JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

STABILIZATION OF EXPANSIVE WEAK SUBGRADE SOIL USING FLY ASH MIXED WITH AND WITHOUT CEMENT KILN DUST:

A CASE STUDY IN JIMMA TOWN

A Thesis submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Highway Engineering

By:

Biniyam Birhanu Desta

January 2022 G.C

Jimma, Ethiopia

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Biniyam Birhanu Desta

Advisor: Dr. Damtew Tsige

Co-Advisor: Eng. Melka Amensa

January 2022 G.C

Jimma, Ethiopia

DECLARATION

I, the undersigned, declare that the work in this thesis entitled: "Stabilization of expansive weak subgrade soil using fly ash with and without cement kiln dust. In case of Jimma town" has been performed by me in school of Civil and Environmental Engineering, under the supervision of main advisor Dr. Damtew Tsige and co-advisor Eng. Melka Amensa. This has not been presented by any other person for an award of a degree in University, and all sources of material used for this thesis have to be duly acknowledged.

Candidate:	--------------------	------/----------/-------
Biniyam Birhanu	Signature	Date

This thesis has been submitted for examination within my approval as university supervisor.

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ACKNOWLEDGMENT

First, I would like to acknowledge the almighty God gratefully.

Secondly, I would like to express my sincere and deepest gratitude to my advisor Dr. Damtew Tsige and co-advisor Eng. Melka Amensa for all their limitless efforts in guiding me through my work. Special thanks would also give to Benishangul Gumuz Regional State Road and transport office for offering this opportunity to me and for civil and environmental engineering department academic and laboratory staff for all supports.

Lastly, I would like to express my humble gratitude to my family & my friends.

ABSTRACT

Expansive Soils are soils that have the ability to shrink and/or swell, and thus change in volume, in relation to changes in their moisture content. Because of this swelling and shrinking behaviors, expansive soils cause structural damage to lightweight structures such as pavement, sidewalks, and driveways. The aim of this study is stabilization of expansive weak subgrade soil using fly ash mixed with and without cement kiln dust. The research conducted through the experimental or laboratory test by using purposive sampling of one representative expansive soil sample based on observation of color and soil texture. The soil sample was disturbed soil sample toked from 2m depth and brought the fly ash and cement kiln dust from coal fired power generation station of Dongfeng textile PLC and Mugher cement enterprise factory respectively. The soil stabilized by fly ash in the proportion of 10%, 15%, 20%, 25% & 30% by dry weight to get the optimum percentage and then activate the mixture by cement kiln dust in the proportion of 5%, 10%, 15%, 20% & 25% by dry weight. To analyze the effect of the stabilizer, the following test was conducted: Atterberg limit, specific gravity, Free swell test, Compaction, UCS, CBR and Percent of CBR swell. The stabilized soil sample tested for compaction, UCS and CBR were cured for 4, 7& 14 days. According to AASHTO and USCS, the soil categorized into A-7-5 and CH soil category respectively. The soil under this category has poor engineering property, which is high plastic index, high free swell index, low UCS, low CBR and high percent of CBR swell. All the engineering properties of virgin soil is improved when blended with non-self-cementing fly ash. However, the analysis result shown that fly ash cannot standalone as stabilizer and its optimum dosage of fly ash was 25% but with addition of cement kiln dust activator, the engineering property of soil was improved as a CKD content increased with respect to curing time. Curing of the sample has a significant effect on the performance of the weak subgrade soil. Stabilization of expansive soil using fly ash mixed with cement kiln dust within respect to curing is an effective option for the improvement of engineering properties of expansive soil.

Key words: Cement kiln dust CKD), expansive soil, optimum percentage (OP), fly ash (FA)

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ACRONYMS

AASHTO	American Association of State Highway and Transport Officials
ASTM	American Society for Testing and Materials
CaO	Calcium Oxide
CBR	California Bearing Ratio
CKD	Cement Kiln Dust
CL	Organic Low Plastic Clay
ERA	Ethiopian Road Authority
FA	Fly Ash
LL	Liquid Limit
MDD	Maximum Dry Density
MoWUD	Ministry of Works and Urban Development
OH	Organic Clays of Medium to High Plasticity
OP	Optimum Percentage
OMC	Optimum Moisture Content
PI	Plastic Index
PL	Plastic Limit
USCS	Unified Soil Classification System
UCS	Unconfined compressive strength
CSH	Calcium Silicate Hydrated
CAH	Calcium Aluminum Hydrate

CHAPTER ONE

INTRODUCTION

1.1 Background

The term soil in soil engineering is defined as an unconsolidated material, composed of solid particles produced by disintegration of rocks. The voids space between particles may contain air, water or both. The solid particles may contain organic matter. The soil particles maybe separated by such mechanical means as agitation and water [1].

Every structure is to be founded on soil. The soil on which the structure is to be built should be capable of withstanding the load to be imposed on it. However, naturally there exist problematic soils to be used as foundation or construction materials, such as expansive soils, whose engineering characteristics are mainly affected by fluctuation of moisture content. Expansive soils originate from complex combination of conditions and processes that result in the formation of clay minerals having a particular chemical makeup which expands when it comes in contact with water. All clay soils are not expansive, and the degree of expansion varies with the type of clay mineral predominantly present in the soil mass. The presence of montmorillonite contributes to high swell-shrink potentials [2].

Expansive soils are encountered in arid and semi-arid regions of the world, where annual evaporation exceeds annual precipitation. In India, expansive soils cover about 20% of the total land area. [3]. In Ethiopia, the distribution of expansive soil covers about 40%of the total surface area of the country. [4]. According to the Ministry of Works and Urban Development of Ethiopia [5], many damages occur each year and roads constructed on such soils exhibit serious problems including increased cost of construction and maintenance.

One of the typical approaches of improving weak subgrade soil such as expansive subgrade soil is removing and replacing with high strength subgrade material in order to resist load coming from surface of pavement, so the cost replacing of weak subgrade soil has caused highway agencies to assess alternative methods to construct the highway over weak Subgrade. As a result, soil stabilization is one of the most suitable alternatives which are widely used in pavement construction [6].

Soil stabilization is the improvement of the original soil properties to meet specific engineering requirements. There are two common methods of soil stabilization such as mechanical stabilization and chemical stabilization. Mechanical stabilization means improving the property of soil by blending two or more different soils. Chemical stabilization means changing the property of soil by adding of some chemical agent. Chemical stabilizing agents like cement, lime and bitumen are used for soil stabilization. Although they are common additives, but due to the production industrially manufactured kept the cost financially high [7].

Fly ash is a byproduct of coal fired electric power generation facilities; it has little cementitious properties as compared to lime and cement. [7]. Fly ash is a finer ash produced in a coal fired power station, which is collected using electro-static precipitator. About greater than 85% of the ash produced is fly ash [8]. Most of the fly ashes belong to secondary binders; these binders cannot produce the desired effect on their own. However, in the presence of a small amount of activator, it can react chemically to form cementitious compound that contributes to improved strength of soft soil [7]. According to world Coal Association [9] study estimation; it has over 850 Giga tonnes of proven coal reserves in the worldwide. Fly ash annual production in India is around 10.0 million tons. [10] In Ethiopia, total of about 500,000,000 metric tons of coal reserve are registered [11], [12]. The first coal factory in Ethiopia has been laid out a foundation stone at Gibe Ibare Kebele in Abeshge Woreda of Gurage Zone on June 14, 2021 by Takele Uma, Minister of Mines and Petroleum [13]. Ethiopia has given great attention for the establishment of industries [14]. These industries most probably will use coal as an electric power source in addition to hydroelectric for their sustainable function and power demand [15]. According to techno-economic viability study**,** Yayu under construction coal-based urea fertilizer power plant project will produce annual 75,000 metric ton of fly ash [16].

Portland cement clinker production is one of the major sources of CO2 and other greenhouse gases within the contribution of 5 % of the annual global atmospheric CO2 emission [17]. Cement kiln dust (CKD) is a by-product of the cement manufacturing process and has traditionally been considered as an industrial waste product. Global cement production capacity in 2017 was ~4.99 billion tons per year [18], while the CKD production rate ranged from 54 to 200 kg per ton of produced cement clinker [19]. CKD is composed of fine, powdery solids and highly alkaline particulate material, and is similar in appearance to Portland cement. Generally, the general trend of cement production and consumption in Ethiopia has been increasing. The total estimated annual local production is 26.21 million of MT. but our country's production capacity is around 60 % of their annual estimated production capacity. As a result, the country's' annual production is 15,726,000 MT [17]. The mother plant of the muhger cement enterprise has three production lines with a total production capacity is 1.83 million tons per annum [20].

1.2 Problem Statement

Expansive soil is the major problem encountered in the worldwide especially in engineering construction sites such as road and building construction. Because of swelling and shrinking behaviors, it may cause the following problem in road structures such as road cracking, sliding, bumping, and settlement. According to the Ministry of Works and Urban Development of Ethiopia [5], many damages occur each year and roads constructed on such soils exhibit serious problems including increased cost of construction and maintenance. Expansive soils are encountered in arid and semi-arid regions of the world, where annual evaporation exceeds annual precipitation. In India and Mongolia, expansive soils cover about 20% & 35% of the total land area respectively [3] [21].

The typical approaches of improving weak subgrade soil are removing and replacing with high strength subgrade material and stabilization. But cost of replacing of weak subgrade soil is high when as compared to stabilization. As a result, soil stabilization is one of the most suitable alternatives which are widely used in pavement construction [6]. Commercial stabilizing agents like cement, lime and bitumen are used for soil stabilization. Although they are common additives, but due to the production industrially manufactured kept the cost financially high.

In Ethiopia, the distribution of expansive soil covers about 40%of the total surface area of the country. [4]. Large parts of the Jimma town are covered with soils colored from dark to gray clay soils, there are also red- and yellow-colored clay soils [22]. This type of soil has high plastic index and low CBR value, this implies that the soil has low resistance to axial load applied on the surface of the pavement and it deteriorate easily. As previous study shows that class f fly ash should be used in soil stabilization with the addition of cementitious agent lime and cement. However, both lime and cement are industrially product and it kept the cost financially high. Therefore, this study investigates stabilization of expansive subgrade soil using fly ash mixed with and without cement kiln dust. They are locally available and industry waste by-product, and they harm the environment when removed in uncontrolled disposing systems. So that, reusing the waste materials as stabilization are the best option to improve engineering properties of expansive subgrade soils, and to ensure the healthy environment and cost-effective.

1.3 Research Question

1. What is the pozzolanic properties of fly ash and cement kiln dust?
2. What is the geotechnical engineering property of natural expansive soils?
3. Can fly ash alone improve the geotechnical engineering properties of expansive soil?
4. Can expansive soil containing fly ash mixed with cement kiln dust improve the geotechnical engineering properties of expansive soil?

1.4 Research Objective

1.4.1 General objective

General objective of the study is stabilization of expansive weak subgrade soil using fly ash mixed with and without cement kiln dust.

1.4.2 Specific objective

1. To determine the pozzolanic properties of fly ash and cement kiln dust.
2. To conduct the geotechnical engineering properties of the natural expansive clay soil
3. To investigate the engineering properties of natural expansive clay soils stabilized with fly ash.
4. To assess the engineering properties of expansive clay soil containing fly ash mixed with cement kiln dust with different proportion.

1.5 Significance of Study

The significance of the research is to use the mixture of Fly Ash (FA) and Cement Kiln Dust (CKD) as a replacement of scares and expensive stabilizer for weak subgrade soil. It is also used as an alternative stabilizer which is environmentally friendly. The positive results from this study indicated that locally available marginal materials used for the stabilizer of expansive subgrade soil. Moreover, this research also serves as a reference guide for scientific world, students and researchers who study on the related area for the application of industrial waste used as an innovative stabilizer.

1.6 Scope of the Study

The study area covers only expansive soils and fly ash mixed with cement kiln dust stabilizer; in order to obtain low Plasticity index, and high value of CBR& UCS. However, the finding of this study was limited to one representative sample of expansive subgrade soil, the soil samples was disturbed sample. According to ERA (2002) site investigation manual, in the case of a new alignment, the depth of any pit should in no case be less than 1.5m unless rock or other material impossible to excavate by hand is encountered. For this investigation it taken from 2m depth in order to avoid organic material. After conducting the required laboratory test, examined the engineering property of soil. To develop the conclusion and recommendation the following laboratory test was conducted; gran size analysis, specific gravity, Atterberg limit, free swell for natural soil, proctor test (MDD & OMC), unconfined compressive test (UCS), CBR and CBR swell for stabilizer. For strength test (CBR and UCS) up to 14day curing was conducted. The results were analyzed according to ERA, AASHTO and ASTM specification.

CHAPTER TWO

LITERATURE REVIEW

2.1 Expansive soils

2.1.1 General

Expansive soils are fine grained soils or decomposed rocks that show large volume change when exposed to fluctuations of moisture content. Swelling-shrinkage behavior is likely to take place near ground surface where it is directly subjected to seasonal and environmental variations. Expansive soils are most likely to be unsaturated and have highly reactive clay minerals. The three most important groups of clay minerals are Montmorillonite, Illite, and Kaolinite. Montmorillonite is the clay mineral that is mostly present in expansive soil. When these minerals are exposed to moisture, water is absorbed between the inter-layering lattice structures and exerts an upward pressure, which is the cause for most damages associated with expansive soil [23].

Expansive soils are encountered in arid and semi-arid regions of the world, where annual evaporation exceeds annual precipitation. In India & Mongolia, expansive soils cover about 20% & 35% of the total land area respectively. [3]. In Ethiopia, the distribution of expansive soil covers about 40%of the total surface area of the country [4].

2.1.2 Origin of Expansive Soils

The origin of expansive soils is related to a combination of conditions and processes that result in the formation of clay minerals having a particular chemical makeup which, when in contact with water, expands. The conditions or processes, which determine the clay mineralogy, include composition of the parent material and degree of physical and chemical weathering to which the materials are subjected [24].

2.1.2.1 Mineralogy of expansive soils

Expansivity of soils depends on the presence of clay minerals. Clay particles have sizes of 0.002mm or less. Clay minerals are crystalline hydrous alumino-silicates derived from parent rock by weathering. The basic building blocks of clay minerals are the silicate tetrahedron and the alumina octahedron and combine into tetrahedral and octahedral sheets to form the various types of clays [25]. Kaolinite, illite and montmorillonite are the common groups of clay minerals most important in engineering studies [25].

Kaolinite is a typical two-layer mineral having a tetrahedral and an octahedral sheet joined to form a 1-1-layer structure held by a relatively strong hydrogen bond. Kaolinite does not absorb water and hence does not expand when it comes in contact with water [26].

The **montmorillonite** group clays on the other hand have a 2-1-layer structure formed by an octahedron sandwiched between two tetrahedrons. This group of clays can have significant amounts of magnesium and iron substituting into the octahedral layers. The most important aspect of the montmorillonite group is the ability for water molecules to be absorbed between the layers, causing the volume of the minerals to increase when they come in contact with water [27].

The **illite** clays have a structure similar to that of muscovite, but are typically deficient in alkalis, with less aluminum substitution for silicon. Calcium and magnesium can also sometimes substitute for potassium and illites are non-expanding clays [26].

The three common types of clay mineral have different expansiveness property.

Kaolinite => low degree of expansiveness
Illite => moderate degree of expansiveness
Montmorillonite => very high degree of expansiveness

2.1.2.2 Parent Material

The parent materials that give rise to expansive soil are classified into two. The first group comprises the basic igneous rocks, which are low in silica, generally about 45% to 52% and rich in metallic base such as pyroxenes, amphiboles, biotitic and olivine. Such rocks include the gabbro's, basalts and volcanic glass. The second group includes sedimentary rock that contains montmorillonite as a constituent. These include shales and claystone, and limestone and marls rich in magnesium [25].

2.1.2.3 Weathering and Climate

The weathering process by which clay is formed includes physical, biological and chemical process. The most important weathering process responsible for the formation of montmorillonite is the chemical weathering, which include hydrolysis, hydration, oxidation, carbonation and solution, of parent rock mineral which generally consists of ferromagnesium mineral, calcic feldspars, volcanic glass, volcanic rocks and volcanic ash. The formation is aided in alkaline environment, presence of magnesium ion and lack of leaching. Such condition is favorable in semi-arid regions with relatively low rain fall or seasonal moderate rainfall particularly where evaporation exceeds precipitation. Under these conditions enough water is available for the alteration process, but the accumulated cations will not be removed by rainwater [25].

2.1.3 Impact of Expansive Soil

Expansive soils are one of the major natural hazards in the world. In America's expansive soil problems are most destructive natural hazards, next to hurricane wind problem in terms of dollar losses to buildings. According to the study, it was projected that by the year 2000, losses due to expansive soil would exceed 4.5 billion dollars annually [25].

2.1.4 Distribution of expansive soils

Potentially expansive soils can be found almost anywhere in the world. In the underdeveloped nations, many of the expansive soil problems may not have been recognized because of less intensity of construction. It is to be expected that more expansive soil regions related problems would be reported each year as the amount of construction increases. Expansive soils are in abundance where desiccation phenomenon is common i.e., where the annual evaporation exceeds the precipitation. The problem of expansive soil is widespread throughout the five continents [28].

Expansive soils are widespread in African continent, occurring in South Africa, Ethiopia, Kenya, Mozambique, Morocco, Ghana, Nigeria etc. In other parts of the world case of expansive soils have been widely reported in countries like USA, Australia, Canada, India, Spain, Israel, Turkey, Argentina, Venezuela etc [28].

In Ethiopia, the distribution of expansive soil covers about 40%of the total surface area of the country. [4]. According to the Ministry of Works and Urban Development [5] expansive soils form a major soil group occurring in the high lands mostly in the western, central and southwestern part of Ethiopia.

2.1.5 Nature of Expansive Clay Soils

Soil materials which have high clay content are mostly responsible for expansiveness behavior. This material becomes to swell when the moisture through it increases and It becomes shrinks greatly on drying and develop cracks on the surface. These soils possess a high plasticity index [29] & [30] and their color varies from dark grey to black. The general characteristics of Black cotton soils are:

- Easy to recognize these soils in the field during either dry or wet seasons.
- Shrinkage cracks are visible on the ground surface during dry seasons.
- The maximum width of these cracks may be up to 20 mm or more and they travel deep into the ground.
- Dry black cotton soil requires a hammer to break.
- During rainy seasons, these soils become very sticky and very difficult to traverse.

2.1.5.1 Water clay interaction

In nature every soil particle is surrounded by water. Since the centers of positive and negative charges of water molecules do not coincide, the molecules behave like dipoles. The negative charge on the surface of the soil particle attracts the positive (hydrogen) end of the water molecules [31] & [32].

2.1.5.2 Cation Exchange

Clay particle are normally negatively charged. Similarly charged particles repel each other and cause a dispersion in soil. These negatively charged clay particles can be held together with positively charged cations. The process is termed as flocculation. Different cations. have different flocculation power. Cation exchange is the process in which weak flocculator cations are replaced with cations of high flocculating power.

2.1.5.3 Cation exchange capacity (CEC)

Cation exchange capacity of soil represents the number of exchangeable cations in the clay mineral which can be replaced by the cations of higher replacing power than the absorbed cations. The CEC of a soil is a function of the amount and type of soil colloids present.

2.1.5.4 Swell potential

Swell potential is the measure of volumetric change in various soils on their interaction with water. Different experimental and empirical methods have been developed to determine swell potential of clayey soils.

Table 2. 1 Soil Classification Based on Swell Potential, CEC and PI [33]

Soil type	Swell Potential [33]	cation exchange capacity [34]	Plasticity Index PI
Very High swelling	> 25	> 55	>35
High swelling	5 – 25	37 – 55	20-35
Medium swelling	1.5 – 5	27 – 37	10-25
Low swelling	< 1.5	< 27	0-1

2.1.6 Identification of Expansive Soils

Expansive soils that exhibit high swelling potential can be recognized by both field observation and laboratory tests [25].

2.1.6.1 Field identification

Some of the important field identification method that indicates the potential for expansiveness of a soil is the following: [25].

A shiny surface is easily obtained when a partially dry piece of the soil is polished with a smooth object such as the top of a fingernail.

- The wet samples of the soil are sticky, and it will be relatively difficult to clean the soil from the hands
- The appearance of cracking in nearby structures
- They usually have a color of black and/or gray
- Open or closed fissures, (a joint or similar discontinuity)
- Slickenside, (highly polished or glossy fissure surface)
- Shattering or micro-shattering, (presence of fissures forming granular fragments of clayey soils)

2.1.6.2 Laboratory identification

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

1. Mineralogical identification

This method is used for identifying the mineralogy of clay particles such as characteristic crystal dimensions, characteristic reaction to heat treatment, size and shape of clay particles and charge deficiency and surface activity of clay particle. These properties are a fundamental factor controlling expansive soil behavior. [25]. The various techniques under these methods are: X-ray diffraction, Differential thermal analysis, Dye absorption, Electron microscope, Base exchange capacity, etc.

These methods are not suitable for routine tests. This is because they are time consuming, require expensive test equipment and the results can only be interpreted by specially trained technicians.

2. Indirect methods

These methods include simple soil property test that a practicing engineer resort to use for identifying expansive soil. Such tests are easy and can be performed in average soil mechanics laboratory and yield an excellent index of expansive properties. In this method, the following tests are conducted: [25].

- Atterberg limit test
- Linear shrinkage test
- Free swell test
- Soil classifications

Atterberg limit test:

Here measurements of the plasticity index and liquid limit are useful indices for the identification of the swelling of expansive soils. The Atterberg limits test results and degree of expansion on expansive soils are expressed as follows

Table 2.2 Atterberg limit results and Degree of Expansion [27]

Swelling potential	Plasticity	Index Liquid limit
Low	0-15	<30
Medium	10-35	30-40
High	20-55	40-60
Very High	55 and above	>60

Linear shrinkage test

The swell potential is presumed to be related to the opposite property of linear shrinkage measured in a very simple test. In theory the shrinkage characteristics of the clay should be a consistent and reliable index to the swelling potential.

According to Altmeyer [35] suggested: as a guide to the determination of potential expansiveness for various values of shrinkage limits and linear shrinkage was as follows:

Table 2.3 Shrinkage limits and Degree of Expansion [35]

Shrinkage limit %	**linear shrinkage %**	**degree of expansion**
<10	>8	Critical
10-12	5-8	Marginal
>12	0-5	Non-critical

Free swell test

A free swell test consists of placing a known volume of dry soil in water and noting the swelled volume after the material settles without any surcharge, to the bottom of a graduated cylinder. The difference between the final and initial volume, expressed as a percentage of the initial volume is a free swell volume.

Table 2.4 Atterberg limit results and Degree of Expansion [36]

Index tests	Usually non problematic	Almost always problematic
Plasticity index	<20	>32
Shrinkage limit	>13	<10
Free swell	<50	>100

Soil classifications

The AASHTO (M 145) soil classification system differentiates soils, first based on particle size and secondly based on Atterberg limits. If 35 percent or more of the mass of the soil is smaller than 75µm in diameter, then the soil is considered either a silt or clay and if less than 35 percent of particles are smaller than 75micron sieve, then the soil is considered to be coarse-grained, either a sand or gravel.

AASHTO Classification

Soils that are considered to be potentially expansive are rated by A-6 or A-7 by AASHTO classification [37].

Table 2.5 AASHTO soil classification chart [38]

General Classification	Granular Materials (35 per cent or less passing No. 200)							Silt-clay Materials (More than 35 percent passing No. 200)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve analysis per cent passing No. 10 No. 40 No. 200	50 max 30 max 15 max	50 max 10 max	51 min 10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing No. 40 sieve Liquid limit Plasticity Index	6 (max)		N.P	40max 10max	41 min 10max	40max 11 min	41 min 11min	40 max 10 max	41 min 10 max	40 max 11 min	41 min 11 min
Group index	0		0	0		4 max		8 max	12 max	16max	20 max
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 sub-grade	Excellent to good							Fair to poor			

The A-7 group is subdivided into A-7-5 or A-7-6 depending on the plastic limit. For P.L.<30, the classification is A-7-6; for P.L ≥30, it is A-7-5.

Unified Soil Classification Systems

In this classification system a correlation is made between swell potential and unified soil classification as follows.

Table 2.6 USCS soil classification

Category	Soil classification system
Little or no expansion	GW, GP, GM, SW, SP, SM
Moderate expansion	GW, SC, ML, MH
High volume change	CL OL, CH, OH
No rating	Pt

In the above classification soils rated as CL or OH may be considered as potentially expansive.

For stabilization purposes, soils can be classified into subgrade and base materials based on fractions passing No. 200 sieve. If 25 percent or more passes through the no. 200 sieve the soil can be considered as a subgrade, and if not, they may be classified as a base material.

3. Direct methods

These methods offer the most useful data by direct measurement; and tests are simple to perform and do not require complicated equipment. Direct measurement of expansive soils can be achieved by the use of conventional one-dimensional consolidometer carried out on representative undisturbed samples. These methods are usually performed through actual measurement of swelling pressure and volume change of soil [25].

2.1.7 Physical Properties of Expansive Soil

The most important physical properties of expansive soils are: [25]

- Moisture content
- Dry density
- Index properties and
- Fatigue of Swelling

Moisture

If the moisture content of the clay remains unchanged, there will be no volume change irrespective of the high swelling potential. When the moisture content of the clay is changed volume expansion both in the vertical and Horizontal direction will take place. Complete saturation is not necessary to accomplish swelling. Slight changes of moisture content in the magnitude of only 1 to 2 percent are enough to cause detrimental swelling [25].

Very dry clays with natural moisture content below 15 percent usually indicate danger. Such expansive soils easily absorb moisture as high as 35 percent with a resultant damaging expansion to structures. Conversely clays with moisture contents above 30 percent indicate that most of the expansion has already taken place and further expansion will be small. However moist clays may desiccate due to lowering of water table or other changes in physical condition and up on subsequent wetting will again exhibit swelling potential [25].

Dry density

The dry density of the clay is another index property of the expansive soils. Soils with dry density in excess of 110pcf generally exhibit high swelling potential. The dry density of the clays is also reflected by standard penetration resistance test results. Clays with penetration resistance in excess of 15 usually possess some swelling potential [25].

Index property

The simplified classification of expansive properties can be conventionally used by Engineers as a guide for the choice of structures on expansive soils. Some of the index properties to be identified and used are Soil Classification, Liquid Limit, Standard penetrations and the likes [25].

Fatigue of Swelling

A clay sample is subjected to full swelling in the consolidometer, allowed to desiccate to its initial moisture content and is then saturated again. These steps can be repeated for a number of cycles and observed that the soil has shown a sign of fatigue after each cycle of drying and wetting. It has been noted that pavements founded on expansive clays which have undergone seasonal movement due to wetting and drying have a tendency to reach a point of stabilization after a number of years. The fatigue of the swelling can answer the situation [25].

2.2 Soil Stabilization

In the past when the soil on the site was poor engineering characteristics and Bearing capacity, the site/alignment should be change to a suitable location. Otherwise remove poor subsoil and replace the selected material and compact it to achieve the required design specification. The current practice due to the lack of alternative land for high expansion construction of highway and other civil engineering structures, soil stabilization is used. Soil stabilization is a geotechnical technique of increasing and maintaining the stability of soil mass and chemical or mechanical alteration of soil to enhance their engineering properties. Stabilization increases soil strength, decreases plasticity, lowering or sometimes increases permeability, hence resulting in higher soil strength, lower volume changes due to temperature or moisture variations and increases workability of soil [39]. The soil available for construction of any civil engineering structure often do not meet the requirements for construction. The process by which the properties of soil are improved to meet the construction requirement is called stabilization [29].

2.2.1 Definition of Stabilization

According to the Universal Dictionary, stability means, "The quality or state of being stable, strength to stand and to resist being moved, fixedness as contrasting to fluidity, not subject to change or destruction, not easily moved from a state of equilibrium." Additionally, it defined as a modification of an existing soil so as to improve its bearing or load absorbing characteristics [40]. Also, it is the process of blending and mixing materials with a soil to improve certain engineering properties of the soil in order to achieve a desired gradation or the mixing of commercially available additives that may alter the gradation, texture or plasticity act as a binder for cementation of the soil.

2.2.2 Advantages of Soil Stabilization

Individual project conditions dictate different reasons for treatment. These will have great impact on the type and percentage of additive required. Common reasons for the need for stabilizations [41] are:

-Provide a working platform for construction of subsequent layers by drying out wet -areas and/or temporarily increasing strength properties.

-Reduce shrink/swell of expansive soils or existing materials.

-Increase strength to provide long-term support for the pavement structure.

-Reduce pavement thickness and improve durability.

-Reduce moisture susceptibility and improves soil workability.

-Utilize local materials and upgrades materials.

-For the reduction of cost.

2.2.3 Stabilization Mechanism

Soil stabilization mechanism is the method which used to change one or more engineering properties of soil to improve the desired performance. The mechanism of stabilization may be broadly classified in to two categories. Those are mechanical (physical) stabilization and chemical stabilization. Mechanical method includes replacement with non-expansive fill and compaction. Whereas chemical stabilization enhances the geotechnical properties of clayey soil by addition of different materials, in different amount such as fly ash, quick lime, Portland cement, bitumen, calcium chloride, magnesium chloride, potassium chloride, etc.

2.2.3.1 Mechanical Stabilization

Mechanical stabilization is a stabilization technic that improve the engineering properties of subgrade soil without altering any chemical admixtures or stabilizer. This method is used to improve stability weak sub grade and shear strength characteristics of the soil through compaction, replacement unsuitable material with non-expansive fill, addition of aggregates, soil reinforcement and mixing or blending soils with different gradations to obtain a material that meet the required specification [7].

2.2.3.2 Chemical stabilization

Chemical stabilization includes the mixing or injecting of chemical substances into the soil. Expansive clayey soil by addition of different materials with different amount such as Portland cement, lime, asphalt, calcium chloride, sodium chloride, and paper mill wastes are common chemical stabilizing agents [42]. The effectiveness of these additives depends on the soil conditions, stabilizer properties and type of construction. Those stabilizer materials are categorized in to Organic and inorganic chemicals. Organic like Cement, Lime, fly ash, gypsum and Bituminous stabilizer have both been used in the laboratory with successful results. Other inorganic chemicals such as sodium silicate, calcium hydroxide, sodium chloride, calcium chloride, and phosphoric acid have been used to stabilize expansive soil [27].

2.2.3.2.1 Chemical stabilization processes:

Chemical stabilizer modifies the property of soil through:

Cation exchange: Negatively charged clay particles adsorb cations of specific type and amount. The replacement or exchange of cations depends on several factors, primarily the valence of the cation. Higher valance cations such as the calcium ion Ca^{2+} easily replace cations of lower valance such as sodium ions Na^{+} which reduce the space between the clay surface [43]. Other conditions are equal cation with different metallic series replace each other, trivalent cations are held more tightly than divalent, and the divalent cations are held more tightly than monovalent cations [43].

Agglomeration and Flocculation: Cation exchange reaction 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. Agglomeration and Flocculation change the clay texture from that of a plastic, fine grained material to that of a granular soil [44]. Flocculation is the process of clay particles altering their structure from a flat, parallel structure to a more random orientation. Agglomeration is thought to occur as the flocculated clay particles begin to form weak bonds at the edge surface interfaces of the clay particles, because of the deposition of cementitious material at the clay particle interfaces.

Pozzolanic reaction: Pozzolanic reaction is a secondary process of soil stabilization. One prerequisite for the formation of additional cementing materials is the solution of silica and alumina from clay components. The high pH environment of a soil cement system increases the solubility and reactivity of the silica and alumina present in clay particles. The degree of the crystallinity of the minerals and particle size distribution are some factors influencing solubility. It is postulated that calcium ions combine with silica and alumina dissolved from the clay lattice to form additional cementitious material (C-S-H and C-A-H), [45].

Calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) are the two outputs in pozzolanic reactions.

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

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

2.2.4 Stabilizing Agent for Expansive Clay Soil

Stabilizing agents are manufactured commercial products, industrial or agricultural byproduct that, when added to the soil in the proper quantities improve some engineering characteristics of the soil such as strength, texture, workability and plasticity.

2.2.4.1 Common or Traditional Stabilizing Agent

Common stabilizing agents are well known manufactured commercial products that used for stabilizing of problematic soil such as Portland cement, lime, fly ash, gypsum, water soluble salts, various types of bituminous compounds and various combinations of the above have been used with very successful results [40]. Each stabilizer has its own influence on the properties of different sub grade soil.

2.2.4.2 Innovative Stabilizing Agent

Growing cost of traditional stabilizing agents and the need for the economical utilization of industrial and agricultural wastes for beneficial engineering purposes has encouraged an investigation into the stabilizing potential of expansive clay soil. Thus, the possible use of agricultural waste, such as bagasse ash, rice husk ash [46], groundnut ash [47] and industrial wastes, such as molasses [48], iron slag are considerably reducing the cost of construction and as well as reduce or eliminate the environmental hazards caused by such waste. These stabilizing agents is preferable due to the following reason: -

Due accessibility and production of innovative stabilizers such as industrial or agricultural wastes are far cheaper than common/traditional stabilizers.

Innovative stabilizers are environmentally friendly compared with common stabilizers Waste management from the huge factories also can be done economically by using as a stabilizer

2.3 Cement Kiln Dust

2.3.1 General

Cement Kiln dust is a by-product in the production of cement clinker. Disposal of cement kiln dust is an environmental problem. The utilization of this waste material has received increasing attention because it not only solves a potential soil waste problem but also provides an alternative stabilizing agent using in chemical stabilization of problematic soils. The dust is a particulate mixture of partially calcined and unreacted raw feed, clinker dust and ash, enriched with alkali sulfates, halides and other volatiles [49] It is derived from the same raw materials as Portland cement but, as the cement kiln dust fraction has not been fully burnt, it differs chemically from the former. It is a fine powdery material similar in appearance to Portland cement. There are two types of cement kiln processes; wet-process kilns, which accept feed materials in slurry form; and dry – process kilns, which accept feed materials in a dry, ground form. At Mugger Cement Factory the process is dry and large quantities of cement kiln dust are produced during the manufacture of cement clinker [20].

2.3.2 Cement Kiln Dust Availability

Portland cement clinker production is one of the major sources of CO_2 and other greenhouse gases within the contribution of 5 % of the annual global atmospheric CO_2 emission. [17]. Cement kiln dust (CKD) is a by-product of the cement manufacturing process and has traditionally been considered as an industrial waste product. Global cement production capacity in 2017 was ~4.99 billion tons per year [18], while the CKD production rate ranged from 54 to 200 kg per ton of produced cement clinker [19]. CKD is composed of fine, powdery solids and highly alkaline particulate material, and is similar in appearance to Portland cement. Generally, the general trend of cement production and consumption in Ethiopia has been increasing. The total estimated annual local production is 26.21 million of MT. but our country's production capacity is around 60 % of their annual estimated production capacity. As a result, the country's' annual production is 15,726,000 MT [17]. The mother plant of the mugger cement enterprise has three production lines with a total production capacity of is 1.83 million tons per annum [20]. The same amount is brought to the landfill because of its physical and chemical characteristics; it is dangerous to the environment [50].

2.3.3 Cement kiln dust soil stabilization

According to Ismaiel [51], states that CKD having self-cementing characteristics reacts with soil in a manner like Portland cement. Typically, CKD has approximately one-third of the amount of cement oxides (CaO, Al2O3, SiO2, and Fe2O3) present in Portland cement. The primary value of CKD is its cementitious property. Depending on the concentration of free lime (CaO), CKD can be highly cementitious. Therefore, it can be used as a replacement for cements. The formed cementitious compounds obtained because of the chemical reactions between the silica and the alumina existing in the soil and the additives reduced the volume of the void spaces and participate in the soil particles.

According to Adey [20], the expansive soil used for study, as per AASHTO soil classification system categorized as an A-7-5 with rating of Fair-to-Poor to be used as a sub-grade material. The cement kiln dust used for this study was collected from muhger cement factory and it is a good pozzolana that could help to mobilize the calcium ion with the combination of clay to form pozzolanic reaction. The plasticity index is reduced by increasing the CKD content and curing has also significant effect on the plasticity of the expansive soil. With increment of cement kiln dust content, the optimum moisture content decreased while the maximum dry density values increased. Swell –pressure and CBR swell of the stabilized samples decreased with increasing cement kiln dust content. However, the influence of cement kiln dust stabilization on free swell properties of the expansive soil is not that much satisfactory. CBR values and UCS values also increased with increase of cement kiln dust. Finally, it concludes cement kiln dust can be used as stabilizer for improvement of expansive soils.

2.4 Fly ash

2.4.1 General

Fly ash is a byproduct of coal fired electric power generation facilities; it has little cementitious properties as compare to lime and cement. The quality of fly ash depends on the type of coal used for the power generation. [52]. Based on calcium contents fly ash are categorized in to self-cementing (Class-C) fly ash and non-self-cementing (Class-F) fly ash.

According to ASTM 618 Class C fly ash has a high calcium oxide content and originated from subbituminous and lignite (soft) coal and the sum of three oxides (SiO2+Al2O3+Fe2O3) are in between 50-70% by mass. It is stand-alone stabilizing agent.

Class F fly ash has low calcium oxide content and originated from bituminous and anthracite coal and the sum of three oxides (SiO2+Al2O3+Fe2O3) are greater than 70% by mass. It is not stand-alone as stabilizing agent. It has an insufficient calcium oxide content for pozzolanic reaction to occur. And it is not effective as stabilizing agent by itself. But when mixed with either lime, cement, lime kiln dust and cement kiln dust; the fly ash mixture becomes an effective stabilizing agent [53].

A fly ash material that does not conform to the requirements established by ASTM C618 are referred to herein as off-specification fly ash. Typical off specification of fly ash includes high sulfate (SO_3) or high loss on ignition. It is neither class-c fly ash nor class-f fly ash.

Fly ash has the following benefits [53]. It is used to: Lower the water content of soils, reduce shrink-swell potential, and increase soil strength and stiffness.

2.4.2 Generation of Fly Ash

In the process of generating power from coal, large quantities of coal combustion products (CCPs) are produced. CCPs are the solid residues that remain after the combustion of coal within a furnace and are collected in emission control processes [54].

In the coal combustion process, CCPs are also generated in direct proportion to the variety, quantity and ash content of coal consumed. The pulverized coal is burned in the furnace to generate heat, and the hot gases then pass around the bank of tubes in the boiler and are eventually cleaned and discharged through the plant chimney. In large power plants that consume large quantities of coal, substantial quantities of coal ash are produced [54].

The ash that is collected in electrostatic precipitators or bag houses is called fly ash. The ash collected from pulverized-coal-fired furnaces is fly ash and bottom ash. For such furnaces, fly ash constitutes a major component (80 to 90%) and the bottom ash component is in the range of 10 to 20% [8].

2.4.3 Fly ash Availability

According to world Coal Association [9] study estimation; it has over 850 Giga tonnes of proven coal reserves in the worldwide. This is over enough for 130 years at the current rate of productions. The largest reserves are found in Northern America, Russia, Europe, China, and Australia respectively. Coal currently supplies around 30% of primary energy and 41% of global electric-city generation. In Ethiopia, total of about 500,000,000 metric tons of coal reserve are registered [11]. The first coal factory in Ethiopia has been laid out a foundation stone at Gibe Ibare Kebele in Abeshge Woreda of Gurage Zone, Southern Nations, Nationalities and People's Region on June 14, 2021 by Takele Uma, Minister of Mines and Petroleum [13]. Ethiopia has given great attention for the establishment of industries [14]. The Ethiopian government has been building industrial parks in different cities of the country that are believed to enhance the industrialization, such as textile factories [14]. These industries most probably will use coal as an electric power source in addition to hydroelectric for their sustainable function and power demand [15].

2.5 Fly ash soil stabilization

The experimental was undertaken to study the effect of fly ash stabilization on the geotechnical characteristics of expansive subgrade soils. The fly ash was added in 10%, 20%, 30%, 40% & 50% by dry weight. Based on the study result the following conclusion are drawn; [55]

The Maximum Dry Density (MDD) value of the expansive soil initially decreased with the addition of fly ash. Then, it showed increment with increasing fly ash content in the soil-fly ash mixture. The maximum value of MDD was observed for a mixture of soil and 30% of fly ash content by weight. The MDD values consistently decreased thereafter. The Unconfined Compressive Strength (UCS) of the soil with variation of fly ash content showed similar trend as that of the MDD values, except the fact that the peak value was observed for a fly ash content of 20% by weight. The change in case of soaked California Bearing Ratio (CBR) tests of soil with varying fly ash content was, decreased with the initial addition of fly ash (10% by weight of total mixture), and then increased till fly ash content reached 30% by weight of total mixture. The values decreased thereafter. Finally, fly ash additive; decreases the swelling, and increases the strength of the expansive soil.

According Evren S. [56] high plastic clay soil treated by class f fly ash improve the following engineering properties: as the fly ash content increase from 5% to 30% the plastic index, swelling potentially and MDD of the soil decreases while, the OMC and UCS increase.

According Purkhosrow [57] off-specification fly ash mixed with high plastic soil (CH) and low plastic soil the following result was draw: the liquid limit, plastic index, swell potential and maximum dry density decrease, and its optimum moisture content and unconfined compressive (with long curing time) increases as the fly content increases.

Depending on the soil type, the effective fly ash content for improving the engineering properties of the soil varies from 15 to 30% [58].

2.6 Fly ash-cement soil stabilization review

According to ACAA) [59], class F fly ash should be used in soil stabilization with the addition of cementitious agent (lime, lime kiln dust, cement, cement kiln dust). However, there are research indicating that this fly ash can effectively improve some engineering properties of soil without activators [60].

According to M. Vukicevic [61], the laboratory research conducted on high plasticity clay soil stabilization using non-self-cementing class F fly ash with and without cement activator. Soil-fly ash mixtures were prepared at different fly ash contents (10-25%). Effects of fly ash on physical and mechanical properties of soil such as plasticity, unconfined compressive strength, effective shear strength parameters, CBR, deformation parameters and swell potential were evaluated. Results of the research indicate that used fly ash without activator can effectively improve some engineering properties of the soil and its optimum percentage was 20%. After addition of cement the stabilization effects substantially were significantly improved at 20% fly ash and 3% cement.

Also, other experimental was undertaken to study the effect caused by the combined action of fly ash and cement stabilization on the geotechnical characteristics of expansive subgrade soils. [62]. Expansive soil treated with varying percentages of fly ash, 0, 5, 10, 15, and 20 percent combined with 5% cement content were studied. The experimental results show that addition of cement-fly ash admixture to the soil has great influence on its properties. It was found that the optimum dosage of fly ash is 15% mixed with 5% cement revealed in significant improvement in strength, durability and reduction in swelling and plasticity properties of the soil. [62] From the results, it is clearly understood that there is a great improvement in strength and a marked reduction in swelling of expansive soils treated with 5% cement and 15% fly ash. Hence, 5% cement with 15% fly ash can be effectively adopted in stabilization of expansive soils as road pavement without much cost. Most of the strength gains over the soaking period, suggesting that stabilization reactions and strength gains were ongoing. Cement-treated soil may be experiencing the formation of additional inter-particle bonds over time, while most of the fly ash stiffness gains were achieved very early in the curing process with little additional gains over time. According to the results obtained from experiment, it was recommended that cement-fly ash admixture be considered as a viable option for the stabilization of expansive subgrades [62].

Fly ash mixed with cement/lime/combination can be successfully stabilized to produce adequate strength and durability by allowing the mixture to cure for a sufficiently long period. Cement stabilization, in general, produced better strength and durability than lime stabilization for a given stabilizer content for curing periods up to 56 days. The length of curing has a very dramatic effect on all mixtures. The longer the curing period, the higher the strength [63].
One study conducted in Sudan on off-specification fly ash mixed with 5% cement revealed the following results: at 20% fly ash the liquid limit and plastic index reduction is from 54.12%, and 29.57% respectively while the soaked CBR of the soil increased from 3 to 56% [64].

2.7 Fly ash-lime soil stabilization review

According to Zhang J, and Cao X. [65], an experimental program was undertaken to study the individual and admixed effects of lime and fly ash on the geotechnical characteristics of expansive soil. Lime and fly ash were added to the expansive soil at 4% - 6% and 40% - 50% by dry weight of soil, respectively. It is revealed that a change of expansive soil texture takes place when lime and fly ash are mixed with expansive soil. Plastic limit increases by mixing lime and liquid limit decreases by mixing fly ash, which decreases plasticity index. As the amount of lime and fly ash is increased, there are an apparent reduction in maximum dry density, free swell and swelling capacity and a corresponding increase in the percentage of coarse particles, optimum moisture content and CBR value. Based on the results, it can be concluded that the expansive soil can be successfully stabilized by lime and fly ash.

Jagdish P. S., et.al. [66] paper reports the outcome of an experimental investigation into the effect of fly ash mixed with small amount of lime on the strength characteristics of soil, to ascertain its suitability for use as a construction material. In this investigation, a series of laboratory tests (Compaction tests, Triaxial tests, Unconfined compressive strength (UCS) tests and California bearing ratio (CBR)) were conducted on soil specimens added with various percentages of fly ash and fly ash mixed with lime by the weight of dry soil. The test result reveals that the optimum content of admixture for achieving maximum strength is approximately 15% fly ash mixed with 4% lime of the dry weight of the soil.

2.8 Summary of literature review

As a literature reviewed, ash collected from pulverized-coal-fired furnaces is coal ash. For such furnaces coal ash, fly ash constitutes a major component (80 to 90%) and the bottom ash component is in the range of 10 to 20% [8]. There are two type of fly ash, non-self-cementing class f fly ash and self-cementing class c fly ash based on calcium oxide (CaO) composition. The fly ash used for this study was class f non-self-cementing fly ash. It is not stand-alone as stabilizing agent. It has an insufficient calcium oxide content for pozzolanic reaction to occur.

According to M. Vukicevic [61], the laboratory research conducted on high plasticity clay soil stabilization using non-self-cementing class F fly ash with and without cement activator. Results of the research indicate that used fly ash without activator can effectively improve some engineering properties of the soil and its optimum percentage was 20%. After addition of cement from 3-5% by dry weight, the stabilization effects substantially were significantly improved at 20% fly ash and 3% cement. According to Zhang J, and Cao X. [65], an experimental program was undertaken to study the individual and admixed effects of lime and fly ash on the geotechnical characteristics of expansive soil. Based on the results, it can be concluded that the expansive soil can be successfully stabilized by lime and fly ash.

