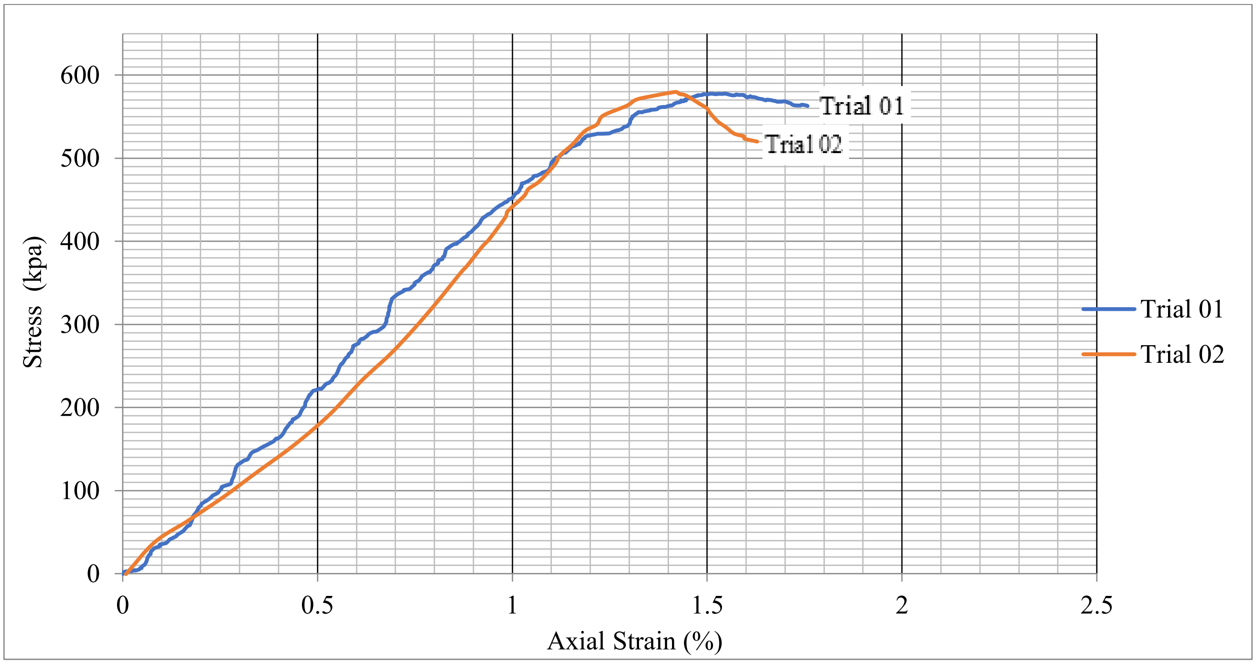


Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (cured for 7 days) (soil sample 01+ 30%CDW)	**Remolded** (cured for 7 days) (soil sample 01+ 30% CDW)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	76	82
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	86.193	92.997
stress (Peak, qu) (kpa)	356.12	355.23
Cohesion (kpa)	178.06	177.615
Corrected Area at peak qu (mm^2)	1183.54	1178.902
Load at peak qu, F, (N)	421.48	418.78

Trial 01					Trial 02			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**		**Axial strain (%)**	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**
0.0007629	1134.0902	5.877E-36	5.183E-36		0.0098554	1134.1933	8.0949888	7.1372216
0.0761534	1134.9458	4.3173134	3.803982		0.7456931	1142.6018	25.364272	22.198698
0.2414001	1136.8258	3.777653	3.3229832		0.9172079	1144.5797	48.56988	42.434687
0.3183164	1137.703	5.3966343	4.7434474		1.0894264	1146.5726	74.473821	64.95343
2.0310251	1157.5925	136.53535	117.94768		1.2912913	1148.9174	98.219119	85.48841
2.1239331	1158.6913	146.78898	126.68515		1.4373954	1150.6205	113.32973	98.494451
2.2031282	1159.6296	155.9633	134.49406		1.5863232	1152.3617	128.44038	111.45839
2.2785287	1160.5244	166.7566	143.69073		1.788893	1154.7385	148.408	128.52087
2.3813348	1161.7466	176.47058	151.9011		2.0126366	1157.3753	172.15326	148.74455
2.5047001	1163.2166	192.66054	165.6274		2.0754547	1158.1177	178.62925	154.24101
2.5496332	1163.7529	200.75554	172.50701		2.2427338	1160.0994	198.0572	170.72433
2.6394995	1164.8271	213.70751	183.46715		2.3415484	1161.2733	209.92985	180.77558
2.7621018	1166.2958	228.81812	196.19219		2.4403619	1162.4495	223.42148	192.19888
2.8839513	1167.7591	249.86508	213.96972		2.5116502	1163.2995	232.5958	199.9449
2.9730546	1168.8315	264.43607	226.23968		2.5991719	1164.3448	246.62709	211.8162
3.0316905	1169.5383	273.61035	233.94733		2.6217577	1164.6149	250.40475	215.01077
3.1124115	1170.5127	287.64164	245.73988		2.7177485	1165.764	266.05505	228.22376
3.1481994	1170.9452	295.73661	252.5623		2.7622153	1166.2971	273.61035	234.59747
3.2944228	1172.7157	320.56123	273.34948		2.8398549	1167.2291	289.26069	247.81826
3.3728549	1173.6676	335.13218	285.54267		2.9069086	1168.0352	298.97463	255.96371
3.4398731	1174.4822	347.54449	295.91295		2.9541981	1168.6044	310.30762	265.53693
3.5076543	1175.3072	356.71884	303.51114		3.1652369	1171.1512	349.16353	298.13702
3.5959946	1176.3842	366.97245	311.94948		3.2068811	1171.6551	356.17918	303.99661
3.6096974	1176.5514	371.28979	315.57463		3.3868638	1173.8378	382.62278	325.95882
3.6942331	1177.5842	383.7021	325.83835		3.5499084	1175.8221	404.74904	344.22642
3.8632945	1179.655	398.81271	338.0757		3.6233134	1176.7177	412.3044	350.38515
3.8838537	1179.9074	402.05073	340.74771		3.7553008	1178.3314	416.08202	353.11121
4.0468216	1181.9113	416.08202	352.04165		**3.8018855**	**1178.902**	**418.78039**	**355.22918**
4.1184074	1182.7938	419.31999	354.51657		3.8519987	1179.5165	417.16135	353.67149
4.1602888	1183.3106	420.39937	355.27388		3.9875158	1181.1813	414.46304	350.88859
4.1785692	**1183.5364**	**421.47869**	**356.11807**		4.026335	1181.6591	411.76474	348.46324
4.3377324	1185.5056	419.85971	354.16089		4.068684	1182.1807	408.52672	345.57045
4.365148	1185.8454	416.08202	350.87375		4.1046805	1182.6245	403.66971	341.33381
4.4253098	1186.5919	413.92338	348.83383		4.1830272	1183.5915	395.03509	333.75967
4.4534884	1186.9418	410.68536	346.00294		4.2345512	1184.2283	388.01944	327.65596
4.4786152	1187.254	407.98706	343.63922		4.279724	1184.7871	382.08312	322.49095
4.6796598	1189.7581	381.54346	320.68993		4.3623052	1185.8102	367.51217	309.92496

