JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

Stabilization of Expansive subgrade soil using Lime and Sorghum husk ash mixed with lime for pavement construction

A final thesis submitted to the school of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Highway Engineering)

By:

Abdirahman Abdilaahi Mohamed

July, 2021

Jimma, Ethiopia

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DECLARATION

I, the undersigned, declare that this thesis entitled "Stabilization of Expansive subgrade soil using Lime and Sorghum husk ash mixed with lime for pavement construction" is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for thesis have been duly acknowledged.

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As Master research Advisors, we hereby certify that we have read and evaluated this MSc research prepared under our guidance, by **Abdirahman Abdilaahi Mohamed** entitled: "Stabilization of Expansive subgrade soil using Lime and Sorghum husk ash mixed with lime for pavement construction". We recommend that it can be submitted as fulfilling the MSc Thesis requirements.

Dr. Getachew Kebede	____________	___________
Advisor	Signature	Date
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ABSTRACT

Expansive soils have considerable volume changes, which related to the change in its moisture content. The sudden change of the volume in the expansive soil can cause major damages to the overlying structures such as highway pavements. Stabilization is one of the methods by which the engineering properties of expansive soil can be improved.

The main objective of this research is to evaluate the feasibility using of sorghum husk ash with lime as a stabilizer of an expansive subgrade soil material. A series of laboratory experiment has been conducted on 0, 2, 4, 6 and 8% lime and a mixture of both by keeping 5% lime constant and varying sorghum husk ash content to 3, 5, 7 and 9% by dry weight of the soil. In this study Atterberg Limits Tests, Particle Size Distribution, soil Classification, Free Swell Index, linear Shrinkage, Specific Gravity, Compaction tests, and CBR tests have been determined. The research design was followed the experimental type of study which begins by collecting samples. The sampling technique used for this research was a purposive sampling which is non– probability method. Two expansive soil samples were taken from different borrow pits in Jimma town, the Hermata - Mentina Kebele and Kito Furdisa by observation and free swell index tests at a depth of 1.50 m to remove organic matter. Sorghum husk ash (SHA) was taken from farmer area in Somali region, Ethiopia and Lime was taken from Sankale Lime Factory.

Result of the chemical composition of SHA shows that the total content of Silicon Dioxide (SiO_2), Aluminum Oxide (Al_2O_3) and Iron Oxide (Fe_2O_3) was 77.30% and specific gravity was 2.27. The chemical properties was fulfilling the requirements according to ASTM C-618. The Hermata - Mentina Kebele soil sample has plastic index 56.85%, free swell index 91.70%, linear shrinkage 18.93%, and CBR value 1.17%. Similarly, Kito Furdisa (Bossa-Addis Kebele) soil sample has plastic index 65.99%, free swell index 111%, linear shrinkage 21.07%, and CBR value 0.92%. Since both the given soil samples were found with high degree of expansion, stabilization was made with mix-ratio 2,4,6 and 8% of only lime and a mixture of SHA3% and L5%, SHA5% and L5%, SHA7% and L5%, and SHA9% and L5%.

Accordingly, CBR-swell value for both soil samples shows a significant reduction as the ratio of SHA-lime material increase. The CBR-Swell for (Hermata - Mentina Kebele) HMK soil sample reduced by 2.52% (from 3.42% to 0.90%) and that of the (Kito Furdisa) KF soil sample reduced by 3.15% (from 4.26% to 1.11%). This result indicates that blending of SHA-lime material to expansive clay soil minimizes the heaving tendency which occurs due to seasonal moisture variations.

Generally, based on the test result performed under this study, the maximum value of CBR for both (Hermata - Mentina Kebele) HMK and (Kito Furdisa) KF soil samples were achieved at 6% lime alone and SHA7% +L5% with CBR value of 8.76% and 8.38%, respectively. And it was the optimum ratio which achieved by most geotechnical parameters of the study. All the laboratory result was compared with standard specifications.

Key Words: Expansive soil, Lime, Sorghum husk ash, Stabilization, Subgrade Strength.

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ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ERA	Ethiopian Road Authority
ASTM	American Society for Testing and Materials
USCS	Unified soil classification system
IS	Indian Standard
CSA	Central Statistical Agency
SHA	Sorghum Husk Ash
L	Lime
GSE	Geological Survey of Ethiopia
CBR	California Bearing Ratio
LL	Liquid Limit
PL	Plastic Limit
PI	Plasticity Index
SHA	Sorghum husk ash
Gs	Specific Gravity
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
LS	Linear Shrinkage
FSI	Free Swell Index
HMK	Hermata Mentina kebele
KF	Kito Furdisa

CHAPTER ONE

INTRODUCTION

1.1 Background

Expansive soil or "black cotton soil" are found in the world parts and it's a very problematic challenge in engineering works such as the construction of buildings and Roads. There is a considerable volume change of the expansive soils, which related to the change in its moisture content. So that, there are two form of volume changes in an expansive soil, which are swelling form and shrinkage form. However, the sudden change of the volume in the expansive soil can cause major damages to the overlying structures. This problem forced us to advance the engineering properties of weak subgrade soil by the way of stabilizing. The swelling behavior of this soil is possibly responsible for the damage of light loaded structures in the form of cracking, while the other aspects of foundation movement cannot be ignored [1]. The shrink-swell behavior of the expansive soils is caused by the forces due to evaporation, transpiration at the surface, and the capillary forces. The moisture seeping by gravity and water rise into the capillary fringe for fine-grained soils are the methods that the moisture can migrate in all directions of the soil. Vapor transfer also plays a vital role in providing the means for the volume increase or swell behavior of expansive soils [2].

Soil stabilization is the alteration of one or more soil properties, by mechanical or chemical means, to create an improved soil material possessing the desired engineering properties. Stabilization for roadway really depends on subgrade stability, which support the main body of road for supporting the design load and Subgrade soil is expected to have a basic desirable characteristics to fulfill the specified requirement of subgrade material, these properties are related to strength, stiffness, and permeability. In Ethiopia there is an increasing demand of naturally occurring construction material which unfortunately not suitable for proposed road construction, for the reason of not fulfilling the standard quality requirement and this also significantly influence on planning, design, construction, and maintenance [3].

From these problems, it is necessary to conduct researches specifically on this clay soil. According to [4] who studied the strength and compressibility behavior of expansive soil treated with coffee husk ash revealed that stabilization is the most used technique adopted to enhance the physical and chemical properties of weak subgrade soil, also this experimental investigation deals with the expansive soil strength after treatment of coffee husk ash.

The shrink-swell behavior and low bearing capacity of expansive soil has not suitable for an engineering works and stabilization been the best way we can improve the engineering properties of this soil, this study was conducted to investigate the untreated and treated of expansive soil by using lime and fly ash [5]. Stabilization is a very important technique that is used to treat problematic subgrade soil from an engineering point of view that is used to altered or preserved the characteristics of weak subgrade soil adopted to enhance the engineering properties and performance of a soil [6].

Sorghum is grown in Ethiopia in 12 of the 18 major agro-ecological zones. It is one of the important indigenous food crops and is only second to tef as injera (leavened local flat bread) making cereal. In the dry land areas of Ethiopia which covers 66 percent of total area, it is the major cereal crops grown. In these areas crop production is mainly rain-fed. Because of the low amount, uneven distribution and erratic nature of the rainfall crop production is seriously affected in these areas [7]. There are several agro-wastes readily available, which have potentials to be used for construction purposes but have not been exploited by construction industry. Among them is SHA which is usually obtained by burning of sorghum husk, a protective shell of sorghum seed [8]. Sorghum husk is one of the main agricultural wastes in milling processes that is available in large quantity. The available methods of handling sorghum husk have serious health and environmental implications. Hence, there is need for proper disposal of this agricultural waste [9].

Due to the growing cost and environmental pollution of traditional stabilizing agents like cement and lime, the need for the economical and environmentally friendly utilization of industrial waste and agricultural wastes for helpful engineering purposes will encourage the investigation and evaluation of the potential sorghum husk ash mixed with lime for the improvement of the expansive soil characteristics related to the strength, permeability, and stiffness; reducing the cost of construction and elimination of the environmental hazards.

1.2 Statement of problem

Expansive soils or Black cotton soils can be found anywhere in the world, its problems are unexpectedly being faced with in foundation engineering designs for highway embankments and other engineering structures. This type of soil is normally found in semi-arid regions of tropical and moderate temperature zones where the yearly evaporation exceeds the precipitation. On the other hand, the presence of montmorillonite minerals in this soil is what characterizes the swell-shrink behavior of it in various seasons [10].

The most abundant problematic soil in Ethiopia is an expansive clay soil which is inappropriate subgrade soil, and it covers about 40% of the area of Ethiopia. Over the past 13 years, 40% of the total road sector development expenses in Ethiopia were allocated for the rehabilitation and upgrading of trunk roads and this problem needs improvement of soil properties by the application of cost-effective and environmentally friendly technique, such as chemical stabilization, to be modified and adopted to the present road construction development in the country [11]. Cities like Addis Ababa, Bahir-Dar, Mekelle, and Jimma as well as main trunk roads are situated on expansive soil. The aerial coverage of expansive soils in Ethiopia is estimated to be 24.7 million acres [12].

SHA because of its plentiful availability and environmental hazard associated with its disposal. This is because the second biggest manufacturer of sorghum worldwide is Nigeria with approximately 6.6 million metric tons being produced in the country every year. About 4 to 11 % content of SHA is produced from burning of sorghum husk. SHA has a good pozzolanic property when properly burnt [8].

The problematic expansive soil can be improved by chemical or mechanical stabilization to enhance its engineering properties. Chemical stabilizers are mostly used to improve the performance of soils with high plasticity, poor workability, and low strength and stiffness. The future investigation will describe the behavioral aspect of soils stabilizes with agricultural waste material Sorghum husk ash (SHA) to improve the load bearing capacity of the expansive soil. The discovery for the use of sorghum husk ash as an expansive soil stabilizer solved the disposal problem faced by abattoir agencies and also reduced the cost of improving infrastructure that is maintenance cost.

1.3 Research Questions

The research will be aimed to answer the following research questions:

1. What are the physical and chemical properties of Sorghum husk ash and properties of expansive soil?

2. What are the potential effects of Sorghum husk ash mixed with lime on engineering properties of expansive subgrade soil?
3. What is the optimum contents of the stabilizer needed to attain the required properties of soils that can be used as subgrade material?

1.4 Research Objectives

1.4.1 General objectives

The general objective of this study is to investigate the suitability of Lime and Sorghum husk ash mixed with lime as a stabilizing agent for road subgrade expansive soil materials.

1.4.2 Specific objectives

The specific objectives of the study are:

- To identify the physical and chemical properties of Sorghum husk ash and properties of expansive soil.
- To investigate the potential effects of Sorghum husk ash mixed with lime on engineering properties of expansive sub grade soil.
- To determine the optimum contents of the stabilizers needed to attain the required properties of soils that can be used as subgrade material.

1.5 Significant of the study

The two basic classifications of soil stabilizers are manufactured products and waste products. The two commonly used manufactured soil stabilizers are lime and Portland cement for the reason of improving the engineering properties of soil, while the bituminous materials sometimes used as stabilizing agents. The production of industrially manufactured stabilizers, such as cement and lime released carbon dioxide gas into the atmosphere during the production process, which is a key and a major reason that causes global warming and that is why we partially replace or mixing this dangerous chemicals by environmentally safe products to reduce the air pollution and other contamination of natural resources such as water and soils.

Furthermore, this research serves as a reference guide for practicing Civil Engineers and researchers that practice in the area of such study. This is useful in the sense that, it will cut down initial costs of new projects which are to commence and add our knowledge on the physical and Engineering behaviors of expansive soils and stabilizers.

1.6 Scope of the study

The scope of this study is to investigate the potential effect of Sorghum husk ash mixed with lime for expansive soil stabilization by using experimental laboratory tests. Two representative sample of expansive soil from different location was collected. The collected samples were disturbed and taken from 1.5 m depth. Sorghum husk ash was collected from Wajaale and the hydrated lime source was from Sankale Lime Factory.

The present study was conducted by taking limited parameters of Grain size analysis, Specific Gravity, Atterberg limits, linear shrinkage, free swell test, moisture density relation, CBR and CR swell tests are used to assess the properties of expansive soil after stabilization with sorghum husk ash and lime. Then the study was comparing the results with ERA, AASHTO and ASTM specification likewise a recommendation was drawn and forwarded.

CHAPTER TWO

LITERATURE REVIEW

2.1 Expansive soils

Expansive soil or "black cotton soil" are found in the world parts and it is a very problematic challenge in an engineering works such as the construction of buildings and Roads. There is a considerable volume change of the expansive soils, which related to the change in its moisture content. So that, there are a two form of volume changes in an expansive soil, which are swelling form and shrinkage form. However, the sudden change of the volume in the expansive soil can cause major damages to the overlying structures. This problem forced us to advance the engineering properties of weak subgrade soil by the way of stabilizing. The swelling behavior of this soil is possibly responsible for the damage of light loaded structures such as cracking of the structure, while the other aspects of foundation movement cannot not be ignored [1]. Expansive soil is referred to as the soil that has shrink-swell behavior after the potential change of moisture content. The movement of expansive soil usually causes extensive structural damages, especially in the pavement or other light structures laying on it. On the other hand, the deformation of this soil cannot be predicted [13].

2.1.1 Origin of Expansive Soil

Expansive soils are originated from two groups of rock materials and the formation of it associated with these groups. The first group contains basic igneous rocks, the igneous rock minerals are decomposed into montmorillonite to form an expansive soil. The second group involves sedimentary rocks, which normally comprises montmorillonite, and the breaking down of this montmorillonite forms an expansive soil [1].

2.1.2 Distribution of Expansive Soil

The distribution of expansive soil in the world is governed by many factors like climate conditions, geology, vegetation, hydrology, and other factors. Expansive soils are mostly found in arid and semi-arid regions of the world. There is an expansive soil in some African countries, including Ethiopia, South Africa, Kenya, Morroco, Ghana, and Zimbabwe also expansive soil occurred in the USA, China, India, Germany, Australia and other European and Asian countries. In those countries, the construction cost rises due to the sudden volume change of the expansive soil [14].