Here both lime and cement are industry manufactured product and its cost is high to be used as activator. To reduce the cost of the stabilizer used for fly ash activator, this study utilizes industrial waste by-product cement kiln dust activator to improve the engineering properties of class f fly ash treated soil. In Ethiopia, annually about 20 cement plants can generate 6.3 Mt of cement. The same amount is brought to the landfill because of its physical and chemical characteristics; it is dangerous to the environment. This study also reveals the stabilizing potential of class f fly ash alone on expansive subgrade soil.

CHAPTER THREE
RESEARCH DESIGN AND METHODS

3.1 Study Area

The study area was located in Jimma town, Jimma institute of technology (JIT) Kitto furdisa campus. Its latitude and longitude are 7º40’N and 36º50’E respectively and it fares 350km from Addis Ababa. The town has a rolling terrain with an elevation ranging from 1670m to 1770m above mean sea level. Jimma is predominantly covered with red, black and gray soils.

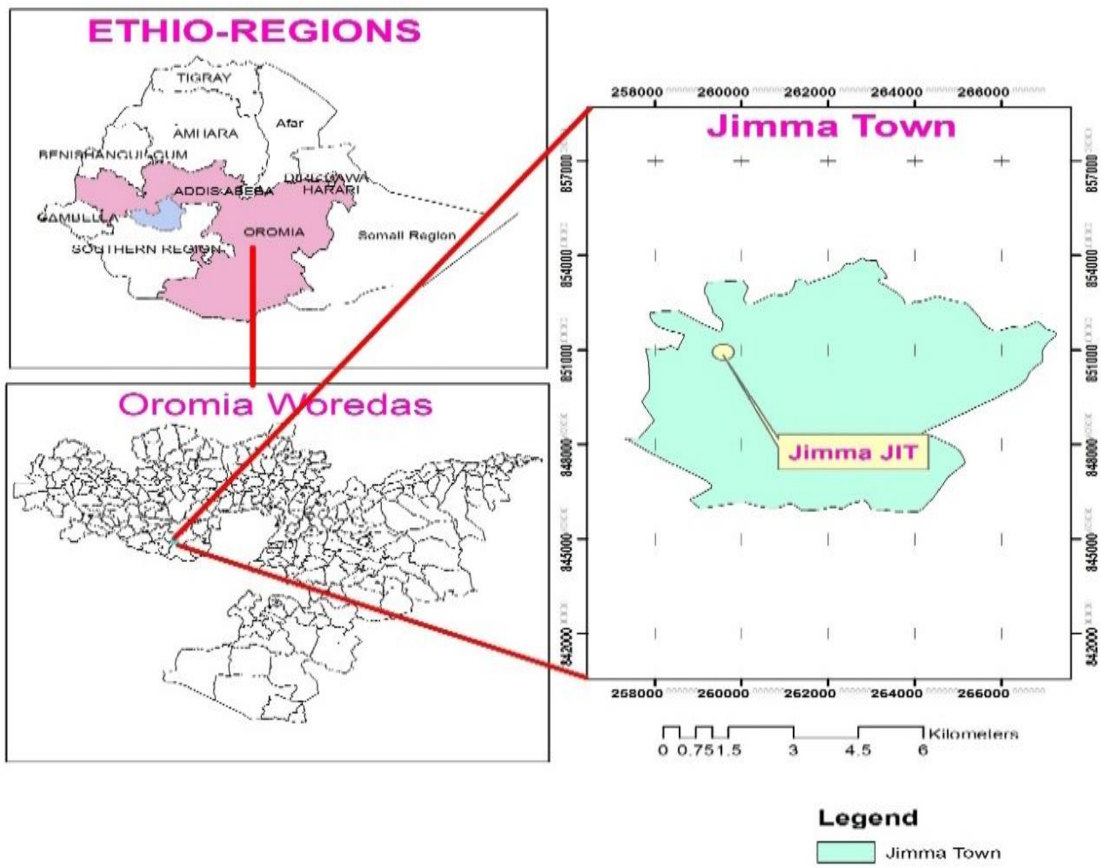

Figure 3. 1 Map of study area taken from www.google using ArcGIS

3.2 Materials

Material detail used for the study:

3.2.1 Expansive soil

The soil sample was collected from here in Jimma Institute of technology (JIT) around under construction road project at 2m depth below natural ground surface to execute detail laboratory test. By using different field identification technique mentioned in literature review, the location of the sample was identified.

Figure 3. 2 Soil sample collection and preparation taken from my own phone

3.2.1 Fly ash:

Fly Ash used for this study was collected from coal fired power generation station of Dongfeng textile PLC. This industry used local coal from here in Ethiopia and sometime imported from South Africa. Fly ash from Dongfeng textile PLC is collected by a wet and dry system of collection or disposal. For this investigation sample token from dry system. Fly ash is mixed with bottom ash in slurry before transporting to the ash disposal area. It is located in eastern industry zone.

Figure 3. 3 Fly ash production station taken from my own phone

3.2.3 Cement kiln dust:

Cement kiln dust used for this study was collected from Mugher Cement enterprise factory. Which are located in Oromia region Mugher town, 90 km far from Addis Ababa.

Figure 3. 4 Muhger cement enterprise factory and its product of CKD taken from my own phone

3.3 Study Design

Experimental study designs were used in this study. It was attempted to conduct laboratory tests such as Grain size analysis, Atterberg limits, Linear shrinkage, free swell test, Specific gravity, UCS, CBR value, CBR swelling percentage and modified Proctor compaction tests on natural expansive soil samples treat with different proportion of Fly ash and cement kiln and checking to standard specification.

The stages involve in the study include-

1. Problem statement
2. Formulation of research objective and research question
3. Continuous literature review (AASHTO, ASTM, ERA & literature)
4. Sample was taken.
5. The sample was Prepared for each laboratory tests.
6. Conducted laboratory tests were Grain size analysis, specific gravity, Atterberg limit, Free swell test, Linear shrinkage, Compaction, UCS, CBR and Percent swell of CBR for natural expansive soil.
7. Mixed the fly ash with expansive soil in different proportion and determined the Optimum percentage of fly ash.
8. Conducted laboratory tests Atterberg limit, Specific gravity Free swell test, Linear shrinkage, Compaction, UCS, CBR and Percent of CBR swell on the blended sample of expansive soil, optimum fly ash by adding varying percentage of CKD.

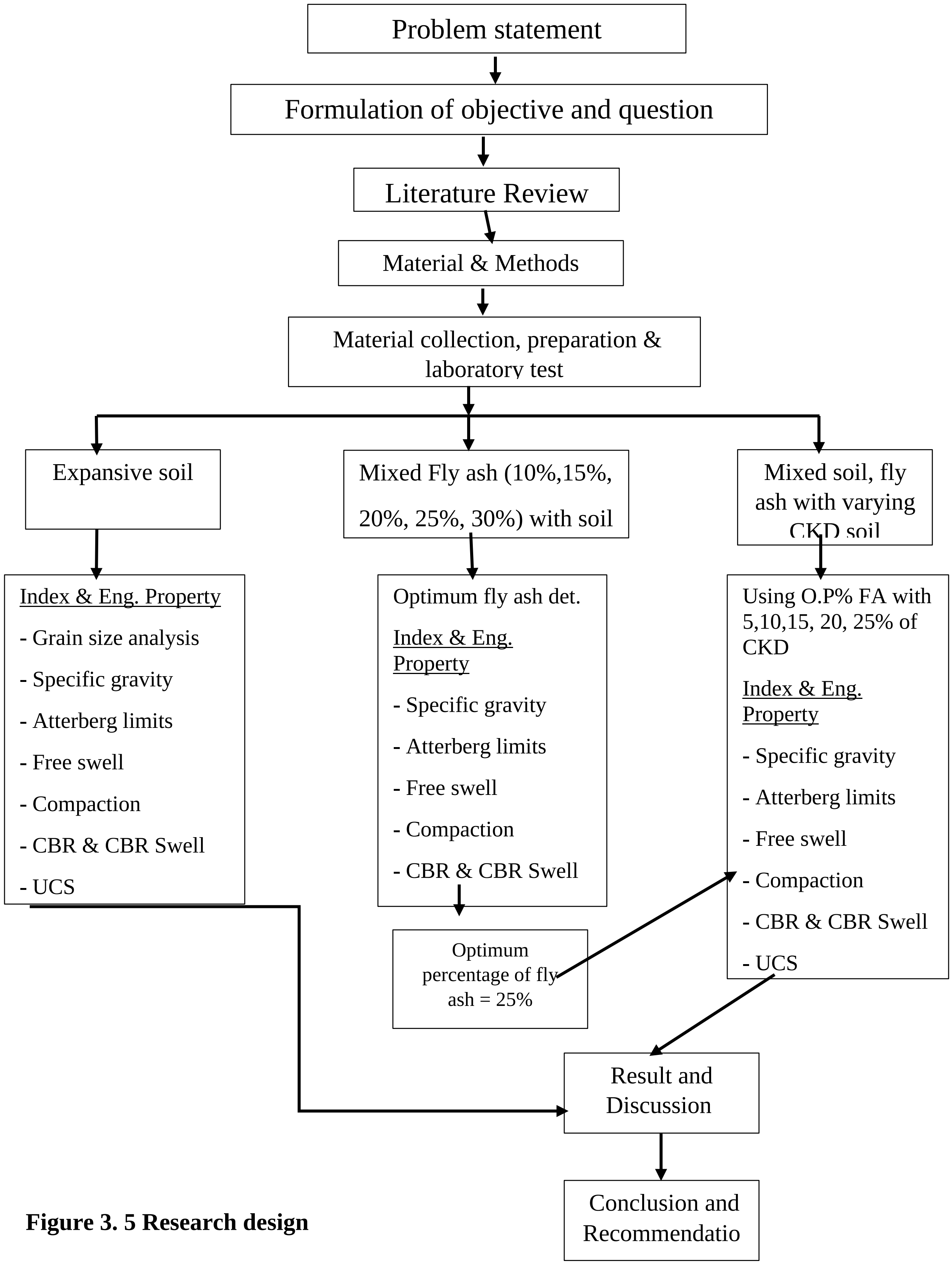

Figure 3. 5 Research design

3.4 Study Variable

The study variables consist both independent and dependent variables.

3.4.1 Dependent Variable

The dependent variable of this research was stabilization of expansive subgrade soil.

3.4.2 Independent Variable

Independent variables are a variable that cause of dependent variable to be change.

- Percentage of fly ash and cement kiln dust
- Plastic limit, liquid limit, free swell index, linear shrinkage, MDD, OMC, CBR and UCS of treated and untreated expansive soil.

3.5 Sampling method and techniques

The sampling technique used for this research is a purposive sampling, which is non-probability method. The experimental investigation of the study executed particularly on the expansive subgrade soil sample by taking one representative sample pit with 113 specimens.

3.5.1 Sample size

The sample size of the study depends on the number of the pit and the type of the laboratory test conducted. The soil sample was collected from Jimma university institute of technology kitto furdise campus from one test pit by took 9 specimens for natural expansive subgrade soil, 40 specimens for fly ash treated soil, and 64 specimens for soil-fly ash- cement kiln dust mixture. Totally around 113 specimens of soil sample were taken.

3.6 Data Collection and Process

During data collection, data collected from primary and secondary source. Primary data obtained from laboratory tests result and secondary data were literature and materials used for this research from different source.

The samples and data collected in the following ways:

1. Visited the site to collect black cotton soil/expansive soil by identification of soil based on observation of color and soil texture. and visit locally available coal and cement industry to brought fly ash and cement kiln dust respectively and packing them in plastic bags for laboratory test.
2. Laboratory test was conducted to ascertain the engineering properties of expansive soil.
3. Laboratory test was done to improve expansive soil by mixing with fly ash.
4. Laboratory test was done to improve expansive soil by blending optimum percentage of fly ash with varying percentage of cement kiln dust.

Laboratory test was conducted in Jimma University Institute of Technology, Highway and Geotechnical Laboratories according to AASHTO and ASTM.

3.7 Laboratory Work

A construction site where soil samples for laboratory testing was collected from the selected site in Jimma University Institute of technology around new stadium under construction project. The relevant data collected from literature review on expansive soils, field observations, collection of samples for laboratory testing and analysis of the laboratory test results. Sample preparation was made on the natural soil mixed with fly ash and cement kiln dust waste material in order to make them suitable for the successive laboratory tests.

3.7.1 Sample preparation

Prior to test, sample preparation basically made in accordance with the method described in AASHTO T87-86. The following preparation procedures was followed.

The sample was collected from the Jimma University Institute of technology around new stadium under construction site by 5 sacks about of 300kg using manual excavation and also took 500grams of natural soil sample in the plastic bag and enter the weighted soil sample on oven for 24 hours to determined initial moisture contents.

Then air dried the natural soil samples by spreading the material out for seven day and broken up the soil aggregates by rubber covered hammer. Sieved the fly ash and cement kiln dust samples to separate the dust from granular waste. Then sieved the soil sample was mixed manually with 10%, 15%, 20%, 25% & 30% of fly ash until to get a uniform mix.

Finally, treated the soil samples with optimum percentage of fly ash mix with each 5%, 10% 15%, 20% & 25% of cement kiln dust and cure for 14 days by sealing the samples with plastic bag and keeping them in humidity chamber/water bath. For the present research the amount of fly ash and CKD to be applied on the expansive soil is from 10% to 30% and 5 % to 25 % by weight of the native soil respectively with a 5 % increment as per literature and related soil stabilization research works.

The following laboratory tests were conducted:

3.7.2 Initial moisture content

The initial moisture content of expansive soil conducted by AASHTO T-265 test procedure. The oven-drying method was used to determine the moisture contents of the disturbed soil samples. Small representative natural soil specimens obtained from large bulk samples from the site are placed in plastic bags. The samples were then weighed as received and placed in moisture can, oven-dried at 105°C for 24 hours. Final dry weight is determent and the difference in weight was assumed to be the weight of the water driven off during drying. The difference in weight was divided by the weight of the dry soil, recorded as the initial moisture content for the disturbed natural soil.

3.7.3 Grain size analysis (ASTM D422 & ASTM D1140)

The particle size analysis is a method of separation of soils into different fractions based on the sizes of particles present in soil. The particle size analysis was made by mechanical (sieve) analysis and sedimentation analysis. Sieve analysis is used to separate the coarse-grained fraction of soil, i.e., the fraction of soil whose particle size is greater than No.200 (75µm) based on ASTM D422 standard. Sedimentation analysis is used for the analysis of fine-grained soil (silt and clay) whose particle size is less than No.200 (0.075 mm). It is performed by hydrometer analysis as per ASTM D1140 standard. For this study both wet sieve analysis and hydrometer analysis was done according to ASTM D422-63. Finally, particle size distribution curve was plotted as figure 4.6

Figure 3. 6 Sieve analysis taken from my own phone

3.7.4 Specific gravity (ASTM D-854)

Specific gravity of soil is the ratio of weight in air of a given volume of soil particles at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature. The heaviness of soil particle was determined the pycnometer method using a soil sample passing #40(0.425mm) sieve as per ASTM D 854 standards.

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

$$\text{Specific gravity (Gs)} = \frac{W2-W1}{(W4-W1)-(W3-W2)} \tag{3.1}$$

Where:

W1- Weight of bottle in gms

W2- Weight of bottle + Dry soil in gms

W3- Weight of bottle + Soil + Water in gms

W4- Weight of bottle + Water in gms

The specific gravity at a standard temperature of 20oC.

$$\text{Specific gravity (Gs)}\,at\ 20oC = \text{k} * \left(\frac{\text{W2}-\text{W1}}{(\text{W4}-\text{W1})-(\text{W3}-\text{W2})}\right) \quad (3.2)$$

$$\text{Specific gravity (Gs)} = \frac{\text{W2}-\text{W1}}{(\text{W4}-\text{W1})-(\text{W3}-\text{W2})} \quad (3.3)$$

Where: k- correction factor based on the density of water refer on appendix-1

3.7.5 Atterberg limits

Representative samples of each soil were subjected to Atterberg limits testing to determine the consistency of the soils. An Atterberg limits device was used to determine the liquid limit of each soil using the material passing through a 475 µm (No. 40) sieve.

3.7.5.1 Liquid Limit Test

Liquid limit (LL) defines the transition between the liquid and plastic states. There are two standard methods used to determine the liquid limit of fine-grained soils. This study used Casagrande standard methods.

Casagrande methods (ASTM D4318-93).

It was carried on remolded soil sample, the fraction passing through No.40 (0.425mm) By convention, the liquid limit is defined as water content at which the groove cut into the soil pal in the standard liquid limit device requires 25 blows to close along a distance of 13mm ASTM D4318-93. sieve being used.

Figure 3. 7 Casagrande test taken from my own phone

3.7.5.2 Plastic Limit

The transition between the plastic and semi-solid states defines the plastic limit. Plastic limit test is used to determine the lowest moisture content at which the soil behaves plastically. It is carried out only on the soil fraction passing #40 (0.425 mm) sieve and is usually performed in conjunction with the liquid limit test. By convention, the plastic limit of a soil is defined as the water content at which the soil begins to crack when rolled into a thread 3 mm in diameter.

3.7.5.3 Plasticity Index

Plasticity Index is the difference between liquid limit and plastic limit value of sub-grade soil.

$$\text{Plastic index (Pl)} = \text{LL} - \text{PL} \tag{3.4}$$

where: LL-Liquid limit and PL- Plastic limit

3.7.6 Soil classification (AASHTO M-145)

The most widely used soil classification systems for engineering purposes are American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS). The AASHTO system of soil classification comprises seven groups of inorganic soils from A-l to A-7 with twelve subgroups in all. The system is based on particle-size distribution, liquid limit and plasticity index of the soil. Whereas 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 into three major divisions: coarse-grained soils, fine grained soils and highly organic soils.

3.7.7 Linear shrinkage (AASHTO D4943)

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.

$$\text{Linear shrinkage (Ls)} = \frac{\text{Lo} - \text{Ld}}{\text{Lo}} \tag{3.5}$$

Where: Lo-Original length sample at about the liquid limit.

Ld-Length of the sample after dried

3.7.7 Free swell test (IS 2720)

The test was conducted in accordance with the United States Bureau of Reclamation (USBR) method (Holtz and Gibbs, 1956). About 10 g of soil passing BS No 4 sieve (425μm aperture) was oven dried and allowed to cool in a desiccator. The sample was slowly poured into a 100 cm3 measuring cylinder to which water was added in order to fill the cylinder. The cylinder was then agitated in order to obtain a homogenous mixture of soil and water after which it could settle for 2 hours or more before the initial volume was recorded. The final volume recorded after 24 hrs.

The Free Swell can be obtained using the following equation:

$$\text{Free swell (Fs)} = \left(\frac{\text{Vf} - \text{Vi}}{\text{Vi}}\right) * 100 \tag{3.6}$$

Where: Vf-Final volume in ml Vi-Initial volume in ml

3.7.9 Proctor compaction test (AASHTO T 180-95)

This test was done by modified (heavy) compaction to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the material. It was done on the natural expansive soil, on the mixture various percentages of fly ash and cement kiln dust added on the Expansive clay soil and its MDD and OMC were determined.

The apparatus setup consists of (i) cylindrical metal mould (internal diameter- 15.24 cm and internal height-11.7 cm), (ii) detachable base plate, (iii) collar (5 cm effective height), (iv) rammer (4.54 kg). Compaction process helps in Increasing the bulk density by driving out the air from the voids. The theory used in the experiment is that for any compactive effort, the dry density depends upon the moisture content in the soil. The maximum dry density (MDD) is achieved when the soil is compacted at relatively high moisture content and almost all the air is driven out, this moisture content is called optimum moisture content (OMC).

The result was determined by using the following equation:

$$\text{Moisture content (Mc)} = \left(\frac{\text{Wws}-\text{Wds}}{\text{Wds}-\text{Wc}}\right) * 100 \quad (3.7)$$

Where: Wws-weight of can + wet soil in gms   Wc- weight of can in gms

Wds- weight of can + dry soil in gms

$$\text{Dry density } (\rho d) = \frac{\text{wet density(Wd)}}{1+(\frac{\text{Mc}}{100})} \quad (3.8)$$

where:

$$\text{Wet density (Wd)} = \frac{\text{weight of wet soil in mould in gms}}{\text{weight of mould in cc}} \quad (3.9)$$

3.7.10 California Bearing Ratio (CBR) (AASHTO T 193-93)

The CBR test measures the shearing resistance of a soil under controlled moisture and density conditions. It is a major laboratory test conducted on subgrade and other pavement layers of roads. CBR value is the ratio of load required to affect a certain depth of penetration in to a soil specimen compacted at given moisture content and dry density to the load required to obtain the same depth of penetration on a standard sample of crushed stone.

For this research three-point CBR test (10, 30, 65 blows) was conducted. As per AASHTO T 193-93 test procedure, CBR test with curing durations of 4, 7, & 14 days was conducted for cement kiln dust-soil-fly ash mixture. To make a general evaluation on the effect of applying the mixture of fly ash and cement kiln dust on strength development, CBR samples were prepared using soil passing No. 19 sieve and treated samples were compacted using moisture content at maximum dry density obtained from compaction results. And swelling potential of soil sample was measured. No surcharge loads have been applied to compacted samples during curing durations assuming no traffic flow is allowed during construction and hence curing process undertaken by using plastic bag and immerse into water bath to obtain uniform temperature inside and outside the plastic bag as shown in 3.11. When the allocated curing period is finished, the compacted soil in CBR mold was then soaked in water for four days to simulate the saturated condition of the site.

Table 3.1. ERA manual-2002 rating of subgrade, sub-base & base-course materials based on CBR value

CBR (%)	General Rating	Uses
0-3	Very poor	Sub-grade
3-7	Poor to fair	Sub-grade
7-20	Fair	Sub-base
20-50	Good	Base Coarse/base
>50	Excellent	Base coarse

From the CBR test it was found that the natural subgrade soil has very low CBR value 0.8 which is much less than the minimum requirement for a soil to be used as subgrade material.

$$\text{CBR (\%)} = \left(\frac{\text{Unit load @ 2.54 penteration(MPa)}}{\text{standared load for crushed stone(13.2)}}\right) * 100 \quad (3.10)$$

$$\text{CBR (\%)} = \left(\frac{\text{Unit load @ 5.08 penteration(MPa)}}{\text{standared load for crushed stone(20)}}\right) * 100 \quad (3.11)$$

3.3.11 CBR Swell test

The volume change/swell-shrink of expansive soils as a result of moisture change is one of the significant identification features. The potential swell of expansive soils is an important parameter to classify subgrade soils based on their expansiveness. For the soaked case of CBR test, the volume change of the compacted specimen is measured before and after soaking using dial gage reading using the following formula. The calculated swell value is

$$\text{CBR swell} = \left(\frac{\text{Final swelling gaug reading} - \text{inital swelling gaug readin}}{\text{Height of soil specimen(116.3mm)}}\right) * 100 \quad (3.12)$$

3.3.12 Unconfined compressive test (ASTM D- 2116)

The unconfined compressive strength (qu) is defined as the compressive stress at which unconfined cylindrical specimen of soil will fail in a simple compression test. This test was conducted to determine the UCS of the natural soil, Soil-Fly ash and Soil-Fly ash-CKD specimens prepared by mixing, compacting and curing. For stabilized subgrade, a minimum 30 psi (207kpa) increase from untreated natural soil is required. [20]

The prepared specimens were molded in the standard compaction mold, extracted using Shelby tube samplers and cut to size with a height-to-diameter ratio of 2. The dimeter and height of the specimen tube were 38mm and 80mm respectively. And the extracted specimens placed in an airtight plastic bag and allowed to cure in bath for 4, 7, and 14 days to avoid any moisture loss from the sample. At the end of the curing period, the specimen was carefully placed in the compression device as shown in Figure 4.12 Finally, UCS of the sample was determined at the point on the stress -strain curve at which failure occurred.

$$\text{Compresive strength} = \frac{\text{Failure load}}{\text{Surfacearea of the specimen}} \quad (3.13)$$

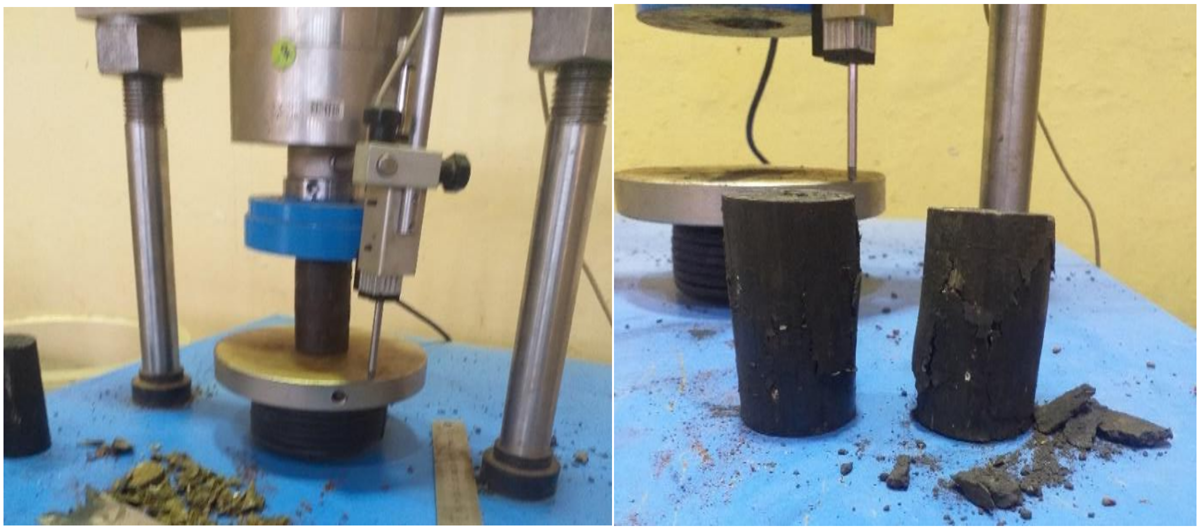

Figure 3.8 Unconfined compressive strength test taken from my own phone

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Genral

In this chapter, the results are analyzed and discussed briefly, based on the different types of laboratory test listed on the research design and methods sections.

4.2 Chemical properties of material

It discussed about the chemical properties of fly ash and cement kiln dust used in this research. ASTM standards and specifications used for checking of requirements. Complete silica analysis was conducted in chemical laboratory using LIBO2 FUSION, HF ATTACK, GRAVIMETERIC, COLORIMETRIC AND AAS analytical method and the detail was attached on appendix. The chemical constituents of material were stated in table below**.**

4.2.1 Fly ash properties

According to ASTM C618, oxide composition (SiO_2+ Al_2O_3+ Fe_2O_3) of fly ash is ≥ 70% and classified under class F, which fulfils the pozzolanic requirement of the standard. This type of fly ash is non-self-cementing fly ash because its calcium oxide (CaO) composition is less than 15%. According ACI [67] states that, the analytic bulk chemical composition used to determine compliance with ASTM C- 618 does not address the nature or reactivity of the particles. Fly ash can thus produce an assortment of divalent and trivalent cations (Ca^{+2}, Al^{+3}, Fe^{+3}) under conditions that are ionized in nature, which in return can encourage flocculation of dispersed clay particles by cation exchange. In general, as the amounts SiO_2, Al_2O_3 and free lime (CaO) increases the pozzolanic activity of the fly ash increases [68]. The general chemical properties of coal fly ashes are summarized in Table 4.1.

Table 4.1 Chemical composition of fly ash

Chemical composition	Test result (%)	ASTM (C618) requirement in %	Remark
SiO_2	46.02		
Al_2O_3	26.46		
Fe_2O_3	2.80		
CaO	5.32	15 Max (Class-F)	Satisfied
MgO	1.88	5 Max	Satisfied
Na_2O	0.28	1.5 Max	Satisfied
K_2O	< 0.01		
MnO	< 0.01		
P_2O_5	0.77		
TiO_2	0.28		
H_2O	1.25	3 Max	Satisfied
SiO_2+ Al_2O_3+ Fe_2O_3	75.28	70 Min (Class-F)	Satisfied

LOI	15.01		

This type of fly ash is not effective as stabilizing agent by itself. However, when mixed with either lime, cement, lime kiln dust and cement kiln dust; the fly ash mixture becomes an effective stabilizing agent [53].

According to Rakesh [69] fly ash particles are generally spherical in shape and range in size from 0.5 µm to 100 µm. It is very fine, light weight and spherical (specific surface area 3000-10,000 cm2/g; diameter, 1-150µ), and have pozzolanic ability. Specific gravity of fly ash varies in range between 2.1 to 2.6 [70]. In this case the specific gravity of fly ash was 2.15 and its detail was attached on appendix section. For this study the sample taken from the factories was sieved by 200µm sieve (0.075mm sieve size).

4.2.2 Cement kiln dust properties

Cement kiln dust used for study was collected from Muhger Cement enterprise factory and its chemical composition is shown on the following table 4.2. As per the classification of ASTM C618, the oxide composition (SiO_2+ Al_2O_3+ Fe_2O_3) of CKD was ≤ 70% and it denies the pozzolanic property. However, due to rich in free lime (CaO) content of the CKD, it made pozzolanic reaction when mixed with rich silica and aluminum fly ash-soil mixture.

Table 4.2 Chemical composition of CKD

Chemical composition	Test result (%)	ASTM (C618) requirement in %	Remark
SiO_2	15.22	35 Min	Unsatisfied
Al_2O_3	3.98		
Fe_2O_3	2.24		
CaO	52.62		
MgO	0.72	5 Max	Satisfied
Na_2O	0.36	1.5 Max	Satisfied
K_2O	< 0.01		
MnO	0.04		
P_2O_5	0.17		
TiO_2	0.05		
H_2O	0.86	3 Max	Satisfied
SiO_2+ Al_2O_3+ Fe_2O_3	21.44	70 Min	Unsatisfied
LOI	23.88		

According to Adey **[20]** litrature reviewed, the cement kiln dust are fine grained and non-plastic material. Its consistuence test result shows that the plastic index of cement kiln dust is 4%. Finness (retained on No.9 μm sieve (No. 325 sieve) and specific gravity were 4.48% and 2.65% respectivelly.

4.3 Engineering properties of Natural soil

To determine the engineering properties of natural soil, the following laboratory tests were conducted.

4.3.1 Initial moisture 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. To increase the accuracy of the test result two specimen was taken. The average initial moisture content of the soil sample used for this study was 49.95%.

Table 4.3 Initial moisture content of soil.

Calculation of Initial Moisture Content of the Soil		
Trial No.	1	2
Container No.	C11	T1
Mass of container, g	37.65	35.2
Mass of container + Wet soil, g	117.36	105.28
Mass of container + Dry soil, g	90.85	81.9
Mass of water, g	26.51	23.38
Mass of dry soil, g	53.2	46.7
Water content, %	49.83	50.06
Average initial moisture content, %	**49.95**	

The results in Table 4.3 show that these soils can hold a significant level of moisture. As stated by Terzaghi [71], most of the typical values of the natural moisture content of clay soil are within the ranges of 22–70%. The study results are also in agreement with the specified standard. From the test result, the study suggest that the soil is unsuitable for road construction and it needs modification to serve as subgrade.

4.3.2 Grain size analysis

Grain size analysis was carried out to determine the grain size distribution and its classification of subgrade natural soil. Sieve analysis is used to separate the coarse-grained fraction of soil, i.e., the fraction of soil whose particle size is greater than No.200 (75μm) based on ASTM D422 standard. Wet sieve analysis was conducted to determine the grain size distribution of the soil retained on #200sieve as per AASHTO T-88 test method. It was conducted by taking 1000g of soil sample.

Hydrometer analysis was performed as per ASTM D1140 standard by taking 50gm of soil sample which passing No.200 sieve and soaked for 24 hours in chemical solution (Sodium hexa-meta phosphate) to disintegrate the large particle.

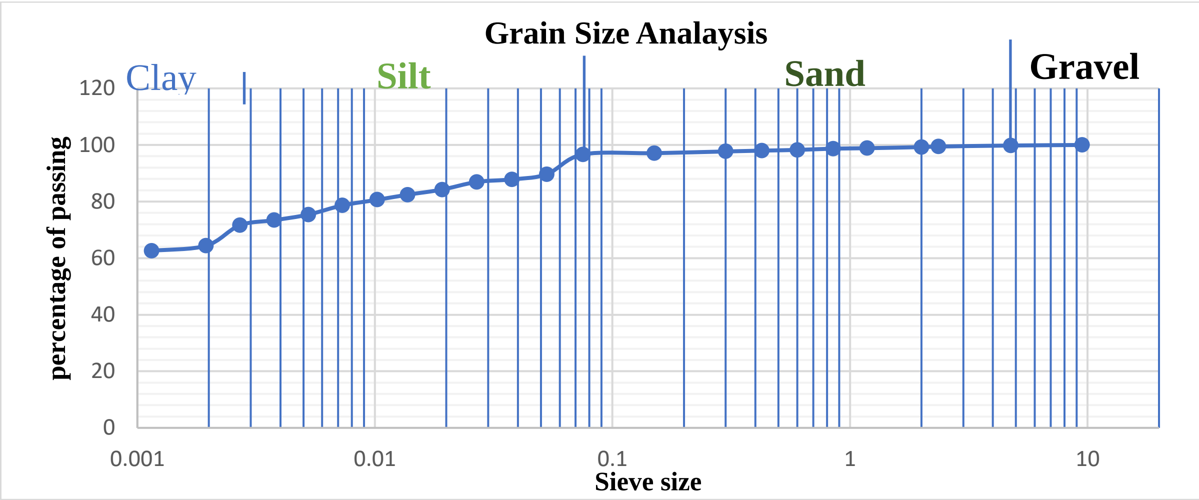

Figure 4. 1 Grain size analysis result of natural soil

The soil was light gray clay, 96.65% of the soil was passing under #200seive. According to wet sieve analysis and hydrometer analysis result the soil sample have(contain) 0.2%age of gravel, 3.15%age of sand, 32.27%age of silt and 64.38%age of clay.

Percent passing No.200 (75 µm) for soil sample is greater than 35%, which indicates that the soil sample is categorized as fine-grained soil (clay material) according to AASHTO M145. The percent passing of each test is not only used to categorize soil as coarse grained and fine grained but it also helps to determine the soil class together with the Atterberg limits. Therefore, the soil sample was clay and has poor engineering properties to be used as subgrade materials and required some level of improvement to be used as subgrade material based on ERA standard.

4.3.3 Atterberg limit

It is basically measuring the critical moisture content of fine grain soil and it appears in four state solid, semi-solid, plastic, and liquid states. The liquid limit determined the water content at which the soil had weakened so much that it started to flow like a liquid. On the other hand, the plastic limit determined the water content at which the soil had become so brittle that it crumbled. Casagrande method was used for the determination of liquid limit using the material passing through a 475 µm (No. 40) sieve as AASHTO T-89. Plastic limit was determined by rolling the soil sample making threads of 1/8” (3mm) thickness as per AASHTO T-90.

Liquid limit, Plastic limit, and plastic index of the soil sample were 80.6, 34.2 and 46.4 respectively. According to ERA specification the soil is poor subgrade material because its plastic index is greater 30%. According to British practice, the plasticity chart is divided in to five zone based on the value liquid limit of clay soil. When the liquid limit (LL) <35%, in between 35-50%, in between 50-70%, in between 70-90% and > 90% the plasticity is categorized as low, medium, high, very high and extremely very high respectively [72].

The liquid limit of the soil sample is rated in between70 and 90 which means the soil sample is very high plastic soil. Based on literature review on table 2.1 the swelling potential of the soil has categorized under very high swelling potential soil. Detail laboratory analysis was attached on appendix A.

Table 4.4 Atterberg limit test result

Atterberg limit	Soil sample result in %
Liquid Limit	80.6
Plastic Limit	34.2
Plasticity Index	46.4

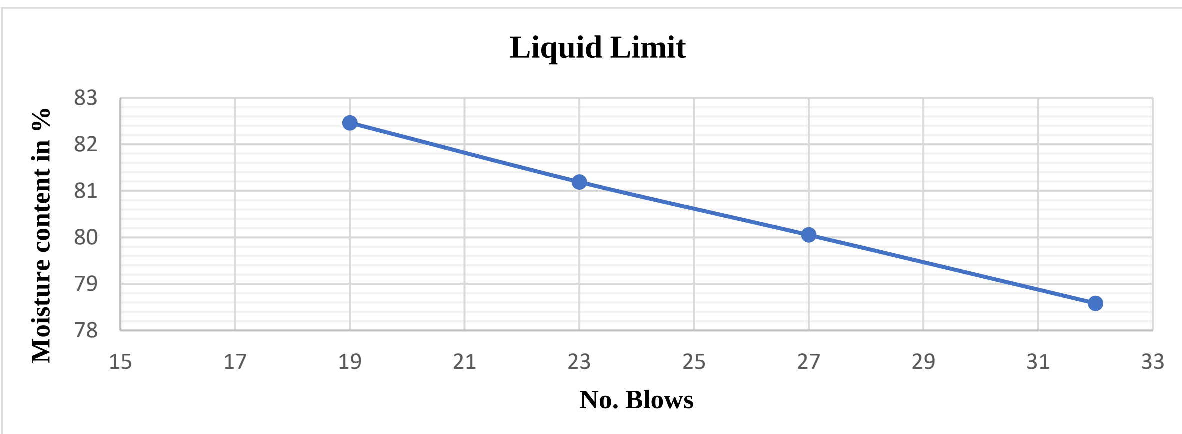

Figure 4. 2 Atterberg limit test result of natural soil

The plastic index of the soil sample was 46.4%, which indicates that the soil sample was poor subgrade material. A high numerical value of PI is an indication of the presence of a high percentage of clay in the soil sample. Based on the liquid limit, the soil sample is categorized to clay soil with high plasticity or high swelling potential. Since the PI value of sample was greater than 30%, according to ERA specification the subgrade soil is poor. According to ERA site investigation manual a soil whose PI value is greater than 40% shows that the soil is very plastic. Hence, these findings result suggested that the soil sample is expansive soil, unsuitable for road construction as subgrade materials and it needs modification to serve as good quality materials.

4.3.4 Soil classification

The soil was classified based on AASHTO and USCS system and the result is summarized below in Table 4.2 and 4.3.

4.3.4.1 USCS soil classification system

According to USCS the experimental results of soils tested from different parts of the world were plotted on a graph of plasticity index (ordinate) versus liquid limit (abscissa). It was found that clays, silts, and organic soils lie in distinct regions of the graph called the plasticity chart, figure4.4. The A-line separates clays from silts and the U-line indicates the upper limit of the relationship Between PI and LL. Accordingly, the soil under study is plotted on the plasticity chart.

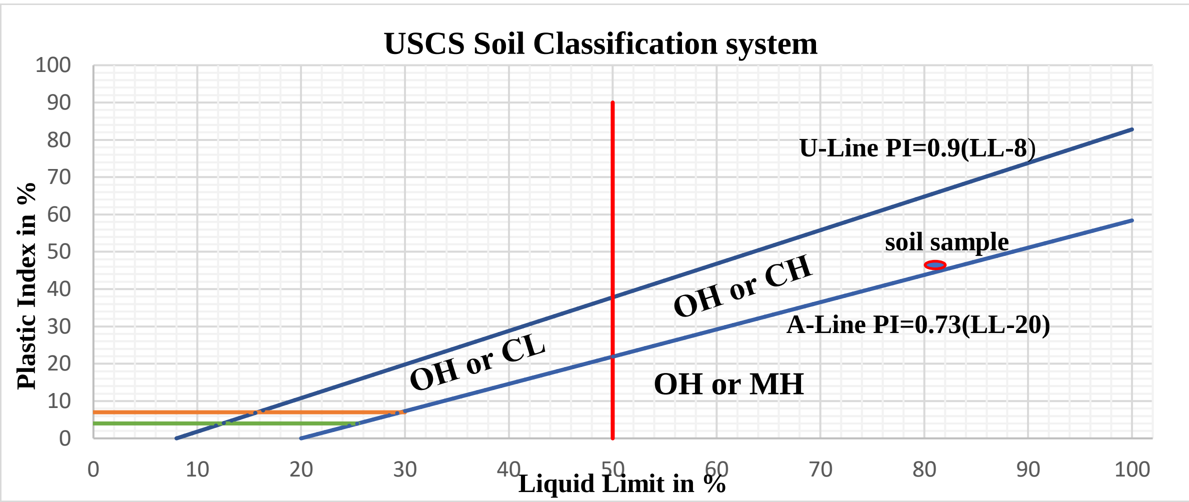

Figure 4. 3 Soil classifications according to USCS system

According to unified soil classification system (USCS), if the liquid limit soil is greater or equal to 50%, the soil can be clay, silt, or organic depends on the position of soil sample above or below the A line. Casagrande chart recommends that the soil with plastic index is greater than four (PI>4) and plots on A-line or above A-line, the soil is classified to clay soil. Therefore, liquid limit of the soil sample was 80.6 and it falls above A line. So that, the soil used for this study was categorized under high to very high plastic soil.

4.3.4.2 AASHTO soil classification system

According to this system, soil is classified into seven major groups: A-1 through A-7. Soils classified under groups A-1, A-2, and A-3 are granular materials of which 35% or less of the particles passing through the No.200 sieve. Soils of which more than 35% pass through the No.200 sieve are classified under groups A-4, A-5, A-6, and A-7.

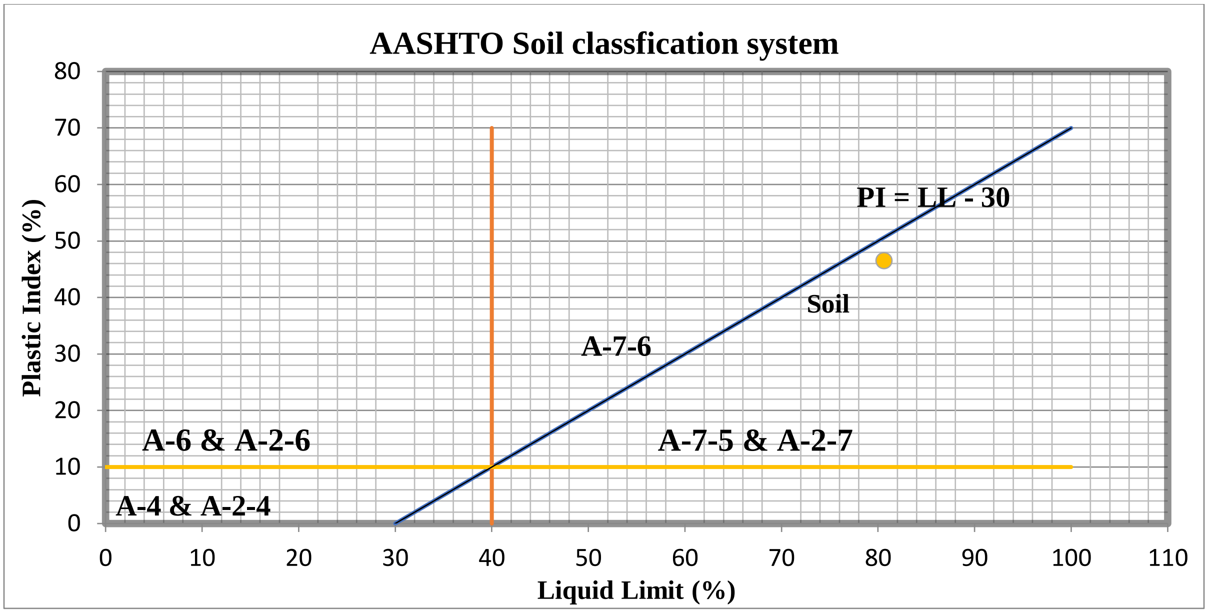

Figure 4. 4 Soil classifications according to AASHTO system

With the required data in mind, proceed from left to right in the chart. The correct group will be found by a process of elimination. Based on the liquid limit and plastic index of soil sample, the soil falls under A-7-5 soil category. These types of soils are not favorable for the construction of sub-grade of roads.

Generally, according to ERA [73], clay material having a PI (%) exceeding 30; of weak soils are not fair to use as the subgrade for road construction. If the PI is greater than 35%, the material must be treated to minimize the problem or it should be discarded.

Table 4.5 Summarized result of USCS and AASHTO soil classification system of soil

Test result	In percentage (%)	Soil category under USCS System	Soil category under AASHTO System
Liquid Limit	80.6	CH (high plasticity clay)	A-7-5 (Fair to poor)
Plastic Limit	34.2		
Plasticity Index	46.4		

4.3.5 Specific Gravity (Gs) of soil

The specific gravity of a soil is the ratio of the unit weight of soil to the unit weight of water at varies degree centigrade. The specific gravity of a soil depends on the mineralogy of the soil grains. Most soils are a blend of several basic minerals. The subgrade soil under study is expansive soil composed of different minerals. According to ASTM D-854 standard test method, the average specific gravity of soil sample under study was **2.68**.

Table 4.6 Specific gravity table for natural soil

Determination code		D7	11
Specific gravity at 20oc, Gs		2.67	2.69
Average Specific gravity at 20oc, Gs		**2.68**	

According to Das [74] specific gravity values ranging from 2.67 to 2.90 were assigned to clay and silty clay soils. As the test result shows that the specific gravity of the subgrade soil was 2.68 and categorized under clay and weak soil. From the result, the study suggests that the soil is unsuitable for road construction and it needs modification to serve as subgrade.

4.3.6 Free swell index

Table 4.7 Free swell index value of expansive soil

STATION	Measuring Cylinder No.(ml)		Reading after 24 hrs. (ml)		Free Swell Index, %
	Kerosene	Distilled water	Kerosene	Distilled water	
Natural soil	10	10	10	20	**100.00**

The test procedure followed for the determination of free swell index is in accordance with IS:2720(Part 40) 1977. Free swell index of the soil sample used for study was 100%.

In table 2.4 of literature review the free swell and degree of expansions have been stated. The sample has free swell values >50% which is categorized as problematic. This result indicated that the soils is highly expansive soils. 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.

4.3.7 Linear shrinkage

The test was conducted by using the soil sample passed under #40(0.425mm) sieve to determine the one direction shrinkage of soil sample. The linear shrinkage of the soil sample was 15.54%.