Appendix C-11: Unconfined Compression strength Test Data Analysis According to ASTM D-2166 (Cured for 7 days): Soil Sample One Stabilized with CDW and PWF

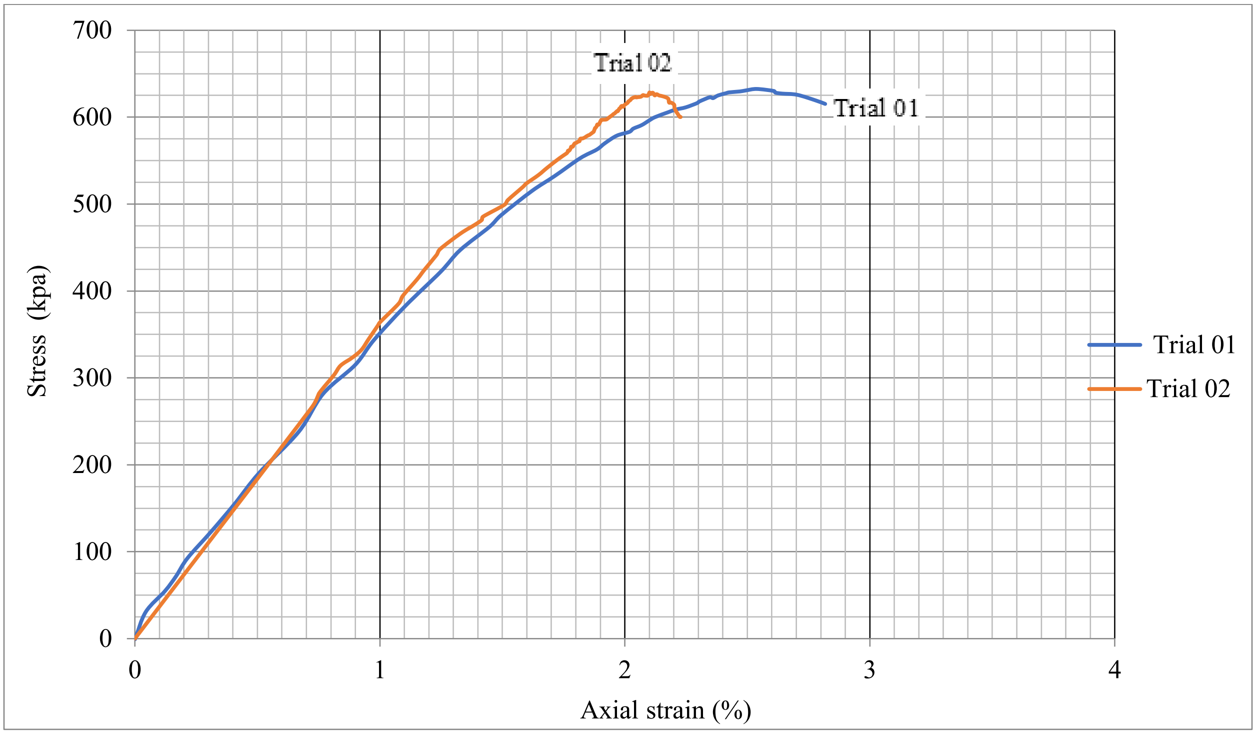
A) UCS test result summary of soil sample 01 + 20% CDW + 0.5% PWF (Cured for 7 days)



Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (cured for 7 days) (S01+ 20%CDW+0.5%PWF)	**Remolded** (cured for 7 days) (S01+20%CDW+0.5%PWF)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	84	83
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	95.265	94.132
stress (Peak, qu) (kpa)	577.87	579.82
Cohesion (kpa)	288.935	289.91
Corrected Area at peak qu (mm^2)	1151.90	1150.40
Load at peak qu, F, (N)	665.65	667.03

Trial 01					Trial 02			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**		**Axial strain (%)**	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**
6.997E-39	1134.0815	5.877E-36	5.183E-36		0.0083682	1134.1764	-0.5396605	-0.475817
6.997E-39	1134.0815	5.877E-36	5.183E-36		0.0822837	1135.0154	43.173224	38.037565
0.0137738	1134.2377	3.2683313	2.8815223		0.1687498	1135.9985	72.854817	64.132846
0.095045	1135.1604	37.585795	33.110558		0.2635852	1137.0787	106.85375	93.972173
0.2031758	1136.3904	95.871016	84.36451		0.3354084	1137.8981	135.45603	119.04056
0.3106185	1137.6151	154.70095	135.98707		0.4400058	1139.0936	176.47058	154.92193
0.436658	1139.0553	211.89673	186.02849		0.531354	1140.1397	218.56448	191.69974
0.5379018	1140.2147	265.8242	233.13521		0.6129391	1141.0756	264.97573	232.21575
0.5744049	1140.6334	296.87333	260.2706		0.6875521	1141.9329	302.2126	264.65005
0.6329468	1141.3054	329.55664	288.75414		0.747521	1142.6228	336.75122	294.71774
0.6811573	1141.8594	355.15857	311.0353		0.8053986	1143.2895	372.90877	326.17177
0.7217929	1142.3267	388.93127	340.47288		0.8667613	1143.9972	413.92338	361.82202
0.757608	1142.739	402.54933	352.26708		0.8848914	1144.2065	424.71665	371.18882
0.8058185	1143.2944	425.97234	372.58326		0.9218492	1144.6333	450.08093	393.20972
0.8278574	1143.5485	441.7693	386.31446		0.9413742	1144.8589	461.41392	403.03125
0.9036178	1144.4227	476.08674	416.00602		0.9880939	1145.3991	499.73017	436.29348
0.9559631	1145.0275	502.77811	439.09696		1.0299338	1145.8833	520.77711	454.47655
0.9559631	1145.0275	502.77811	439.09696		1.0703776	1146.3518	541.82404	472.65076
0.9910879	1145.4338	515.85144	450.35467		1.110124	1146.8125	565.56934	493.16634
1.0737351	1146.3907	551.80305	481.33944		1.1212809	1146.9419	576.90233	502.99175
1.0992186	1146.6861	564.33165	492.14136		1.1861319	1147.6947	611.4409	532.75572
1.1123044	1146.8378	574.13667	500.62586		1.2328516	1148.2376	633.02749	551.30359
1.1722247	1147.5332	594.83606	518.36067		1.2935179	1148.9433	647.05884	563.17736
1.1853105	1147.6851	601.37272	523.98755		1.3137404	1149.1787	654.61415	569.6365
1.2183689	1148.0692	607.90938	529.50586		1.3318694	1149.3899	657.85211	572.34897
1.305839	1149.0867	629.15355	547.52486		**1.4183366**	**1150.398**	**667.02646**	**579.82233**
1.3327008	1149.3996	638.41379	555.43243		1.4287972	1150.5201	664.3281	577.41547
1.3540495	1149.6483	641.68215	558.15517		1.4462299	1150.7236	662.16946	575.43745
1.3871102	1150.0337	646.0399	561.75735		1.4797004	1151.1145	651.37613	565.8656
1.4718237	1151.0225	661.83686	574.99905		1.4992266	1151.3427	644.90014	560.12873
1.5468961	**1151.9002**	**665.64989**	**577.87115**		1.5082899	1151.4487	637.8845	553.9843
1.5489624	1151.9244	665.10516	577.38614		1.5278161	1151.677	626.55151	544.03405
1.5799545	1152.2871	664.01571	576.25891		1.5480386	1151.9136	618.9962	537.36341
1.6329879	1152.9084	659.11323	571.69612		1.5689574	1152.1584	610.36158	529.75493
1.6584714	1153.2071	657.47905	570.13093		1.5940609	1152.4523	606.58389	526.34187
1.6894636	1153.5707	655.3002	568.06247		1.5961521	1152.4768	603.34593	523.52112
1.743185	1154.2014	651.48711	564.4484		1.6282277	1152.8526	599.56825	520.07366