In Ethiopia, the expansive soil covers a significant part of the country. Every civil engineering structures build on expansive soils like roads, commercial buildings, lightweight residential buildings, and proposed railway routes encountered severe damage due to the movement or volume change of the soil. However, the potential problem associated with construction on this soil can form disrupts of the financial and the quality of life of these structures. The distributions are shown in Figure [15].

Figure 2.1 Distribution of Expansive soil in Ethiopia [15]

2.2 Mineralogical structure

2.2.1 General

The minerals of clays are formed by the weathering of rocks and the soil behavior mostly depends on the chemical structure, type and amount of clay minerals, and other factors which are the fundamental factors in controlling the soil behavior. Mostly there are three groups of clay minerals, which are montmorillonite, illite, and kaolinite. The expansive soils contain Montmorillonite clay mineral which causes expansive soil problems[16, 17].

2.2.2 Montmorillonite

Montmorillonite has excessive swelling in a wet period; this behavior can damage the overlying structures such as road pavement. Montmorillonites are formed by an alumna octahedral sheet between two silica tetrahedral sheets like unit comprise. This clay mineral is not stable and is responsible for the damages caused by the expansive soils. Actually, monmorillonite exhibit a considerable attraction for water, with a consequent expansion and swelling [17].

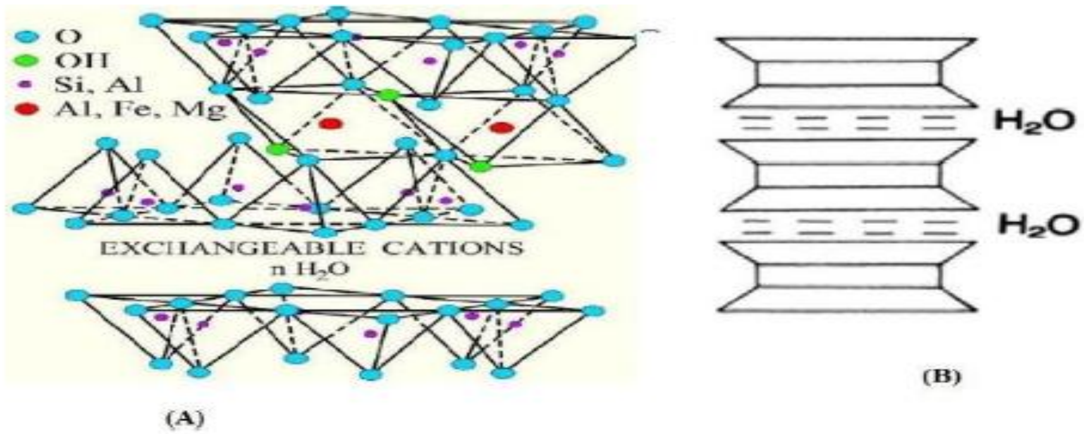

Figure 2.2 Diagrammatic and schematic representation of Montmorillonite [17]

2.2.3 Kaolinite

Kaolinite is reasonably stable and the ability the water to penetrate between the layers is very difficult as a result of very minor swelling in the wet period. Kaolinite structure are made up two layers of (Silica and Alumina) which are tightly held together by a hydrogen bond. The clay mineral called kaolinite is found in the soil undergone a warm and moist climate and they have a low liquid limit [17].

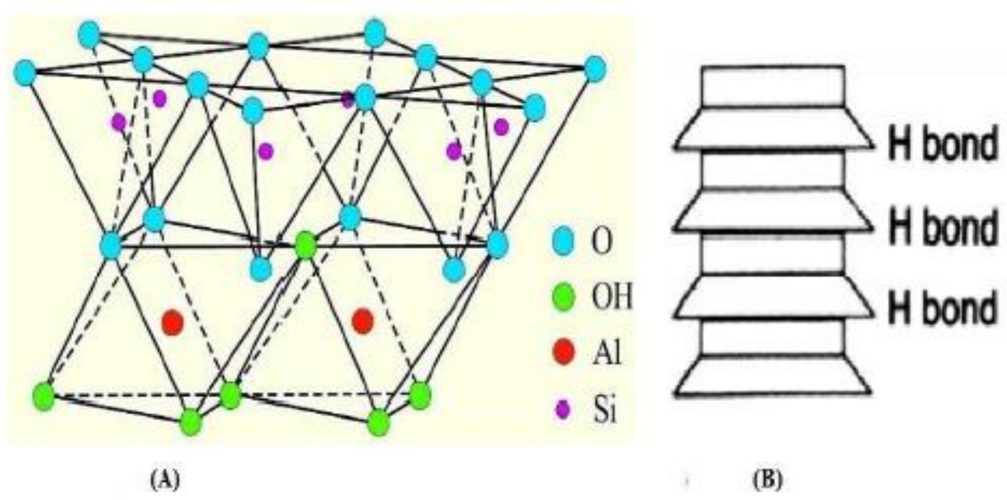

Figure 2.3 Diagrammatic and schematic representation of Kaolinite [17]

2.2.4 Illite

Illite and montmorillonite are somewhat similar to the structural units and differences in chemical composition. The illite particles will normally expand less affinity for moisture than montmorillonites which exhibit great affinity and They have less expansion properties compared to the monmorillonite [17].

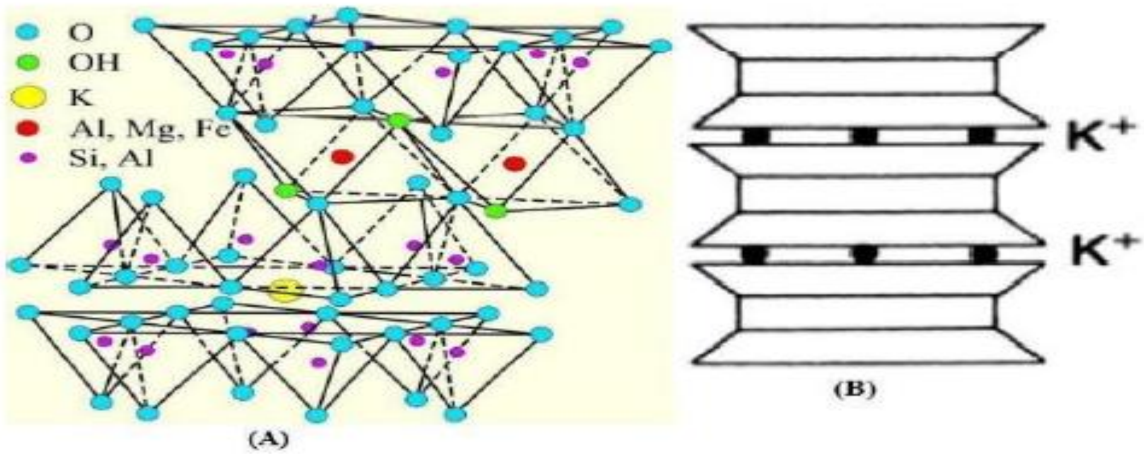

Figure 2.4 Diagrammatic and schematic representation of Illite [17]

2.3 Identification of Expansive soil

2.3.1 General

In general, expansive soil identification consists of two phases. The first phase is a visual identification of expansive soil by observing the deep cracks of it in the dry season and the second phase is a material sampling and measurement to determine the expansive soil properties[16, 17].

2.3.2 Visual Identification

Visual Identification is the estimation of the shrink-swell potential of the expansive soil in the field during preliminary stages of the investigation. Have black or gray color, deep shrinkage crack, stickiness, and low trafficability when wet, high strength in the dry period and low strength in the wet period are the observational importance of visual identification [17].

2.3.3 Laboratory identification

Identification of expansive soil in laboratory can be classified into three different methods which are Mineralogical, indirect and direct methods[16. 17].

2.3.3.1 Mineralogical identification

The swelling behavior of any clay is identified by their mineral constituent and the swelling potential of expansive soil is identified and explained by clay structure and mineralogical ingredient. There are five techniques of identifying the mineral composition of any clay as follows [1].

1) X-ray diffraction,
2) Differential thermal analysis,
3) Dye adsorption,
4) Chemical analysis, and
5) Electron microscope resolution.

2.3.3.2 Indirect Methods

This method has been used to investigate the swelling potential of soil by examining other parameters, which indirectly give information about the soil property. These include Index Property Tests, Cation Exchange Capacity, and Potential Volume Change tests [1]. The liquid limit and plasticity index are useful for determining the swelling characteristics of most of the clays and prepared a chart to support the identification [39].

2.3.3.3 Direct Methods

The second method is called direct measurements. These methods are the most useful data for practicing Engineers. These methods offer the most useful data by direct measurement, and tests are simple to perform and do not require complicated equipment. Testing should be performed on many samples to avoid erroneous conclusions. Direct measurements are the most satisfactory and convenient methods to determine the swelling potential and swelling pressure of expansive clay [1]. Direct measurements of expansive soils can be achieved by the use of the conventional one-dimensional consolidometer. The consolidometer can be platform type, Scale type, or other arrangements. The soil sample is enclosed between two porous plates and confined in a metal lying. The soil sample can be flooded both from the bottom and from the top [1].

Generally, the Ministry of Works and Urban Development (2009) described that in Ethiopia all grayish or brownish clays with a plasticity index greater than 25% can identify as expansive. The classification or rating from low potential to high heaving potential usually depends on the clay content and plasticity. These methods are related to laboratory soil identification and are vital for the intended purposes [13].

2.4 Classification of Expansive soil

A soil classification system is an arrangement of different soils into groups having similar properties. The purpose of soil classification is to make possible the estimation of soil properties by association with soils of the same class whose properties are known and to provide the engineer with an accurate method of soils description [23].

Expansive soils are classified by measuring their swelling potential which can be measured directly in the laboratory or indirectly by correlating with other test results of swell test data. There are some classification systems. The following are some of the standard methods.

2.4.1 General

Most of the classification systems are used to categorize soils by involving their appearance and behavior and the most widely used general classification systems [18].

The two commonly classification system used are:

I. American Association of State Highway and Transportation Officials (AASHTO) System (preferred by Transportation engineers).

II. Unified Soil Classification System (USCS) (preferred by geotechnical engineers)

I. AASHTO soil Classification system

The AASHTO soil classification system is used to determine the suitability of soils for earthworks, embankments, and road bed materials such as subgrade, sub-base and base. According to this classification system, granular soils are soils in which 35% or less are finer than the No. 200 sieve (75 μm). Silt-clay soils are soils in which more than 35% are finer than the No. 200 sieve (75 μm). The system classifies soils into seven major groups, A-1 through A-7. The first three groups, A-1 through A-3 are granular (coarse-grained) soils, while the last four groups, A-4 through A-7 are silt-clay (fine-grained) soils [23]. The group index is a function of the liquid limit, the plasticity index, and the amount of material passing the 0.075mm sieve. Under average conditions of good drainage and thorough compaction, the supporting value of a material may be assumed an inverse ratio to its group index, i.e. a group index of 0 indicates a “good” subgrade material and a group index of 20 or more indicates a poor subgrade material.

Table 2.1 AASHTO soil classification system chart for Granular materials [19].

General Classification	**Granular Materials (35% or less of total sample passing No. 200**						
Group classification	A-1			A-2			
	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7
Sieve analysis (Percentage passing)							
No. 10	50 max.						
No. 40	30 max.	50 max.	51 min.				
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.
Characteristics of fraction passing No. 40							
Liquid limit				40 max.	41 max.	40 max.	41 max.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.
Usual types of significant Constituent materials	Stone fragments, gravel, and sand		Fine Sand	Silt or clayey gravel and sand			
General Subgrade rating	Excellent to good						

Table 2.2 AASHTO soil classification system chart for Silt-clay materials [19].

General Classification	**Silt-clay Materials More than 35% of total sample passing No. 200)**			
Group classification	A-4	A-5	A-6	A-7 A-7-5 A-7-6
Sieve analysis (Percentage passing)				
No. 10				
No. 40				
No. 200	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction Passing No. 40				
Liquid limit	40 max.	41 min.	40 max.	41 min.
Plasticity index	10 max.	10 max.	11 min.	11 min.
Usual types of significant Constituent materials	Silty soils		Clayey soils	
General Subgrade rating	Fair to poor			
aFor A-7-5, Pl ≤ LL – 30				
bFor A-7-6, Pl > LL – 30				

II. Unified soil Classification system

Unified Soil Classification System (USCS) is an another classification system used generally throughout the engineering community and it was adopted by the Bureau of Reclamation and the Corps of Engineers, with Professor A. Casagrande as consultant in 1952 [18].

Table 2.3 category of soils and their letter symbols are as follows [17].

Symbol	Soil Type
G	Gravel and gravelly Soils
S	Sand and sandy Soils
M	Silt
C	Clay
O	Organic Soils
Pt	Peat
W	Well graded
P	Poorly graded
H	High plastic
L	Low plastic

Table 2. 4 Unified soil classification chart for gravelly soil [19].

Gravelly Soils			
Coarse grained soils	more than 50%	Clean Gravels	$Cu \geq 4$ and $1 \leq Cc \leq 3$
	of coarse fraction	Less than 5% fines	$Cu < 4$ and $1 > Cc > 3$
	retaining on No. 4	Gravels with fines	Pl < 4 or plots below "A" line
More than 50% of material is larger than N0. 200 sieve size	Sieve	more than 12% fines	Pl > 7 or plots on or above "A" line
Sands	50% or more of	Clean sand less than	$Cu \geq 6$ and $1 \leq Cc \leq 3$
	coarse fraction passes	5% fines	$Cu < 6$ and/or $1 > Cc > 3$
	No. 4 sieve	Sands with fines	Pl < 4 or plots below "A" line
		more than 12% fines	Pl > 7 or plots on or above "A" line
Fine-grained soils	**Silts and clays**	Inorganic	Pl > 7 and plots on or above "A" line
	Liquid limit less than 50		Pl < 4 or plots below "A" line
		Organic	LL - oven dried/LL – not dried < 0.75
50% or more passes No. 200 sieve	**Silts and clays**	Inorganic	Pl plots on or above "A" line
	Liquid limit 50 or more		Pl plots below "A" line
		Organic	LL - oven dried/LL - not dried < 0.75

2.2 Soil Stabilization

Stabilization is a process of mixing and blending material into the soils to modify their properties in an engineering point of view. In general, there are two types of stabilization process which are Chemical stabilization and Mechanical stabilization. In chemical stabilization, the soil properties are changed and modified by adding chemical active material to the soil. On the other hand, mechanical stabilization is related to the mixing of the soil into other types of soils which have a different grades to change its properties [20]. The stabilization type used in this used in this study is chemical stabilization by adding expansive soil sorghum husk ash and lime.