Table 4.8 Linear shrinkage test result of Expansive Soil Sample

Natural soil linear shrinkage test		
Determination No.	1	2
Semi cylindrical trough No.	A	B
Initial wet length of soil Lo (mm)	140	140
Dry length of soil Ld (mm)	118	118.5
Linear shrinkage LS in %	15.71	15.36
Average Linear shrinkage	**15.54**	

According to Altemeyer on table 2.3 of the literature review the degree of expansion of natural expansive soil sample was categorized in to critical. This result directs that soil was needed a treatment to be used as road subgrade.

4.3.8 Compaction characteristics

The test was conducted for the expansive soil under consideration to determine the maximum dry density and optimum moisture content of the soils. It was made by modified proctor compaction test as per ASTM D1557 method A or AASHTO T180-98. The soil sample was first air dried and pulverized boulder one by hammer and sieve the material by # 19sieve and weight 4.5kg of soil sample and mixed with a different percentage of moisture content and compact the soil sample in mould by five layers using 56 blows per layer and repeated the procedure until the graph seams crest parabola curve.

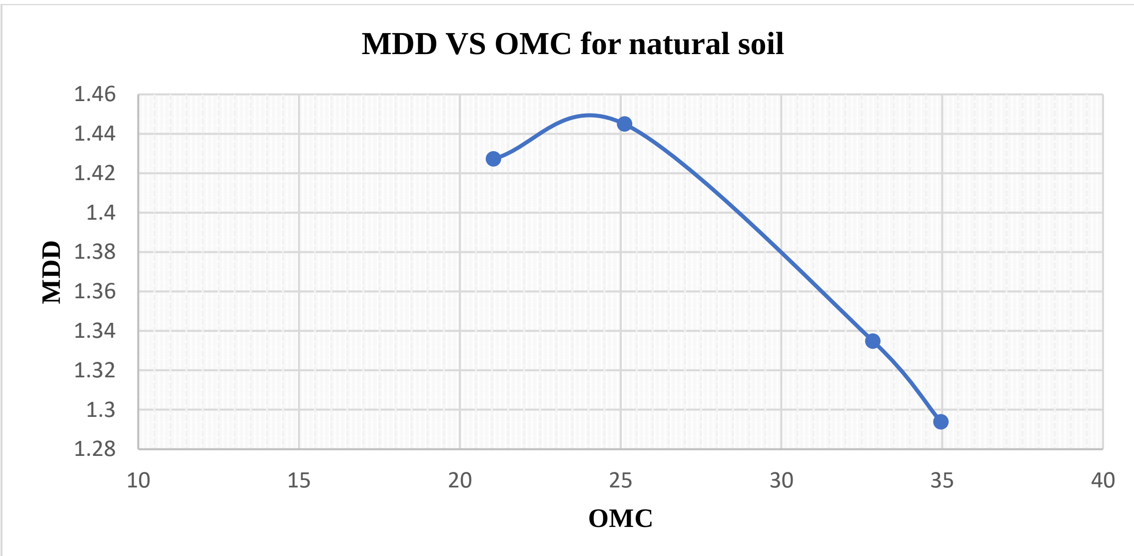

Figure 4. 5 Compaction test result of Expansive Soil Sample

As depicted from the graph the soil was 1.44g/cc and 25.12% maximum dry density and optimum moisture content respectively. The maximum dry density and optimum moisture content obtained are used to determine the strength to be attained during construction of a road especially subgrade layer. During road construction the CBR value is obtained using the compaction test result. And these CBR results used to determine the class and thickness of the subgrade layer of a road construction. Refer the detail on appendix A

2.3.9 California Bearing ratio

This test is conducted by using compaction characteristics data of maximum dry density, optimum moisture content and natural water content of the soil sample. Samples were soaked for 96 hours, CBR and CBR swell determined as per ASTM standard. The sample have CBR and CBR swell of 0.8% and 12% respectively. According to ERA 2002 manual the CBR value was rated in poor subgrade materials plus, with regard to CBR swell it did not fulfill the minimum requirement of ERA specification. ERA allowed for CBR greater than 3%. The result indicates that the soil had low bearing capacity and high plasticity index which was not satisfied the standard requirement of sub grade for highway construction. Therefore, the soil requires initial treatment and stabilization to improve its workability and engineering property. Refer the detail on appendix A

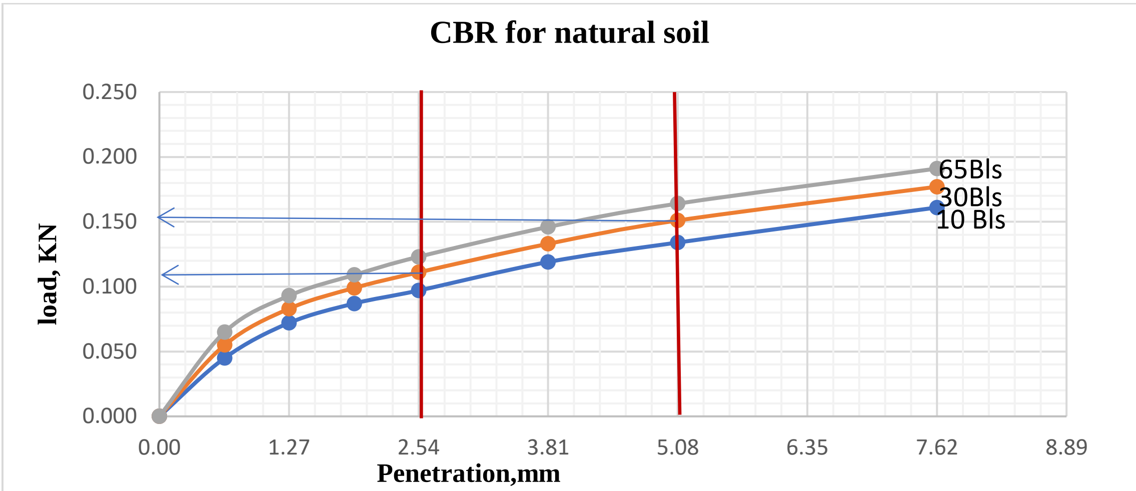

Figure 4. 6 CBR test result of expansive soil

2.3.10 Unconfined compressive strength (UCS)

The test was conducted for remold disturbed soil sample in cylindrical specimen with dimensions of 38 mm diameter, 76mm in length. In this test the soil goes to failure by axial load only with no confining surrounding stresses. The criteria to select the UCS values is from the analysis of stress Vs strain relation by selecting the maximum point on the graph. The UCS values are determined in accordance with ASTM D- 2116.

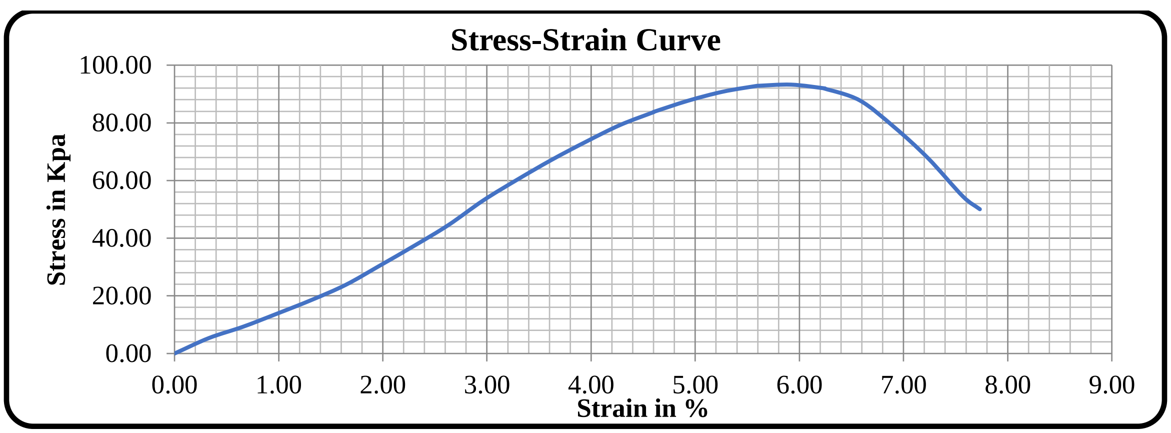

Figure 4. 7 Unconfined compressive strength test result of expansive soil

As the test result shows that unconfined compressive strength of the natural expansive soil was 93Kpa and its cohesiveness was 47Kpa. According to Das [75] the extracted soil sample are categorized as medium soft clay soils since the unconfined compression strength test results of specimens failed at a pressure of between 50 and 100kpa. This failure indicates the deterioration of soil samples starts at the stage of the axial stress become decreases as the axial deformation increases. Therefore, the results show that the soil samples meet the general principles of medium soft clay soil and it indicated that the soil samples have low strengths that are not suitable as subgrade materials for roadway pavement design. Refer the detail on appendix A

Table 1 Summarized laboratory test result for natural expansive soil.

Properties	Observed Values	
Initial moisture content (%)	49.95	
Grain size distribution		
Gravel (%)	0.2	
Sand (%)	3.15	
Fines (%)	96.65	
Silt	32.27	
Clay	64.38	
Atterberg limit		
Liquid limit (%)	80.6	If PI ≥ 30, according to ERA the subgrade soil is poor.
Plastic limit (%)	34.2	
Plastic index (%)	46.4	
Soil classification	AASHTO	A-7-5
	ASTM	CH
Free swell index (%)	100	
Specific gravity	2.68	
Linear shrinkage (%)	15.54	
Compaction characteristics:		
OMC (%)	25.12	
MDD (g/cm^3)	1.44	
Strength characteristics		
California bearing ratio (CBR) (%)	0.8	Poor subgrade according to ERA standard.
Unconfined compressive strength (UCS) (Kpa)	93	

Generally, from summary of Table 4.9, the result shows that natural subgrade soils are expansive soil according to ERA and AASHTO standards. Natural soil has high degree of expansion and shrinkage rate, and clay soil. And also, the natural expansive soil shows that it has low bearing capacity. Therefore, to be used this soil as subgrade materials it needs stabilization to improve the bearing capacity of the soil. In this investigation fly ash mixed with and without cement kiln dust stabilization were used.

4.4 Laboratory test result of expansive soil treated with fly ash

4.4.1 Effect of addition of fly ash on Atterberg limit and linear shrinkage

The basic Atterberg limit lab result like liquid limit, plastic limit, and linear shrinkage tests were conducted to study the effect of fly ash. Soil passing on #40sieve was mixed with different proportion of fly ash chemical additives at optimum moisture content and cured for 1 day by dissector to protect loss of moisture. The proportion of fly ash (FA) used for this investigation was 10 %, 15 %, 20%, 25%, and 30 % as per literature reviewed.

Table 4.10 Plasticity index and linear shrinkage for fly ash treated soil

Fly ash in %	LL (%)	PL (%)	PI (%)	ERA requirement	Remark	LS (%)
0	80.6	34.2	46.4	PI ≤ 30 %	Unsatisfied. It needs additional activator to be used as subgrade.	15.54
10	77.2	32.3	44.9			11.39
15	75.6	31.4	44.2			10.59
20	74.6	30.8	43.8			9.79
25	73.0	29.9	43.1			8.15
30	70.8	28.3	42.5			7.63

As the test result indicated that, when the fly ash added on the expansive soil the plastic limit liquid limit, and linear shrinkage of soils decrease. Consequently, the plastic index slightly decreases. The percentage of fly ash varies from 10% - 30% the plastic index decreases from 46.4% -42.5% and the linear shrinkage also decrease from 15.54% - 7.63% as shown in Table 4.10 and Figure 4.8. According the test result the category of plasticity based on liquid limit slightly changes from very high plastic to high plastic. The probable reason beyond to this result, the content of silica, aluminum and iron ions in fly ash was high, that are used to reduce water affinity of expansive soil by promote cation exchange, pozzolanic reaction, agglomeration, and flocculation of dispersed clay particle [68].

According to ERA specification the plastic index value of fly ash treated soil is ≥ 30%, and it does not meet the minimum requirement for utilization of the soil as subgrade in road construction. Due to this reason soil-fly ash treated soil needs additional activators. The PL, PL, PI, LS Vs percentage of fly ash plot of expansive soil samples with respect to fly ash contents is shown in figure 4.8. Refer the detail on appendix B.

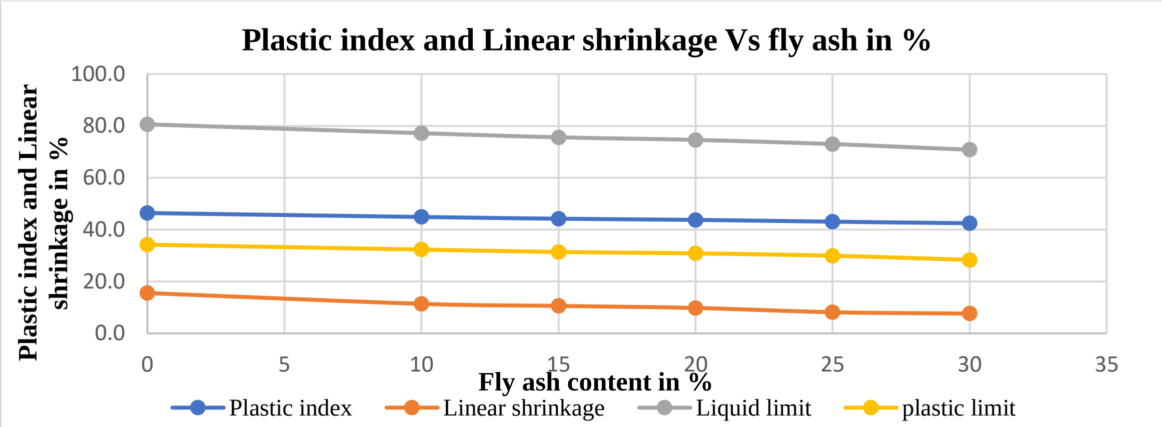

Figure 4. 8 Effect of addition of fly ash on Atterberg limit and linear shrinkage

The previous study conducted on high plastic clay (CH) soil treated with class f fly ash shows similar finding with this study. It showed that as the fly ash content increase from 5% to 30% the liquid limit, plastic limit and plastic index of the soil mixture decrease within respect the percentage of fly ash. The plasticity index of fly ash treated soil decrease from 45% to 22.9 %. This change of consistency limits occurs due to two reason: firstly, fly ashes consist of particles in the silt dimension and as the fly ash amount increases, clay fraction decreases. Secondly, the fly ashes cause flocculation of the clay soil particles and decrease the diffuse double layer thickness of the clay particles [56]. Also, other study conducted on expansive soil treated with class f fly ash shows that as the fly ash increase, the liquid limit, plastic limit and plastic index of the soil decrease. This decrement is due to cation exchange and non-plastic nature of the fly ash [55].

4.4.2 Effect of addition of fly ash on free swell index

Free swell tests were conducted by mixing fly ash at different proportion of 0, 10, 15, 20, 25 and 30 percentages by dry weight of soil sample. The results show that a reduction in the swell potential of the soil sample was observed by adding different proportion of fly ash. The free swell index value decreased from 100% to 37.50%. This result was achieved by addition 30% fly ash proportion to the soil sample, which shows about 63% decrease in the free swell index.

Table 4.11 Summarized result of different amount of fly ash on free swell index

Fly ash additive content in %	Measuring Cylinder No.(ml)		Reading after 24 hrs. (ml)		FSI	**IS** 2720 requirement
	Kerosene	Distilled water	Kerosene	Distilled water	Index, %	**FSI ≤ 50%**
Natural soil	10	10	10	20	100.00	Control
10%	11	11	11	19	72.73	Slight reduction
15%	11	11	11	18	63.64	Slight reduction
20%	12	12	12	18	50.00	Slight reduction

25%	12	12	12	17	41.67	In range
30%	12	12	12	16.5	37.50	In range

As shown in the table above, the free swell of the sample has decreased with the increase in fly ash. The maximum decrease in free swell was 37.50% with addition of 30% fly ash. The reason for selection of 25% of fly ash as optimum was the CBR value of the soil sample reached maximum at this percentage and consistently decreased thereafter. Generally, increase in percentage of fly ash decrease potential swell of the soil. This might be due to chemical reaction and Cation exchange between the soil and fly ash.

A previous study conducted on expansive soil on India showed that, addition of class f fly ash from 10 to 50% by weight, decreases the free swell index ratio value from 2.05 to 1.53. [55] It shows similar finding with this investigation.

4.4.3 Effect of addition of fly ash on Specific gravity

The test procedure followed for the determination of Specific gravity is in accordance with ASTM D 854. A sample weighting about 25gm is used in the test on oven dry basis as the volumetric flask is used in our test procedure. Tests were performed with the addition of fly ash 0, 10, 15, 20, 25 and 30% by weight of oven dry fly ash. The results of specific gravity with the addition of fly ash are tabulated in table 4.12 and are illustrated in figure 4.9 below.

Table 4.12 Effect of fly ash on specific gravity

Fly ash in %	0	10	15	20	25	30
Specific gravity (Gs)	2.68	2.59	2.57	2.55	2.51	2.48

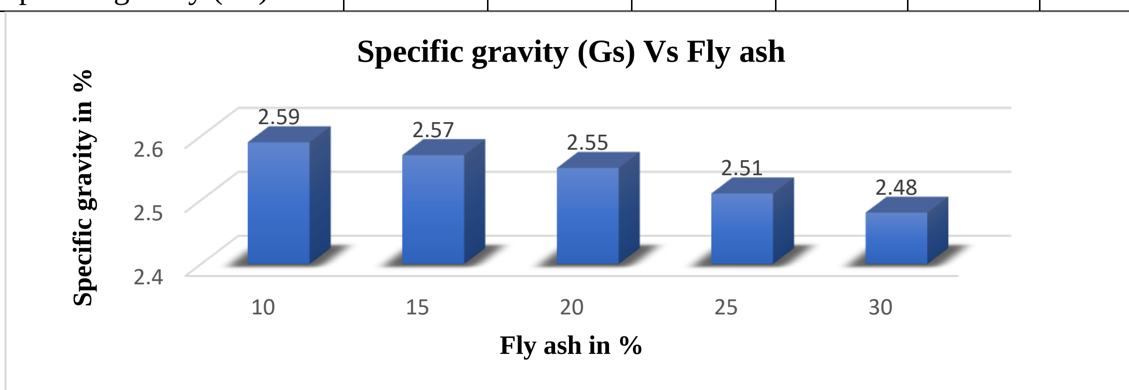

Figure 4. 9 Effect of different percentage of fly ash on specific gravity of soil

As the test result shows specific gravity of the soil sample was decreasing from 2.68 to 2.48 as the fly ash content increase from 10-30%. The probable reason for decrement in specific gravity may be fly ash particles are hollow, thin-walled spherical material, having low weight than conventional soil, so in mixed samples the overall weight become less. The specific gravity of this research finding is having similar result with the past studied research conducted on clay expansive soil. This previous work shows that, as the fly percentage increase from 0%

to 30%, the specific gravity decreases from 2.63 % to 2.33% respectively. This decrement is due hollow and light weight of fly ash [68].

4.4.4 Effect of addition of fly ash on compaction characteristics

Air dried and pulverized soil passing # 19sieve was used to determine moisture-density relation of the soil mixed with varying proportions of the fly ash additives in accordance to AASHTO T180-97. The results of modified Proctor tests on expansive soil treated with different percentages of fly ash are shown in Table 4.13 and Figure 4.10. The summary of the test result is tabulated while the laboratory test analysis and plots are given in Appendix (B).

Table 4.13 Effect of fly ash on maximum dry density and optimum moisture contents

Mixture	Tag	MDD (g/cm3)	OMC (%)
natural soil	NS	1.44	25.12
Soil+ 10% Fly ash	NS+ 10%FA	1.41	22.22
Soil+ 15% Fly ash	NS+ 15%FA	1.38	21.77
Soil+ 20% Fly ash	NS+ 20%FA	1.32	25.08
Soil+ 25% Fly ash	NS+ 25%FA	1.34	25.41
Soil+ 30% Fly ash	NS+ 30%FA	1.31	26.44

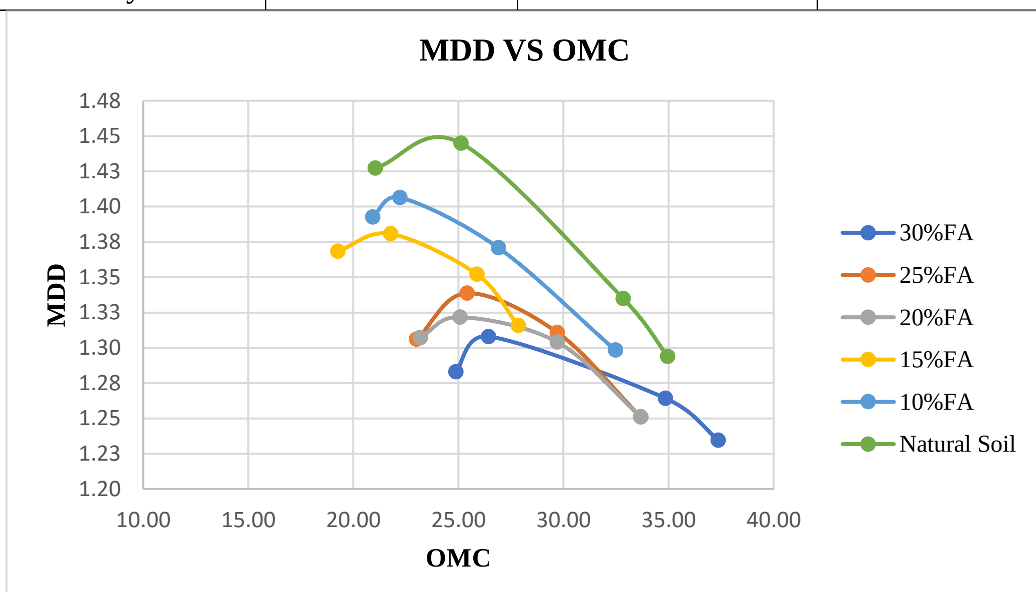

Figure 4. 10 Effect of fly ash on maximum dry density and optimum moisture content.

As test result shows that the additions of fly ash on expansive soil in the proportion of 10-30% by dry weight decrease the maximum dry density and increase optimum moisture contents of mixed soil. The maximum dry density decreases from 1.44g/cm3 to 1.31g/cm3 and the optimum moisture content gradually increase from 25.12 to 26.44%. The probable reason for the decrement of maximum dry density maybe attributed to agglomeration and flocculation of clay minerals through cation exchange reaction, leading to the occupation of large space as well as reducing of the weight volume ratio.

The finding of this study is similar with previous study conducted on high plastic clay (CH) soil. The previous studied result shows that as class f fly ash content increase from 10 to 25%, the maximum dry density of high plastic clay soil increases and its optimum moisture content decreases, due to the reason of fly ash has low specific gravity than the original soil [61].

4.4.5 Effect of addition of fly ash on CBR and CBR swell

According to Magdi M. & E. Zumrawi [62] fly ash treated soil gain its strength at the early curing period. Due to this reason this study determined the strength of fly ash treated expansive soil without curing.

CBR test for this study was conducted by taking air dried sample which pass through sieve No.19 for natural soil mixed with different percent of fly ash (10%, 15%, 20%, 25% & 30%) and applied modified compaction. The value was determined by three-point CBR methods through modified compaction with 5 layers, 10, 30, and 65 blows and soaked for 96 hours for all samples. CBR swells also conducted after four days soaked with different percent of fly ash add to the soil.

Table 4.14 Effect of fly ash on CBR and CBR swell

Percent of Fly ash	0	10	15	20	25	30	**ERA** (2002) requirement	**Remark**
CBR value	0.8	1.4	1.6	1.9	2.3	2.2	**CBR ≥ 3%**	Unsatisfied
CBR swell	12	9.9	9.1	8.7	6.96	6.95		

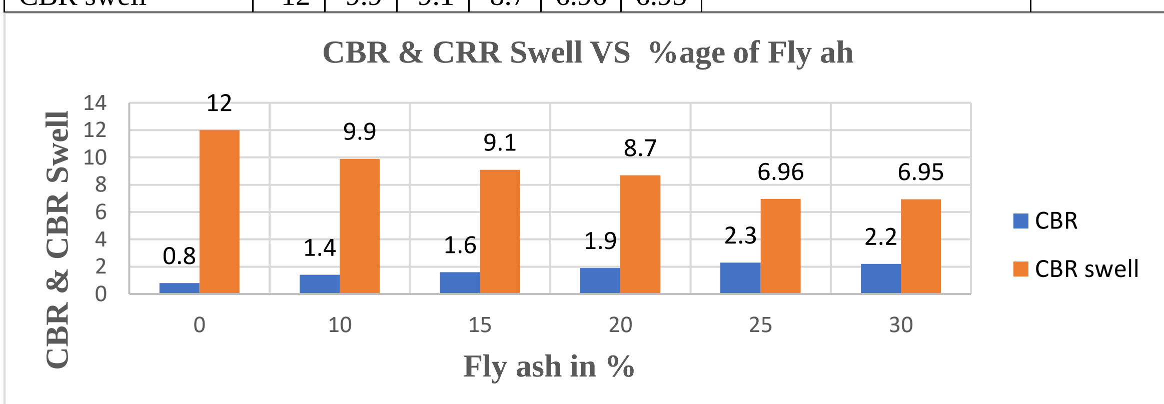

Figure 4.11 Effect of fly ash on CBR and CBR swell of expansive soil

From the test result it was found that the CBR values increase as the percentage of fly ash increase from 10% to 25%, and decrease then after as fly ash content increase. The CBR value increases from 0.8 to 2.3, which means around 188% increment was made as the fly ash percentage increase from 10% to 25%. Additionally, the CBR swell of the soil decrease from 12% to 6.95 % as the fly ash content increase from 10% to 30 %. Here the CBR value of fly ash treated expansive soil did not meet the minimum requirement of ERA subgrade manual.

According to ERA 2002, the minimum requirement of CBR value and CBR swell to be used for subgrade soil is greater than or equal to 3% and less than or equal 2% respectively. So that the fly ash treated expansive soil needs an activator to serve as stabilizer for weak subgrade soil. From this point of view, the optimum percentage of fly ash was taken at 25%.

4.4.6 Effect of addition of fly ash on UCS

The results of UCS tests are shown in Figure 4.12 below. For mixtures without activator, the strength gain is not significant because UCS of used fly ash has not a significant difference from untreated expansive soil. Unconfined compressive strength of fly ash treated soil was 111Kpa and for untreated natural soil was 93kpa, so that the difference did not meet the minimum requirement of stabilized soil. For stabilized subgrade, a minimum 30 psi (207kpa) increase from untreated natural soil is required. [20] With addition of cement kiln dust, there is significant strength gain, which depends on curing time.

Table 4.15 Summarized result of effect of fly ash on UCS

Additive content by weight (%)	Sample Height (mm)	Peak UCS, (kPa)	Cohesion, (kPa)
Natural soil (0%)	76	93	47
10	78	92	46
15	77	97	48
20	78	103	53
25	78	109	55
30	77	111	56

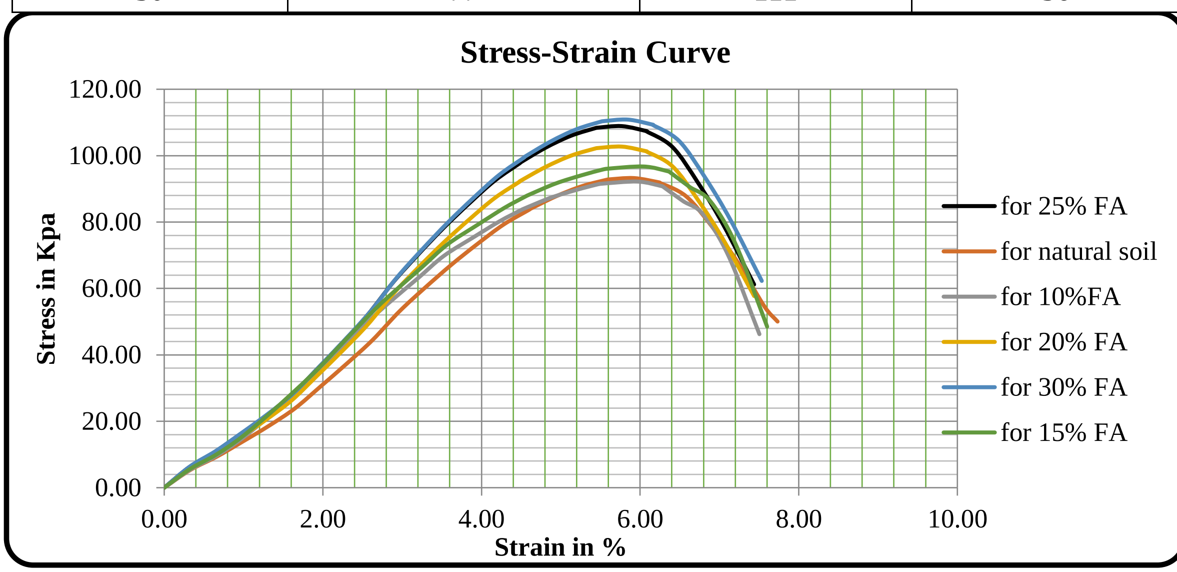

Figure 4. 12 UCS of different % of fly ash treated expansive soil

As the test result shows that the addition of the fly ash from 10-30% has a slight increment in unconfined compressive strength from 93Kpa to 111Kpa respectively except 10% fly ash. The addition of fly ash on untreated soil increases UCS around 20 %, it did not form an efficient improvement on soil to select the optimum percentage of fly ash.

This investigation found similar finding with previously studied results. The previous study conducted on high plastic clay soil treated by class f fly ash result shows that as the fly ash content increase from 5% to 30%, unconfined compressive strength of soil mixture within the curing period of 1 day initially decreases at 5% and then after increase up to 30%. The increment of unconfined compressive strength was in between 1.15 to 1.30 times UCS of untreated soil and its increment was insignificant [56].

4.4.7 Optimum percentage of fly ash

In order to determine the optimal dosage of fly ash, strength tests were performed 1 day after compaction, on specimens with different fly ash-soil ratios (10%, 15%, 20%, 25% and 30%). Due to the fact that increase of UCS after 1day compaction was not significant. It was not possible to choose optimum amount of fly ash using unconfined compressive strength test. The soil-fly ash improvement in CBR has better than improvement in UCS test whatever the treatment gave insignificant improvement. And according to ERA and different road manual the subgrade class of the road are classified based on the CBR value of the subgrade soil. Therefore, CBR tests were performed on the specimens with the same fly ash-soil ratios as stated above. The highest CBR value was achieved for the mixture with 25% of fly ash, which was adopted as the optimum dosage.

Table 4.16 Summarized laboratory test result for fly ash treated expansive soil.

Properties	Original soil	Fly ash in %					Specification
		10	15	20	25	30	
Atterberg limit							**ERA** 2002 Minimum requirement PI ≤ 30%
Liquid limit (%)	80.6	77.2	75.6	74.6	73	70.8	
Plastic limit (%)	34.2	32.3	31.4	30.8	29.9	28.3	
Plastic index (%)	46.4	44.9	44.2	43.8	43.1	42.5	Unsatisfied
Free swell index (%)	100	72.73	63.64	50.00	41.67	37.5	**IS:**2720 FSI ≤ 50%
Specific gravity	2.68	2.59	2.57	2.55	2.51	2.48	
Linear shrinkage (%)	15.54	11.39	10.59	9.79	8.15	7.63	
Compaction characteristics:							
OMC (%)	25.12	22.22	21.77	25.08	25.41	26.44	
MDD (%)	1.44	1.41	1.38	1.32	1.34	1.31	
Strength characteristics							**ERA** 2002 Min. requirement
CBR (%)	0.8	1.4	1.6	1.9	2.3	2.2	**CBR ≥ 3%** (unsatisfied)
UCS (Kpa)	93	92	95	103	109	111	
CBR swell	12	9.9	9.1	8.7	6.96	6.95	

Generally, according to ERA and other different road specifications manual, the fly ash treated expansive subgrade soil does not meet the minimum requirement. And the fly ash does not stand alone as stabilizer. Therefore, the fly ash needs additional activator to be used as stabilizer for subgrade soil. In this investigation cement kiln dust activator was used to stabilize the expansive subgrade soil.

4.5 Laboratory test result of expansive soil treated with mixture of fly ash and cement kiln dust

4.5.1 Effect of fly ash - cement kiln dust on Atterberg limit and linear shrinkage

The variation in soil consistency properties such as liquid limit, plastic limit, plasticity index and linear shrinkage of the expansive soil treated with Fly ash-cement kiln dust is shown in figure 4.13 The blended sample was cured for 1day in dissector to maintain the moisture lose and tested for Atterberg limit and linear shrinkage. From the figure below, it is clearly observed that as the percentage of cement kiln dust increase with constant fly ash of 25%, there is gradual decrease in plasticity index and linear shrinkage. Also, there is increase for plastic limit values with addition of fly ash-cement kiln dust as shown in figure 4.13. As test result shown that when the percentage cement kiln dust increases from 5% to 25%, the plastic limit of the soil-fly ash mixture has increased from 29.9 to 38.3% and its liquid limit decrease from 73 to 61.4% due to the probable reason of pozzolanic reaction of (CaO) in cement kiln dust with high silica, aluminum containing soil-fly ash mixture and they form calcium silica hydrated and calcium aluminum hydrated bond. Also, the linear shrinkage value of cement kiln dust activated soil fly ash decrease the from 8.15% to 6.03%.

Table 4.17 Effect of fly ash-cement kiln dust on Atterberg limit and linear shrinkage

25%FA+ CKD	LL	PL	PI	ERA requirement	Remark	LS
Natural soil only	80.6	34.2	46.4	PI ≤ 30%	Unsatisfied	15.54
0 (25% fly ash)	73	29.9	43.07		Unsatisfied	8.15
5	72.4	30.7	41.68		Unsatisfied	7.27
10	68	32.6	35.42		Unsatisfied	6.92
15	64	34.1	29.90		Satisfied	6.71
20	62.8	35.7	27.11		Satisfied	6.58
25	61.4	38.3	23.14		Satisfied	6.03

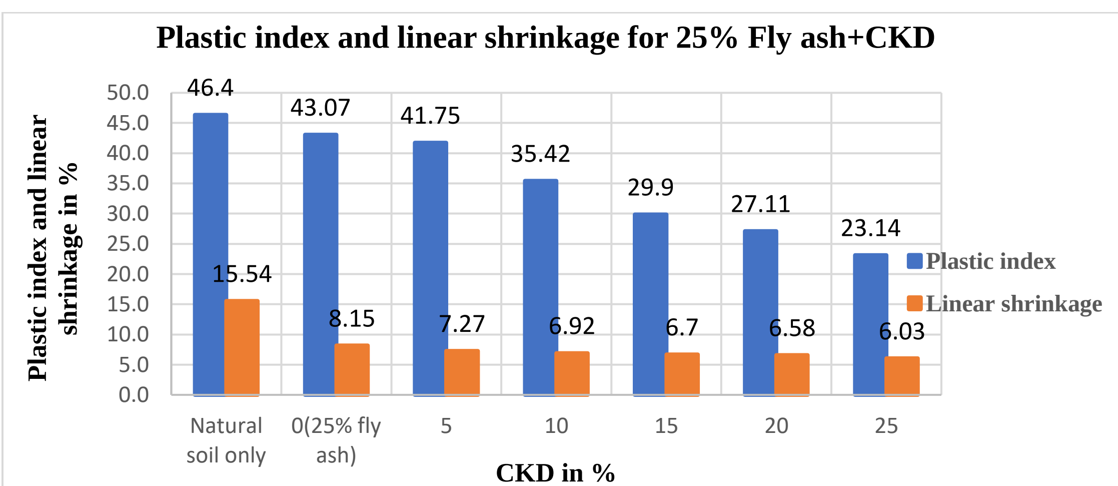

Figure 4. 13 Effect of fly ash + cement kiln dust on plastic index and linear shrinkage.

From above test result, it is certain for expansive soil that the PL value is able to increase by mixing cement kiln dust and the LL value will decrease by mixing fly ash, thus whichever cement kiln dust and fly ash is mixed with expansive soil will decrease the PI value. This result is in line with previously studied research on high plastic clay soil stabilized using class f fly ash activated by cement and lime respectively [63] & [66].

The plastic index value for 15% and above cement kiln dust addition on the soil-fly ash mixture meet the minimum requirement of ERA specification for utilization of stabilized soil mixture as the subgrade. Based on linear shrinkage according to Altemeyer [35] suggestion, the increment of cement kiln dust on soil-fly ash mixture change from critical to marginal degree of expansion.

4.5.2 Effect of fly ash - cement kiln dust on specific gravity

The test procedure followed for the determination of Specific gravity is in accordance with ASTM D 854. A sample weighting about 25gm is used in the test on oven dry basis as the volumetric flask is used in our test procedure. Tests were performed with the addition of 25 percent fly ash with different percentage of cement kiln dust of 5, 10, 15, 20 and 25% by dry weight.

Table 4.18 Summarized result of specific gravity

25% fly ash -cement kiln dust in %	0	5	10	15	20	25
Specific gravity (Gs)	2.51	2.55	2.60	2.62	2.64	2.67

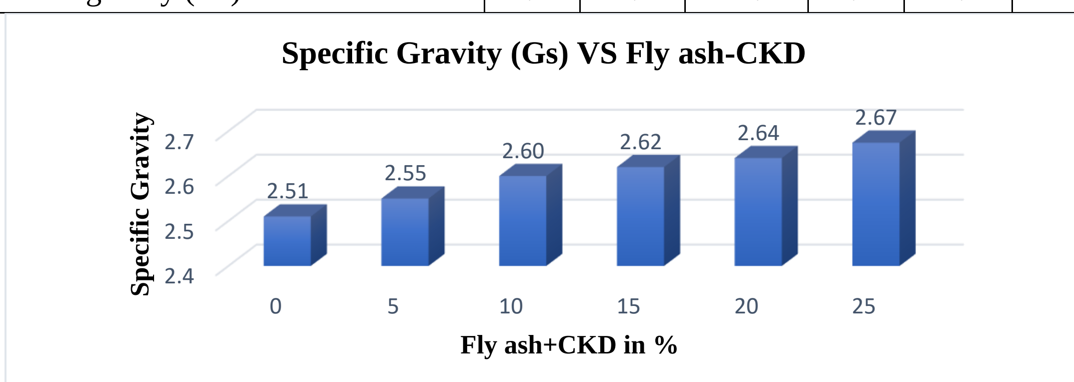

Figure 4. 14 Effect of CKD on specific gravity of soil-fly ash mixture

As the test result revealed that the percentage of cement kiln dust increase from 5 to 25% the specific gravity of soil-fly ash increases from 2.51 to 2.67%. The probable reasons of the increment maybe due to pozzolanic reaction and its weight of CKD.

4.5.3 Effect of fly ash - cement kiln dust on free swell index

Table 4.19 Effect of addition of CKD on free swell index of soil-fly ash mixture reading

Additive content in %	Measuring Cylinder No.(ml)		Reading after 24 hrs. (ml)		Free Swell	**IS** 2720 requirement
	Kerosene	Distilled water	Kerosene	Distilled water	Index, %	**FSI ≤ 50%**
0%	12	12	12	17	41.67	In range
5%	12	12	12	16.5	37.50	In range
10%	12	12	12	16	33.33	In range
15%	12	12	12	15.5	29.17	In range
20%	12	12	12	15	25.00	In range
25%	12	12	12	14.5	20.83	In range

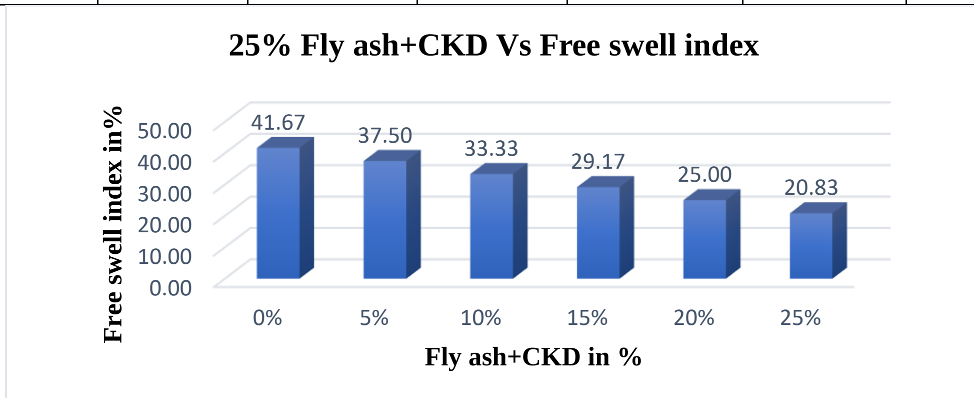

Figure 4. 15 Effect of CKD on free swell index of soil-fly ash mixture

In tables 4.19 above the free swell of samples has improved through stabilization. In table 2.4 in the literature review the free swell and degree of expansions have been stated. The untreated free swell values determined in laboratory were 100% for samples. The sample has free swell values >50% which is categorized as problematic. With 25% CKD treatment on soil-fly ash mixture, the free swell values become 20.83%. Here it can be seen that the addition of 5% to 25% of CKD for samples has well improved the swelling potential of the problematic soils from a class of problematic soils to non-problematic soils which is a satisfactory and required range**.**

4.5.4 Effect of fly ash - cement kiln dust on compaction characteristics

Without curing

To simulate the effect of curing on the maximum dry density and optimum moisture content of the CKD-soil-fly ash mixture, the study was conducted on 10 and 20% of CKD added on soil-fly ash mixture for immediate compaction without curing. The detail of the result is attached on Appendix C.

Table 4.20 Effect of CKD on soil-fly ash mix without curing

%age of CKD added on soil-fly ash mix	MDD	OMC
10	1.45	21.46
20	1.46	19.75

Here the study was not done any further investigation on uncured sample, because the strength test result of the mix has not gain significant result.

Four day curing effect of CKD and fly ash mixture on expansive soil

The table 4.21 below showed that the variation of MDD and OMC on different percentage of CKD mixed with 25% optimum dosage of fly ash treated soil for four-day cured sample.

Table 4.21 Variation of MDD and OMC for different percentage of CKD treated fly ash soil mix.

Percentage of CKD added on 25% fly ash treated expansive soil	MDD	OMC
0	1.34	25.41
5	1.42	21.87
10	1.45	18.78
15	1.43	19.01
20	1.47	21.72
25	1.51	21.98

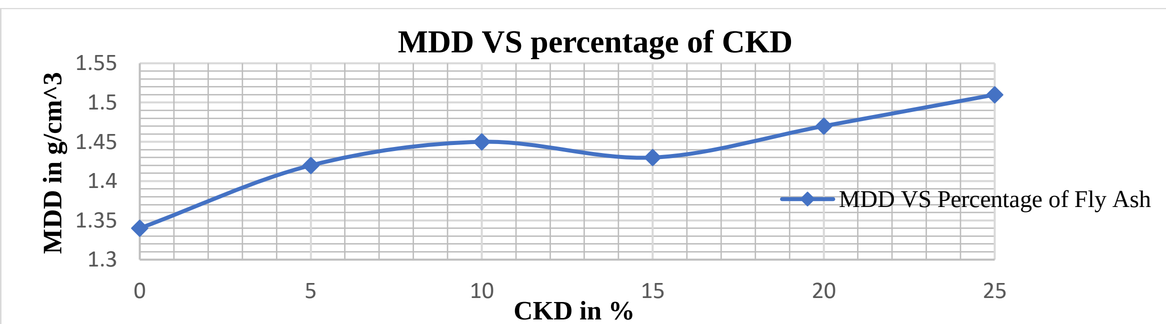

Figure 4. 16 Effect of addition CKD on MDD of fly ash treated soil with four-day curing

As the test result revealed that addition of cement kiln dust on fly ash treated soil has a great effect on the maximum dry density of the soil mixture. As the cement kiln dust content increase the maximum dry density of the mixture increase from 1.34g/cm^3 to 1.51g/cm^3 with a four-day curing period. The trend indicates that the MDD go on increasing with increase in percentage of CKD. The probable reason for the increment in MDD may be the pozzolanic reaction, gradation of CKD and as the specific gravity of CKD is more than the soil-fly ash mix.

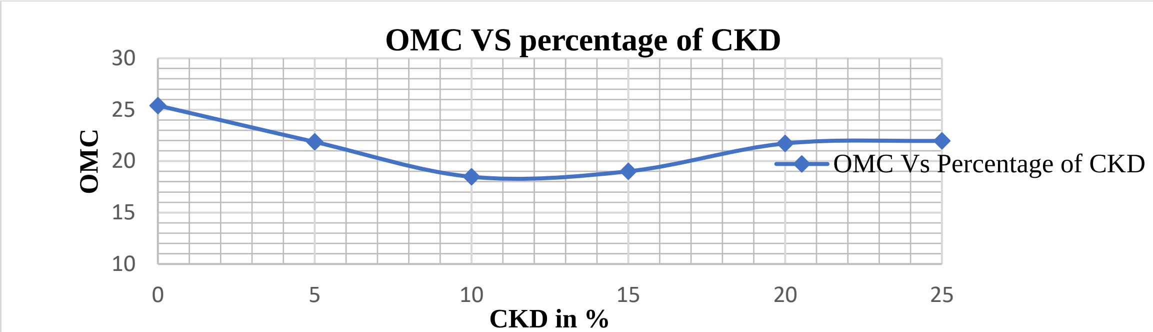

Figure 4. 17 Effect of addition CKD on OMC of fly ash treated soil with seven-day curing

From the above figure 4.17 the optimum moisture content of the mixture decreases from 25.41% to 18.48% as the CKD content increase from 0-25%. In general, the optimum moisture content of the treated soil was less when as compared with the untreated soil. The probable reason for the decrement may be the void spaces are plugged in with proper gradation and specific surface area of mix also decreases which requires less water.

Seven-day curing effect of CKD and fly ash mixture on expansive soil

The table 4.22 below showed that the variation of MDD and OMC on different percentage of CKD mixed with 25% optimum dosage of fly ash treated soil for seven-day cured sample.

Table 4.22 Variation of MDD and OMC for different %age of CKD treated fly ash soil mix.