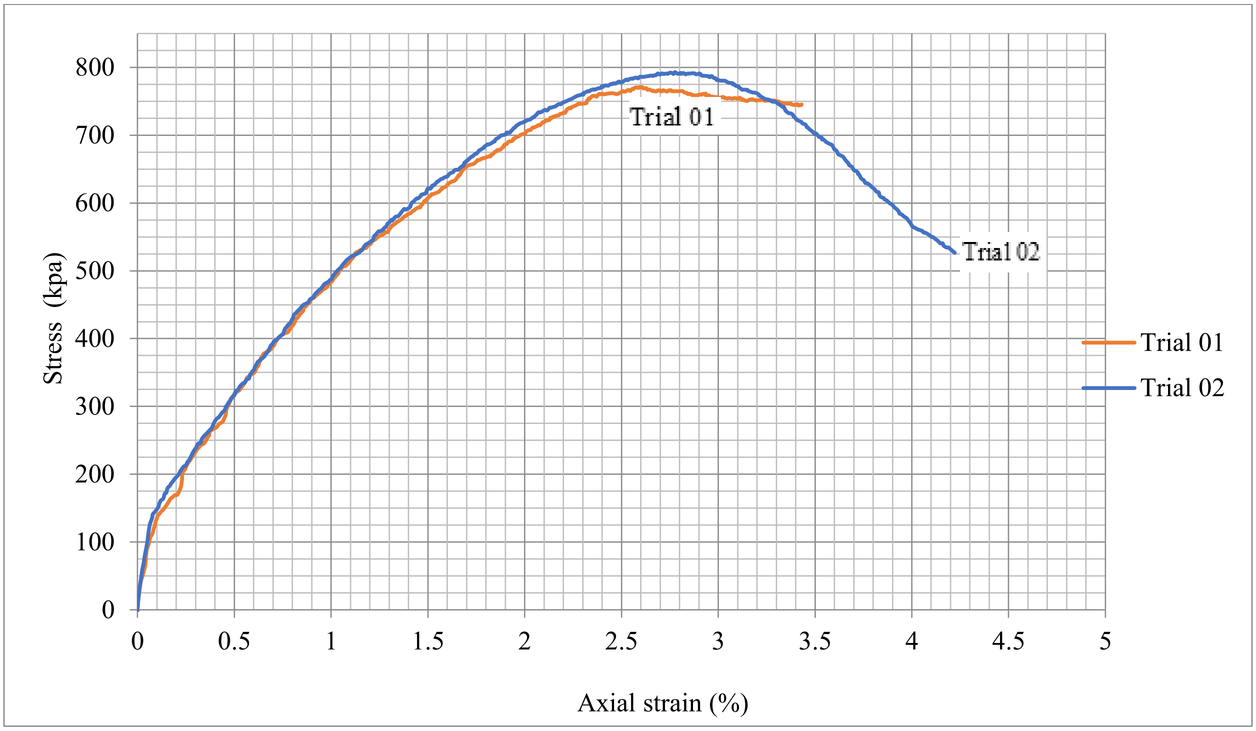
B) UCS test result summary of soil sample 01 + 20% CDW + 1% PWF (cured for 7 days)



Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (cured for 7 days) (S01+ 20%CDW+1%PWF)	**Remolded** (cured for 7 days) (S01+ 20%CDW+1%PWF)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	85	76
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	96.40	86.192
stress (Peak, qu) (kpa)	632.44	628.452
Cohesion (kpa)	316.22	314.226
Corrected Area at peak qu (mm^2)	1163.623	1158.42
Load at peak qu, F, (N)	735.919	728.01

Trial 01					Trial 02			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**		**Axial strain (%)**	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**
6.915E-39	1134.0815	-1.0894388	-0.9606354		7.734E-39	1134.0815	5.877E-36	5.183E-36
0.0442404	1134.5834	34.862205	30.726877		0.7230194	1142.3408	304.3713	266.44525
0.1225135	1135.4726	62.09828	54.689368		0.7511202	1142.6643	322.18027	281.95532
0.168116	1135.9913	81.708267	71.926844		0.811878	1143.3642	346.46523	303.02263
0.2143983	1136.5182	105.13128	92.502949		0.8399788	1143.6882	359.4172	314.26152
0.3110482	1137.62	139.99347	123.0582		0.9539002	1145.0037	394.49543	344.53638
0.407017	1138.7163	176.48982	154.99016		1.0769342	1146.4278	441.98596	385.5332
0.5057088	1139.8458	216.79921	190.20048		1.0936436	1146.6215	452.23963	394.41058
0.6690598	1141.7203	271.81613	238.07594		1.1521226	1147.2998	474.36589	413.46289
0.7684315	1142.8636	321.93053	281.68761		1.1825022	1147.6525	487.31786	424.62144
0.899794	1144.3785	360.60578	315.11057		1.3298399	1149.3662	535.88778	466.24632
0.975344	1145.2516	393.28909	343.40845		1.3883189	1150.0478	547.76043	476.2936
1.1026214	1146.7255	438.50094	382.39398		1.4164197	1150.3756	554.23641	481.78733
1.2482767	1148.4169	484.80231	422.14835		1.4209772	1150.4288	558.5537	485.51782
1.3272297	1149.3358	513.67253	446.92989		1.5083162	1151.449	574.74369	499.1482
1.4477012	1150.7408	545.26639	473.83946		1.5227468	1151.6177	581.21967	504.69844
1.4953456	1151.2974	561.06335	487.33139		1.6480596	1153.085	615.21858	533.54138
1.6205821	1152.763	593.74666	515.06396		1.6829955	1153.4948	624.93253	541.77318
1.712467	1153.8406	613.90132	532.05035		1.7657782	1154.4668	645.97952	559.54793
1.8172836	1155.0724	638.41379	552.70454		1.8280544	1155.1992	664.86782	575.54389
1.9186985	1156.2668	659.11323	570.0356		1.8379287	1155.3154	666.4868	576.88733
1.9670228	1156.8367	669.46298	578.70134		1.8872939	1155.8967	683.75611	591.5374
2.0187513	1157.4475	674.91019	583.10221		1.9488109	1156.6219	696.70808	602.36461
2.034405	1157.6324	679.26794	586.77342		1.993621	1157.1507	708.04101	611.88315
2.1766573	1159.3158	702.14623	605.65569		2.0657702	1158.0032	722.0723	623.5495
2.2079659	1159.687	705.95932	608.74988		2.0741249	1158.102	724.231	625.3603
2.3808468	1161.7408	726.11398	625.02238		2.0984273	1158.3895	726.38965	627.06859
2.4141974	1162.1378	729.38234	627.62121		**2.1007061**	**1158.4164**	**728.00863**	**628.45158**
2.4700097	1162.8028	732.10597	629.60456		2.106782	1158.4883	726.92931	627.48091
2.4958734	1163.1113	733.74009	630.84255		2.1402861	1158.885	724.231	624.93779
2.5387528	**1163.623**	**735.919**	**632.43765**		2.1776011	1159.327	719.91366	620.97549
2.608177	1164.4525	733.74009	630.11596		2.1806479	1159.3631	715.05666	616.76678
2.6143029	1164.5257	731.56124	628.20531		2.2027317	1159.6249	708.04101	610.57761
2.6428896	1164.8677	730.47179	627.08564		2.2088239	1159.6972	703.72373	606.8168
2.7027848	1165.5847	729.38234	625.76517		2.2141557	1159.7604	701.02537	604.45706
2.7796958	1166.5068	722.30095	619.19992		2.2187246	1159.8146	698.86672	602.56763
2.8178114	1166.9644	717.94319	615.2229		2.2278623	1159.923	696.16836	600.18499