2.2.1 Uses of stabilization

Pavement design is based on achieving the minimum structural quality of each layer in the pavement system. Each layer must resist shearing, prevent excessive permanent deformation through densification, and avoid excessive deflections that cause fatigue cracking within the layer or in overlying layers. As the quality of a subgrade soil increased, the layer ability to distribute the load over a larger area commonly increased and that helps us the reduction of the thickness of subgrade soil and surface layers [21].

- ✓ Quality improvement: Better soil gradation, reduction of plasticity index or swelling potential, and increases in durability and strength are the most common improvement achieved through stabilization.
- ✓ Thickness reduction: The strength of the soil layer and its stiffness can be enhanced through the uses of additives to permit the design pavement thickness reduction of the stabilized material.

2.2.1 Chemical stabilization

As stated before, Chemical stabilization is a process of changing and advancing the soil properties by altering its chemical structure with different additives such as cement, lime, fly ash, or by the addition of chemicals, enzymes, and resins [20].

2.2.1.1 Cement stabilization

Portland cement consists of calcium-aluminates and calcium-silicates that produce cementing compounds. Portland cement is one of the most established and widely used materials for soil stabilization. However, this cement can be used for the stabilization of almost all types of soils and the quantity of cement required for each type of soil is about 5%–10% in gravels, 7%–12% in sands,12%–15% in silts, and 12%–20% in clays [20].

2.2.1.2 Lime stabilization

Lime stabilization is mostly used for modifying the properties of base materials, subbase materials and subgrade soils, in road projects. The addition of lime is a suitable technique for the stabilization of fine-grained soils by reducing the swelling potential of the clay soils and enhancing its strength. The required lime quantities can be determined on a trial and error basis, keeping in view the strength required of the treated soils [20].

2.2.1.3 Fly ash stabilization

Fly ash is a byproduct of coal-based thermal power plants and is rich in silica and alumina. The fly ash stabilization can be used to modify the properties of soils and to produce a sound platform for construction purposes. When mixed with lime and water, or with lime, cement, and water, the fly ash can effectively stabilize granular soils with little or no fine-material content. Generally, 8%–16% based on the dry weight of soil is used for stabilization [20].

2.2.1 Mechanical stabilization

As mentioned before, Mechanical stabilization is a process used to achieve dense-well graded material by mixing and compacting two or more soils of different grades and/or aggregate. The mechanical stability of mixed soil depends upon several factors like (i) the mechanical strength and purity of the constituent mate-rials, (ii) the percentage of materials and its gradation in the mix, (iii) the degree of soil binding taking place, (iv) the mixing, rolling, and compaction procedures adopted infield, and (v) the environmental and climatic conditions [20].

2.3 Problem associated with expansive soil

Most of the issues related to comprehensive soils arise mostly from the nature of the soil itself and drainage facilities provided. As a result of their low CBR and strength, expansive soils fail to support the loads transmitted from the pavement structure and cause excessive deformation beyond permissible limits. The common problems associated with expansive soils are described below [25].

2.4 Research gaps

Expansive soils have a tendency to put a challenging task for civil engineering applications, efforts have been made by many researchers in trying to offer solutions of this problem by experimenting in modern ways with different materials that could possibly advance engineering properties of the soil, very cost effective, and as well reduce environmental hazards. However, highway engineers need to use materials having acceptable strength, relatively low prices, and being eco-friendly. In order to investigate the potential ability of Sorghum husk ash mixed with lime, in limiting the undesirable effects of expansive soils on road pavements, an array of experimental tests using Sorghum husk ash mixed with lime will be carried out.

2.5 Summary

From the review of literature presented in this chapter, it is found that many researchers are working to reduce the damage posed by the problematic soil by treating/stabilizing the soil by chemical stabilization method. This study will focus on stabilizing the volume change characteristics of the expansive soil by efficiently using Lime and Sorghum husk ash with lime.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Study Area

Jimma town is located about 354 km southwest of Addis Ababa and it has geographical coordinates between 7° 38'52" and 7° 43' 14" N latitude, and between 36° 48' 00" and 36° 53'24" E longitude. The Jimma town has an elevation of 1718 to 2000 meters above sea level, average temperature with the daily mean staying between 20°C and 30°C and an annual rainfall that ranges from 800 to 2500 mm. Jimma had a population of 120,960, according to the Ethiopia central statistical agency (CSA) census report of 2007. The climatic zone of this town, is very appropriate for agriculture as well as human settlement and locally known as Woyna Dega [18]. The main Geological formation of Jimma town is the Cenozoic tertiary volcanic rock of Nazareth series and Jimma volcanic that were formed by lava and debris ejected from fissure eruptions. Basalts, Trachyte, Rhyolite, and Ignimbrite are the major rock types that belong to the trap series formation [17].

Figure 3.1 Map of Jimma Town (Source: Google Earth 2021)

3.2 Study Design

This research was designed to answer the research questions and meet its objectives based on experimental findings. The stages involved in the study were Information gathering and investigating of the study area, Taking samples, Preparation of sample for each laboratory tests, laboratory tests on the treated and untreated expansive soil. The tests done on the treated and untreated expansive soil samples were; Particle size distribution, Specific gravity, Atterberg limit (liquid limit and plastic limit and plasticity index), Proctor compaction test, and California bearing ratio (CBR). Finally, the research findings and recommendations was expressed based on the laboratory test results.

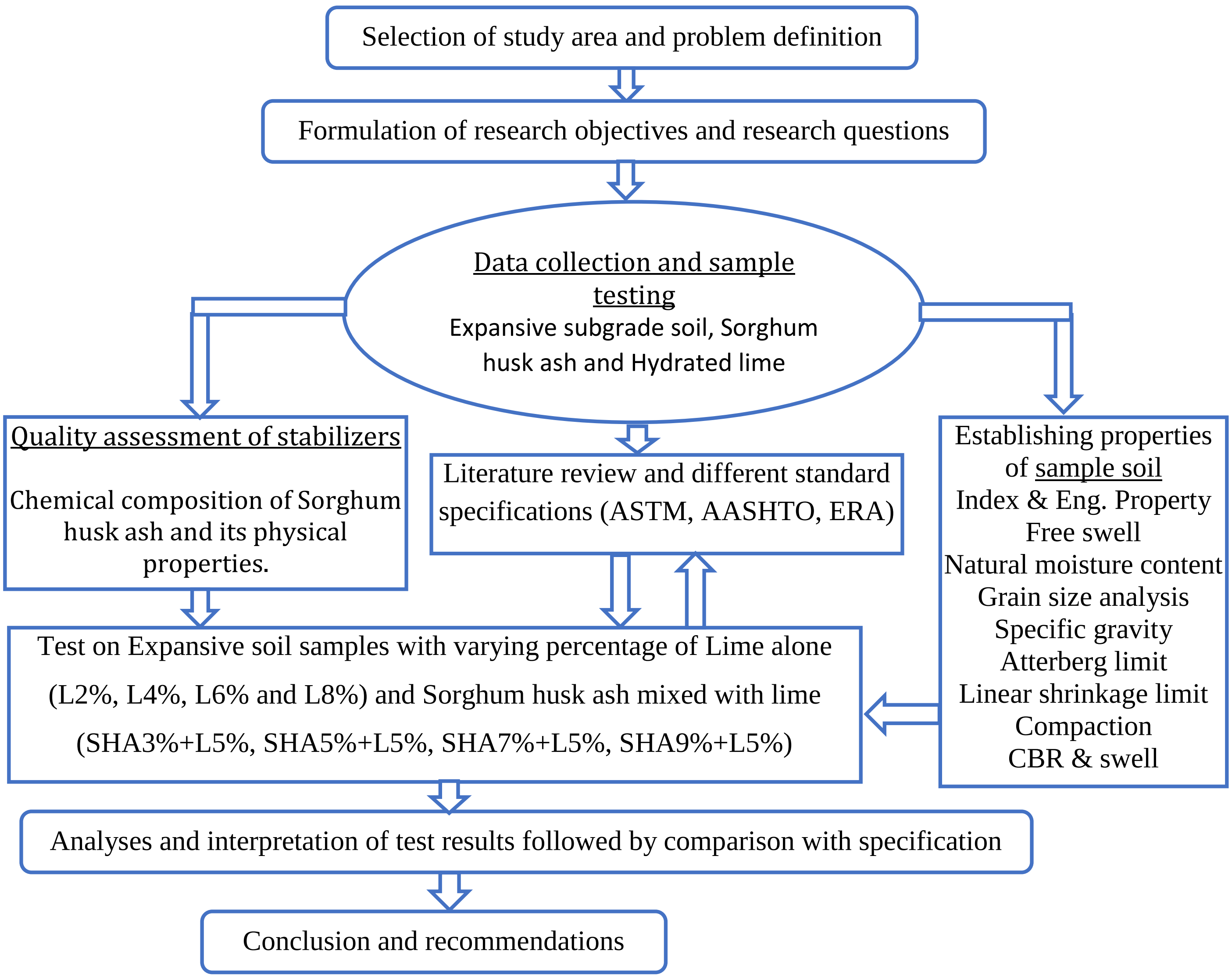

Figure 3.2 Flow chart showing general outline of the study

3.3 Sampling technique

The sampling technique used for this research was a purposive sampling which is non – probability method. This sampling technique was proposed based on goal of the researcher to be achieved and based on the information that to determine the strength of the expansive soil.

3.4 Study Variables

The dependent variables are more related to the general objective of the study. Property of stabilized expansive soil treated with lime and sorghum husk ash mixed with lime was a dependent variable. The independent variables were physical and chemical properties of treated and untreated soil samples and Dosage of lime and sorghum husk ash contents.

3.5 Source of Data

In this study both primary and secondary data sources would be used, Primary research data will be collected through site visits and laboratory experimental outputs, whereas the Secondary data will be collected through reviewing the existing relevant documents, reports, literatures.

3.6 Materials for Laboratory Tests

A. Expansive soil

The two expansive soil samples used in this study is obtained from Jimma town around Hermata Mentina kebele and the second sample were collected from Kifo Furdisa (Bosa-Addis kebele). The soil is Dark gray and black in color respectively. According to ERA, the depth of test pits should not less be than 1.50m from ground level to remove organic matter. Moreover, based on observation and free swell test, expansive soil samples were selected around the Jimma town. Two boreholes were excavated using an excavator and shovel. 200 kilograms disturbed sample was collected at the depth of 1.5m to avoid the inclusion of organic matter.

B. Sorghum husk ash

Sorghum husk is one of the main agricultural wastes in milling processes and collected from Dire Dawa. The sorghum husk was sun dried and then the husk was burnt on an Oven of 900^{o}C temperature to obtain ash form. After that, the ash was allowed to cool before grinding to a very fine texture and then allowed to pass through 750 microns sieve. The fraction passing through the sieved was used during testing as shown in Figure 3-3.

Figure 3.3 Process of Sorghum Husk Ash (SHA) preparation (Picture taken by Eyuel)

C. Lime

The form of lime used in this study was hydrated lime. When the quicklime (Calcium oxide) react rapidly with water it produce hydrated lime (Ca(OH)2) and releasing considerable amount of heat. Twenty-five kilogram of hydrated lime (Ca(OH)2) were donated from Sankale Lime Factory. The chemical composition of Sankale Hydrated Lime studied by [35] and the composition result is presented in Table 3.1.

Table 3.1 Sankale Hydrated Lime chemical composition [35]

Constituent	SiO2	Al2O3	Fe2O3	Cao	MgO	Na2O	K2O	TiO2	P2O5	MnO	SO3
Percentage	6.21	2.18	3.57	59.47	3.91	0.61	0.79	0.3286	0.208	0.2785	0.58

Figure 3.4 Hydrated Lime (Picture taken by Abdirahman)

3.7 Sample Collection

The Expansive soil samples used for this research work is collected from 5 sub grade soils taken from different locations in Jimma town. From those two, most weak soils were selected by observations and free swell index tests, because of time constrain and the intension of the study is to determine the suitability of Sorghum husk ash as subgrade stabilizers, therefore the weakest expansive soil sample believes for representing other populations. Those are Hermata Mentina kebele along the road to Jimma Airport with medium degree of expansion and Kito Furdisa (Bossa-Addisa Kebele) with high degree of expansion properties. The excavation was made manually using the shovel. According to ERA manual, the collected samples for this study were disturbed samples at a depth of below 1.5 m to remove organic matter.

Figure 3.5 Photo of soil sample collection (Picture taken by Ahmed)

3.8 Experimental setup

For the stabilized soil mixtures, specimen were prepared carefully and completely mixed dry quantities of pulverized soil sample with lime alone ith varying proportions of 2, 4, 6, and 8% and the mixture of lime and sorghum husk ash with a fixed optimal amount of hydrated lime 5% by weight of soil sample and varying proportions of 3, 5, 7 and 9% SHA by referring previous studies. Lime will first be added to the pulverized, sieved and air-dried soil sample and dry mixed thoroughly. SHA was added after that and wet mixing was done by sprinkling the measured amount of water followed by a thorough mixing until a uniform soil-additive matrix was obtained.

Conduct laboratory tests with a mixture of lime and sorghum husk ash with different ratios to determine engineering properties to attain the set specific objectives. Also, each test was repeated three times to get a representative result.