Percentage of CKD added on 25% fly ash treated expansive soil	MDD	OMC
0	1.34	25.41
5	1.41	21.64
10	1.44	17.83
15	1.42	18.72
20	1.45	21.67
25	1.50	21.89

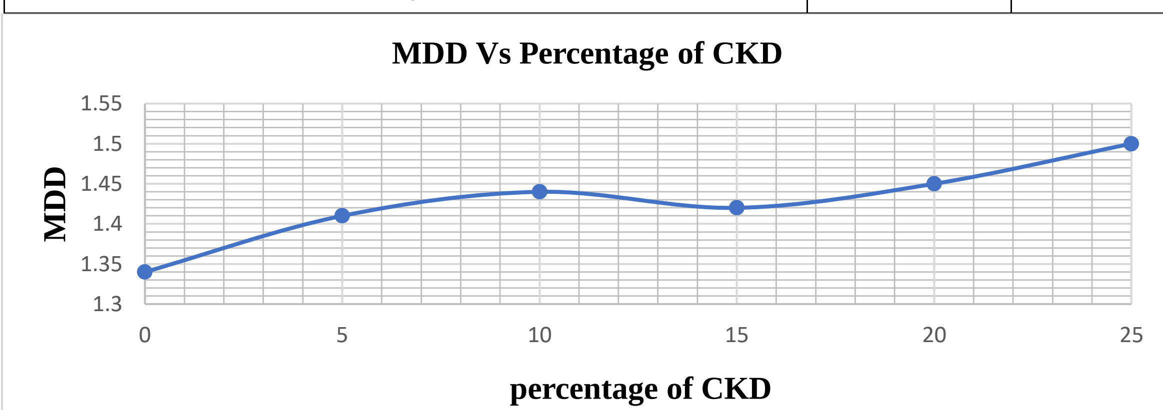

Figure 4. 18 Effect of addition CKD on MDD of fly ash treated soil with seven-day curing

As the Figure 4.18 shows that addition of cement kiln dust on fly ash treated soil has a great effect on the maximum dry density of the soil mixture. As the cement kiln dust content increase the maximum dry density of the mixture increase from 1.34g/cm^3 to 1.50g/cm^3 with a seven-day curing period.

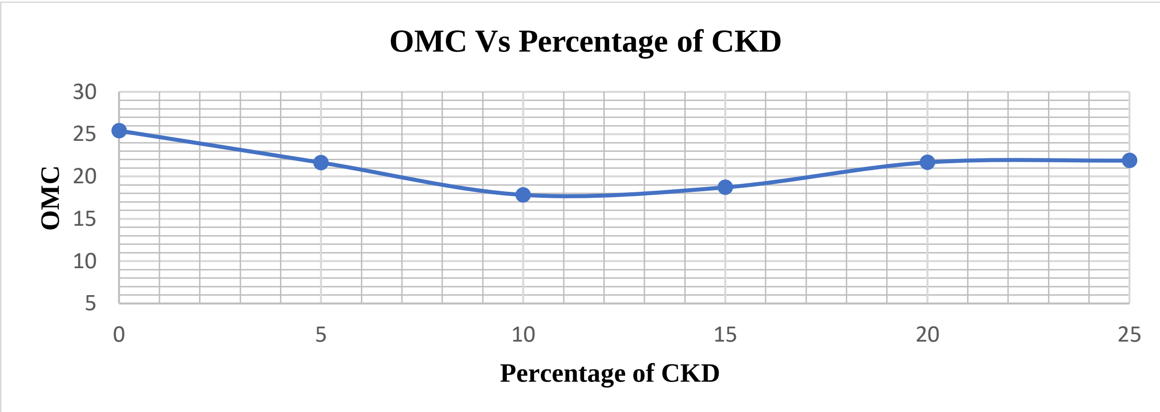

Figure 4. 19 Effect of addition CKD on OMC of fly ash treated soil with seven-day curing

From the figure 4.19, the optimum moisture content of the mixture decreases from 25.41 to 17.83 as the CKD content increase from 0-25%. In general, the optimum moisture content of the treated soil was less when as compared with the untreated soil.

Fourteen-day curing effect of CKD and fly ash mixture on expansive soil

The table 4.23 below showed that the variation of MDD and OMC on different percentage of CKD mixed with 25% optimum dosage of fly ash treated soil for four-day cured sample.

Table 4.23 Variation of MDD and OMC for different CKD treated fly ash soil mix.

Percentage of CKD added on 25% fly ash treated expansive soil	MDD	OMC
0	1.34	25.41
5	1.40	21.47
10	1.43	17.81
15	1.41	18.72
20	1.44	21.40
25	1.49	21.39

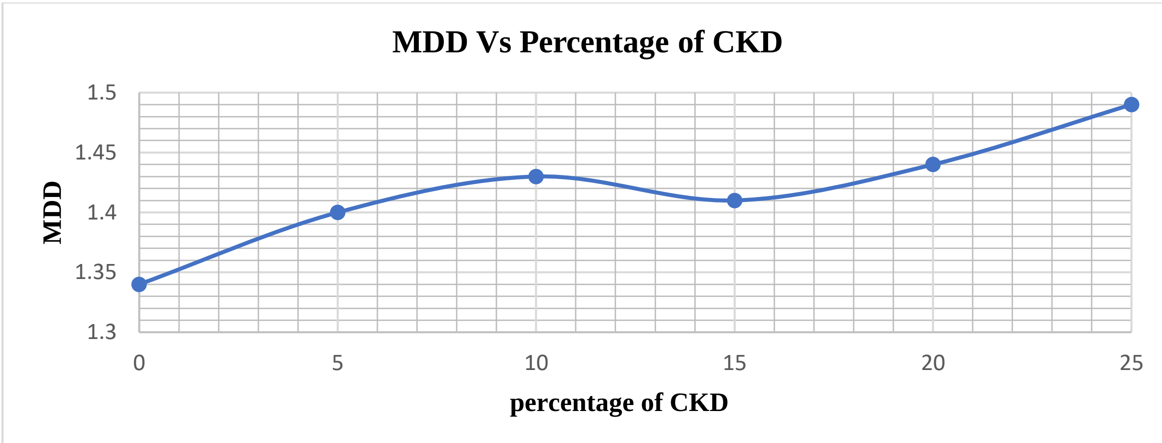

Figure 4. 20 Effect of addition CKD on MDD of fly ash treated soil with fourteen-day curing

As the Figure 4.20 shows that addition of cement kiln dust on fly ash treated soil has a great effect on the maximum dry density of the soil mixture. As the cement kiln dust content increase the maximum dry density of the mixture increase from 1.34g/cm^3 to 1.49g/cm^3 with a fourteen-day curing period.

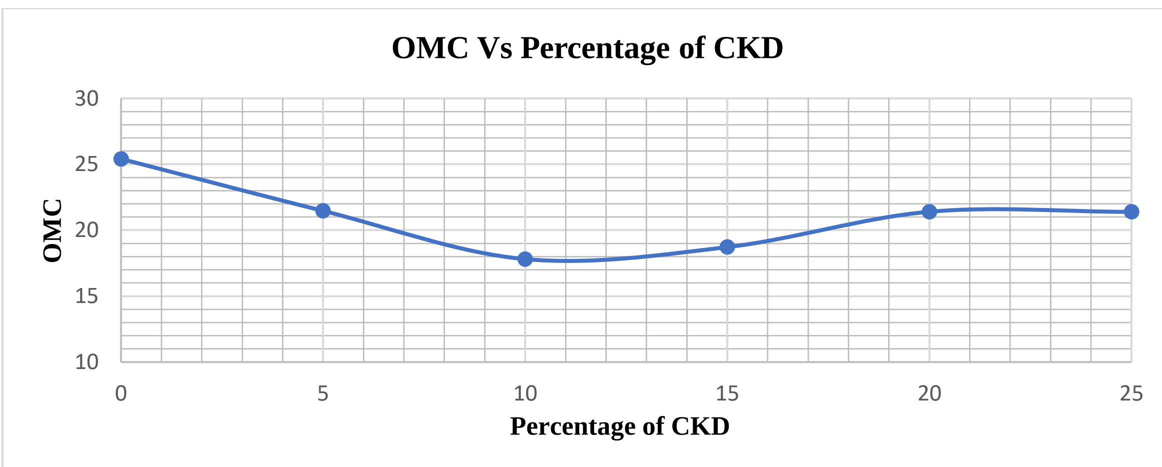

Figure 4. 21 Effect of addition CKD on OMC of fly ash treated soil with fourteen-day curing

From the figure 4.21, the optimum moisture content of the mixture initially decreases from 25.41 to 17.81 as the CKD content increase from 0-25%. In general, the optimum moisture content of the treated soil was less when as compared with the untreated soil.

Table 4.24 Summarized Effect of curing time on MDD and OMC treated soil

Percentage of CKD added on 25% fly ash treated expansive soil	4 Day cured		7 Day cured		14 Day cured	
	MDD	OMC	MDD	OMC	MDD	OMC
0 (25% fly ash)	1.34	25.41	1.34	25.41	1.34	25.41
5	1.42	21.87	1.41	21.64	1.40	21.47
10	1.45	18.78	1.44	17.83	1.43	17.81
15	1.43	19.01	1.42	18.72	1.41	18.72
20	1.47	21.72	1.45	21.67	1.44	21.40
25	1.51	21.98	1.50	21.89	1.49	21.39

In general, as the curing time increase, the maximum dry density and optimum moisture content of the mix were decreased. As the test result depicted that fly ash activated with the cement kiln dust mixture was greater the maximum dry density (MDD) than MDD of untreated soil and its optimum moisture content (OMC) was lower than OMC of untreated soil. Which means the addition of cement kiln dust activator on fly ash mixture increase the maximum dry density and decrease the optimum moisture content of expansive soil. Generally, the trend indicates that the MDD go on increasing with increase in percentage of CKD. The probable reason for the increment in MDD may be due to the pozzolanic reaction, gradation of CKD and as the specific gravity of CKD is more than the soil-fly ash mix. And also, the probable reason for the decrement of OMC may be due to the void spaces are plugged in with proper gradation and specific surface area of mix also decreases which requires less water.

4.5.5 Effect of addition of fly ash mixed with CKD on CBR and CBR swell

Without curing

As the test result of this study revealed that the CBR values of cement kiln dust mixed with soil-fly ash immediately without curing has not a significant improvement on the strength of weak subgrade. To realize the insignificance of CBR value without curing, 10 and 20 % CKD was added on the soil-fly ash mixture and immediately compact on the CBR mould using three-point CBR test method and soak the sample in water bath for 4day. The test result was clearly showed in figure below and refer on Appendix-C.

Table 4.25 Effect of %age CKD added on soil-fly ash mixture without curing

CBR without curing		
Additive in % (CKD in %)	CBR	CBR Swell in %
0	2.3	6.69
10	2.4	6.47
20	2.8	5.99

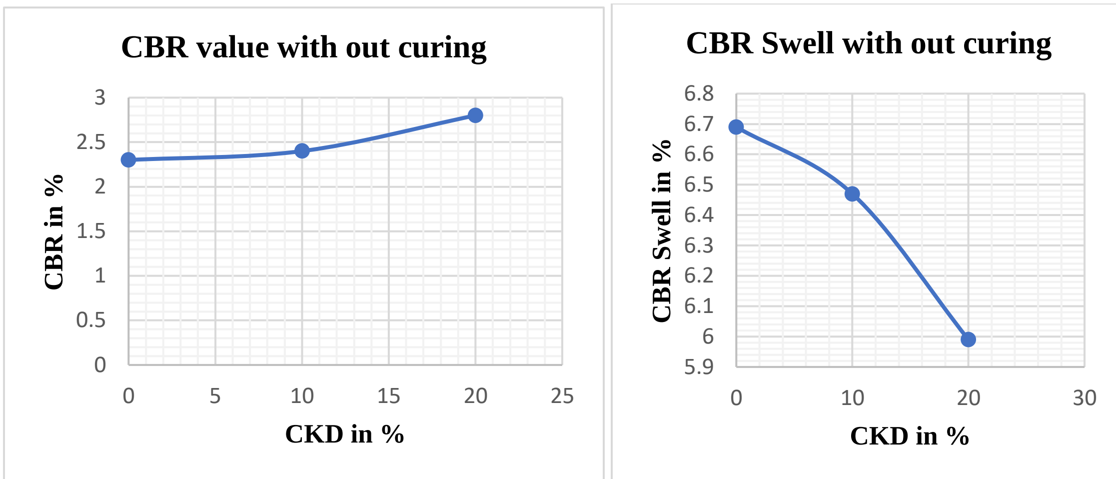

Figure 4. 22 Effect percentage of CKD added on uncured mixture

Effects of variation of curing period on CBR and CBR swell

Soil-fly ash and cement kiln mixture were kept compacted in CBR molds for 4, 7, and 14 days of curing periods for 25% fly ash-soil mixed sample with respect to 5%, 10 % ,15 %, 20% and 25 % Cement Kiln Dust (CKD) to estimate the influence of curing period on CBR value. For this study, three-point CBR with 10, 30 and 65 blows soaked for 4 days (96 hours) was used after curing periods to simulate worst condition of the site in rainy season. CKD of 5%, 10 %, 15%, 20%, and 25% were added on soil-fly ash blended samples and kept in plastic bags for the periods of 4, 7, and 14 days and the CBR and CBR swell values are investigated after the end of the respective curing period. The CBR test results are shown in Table 4.26. For details, refer Appendix C,

Table 4.26 Effect of CKD and curing on CBR and CBR swell of soil-fly ash mix.

Percentage of CKD added on 25% fly ash treated expansive soil	4 Day cured		7 Day cured		14 Day cured		ERA 2002 Requirement
	CBR	CBR swell	CBR	CBR swell	CBR	CBR swell	CBR ≥ 3%
Natural soil	0.8	12	0.8	12	0.8	12	Unsatisfied
0	2.3	6.96	2.3	6.96	2.3	6.96	Unsatisfied
5	3.1	5.34	3.2	5.08	3.6	4.85	Satisfied
10	3.7	4.80	3.8	3.85	4.0	3.65	Satisfied
15	4.1	3.57	4.3	2.99	4.6	2.79	Satisfied
20	4.9	2.34	5.1	2.12	5.3	1.94	Satisfied
25	5.7	1.88	5.8	1.75	6.1	1.62	Satisfied

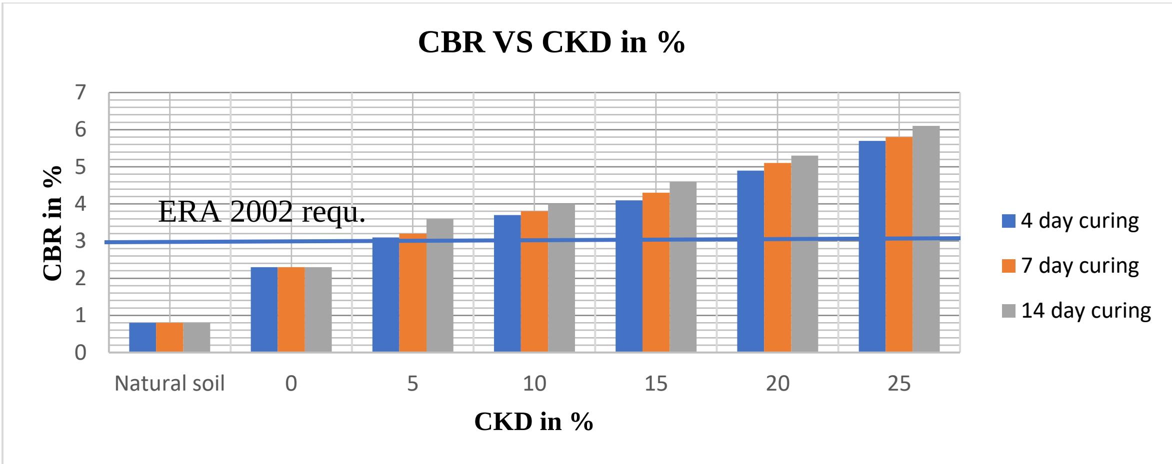

Figure 4. 23 Effect of curing on CBR of CKD-soil-fly ash blended sample

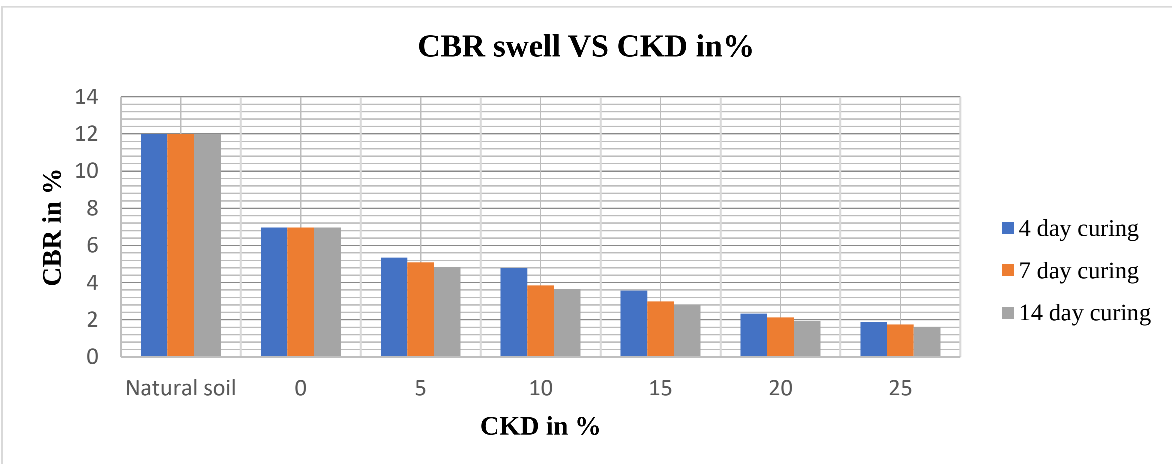

Figure 4. 24 Effect of curing on CBR swell of CKD-soil-fly ash blended sample

The study reveals that the CBR value for subgrade soil increases with the increase in cement kiln dust content and curing time and CBR swell has also decreased. As shown from the table above the CBR value increase from 0.8 to 6.1% and CBR swell decrease from 12 to 1.62% as the CKD content and curing time increase from 5 to 25% and 4 to 14 day respectively. Finally, it was observed that, CBR Values of soil-fly ash mixture increased significantly as cement kiln dust content increased with respect to curing time. This improvement in CBR within respect to curing time may be attributed to change of soil structure from dispersed to flocculate or inter particle bond was made over the time.

According to ERA 2002 specification, cement kiln dust treated soil-fly ash mixture meets the minimum requirement for utilization of treated soils as subgrade. Based on CBR value, addition of all percentage (from 5% to 25%) of cement kiln dust on fly ash treated soil mixture satisfied the minimum requirement which are greater than 3%, while based on CBR swelling meet the ERA requirement beyond 15% of cement kiln dust.

Therefore, according the results the subgrade soil class changed in its strength from S1 which are consider as poor subgrade to S3 which is good as subgrade material according to ERA design manual classification.

4.5.6 Effect of addition of fly ash mixed with CKD on UCS test

In this research the stress-strain behavior of soil-fly ash sample specimen treated with cement kiln admixtures, with different proportions and curing times has been investigated based on unconfined compression test. To conduct unconfined compressive strength of soil, the sample was cured for 7 and 14 days for 25% fly ash mixed with each percentage of 10%, 20% and 25% of cement kiln dust.

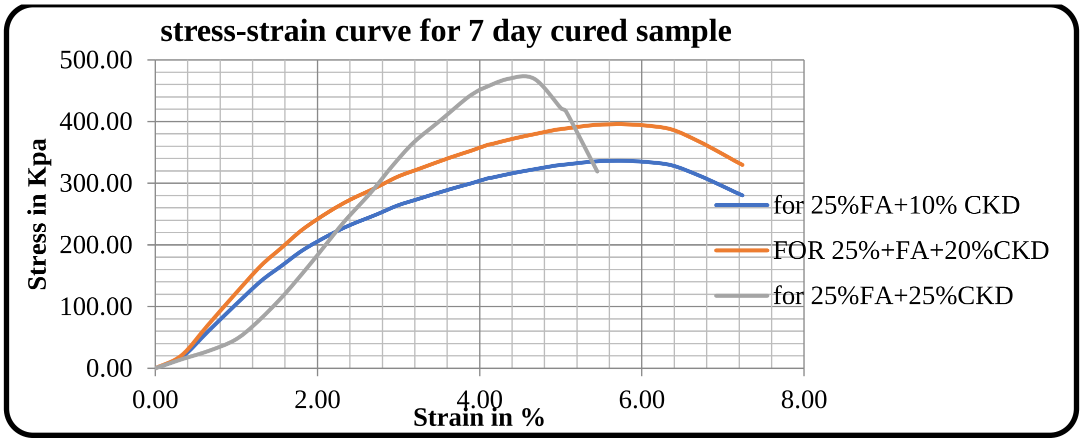

Figure 4. 25 Effect of 7day curing on CKD-soil-Fly ash mixture

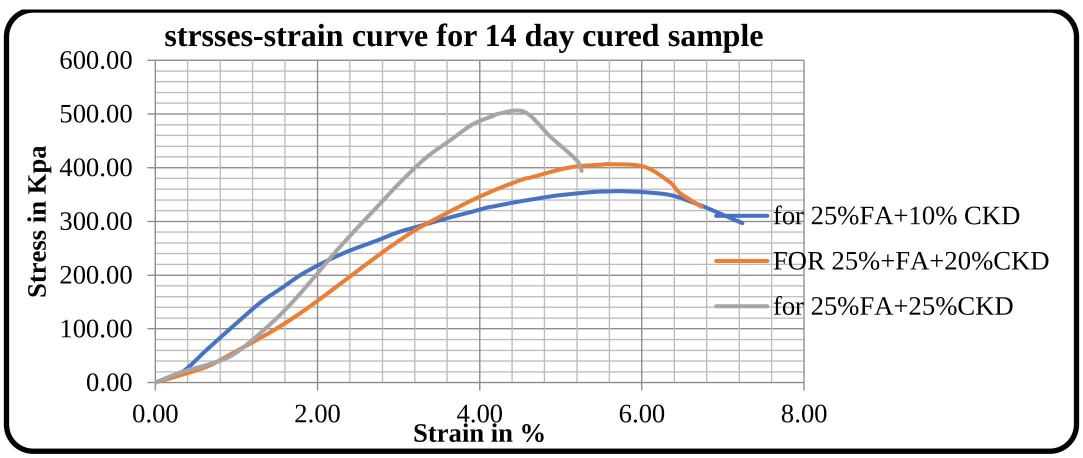

Figure 4.26 Effect of 14 day curing on CKD-soil-Fly ash mixture

At its natural state, the maximum UCS of untreated expansive soil has reached 93Kpa with the strain rate of 5.92%. Upon treatment with a considerable amount of 10%, 20% and 25% of CKD unconfined compressive strength of soil-fly ash mixture has increased to 356Kpa, 407Kpa and 505Kpa respectively with corresponding strain of 5.65, 5.57 and 4.55% for 14 days curing time. And, with in a considerable amount of 10%, 20% and 25% of CKD unconfined compressive strength of soil-fly ash mixture has increased to 337Kpa, 396Kpa and

472Kpa respectively with corresponding strain of 5.72, 5.65 and 4.67% for 7 days curing time. The shear failure mode of the cement kiln dust-soil-fly ash mixture specimen was probably closing to brittle failure.

Here from the test result unconfined compressive strength of treated soil increased as the CKD content and curing time increased. All treated specimen has gained significant unconfined compressive strength. The probable reason for increment of UCS may be due pozzolanic reactions between reach silica and alumina from clayey soil-fly ash mix & free lime (CaO) in CKD in the presence of moisture, results cementitious products, and may also due to the cation exchange, flocculation and agglomeration of the mix over a long period of curing.

Generally, the lowest consistency test result and maximum strength test result were observed at 25% cement kiln dust of soil-fly ash blended sample. However, based on economic point of view 20% cement kiln dust was taken as optimum percentage of cement kiln dust additive on soil-fly ash blended subgrade soil. Finally, the study revealed that cement kiln dust (CKD) activated fly ash are effective stabilizer for weak subgrade expansive soil.

Chapter Five

Conclusion and Recommendation

6.1 Conclusion

As the test result revealed that the following conclusion can be drew:

1. According to ASTM C618, fly ash has a pozzolanic property ($SiO_2+Al_2O_3+Fe_2O_3 \geq$ 70%) and categorized into Class-F fly ash (non-self-cementing fly ash). Cement kiln dust dines pozzolanic property requirement of ASTM, but due to rich in free lime (CaO) it made pozzolanic reaction in the presence of moisture.
2. The expansive soil used in this study has a liquid limit (LL=80.6), plastic limit (PL=34.2), plastic index (PI=46.4) and more than 35% passes under #200 sieve. Thus, as per AASHTO soil classification system, the soil categorized as an A-7-5 with rating of Fair-to-Poor to be used as a sub-grade material. And, in USCS the soil has categorized as CH (high plastic clay) soil. The soil has CBR value of 0.8 %.
3. Expansive soil treated with fly ash have drawn the following results:

   3.1 As the fly ash content increases from 10 to 30% the plasticity index, linear shrinkage, free swell index and specific gravity decrease from 46.4 to 42.5%, 15.54% to 8.15%, 100% to 37.50% and 2.68 to 2.48% respectively.

   3.2 As fly ash content increases the MDD and OMC of the expansive soil decrease and increase respectively due to the probable reason of its light weight & large surface area respectively.

   3.3 The soaked CBR increased with increasing in fly ash till a 25% fly ash, then decreased gradually. Due to this reason optimum dosage of fly ash used for this study was 25%. And the CBR value and UCS soil has increased from 0.8 to 2.3% and 93kpa to 111Kpa respectively.

   3.4 All the engineering properties of virgin soil is improved when blended with fly ash. However, the improvement was not significant because it has not met the minimum specification requirement for subgrade. So that it needs an additional activator to be used as stabilizer. In this investigation cement kiln dust activator was used.

4. Soil -fly ash blended sample activated with cement kiln dust has drawn the following results:
   4.1 As the cement kiln dust content increase the plasticity index, linear shrinkage, and free swell index decreases from 46.4% to 23.14, 15.54% to 6.03% and 100% to 20.83% respectively.
   4.2 As the CKD content increase the maximum dry density of treated expansive soil increase and its optimum moisture content decrease with respect to curing time.
   4.3 As the CKD content increase the CBR and UCS values of soil increases with in respect to the curing time. As the curing period increase from 4 to 14 day the CBR and UCS of soil increase from 0.8 to 6.1% and from 93Kpa to 507Kpa respectively for 5% to 25% CKD increments. Long curing period has the significant effect on the strength test of both CBR and UCS of expansive soil.
   4.4 Generally, the lowest consistency test result and maximum strength test result were observed at 25% cement kiln dust of soil-fly ash blended sample. However, based on economic point of view 20% cement kiln dust was taken as optimum percentage
   4.5 Study revealed that CKD activated fly ash are effective stabilizer for subgrade soil.
   4.6 Utilization of industry waste by-product indirectly has an advantage for protecting the adverse effect on the surrounding environment.

6.2 Recommendation

-This study also recommended identifying minerology of chemical stabilizer has a great role to understand inter particle bond and its strength gain on expansive soil.

-Study the effect of long period curing on cement kiln dust-soil-fly ash specimen.

-Explore the performance cement kiln dust activated fly ash on different types expansive soil.

-Study on stabilization of expansive subgrade soil by using fly ash activated by lime kiln dust.

-Analyzing the effect of curing on soil-fly ash mixture needs further investigation.

-Study the cost of stabilization with respect to: fly ash activated by cement & lime and also with cart away and borrow fill.

-Stabilization of expansive weak soil using fly ash mixed with cement kiln dust within respect to curing is an effective option for the improvement of engineering properties of expansive soil.

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Appendix

Appendix: A

Engineering properties of Natural Expansive clay soil

1. **Grain size analysis**

Wet sieve analysis

Sieve size (mm)	Mass of retain on each sieve (gms) Wt=1000gms.	Percentage of retained soil	Cumulative % of retain soil	Percentage of passing particle
9.5	0	0	0	100
4.75	2	0.2	0.2	99.8
2.36	3.5	0.35	0.55	99.45
2	2	0.2	0.75	99.25
1.18	4	0.4	1.15	98.85
0.85	1.5	0.15	1.3	98.7
0.6	4.5	0.45	1.75	98.25
0.425	2.5	0.25	2	98
0.3	3	0.3	2.3	97.7
0.15	6	0.6	2.9	97.1
0.075	4.5	0.45	3.35	96.65

Hydrometer Analysis

For 50gram sample	Elapsed time,min	temp. 0c	Rh	Meniscus Correction Cm = +1	Hydrometer reading corrected for meniscus(RC)	Effective Depth, L (mm)	K (Table)	Particle Diameter (mm)	Ct from Table	Cd	Corr. Hydr. Rdg. Rc	a	% Finer Par	% Adjusted Finer PA
0.049	0.5	23	55	1	56	7.3	0.01297	0.049	0.7	7	49.7	0.993	98.72	89.63
0.035	1	23	54	1	55	7.4	0.01297	0.035	0.7	7	48.7	0.993	96.74	87.83
0.025	2	23	53.5	1	54.5	7.5	0.01297	0.025	0.7	7	48.2	0.993	95.74	86.93
0.018	4	23	52	1	53	7.8	0.01297	0.018	0.7	7	46.7	0.993	92.76	84.22
0.013	8	23	51	1	52	7.9	0.01297	0.013	0.7	7	45.7	0.993	90.78	82.42
0.010	15	23	50	1	51	8.1	0.01297	0.010	0.7	7	44.7	0.993	88.79	80.61
0.007	30	23	48.9	1	49.9	8.3	0.01297	0.007	0.7	7	43.6	0.993	86.61	78.63
0.005	60	23	47.1	1	48.1	8.6	0.01297	0.005	0.7	7	41.8	0.993	83.03	75.38
0.004	120	23	46	1	47	8.8	0.01297	0.004	0.7	7	40.7	0.993	80.85	73.40
0.003	240	23	45	1	46	8.9	0.01297	0.002	0.7	7	39.7	0.993	78.86	71.60
0.002	480	23	41	1	42	9.6	0.01297	0.002	0.7	7	35.7	0.993	70.91	64.38
0.001	1440	23	40	1	41	9.7	0.01297	0.001	0.7	7	34.7	0.993	68.93	62.58

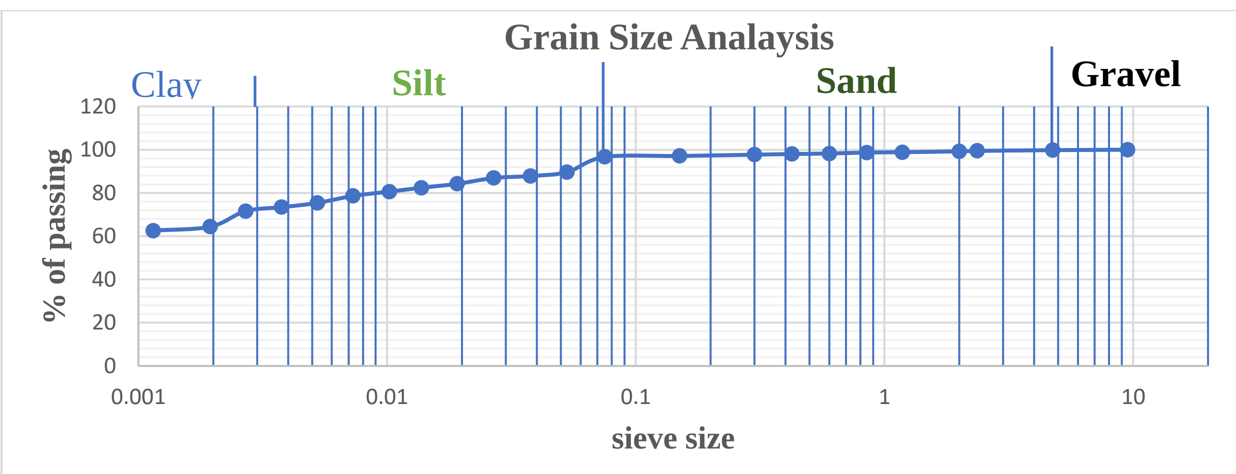
Combined analysis

Combined of wet sieve analysis and Hydrometer analysis

Sieve size (mm)	Mass of retain on each seive(g) wt=1000gms.	Percentage of retained soil	Cumulative % of retain soil	Percentage of passing particle
9.5	0	0	0	100
4.75	2	0.2	0.2	99.8
2.36	3.5	0.35	0.55	99.45
2	2	0.2	0.75	99.25
1.18	4	0.4	1.15	98.85
0.85	1.5	0.15	1.3	98.7
0.6	4.5	0.45	1.75	98.25
0.425	2.5	0.25	2	98
0.3	3	0.3	2.3	97.7
0.15	6	0.6	2.9	97.1
0.075	4.5	0.45	3.35	96.65

Hydrometer Analysis

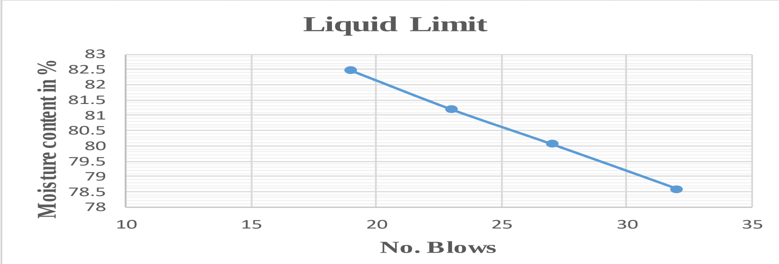
For 50gram sample	Elapsed time,min	temp. 0c	Rh	Meniscus Correction Cm = +1	Hydrometer reading corrected for meniscus(RC)	Effective Depth, L (mm)	K (Table)	Particle Diameter (mm)	Ct from Table	Cd	Corr. Hydr. Rdg. Rc	a	% Finer Par	% Adjusted Finer PA
0.049	0.5	23	55	1	56	7.3	0.01297	0.049	0.7	7	49.7	0.993	98.72	89.63
0.035	1	23	54	1	55	7.4	0.01297	0.035	0.7	7	48.7	0.993	96.74	87.83
0.025	2	23	53.5	1	54.5	7.5	0.01297	0.025	0.7	7	48.2	0.993	95.74	86.93
0.018	4	23	52	1	53	7.8	0.01297	0.018	0.7	7	46.7	0.993	92.76	84.22
0.013	8	23	51	1	52	7.9	0.01297	0.013	0.7	7	45.7	0.993	90.78	82.42
0.010	15	23	50	1	51	8.1	0.01297	0.010	0.7	7	44.7	0.993	88.79	80.61
0.007	30	23	48.9	1	49.9	8.3	0.01297	0.007	0.7	7	43.6	0.993	86.61	78.63
0.005	60	23	47.1	1	48.1	8.6	0.01297	0.005	0.7	7	41.8	0.993	83.03	75.38
0.004	120	23	46	1	47	8.8	0.01297	0.004	0.7	7	40.7	0.993	80.85	73.40
0.003	240	23	45	1	46	8.9	0.01297	0.002	0.7	7	39.7	0.993	78.86	71.60
0.002	480	23	41	1	42	9.6	0.01297	0.002	0.7	7	35.7	0.993	70.91	64.38
0.001	1440	23	40	1	41	9.7	0.01297	0.001	0.7	7	34.7	0.993	68.93	62.58



2. Atterberg limit

NATURAL SOIL

Determination	Liquid Limit				Plastic Limit		
Number of blows	32	27	23	19	Test	1	2
Test No	3	4	1	2	Container	A7	13
Container No	G3	3L	2	G8	Wt. of container + wet soil, g	24.23	24.49
Wt. of container + wet soil, g	38.31	40.27	35.53	37.98	Wt. of container + dry soil, g	22.44	22.58
Wt. of container + dry soil, g	29.87	31.04	27.76	29.28	Wt. of container, g	17.24	16.97
Wt. of container, g	19.13	19.51	18.19	18.73	Wt. of water, g	1.79	1.91
Wt. of water, g	8.44	9.23	7.77	8.70	Wt. of dry soil, g	5.20	5.61
Wt. of dry soil, g	10.74	11.53	9.57	10.55	Moisture container, %	34.42	34.0
Moisture content, %	78.6	80.1	81.2	82.5	Average Moisture Content, %	34.2	



Liquid Limit	**80.6**
Plastic Limit	**34.2**
Plasticity Index	**46.4**

3. Linear shrinkage

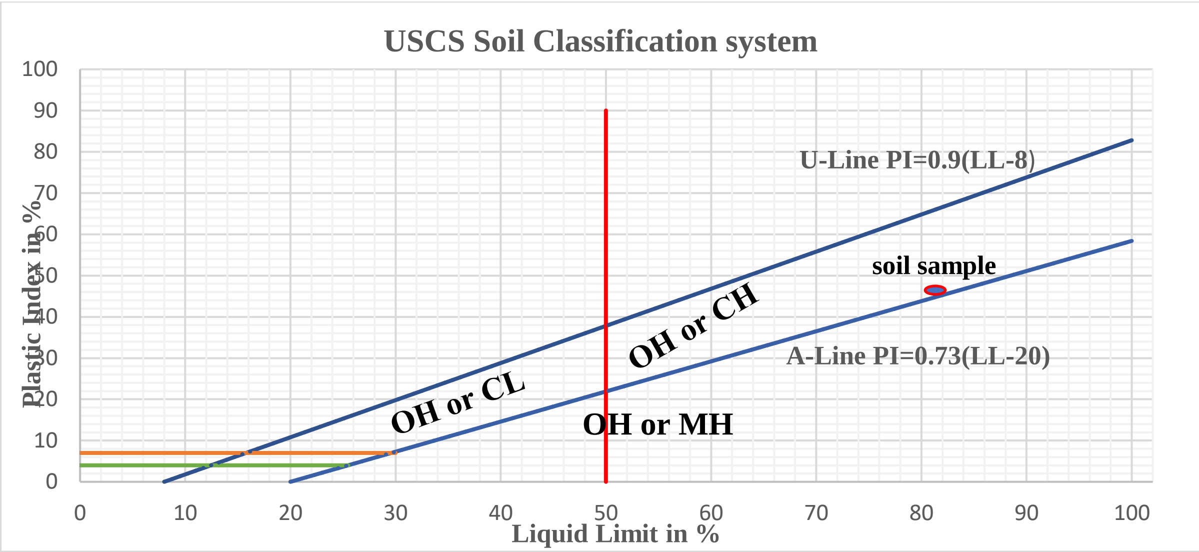
Natural soil linear shrinkage test		
Determination No.	1	z
Semi cylindrical trough No.	A	B
Initial wet length of soil Lo (mm)	140	140
Dry length of soil Ld (mm)	118	118.5
Linear shrinkage LS in %	15.71	15.36
Average Linear shrinkage	15.54	

4. Free swell index

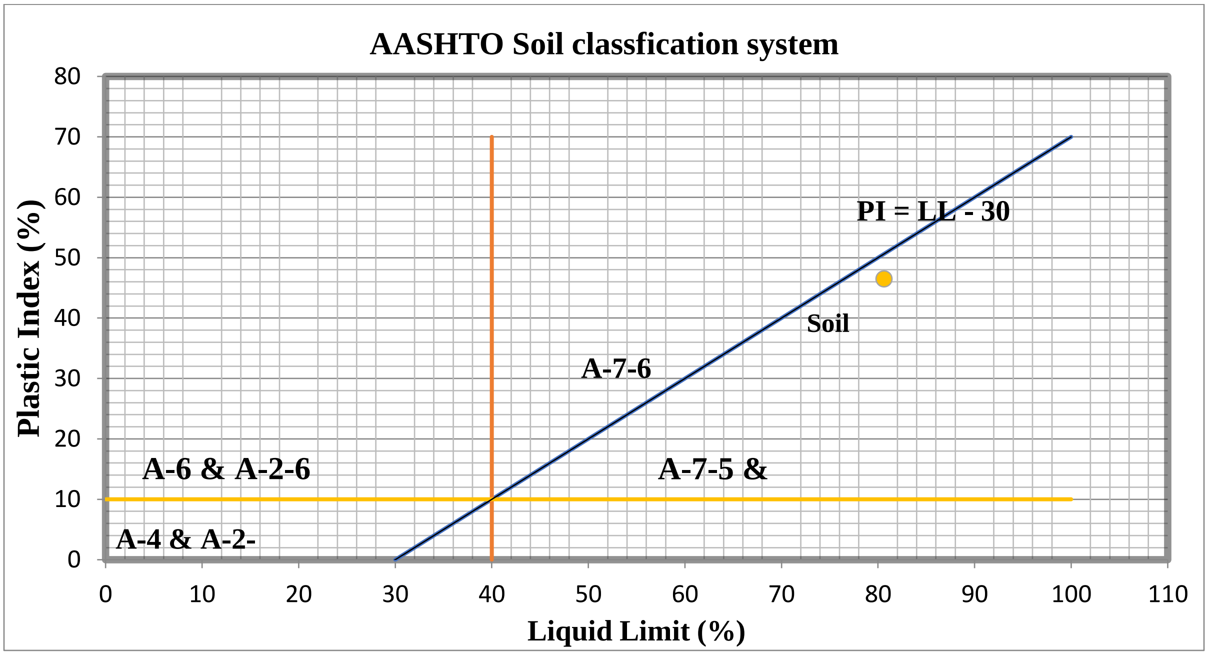
Station	Measuring Cylinder No.(ml)		Reading after 24 hrs(ml)		Free Swell Index, %
	Kerosene	Distilled water	Kerosene	Distilled water	
Natural soil	10	10	10	20	**100.00**

5. Soil classification

Unified soil classification system (USCS)



AASHTO



6. Specific Gravity

Natural soil specific gravity									
Determination code								D7	11
Mass of dry, clean calibrated pycnometer, Mp, in (gm)								30.31	32.14
A. Mass of oven dry sample (gm)								25	25
B. Mass of pycnometer +water (gm)								121.03	123.18
C. Mass of pycnometer + water + sample (gm)								136.67	138.91
Observation temperature of water, Ti in (^{o}C)								24	24
Water temperature in (^{o}C)									
(^{o}C)	18	19	20	21	22	23	24	25	26
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.9991	0.9988	0.9986
Temperature of contents of pycnometer when Mpsw was taken, Tx, (^{o}C)								23	23
K for Tx								0.9993	0.9993
Specific gravity at 20oc, Gs						Gs=A*k/(A+B-C)		2.67	2.69
Average Specific gravity at 20oc, Gs								**2.68**	

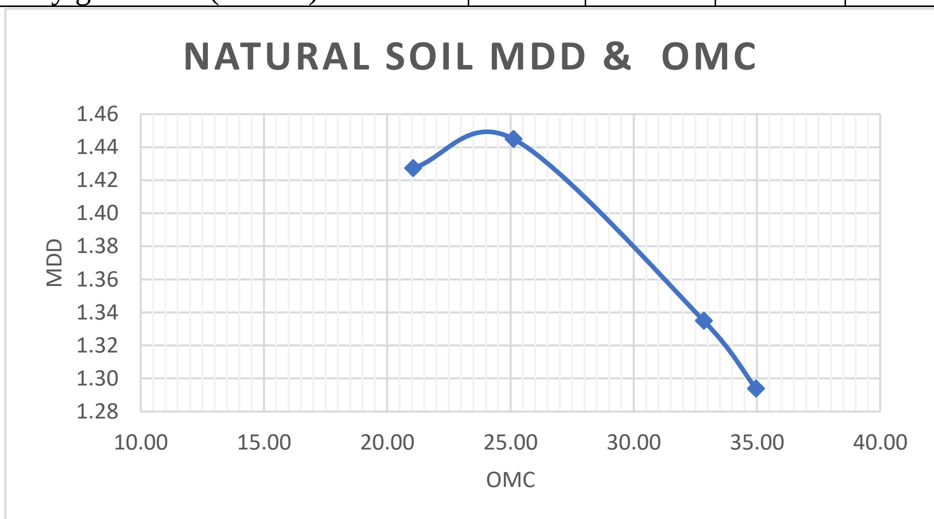
Density of water and correction factor K for various temperature (for specific gravity)

Temperature in Oc	Density of water (g/ml)	Correction factor, K
16	0.99897	1.0007
17	0.99880	1.0006
18	0.99862	1.0004
19	0.99843	1.0002
20	0.99823	1.0000
21	0.99802	0.9998
22	0.9978	0.9996
23	0.99757	0.9993
24	0.99732	0.9991
25	0.99707	0.9988
26	0.99681	0.9986
27	0.99654	0.9983
28	0.99626	0.9980
29	0.99597	0.9977
30	0.99567	0.9974

7. Compaction characteristics

NATURAL SOIL

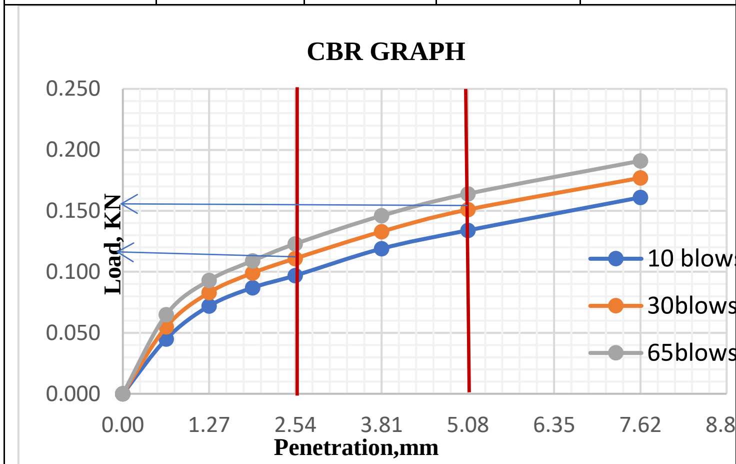
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4500	4500	4500	4500
Water Added(cc)	320	500	680	860
Mass of Mold & Wet soil(gm)(A)	6376.5	6555.5	6485.5	6428
Mass of Mold(gm)(B)	2707	2715.5	2719	2719
Mass of Wet Soil(gm)A-B=C	3669.5	3840	3766.5	3709
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.73	1.81	1.77	1.75
Moisture Content Determination				
Container Code.	P15	P65	E	G34
Mass of Wet soil & Container(gm)(F)	117	168.5	159.5	185.5
Mass of dry soil & container(gm)(G)	99.7	142.1	128.1	146
Mass of container(gm)(H)	17.5	37	32.5	33
Mass of moisture(gm)F-G=(I)	17.3	26.4	31.4	39.5
Mass of Dry soil(gm)G-H=(J)	82.2	105.1	95.6	113
Moisture content % (I/J) *100=K	**21.05**	**25.12**	**32.85**	**34.96**
Dry Density gm/cm^3 E/(100+K) *100	**1.43**	**1.44**	**1.33**	**1.29**