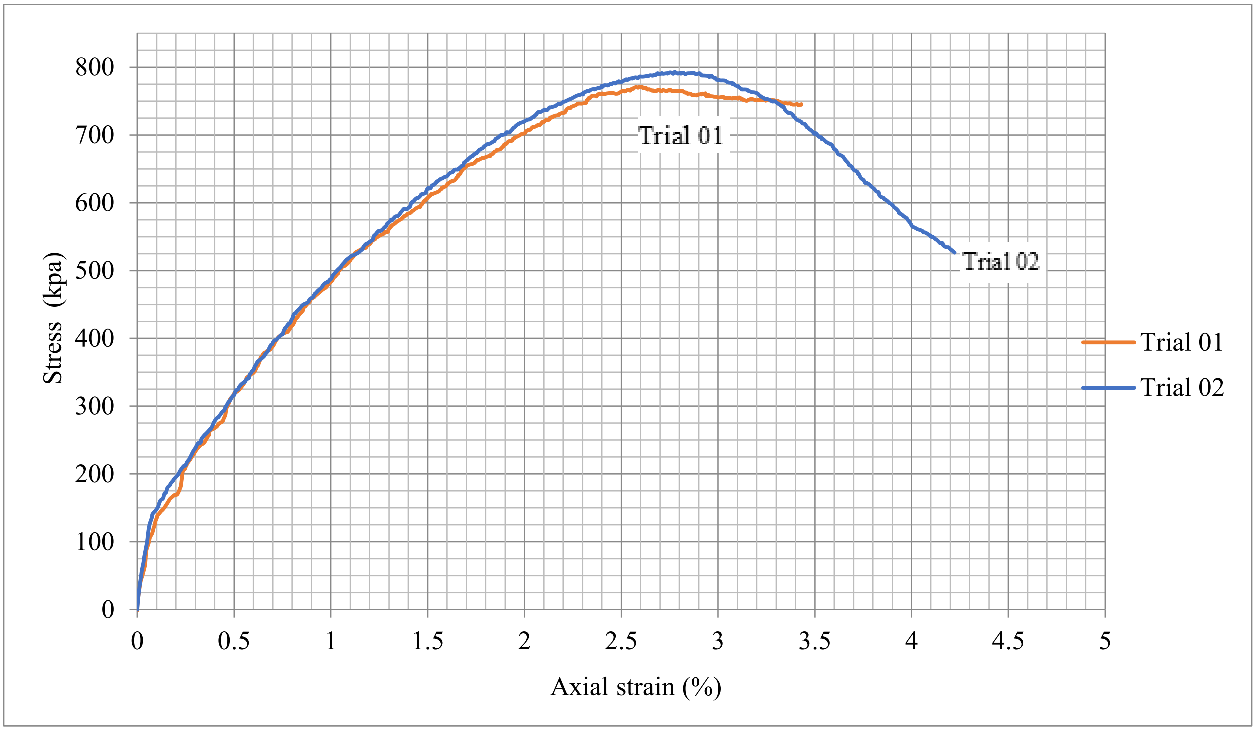
C) UCS test result summary of soil sample 01 + 20% CDW + 1.5% PWF (cured for 7 days)



Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (cured for 7 days) (S01+ 20%CDW+1.5%PWF)	**Remolded** (cured for 7 days) (S01+ 20%CDW+1.5%PWF)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	80	84
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	90.73	92.266
stress (Peak, qu) (kpa)	875.96	867.53
Cohesion (kpa)	437.98	433.765
Corrected Area at peak qu (mm^2)	1153.54	1152.20
Load at peak qu, F, (N)	1010.46	999.56