The optimum stabilizing ratio for maximum improvement of the engineering properties of the soil was assessed and the result from the laboratory test was compared with the standard and specification of AASHTO and ERA. Finally, the research findings and recommendations were be forwarded based on the laboratory results.

3.9 Laboratory tests

Tests for soil classification which included grain size distribution, free swell, specific gravity, and Atterberg limits. These are indicative tests that are usually used for identifying whether the soil is expansive or not. The conducted tests however included wet sieve analysis, hydrometer analysis, Atterberg limits, specific gravity, moisture density relation, free swell, linear shrinkage, CBR and CBR swell to fully characterize and attain the objective of the research

39.1 Chemical properties of sorghum husk ash (SHA)

Chemical composition of SHA was tested as per ASTM C 618. The ash was analyzed to determine the composition of its constituent chemicals and its suitability as a pozzolana by using X-ray fluorescence equipment (Spectro X-lab). For this test 10 g of SHA sample was taken and put it into the container and the container has a provided space in the equipment, and also the equipment is digital, it is connected with computer. Finally, the percent composition of the oxide constituents of the SHA was recorded from computer and test results are shown in table 4.1.

3.9.2 Subgrade soil

3.9.2.1 Natural Moisture content

The moisture content of the expansive soil which is defined as the ratio between mass of water to mass of soil solid was determine immediately after the sample was taken from the site according to (AASHTO T-256). The samples from the site are placed in plastic bags to prevent moisture loss during transportation from site to laboratory. The oven-drying method was used to determine the moisture contents of the disturbed soil samples. The samples were then weighed as received and placed in moisture can, oven-dried at 105°C for 24 hours and examined for weight loss. The result of moisture content determination is attached in appendix H.

3.9.2.2 Sample preparation

The samples were prepared in accordance with the method described in AASHTO T87-86. The soil moist samples were properly air dried then soil boulders were pulverized and additives were mixed in such a way that the additive is first added to the prepared sample and dry mixed with the soil. The weak expansive soil was mixed with SHA and lime by percentage of the weight of soil taken for each test starting from 0% to 9% within 2% difference for SHA and 5% constant percentage of lime.

3.9.2.3 Grain size Analysis

The grain-size analysis is carried out to determine the relative proportions of different grain sizes which makes up a given soil mass. The mechanical or wet sieve analysis is performed to determine the distribution of the coarser, larger-sized particles larger than (75 μm) while hydrometer analysis method is used to determine the distribution of the finer particle size smaller than (75 μm). For this study both wet sieve analysis and hydrometer analysis was done according to ASTM D422-63.

Figure 3.6 Photo of both wet sieving and hydrometer analysis (Picture taken by Ahmed)

3.9.2.4 Soil Classification

The most widely used soil classification systems for engineering purposes are American Association of State High Way and Transportation Officials (AASHTO) and Unified soil classification system (USCS). The AASHTO system of soil classification comprises seven groups of inorganic soils from A-1 to A-7 with 12 subgroups in all. The system is based on particle-size distribution, liquid limit and plasticity index. On the other hand, the Unified Soil classification system is based on the recognition of the type and predominance of the constituents considering grain – size, gradation, plasticity and compressibility. It divides soil in to three major divisions: coarse grained soils, fine grained soils and highly organic soils.

3.9.2.5 Specific Gravity

The specific gravity (Gs) is the measure of heaviness of the expansive soil, sorghum husk ash, lime and was determined by using the small pycnometer method using a soil sample passing 2mm sieve and oven dried at 110±5^o degrees centigrade. It is defined as the ratio of the mass in air of a given volume of soil particles to the mass in air of an equal volume of gas free distilled water at a stated temperature. The specific gravity test was conducted on the soil in accordance with ASTM D 854-98 testing procedure.

Figure 3. 7 Photo of Specific gravity Test (Picture taken by Abdirahman)

3.9.2.6 Atterberg Limit

The nature and response of soil upon change to moisture content is determined by Atterberg limit tests. Atterberg limits (liquid limit, plastic limit and plasticity index) were determined according to AASHTO T 89-90 and T90-96 testing procedures. A sample weighting about 250gm was taken from the mixture prepared for liquid limit and plastic limit test for each samples. Liquid limit is the water content at which a soil changes from the liquid state to a plastic state. Casagrande apparatus was used to determine the liquid limit of each soil using the material passing through

No. 40 sieve (425μm) sieve. Plastic limit is the water content at which a soil changes from the plastic state to a semisolid state. This is determined by rolling out soil till its diameter reaches approximately 3 mm and measuring water content for the soil which crumbles on reaching this diameter. Plasticity index of the natural soil and the mixture of soil, SHA and Lime is the difference between the liquid limits and their corresponding plastic limits. The plasticity index was then computed for each soil based on the liquid and plastic limit obtained.

Figure 3. 8 Photo of Atterberg limit determination (Picture taken by Abdirahman)

3.9.2.7 Free swell index

The free swell test is one of the most frequently used simple tests to estimate the swelling Potential of expansive clay. This test has not yet been standardized by AASHTO and ASTM. According to Holtz and Gibbs (1956), the free swell test is defined as the ratio of the increase in volume of the soil from a loose dry powder form to the equilibrium sediment when it is poured into water, expressed as the percentage of the original volume. But, in this research Indian standard IS 2720 (part XL) was used. The test is performed by pouring, two (10g) of oven dry soil passing a sieve size of 0.425mm (No. 40), into a two different 100ml graduated cylinder. One cylinder was filled with distilled water and the other was filled kerosene up to 100ml mark. Samples are left undisturbed for 24 hours. Then the swelled Volume of the soil after the material settles (24hr) is measured to calculate the free swell index (FSI). The free sell index of the soil shall be calculated as follows:

$$\text{Free Swell Index} = \frac{\text{Final volume of in water} - \text{Final volume in kerosene}}{\text{Final volume in kerosene}} \times 100 \text{.................. (3.1)}$$

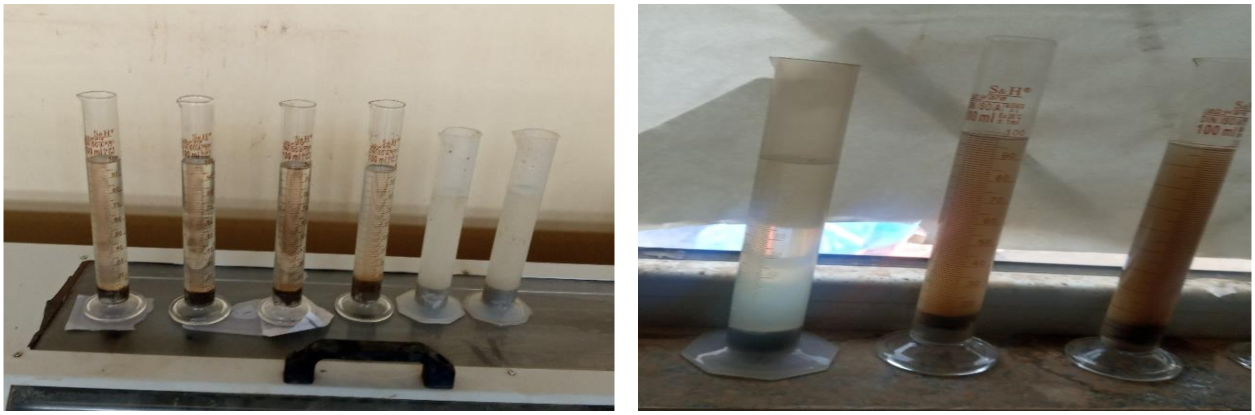

Figure 3. 9 Photo of Free Swell Index test

3.9.2.8 Linear Shrinkage Test

Linear shrinkage is a measure of how a sample will reduce in length upon complete drying expressed as a percentage of the original length. This test was carried out to determine the linear shrinkage characteristics of the natural soil as well as the stabilized soil, when various percentages of Sorghum husk ash mixed with lime were used and this test followed by British standard (BS1377: Part 2:1990). A standard bar of length 140 mm with a semicircular section of diameter 25 mm was filled with soil sample passing through 0.425mm (No. 40) test sieve originally having the moisture content of the liquid limit was then put in to the oven. The linear shrinkage of the soil shall be calculated as follows:

$$\text{Linear Shrinkage} = \frac{\text{Original length of the mold} - \text{Length of dry specimen}}{\text{Original length of the mold}} \times 100. \text{ .... (3.2)}$$

Figure 3. 10 Photo of Linear Shrinkage Test (Picture taken by Eyuel)

3.9.2.9 Compaction Test

Modified Proctor compaction test gives a clear relationship between the dry density of the soil and the moisture content of the soil accordance with AASHTO T99-94 testing procedures. The test was performed on disturbed samples of soil passing sieve sizes 19mm mixed with water to form samples at various moisture contents ranging from dry state to wet state. 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 termed optimum moisture content (OMC).

Figure 3. 11 Photo Compaction test and procedures (Picture taken by Ahmed)

3.9.2.10 California Bearing Ratio Test

The CBR test measures the Penetration resistance of a soil under controlled moisture and density conditions; it is aimed at determining the relationship between force and penetration. The three point CBR and CBR-swell tests were carried according to AASHTO T193-99 testing procedures for the both natural soil samples and the treated soil samples with SHA and lime. The soil sample is compacted in five different layers for each mold and the molds have a different number of blows (65, 30, and 10). The compacted soil samples of the CBR mould are soaked for 96 hours in a water bath to get the soaked CBR value of the soil. The CBR values at 95% MDD was determined and the equation to be computing the CBR value. The CBR of the soil shall be calculated as follows:

$$\text{CBR (\%)} = \frac{\text{Applied load on sample}}{\text{standard load on the crushed stone}} \times 100 \quad (3.3)$$

Figure 3. 12 Photo of CBR test procedure (Picture taken by Ahmed)

3.9.2.11 California Bearing Ratio (CBR Swell) test

The CBR swell of the soil is measured by placing the tripod with the dial indicator on the top of the soaked CBR mold in the bath. The initial dial reading of the dial indicator on the soaked CBR mold is taken just after soaking the sample. At the end of 96 hours the final dial reading of the dial indicator is taken hence the swell percentage of the initial sample is given. The CBR swell of the soil shall be calculated as follows:

$$\text{CBR Swell (\%)} = \frac{\text{Change length in mm during soaking}}{116.43\text{mm}} \times 100 \qquad (3.4)$$

3.10 Symbolization

For this study sample collected from two different sites one of them is Hermata Mentina kebele along the road to Jimma Airport was abbreviated as HMK and the other is Kito Furdisa (Bossa-Addis Kebele) was abbreviated as KF. Additionally, Sorghum husk ash and Lime were also abbreviated as SHA and L respectively.

3.11 Summary of chapter three

In this chapter the test material and their characterization have been determined. The test method of sample preparation and test procedure are discussed. The details of planning of the experiment have been presented. The result of the experimental tests are analyzed and discussed in the subsequence chapter.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the laboratory experimental test results and discusses underlying issues with results obtained. The relevant engineering property of the soil is evaluated both for untreated and treated soil samples with lime and sorghum husk ash and lime combination mixtures. The tests include Atterberg limits, moisture-density relation, linear shrinkage, free swell index, CBR, and CBR swell values were investigated by varying percentage of lime from 2% to 8% by 2% increment and Varying percentage of sorghum husk ash from 3% to 9% by 2% increment with constant 5% of lime and compared with native soil/untreated soil engineering properties.

4.2 Properties of Materials

4.2.1 Sorghum husk ash (SHA)

The reactivity of pozzolanic reaction depends on the properties of the Pozzolana such as the chemical and mineralogical composition, particle size, and surface area. In addition, Pozzolana reactivity can also affected by external factors such as the mix proportions, the amount of water, curing time and temperature. The chemical composition of SHA was shown in Table 4.1 and the physical properties of sorghum husk ash were summarized in Table 4.2.

Table 4.1 Chemical composition of Sorghum Husk Ash (SHA)

Oxide composition	**Test Result in (%)**	**Requirement ASTM C-618 (%)**	**Remark**
SiO2	55.30	35 Min	Satisfied
AL2O3	10.10		
Fe2O3	11.90		
CaO	10.40		
MgO	1.40	5 Max	Satisfied
Na2O	0.70		
K2O	4.50		
SiO2 + Al2O3 + Fe2O3	77.30	70 Min	Satisfied

As test result indicates the combined percent composition of main oxides (SiO2, Al2O3 & Fe2O3) was 77.30% which is above the minimum of (70%) specified by ASTM (C618) which is acceptable as a good Pozzolana. Sorghum huska ash is non-plastic in nature.

Table 4.2: Physical properties test results of SHA

Properties	Symbol	Test result
Plasticity index, (%)	PI	Non plastic
Specific Gravity	Gs	2.27

4.2.2 Properties of untreated soils

In order to determine the quality of the materials, laboratory tests were carried out on both HMK and KF untreated soil samples. The laboratory results of the tests conducted for identification and/or determination of properties of the natural soil on both HMK and KF before treating with SHA and lime are presented in Table 4.3.

Table 4.3 General Geotechnical properties of both soil samples

Parameters	Laboratory Results (%)	
	HMK soil sample	KF soil sample
Natural Moisture Content, %	45.52	42.39
Percentage of passing No.200sieve	93.65	95.64
Liquid limit (%)	92.96	105.24
Plastic limit (%)	38.62	36.30
Plasticity index (%)	54.34	68.80
Linear Shrinkage (%)	18.93	21.07
AASHTO classification system	A-7-5 (62.11)	A-7-5(79.28)
USCS	CH	CH
Specific Gravity	2.70	2.68
Free swell index, (%)	91.7	111
Maximum dry density, (g/cm3)	1.36	1.38
Optimum moisture content, (%)	32.46	33.21
Soaked CBR value, (%)	1.17	0.94
CBR-swell, (%)	3.42	4.26
Color	Grayish black	Black

4.2.2.1 Grain size analysis

Grain size distribution is a common method used in classification of soils. Distribution of particle sizes greater than 0.075 mm is determined by wet sieving, and the distribution of particle sizes smaller than 0.075 mm is determined by hydrometer test. For hydrometer test sodium hexametaphosphate is using as dispersing agent. The Grain size distribution test results for both HMK and KF natural soil samples are given in Figure 4.1, Figure 4.2 and The detailed grain size analysis test results of both soil samples are attached in Appendix E.