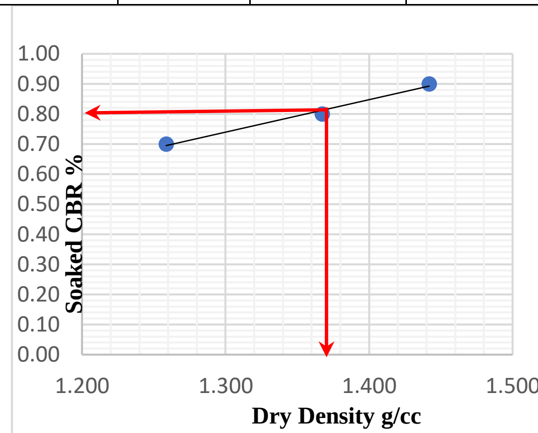


8. California Bearing Ratio (CBR) of Natural soil

Natural soil sample only

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.065		0.64	0.055		0.64	0.045	
1.27	0.093		1.27	0.083		1.27	0.072	
1.91	0.109		1.91	0.099		1.91	0.087	
2.54	0.123	**0.93**	2.54	0.111	**0.84**	2.54	0.097	**0.73**
3.81	0.146		3.81	0.133		3.81	0.119	
5.08	0.164	**0.82**	5.08	0.151	**0.76**	5.08	0.134	**0.67**
7.62	0.191		7.62	0.177		7.62	0.161	
Modified Max. Dry Density g/cc			**1.44**		OMC %		**25.12**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
	Read in %			Read in %			Read in %	
Initial	0.50	11.52	Initial	0.5	11.86	Initial	0.50	12.63
Final	13.91		Final	14.31		Final	15.20	

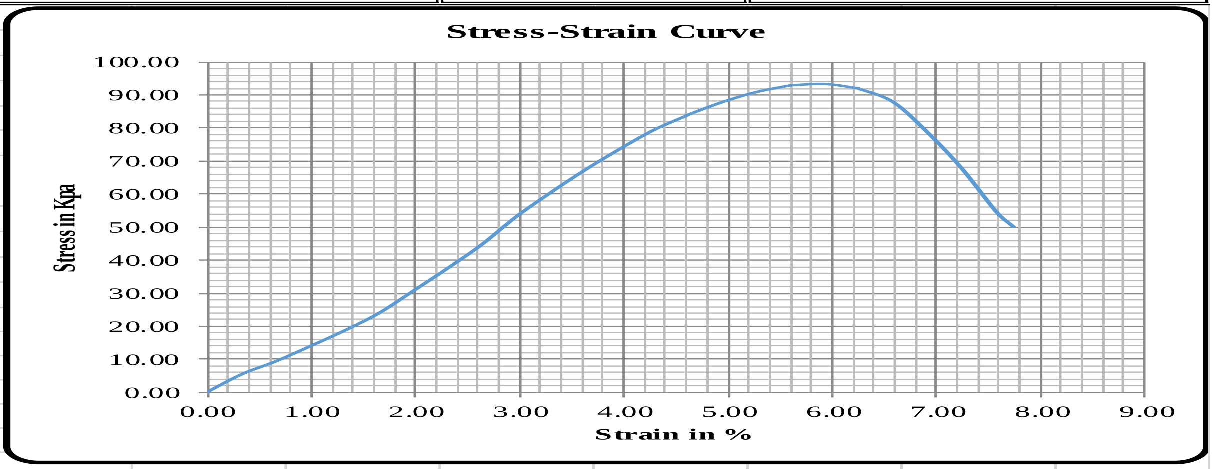




			Dry Density at 95% of MDD:	**1.368**
No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction
10	31.4	1.259	0.7	87
30	29.7	1.367	0.8	95
65	26.0	1.442	0.9	100
CBR (%) @ 95 % MDD			**0.8** **% Swell**	**12.00**

9. Unconfined compressive strength test (UCS) of natural expansive soil

Test Type:	Unconfined Compression Test (ASTM D-2166)	
Type of Sample:	Remoled Soil Sample	
Sample:	Sample Light gray clay soil	
Pit Code:	Natural expansive soil	
Sample Height (mm)	Peak UCS, (kPa)	Cohesion, (kPa)
76	93	47



Sample Deformation ΔL (mm)	Load In (N) Trial-1	Sample Heght (mm)	Sample Actule Area (cm^2)	Strain	Strain in %	Corrected Area (cm^2)	Stress (kPa)
0.00	0	76.00	11.34	0.00	0.00	11.34	0.00
0.25	6	76.00	11.34	0.00	0.33	11.38	5.36
0.50	11	76.00	11.34	0.01	0.66	11.42	9.29
0.75	16	76.00	11.34	0.01	0.98	11.45	13.79
1.00	21	76.00	11.34	0.01	1.31	11.49	18.53
1.25	28	76.00	11.34	0.02	1.65	11.53	23.85
1.50	35	76.00	11.34	0.02	1.97	11.57	30.51
1.75	44	76.00	11.34	0.02	2.31	11.61	37.47
2.00	52	76.00	11.34	0.03	2.63	11.65	44.56
2.25	62	76.00	11.34	0.03	2.96	11.69	53.05
2.50	71	76.00	11.34	0.03	3.29	11.73	60.21
2.75	79	76.00	11.34	0.04	3.62	11.77	67.14
3.00	87	76.00	11.34	0.04	3.95	11.81	73.43
3.25	94	76.00	11.34	0.04	4.28	11.85	79.25
3.50	100	76.00	11.34	0.05	4.60	11.89	83.70
3.50	100	76.00	11.34	0.05	4.60	11.89	83.78
3.75	105	76.00	11.34	0.05	4.93	11.93	87.68
4.00	109	76.00	11.34	0.05	5.27	11.97	90.80
4.25	112	76.00	11.34	0.06	5.59	12.01	92.82
4.25	112	76.00	11.34	0.06	5.59	12.01	92.82
4.50	112	76.00	11.34	0.06	5.92	12.05	93.24
4.75	111	76.00	11.34	0.06	6.24	12.10	91.93
4.75	111	76.00	11.34	0.06	6.24	12.10	91.84
4.75	111	76.00	11.34	0.06	6.24	12.10	91.84
5.00	107	76.00	11.34	0.07	6.58	12.14	87.81
5.25	96	76.00	11.34	0.07	6.91	12.18	78.55
5.50	83	76.00	11.34	0.07	7.24	12.23	67.73
5.75	67	76.00	11.34	0.08	7.57	12.27	54.44
5.88	62	76.00	11.34	0.08	7.73	12.29	50.03

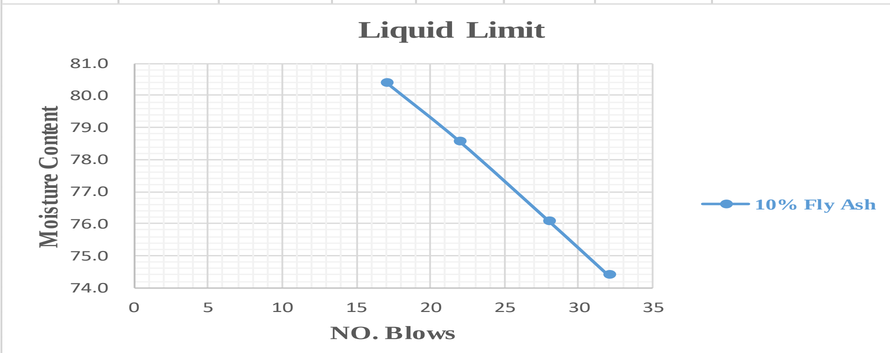
Appendix: B

Laboratory analysis data for expansive soil treated with fly ash

1. Atterberg limit test

Natural soil mixed with 10% Fly Ash

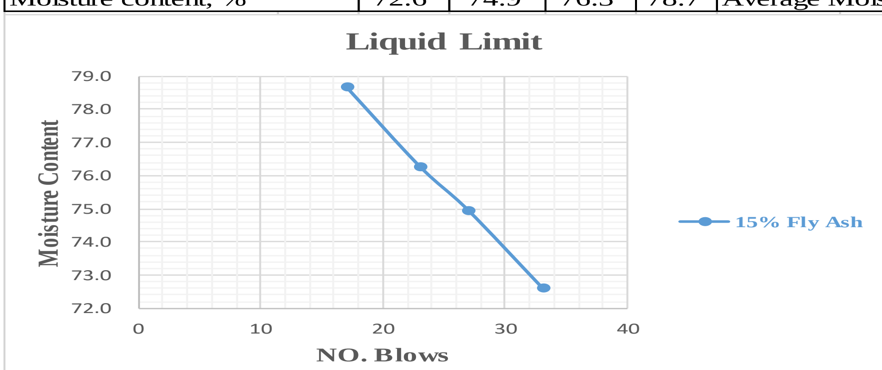
Determination	Liquid Limit				Plastic Limit		
Number of blows	32	28	22	17	Test	1	2
Test No	1	2	3	4	Container	A7	13
Container No	2	G8	G3	3L	Wt. of container + wet soil, g	26.51	28.86
Wt. of container + wet soil, g	37.86	34.85	37.52	36.39	Wt. of container + dry soil, g	24.47	26.45
Wt. of container + dry soil, g	29.05	27.88	29.42	29.49	Wt. of container, g	18.15	19.00
Wt. of container, g	17.21	18.72	19.11	20.91	Wt. of water, g	2.04	2.41
Wt. of water, g	8.81	6.97	8.10	6.90	Wt. of dry soil, g	6.32	7.45
Wt. of dry soil, g	11.84	9.16	10.31	8.58	Moisture container, %	32.28	32.3
Moisture content, %	74.4	76.1	78.6	80.4	Average Moisture Content, %	32.3	



Liquid Limit	**77.2**
Plastic Limit	**32.3**
Plasticity Index	**44.9**

Natural soil mixed with 15% Fly Ash

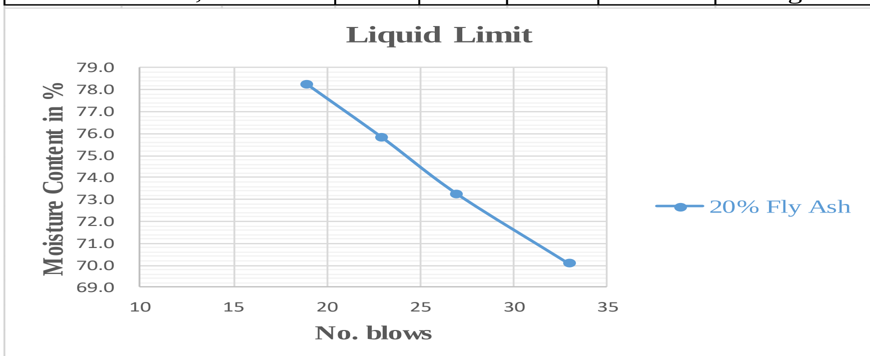
Determination	Liquid Limit				Plastic Limit		
Number of blows	33	27	23	17	Test	1	2
Test No	1	2	3	4	Container	A7	13
Container No	2	G8	G3	3L	Wt. of container + wet soil, g	28.64	30.97
Wt. of container + wet soil, g	35.86	37.05	39.79	38.7	Wt. of container + dry soil, g	26.65	28.63
Wt. of container + dry soil, g	27.13	30.11	31.75	31.8	Wt. of container, g	20.34	21.14
Wt. of container, g	15.11	20.85	21.21	23	Wt. of water, g	1.99	2.34
Wt. of water, g	8.73	6.94	8.04	6.90	Wt. of dry soil, g	6.31	7.49
Wt. of dry soil, g	12.02	9.26	10.54	8.77	Moisture container, %	31.54	31.2
Moisture content, %	72.6	74.9	76.3	78.7	Average Moisture Content, %	31.4	



Liquid Limit	**75.6**
Plastic Limit	**31.4**
Plasticity Index	**44.2**

Natural soil mixid with 20% Fly Ash

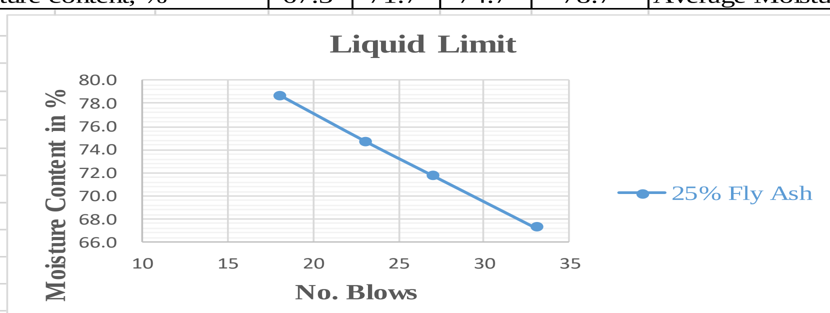
Determination	Liquid Limit				Plastic Limit			
Number of blows	33	27	23	19	Test		1	2
Test No	1	2	3	4	Container		A7	13
Container No	2	G8	G3	3L	Wt. of container + wet soil, g		31.95	24.01
Wt. of container + wet soil, g	38.22	33.57	34.48	41.04	Wt. of container + dry soil, g		30.15	22.35
Wt. of container + dry soil, g	30.59	26.78	27.68	30.91	Wt. of container, g		24.31	16.97
Wt. of container, g	19.70	17.51	18.71	17.96	Wt. of water, g		1.80	1.66
Wt. of water, g	7.63	6.79	6.80	10.13	Wt. of dry soil, g		5.84	5.38
Wt. of dry soil, g	10.89	9.27	8.97	12.95	Moisture container, %		30.82	30.9
Moisture content, %	70.1	73.2	75.8	78.2	Average Moisture Content, %		30.8	



Liquid Limit	**74.6**
Plastic Limit	**30.8**
Plasticity Index	**43.8**

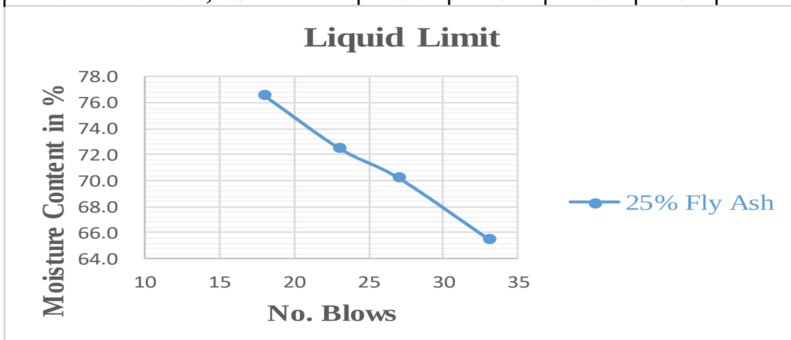
Natural soil mixid with 25% Fly Ash

Determination	Liquid Limit				Plastic Limit			
Number of blows	33	27	23	18	Test		1	2
Test No	1	3	2	4	Container		A7	13
Container No	2	G3	G8	3L	Wt. of container + wet soil, g		30.25	33.72
Wt. of container + wet soil, g	33.07	35.29	33.11	38.86	Wt. of container + dry soil, g		27.79	31.54
Wt. of container + dry soil, g	26.58	29.71	27.35	32.45	Wt. of container, g		19.58	24.25
Wt. of container, g	16.93	21.93	19.64	24.3	Wt. of water, g		2.46	2.18
Wt. of water, g	6.49	5.58	5.76	6.41	Wt. of dry soil, g		8.21	7.29
Wt. of dry soil, g	9.65	7.78	7.71	8.15	Moisture container, %		29.96	29.9
Moisture content, %	67.3	71.7	74.7	78.7	Average Moisture Content, %		29.9	



Liquid Limit	**73**
Plastic Limit	**29.9**
Plasticity Index	**43.1**

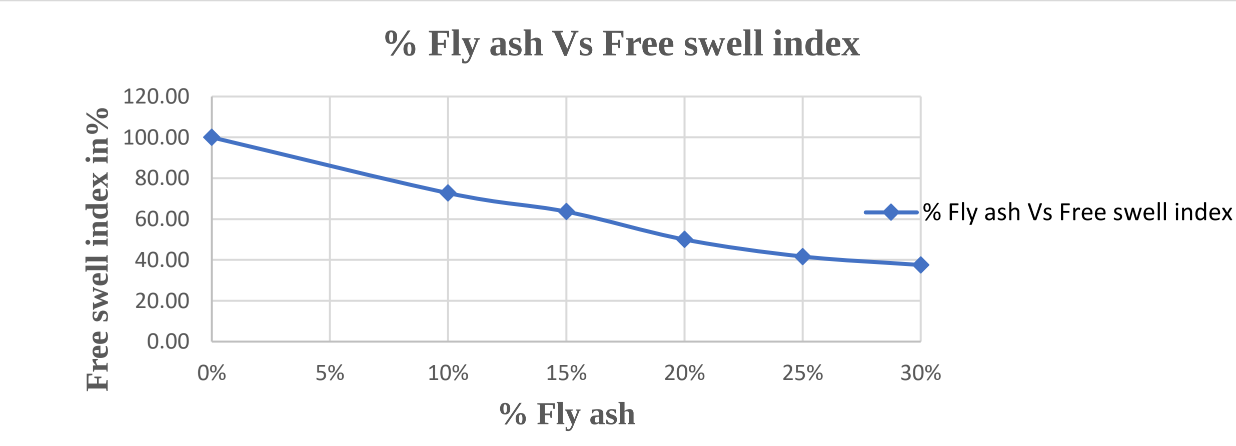
Natural soil mixid with 30% Fly Ash							
Determination	**Liquid Limit**				**Plastic Limit**		
Number of blows	33	27	23	18	Test	1	2
Test No	1	3	2	4	Container	A7	13
Container No	2	G3	G8	3L	Wt. of container + wet soil, g	30.15	33.62
Wt. of container + wet soil, g	32.97	35.19	33.01	38.8	Wt. of container + dry soil, g	27.84	31.53
Wt. of container + dry soil, g	26.62	29.72	27.39	32.5	Wt. of container, g	19.58	24.25
Wt. of container, g	16.93	21.93	19.64	24.3	Wt. of water, g	2.31	2.09
Wt. of water, g	6.35	5.47	5.62	6.27	Wt. of dry soil, g	8.26	7.28
Wt. of dry soil, g	9.69	7.79	7.75	8.19	Moisture container, %	27.97	28.7
Moisture content, %	65.5	70.2	72.5	76.6	Average Moisture Content, %	28.3	



Liquid Limit	**70.8**
Plastic Limit	**28.3**
Plasticity Index	**42.5**

2. Free swell index

Expansive soil mixed with different %age of fly ash					
Additive content in %	Measuring Cylinder No.(ml)		Reading after 24 hrs. (ml)		Free Swell Index, %
	Kerosene	Distilled water	Kerosene	Distilled water	
0%	10	10	10	20	100.00
10%	11	11	11	19	72.73
15%	11	11	11	18	63.64
20%	12	12	12	18	50.00
25%	12	12	12	17	41.67
30%	12	12	12	16.5	37.50



3. Linear Shrinkage

Natural soil mixid with 10% Fly Ash linear shrinkage test		
Determination No.	1	2
Semi cyliderical trough No.	C	D
Initial wet length of soil Lo (mm)	141	140
Dry length of soil Ld (mm)	125	124
Linear shrinkage LS in %	11.35	11.43
Average Linear shrinkage	**11.39**	

Natural soil mixid with 20% Fly Ash linear shrinkage test		
Determination No.	1	2
Semi cyliderical trough No.	I	J
Initial wet length of soil Lo (mm)	141	140
Dry length of soil Ld (mm)	127	126.5
Linear shrinkage LS in %	9.93	9.64
Average Linear shrinkage	**9.79**	

Natural soil mixid with 25% Fly Ash linear shrinkage test		
Determination No.	1	2
Semi cyliderical trough No.	E	F
Initial wet length of soil Lo (mm)	142	140
Dry length of soil Ld (mm)	130	129
Linear shrinkage LS in %	8.45	7.86
Average Linear shrinkage	**8.15**	

Natural soil mixid with 30% Fly Ash linear shrinkage test		
Determination No.	1	2
Semi cyliderical trough No.	E	F
Initial wet length of soil Lo (mm)	142	140
Dry length of soil Ld (mm)	131.5	129
Linear shrinkage LS in %	7.39	7.86
Average Linear shrinkage	**7.63**	

Natural soil mixid with 15% Fly Ash linear shrinkage test		
Determination No.	1	2
Semi cyliderical trough No.	E	F
Initial wet length of soil Lo (mm)	140	140
Dry length of soil Ld (mm)	125.3	125.1
Linear shrinkage LS in %	10.51	10.66
Average Linear shrinkage	10.59	

4. Specific Gravity

Natural soil mixed with 10% Fly ash

Determination code							D7	11
Mass of dry, clean calibrated pycnometer, Mp, in (gm)							31.29	27.14
A. Mass of oven dry sample (gm)							25	25
B. Mass of pycnometer +water (gm)							123.66	120.02
C. Mass of pycnometer +water+sample (gm)							138.97	135.39
Observation temperature of water, Ti in (°C)							24	24
Water temperature in (°C)								
(°C)	18	19	20	21	22	23	24	25	26
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.9991	0.9988	0.9986
Temperature of contents of pycnometer when Mpsw was taken, Tx, (°C)							24	24
K for Tx							0.9991	0.9991
Specific gravity at 20oc, Gs					Gs=A*k/(A+B-C)		2.58	2.59
Average Specific gravity at 20oc, Gs							**2.59**	

Natural soil mixed with 20% Fly ash									
Determination code								D7	11
Mass of dry, clean calibrated pycnometer, Mp, in (gm)								31.66	30.33
A. Mass of oven dry sample (gm)								25	25
B. Mass of pycnometer +water (gm)								123.57	120.11
C. Mass of pycnometer +water+sample (gm)								138.8	135.32
Observation temperature of water, Ti in (°C)								25	25
Water temperature in (°C)									
(°C)	18	19	20	21	22	23	24	25	25
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.9991	0.9988	0.9986
Temperature of contents of pycnometer when Mpsw was taken, Tx, (°C)								25	25
K for Tx								0.9988	0.9988
Specific gravity at 20oc, Gs					Gs=A*k/(A+B-C)			2.56	2.55
Average Specific gravity at 20oc, Gs								**2.55**	

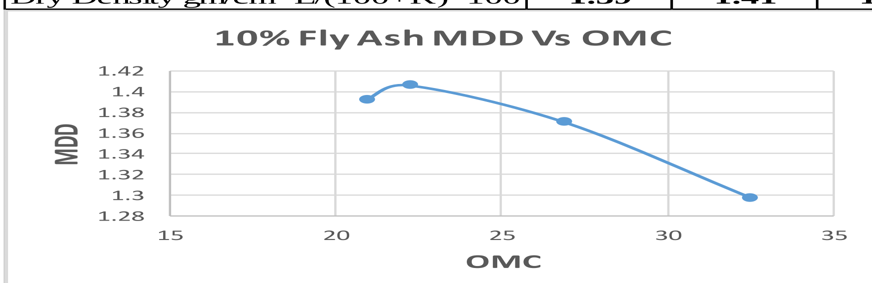
Natural soil mixed with 25% Fly ash									
Determination code								D7	11
Mass of dry, clean calibrated pycnometer, Mp, in (gm)								31.66	27.51
A. Mass of oven dry sample (gm)								25	25
B. Mass of pycnometer +water (gm)								124.45	120.82
C. Mass of pycnometer +water+sample (gm)								139.51	135.88
Observation temperature of water, Ti in (°C)								25	25
Water temperature in (°C)									
(°C)	18	19	20	21	22	23	24	25	26
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.9991	0.9988	0.9986
Temperature of contents of pycnometer when Mpsw was taken, Tx, (°C)								25	25
K for Tx								0.9988	0.9988
Specific gravity at 20oc, Gs					Gs=A*k/(A+B-C)			2.51	2.51
Average Specific gravity at 20oc, Gs								**2.51**	

Natural soil mixed with 30% Fly ash									
Determination code								D7	11
Mass of dry, clean calibrated pycnometer, Mp, in (gm)								31.46	27.31
A. Mass of oven dry sample (gm)								25	25
B. Mass of pycnometer +water (gm)								125.25	121.6
C. Mass of pycnometer +water+sample (gm)								140.18	136.53
Observation temperature of water, Ti in (°C)								25	25
Water temperature in (°C)									
(°C)	18	19	20	21	22	23	24	25	26
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.9991	0.9988	0.9986
Temperature of contents of pycnometer when Mpsw was taken, Tx, (°C)								25	25
K for Tx								0.9988	0.9988
Specific gravity at 20oc, Gs					Gs=A*k/(A+B-C)			2.48	2.48
Average Specific gravity at 20oc, Gs								**2.48**	

Fly ash only									
Determination code								D7	11
Mass of dry, clean calibrated pycnometer, Mp, in (gm)								31.22	27.10
A. Mass of oven dry sample (gm)								25	25
B. Mass of pycnometer +water (gm)								124.39	120.98
C. Mass of pycnometer +water+sample (gm)								137.51	134.59
Observation temperature of water, Ti in (°C)								26	26
Water temperature in (°C)									
(°C)	18	19	20	21	22	23	24	25	26
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.9991	0.9988	0.9986
Temperature of contents of pycnometer when Mpsw was taken, Tx, (°C)								26	26
K for Tx								0.9986	0.9986
Specific gravity at 20oc, Gs					Gs=A*k/(A+B-C)			2.10	2.19
Average Specific gravity at 20oc, Gs								**2.15**	

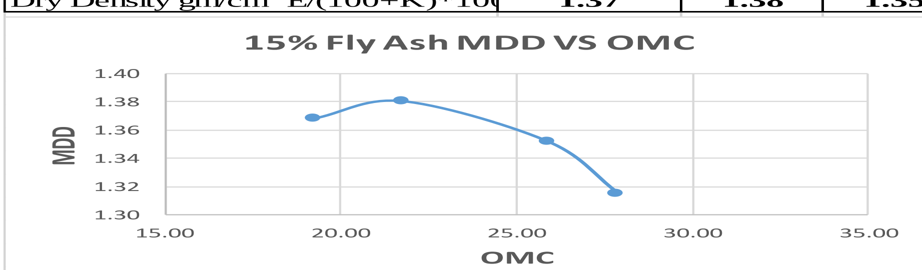
5. Compaction test

10% FLY ASH MIXED WITH NATURAL SOIL					
Density Determination					
Test No.	1	2	3	4	
Mass of sample (gm)	4000	4000	4000	4000	
Water Added(cc)	240	400	560	720	
Mass of Mold+Wet soil(gm)(A)	6297.63	6359.5	6410.5	6369	
Mass of Mold(gm)(B)	2720.9	2708.5	2715.5	2716	
Mass of Wet Soil(gm)A-B=C	3576.73	3651	3695	3653	
Volume of Mold cm^3(D)	2124	2124	2124	2124	
Bulk Density gm/cm^3 C/D=(E)	1.68	1.72	1.74	1.72	
Moisture Content Determination					
Container Code .	A	2	P3	G53	NMC
Mass of Wet soil+Container(gm)(F)	173.24	187.26	172.5	160.5	186.5
Mass of dry soil+container(gm)(G)	149.68	159.22	143.25	130.35	169.75
Mass of container(gm)(H)	37.1	33	34.5	37.5	37
Mass of moisture(gm)F-G=(I)	23.56	28.04	29.25	30.15	16.75
Mass of Dry soil(gm)G-H=(J)	112.58	126.22	108.75	92.85	132.75
Moisture content % (I/J)*100=K	**20.93**	**22.22**	**26.90**	**32.47**	**12.62**
Dry Density gm/cm^3 E/(100+K)*100	**1.39**	**1.41**	**1.37**	**1.30**	



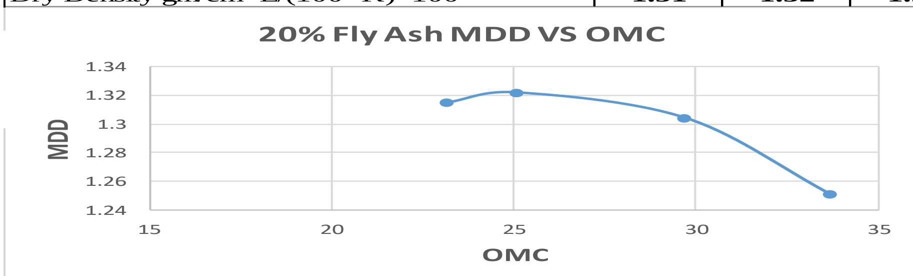
MDD	**1.41**
OMC	**22.22**

15% FLY ASH MIXED WITH NATURAL SOIL					
Density Determination					
Test No.	1	2	3	4	
Mass of sample (gm)	4000	4000	4000	4000	
Water Added(cc)	300	460	620	780	
Mass of Mold+Wet soil(gm)(A)	6187.23	6279.5	6330.5	6289.1	
Mass of Mold(gm)(B)	2720.9	2708.5	2715.5	2716	
Mass of Wet Soil(gm)A-B=C	3466.33	3571	3615	3573.1	
Volume of Mold cm^3(D)	2124	2124	2124	2124	
Bulk Density gm/cm^3 C/D=(E)	1.63	1.68	1.70	1.68	
Moisture Content Determination					
Container Code .	A	2	P3	G53	NMC
Mass of Wet soil+Container(gm)(F)	193.04	207.26	192.5	180.5	186.5
Mass of dry soil+container(gm)(G)	167.86	176.11	160.02	149.35	170.05
Mass of container(gm)(H)	37.1	33	34.5	37.5	37
Mass of moisture(gm)F-G=(I)	25.18	31.15	32.48	31.15	16.45
Mass of Dry soil(gm)G-H=(J)	130.76	143.11	125.52	111.85	133.05
Moisture content % (I/J)*100=K	**19.26**	**21.77**	**25.88**	**27.85**	**12.36**
Dry Density gm/cm^3 E/(100+K)*10	**1.37**	**1.38**	**1.35**	**1.32**	



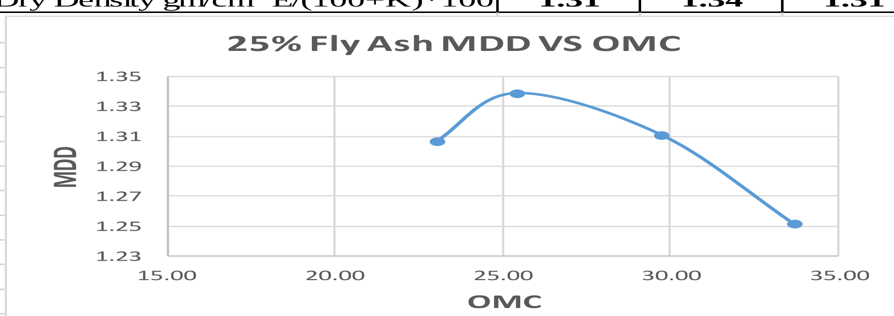
MDD	**1.38**
OMC	**21.77**

20% FLY ASH MIXED WITH NATURAL SOIL					
Density Determination					
Test No.	1	2	3	4	
Mass of sample (gm)	4000	4000	4000	4000	
Water Added(cc)	340	500	660	820	
Mass of Mold+Wet soil(gm)(A)	6158.51	6229.3	6310.4	6270	
Mass of Mold(gm)(B)	2717.8	2717.8	2717.8	2717.8	
Mass of Wet Soil(gm)A-B=C	3440.71	3511.5	3592.6	3552.2	
Volume of Mold cm^3(D)	2124	2124	2124	2124	
Bulk Density gm/cm^3 C/D=(E)	1.62	1.65	1.69	1.67	
Moisture Content Determination					
Container Code .	A2	2	T1	P15	NMC
Mass of Wet soil+Container(gm)(F)	145.3	199.53	171.71	173.4	231.6
Mass of dry soil+container(gm)(G)	123.5	166.14	140.35	139.29	208.48
Mass of container(gm)(H)	29.5	33	34.8	38	36
Mass of moisture(gm)F-G=(I)	21.8	33.39	31.36	34.11	23.12
Mass of Dry soil(gm)G-H=(J)	94	133.14	105.55	101.29	172.48
Moisture content % (I/J)*100=K	**23.19**	**25.08**	**29.71**	**33.68**	**13.40**
Dry Density gm/cm^3 E/(100+K)*100	**1.31**	**1.32**	**1.30**	**1.25**	



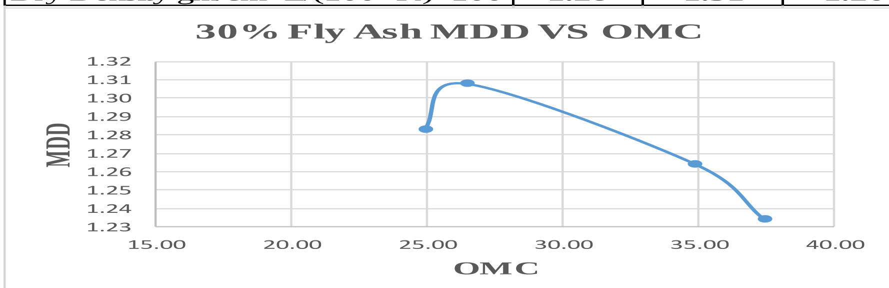
MDD	**1.32**
OMC	**25.08**

25% FLY ASH MIXED WITH NATURAL SOIL					
Density Determination					
Test No.	1	2	3	4	
Mass of sample (gm)	4000	4000	4000	4000	
Water Added(cc)	290	450	610	770	
Mass of Mold+Wet soil(gm)(A)	6128.6	6281.9	6327.5	6271.5	
Mass of Mold(gm)(B)	2716.1	2716.1	2716.1	2719.6	
Mass of Wet Soil(gm)A-B=C	3412.5	3565.8	3611.4	3551.9	
Volume of Mold cm^3(D)	2124	2124	2124	2124	
Bulk Density gm/cm^3 C/D=(E)	1.61	1.68	1.70	1.67	
Moisture Content Determination					
Container Code .	P15	P65	E-12	K23	NMC
Mass of Wet soil+Container(gm)(F)	145.13	199.97	171.71	173.4	232.98
Mass of dry soil+container(gm)(G)	123.5	166.14	140.35	139.29	210.67
Mass of container(gm)(H)	29.5	33	34.8	38	34.8
Mass of moisture(gm)F-G=(I)	21.63	33.83	31.36	34.11	22.31
Mass of Dry soil(gm)G-H=(J)	94	133.14	105.55	101.29	175.87
Moisture content % (I/J)*100=K	**23.01**	**25.41**	**29.71**	**33.68**	**12.69**
Dry Density gm/cm^3 E/(100+K)*100	**1.31**	**1.34**	**1.31**	**1.25**	



MDD	**1.34**
OMC	**25.41**

30% FLY ASH MIXED WITH NATURAL SOIL					
Density Determination					
Test No.	1	2	3	4	
Mass of sample (gm)	4000	4000	4000	4000	
Water Added(cc)	320	480	640	800	
Mass of Mold+Wet soil(gm)(A)	6119.5	6228.7	6337.2	6318.3	
Mass of Mold(gm)(B)	2716.1	2716.1	2716.1	2716.1	
Mass of Wet Soil(gm)A-B=C	3403.4	3512.6	3621.1	3602.2	
Volume of Mold cm^3(D)	2124	2124	2124	2124	
Bulk Density gm/cm^3 C/D=(E)	1.60	1.65	1.70	1.70	
Moisture Content Determination					
Container Code .	P15	P65	E-12	K23	NMC
Mass of Wet soil+Container(gm)(F)	182.3	178.23	190.8	187.3	232.98
Mass of dry soil+container(gm)(G)	153.4	148.9	151.07	146.49	210.67
Mass of container(gm)(H)	37.26	37.95	37.05	37.27	34.8
Mass of moisture(gm)F-G=(I)	28.9	29.33	39.73	40.81	22.31
Mass of Dry soil(gm)G-H=(J)	116.14	110.95	114.02	109.22	175.87
Moisture content % (I/J)*100=K	**24.88**	**26.44**	**34.84**	**37.36**	**12.69**
Dry Density gm/cm^3 E/(100+K)*100	**1.28**	**1.31**	**1.26**	**1.23**	

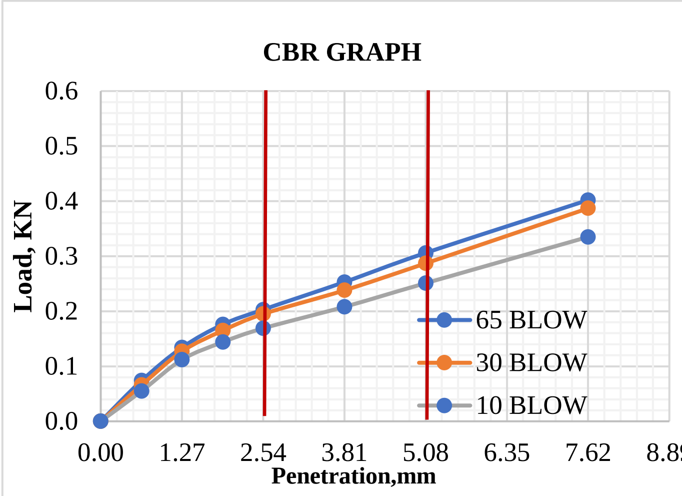


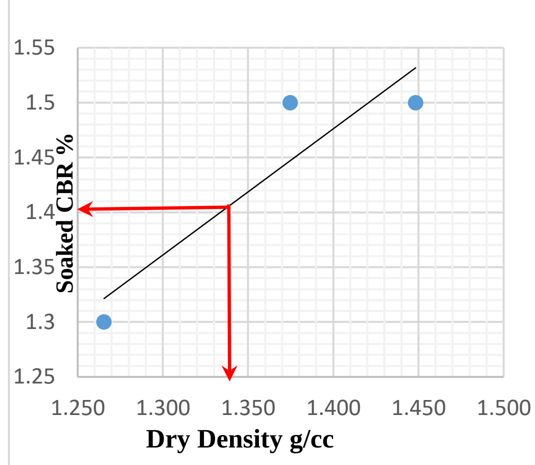
MDD	**1.31**
OMC	**26.44**

6. California Bearing Ratio (CBR)

Natural soil sample + 10% Fly ash

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.074		0.64	0.066		0.64	0.055	
1.27	0.134		1.27	0.127		1.27	0.112	
1.91	0.176		1.91	0.165		1.91	0.144	
2.54	0.203	**1.54**	2.54	0.195	**1.48**	2.54	0.169	**1.28**
3.81	0.253		3.81	0.238		3.81	0.208	
5.08	0.306	**1.53**	5.08	0.287	**1.44**	5.08	0.251	**1.26**
7.62	0.402		7.62	0.387		7.62	0.335	
Modified Max. Dry Density g/cc			**1.41**		OMC %		**22.22**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
	Read in %			Read in %			Read in %	
Initial	0.00	9.11	Initial	0.00	9.97	Initial	0.00	10.70
Final	10.60		Final	11.61		Final	12.45	

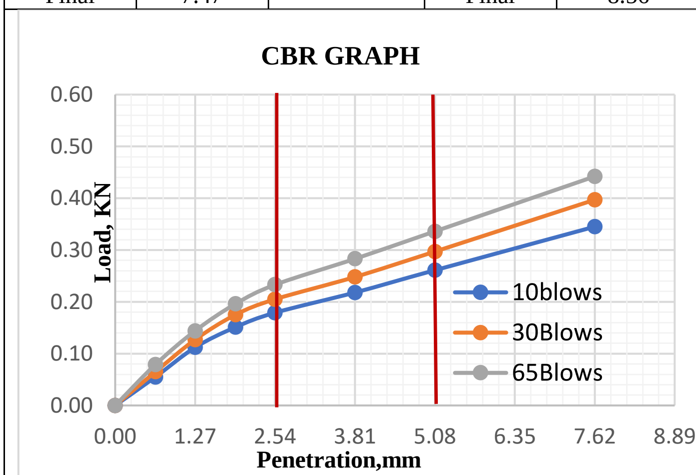


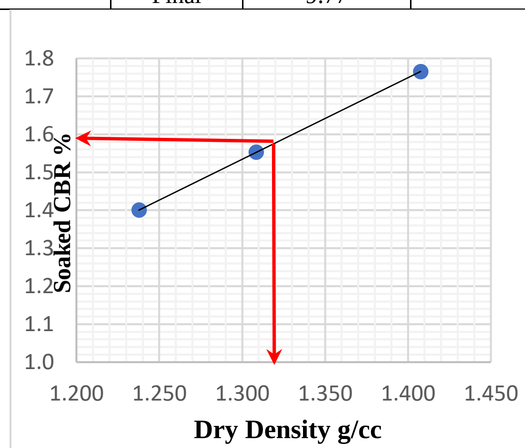


			Dry Density at 95% of MDD:	**1.340**
No. of blows	**MCBS %**	**DDBS g/cm3**	Corrected CBR %	% Compaction
10	23.4	1.265	1.3	90
30	22.1	1.375	1.5	97
65	21.7	1.448	1.5	103
CBR (%) @ 95 % MDD			**1.4** **% Swell**	**9.9**

Natural soil sample + 15% Fly ash

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.079		0.64	0.065		0.64	0.055	
1.27	0.144		1.27	0.127		1.27	0.112	
1.91	0.196		1.91	0.175		1.91	0.151	
2.54	0.233	**1.8**	2.54	0.205	**1.6**	2.54	0.179	**1.36**
3.81	0.283		3.81	0.248		3.81	0.218	
5.08	0.336	**1.7**	5.08	0.297	**1.5**	5.08	0.261	**1.31**
7.62	0.442		7.62	0.397		7.62	0.345	
Modified Max. Dry Density g/cc			**1.38**		OMC %		**21.77**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
	Read in %			Read in %			Read in %	
Initial	0.50	5.99	Initial	0.5	6.92	Initial	0.50	7.96
Final	7.47		Final	8.56		Final	9.77	



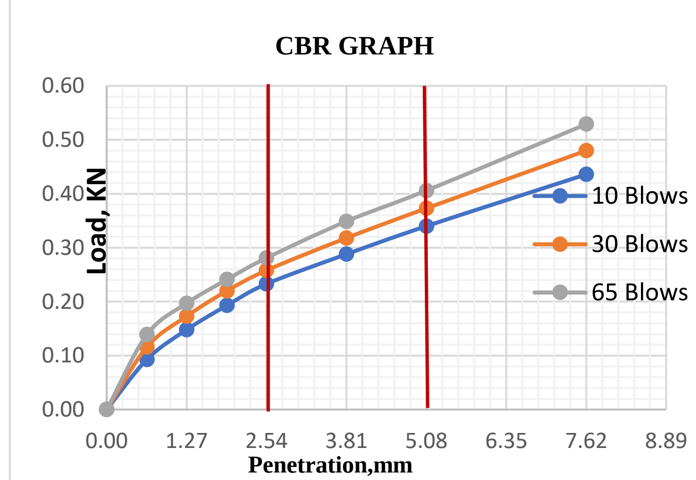


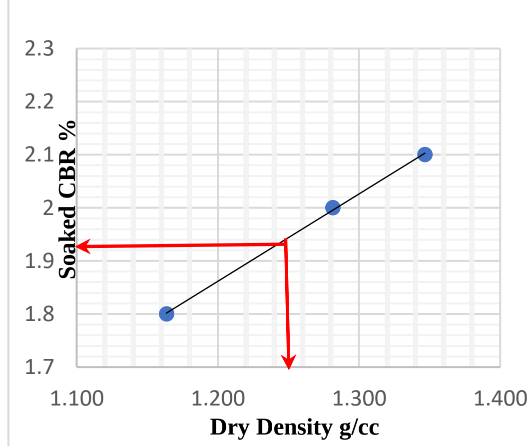
Dry Density at 95% of MDD:	**1.311**

No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %		% Compaction
10	27.8	1.238	1.4		90
30	26.4	1.308	1.6		95
65	25.0	1.408	1.8		102
CBR (%) @ 95 % MDD			**1.6**	**% Swell**	**6.96**

Natural soil sample + 20% Fly ash

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.139		0.64	0.116		0.64	0.093	
1.27	0.197		1.27	0.173		1.27	0.148	
1.91	0.241		1.91	0.220		1.91	0.193	
2.54	0.281	**2.13**	2.54	0.258	**1.95**	2.54	0.233	**1.77**
3.81	0.349		3.81	0.318		3.81	0.288	
5.08	0.406	**2.03**	5.08	0.373	**1.87**	5.08	0.340	**1.70**
7.62	0.529		7.62	0.480		7.62	0.436	
Modified Max. Dry Density g/cc			**1.32**		OMC %		**25.08**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
	Read in %			Read in %			Read in %	
Initial	0.00	7.90	Initial	0	8.68	Initial	0.10	9.54
Final	9.20		Final	10.10		Final	11.20	



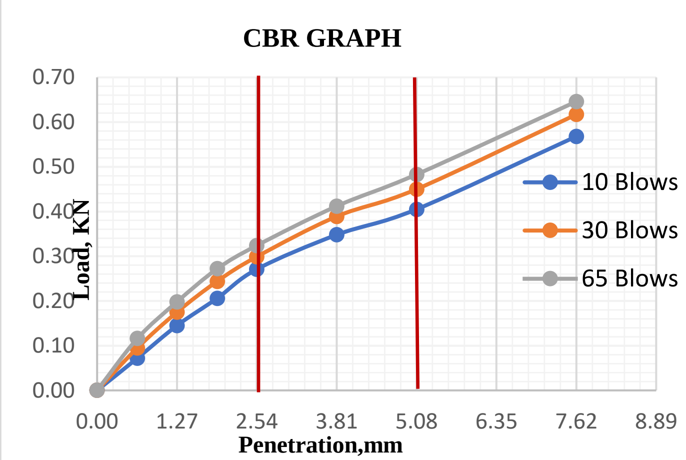


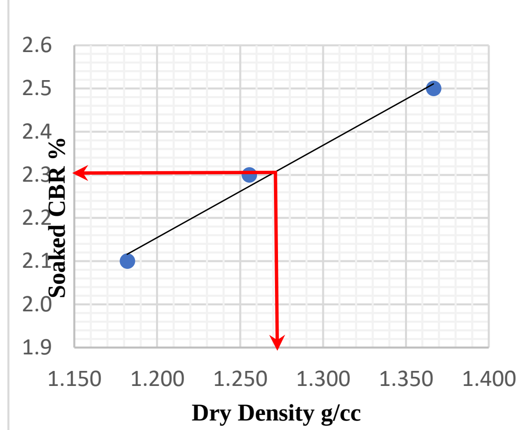
			Dry Density at 95% of MDD:		**1.254**
No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %		% Compaction
10	25.6	1.164	1.8		88
30	24.3	1.281	2.0		97
65	23.9	1.347	2.1		102
CBR (%) @ 95 % MDD			**1.9**	**% Swell**	**8.71**