Trial 01					Trial 02			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**		**Axial strain (%)**	**Ac (mm^2)**	**F (N)**	**stress (kpa)**
7.347E-39	1134.0815	-1.0894537	-0.9606485		6.997E-39	1134.0815	-1.6341507	-1.4409465
0.0245881	1134.3604	81.163526	71.550033		0.0158321	1134.2611	94.236851	83.082152
0.0556839	1134.7134	138.35928	121.93324		0.0536902	1134.6907	217.34393	191.54464
0.1034129	1135.2555	204.81536	180.41345		0.0784704	1134.9721	270.18195	238.05162
0.1533115	1135.8228	260.37696	229.24082		0.1183941	1135.4258	317.02805	279.21512
0.2314138	1136.712	357.33739	314.36053		0.1383554	1135.6527	347.53245	306.02
0.2762508	1137.2231	413.98844	364.0345		0.1810324	1136.1383	383.48407	337.53292
0.348568	1138.0484	483.71282	425.03714		0.2429826	1136.8438	442.85876	389.55109
0.3926814	1138.5524	532.73773	467.90797		0.2980493	1137.4717	480.98922	422.85817
0.4375184	1139.0651	574.6814	504.52023		0.344168	1137.9981	514.21726	451.86125
0.5054963	1139.8434	634.05597	556.26588		0.3882215	1138.5014	552.34778	485.15336
0.569135	1140.5729	672.18661	589.34121		0.4357168	1139.0445	589.93363	517.91974
0.6060171	1140.9961	710.8618	623.01859		0.4825234	1139.5802	614.44604	539.18629
0.6942439	1142.0098	784.39927	686.8586		0.5396553	1140.2348	658.5685	577.57269
0.7159388	1142.2594	802.37508	702.4456		0.5754488	1140.6453	676.54431	593.12416
0.7774079	1142.967	829.61106	725.8399		0.6552957	1141.5621	727.20349	637.0249
0.8063352	1143.3003	854.12359	747.06844		0.7206877	1142.314	754.43947	660.44841
0.8526182	1143.834	878.09134	767.67372		0.7785076	1142.9797	780.58606	682.93958
0.9133637	1144.5353	891.70933	779.10166		0.8081061	1143.3207	795.29363	695.59975
0.9531379	1144.9949	906.96144	792.1096		0.8149896	1143.4001	800.19623	699.83922
1.0579979	1146.2084	945.63675	825.01296		0.8989663	1144.369	833.42415	728.28271
1.2612092	1148.5673	972.32819	846.55741		1.0056581	1145.6023	872.64401	761.73378
1.4000583	1150.1848	988.66987	859.57483		1.1515856	1147.2936	914.5878	797.16981
1.4579117	1150.86	996.29593	865.69688		1.1687937	1147.4933	919.49016	801.30327
1.5302289	1151.7052	999.56417	867.89931		1.3938796	1150.1127	964.1574	838.3156
1.6784787	1153.4418	1008.2798	874.14885		1.4819866	1151.1413	983.76733	854.60175
1.687156	**1153.5436**	**1010.4587**	**875.96058**		1.5136497	1151.5113	989.75927	859.53062
1.6951108	1153.6369	1007.1902	873.05651		1.5432483	1151.8575	995.20642	864.00132
1.7500722	1154.2823	1005.5561	871.15269		**1.5721582**	**1152.1958**	**999.56423**	**867.5298**
1.8021405	1154.8943	997.93005	864.08776		1.5948733	1152.4618	996.29599	864.49372
1.8100953	1154.9879	995.75114	862.13125		1.7084491	1153.7935	969.60455	840.36231
1.9033837	1156.0863	984.85684	851.88872		1.7339173	1154.0925	965.24674	836.3686
1.9525599	1156.6661	975.59643	843.45554		1.8144522	1155.0391	957.07589	828.60906
2.0039046	1157.2721	967.97037	836.42416		1.8729613	1155.7278	948.90505	821.04542
2.0227075	1157.4942	957.07583	826.8515		1.9328464	1156.4336	932.01882	805.94236
2.1123803	1158.5546	943.45784	814.34044		1.9624449	1156.7827	924.93731	799.57739
2.1225047	1158.6744	933.65288	805.79399		2.0553697	1157.8802	885.71745	764.94739

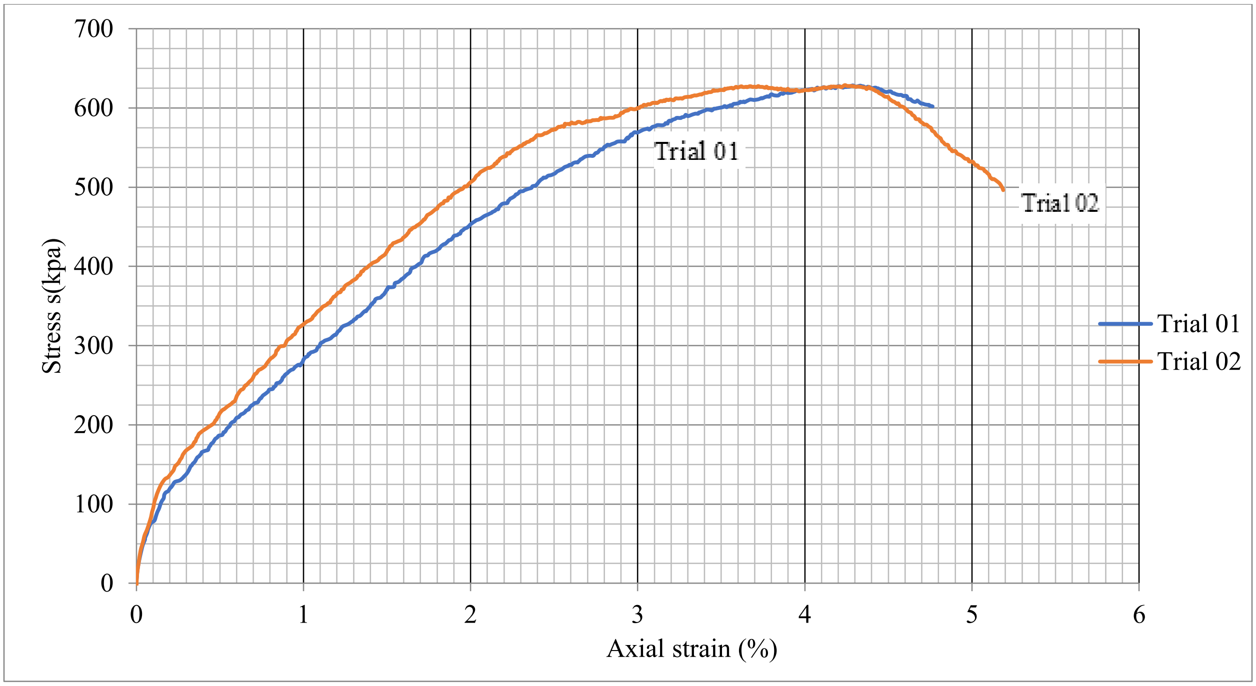
D) UCS test result summary of soil sample 01 + 20% CDW + 2% PWF (cured for 7 days)



Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (cured for 7 days) (S01+ 20%CDW+2%PWF)	**Remolded** (cured for 7 days) (S01+ 20%CDW+2%PWF)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	84	79
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	92.2668	89.595
stress (Peak, qu) (kpa)	771.02	792.99
Cohesion (kpa)	385.51	396.495
Corrected Area at peak qu (mm^2)	1164.31	1166.46
Load at peak qu, F, (N)	897.70	924.99

Trial 01					Trial 02			
Axial strain %	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**		**Axial strain %**	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**
6.997E-39	1134.0815	0.5447268	0.4803243		7.44E-39	1134.0815	5.877E-36	5.183E-36
0.0392585	1134.5269	72.992682	64.337551		0.035898	1134.4888	88.505119	78.013218
0.0461453	1134.6051	97.505182	85.937552		0.1186842	1135.4291	182.40693	160.65022
0.0936678	1135.1448	148.1643	130.52459		0.1677694	1135.9873	208.31087	183.37429
0.1439458	1135.7163	172.67674	152.04214		0.271802	1137.1724	254.72209	223.99603
0.2286604	1136.6806	216.25447	190.25086		0.3472618	1138.0335	293.03834	257.49536
0.2741167	1137.1988	252.20615	221.77842		0.419059	1138.854	323.25956	283.84637
0.3526324	1138.0948	283.80001	249.36412		0.5003796	1139.7848	360.49649	316.28471
0.4593861	1139.3154	337.1827	295.95204		0.5758394	1140.6498	389.09873	341.12024
0.4979554	1139.757	361.15044	316.86618		0.6395775	1141.3815	422.01832	369.74343
0.5957547	1140.8783	398.19151	349.02189		0.754599	1142.7043	467.88988	409.45839
0.6322577	1141.2974	418.34623	366.5532		0.8915998	1144.2839	524.01507	457.94147
0.7741372	1142.9293	467.37117	408.92394		1.0234712	1145.8085	569.88668	497.36642
0.8147728	1143.3976	488.07061	426.85992		1.2227445	1148.1201	633.02755	551.36006
1.0337898	1145.928	567.59995	495.31904		1.2901451	1148.904	653.53477	568.83321
1.0799351	1146.4626	583.39691	508.86696		1.3692687	1149.8257	676.74041	588.55912
1.3092836	1149.1268	649.85293	565.51889		1.5260491	1151.6563	720.45338	625.58018
1.5069496	1151.433	701.60151	609.32898		1.6015089	1152.5395	737.18297	639.61622
1.7473175	1154.2499	762.06565	660.22587		1.6396052	1152.9859	747.9763	648.72978
1.947051	1156.6011	803.46441	694.67719		1.9363174	1156.4745	818.6723	707.90345
2.0069701	1157.3083	815.99307	705.07837		2.3575747	1161.4639	891.52718	767.58924
2.3478939	1161.3487	879.72552	757.50331		2.5165534	1163.358	908.25677	780.71991
2.4016153	1161.988	884.62788	761.30553		2.6367031	1164.7936	916.89146	787.17072
2.5662218	1163.9511	895.52242	769.3815		2.6762648	1165.2671	918.51044	788.24023
2.5917053	1164.2556	897.15654	770.58385		2.6989756	1165.5391	920.12942	789.44534
2.5958379	**1164.305**	**897.70132**	**771.01906**		2.7334093	1165.9517	922.28806	791.01736
2.7163664	1165.7475	893.34351	766.32678		**2.7759009**	**1166.4613**	**924.98636**	**792.98503**
2.7962594	1166.7056	892.25417	764.76376		2.8381734	1167.2089	922.82772	790.62772
2.8348287	1167.1687	890.07527	762.59348		2.9297515	1168.3101	920.12942	787.57295
2.8430927	1167.268	887.89636	760.66195		2.9868959	1168.9983	916.3518	783.87781
3.0008134	1169.166	882.99376	755.23387		3.1041157	1170.4125	903.39983	771.8645
3.0331839	1169.5563	882.44921	754.51623		3.1803083	1171.3335	893.68582	762.96444
3.1199637	1170.6039	881.35964	752.91021		3.2154735	1171.7591	888.28921	758.08177
3.1275397	1170.6955	880.2703	751.92083		3.3121797	1172.9311	874.79758	745.82181
3.246002	1172.1288	879.72552	750.53654		3.3869067	1173.8383	856.44889	729.61402
3.3238297	1173.0724	877.54661	748.07538		3.4565056	1174.6845	837.02099	712.5496
3.4257616	1174.3106	874.27837	744.50352		3.4924048	1175.1215	826.76733	703.55902