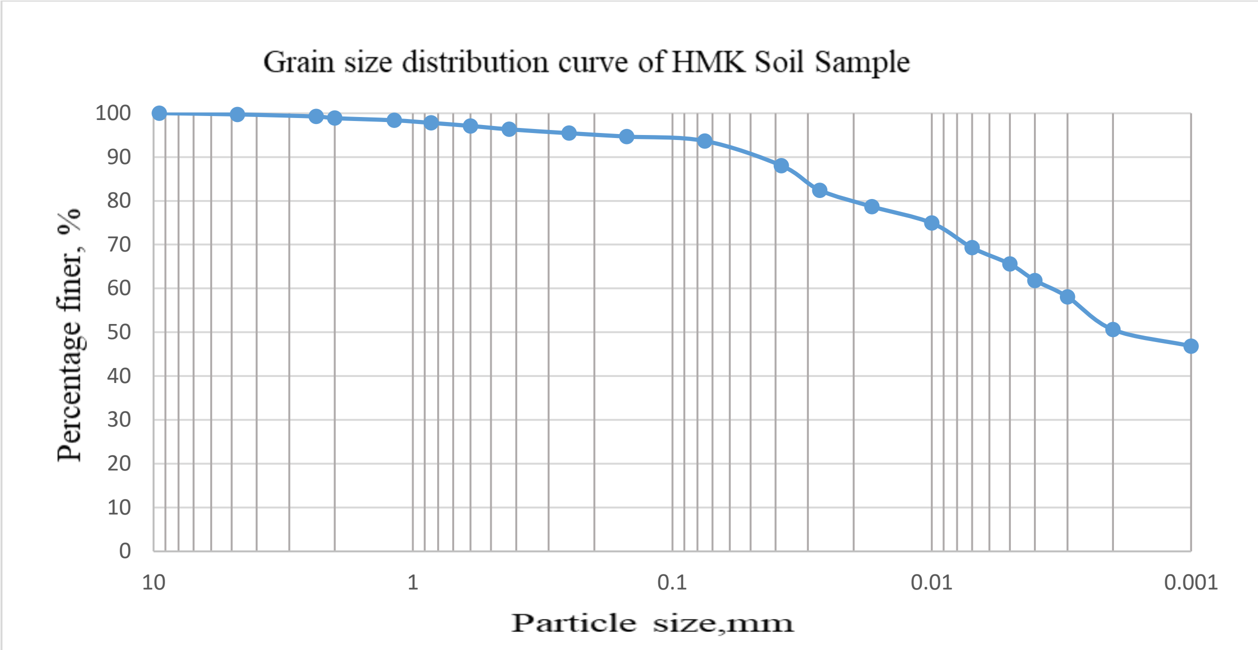

Figure 4.1 Grain size distribution curve of HMK untreated soil sample

The soil sample from HMK was Grayish black in color, and 93.65% of the soil was passing through No.200 sieve (75µm), this indicates that, almost the given soil sample was clay soil as were presented in Figure 4.1.

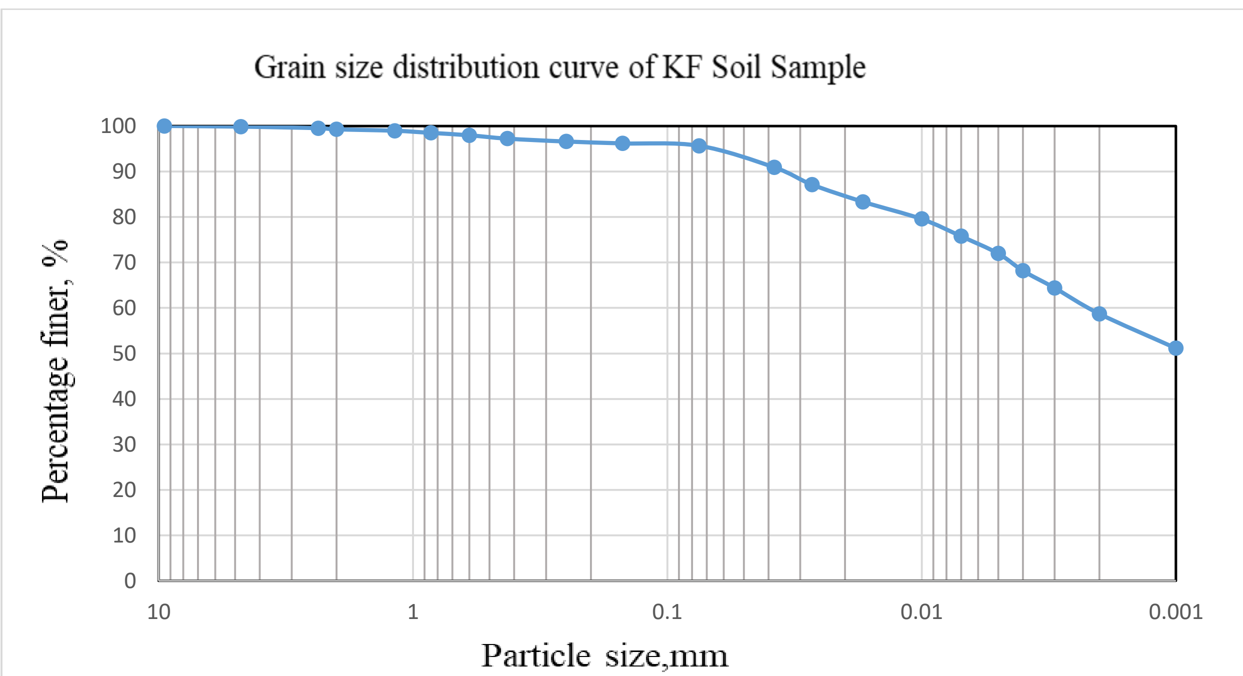

Figure 4.2 Grain size distribution curve of KF untreated soil sample

The soil sample from KF was dark gray in color, and 95.64 % of the soil is passing through No.200 sieve (75µm), this indicates that almost all given soil sample was a clay soil as were presented in Figure 4.2.

4.2.2.2 Atterberg limit test on natural subgrade

Atterberg limits test is a consistency Limit identification test on the basis of moisture content. Atterberg limits determination of liquid limit, plastic limit and plasticity index for the HMK and KF natural soil samples were determined according to AASHTO T 89-90 and T90-96 testing procedures. The soil samples obtained from HMK and KF were subjected to varying water content and the Atterberg test results summary for both HMK and KF natural soil samples are tabulated below in table 4.4. While the detailed laboratory data analysis of the soil samples Atterberg limits was shown in appendix A.

Table 4.4 Atterberg Limit test results of untreated soil samples

Sample location	Atterberg limits		
	Liquid Limit (%)	**Plastic Limit (%)**	**Plasticity Index (%)**
HMK	92.96	38.62	54.34
KF	105.10	36.30	68.80

The soil samples of HMK and KF have Liquid Limit of 92.96% and 105.10% and also have Plasticity Index of 54.34% and 68.80% for both soil sample respectively. As result of Liquid Limit and Plasticity Index indicates both the native subgrade soil samples have poor for sub grade material unless it treated according to ERA-a (2013) specification.

4.2.2.3 Soil Classification

4.2.2.3.1 AASHTO Soil Classification System

According to AASHTO Classification system as shown in table 4.5, and figure 4.3 can be concluded that both MHK and KF soil samples fall under the A-7-5 soil class, which were clayey soils with group index of 62.11 and 79.28 respectively. The group index results indicate that generally the soils of the study area were very poor engineering property to be used as a sub-grade material. The soil samples are grayish black and black in color respectively.

Table 4.5 Classification of soil samples based on AASHTO classification system

Sample location	Sieve Analysis Percentage of Passing			LL %	PI %	LL - 30	Group Index	Soil Group	Material Type
	No.10	No.40	No.200						
HMK	98.85	96.30	93.65	92.96	54.34	62.96	62.11	A-7-5	Clay
KF	99.25	97.20	95.64	105.10	68.80	75.10	79.28	A-7-5	Clay

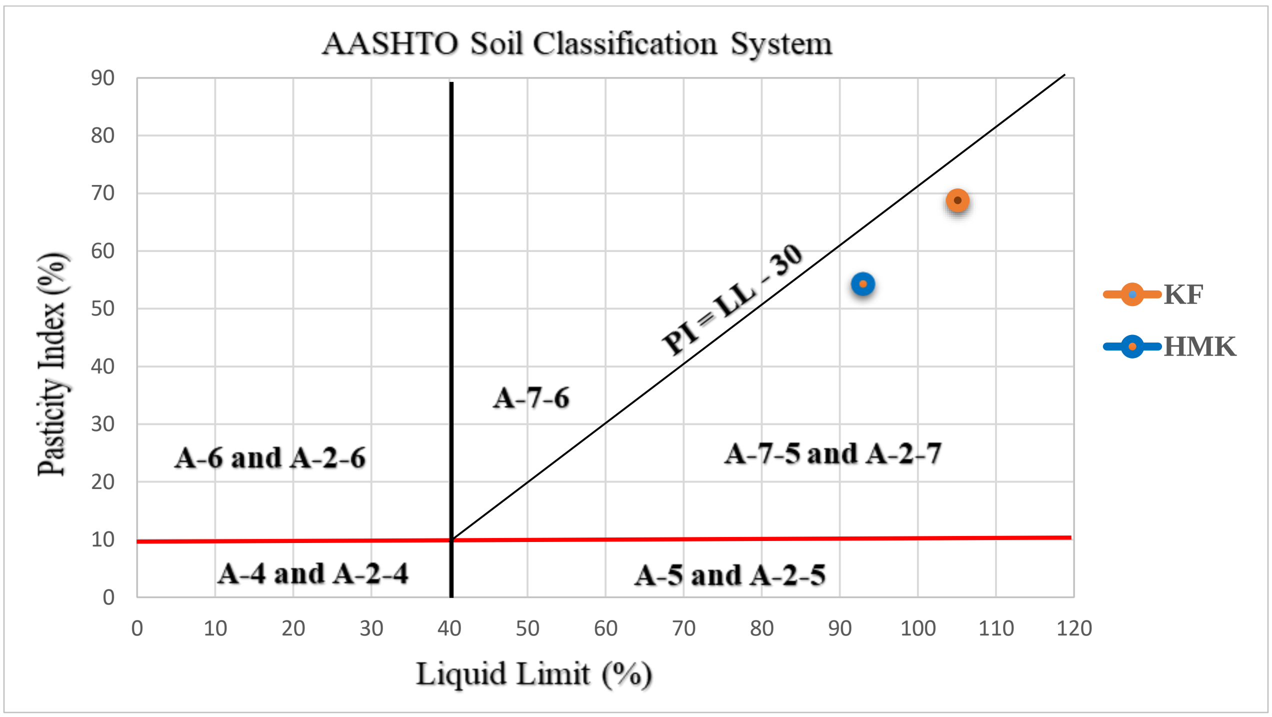

Figure 4.3 Plasticity chart of untreated soil samples according to AASHTO

According to the AASHTO soil classification system, both of the HMK and KF soil samples have been classified as A-7-6, have found to have group index value above 20. Soils under this category are classified as a material of reduced engineering property to be used as a sub-grade material.

4.2.2.3.2 Unified Soil Classification System

According to USCS Classification system as shown in table 4.6, and figure 4.4 can be concluded that both MHK and KF soil samples lie above the A- line in CH region, which means clayey soils with high plasticity.

Table 4.6 Classification of soil samples based on USCS classification system

Sample location	Minimum sampling depth(m)	Quantity of grain size				LL %	PI %	USCUS Classification
		Gravel	Sand	Silt	Clay			
HMK	1.5	0.29	6.06	39.60	53.46	92.96	54.34	CH
KF	1.5	0.16	4.20	32.73	59.68	105.10	68.80	CH

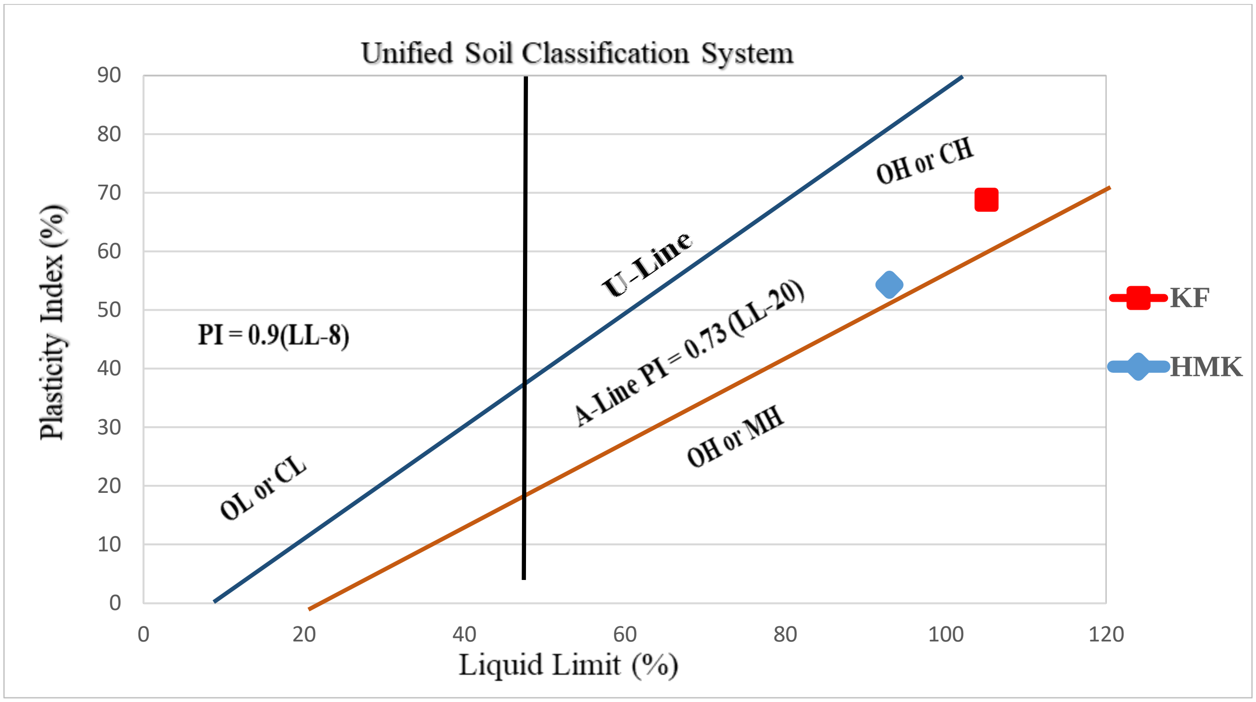

Figure 4.4 Plasticity chart of untreated soil samples according to USCS

According to Unified soil classification system, both soil samples fall under CH (Fat clay) and soils under this category are classified as a material of reduced engineering property to be used as a sub-grade material.