Natural soil sample + 25% Fly ash

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.116		0.64	0.095		0.64	0.072	

1.27	0.198		1.27	0.175		1.27	0.145	
1.91	0.272		1.91	0.244		1.91	0.206	
2.54	0.324	**2.5**	2.54	0.299	**2.27**	2.54	0.271	**2.1**
3.81	0.412		3.81	0.389		3.81	0.348	
5.08	0.483	**2.4**	5.08	0.450	**2.25**	5.08	0.405	**2.0**
7.62	0.646		7.62	0.617		7.62	0.568	
Modified Max. Dry Density g/cc			**1.34**		OMC %		**25.41**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
	Read in %			Read in %			Read in %	
Initial	0.50	5.99	Initial	0.5	6.92	Initial	0.50	7.96
Final	7.47		Final	8.56		Final	9.77	



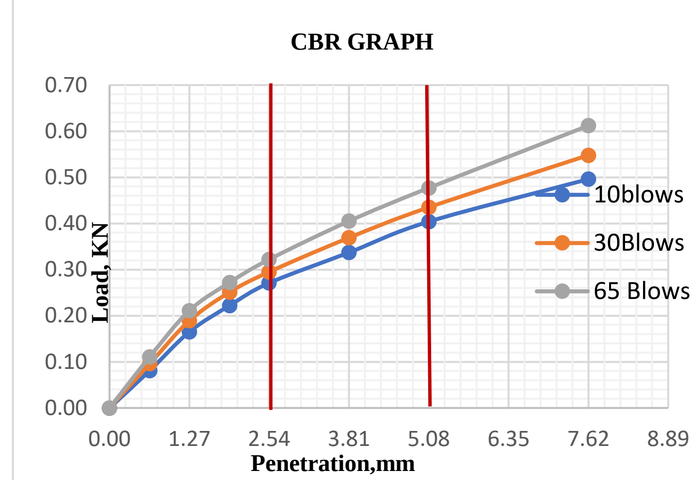


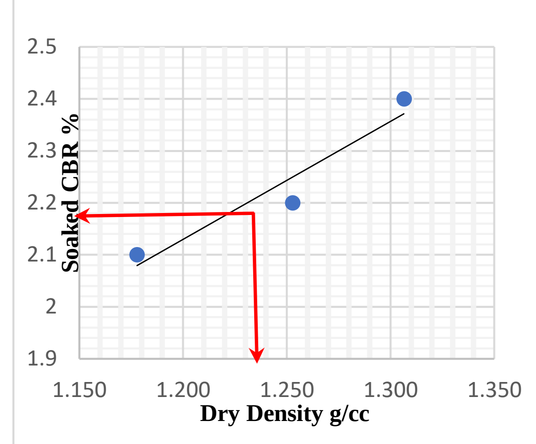
Dry Density at 95% of MDD: **1.273**

No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %		% Compaction
10	27.8	1.182	2.1		88
30	25.4	1.255	2.3		94
65	24.7	1.367	2.5		102
CBR (%) @ 95 % MDD			**2.3**	**% Swell**	**6.96**

Natural soil sample + 30% Fly ash

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.111		0.64	0.096		0.64	0.081	
1.27	0.211		1.27	0.189		1.27	0.165	
1.91	0.272		1.91	0.251		1.91	0.222	
2.54	0.322	**2.44**	2.54	0.295	**2.23**	2.54	0.271	**2.05**
3.81	0.405		3.81	0.369		3.81	0.337	
5.08	0.477	**2.39**	5.08	0.435	**2.18**	5.08	0.404	**2.02**
7.62	0.612		7.62	0.548		7.62	0.496	
Modified Max. Dry Density g/cc			**1.30**		OMC %		**26.44**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
	Read in %			Read in %			Read in %	
Initial	0.20	5.96	Initial	0.1	6.97	Initial	0.20	7.92
Final	7.14		Final	8.21		Final	9.42	



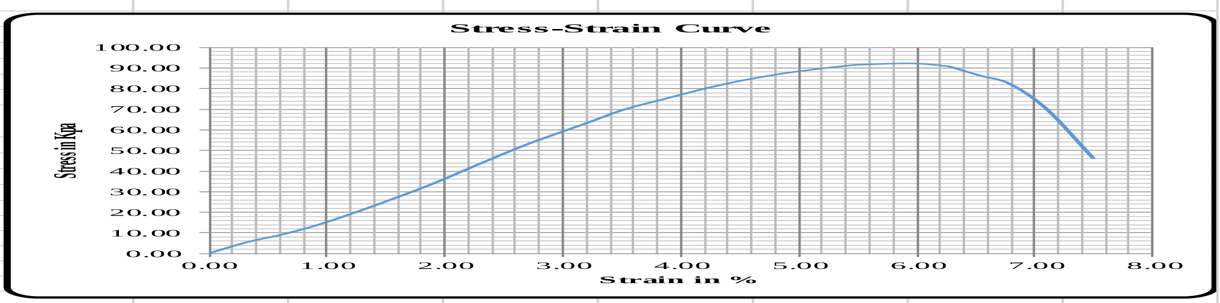


			Dry Density at 95% of MDD:		**1.235**
No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %		% Compaction
10	26.9	1.178	2.1		91
30	26.1	1.253	2.2		96
65	25.7	1.306	2.4		100
CBR (%) @ 95 % MDD			**2.2**	**% Swell**	**6.95**

7. Unconfined Compressive Strength of Soil Mixture (UCS)

10% Fly ash treated expansive soil

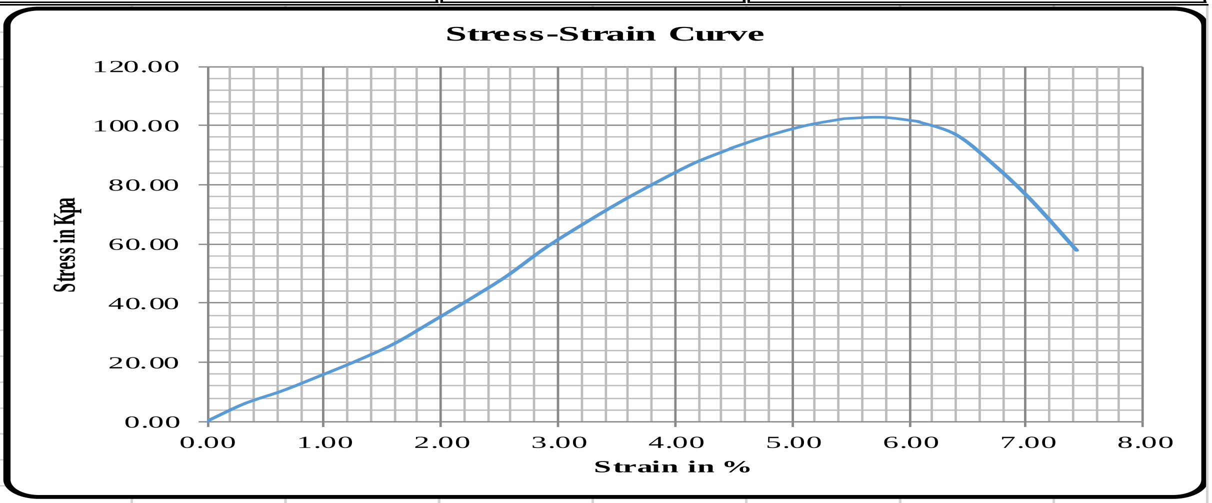
Test Type:	Unconfined Compression Test (ASTM D-2166)	
Type of Sample:	Remoled Soil Sample	
Sample:	Sample -Light gray clay Soil	
Pit Code:	Natural + 10% FA	
Sample Height (mm)	Peak UCS, (kPa)	Cohesion, (kPa)
78	92	46



Sample Deformation ΔL (mm)	Load In (N) Trial-1	Sample Height (mm)	Sample Actule Area (cm²)	Strain	Strain in % 2	Corrected Area (cm²)	Stress (kPa)
0.00	0	78.00	11.34	0.00	0.00	11.34	0.00
0.25	6	78.00	11.34	0.00	0.32	11.38	5.36
0.50	11	78.00	11.34	0.01	0.64	11.41	9.46
0.75	17	78.00	11.34	0.01	0.96	11.45	14.50
1.05	25	78.00	11.34	0.01	1.35	11.50	22.01
1.30	33	78.00	11.34	0.02	1.66	11.53	28.61
1.50	40	78.00	11.34	0.02	1.92	11.56	34.33
1.75	49	78.00	11.34	0.02	2.24	11.60	42.15
2.05	60	78.00	11.34	0.03	2.63	11.65	51.26
2.25	66	78.00	11.34	0.03	2.89	11.68	56.77
2.50	74	78.00	11.34	0.03	3.21	11.72	63.24
2.75	82	78.00	11.34	0.04	3.53	11.76	69.84
3.05	89	78.00	11.34	0.04	3.91	11.80	75.58
3.30	95	78.00	11.34	0.04	4.23	11.84	80.30
3.50	99	78.00	11.34	0.04	4.49	11.87	83.46
3.55	100	78.00	11.34	0.05	4.55	11.88	84.16
3.80	104	78.00	11.34	0.05	4.87	11.92	87.32
4.05	107	78.00	11.34	0.05	5.20	11.96	89.69
4.25	110	78.00	11.34	0.05	5.45	12.00	91.29
4.30	110	78.00	11.34	0.06	5.52	12.00	91.56
4.65	111	78.00	11.34	0.06	5.97	12.06	92.20
4.89	110	78.00	11.34	0.06	6.27	12.10	90.83
4.91	110	78.00	11.34	0.06	6.29	12.10	90.56
4.91	110	78.00	11.34	0.06	6.29	12.10	90.56
5.10	105	78.00	11.34	0.07	6.54	12.13	86.36
5.30	100	78.00	11.34	0.07	6.79	12.17	82.35
5.55	85	78.00	11.34	0.07	7.11	12.21	69.95
5.85	57	78.00	11.34	0.08	7.50	12.26	46.24

20% Fly ash treated expansive soil

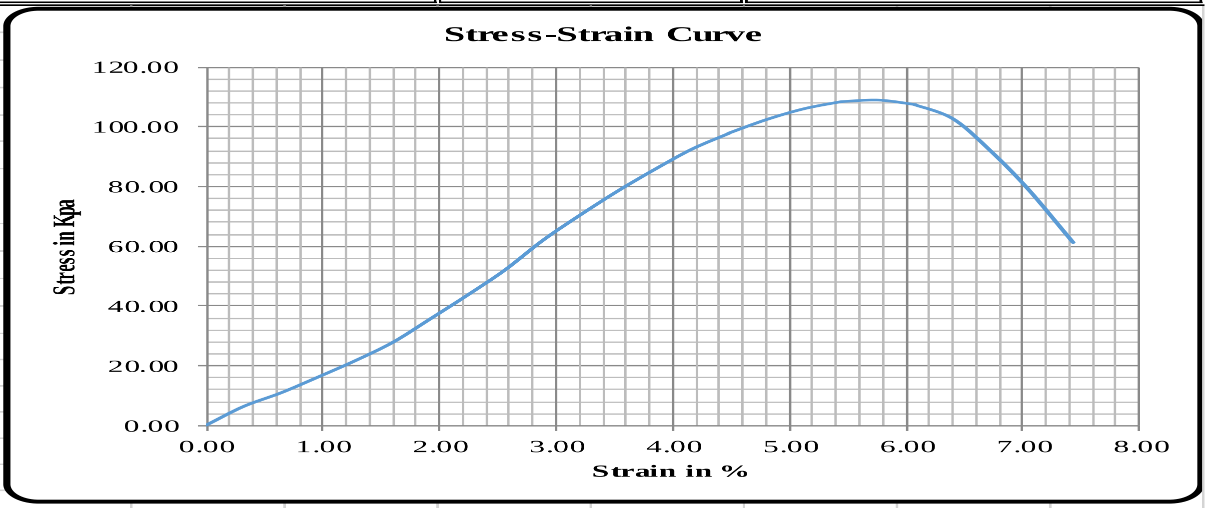
Test Type:	Unconfined Compression Test (ASTM D-2166)	
Type of Sample:	Remoled Soil Sample	
Sample:	Sample -Light gray Clay Soil	
Pit Code:	Natural + 20% FA	
Sample Height (mm)	**Peak UCS, (kPa)**	**Cohesion, (kPa)**
78	**103**	**51**



Sample Deformation ΔL (mm)	Load In (N) Trial-1	Sample Heght (mm)	Sample Actule Area (cm^2)	Strain	Strain in % 2	Corrected Area (cm^2)	Stress (kPa)
0.00	0	78.00	11.34	0.00	0.00	11.34	0.00
0.25	7	78.00	11.34	0.00	0.32	11.38	5.90
0.50	12	78.00	11.34	0.01	0.64	11.41	10.22
0.75	17	78.00	11.34	0.01	0.96	11.45	15.18
1.00	23	78.00	11.34	0.01	1.28	11.49	20.39
1.25	30	78.00	11.34	0.02	1.60	11.53	26.24
1.50	39	78.00	11.34	0.02	1.92	11.56	33.58
1.75	48	78.00	11.34	0.02	2.25	11.60	41.24
2.00	57	78.00	11.34	0.03	2.56	11.64	49.05
2.25	68	78.00	11.34	0.03	2.89	11.68	58.40
2.50	78	78.00	11.34	0.03	3.20	11.72	66.28
2.75	87	78.00	11.34	0.04	3.53	11.76	73.92
3.00	95	78.00	11.34	0.04	3.85	11.80	80.86
3.25	103	78.00	11.34	0.04	4.17	11.83	87.28
3.50	109	78.00	11.34	0.04	4.48	11.87	92.18
3.50	110	78.00	11.34	0.04	4.48	11.87	92.27
3.75	115	78.00	11.34	0.05	4.81	11.91	96.58
4.00	120	78.00	11.34	0.05	5.13	11.95	100.02
4.25	123	78.00	11.34	0.05	5.45	11.99	102.25
4.25	123	78.00	11.34	0.05	5.45	11.99	102.25
4.50	124	78.00	11.34	0.06	5.77	12.04	102.73
4.75	122	78.00	11.34	0.06	6.08	12.08	101.29
4.75	122	78.00	11.34	0.06	6.08	12.08	101.20
4.75	122	78.00	11.34	0.06	6.08	12.08	101.20
5.00	117	78.00	11.34	0.06	6.41	12.12	96.77
5.25	105	78.00	11.34	0.07	6.73	12.16	86.57
5.50	91	78.00	11.34	0.07	7.05	12.20	74.65
5.80	71	78.00	11.34	0.07	7.44	12.25	57.73

25% Fly ash treated expansive soil

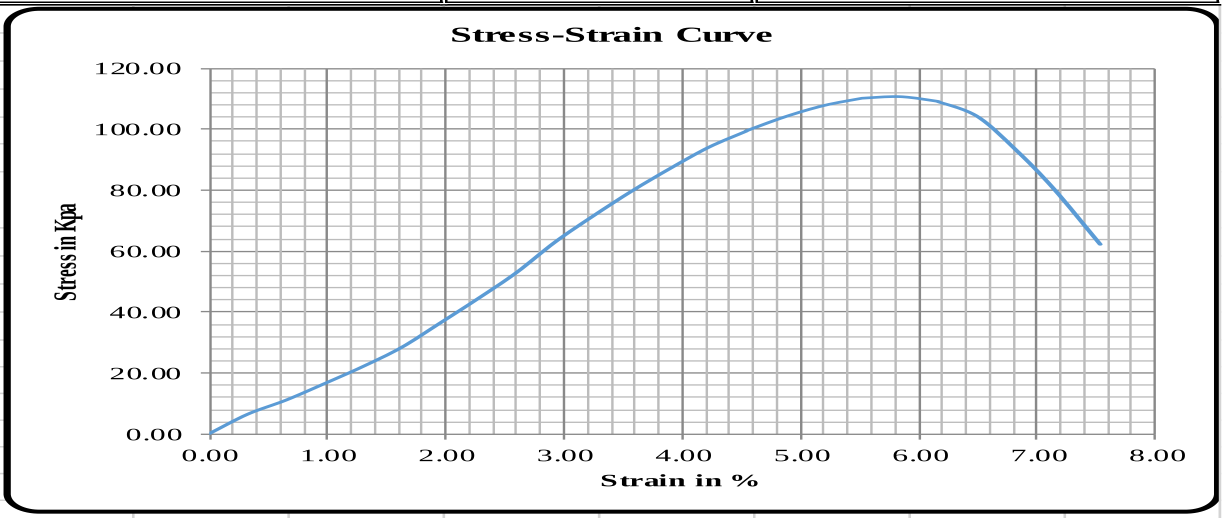
Test Type:	Unconfined Compression Test (ASTM D-2166)	
Type of Sample:	Remoled Soil Sample	
Sample:	Sample -Light gray Clay Soil	
Pit Code:	Natural + 25% FA	
Sample Height (mm)	**Peak UCS, (kPa)**	**Cohesion, (kPa)**
78	**109**	**55**



Sample Deformation ΔL (mm)	Load In (N) Trial-1	Sample Hegth (mm)	Sample Actule Area (cm^2)	Strain	Strain in % 2	Corrected Area (cm^2)	Stress (kPa)
0.00	0	78.00	11.34	0.00	0.00	11.34	0.00
0.25	7	78.00	11.34	0.00	0.32	11.38	6.25
0.50	12	78.00	11.34	0.01	0.64	11.41	10.83
0.75	18	78.00	11.34	0.01	0.96	11.45	16.09
1.00	25	78.00	11.34	0.01	1.28	11.49	21.62
1.25	32	78.00	11.34	0.02	1.60	11.53	27.82
1.50	41	78.00	11.34	0.02	1.92	11.56	35.59
1.75	51	78.00	11.34	0.02	2.25	11.60	43.72
2.00	61	78.00	11.34	0.03	2.56	11.64	51.99
2.25	72	78.00	11.34	0.03	2.89	11.68	61.90
2.50	82	78.00	11.34	0.03	3.20	11.72	70.26
2.75	92	78.00	11.34	0.04	3.53	11.76	78.36
3.00	101	78.00	11.34	0.04	3.85	11.80	85.71
3.25	109	78.00	11.34	0.04	4.17	11.83	92.51
3.50	116	78.00	11.34	0.04	4.48	11.87	97.71
3.50	116	78.00	11.34	0.04	4.48	11.87	97.81
3.75	122	78.00	11.34	0.05	4.81	11.91	102.37
4.00	127	78.00	11.34	0.05	5.13	11.95	106.02
4.25	130	78.00	11.34	0.05	5.45	11.99	108.39
4.25	130	78.00	11.34	0.05	5.45	11.99	108.39
4.50	131	78.00	11.34	0.06	5.77	12.04	108.89
4.75	130	78.00	11.34	0.06	6.08	12.08	107.37
4.75	130	78.00	11.34	0.06	6.08	12.08	107.27
4.75	130	78.00	11.34	0.06	6.08	12.08	107.27
5.00	124	78.00	11.34	0.06	6.41	12.12	102.57
5.25	112	78.00	11.34	0.07	6.73	12.16	91.77
5.50	97	78.00	11.34	0.07	7.05	12.20	79.13
5.80	75	78.00	11.34	0.07	7.44	12.25	61.19

30% Fly ash treated expansive soil

Test Type:	Unconfined Compression Test (ASTM D-2166)		
Type of Sample:	Remoled Soil Sample		
Sample:	Sample -Light gray Clay Soil		
Pit Code:	Natural + 30% FA		
Sample Height (mm)	**Peak UCS, (kPa)**	**Cohesion, (kPa)**	
77	111	56	



Sample Deformation ΔL (mm)	Load In (N) Trial-1	Sample Heght (mm)	Sample Actule Area (cm^2)	Strain	Strain in % 2	Corrected Area (cm^2)	Stress (kPa)
0.00	0	77.00	11.34	0.00	0.00	11.34	0.00
0.25	7	77.00	11.34	0.00	0.32	11.38	6.37
0.50	13	77.00	11.34	0.01	0.65	11.42	11.03
0.75	19	77.00	11.34	0.01	0.97	11.45	16.39
1.00	25	77.00	11.34	0.01	1.30	11.49	22.02
1.25	33	77.00	11.34	0.02	1.62	11.53	28.34
1.50	42	77.00	11.34	0.02	1.95	11.57	36.26
1.75	52	77.00	11.34	0.02	2.28	11.61	44.53
2.00	62	77.00	11.34	0.03	2.60	11.64	52.95
2.25	74	77.00	11.34	0.03	2.92	11.68	63.05
2.50	84	77.00	11.34	0.03	3.24	11.72	71.56
2.75	94	77.00	11.34	0.04	3.57	11.76	79.80
3.00	103	77.00	11.34	0.04	3.90	11.80	87.28
3.25	112	77.00	11.34	0.04	4.22	11.84	94.21
3.50	118	77.00	11.34	0.05	4.54	11.88	99.50
3.50	118	77.00	11.34	0.05	4.54	11.88	99.60
3.75	124	77.00	11.34	0.05	4.87	11.92	104.24
4.00	129	77.00	11.34	0.05	5.20	11.96	107.95
4.25	132	77.00	11.34	0.06	5.52	12.00	110.35
4.25	132	77.00	11.34	0.06	5.52	12.00	110.35
4.50	134	77.00	11.34	0.06	5.84	12.05	110.86
4.75	132	77.00	11.34	0.06	6.16	12.09	109.30
4.75	132	77.00	11.34	0.06	6.16	12.09	109.21
4.75	132	77.00	11.34	0.06	6.16	12.09	109.21
5.00	127	77.00	11.34	0.06	6.49	12.13	104.42
5.25	114	77.00	11.34	0.07	6.82	12.17	93.41
5.50	98	77.00	11.34	0.07	7.14	12.21	80.54
5.80	76	77.00	11.34	0.08	7.53	12.27	62.28

Appendix: C

Laboratory Data Analysis for Expansive Soil Treated with 25% Fly Ash Mixed with Varied %age of Cement Kiln Dust

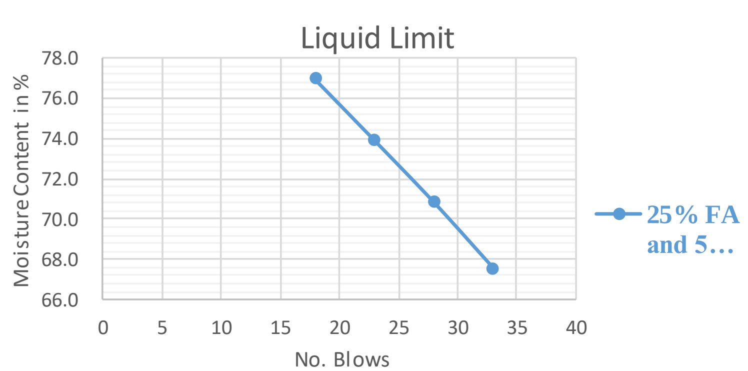
1. Atterberg limit

Fly ash mixed with CKD on expansive soil

25%FA+ CKD	LL	PL	PI	LS
Natural soil only	80.6	34.2	46.4	15.54
0	73	29.9	43.07	8.15
5	72.4	30.7	41.75	7.27
10	68	32.6	35.42	6.92
15	64	34.1	29.9	6.7
20	62.8	35.7	27.11	6.58
25	61.4	38.3	23.14	6.03

25% Fly Ash mixed with 5% CKD on Expansive soil

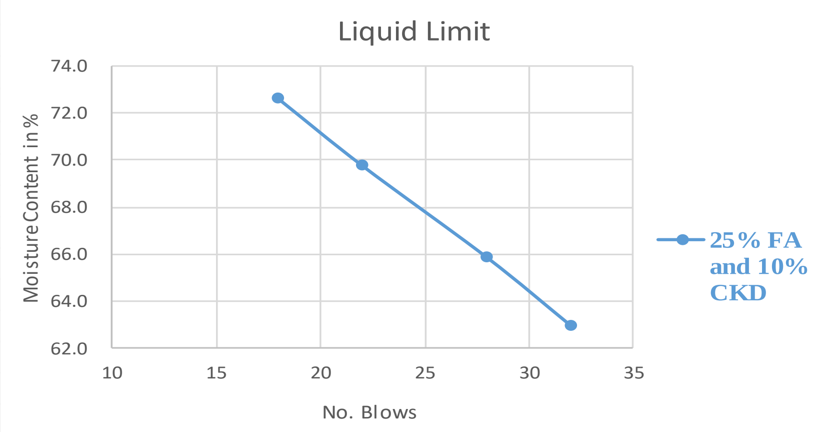
Determination	Liquid Limit				lastic Limit		
Number of blows	33	28	23	18	Test	1	2
Test No	2	3	1	4	Container	A7	13
Container No	G8	G3	2	3L	Wt. of container + wet soil, g	26.63	26.73
Wt. of container + wet soil, g	31.95	35.39	35.53	28.7	Wt. of container + dry soil, g	24.99	25.09
Wt. of container + dry soil, g	26.01	28.87	27.21	23	Wt. of container, g	19.62	19.76
Wt. of container, g	17.21	19.66	15.95	15.5	Wt. of water, g	1.64	1.64
Wt. of water, g	5.94	6.52	8.32	5.74	Wt. of dry soil, g	5.37	5.33
Wt. of dry soil, g	8.80	9.21	11.26	7.46	Moisture container, %	30.54	30.8
Moisture content, %	67.5	70.8	73.9	76.9	Average Moisture Content, %	30.7	



Liquid Limit	**72.4**
Plastic Limit	**30.7**
Plasticity Index	**41.7**

25% Fly Ash mixed with 10% CKD on Expansive soil

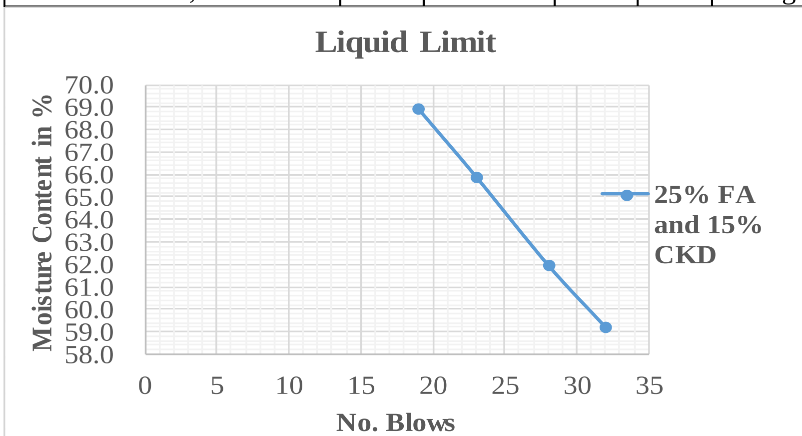
Determination	Liquid Limit				Plastic Limit		
Number of blows	32	28	22	18	Test	1	2
Test No	2	3	1	4	Container	A7	13
Container No	G8	G3	2	3L	Wt. of container + wet soil, g	25.73	25.73
Wt. of container + wet soil, g	34.81	36.56	36.93	30.8	Wt. of container + dry soil, g	24.02	23.99
Wt. of container + dry soil, g	28.01	29.85	29.13	25.21	Wt. of container, g	18.72	18.70
Wt. of container, g	17.21	19.66	17.95	17.51	Wt. of water, g	1.71	1.74
Wt. of water, g	6.80	6.71	7.80	5.59	Wt. of dry soil, g	5.30	5.29
Wt. of dry soil, g	10.80	10.19	11.18	7.70	Moisture container, %	32.26	32.9
Moisture content, %	63.0	65.8	69.8	72.6	Average Moisture Content, %	32.6	



Liquid Limit	**68**
Plastic Limit	**32.6**
Plasticity Index	**35.4**

25% Fly Ash mixed with 15% CKD on Expansive soil

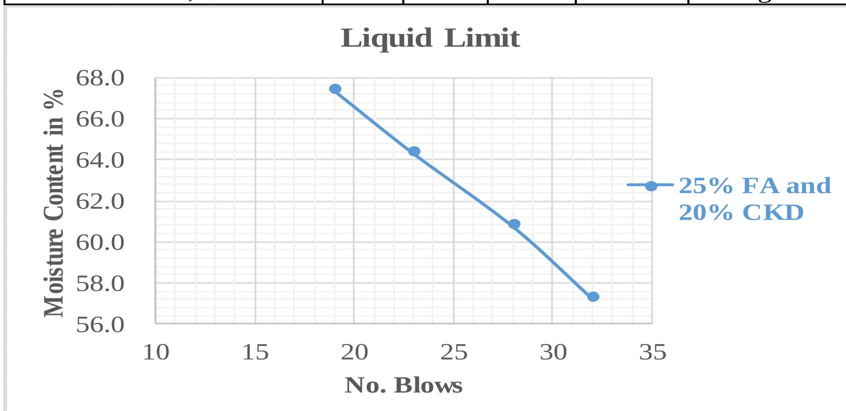
Determination	Liquid Limit				lastic Limit		
Number of blows	19	23	28	32	Test	1	2
Test No	3	1	2	4	Container	A7	13
Container No	2	G8	G3	3L	Wt. of container + wet soil, g	25.34	29.36
Wt. of container + wet soil, g	33.94	34.21	34.11	30.70	Wt. of container + dry soil, g	23.88	27.21
Wt. of container + dry soil, g	26.51	27.50	28.81	24.9	Wt. of container, g	19.60	20.92
Wt. of container, g	15.73	17.32	20.26	15.2	Wt. of water, g	1.46	2.15
Wt. of water, g	7.43	6.71	5.30	5.78	Wt. of dry soil, g	4.28	6.29
Wt. of dry soil, g	10.78	10.18	8.55	9.76	Moisture container, %	34.11	34.2
Moisture content, %	68.9	65.9	62.0	59.2	Average Moisture Content, %	34.1	



Liquid Limit	**64**
Plastic Limit	**34.1**
Plasticity Index	**29.9**

25% Fly Ash mixed with 20% CKD on Expansive soil

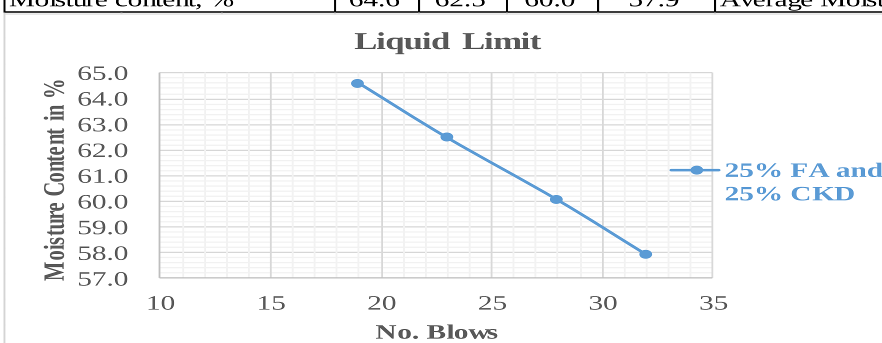
Determination	Liquid Limit				Plastic Limit		
Number of blows	32	28	23	19	Test	1	2
Test No	3	1	2	4	Container	A7	13
Container No	2	G8	G3	3L	Wt. of container + wet soil, g	27.54	29.29
Wt. of container + wet soil, g	34.09	40.03	31.96	30.37	Wt. of container + dry soil, g	25.45	27.09
Wt. of container + dry soil, g	27.84	34.09	26.87	24.99	Wt. of container, g	19.60	20.92
Wt. of container, g	16.93	24.32	18.96	17.01	Wt. of water, g	2.09	2.20
Wt. of water, g	6.25	5.94	5.09	5.38	Wt. of dry soil, g	5.85	6.17
Wt. of dry soil, g	10.91	9.77	7.91	7.98	Moisture container, %	35.73	35.7
Moisture content, %	57.3	60.8	64.3	67.4	Average Moisture Content, %	35.7	



Liquid Limit	**62.8**
Plastic Limit	**35.7**
Plasticity Index	**27.1**

25% Fly Ash mixed with 25% CKD on Expansive soil

Determination	Liquid Limit				Plastic Limit		
Number of blows	19	23	28	32	Test	1	2
Test No	3	1	2	4	Container	A7	13
Container No	2	G8	G3	3L	Wt. of container + wet soil, g	28.31	29.99
Wt. of container + wet soil, g	33.76	39.95	32.06	30.25	Wt. of container + dry soil, g	25.99	27.49
Wt. of container + dry soil, g	27.43	33.94	27.07	25.21	Wt. of container, g	19.96	20.92
Wt. of container, g	17.63	24.32	18.76	16.51	Wt. of water, g	2.32	2.50
Wt. of water, g	6.33	6.01	4.99	5.04	Wt. of dry soil, g	6.03	6.57
Wt. of dry soil, g	9.80	9.62	8.31	8.70	Moisture container, %	38.47	38.1
Moisture content, %	64.6	62.5	60.0	57.9	Average Moisture Content, %	38.3	



Liquid Limit	**61.4**
Plastic Limit	**38.3**
Plasticity Index	**23.1**

2. Free swell index

Free swell index of expansive soil treated with 25% fly ash mixed with varying CKD

Additive content in %	Measuring Cylinder No.(ml)		Reading after 24 hrs.(ml)		Free Swell Index, %
	Kerosene	Distilled water	Kerosene	Distilled water	
Natural soil (0%)	12	12	12	17	41.67
5%	12	12	12	16.5	37.50
10%	12	12	12	16	33.33
15%	12	12	12	15.5	29.17
20%	12	12	12	15	25.00
25%	12	12	12	14.5	20.83

3. Linear shrinkage

Natural soil mixid with 25% Fly Ash& 5% CKD linear shrinkage test		
Determination No.	1	2
Semi cyliderical trough No.	K	L
Initial wet length of soil Lo (mm)	140	142
Dry length of soil Ld (mm)	129.5	132
Linear shrinkage LS in %	7.50	7.04
Average Linear shrinkage	7.27	

Natural soil mixid with 25% Fly Ash& 10% CKD linear shrinkage test		
Determination No.	1	2
Semi cyliderical trough No.	K	L
Initial wet length of soil Lo (mm)	140	142
Dry length of soil Ld (mm)	130	132.5
Linear shrinkage LS in %	7.14	6.69
Average Linear shrinkage	6.92	

Natural soil mixid with 25% Fly Ash& 20% CKD linear shrinkage test		
Determination No.	1	2
Semi cyliderical trough No.	M	N
Initial wet length of soil Lo (mm)	140	141
Dry length of soil Ld (mm)	131	131.5
Linear shrinkage LS in %	6.43	6.74
Average Linear shrinkage	6.58	

Natural soil mixid with 25% Fly Ash& 25% CKD linear shrinkage test		
Determination No.	1	2
Semi cyliderical trough No.	O	K
Initial wet length of soil Lo (mm)	142	140
Dry length of soil Ld (mm)	133	132
Linear shrinkage LS in %	6.34	5.71
Average Linear shrinkage	6.03	

Natural soil mixid with 25% Fly Ash& 15% CKD linear shrinkage test		
Determination No.	1	2
Semi cyliderical trough No.	M	N
Initial wet length of soil Lo (mm)	140	140
Dry length of soil Ld (mm)	130.5	130.7
Linear shrinkage LS in %	6.79	6.64
Average Linear shrinkage	6.71	

4. Specific gravity of CKD treated soil-fly ash mixture

Natural soil mixed with 25% Fly ash+ 5%CKD									
Determination code								D7	11
Mass of dry, clean calibrated pycnometer, Mp, in (gm)								31.46	27.31
A. Mass of oven dry sample (gm)								25	25
B. Mass of pycnometer +water (gm)								123.02	122.76
C. Mass of pycnometer +water+sample (gm)								138.19	137.97
Observation temperature of water, Ti in (°C)								25	25
Water temperature in (°C)									
(°C)	18	19	20	21	22	23	24	25	26
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.9991	0.9988	0.9986
Temperature of contents of pycnometer when Mpsw was taken, Tx, (°C)								25	25
K for Tx								0.9988	0.9988
Specific gravity at 20oc, Gs					Gs=A*k/(A+B-C)			2.54	2.55
Average Specific gravity at 20oc, Gs								**2.55**	

Natural soil mixed with 25% Fly ash+ 10%CKD									
Determination code								D7	11
Mass of dry, clean calibrated pycnometer, Mp, in (gm)								31.31	30.33
A. Mass of oven dry sample (gm)								25	25
B. Mass of pycnometer +water (gm)								124.21	122.02
C. Mass of pycnometer +water+sample (gm)								139.6	137.43
Observation temperature of water, Ti in (°C)								24	24
Water temperature in (°C)									
(°C)	18	19	20	21	22	23	24	25	26
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.9991	0.9988	0.9986
Temperature of contents of pycnometer when Mpsw was taken, Tx, (°C)								24	24
K for Tx								0.9991	0.9991
Specific gravity at 20oc, Gs					Gs=A*k/(A+B-C)			2.60	2.60
Average Specific gravity at 20oc, Gs								**2.60**	

Natural soil mixed with 25% Fly ash+ 15%CKD									
Determination code								D7	11
Mass of dry, clean calibrated pycnometer, Mp, in (gm)								31.72	28.01
A. Mass of oven dry sample (gm)								25	25
B. Mass of pycnometer +water (gm)								125.59	122.8
C. Mass of pycnometer +water+sample (gm)								141.08	138.27
Observation temperature of water, Ti in (°C)								25	25
Water temperature in (°C)									
(°C)	18	19	20	21	22	23	24	25	26
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.9991	0.9988	0.9986
Temperature of contents of pycnometer when Mpsw was taken, Tx, (°C)								25	25
K for Tx								0.9988	0.9988
Specific gravity at 20oc, Gs					Gs=A*k/(A+B-C)			2.63	2.62
Average Specific gravity at 20oc, Gs								**2.62**	

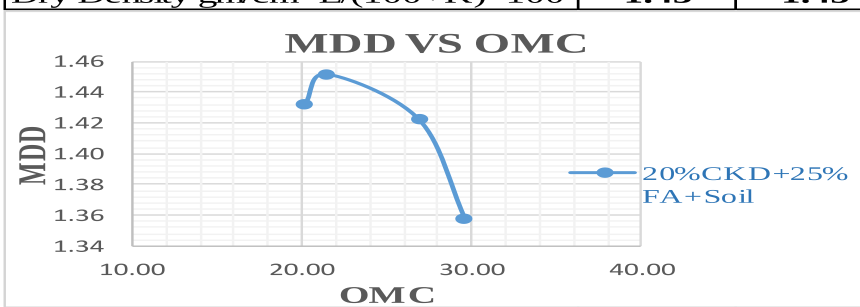
Natural soil mixed with 25% Fly ash+20%CKD									
Determination code								D7	11
Mass of dry, clean calibrated pycnometer, Mp, in (gm)								31.51	30.53
A. Mass of oven dry sample (gm)								25	25
B. Mass of pycnometer +water (gm)								126.1	124.95
C. Mass of pycnometer +water+sample (gm)								141.63	140.51
Observation temperature of water, Ti in (°C)								22	22
Water temperature in (°C)									
(°C)	18	19	20	21	22	23	24	25	26
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.9991	0.9988	0.9986
Temperature of contents of pycnometer when Mpsw was taken, Tx, (°C)								23	23
K for Tx								0.9993	0.9993
Specific gravity at 20oc, Gs					Gs=A*k/(A+B-C)			2.64	2.65
Average Specific gravity at 20oc, Gs								**2.64**	

Natural soil mixed with 25% Fly ash+25%CKD											
Determination code										D7	11
Mass of dry, clean calibrated pycnometer, Mp, in (gm)										32.23	31.25
A. Mass of oven dry sample (gm)										25	25
B. Mass of pycnometer +water (gm)										127.07	126.02
C. Mass of pycnometer +water+sample (gm)										142.71	141.7
Observation temperature of water, Ti in (°C)										24	24
Water temperature in (°C)											
(°C)	18	19	20	21	22		23	24		25	26
K	1.0004	1.0002	1	0.9998	0.9996		0.9993	0.9991		0.9988	0.9986
Temperature of contents of pycnometer when Mpsw was taken, Tx, (°C)										24	24
K for Tx										0.9991	0.9991
Specific gravity at 20oc, Gs						Gs=A*k/(A+B-C)				2.67	2.68
Average Specific gravity at 20oc, Gs										**2.67**	

5. Compaction test for CKD treated soil-fly ash mixture

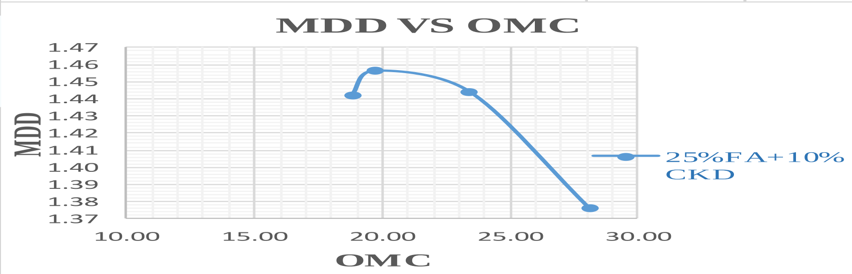
<u>Without curing</u>

25% FLY ASH MIXED WITH 10% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	550	710	870	1030
Mass of Mold+Wet soil(gm)(A)	6363.2	6451.3	6539	6443.5
Mass of Mold(gm)(B)	2706	2706	2706	2706
Mass of Wet Soil(gm)A-B=C	3657.2	3745.3	3833	3737.5
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.72	1.76	1.80	1.76
Moisture Content Determination				
Container Code .		A2	2	T1
Mass of Wet soil+Container(gm)(F)	181.06	185.16	189.95	170.95
Mass of dry soil+container(gm)(G)	156.3	156.93	156.68	139.46
Mass of container(gm)(H)	33.5	25.36	32.85	33.04
Mass of moisture(gm)F-G=(I)	24.76	28.23	33.27	31.49
Mass of Dry soil(gm)G-H=(J)	122.8	131.57	123.83	106.42
Moisture content % (I/J)*100=K	**20.16**	**21.46**	**26.87**	**29.59**
Dry Density gm/cm^3 E/(100+K)*100	**1.43**	**1.45**	**1.42**	**1.36**



MDD	**1.45**
OMC	**21.46**

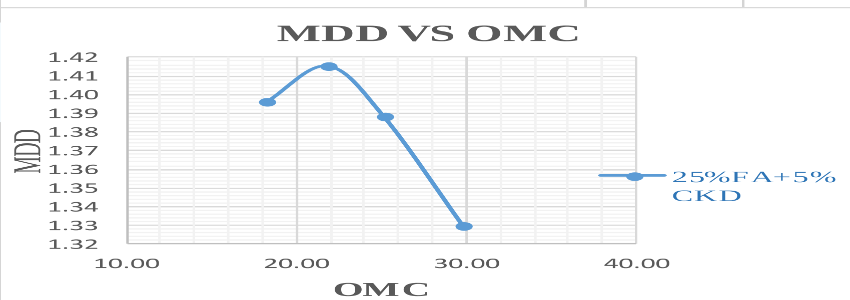
25% FLY ASH MIXED WITH 20% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	400	560	720	880
Mass of Mold+Wet soil(gm)(A)	6345.5	6410.2	6492	6451
Mass of Mold(gm)(B)	2706	2706	2706	2706
Mass of Wet Soil(gm)A-B=C	3639.5	3704.2	3786	3745
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.71	1.74	1.78	1.76
Moisture Content Determination				
Container Code .	A	2	P3	G53
Mass of Wet soil+Container(gm)(F)	162.12	159.49	170.21	165.84
Mass of dry soil+container(gm)(G)	141.08	138.8	144.26	136.71
Mass of container(gm)(H)	29.28	34.04	33.5	33.04
Mass of moisture(gm)F-G=(I)	21.04	20.69	25.95	29.13
Mass of Dry soil(gm)G-H=(J)	111.8	104.76	110.76	103.67
Moisture content % (I/J)*100=K	**18.82**	**19.75**	**23.43**	**28.10**
Dry Density gm/cm^3 E/(100+K)*100	**1.44**	**1.46**	**1.44**	**1.38**



MDD	1.46
OMC	19.75

For Four-day Curing

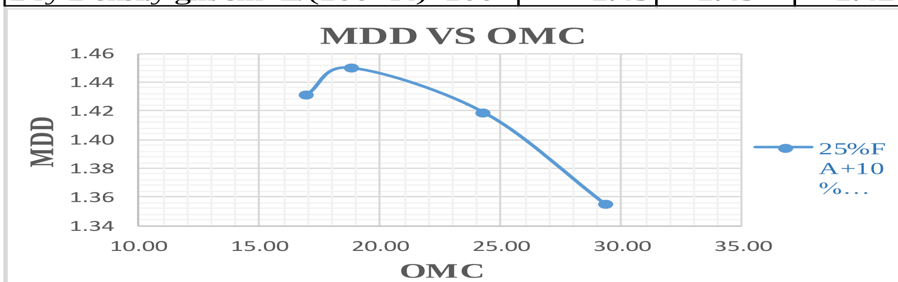
25% FLY ASH MIXED WITH 5% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	340	500	660	820
Mass of Mold+Wet soil(gm)(A)	6224.3	6381.2	6409.2	6385.4
Mass of Mold(gm)(B)	2718.2	2718.2	2718.2	2718.2
Mass of Wet Soil(gm)A-B=C	3506.1	3663	3691	3667.2
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.65	1.72	1.74	1.73
Moisture Content Determination				
Container Code .	A	2	P3	G53
Mass of Wet soil+Container(gm)(F)	176.41	175.89	156.8	163.28
Mass of dry soil+container(gm)(G)	155.04	151.31	131.97	133.79
Mass of container(gm)(H)	38.05	38.94	33.5	35.04
Mass of moisture(gm)F-G=(I)	21.37	24.58	24.83	29.49
Mass of Dry soil(gm)G-H=(J)	116.99	112.37	98.47	98.75
Moisture content % (I/J)*100=K	**18.27**	**21.87**	**25.22**	**29.86**
Dry Density gm/cm^3 E/(100+K)*100	**1.40**	**1.42**	**1.39**	**1.33**