E) UCS test result summary of soil sample 01 + 20% CDW + 2.5% PWF (cured for 7 days)



Sample information	Trial number: 01	Trial number:02
Sample Type	**Remolded** (cured for 7 days) (S01+ 20%CDW+2.5%PWF)	**Remolded** (cured for 7 days) (S01+ 20%CDW+2.5%PWF)
Sample Shape	cylindrical	cylindrical
Sample Height (mm)	80	79
Sample Diameter (mm)	38	38
Area (mm^2)	1134.115	1134.115
Volume (cm^3)	90.73	89.595
stress (Peak, qu) (kpa)	628.46	628.85
Cohesion (kpa)	314.23	314.43
Corrected Area at peak qu (mm^2)	1184.85	1184.28
Load at peak qu, F, (N)	744.63	744.74

Trial 01			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**
7.347E-39	1134.0815	5.877E-36	5.183E-36
0.0519025	1134.6704	64.821884	57.128381
0.1405704	1135.6779	110.57849	97.367827
0.2177048	1136.5558	141.08293	124.13198
0.3489041	1138.0522	174.31094	153.16603
0.4837072	1139.5938	209.71785	184.0286
0.5896771	1140.8086	234.77505	205.79706
0.8744228	1144.0856	296.3286	259.00911
1.0106683	1145.6603	326.83301	285.27916
1.1613321	1147.4067	354.61378	309.05675
1.290369	1148.9066	379.67098	330.46286
1.4814007	1151.1344	419.98041	364.84046
1.6428769	1153.0243	457.02147	396.36761
1.7915273	1154.7695	484.25758	419.35432
2.1755302	1159.3025	552.34778	476.44837
2.2247064	1159.8855	559.97384	482.7837
2.390312	1161.8534	583.39691	502.12609
2.7540672	1166.1994	633.5113	543.22725
2.9587245	1168.6589	661.8368	566.32162
3.2074952	1171.6625	685.25988	584.86114
3.5314751	1175.5974	706.50399	600.97442
3.6392272	1176.912	714.67483	607.24577
3.7209451	1177.9109	719.57731	610.89281
3.8525629	1179.5234	728.83761	617.90857
3.8829362	1179.8961	731.01646	619.56002
4.1251981	1182.8775	738.64257	624.44551
4.2329502	1184.2085	742.4556	626.96361
4.2850184	**1184.8527**	**744.63451**	**628.4617**
4.3710756	1185.9189	742.4556	626.05933
4.4455624	1186.8434	739.1873	622.81791
4.4766593	1187.2297	737.00839	620.77993
4.577179	1188.4804	732.65064	616.46002
4.5995975	1188.7597	731.56118	615.39873
4.6907175	1189.8962	721.75622	606.57076
4.6950567	1189.9503	720.66677	605.6276
4.7341073	1190.4381	719.03259	604.00669
4.7644806	1190.8178	716.85368	601.98436

Trial 01			
Axial strain (%)	**Ac (mm^2)**	**F (N)**	**Stress (kpa)**
0.0007303	1134.0898	-2.1586418	-1.9034135
0.0644672	1134.8131	77.17216	68.004292
0.1164823	1135.404	122.50406	107.89468
0.189745	1136.2375	152.18565	133.93824
0.2769265	1137.2308	184.02591	161.81932
0.4000072	1138.6361	219.64386	192.90084
0.5245523	1140.0617	250.40475	219.64139
0.6168631	1141.1207	275.76903	241.66509
0.7333502	1142.4597	307.60929	269.25176
0.8527671	1143.8358	339.98922	297.23604
0.9787777	1145.2914	370.75016	323.71689
1.0872056	1146.5468	393.95574	343.60196
1.2212753	1148.103	422.01838	367.57885
1.3465543	1149.561	452.2396	393.40202
1.5670728	1152.1363	497.5715	431.8686
1.6923506	1153.6045	522.93575	453.30591
1.8044423	1154.9214	548.83969	475.21822
1.9304529	1156.4054	573.66431	496.07545
2.1172717	1158.6125	607.66327	524.475
2.2330248	1159.9842	629.24993	542.46421
2.4322981	1162.3534	658.39183	566.43
2.9063044	1168.0279	693.47	593.71011
3.0498975	1169.7579	705.88231	603.44307
3.1085075	1170.4655	710.19959	606.76679
3.3869031	1173.8383	725.31033	617.8963
3.4587003	1174.7112	730.16727	621.57171
3.5422192	1175.7284	734.48455	624.70598
3.7707969	1178.5211	738.80196	626.88902
4.2389423	**1184.2826**	**744.73822**	**628.8518**
4.3612903	1185.7976	742.03992	625.77284
4.4770434	1187.2345	729.62761	614.56065
4.4990226	1187.5077	729.08795	613.9648
4.5048834	1187.5806	726.38965	611.65502
4.6895039	1189.881	694.00966	583.25971
4.7613011	1190.778	680.51803	571.49025
4.8411562	1191.7773	660.01081	553.80381
4.9825523	1193.5508	635.72586	532.6341