4.2.2.4 Specific Gravity

The specific gravity of soil is an important weight-volume property that is helpful in classifying of soils. For the present study the specific gravity of soil were determined by using a pycnometer according to AASHTO T100-95. The test was done at 20°c water temperature and the test result values of both HMK and KF untreated soil samples were 2.70 and 2.65 as given in table 4.7 and the laboratory data analysis was attached in Appendix D.

Table 4.7 Specific Gravity test results of untreated soil samples

Sample Location	Specific Gravity (Gs)
HMK	2.70
KF	2.65

4.2.2.5 Linear Shrinkage Test

The linear shrinkage test is a more effective test to indicate material performance and was conducted on both of the HMK and KF untreated soil samples. Results of the Linear Shrinkage Test of the untreated soil samples was given in Table 4.8 and the laboratory data analysis was attached in appendix B.

Table 4.8 Linear shrinkage test results of untreated soil samples

Sample Location	Linear Shrinkage (LS %)
HMK	18.86
KF	21.07

The Linear shrinkage value of both HMK and KF were 18.86% and 21.07%. The Linear shrinkage values exceeds 8% and that indicates the both soil samples have critical degree of expansion and such soils undergo volumetric changes leading to pavement distortion, cracking and general unevenness due to seasonal wetting and drying.

4.2.2.6 Free swell index test

Free swell index is the increase in volume of a soil, without any external constrains, on submergence in water. Free swell index test helps to identify the potential of a soil to swell. Results of the free swell tests of the soil was given in Table 4.9. The laboratory data analysis was attached in appendix F.

Table 4.9 Free swell index test results of untreated soil samples

Sample Location	Free Swell Index (FSI%)
HMK	91.70
KF	111

The free swell index value of both HMK and KF soil samples were 91.70% and 111%. The free swell index value of HMK soil sample exceeds 50% and it could present swell problems while KF soil sample exceeds 100% values and it associated with clay which could swell considerably, especially under light loadings.

4.2.2.7 Compaction Test

To determine the maximum dry density and optimum moisture content of the untreated soil samples, Modified proctor compaction test has been conducted according to AASHTO T-99. The results of compaction test showing the maximum dry density (MDD) and optimum moisture content (OMC) of the natural soil samples are given in figure 4.5. The detailed laboratory results was attached as an Appendix C.

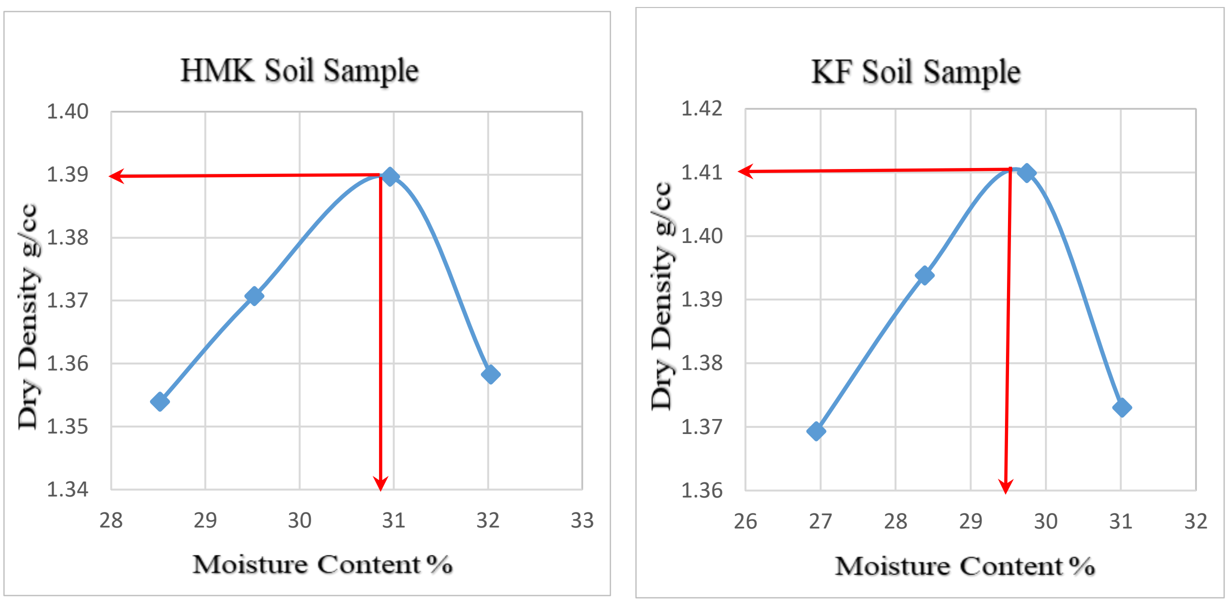

Figure 4.5 Density-Moisture content relationship for untreated soil samples

The HMK soil sample has a maximum dry density and optimum moisture content of 1.389 g/cm^3 and 30.961 % respectively. Similarly, The KF soil sample has a maximum dry density and optimum moisture content of 1.409 g/cm^3 and 29.749 %.

4.2.2.8 Soaked California Bearing Ratio (CBR) and CBR swell Tests

For the present study three point CBR test was performed as per AASHTO 193. The CBR at 95% maximum dry density is determined from graph of CBR versus dry unit weight. The CBR value of both HMK and KF untreated soil samples were shown in the figure 4.6. The detailed laboratory results was attached as an Appendix G.

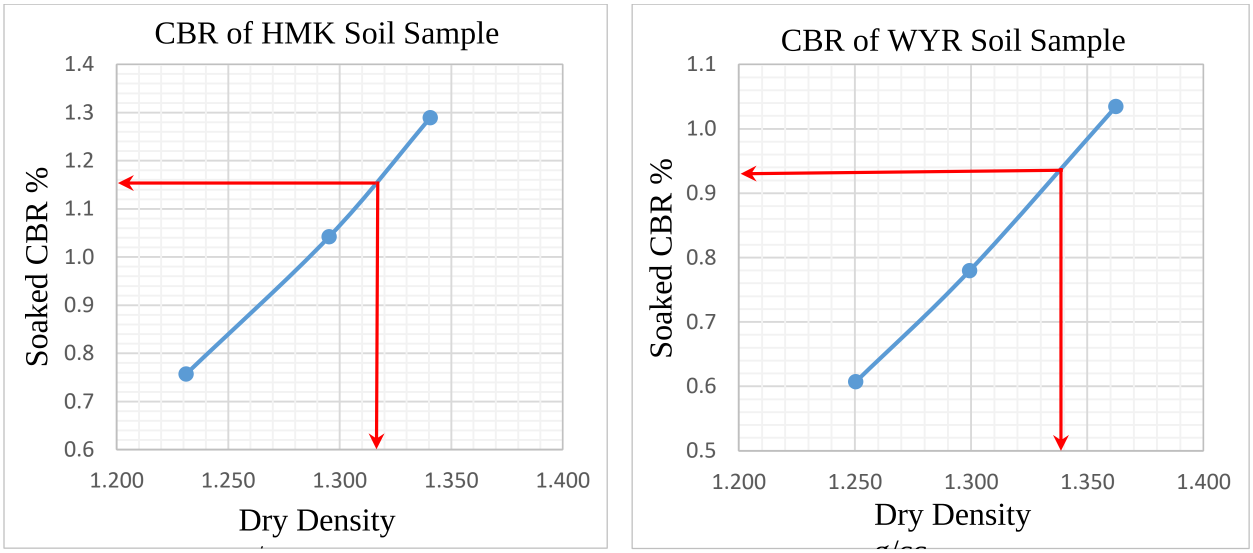

Figure 4.6 CBR test result of untreated soil samples

As shown in figure 4.6, HMK soil sample had 1.17% CBR value at maximum dry density with 3.42% CBR swell and KF soil sample had 0.94% CBR value with 4.26% CBR swell. The test result showed that both soil samples has low CBR value, which does not satisfy the minimum requirements as sub-grade material. Also, CBR swell values are above the specified maximum value of 2%. According to ERA standard specification a soil has a CBR value of less than 3% and CBR swell above 2% requires a special treatment is required.

4.3 Laboratory test results of stabilized expansive soil

4.3.1 The effect of addition of Sorghum Husk Ash and Lime on Atterberg limits

The effect of Sorghum husk ash and Lime addition in varying proportion with natural expansive soil samples had been studied and the variation in consistency limit for various additive mix-ratio were presented in Table 4.9. According to the results observed from the laboratory test, one can judge that the behavior of soil sample was changed from high plasticity soil to low plasticity soil and it was found that as the percentage of additive content increases the liquid limit continuously decreases from water content on the other hand the plastic limit increases. As a result, the plasticity index also decreased followed with increase in additives content. The summary of the laboratory test result was analyzed and given in Appendix A.

Table 4.10 Atterberg limit test results of SHA-Lime to treated soil samples

Sample Location	Mix-Proportion of additives (%)		Atterberg Limits (%)		
	SHA	Lime	Liquid Limit	Plastic Limit	Plasticity Index
HMK	Natural Soil		92.96	38.62	54.34
	0	2	86.40	40.77	45.63
	0	4	77.33	42.38	34.95
	0	6	70.20	44.46	25.74
	0	8	59.38	50.44	8.94
	3	5	73.76	46.98	26.78
	5		70.14	48.17	21.97
	7		58.82	50.29	8.23
	9		67.20	52.32	14.88
Sample Location	**Mix-Proportion of additives (%)**		**Atterberg Limits (%)**		
	SHA	**Lime**	**Liquid Limit**	**Plastic Limit**	**Plasticity Index**
KF	Natural Soil		105.10	36.30	68.80
	0	2	88.18	39.13	49.05
	0	4	79.15	41.47	37.68
	0	6	69.77	43.50	26.27
	0	8	61.83	48.46	13.37
	3	5	82.57	43.40	39.17
	5		78.28	45.55	32.68
	7		60.83	48.63	12.20
	9		69.25	50.66	18.59

As shown in Table 4.10, Addition of lime (L8%) the Liquid limit decreases from control value 92.96% to 59.38% and 105.10% to 61.83% for HMK and KF soil samples respectively. Similarly, addition of SHA-lime mixture (SHA7%+L5%), the Liquid limit decreases from control value 92.96% to 58.82% and 105.10% to 60.83% for HMK and KF soil samples respectively. The Atterberg limit depends on the type of predominant clay mineral available in the soil mass. If the predominant clay is montmorillonite the liquid limit can reach or even exceed 100%. It is also expected that the Atterberg limit is less for illite dominated soil and even lesser for kaolinite dominated soils. However, the additives not shown significant change on liquid limit of the soil because the dispersing effect of the additive doesn’t affect the liquidity natures of the soil but its plastic limit only.

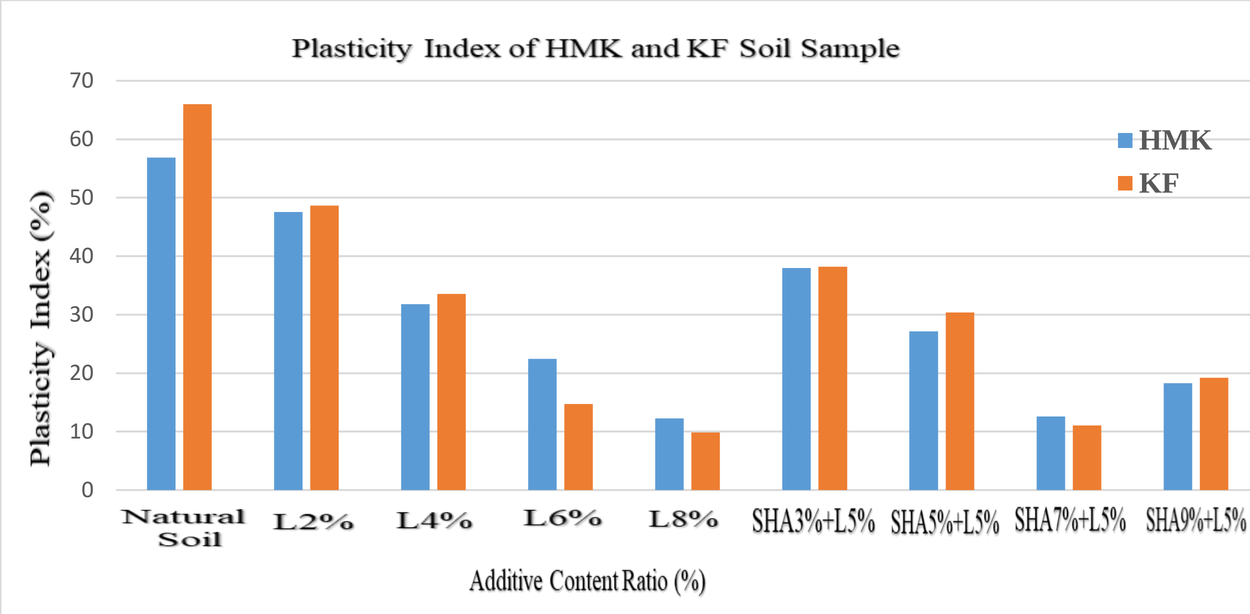

Figure 4.7 Effect of addition of SHA-Lime on PI of HMK and KF soil samples

From Figure 4.7, it indicated that highest reduction in plasticity index was observed when adding the ratio of the mixture of SHA and Lime at SHA7% + L5% ratio, but increase of the SHA after that the plasticity index increases. Sodium in comparison with calcium as the exchangeable cation would be expected to reduce particle attractions resulting in lower values for the liquid limit. Due to this reason, the content of calcium ions in SHA was not enough to replace the sodium ion in soil particle montmorillonite, therefore it is necessary confident amount of calcium ion from lime in anticipation of replacing the sodium montmorillonite.