MDD	1.42
OMC	21.87

25% FLY ASH MIXED WITH 10% CKD+ EXPANSIVE SOIL

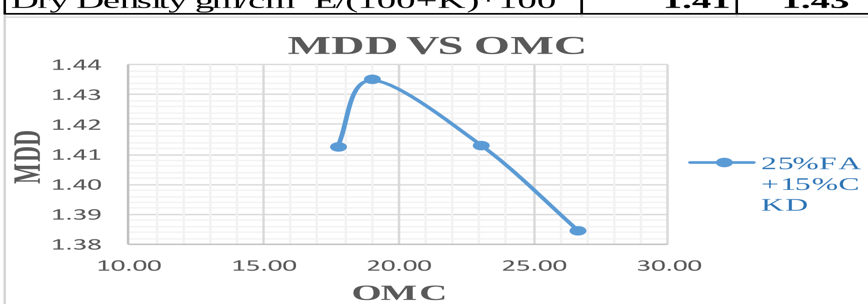
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	390	550	710	870
Mass of Mold+Wet soil(gm)(A)	6261.65	6363.2	6451.3	6429
Mass of Mold(gm)(B)	2706	2706	2706	2706
Mass of Wet Soil(gm)A-B=C	3555.65	3657.2	3745.3	3723
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.67	1.72	1.76	1.75
Moisture Content Determination				
Container Code .		A	2	P3
Mass of Wet soil+Container(gm)(F)	192.06	196.13	203.15	185.15
Mass of dry soil+container(gm)(G)	169.07	169.13	169.88	150.66
Mass of container(gm)(H)	33.5	25.36	32.85	33.04
Mass of moisture(gm)F-G=(I)	22.99	27	33.27	34.49
Mass of Dry soil(gm)G-H=(J)	135.57	143.77	137.03	117.62
Moisture content % (I/J)*100=K	**16.96**	**18.78**	**24.28**	**29.32**
Dry Density gm/cm^3 E/(100+K)*100	**1.43**	**1.45**	**1.42**	**1.36**



MDD	**1.45**
OMC	**18.78**

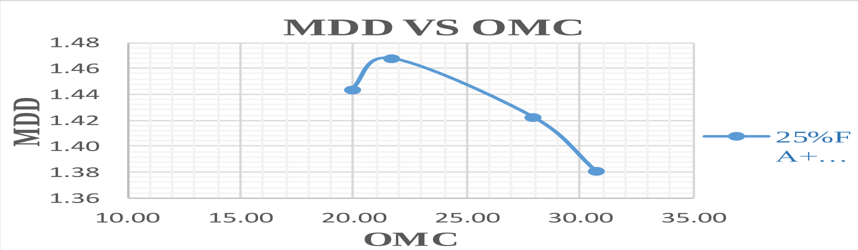
25% FLY ASH MIXED WITH 15% CKD+ EXPANSIVE SOIL

Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	240	400	560	720
Mass of Mold+Wet soil(gm)(A)	6251.2	6345.5	6400.2	6432
Mass of Mold(gm)(B)	2718.2	2718.2	2706	2706.5
Mass of Wet Soil(gm)A-B=C	3533	3627.3	3694.2	3725.5
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.66	1.71	1.74	1.75
Moisture Content Determination				
Container Code .	C	A	2	P3
Mass of Wet soil+Container(gm)(F)	171.33	168.49	179.92	176.05
Mass of dry soil+container(gm)(G)	150.49	147.01	152.47	145.92
Mass of container(gm)(H)	33.09	34.04	33.5	33.04
Mass of moisture(gm)F-G=(I)	20.84	21.48	27.45	30.13
Mass of Dry soil(gm)G-H=(J)	117.4	112.97	118.97	112.88
Moisture content % (I/J)*100=K	**17.75**	**19.01**	**23.07**	**26.69**
Dry Density gm/cm^3 E/(100+K)*100	**1.41**	**1.43**	**1.41**	**1.38**



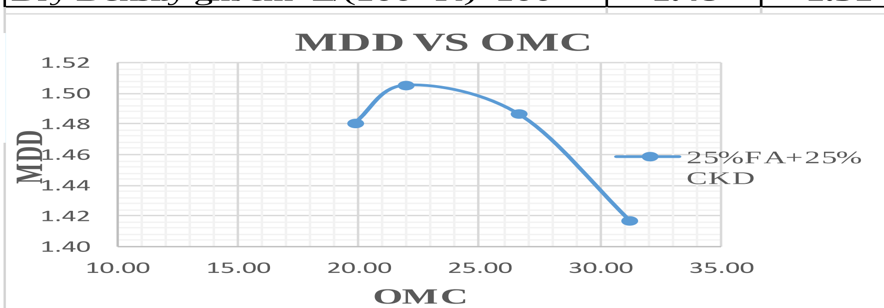
MDD	**1.43**
OMC	**19.01**

25% FLY ASH MIXED WITH 20% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	300	460	620	780
Mass of Mold+Wet soil(gm)(A)	6382.3	6499.94	6572.1	6541.5
Mass of Mold(gm)(B)	2706	2706	2706	2706
Mass of Wet Soil(gm)A-B=C	3676.3	3793.94	3866.1	3835.5
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.73	1.79	1.82	1.81
Moisture Content Determination				
Container Code .		A2	2	T1
Mass of Wet soil+Container(gm)(F)	191.3	196.71	182.72	198.95
Mass of dry soil+container(gm)(G)	165.51	168.12	151.09	160.54
Mass of container(gm)(H)	35.9	36.5	37.94	35.5
Mass of moisture(gm)F-G=(I)	25.79	28.59	31.63	38.41
Mass of Dry soil(gm)G-H=(J)	129.61	131.62	113.15	125.04
Moisture content % (I/J)*100=K	**19.90**	**21.72**	**27.95**	**30.72**
Dry Density gm/cm^3 E/(100+K)*100	**1.44**	**1.47**	**1.42**	**1.38**



MDD	**1.47**
OMC	**21.72**

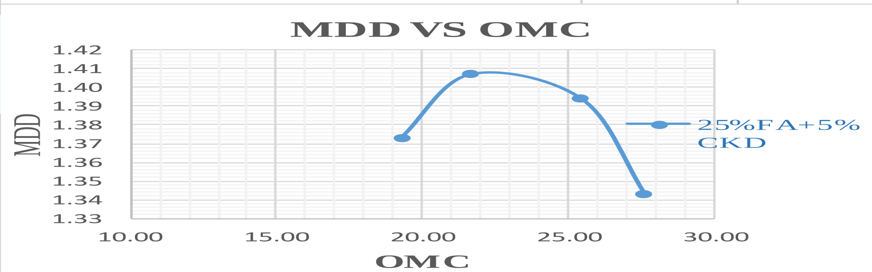
25% FLY ASH MIXED WITH 25% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	390	550	710	870
Mass of Mold+Wet soil(gm)(A)	6475.1	6605.5	6703.5	6654.9
Mass of Mold(gm)(B)	2706	2706	2706	2706
Mass of Wet Soil(gm)A-B=C	3769.1	3899.5	3997.5	3948.9
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.77	1.84	1.88	1.86
Moisture Content Determination				
Container Code .	A	2	P3	G53
Mass of Wet soil+Container(gm)(F)	212.1	215.75	206.92	200.14
Mass of dry soil+container(gm)(G)	182.91	183.45	171.39	160.47
Mass of container(gm)(H)	35.9	36.5	37.94	33.5
Mass of moisture(gm)F-G=(I)	29.19	32.3	35.53	39.67
Mass of Dry soil(gm)G-H=(J)	147.01	146.95	133.45	126.97
Moisture content % (I/J)*100=K	**19.86**	**21.98**	**26.62**	**31.24**
Dry Density gm/cm^3 E/(100+K)*100	**1.48**	**1.51**	**1.49**	**1.42**



MDD	**1.51**
OMC	**21.98**

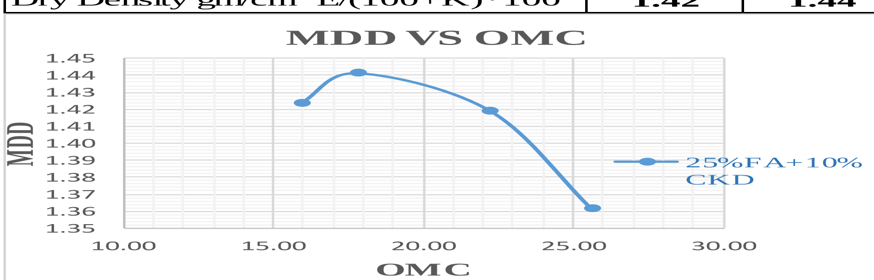
For seven-day curing

25% FLY ASH MIXED WITH 5% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	340	500	660	820
Mass of Mold+Wet soil(gm)(A)	6194.1	6351	6429	6355.2
Mass of Mold(gm)(B)	2716	2716	2716	2716
Mass of Wet Soil(gm)A-B=C	3478.1	3635	3713	3639.2
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.64	1.71	1.75	1.71
Moisture Content Determination				
Container Code .	A	2	P3	G53
Mass of Wet soil+Container(gm)(F)	175.5	173.61	158.8	163.28
Mass of dry soil+container(gm)(G)	153.04	149.42	132.01	136.19
Mass of container(gm)(H)	36.5	37.64	26.63	37.93
Mass of moisture(gm)F-G=(I)	22.46	24.19	26.79	27.09
Mass of Dry soil(gm)G-H=(J)	116.54	111.78	105.38	98.26
Moisture content % (I/J)*100=K	**19.27**	**21.64**	**25.42**	**27.57**
Dry Density gm/cm^3 E/(100+K)*100	**1.37**	**1.41**	**1.39**	**1.34**



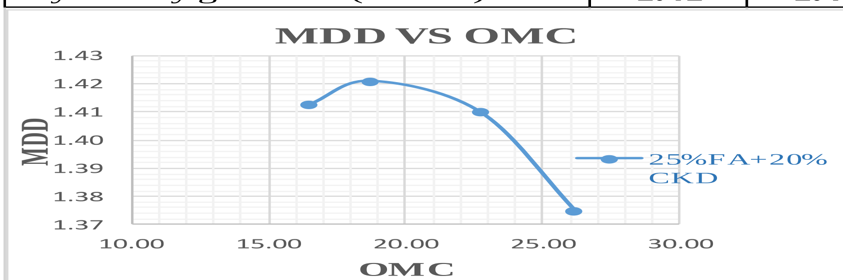
MDD	**1.41**
OMC	**21.64**

25% FLY ASH MIXED WITH 10% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	420	580	740	900
Mass of Mold+Wet soil(gm)(A)	6212.33	6313.2	6391.02	6339
Mass of Mold(gm)(B)	2706	2706	2706	2706
Mass of Wet Soil(gm)A-B=C	3506.33	3607.2	3685.02	3633
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.65	1.70	1.73	1.71
Moisture Content Determination				
Container Code .	1	A	2	P3
Mass of Wet soil+Container(gm)(F)	164.25	171.39	180.65	151.55
Mass of dry soil+container(gm)(G)	146.27	150.19	153.76	126.76
Mass of container(gm)(H)	33.5	31.26	32.85	30.04
Mass of moisture(gm)F-G=(I)	17.98	21.2	26.89	24.79
Mass of Dry soil(gm)G-H=(J)	112.77	118.93	120.91	96.72
Moisture content % (I/J)*100=K	**15.94**	**17.83**	**22.24**	**25.63**
Dry Density gm/cm^3 E/(100+K)*100	**1.42**	**1.44**	**1.42**	**1.36**



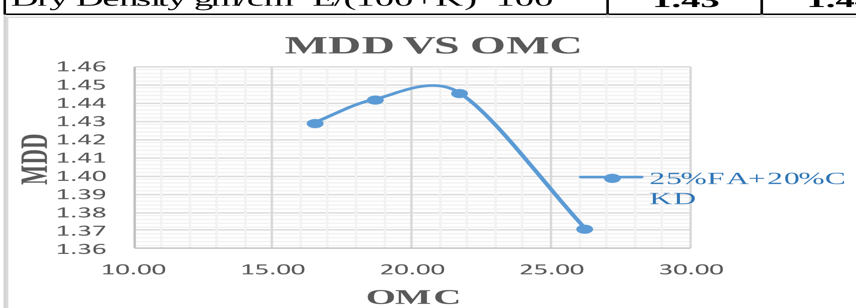
MDD	**1.44**
OMC	**17.83**

25% FLY ASH MIXED WITH 15% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	240	400	560	720
Mass of Mold+Wet soil(gm)(A)	6201.9	6289.4	6380.5	6389.7
Mass of Mold(gm)(B)	2706	2706	2706	2706
Mass of Wet Soil(gm)A-B=C	3495.9	3583.4	3674.5	3683.7
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.65	1.69	1.73	1.73
Moisture Content Determination				
Container Code .		A2	2	T1
Mass of Wet soil+Container(gm)(F)	170.33	175.59	168.91	176.95
Mass of dry soil+container(gm)(G)	150.89	153.22	143.86	147.92
Mass of container(gm)(H)	33.09	33.73	33.5	36.84
Mass of moisture(gm)F-G=(I)	19.44	22.37	25.05	29.03
Mass of Dry soil(gm)G-H=(J)	117.8	119.49	110.36	111.08
Moisture content % (I/J)*100=K	**16.50**	**18.72**	**22.70**	**26.13**
Dry Density gm/cm^3 E/(100+K)*100	**1.41**	**1.42**	**1.41**	**1.37**



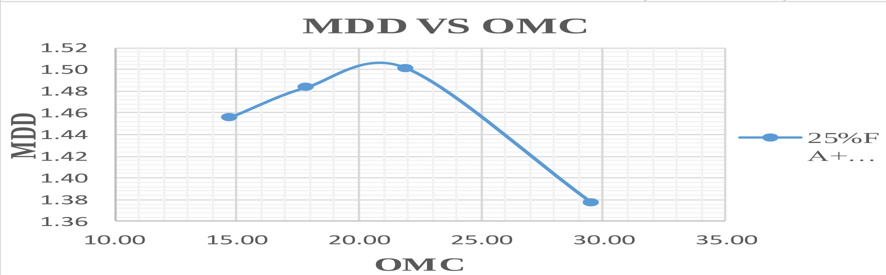
MDD	1.42
OMC	18.72

25% FLY ASH MIXED WITH 20% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	300	460	620	780
Mass of Mold+Wet soil(gm)(A)	6252.3	6352.4	6452.1	6391.5
Mass of Mold(gm)(B)	2716	2716	2716	2716
Mass of Wet Soil(gm)A-B=C	3536.3	3636.4	3736.1	3675.5
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.66	1.71	1.76	1.73
Moisture Content Determination				
Container Code .	B	A2	2	T1
Mass of Wet soil+Container(gm)(F)	170.33	175.59	167.78	177.05
Mass of dry soil+container(gm)(G)	150.89	153.22	143.86	147.92
Mass of container(gm)(H)	33.09	33.73	33.5	36.84
Mass of moisture(gm)F-G=(I)	19.44	22.37	23.92	29.13
Mass of Dry soil(gm)G-H=(J)	117.8	119.49	110.36	111.08
Moisture content % (I/J)*100=K	**16.50**	**18.72**	**21.67**	**26.22**
Dry Density gm/cm^3 E/(100+K)*100	**1.43**	**1.44**	**1.45**	**1.37**



MDD	1.45
OMC	21.67

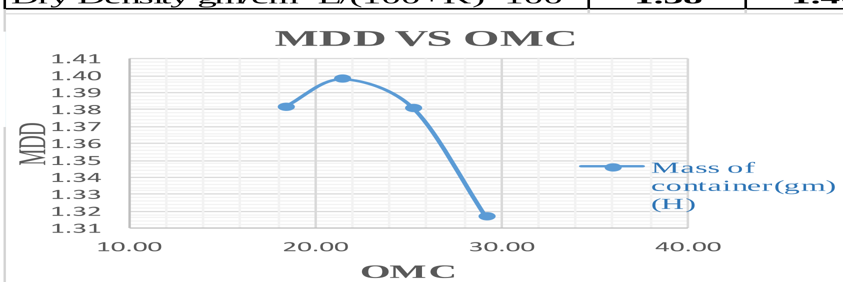
25% FLY ASH MIXED WITH 25% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	490	650	810	970
Mass of Mold+Wet soil(gm)(A)	6253.2	6419.3	6593.9	6494.7
Mass of Mold(gm)(B)	2706	2706	2706	2706
Mass of Wet Soil(gm)A-B=C	3547.2	3713.3	3887.9	3788.7
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.67	1.75	1.83	1.78
Moisture Content Determination				
Container Code .	A	2	P3	G53
Mass of Wet soil+Container(gm)(F)	179.08	191.14	181.71	176.82
Mass of dry soil+container(gm)(G)	160.72	167.74	155.89	144.15
Mass of container(gm)(H)	35.9	36.5	37.94	33.5
Mass of moisture(gm)F-G=(I)	18.36	23.4	25.82	32.67
Mass of Dry soil(gm)G-H=(J)	124.82	131.24	117.95	110.65
Moisture content % (I/J)*100=K	**14.71**	**17.83**	**21.89**	**29.53**
Dry Density gm/cm^3 E/(100+K)*100	**1.46**	**1.48**	**1.50**	**1.38**



MDD	**1.50**
OMC	**21.89**

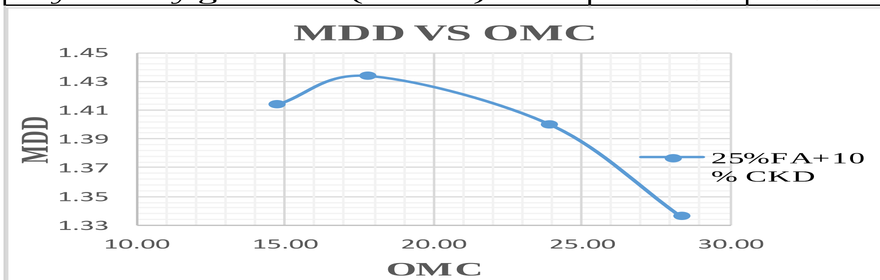
For Fourteen-day Curing

25% FLY ASH MIXED WITH 5% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	420	580	740	900
Mass of Mold+Wet soil(gm)(A)	6192.22	6323.2	6391.12	6329.3
Mass of Mold(gm)(B)	2716	2716	2716	2716
Mass of Wet Soil(gm)A-B=C	3476.22	3607.2	3675.12	3613.3
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.64	1.70	1.73	1.70
Moisture Content Determination				
Container Code .	A	2	P3	G53
Mass of Wet soil+Container(gm)(F)	156.18	164.41	179.55	169.2
Mass of dry soil+container(gm)(G)	137.27	141.19	149.96	137.76
Mass of container(gm)(H)	34.7	33.06	32.85	30.04
Mass of moisture(gm)F-G=(I)	18.91	23.22	29.59	31.44
Mass of Dry soil(gm)G-H=(J)	102.57	108.13	117.11	107.72
Moisture content % (I/J)*100=K	**18.44**	**21.47**	**25.27**	**29.19**
Dry Density gm/cm^3 E/(100+K)*100	**1.38**	**1.40**	**1.38**	**1.32**



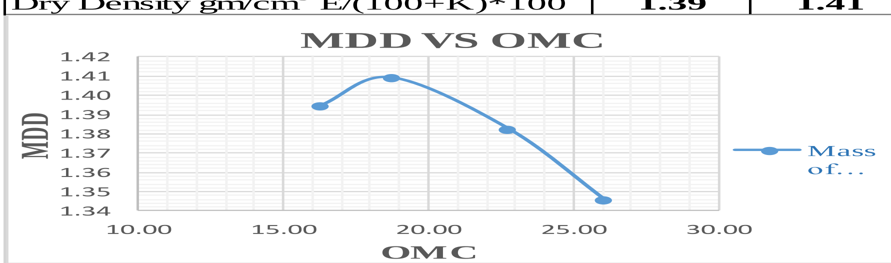
MDD	**1.40**
OMC	**21.47**

25% FLY ASH MIXED WITH 10% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	420	580	740	900
Mass of Mold+Wet soil(gm)(A)	6162.22	6303.2	6401.12	6359.3
Mass of Mold(gm)(B)	2716	2716	2716	2716
Mass of Wet Soil(gm)A-B=C	3446.22	3587.2	3685.12	3643.3
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.62	1.69	1.73	1.72
Moisture Content Determination				
Container Code .		A	2	P3
Mass of Wet soil+Container(gm)(F)	189.79	188.32	186.78	183.28
Mass of dry soil+container(gm)(G)	170.09	165.59	157.01	150.09
Mass of container(gm)(H)	36.5	37.94	32.5	33.04
Mass of moisture(gm)F-G=(I)	19.7	22.73	29.77	33.19
Mass of Dry soil(gm)G-H=(J)	133.59	127.65	124.51	117.05
Moisture content % (I/J)*100=K	**14.75**	**17.81**	**23.91**	**28.36**
Dry Density gm/cm^3 E/(100+K)*100	**1.41**	**1.43**	**1.40**	**1.34**



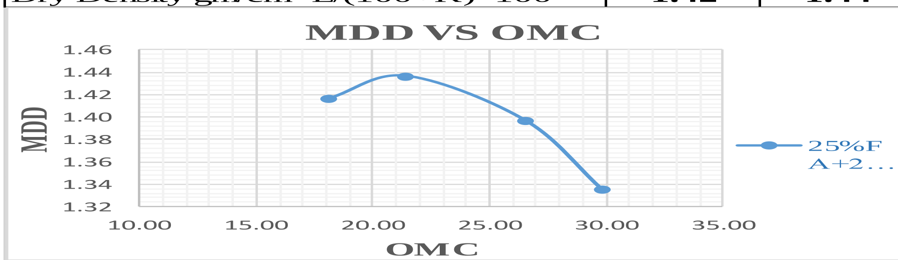
MDD	**1.43**
OMC	**17.81**

25% FLY ASH MIXED WITH 15% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	240	400	560	720
Mass of Mold+Wet soil(gm)(A)	6151.2	6259.7	6310.9	6309.7
Mass of Mold(gm)(B)	2706	2706	2706	2706
Mass of Wet Soil(gm)A-B=C	3445.2	3553.7	3604.9	3603.7
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.62	1.67	1.70	1.70
Moisture Content Determination				
Container Code .	B	A2	2	T1
Mass of Wet soil+Container(gm)(F)	161.55	170.97	158.08	168.71
Mass of dry soil+container(gm)(G)	143.72	149.33	134.39	140.69
Mass of container(gm)(H)	34.23	33.73	30.29	33.19
Mass of moisture(gm)F-G=(I)	17.83	21.64	23.69	28.02
Mass of Dry soil(gm)G-H=(J)	109.49	115.6	104.1	107.5
Moisture content % (I/J)*100=K	**16.28**	**18.72**	**22.76**	**26.07**
Dry Density gm/cm^3 E/(100+K)*100	**1.39**	**1.41**	**1.38**	**1.35**



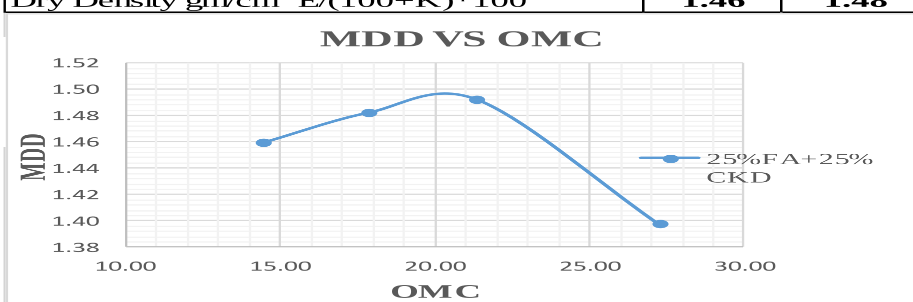
MDD	**1.41**
OMC	**18.72**

25% FLY ASH MIXED WITH 20% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	300	460	620	780
Mass of Mold+Wet soil(gm)(A)	6272.8	6422.7	6472.5	6401.6
Mass of Mold(gm)(B)	2719	2719	2719	2719
Mass of Wet Soil(gm)A-B=C	3553.8	3703.7	3753.5	3682.6
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.67	1.74	1.77	1.73
Moisture Content Determination				
Container Code .		A2	2	T1
Mass of Wet soil+Container(gm)(F)	163.55	174.07	161.98	172.71
Mass of dry soil+container(gm)(G)	143.72	149.33	134.39	140.69
Mass of container(gm)(H)	34.23	33.73	30.29	33.19
Mass of moisture(gm)F-G=(I)	19.83	24.74	27.59	32.02
Mass of Dry soil(gm)G-H=(J)	109.49	115.6	104.1	107.5
Moisture content % (I/J)*100=K	**18.11**	**21.40**	**26.50**	**29.79**
Dry Density gm/cm^3 E/(100+K)*100	**1.42**	**1.44**	**1.40**	**1.34**



MDD	**1.44**
OMC	**21.40**

25% FLY ASH MIXED WITH 25% CKD+ EXPANSIVE SOIL				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	490	650	810	970
Mass of Mold+Wet soil(gm)(A)	6253.3	6417.21	6553.02	6484.05
Mass of Mold(gm)(B)	2706	2706	2706	2706
Mass of Wet Soil(gm)A-B=C	3547.3	3711.21	3847.02	3778.05
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.67	1.75	1.81	1.78
Moisture Content Determination				
Container Code .	A	2	P3	G53
Mass of Wet soil+Container(gm)(F)	197.09	211.24	189.41	184.54
Mass of dry soil+container(gm)(G)	176.53	184.44	162.19	152.93
Mass of container(gm)(H)	34.09	34.5	34.94	37.07
Mass of moisture(gm)F-G=(I)	20.56	26.8	27.22	31.61
Mass of Dry soil(gm)G-H=(J)	142.44	149.94	127.25	115.86
Moisture content % (I/J)*100=K	**14.43**	**17.87**	**21.39**	**27.28**
Dry Density gm/cm^3 E/(100+K)*100	**1.46**	**1.48**	**1.49**	**1.40**

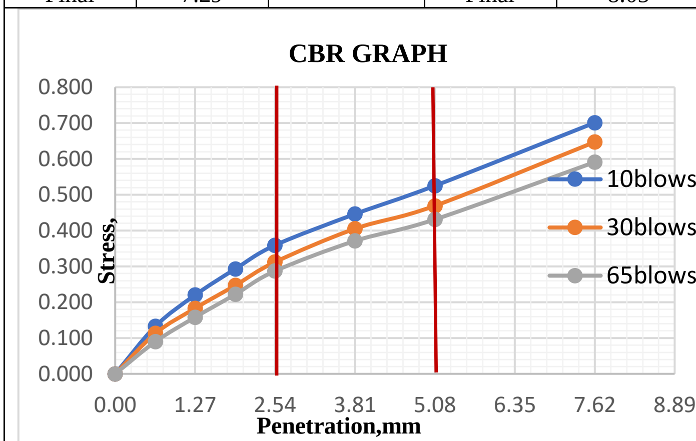


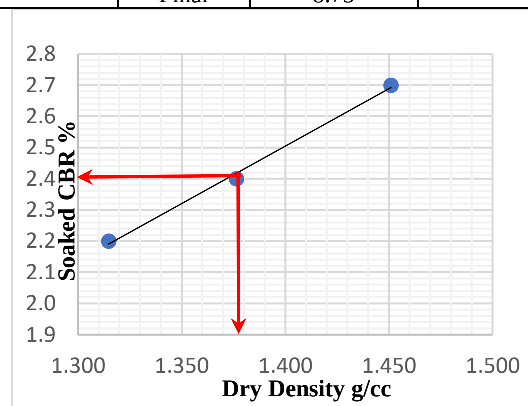
MDD	**1.49**
OMC	**21.39**

6. California Bearing Ration
Without curing

Soil-Fly ash mix treated by 10 % CKD

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.133		0.64	0.113		0.64	0.090	
1.27	0.220		1.27	0.183		1.27	0.158	
1.91	0.293		1.91	0.247		1.91	0.222	
2.54	0.359	2.72	2.54	0.312	2.36	2.54	0.287	2.17
3.81	0.446		3.81	0.405		3.81	0.371	
5.08	0.525	2.63	5.08	0.469	2.35	5.08	0.431	2.16
7.62	0.701		7.62	0.647		7.62	0.591	
Modified Max. Dry Density g/cc			**1.46**		**OMC %**		**19.75**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
	Read in %			Read in %			Read in %	
Initial	0.50	5.83	Initial	0.5	6.49	Initial	0.50	7.09
Final	7.29		Final	8.05		Final	8.75	





Dry Density at 95% of MDD:	**1.378**

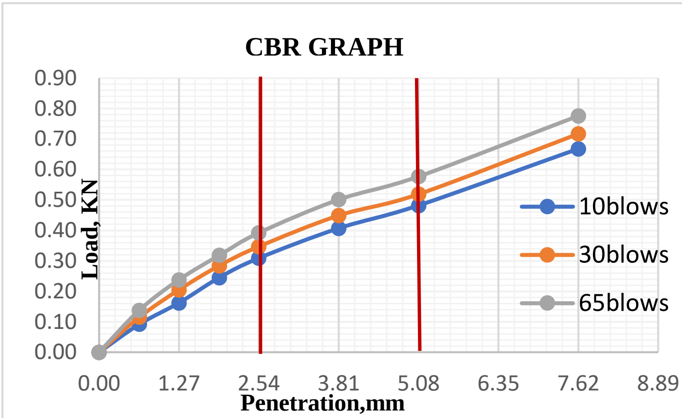
No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %		% Compaction
10	20.9	1.315	2.2		91
30	20.6	1.376	2.4		95
65	19.5	1.451	2.7		100
CBR (%) @ 95 % MDD			**2.4**	**% Swell**	**6.47**

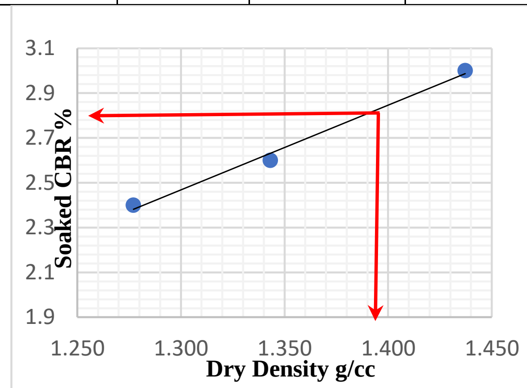
Soil-Fly ash mix treated by 20 % CKD

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.00	
0.64	0.138		0.64	0.115		0.64	0.092	
1.27	0.238		1.27	0.205		1.27	0.162	
1.91	0.318		1.91	0.284		1.91	0.245	
2.54	0.392	2.97	2.54	0.347	2.63	2.54	0.309	2.34
3.81	0.501		3.81	0.449		3.81	0.407	
5.08	0.577	2.89	5.08	0.519	2.60	5.08	0.482	2.41
7.62	0.776		7.62	0.717		7.62	0.668	

Modified Max. Dry Density g/cc		**1.46**		OMC %	**19.75**	
Swelling	**65 blows**	**Swelling**	**30 blows**		**Swelling**	**10 blows**

	Read in %			Read in %			Read in %	
Initial	0.50	5.18	Initial	0.5	5.86	Initial	0.50	6.93
Final	6.53		Final	7.32		Final	8.57	





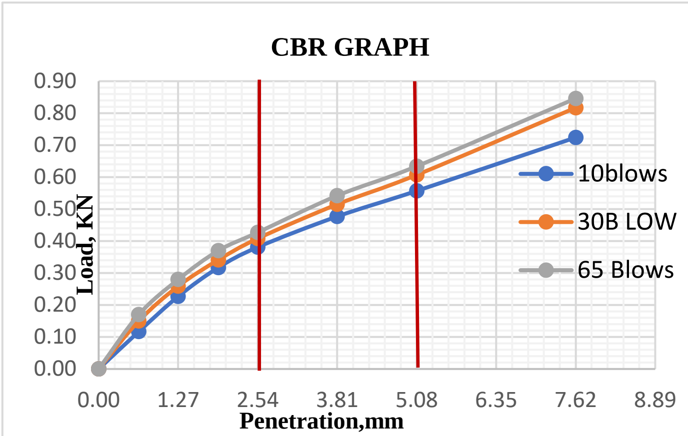
Dry Density at 95% of MDD: **1.387**

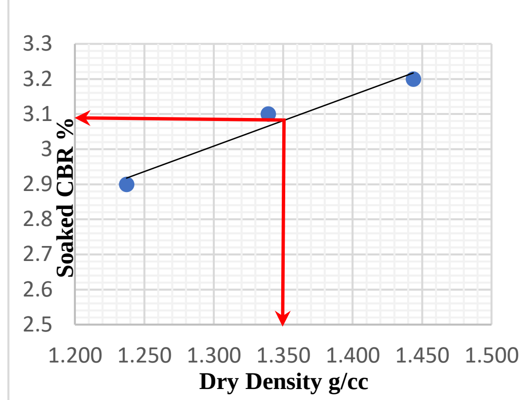
No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction
10	26.8	1.277	2.4	87
30	24.9	1.343	2.6	92
65	23.1	1.437	3.0	98

For four-day curing

Soil-Fly ash mix treated by 5 % CKD (4-day curing)

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.170		0.64	0.150		0.64	0.117	
1.27	0.280		1.27	0.259		1.27	0.227	
1.91	0.370		1.91	0.341		1.91	0.317	
2.54	0.427	3.23	2.54	0.408	3.1	2.54	0.381	2.9
3.81	0.542		3.81	0.515		3.81	0.477	
5.08	0.634	3.17	5.08	0.607	3.0	5.08	0.557	2.8
7.62	0.846		7.62	0.817		7.62	0.724	
Modified Max. Dry Density g/cc			**1.42**		OMC %		**21.87**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
Reading	in mm	in %		in mm	in %		in mm	in %
Initial	0.65	5.05	Initial	1.03	5.28	Initial	0.32	5.67
Final	6.53		Final	7.18		Final	6.92	

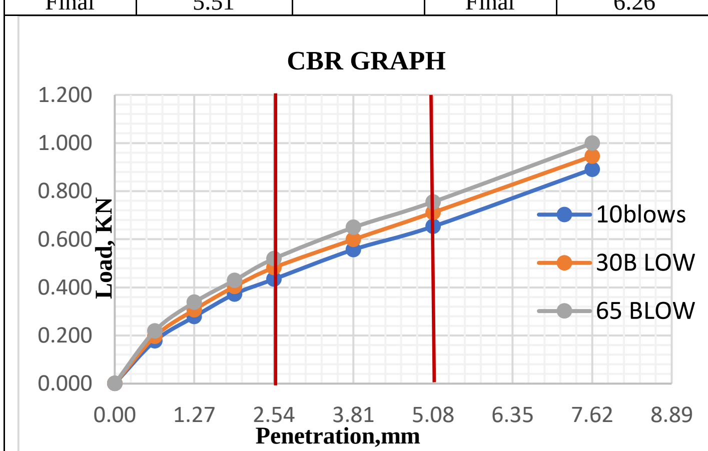


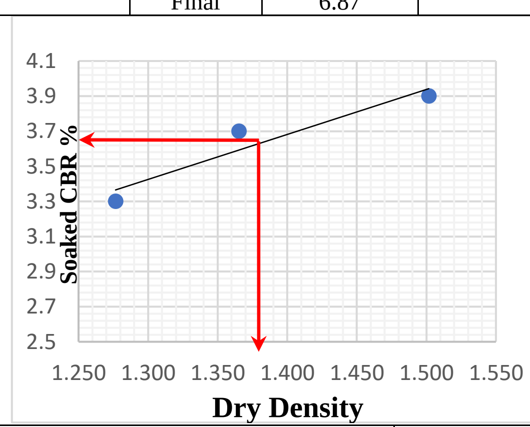


No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction
			Dry Density at 95% of MDD:	**1.349**
10	23.9	1.237	2.9	87
30	23.4	1.339	3.1	94
65	22.7	1.444	3.2	102
CBR (%) @ 95 % MDD		**3.1**	**% Swell**	**5.34**

Soil-Fly ash mix treated by 10 % CKD (4-day curing)

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.219		0.64	0.196		0.64	0.177	
1.27	0.338		1.27	0.307		1.27	0.278	
1.91	0.429		1.91	0.403		1.91	0.372	
2.54	0.519	3.9	2.54	0.482	3.7	2.54	0.434	3.3
3.81	0.649		3.81	0.599		3.81	0.557	
5.08	0.755	3.8	5.08	0.711	3.6	5.08	0.653	3.3
7.62	0.999		7.62	0.945		7.62	0.891	
Modified Max. Dry Density g/cc				**1.45**	OMC %		**18.48**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
Reading	in mm	in %		in mm	in %		in mm	in %
Initial	0.43	4.36	Initial	0.65	4.82	Initial	0.79	5.22
Final	5.51		Final	6.26		Final	6.87	



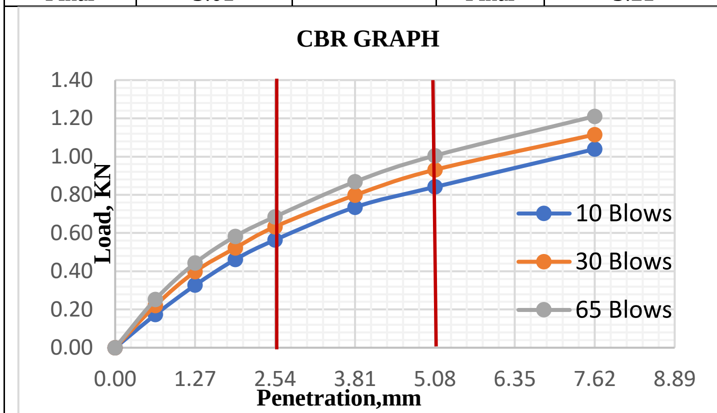


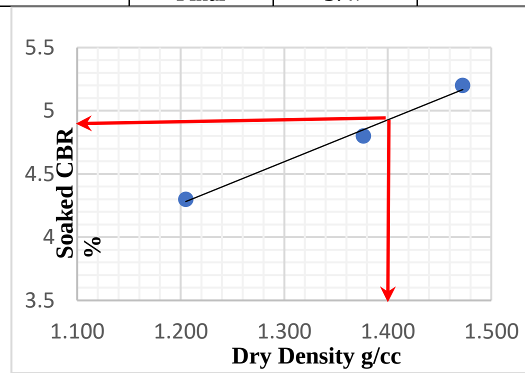
No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction
			Dry Density at 95% of MDD:	**1.378**

10	24.9	1.277	3.3		88
30	23.4	1.365	3.7		94
65	20.8	1.502	3.9		104
CBR (%) @ 95 % MDD			**3.7**	**% Swell**	**4.80**

Soil-Fly ash mix treated by 20 % CKD (4-day curing)

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.253		0.64	0.221		0.64	0.173	
1.27	0.443		1.27	0.398		1.27	0.327	
1.91	0.583		1.91	0.522		1.91	0.462	
2.54	0.685	5.2	2.54	0.633	4.8	2.54	0.564	4.3
3.81	0.868		3.81	0.798		3.81	0.735	
5.08	1.005	5.0	5.08	0.931	4.7	5.08	0.841	4.2
7.62	1.211		7.62	1.115		7.62	1.039	
Modified Max. Dry Density g/cc			**1.47**		OMC %		**21.72**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
	Read in %			Read in %			Read in %	
Initial	0.43	2.22	Initial	0.5	2.33	Initial	0.59	2.47
Final	3.01		Final	3.21		Final	3.47	





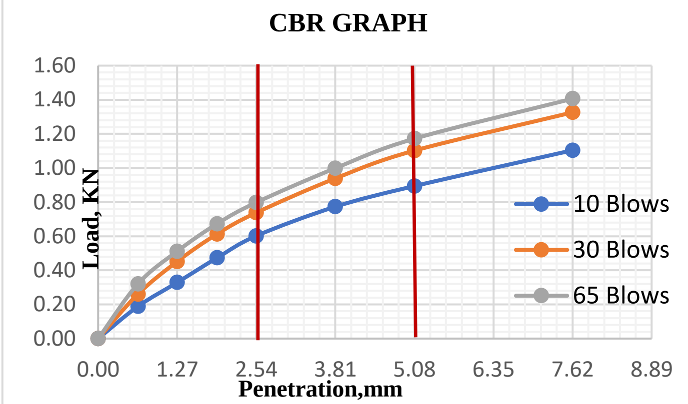
Dry Density at 95% of MDD: **1.397**

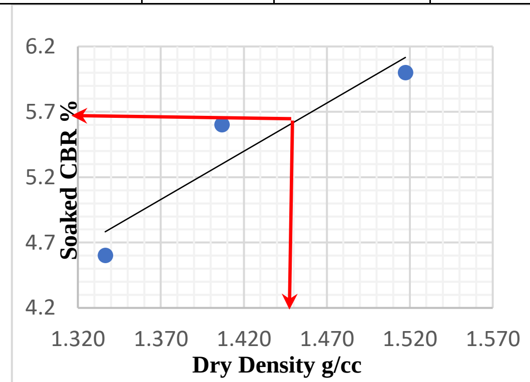
No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %		% Compaction
10	26.0	1.205	4.3		82
30	24.6	1.377	4.8		94
65	22.7	1.472	5.2		100
CBR (%) @ 95 % MDD			**4.9**	**% Swell**	**2.34**

Soil-Fly ash mix treated by 25% CKD (4-day curing)

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.321		0.64	0.261		0.64	0.189	
1.27	0.512		1.27	0.452		1.27	0.329	

1.91	0.673		1.91	0.613		1.91	0.473	
2.54	0.798	6.0	2.54	0.738	5.6	2.54	0.602	4.6
3.81	0.999		3.81	0.939		3.81	0.773	
5.08	1.172	5.9	5.08	1.102	5.5	5.08	0.894	4.5
7.62	1.406		7.62	1.326		7.62	1.104	
Modified Max. Dry Density g/cc			**1.51**		**OMC %**		**21.98**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
Reading	in mm	in %		in mm	in %		in mm	in %
Initial	0.50	1.78	Initial	0.25	1.89	Initial	0.50	1.98
Final	2.57		Final	2.45		Final	2.80	





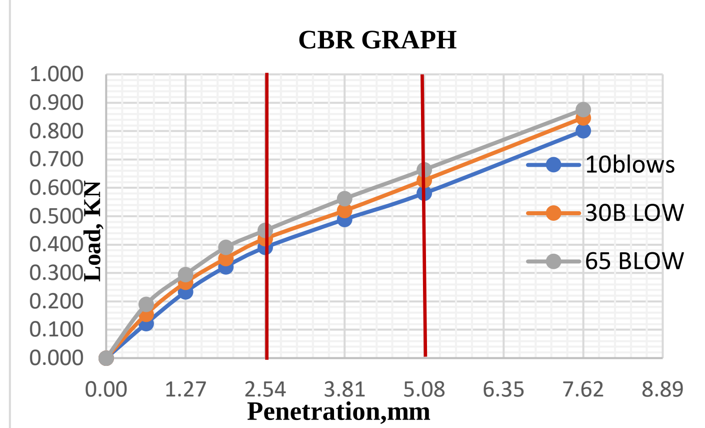
Dry Density at 95% of MDD:	**1.435**

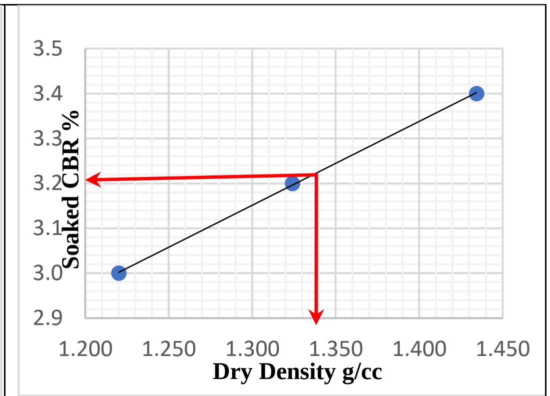
No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %		% Compaction
10	26.0	1.336	4.6		89
30	24.0	1.407	5.6		93
65	21.7	1.531	6.0		101
CBR (%) @ 95 % MDD			**5.7**	**% Swell**	**1.88**

For Seven Day Curing

Soil-Fly ash mix treated by 5 % CKD (7-day curing)

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.190		0.64	0.155		0.64	0.122	
1.27	0.295		1.27	0.267		1.27	0.234	
1.91	0.390		1.91	0.351		1.91	0.322	
2.54	0.450	3.41	2.54	0.421	3.2	2.54	0.390	3.0
3.81	0.562		3.81	0.520		3.81	0.489	
5.08	0.664	3.32	5.08	0.627	3.1	5.08	0.581	2.9
7.62	0.876		7.62	0.847		7.62	0.801	
Modified Max. Dry Density g/cc			**1.41**		**OMC %**		**21.64**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
Reading	in mm	in %		in mm	in %		in mm	in %
Initial	0.23	4.54	Initial	0.52	5.10	Initial	0.64	5.61
Final	5.51		Final	6.46		Final	7.17	



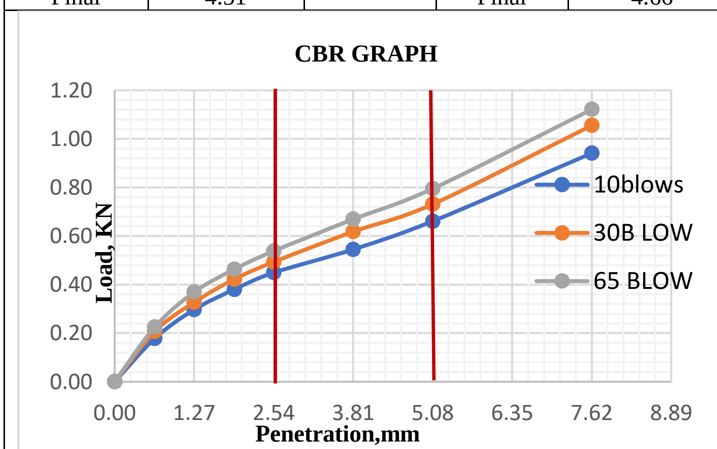


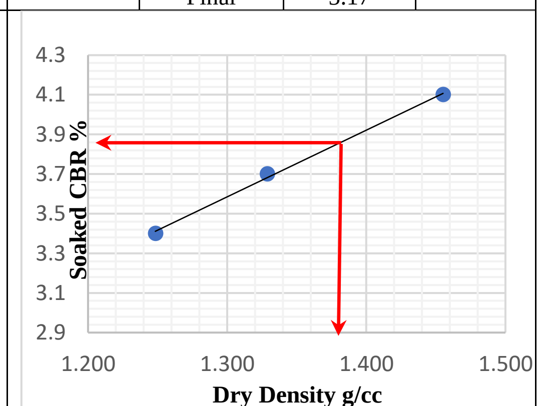
Dry Density at 95% of MDD: **1.340**

No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %		% Compaction
10	23.0	1.220	3.0		87
30	24.1	1.324	3.2		94
65	22.3	1.434	3.4		102
CBR (%) @ 95 % MDD			**3.2**	**% Swell**	**5.08**

Soil-Fly ash mix treated by 10 % CKD (7-day curing)

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.225		0.64	0.207		0.64	0.178	
1.27	0.369		1.27	0.327		1.27	0.297	
1.91	0.463		1.91	0.422		1.91	0.380	
2.54	0.538	4.1	2.54	0.493	3.7	2.54	0.449	3.4
3.81	0.669		3.81	0.618		3.81	0.545	
5.08	0.795	4.0	5.08	0.731	3.7	5.08	0.661	3.3
7.62	1.121		7.62	1.055		7.62	0.941	
Modified Max. Dry Density g/cc			**1.44**		OMC %		**17.83**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
Reading	in mm	in %		in mm	in %		in mm	in %
Initial	0.30	3.62	Initial	0.2	3.82	Initial	0.40	4.10
Final	4.51		Final	4.66		Final	5.17	



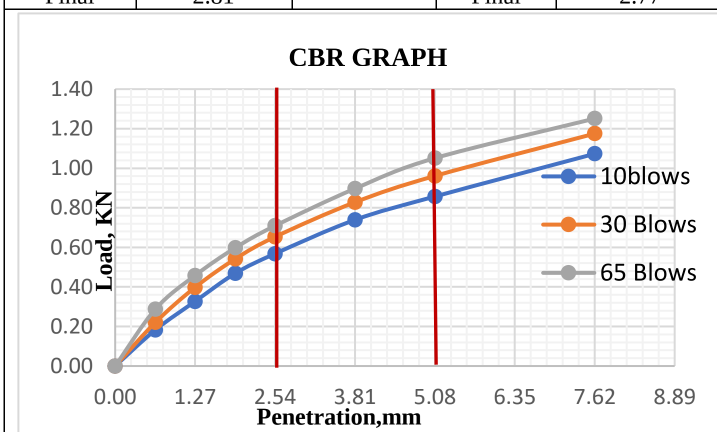


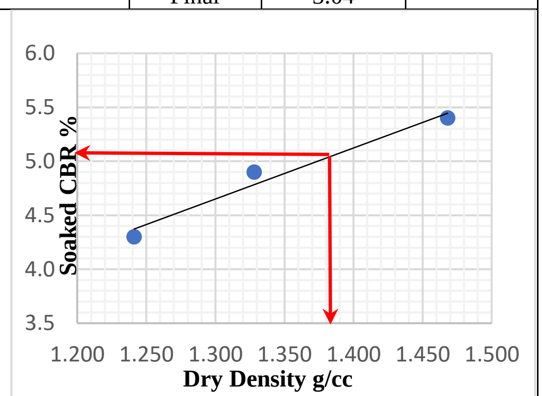
Dry Density at 95% of MDD: **1.368**

No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %		% Compaction
10	27.2	1.248	3.4		87
30	24.1	1.329	3.7		92
65	22.4	1.455	4.1		101
CBR (%) @ 95 % MDD			**3.8**	**% Swell**	**3.85**

Soil-Fly ash mix treated by 20 % CKD (7-day curing)

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.288		0.64	0.221		0.64	0.183	
1.27	0.458		1.27	0.398		1.27	0.327	
1.91	0.598		1.91	0.542		1.91	0.469	
2.54	0.709	5.4	2.54	0.653	4.9	2.54	0.568	4.3
3.81	0.897		3.81	0.828		3.81	0.739	
5.08	1.051	5.3	5.08	0.961	4.8	5.08	0.857	4.3
7.62	1.251		7.62	1.175		7.62	1.073	
Modified Max. Dry Density g/cc			**1.45**		OMC %		**21.67**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
	Read in %			Read in %			Read in %	
Initial	0.50	1.98	Initial	0.30	2.12	Initial	0.40	2.27
Final	2.81		Final	2.77		Final	3.04	





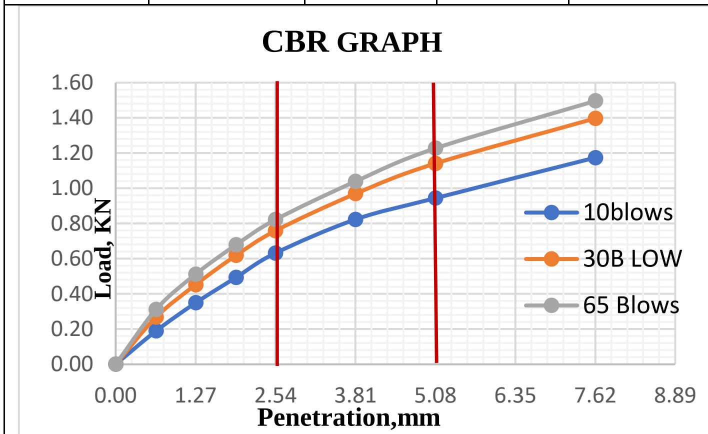
Dry Density at 95% of MDD:	**1.378**

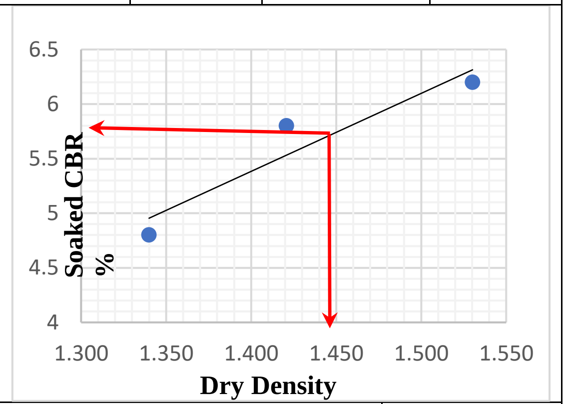
No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %		% Compaction
10	26.0	1.205	4.3		82
30	24.6	1.377	4.8		94
65	22.7	1.472	5.2		100
CBR (%) @ 95 % MDD			**5.1**	**% Swell**	**2.12**

Soil-Fly ash mix treated by 25% CKD (7-day curing)

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.0000		0.00	0.000		0.00	0.000	
0.64	0.311		0.64	0.267		0.64	0.189	

1.27	0.512		1.27	0.452		1.27	0.349	
1.91	0.678		1.91	0.618		1.91	0.493	
2.54	0.822	6.2	2.54	0.759	5.8	2.54	0.632	4.8
3.81	1.039		3.81	0.969		3.81	0.823	
5.08	1.227	6.1	5.08	1.141	5.7	5.08	0.944	4.7
7.62	1.496		7.62	1.397		7.62	1.174	
Modified Max. Dry Density g/cc			**1.50**		**OMC %**		**21.87**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
Reading	in mm	in %		in mm	in %		in mm	in %
Initial	0.50	1.61	Initial	0.25	1.76	Initial	0.50	1.89
Final	2.37		Final	2.30		Final	2.70	



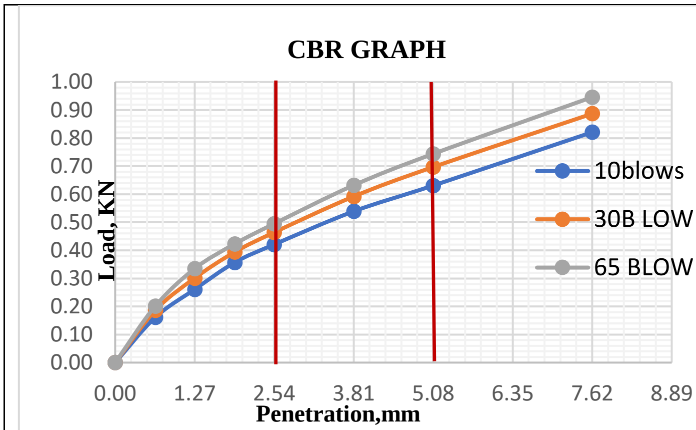


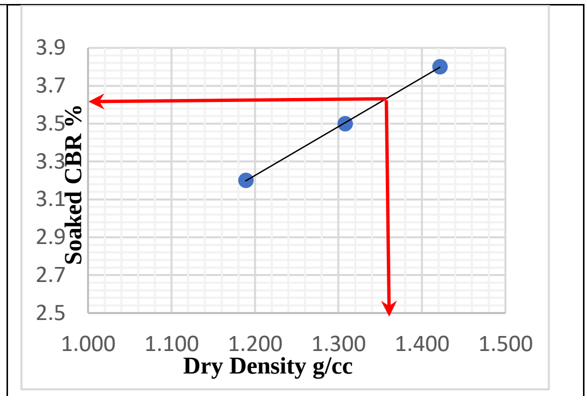
No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %		% Compaction
			Dry Density at 95% of MDD:		**1.425**
10	22.5	1.340	4.8		89
30	21.0	1.421	5.8		95
65	19.1	1.530	6.2		102
CBR (%) @ 95 % MDD			**5.8**	**% Swell**	**1.75**

<u>For Fourteen Day Curing</u>

<u>Soil-Fly ash mix treated by 5 % CKD (14-day curing)</u>

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.201		0.64	0.186		0.64	0.161	
1.27	0.335		1.27	0.301		1.27	0.261	
1.91	0.423		1.91	0.394		1.91	0.357	
2.54	0.495	3.8	2.54	0.464	3.5	2.54	0.421	3.2
3.81	0.632		3.81	0.592		3.81	0.539	
5.08	0.744	3.7	5.08	0.697	3.5	5.08	0.631	3.2
7.62	0.946		7.62	0.887		7.62	0.821	
Modified Max. Dry Density g/cc			**1.40**		**OMC %**		**21.47**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
Reading	in mm	in %		in mm	in %		in mm	in %
Initial	0.40	4.62	Initial	0.7	4.83	Initial	0.90	5.11
Final	5.78		Final	6.32		Final	6.85	



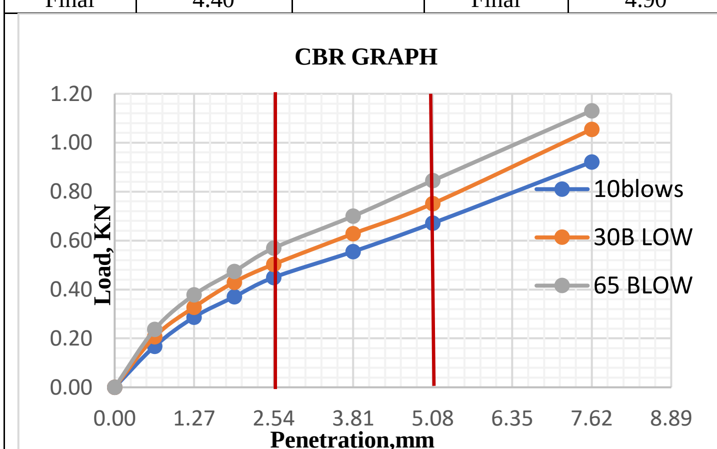


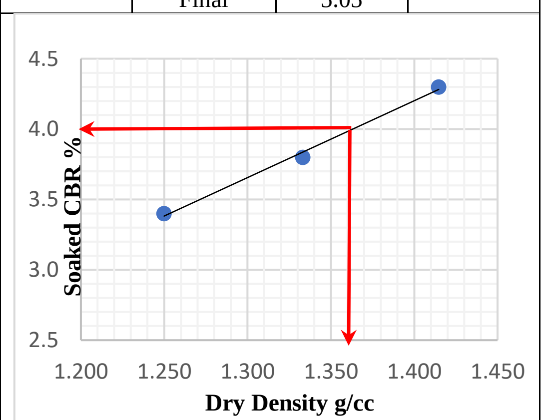
			Dry Density at 95% of MDD:	1.330
No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction
10	25.7	1.189	3.2	85
30	22.9	1.308	3.5	93
65	22.9	1.421	3.8	102
CBR (%) @ 95 % MDD			**3.6** **% Swell**	**4.85**

Soil-Fly ash mix treated by 10 % CKD (14-day curing)

CBR Penetration Determination

Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.237		0.64	0.207		0.64	0.168	
1.27	0.378		1.27	0.328		1.27	0.287	
1.91	0.474		1.91	0.430		1.91	0.370	
2.54	0.569	4.3	2.54	0.503	3.8	2.54	0.449	3.4
3.81	0.700		3.81	0.628		3.81	0.555	
5.08	0.845	4.2	5.08	0.751	3.8	5.08	0.671	3.4
7.62	1.131		7.62	1.055		7.62	0.921	
Modified Max. Dry Density g/cc				**1.43**	**OMC %**		**17.81**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
Reading	in mm	in %		in mm	in %		in mm	in %
Initial	0.40	3.44	Initial	0.7	3.61	Initial	0.50	3.91
Final	4.40		Final	4.90		Final	5.05	



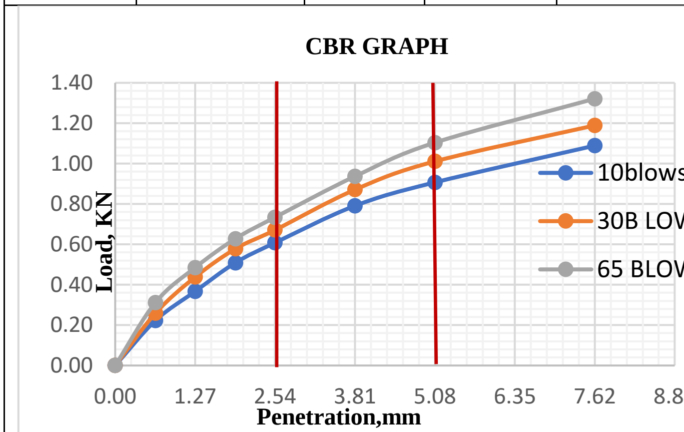


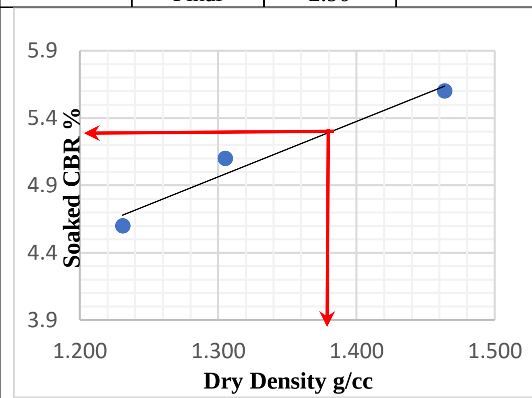
			Dry Density at 95% of MDD:	1.359
No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction
10	23.7	1.250	3.4	87

30	22.0	1.333	3.8		93
65	21.1	1.415	4.3		99
CBR (%) @ 95 % MDD			**4.0**	**% Swell**	**3.65**

Soil-Fly ash mix treated by 20 % CKD (14-day curing)

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.312		0.64	0.259		0.64	0.223	
1.27	0.485		1.27	0.438		1.27	0.367	
1.91	0.628		1.91	0.578		1.91	0.509	
2.54	0.734	5.6	2.54	0.671	5.1	2.54	0.608	4.6
3.81	0.937		3.81	0.871		3.81	0.791	
5.08	1.104	5.5	5.08	1.011	5.1	5.08	0.907	4.5
7.62	1.321		7.62	1.189		7.62	1.089	
Modified Max. Dry Density g/cc			**1.44**		OMC %		**21.40**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
	Reading in %			Reading in %			Reading in %	
Initial	0.20	1.81	Initial	0.40	1.94	Initial	0.50	2.06
Final	2.31		Final	2.66		Final	2.90	



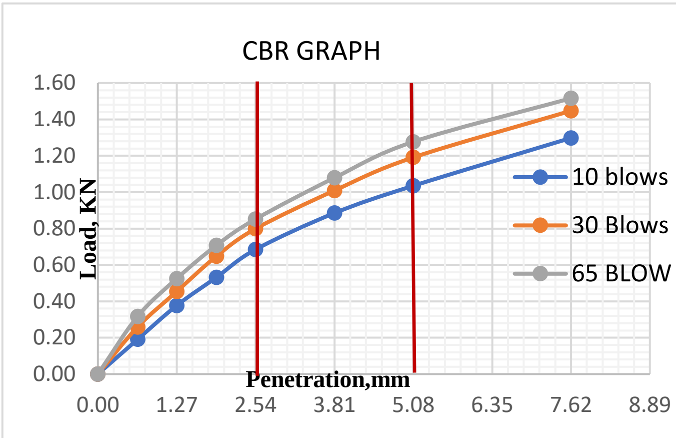


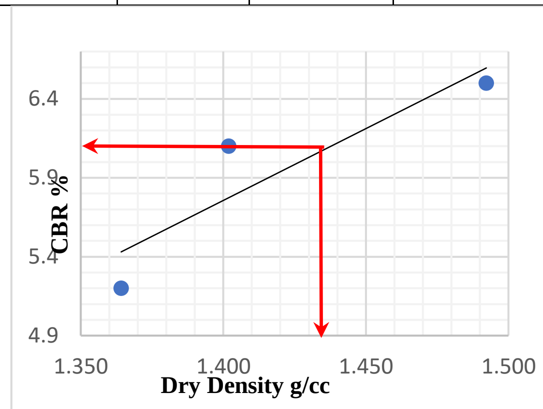
			Dry Density at 95% of MDD:	**1.368**
No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction
10	24.8	1.231	4.6	85
30	23.0	1.305	5.1	91
65	21.0	1.464	5.6	102
CBR (%) @ 95 % MDD			**5.3** **% Swell**	**1.94**

Soil-Fly ash mix treated by 25% CKD (14-day curing)

CBR Penetration Determination								
Penetration after 96 hrs. Soaking Period			Surcharge Weight: -4.55 KG					
65 Blows			**30 Blows**			**10 Blows**		
Pent.mm	**Load, KN**	**CBR %**	**Pent.mm**	**Load, KN**	**CBR %**	**Pent. mm**	**Load, KN**	**CBR %**
0.00	0.000		0.00	0.000		0.00	0.000	
0.64	0.317		0.64	0.259		0.64	0.191	
1.27	0.525		1.27	0.454		1.27	0.377	
1.91	0.708		1.91	0.648		1.91	0.532	
2.54	0.852	**6.5**	2.54	0.799	**6.1**	2.54	0.685	**5.2**

3.81	1.079		3.81	1.009		3.81	0.885	
5.08	1.277	**6.4**	5.08	1.191	**6.0**	5.08	1.035	**5.2**
7.62	1.516		7.62	1.447		7.62	1.298	
Modified Max. Dry Density g/cc			**1.49**		**OMC %**		**21.39**	
Swelling	**65 blows**		**Swelling**	**30 blows**		**Swelling**	**10 blows**	
Reading	in mm	in %		in mm	in %		in mm	in %
Initial	0.50	1.52	Initial	0.25	1.63	Initial	0.50	1.72
Final	2.27		Final	2.15		Final	2.50	



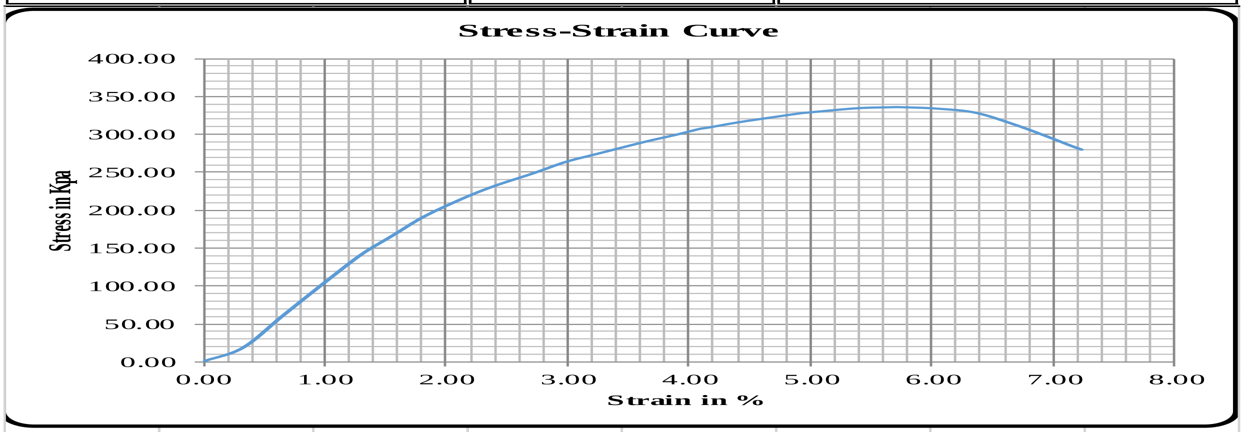


			Dry Density at 95% of MDD:		**1.416**
No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %		% Compaction
10	23.4	1.364	5.2		92
30	21.3	1.402	6.1		94
65	18.1	1.492	6.5		100
CBR (%) @ 95 % MDD			**6.1**	**% Swell**	**1.62**

7. **Unconfined compressive strength test (UCS) of CKD treated Soil-Fly ash mixture**
<u>Seven day cured sample</u>

10% CKD treated with soil-fly ash mixture

Test Type:	Unconfined Compression Test (ASTM D-2166)		
Type of Sample:	Remoled Soil Sample		
Sample:	Sample Light gray Clay Soil		
Pit Code:	Natural+25%FA+10%CKD for 7 day curing		
Sample Height (mm)	Peak UCS, (kPa)	Cohesion, (kPa)	
75	337	168	

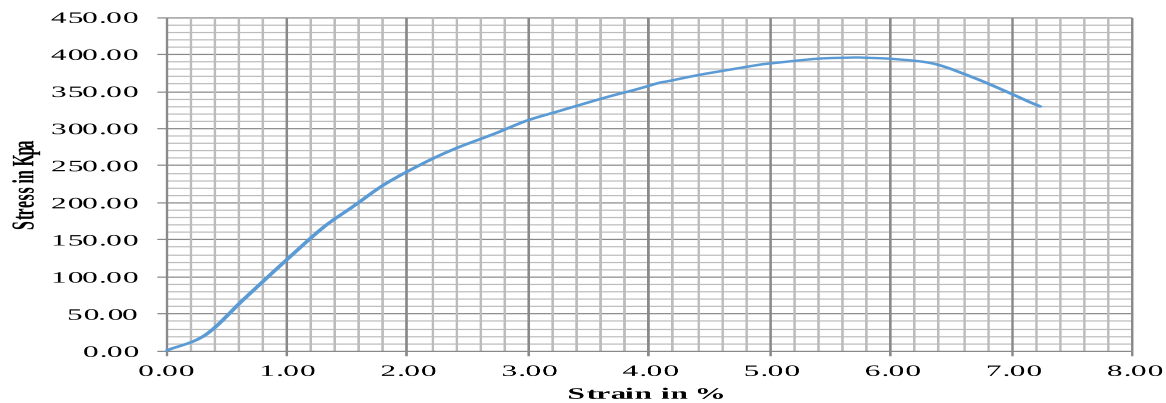


Sample Deformation ΔL (mm)	Load In (N) Trial-1	Sample Heght (mm)	Sample Actule Area (cm^2)	Strain	Strain in %	Corrected Area (cm^2)	Stress (kPa)
0.00	0	75.00	11.34	0.00	0.00	11.34	0.00
0.25	20	77.00	11.34	0.00	0.32	11.38	17.88
0.50	68	77.00	11.34	0.01	0.65	11.42	59.42
0.75	115	77.00	11.34	0.01	0.97	11.45	100.84
1.00	162	77.00	11.34	0.01	1.30	11.49	141.05
1.20	192	77.00	11.34	0.02	1.56	11.52	166.25
1.40	221	77.00	11.34	0.02	1.82	11.55	191.46
1.65	250	77.00	11.34	0.02	2.14	11.59	215.48
1.85	270	77.00	11.34	0.02	2.40	11.62	232.11
2.10	291	77.00	11.34	0.03	2.73	11.66	249.25
2.30	309	77.00	11.34	0.03	2.99	11.69	264.00
2.50	322	77.00	11.34	0.03	3.25	11.72	274.71
2.80	342	77.00	11.34	0.04	3.64	11.77	290.58
3.00	354	77.00	11.34	0.04	3.90	11.80	299.94
3.15	364	77.00	11.34	0.04	4.09	11.82	307.64
3.20	366	77.00	11.34	0.04	4.16	11.83	309.38
3.40	376	77.00	11.34	0.04	4.42	11.87	316.53
3.60	384	77.00	11.34	0.05	4.68	11.90	322.72
3.80	392	77.00	11.34	0.05	4.93	11.93	328.58
3.85	393	77.00	11.34	0.05	5.00	11.94	329.56
4.15	402	77.00	11.34	0.05	5.39	11.99	335.05
4.35	404	77.00	11.34	0.06	5.65	12.02	336.35
4.40	405	77.00	11.34	0.06	5.72	12.03	336.55
4.45	405	77.00	11.34	0.06	5.78	12.04	336.32
4.65	404	77.00	11.34	0.06	6.04	12.07	334.66
4.90	399	77.00	11.34	0.06	6.36	12.11	329.23
5.15	381	77.00	11.34	0.07	6.69	12.15	313.56
5.35	363	77.00	11.34	0.07	6.95	12.19	298.03
5.50	349	77.00	11.34	0.07	7.15	12.21	285.86
5.56	344	77.00	11.34	0.07	7.22	12.22	281.69
5.58	343	77.00	11.34	0.07	7.24	12.23	280.31

20% CKD treated with soil-fly ash mixture

Test Type:	Unconfined Compression Test (ASTM D-2166)
Type of Sample:	Remoled Soil Sample
Sample:	Sample Light gray Clay Soil
Pit Code:	Natural+25%FA+20%CKD for 7 day curing

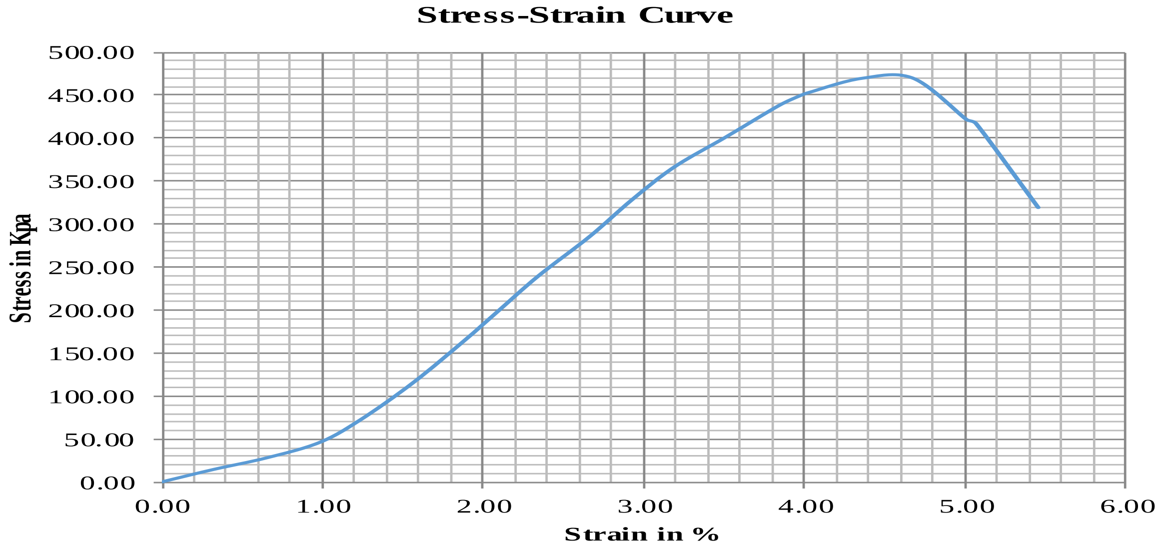
Sample Height (mm)	Peak UCS, (kPa)	Cohesion, (kPa)
75	396	198



Sample Deformation ΔL (mm)	Load In (N) Trial-1	Sample Heght (mm)	Sample Actule Area (cm^2)	Strain	Strain in %	Corrected Area (cm^2)	Stress (kPa)
0	0	75.00	11.34	0.00	0.00	11.34	0.00
0.25	24	77.00	11.34	0.00	0.32	11.38	21.04
0.499	80	77.00	11.34	0.01	0.65	11.42	69.91
0.749	136	77.00	11.34	0.01	0.97	11.45	118.64
1.001	191	77.00	11.34	0.01	1.30	11.49	165.95
1.2	225	77.00	11.34	0.02	1.56	11.52	195.59
1.4	260	77.00	11.34	0.02	1.82	11.55	225.25
1.646	294	77.00	11.34	0.02	2.14	11.59	253.51
1.848	317	77.00	11.34	0.02	2.40	11.62	273.07
2.099	342	77.00	11.34	0.03	2.73	11.66	293.23
2.301	363	77.00	11.34	0.03	2.99	11.69	310.59
2.501	379	77.00	11.34	0.03	3.25	11.72	323.19
2.803	402	77.00	11.34	0.04	3.64	11.77	341.86
3.001	416	77.00	11.34	0.04	3.90	11.80	352.87
3.15	428	77.00	11.34	0.04	4.09	11.82	361.93
3.204	431	77.00	11.34	0.04	4.16	11.83	363.97
3.4	442	77.00	11.34	0.04	4.42	11.87	372.39
3.601	452	77.00	11.34	0.05	4.68	11.90	379.67
3.798	461	77.00	11.34	0.05	4.93	11.93	386.57
3.848	463	77.00	11.34	0.05	5.00	11.94	387.71
4.149	473	77.00	11.34	0.05	5.39	11.99	394.18
4.351	476	77.00	11.34	0.06	5.65	12.02	395.70
4.403	476	77.00	11.34	0.06	5.72	12.03	395.94
4.453	476	77.00	11.34	0.06	5.78	12.04	395.67
4.651	475	77.00	11.34	0.06	6.04	12.07	393.72
4.901	469	77.00	11.34	0.06	6.36	12.11	387.33
5.149	448	77.00	11.34	0.07	6.69	12.15	368.89
5.353	427	77.00	11.34	0.07	6.95	12.19	350.62
5.503	411	77.00	11.34	0.07	7.15	12.21	336.30
5.558	405	77.00	11.34	0.07	7.22	12.22	331.40
5.575	403	77.00	11.34	0.07	7.24	12.23	329.78

25% CKD treated with soil-fly ash mixture

Test Type:	Unconfined Compression Test (ASTM D-2166)	
Type of Sample:	Remoled Soil Sample	
Sample:	Sample Light gray Clay Soil	
Pit Code:	Natural + 25%FA+25%CKD for 7 day curing	
Sample Height (mm)	**Peak UCS, (kPa)**	**Cohesion, (kPa)**
77	**472**	**236**

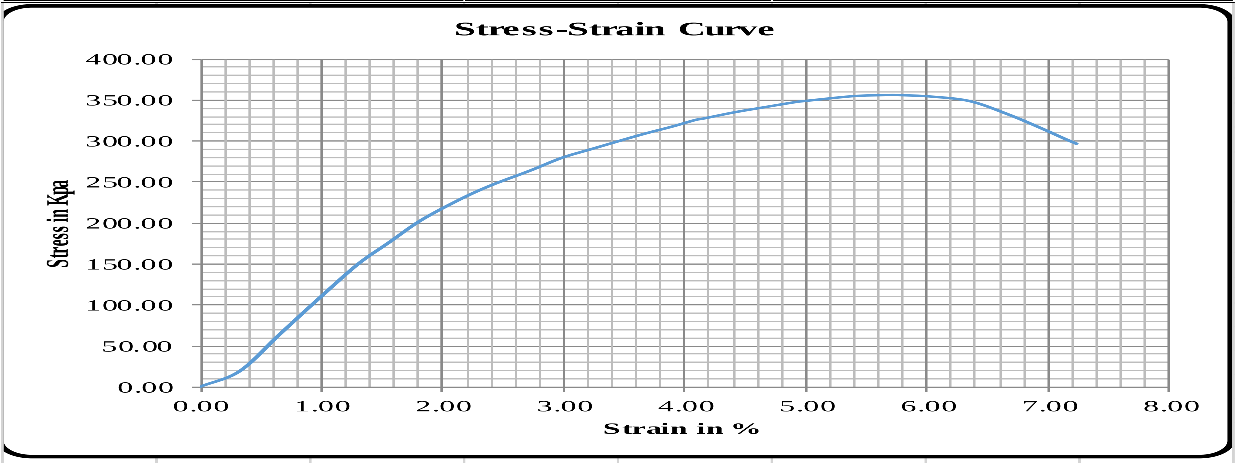


Sample Deformation ΔL (mm)	Load In (N) Trial-1	Sample Heght (mm)	Sample Actule Area (cm^2)	Strain	Strain in % 2	Corrected Area (cm^2)	Stress (kPa)
0.00	0	77.00	11.34	0.00	0.00	11.34	0.00
0.25	17	77.00	11.34	0.00	0.33	11.38	14.62
0.50	32	77.00	11.34	0.01	0.65	11.42	27.75
0.75	52	77.00	11.34	0.01	0.98	11.45	45.54
0.95	83	77.00	11.34	0.01	1.23	11.48	71.90
1.20	133	77.00	11.34	0.02	1.56	11.52	115.54
1.45	190	77.00	11.34	0.02	1.88	11.56	164.45
1.60	228	77.00	11.34	0.02	2.08	11.58	196.45
1.80	277	77.00	11.34	0.02	2.34	11.61	238.91
2.05	333	77.00	11.34	0.03	2.66	11.65	285.63
2.25	383	77.00	11.34	0.03	2.92	11.68	327.87
2.45	429	77.00	11.34	0.03	3.19	11.71	366.05
2.70	471	77.00	11.34	0.04	3.51	11.75	400.78
2.95	516	77.00	11.34	0.04	3.83	11.79	437.14
3.05	530	77.00	11.34	0.04	3.96	11.81	448.73
3.10	535	77.00	11.34	0.04	4.03	11.82	453.04
3.35	556	77.00	11.34	0.04	4.35	11.86	469.32
3.60	558	77.00	11.34	0.05	4.67	11.90	469.35
3.85	503	77.00	11.34	0.05	5.01	11.94	421.35
3.90	498	77.00	11.34	0.05	5.06	11.95	416.53
4.20	383	77.00	11.34	0.05	5.45	11.99	319.07

Fourteen day curing time

10% CKD treated with soil-fly ash mixture

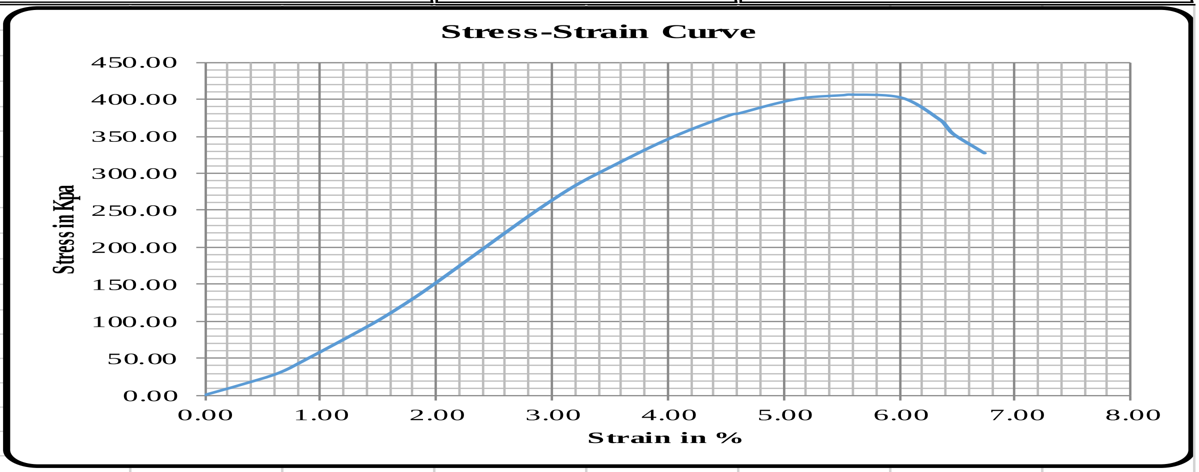
Test Type:DJ185:DQDJ185:DQ	Unconfined Compression Test (ASTM D-2166)	
Type of Sample:	Remoled Soil Sample	
Sample:	Sample Light gray Clay Soil	
Pit Code:	Natural+25%FA+10%CKD for 14 day curing	
Sample Height (mm)	**Peak UCS, (kPa)**	**Cohesion, (kPa)**
75	**356**	**178**



Sample Deformation ΔL (mm)	Load In (N) Trial-1	Sample Heght (mm)	Sample Actule Area (cm^2)	Strain	Strain in %	Corrected Area (cm^2)	Stress (kPa)
0	0	75.00	11.34	0.00	0.00	11.34	0.00
0.25	22	77.00	11.34	0.00	0.32	11.38	18.94
0.499	72	77.00	11.34	0.01	0.65	11.42	62.92
0.749	122	77.00	11.34	0.01	0.97	11.45	106.77
1.001	172	77.00	11.34	0.01	1.30	11.49	149.35
1.2	203	77.00	11.34	0.02	1.56	11.52	176.03
1.4	234	77.00	11.34	0.02	1.82	11.55	202.72
1.646	264	77.00	11.34	0.02	2.14	11.59	228.16
1.848	286	77.00	11.34	0.02	2.40	11.62	245.76
2.099	308	77.00	11.34	0.03	2.73	11.66	263.91
2.301	327	77.00	11.34	0.03	2.99	11.69	279.53
2.501	341	77.00	11.34	0.03	3.25	11.72	290.87
2.803	362	77.00	11.34	0.04	3.64	11.77	307.68
3.001	375	77.00	11.34	0.04	3.90	11.80	317.59
3.15	385	77.00	11.34	0.04	4.09	11.82	325.74
3.204	388	77.00	11.34	0.04	4.16	11.83	327.58
3.4	398	77.00	11.34	0.04	4.42	11.87	335.15
3.601	407	77.00	11.34	0.05	4.68	11.90	341.70
3.798	415	77.00	11.34	0.05	4.93	11.93	347.91
3.848	417	77.00	11.34	0.05	5.00	11.94	348.94
4.149	425	77.00	11.34	0.05	5.39	11.99	354.76
4.351	428	77.00	11.34	0.06	5.65	12.02	356.13
4.403	429	77.00	11.34	0.06	5.72	12.03	356.35
4.453	429	77.00	11.34	0.06	5.78	12.04	356.10
4.651	428	77.00	11.34	0.06	6.04	12.07	354.35
4.901	422	77.00	11.34	0.06	6.36	12.11	348.60
5.149	404	77.00	11.34	0.07	6.69	12.15	332.01
5.353	385	77.00	11.34	0.07	6.95	12.19	315.56
5.503	370	77.00	11.34	0.07	7.15	12.21	302.67
5.558	365	77.00	11.34	0.07	7.22	12.22	298.26
5.575	363	77.00	11.34	0.07	7.24	12.23	296.80

20% CKD treated with soil-fly ash mixture

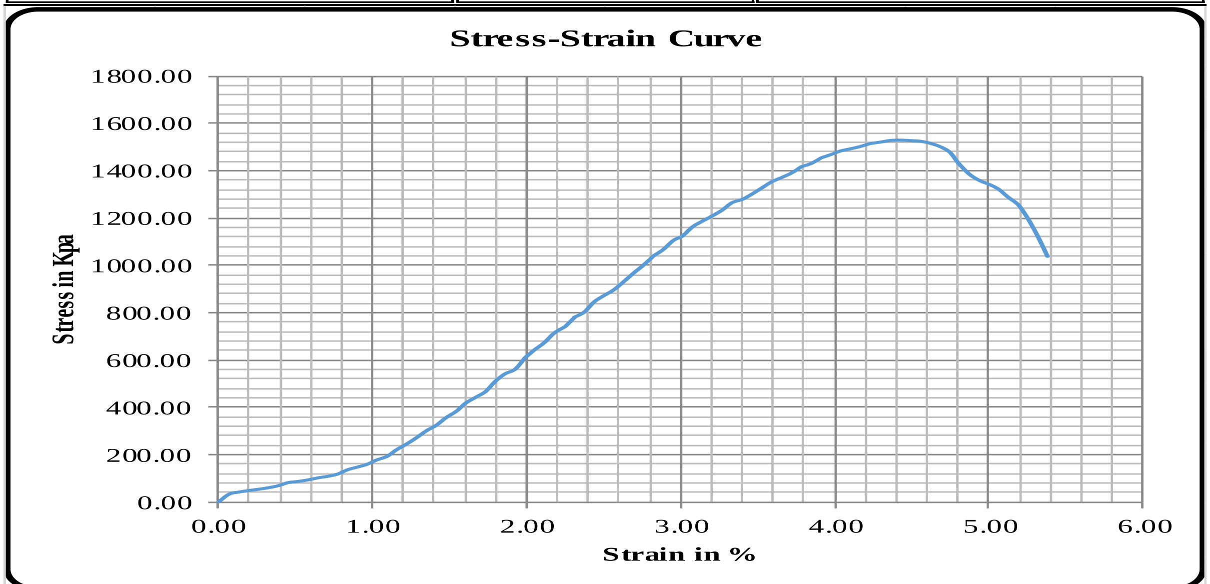
Test Type:+A1:Q23M4A1:Q24/	Unconfined Compression Test (ASTM D-2166)		
Type of Sample:	Remoled Soil Sample		
Sample:	Sample Light gray Clay Soil		
Pit Code:	Natural+25%FA+20%CKD for 14 day curing		
Sample Height (mm)	**Peak UCS, (kPa)**	**Cohesion, (kPa)**	
78	**407**	**203**	



Sample Deformation ΔL (m+A29:H81m)	Load In (N) Trial-1	Sample Heght (mm)	Sample Actule Area (cm^2)	Strain	Strain in %	Corrected Area (cm^2)	Stress (kPa)
0.00	0	78.00	11.34	0.00	0.00	11.34	0.00
0.25	16	78.00	11.34	0.00	0.32	11.38	14.14
0.50	34	78.00	11.34	0.01	0.64	11.41	29.92
0.70	57	78.00	11.34	0.01	0.89	11.44	49.74
1.00	95	78.00	11.34	0.01	1.28	11.49	82.29
1.20	121	78.00	11.34	0.02	1.54	11.52	105.07
1.45	158	78.00	11.34	0.02	1.86	11.56	136.64
1.70	200	78.00	11.34	0.02	2.18	11.59	172.27
2.00	251	78.00	11.34	0.03	2.56	11.64	215.62
2.25	294	78.00	11.34	0.03	2.88	11.68	251.36
2.50	332	78.00	11.34	0.03	3.20	11.72	283.70
2.75	365	78.00	11.34	0.04	3.53	11.76	310.32
3.05	401	78.00	11.34	0.04	3.91	11.80	339.92
3.30	428	78.00	11.34	0.04	4.23	11.84	361.16
3.55	451	78.00	11.34	0.05	4.55	11.88	379.52
3.60	453	78.00	11.34	0.05	4.62	11.89	381.14
3.85	471	78.00	11.34	0.05	4.94	11.93	394.58
4.05	481	78.00	11.34	0.05	5.19	11.96	402.42
4.30	487	78.00	11.34	0.06	5.52	12.00	405.79
4.35	488	78.00	11.34	0.06	5.57	12.01	406.57
4.70	485	78.00	11.34	0.06	6.02	12.07	402.18
4.95	452	78.00	11.34	0.06	6.35	12.11	373.00
5.00	439	78.00	11.34	0.06	6.41	12.12	362.53
5.05	427	78.00	11.34	0.06	6.48	12.13	352.07
5.25	398	78.00	11.34	0.07	6.73	12.16	327.28

25% CKD treated with soil-fly ash mixture

Test Type:	Unconfined Compression Test (ASTM D-2166)		
Type of Sample:	Remoled Soil Sample		
Sample:	Sample -Light gray Clay Soil		
Pit Code:	Natural + 25%FA+25%CKD for 14 day curing		
Sample Height (mm)	**Peak UCS, (kPa)**	**Cohesion, (kPa)**	
78	**505**	**253**	



Sample Deformation ΔL (mm)	Load In (N) Trial-1	Sample Heght (mm)	Sample Actule Area (cm^2)	Strain	Strain in % 2	Corrected Area (cm^2)	Stress (kPa)
0	0	78.00	11.34	0.00	0.00	11.34	0.00
0.25	22	78.00	11.34	0.00	0.32	11.38	19.42
0.503	38	78.00	11.34	0.01	0.64	11.41	33.35
0.751	60	78.00	11.34	0.01	0.96	11.45	52.24
1.053	114	78.00	11.34	0.01	1.35	11.50	99.34
1.301	168	78.00	11.34	0.02	1.67	11.53	145.88
1.551	233	78.00	11.34	0.02	1.99	11.57	201.22
1.699	273	78.00	11.34	0.02	2.18	11.59	235.71
1.9	324	78.00	11.34	0.02	2.44	11.62	278.95
2.149	385	78.00	11.34	0.03	2.76	11.66	330.21
2.349	434	78.00	11.34	0.03	3.01	11.69	371.49
2.599	490	78.00	11.34	0.03	3.33	11.73	417.77
2.851	533	78.00	11.34	0.04	3.66	11.77	453.05
3.052	567	78.00	11.34	0.04	3.91	11.80	480.64
3.248	587	78.00	11.34	0.04	4.16	11.83	496.32
3.298	592	78.00	11.34	0.04	4.23	11.84	500.30
3.552	599	78.00	11.34	0.05	4.55	11.88	503.75
3.803	545	78.00	11.34	0.05	4.88	11.92	457.29
4.051	496	78.00	11.34	0.05	5.19	11.96	414.28
4.101	472	78.00	11.34	0.05	5.26	11.97	394.12