The plastic limits increases from control value of 38.62% to 50.44% and 36.30% to 48.46% with stabilization of Lime increased, as well as the plastic limit increases from control value of 38.62% to 52.32% and 36.30% to 50.66% for HMK and KF soil samples, respectively with stabilization of additives mixture of SHA and lime increased, however Plastic limits of both soil samples radically increase when the mix-ratio of lime increases rather than SHA. The combination of SHA and Lime effectively improve the plasticity index of both soil samples. This is shown by the fact that plasticity index of treated soil decreased with increasing additive content.

Generally, Addition of lime have shown significant reduction in plasticity index of 45.40% (54.34 - 8.94) and 55.10% (68.80 - 13.70), while the mixture of SHA and Lime have shown significant reduction in plasticity index of 46.11% (54.34 - 8.23) and 56.60% (68.80-12.20) for HMK and KF soil samples, respectively with the modest change in liquid limit of both soil samples. According to ERA 2002 specification the maximum value of PI and LL were 30% and 60% respectively to use the soil as a subgrade material. Therefore, the both soil samples are satisfied ERA specification requirements are attained simultaneously at only SHA7+ L5% regard to plasticity index.

4.3.2 The effect of addition of SHA-Lime on Linear Shrinkage

Increment of additive content percentage, especially when the ratio of lime was higher than sorghum husk ash, the LS value was reduced. So the additive contents were effective to reduce the volume change when exposed to variable humidity and weather condition. According to [34] soils having LS values above 8%, between 5 and 8%, and less than 5% possess the critical, marginal, and non-critical degree of expansion, respectively. The laboratory test results of linear shrinkage was presented on table 4.11 and figure 4.8.

Table 4.11 Effect of addition of SHA-Lime on Linear shrinkage

Sample Location	Mix-Proportion of additives (%)		Linear Shrinkage (%)	Degree of Expansion
	SHA	Lime		
HMK	0	0	18.86	Critical
	0	2	14.93	Critical
	0	4	9.21	Critical
	0	6	5.57	Marginal
	0	8	4.71	Non critical
	3	5	8.21	Critical
	5		6.29	Marginal
	7		4.21	Non critical
	9		5.64	Marginal
Sample Location	**Mix-Proportion of additives (%)**		**Linear Shrinkage (%)**	**Degree of Expansion**
	SHA	**Lime**		
KF	0	0	21.07	Critical
	0	2	16.36	Critical
	0	4	10.93	Critical
	0	6	6.79	Marginal
	0	8	5.14	Non critical
	3	5	8.50	Critical
	5		7.43	Marginal
	7		4.93	Non critical
	9		6.14	Marginal

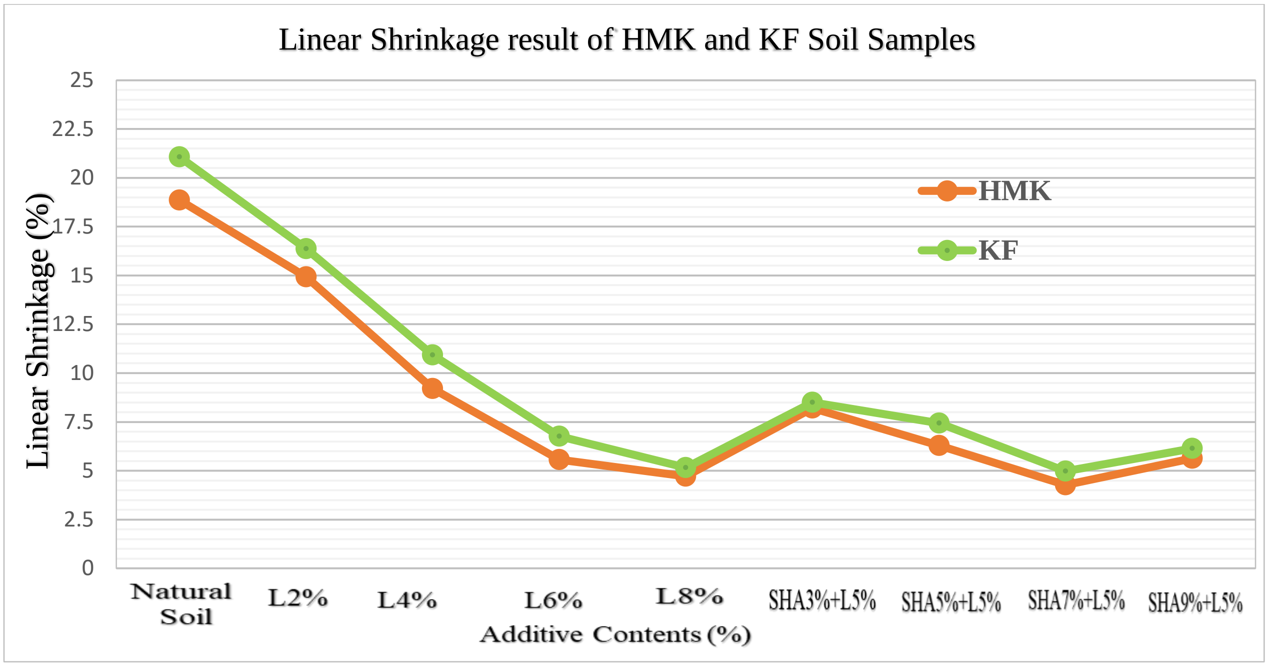

Figure 4.8 Effect of addition of SHA-Lime content on linear shrinkage

As shown in table 4.11 and Figure 4.8, the average linear shrinkage for both HMK and KF soil samples were under critical degree of expansion with 18.86% and 21.07% respectively. For HMK soil sample, both L8% and SHA7%+L5% have significantly improved the natural soil sample into non critical degree of expansion. The rest mix-proportion were not effective to arrest the shrinkage behavior of the natural soil which was under critical degree of Expansion. Similarly, L8% and SHA7%%+L5% reduced the critical degree of expansion of KF soil sample in to non-critical degree of expansion. The linear shrinkage has been decreased with increase in SHA-Lime ratio for both samples. These reactions are responsible for the reduction in swelling and shrinkage characteristic of the soil as such improves its workability

4.3.3 The effect of addition of SHA-Lime on Free Swell Index

The effects of lime and mixture of SHA and Lime on free swell tests are conducted on both soil samples. According to Indian Standard (IS 1498), Soils having a free swell value above 100% or more could swell considerably and can cause damages especially under light loadings whereas soils with free swells value above 50% could present swell problems and soils with free swell value below 50% exhibits appreciable volume change. The effect of lime and SHA-Lime mixture on the free swell index of the treated soil sample was tabulated in the table 4.12 and plotted in figure 4.9. The application of lime and SHS-lime mixture results in modest reduction in the free swell of the both HMK and KF soil samples. The reduction in free swell is directly proportional to the quantity of lime and SHA-lime added to the soil samples. This reduction in free swell is caused due to the reduction of water absorbing clay particles in the mixture of soil with lime and sorghum husk ash.

Table 4.12 Effect of addition of SHA-Lime on Free swell index

Sample location	**Mix-Proportion of Additives (%)**		**FSI (%)**	**Percentage of reduction (%)**	**IS 1498 requirement**	**Test Result Status**
	SHA%	**L%**				
HMK	Natural Soil		91.70	0	FSI < 50%	Control
	0	2	67.52	24.18		Poor
	0	4	44.91	46.79		In rage
	0	6	31.78	59.92		Satisfied
	0	8	18.91	72.79		Satisfied
	3	5	53.30	38.40		In rage
	5		43.40	48.30		In rage
	7		20.50	71.20		Satisfied
	9		33.10	58.60		Satisfied
Sample location	**Mix-Proportion of Additives (%)**		**FSI (%)**	**Percentage of reduction (%)**	**IS 1498 requirement**	**Test Result Status**
	SHA%	**L%**				
KF	Natural Soil		111.00	0.00	FSI < 50%	Control
	0	2	75.41	35.59		Poor
	0	4	52.64	58.36		In rage
	0	6	38.57	72.43		Satisfied
	0	8	28.35	82.65		Satisfied
	3	5	63.90	47.10		Poor
	5		50.20	60.80		In rage
	7		31.50	79.50		Satisfied
	9		46.10	64.90		Satisfied

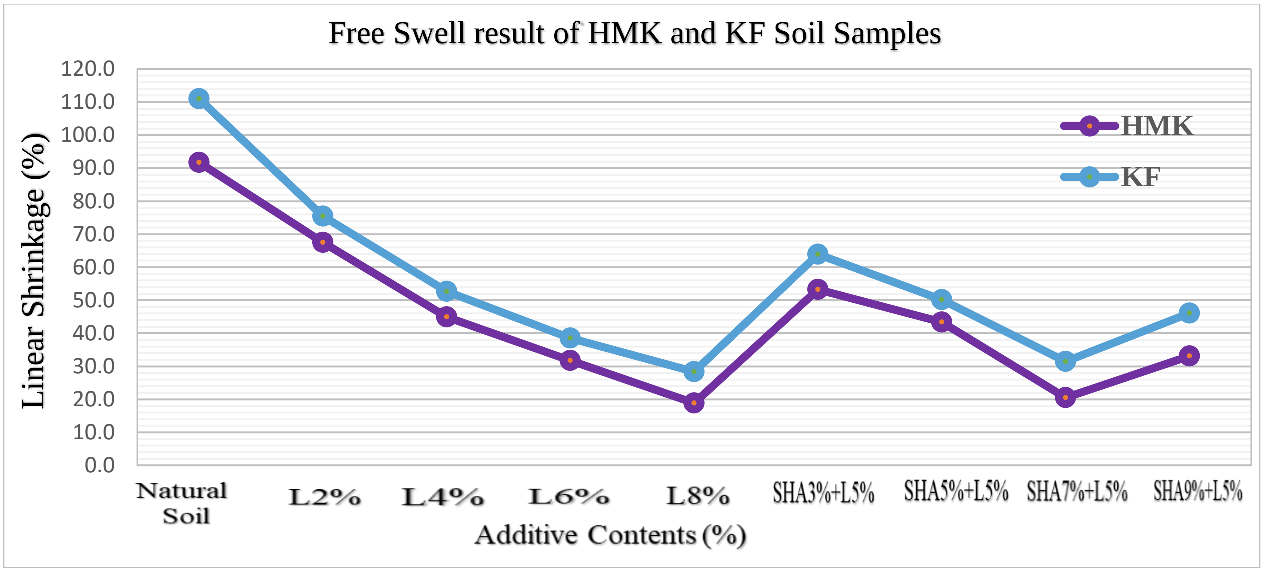

Figure 4.9 Effect of addition of SHA-Lime content on free swell index

Table 4.12 and figure 4.9 shows that both HMK and KF soil samples had reduced their swelling properties, due to chemical reaction and cation exchange between the soil, water, SHA and Lime. For HMK soil sample, the highest reduction of 72.79% was attained when the sample was treated with L8% and 71.20% when stabilized with SHA7%+L5% that means 18.91% and 20.50% reduction was observed from its natural state which was 91.70%. For KF soil sample the maximum reduction of 82.65% was attained when L8% as added, and 79.50% was attained when SHA7%+L5% was added, that means 28.35% and 31.50% reduction was observed from 111%. But, further addition of SHA ratio increases the free swell index. This indicates that, SHA7% +L5% was the optimum ration of additive content to achieve remarkable free swell index value for both soil samples.

4.3.4 The effect of addition of SHA-Lime on Moisture density relationships

The soil samples were compacted with different moisture content in five layers each suffering 56 blows and with different lime contents 2% increment and mixture of SHA and lime with an increment of SHA in 2% and 5% constant Lime. After obtaining the density and moisture of the each compacted soil sample, the following relationships for dry density and moisture content were obtained. For a given soil samples and a given compaction effort there is one moisture content called “Optimum moisture content” that gives a maximum dry density of the soil . Those moisture contents both greater and smaller than the optimum value will result in dry density greater than the optimum. The of increase moisture content and decrease of dry density is caused by the decrease in water absorbing clay particles as the SHA and lime content increases in the soil mixed with lime and SHA. The test result of Modified Procter compaction test of both HMK and KF soil samples was presented and plotted in table 4.13, figure 4.10, and 4.11. The laboratory test analysis are given in Appendix C.

Table 4.13 Effect of SHA-Lime content addition on Moisture-Density relation

Sample Location	Mix-Proportion of additives (%)		OMC %	MDD (g/cm3)
	SHA	Lime		
HMK	Natural Soil		30.961	1.389
	0	2	31.374	1.378
	0	4	32.027	1.373
	0	6	32.664	1.362
	0	8	35.434	1.305
	3	5	33.125	1.349
	5		33.831	1.338
	7		34.338	1.315
	9		35.082	1.327
Sample Location	**Mix-Proportion of additives (%)**		**OMC %**	**MDD (g/cm3)**
	SHA	**Lime**		
KF	Natural Soil		29.748	1.409
	0	2	30.591	1.394
	0	4	31.255	1.379
	0	6	32.025	1.372
	0	8	36.459	1.313
	3	5	32.528	1.364
	5		33.526	1.354
	7		34.645	1.331
	9		35.664	1.344

Table 4.13, figure 4.10 and figure 4.11 shows the variation of OMC of expansive soil with addition of different percentage of lime and SHA-Lime mixture material. The OMC of treated soil samples with lime (L8%) increases from 30.961% to 35.434% and from 29.748% to 36.459% for HMK and KF soil samples respectively with increased in lime from 2% to 8%. Similarly, the OMC of treated soil samples with SHA-lime mixture (SHA7%+L5%) increases from 30.961% to 35.082% and from 29.748% to 35.664% for HMK and KF soil samples respectively with mixture of SHA-

Lime content from 0% to 9% of SHA mixed with a constant 5% of Lime. On the other hand, the MDD of soil treated with lime (L8%) decreases gradually with an increase of lime for both soil samples from 1.389 g/cm^3 to 1.305 g/cm^3 and from 1.409 g/cm^3 to 1.313 g/cm^3 for HMK and KF soil samples respectively. Similarly, the MDD of soil treated with SHA-lime mixture (SHA7%+L5%) decreases from 1.389 g/cm^3 to 1.315 g/cm^3 and 1.409 g/cm^3 to 1.331 g/cm^3 for HMK and KF soil samples respectively.

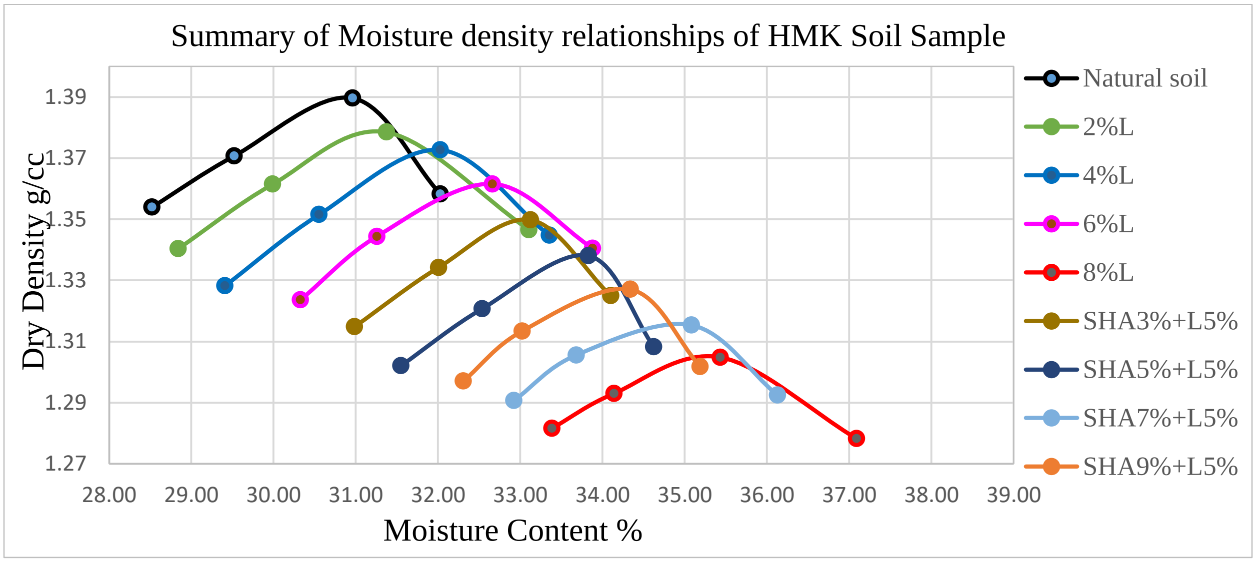

Figure 4.10 Summary of OMC and MDD of treated HMK soil sample

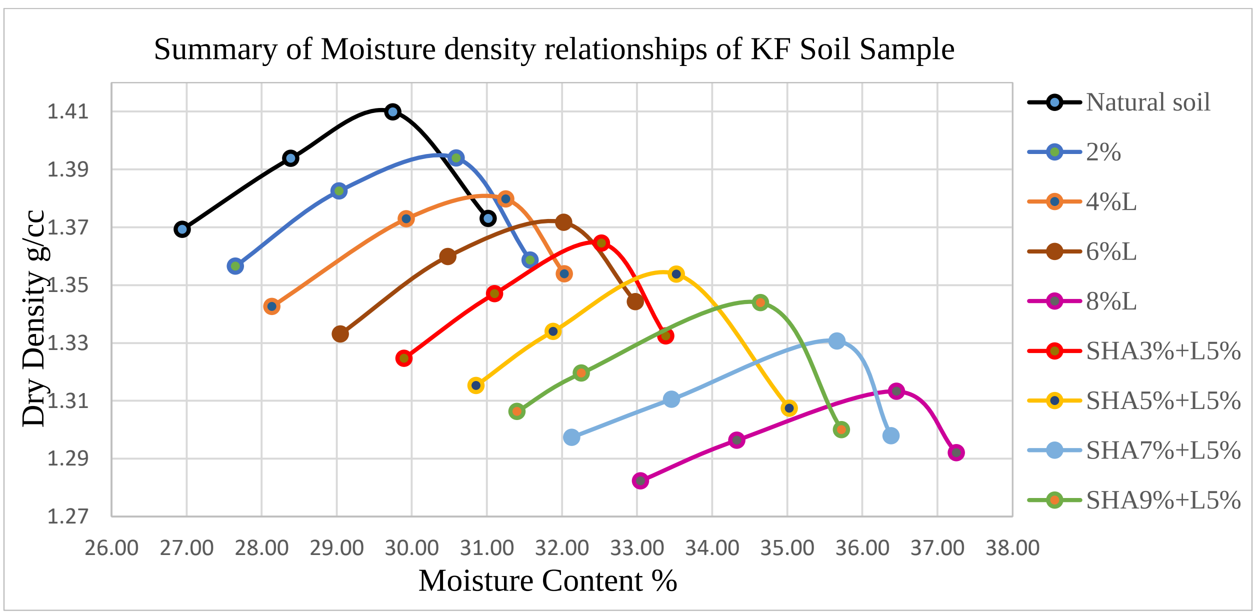

Figure 4.11 Summary of OMC and MDD of treated KF soil sample

Generally the maximum dry density of soil decreases gradually with an increase of lime and mixture of SHA-Lime content for both soil samples. This is due to comparatively low specific gravity and light weight behavior of SHA-Lime material. SHA-Lime (with lower specific gravity) fills the soil voids and it contributes to a decrease in density.

The addition of lime and mixture of SHA-Lime changes the optimum moisture content and maximum dry density of expansive soils because the effects of cation exchange and short-term pozzolanic reactions between lime and the soil results in flocculation and agglomeration of clay particles leading to texture changes.

The advantage of the increase in OMC and corresponding decrease in MDD of the soil samples is that it allowed compaction to be easily achieved with wet soil. Any adverse effect on strength due to reduction in density is unlikely to occur due to the expected substantial gain in strength of treated soils due to the pozzolanic properties of SHA and lime.

4.3.5 The effect of addition of SHA-Lime on CBR value

The CBR is a measure of shearing resistance of the material under controlled density and moisture conditions. The CBR test in this thesis work were done according to AASHTO T-193. The CBR value for 2.54mm and 5.08mm are recorded. This load is expressed as a percentage of standard load value at a respective deformation level to obtain CBR value. Three point CBR test have been done for all samples to determine the strength character of the expansive soil alone and in the stabilized case. The density versus CBR were plotted and the CBR for 10, 30 and 65 blows are determined from the graph of maximum dry density. CBR values of natural sub-grade soils of both HMK and KF soil samples were 1.17% and 0.94% respectively, and did not fulfill the requirement of sub-grade soils as per ERA standard (CBR > 5%). Therefore, since all the samples fulfill the requirement of sub-grade soils as per ERA standard (CBR > 5%) adequate as subgrade materials in highway construction. The summary of the soaked CBR test result is tabulated below in table 4.14, and 4.15 and in figure 4.12.The laboratory test analysis are given in Appendix Appendix-F.

Table 4.14 Summary of CBR test results for HMK treated soil sample

Mix-ratio of additives (%)		CBR Value (%)						CBR@ 95% MDD	CBR Swell (%)	ERA Requirement	Remark
		10 blows		30 blows		65 blows					
SHA	Lime	2.54mm	5.08mm	2.54mm	5.08mm	2.54mm	5.08mm				
Natural soil		0.91	0.80	1.19	0.96	1.44	1.12	1.17	3.42	CBR > 3%	Control
0	2	2.19	2.09	2.49	2.31	2.96	2.56	2.77	2.08		Not satisfied
0	4	3.82	2.99	4.22	3.38	4.84	3.78	4.52	1.78		Satisfied
0	6	5.46	4.34	6.17	4.88	6.86	5.46	6.35	1.27		Satisfied
0	8	7.34	6.04	8.25	6.58	9.41	7.16	8.47	0.98		Satisfied
3	5	4.03	3.79	5.37	4.50	6.42	5.06	5.52	1.43		Satisfied
5		5.57	5.10	6.58	5.81	7.38	6.46	6.68	1.25		Satisfied
7		8.03	6.57	8.56	7.30	10.13	8.36	8.76	0.90		Satisfied
9		6.25	5.35	7.55	6.06	8.73	7.01	7.78	1.10		Satisfied

Table 4.15 Summary of CBR test results for KF treated soil sample

Mix-ratio of additives (%)		CBR Value (%)						CBR@ 95% MDD	CBR Swell (%)	ERA Requirement	Remark
		10 blows		30 blows		65 blows					
SHA	Lime	2.54mm	5.08mm	2.54mm	5.08mm	2.54mm	5.08mm				
Natural soil		0.61	0.52	0.78	0.66	1.03	0.81	0.94	4.26	CBR > 3%	Control
0	2	1.89	1.94	2.30	2.16	2.74	2.36	2.52	2.85		Not satisfied
0	4	3.59	2.64	3.92	2.83	4.31	3.13	4.14	2.14		Satisfied
0	6	5.46	4.19	5.94	4.53	6.33	6.86	6.02	1.48		Satisfied
0	8	7.04	5.14	7.74	5.48	8.43	5.96	8.10	1.22		Satisfied
3	5	4.09	3.42	4.90	3.86	5.43	4.36	5.21	1.74		Satisfied
5		5.51	4.27	6.18	4.76	6.86	5.21	6.43	1.52		Satisfied
7		7.01	5.52	7.94	6.31	9.41	7.06	8.40	1.11		Satisfied
9		5.85	4.96	6.93	5.36	7.80	5.81	7.37	1.31		Satisfied

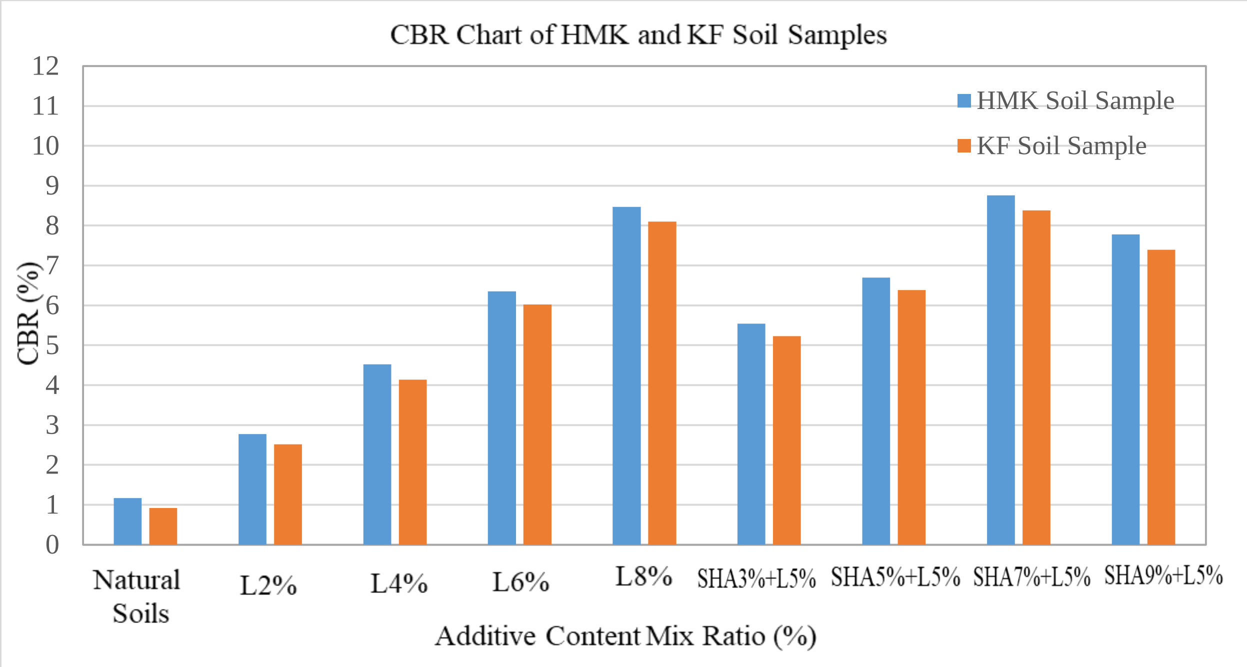

Figure 4.12 Summary of CBR test results of HMK and KF soil samples

As shown from figure 4.12, HMK soil sample treated by lime increased the soaked CBR of the both soil samples. The CBR value of HMK soil sample increased from 1.17% to a maximum of 8.47% at 8% lime stabilization, while the KF soil sample increased from 0.94% and 8.10% at 8% lime stabilization. The addition of SHA-lime mixture increased the soaked CBR of all the samples. The CBR value of HMK soil sample increased from 1.17% to a maximum of 8.76% at SHA7%+L5% stabilization, while that of KF soil sample increased from 0.94% to 8.40% respectively at SHA7%+L5% stabilization. Both soil sample of HMK and KF showed more improvement at the L8% and SHA7%+L5% stabilization, than the other mix-ratio of SHA and lime. The addition of lime and SHA-lime together led to a more increase of the CBR. However, according to ERA pavement design manual specification, the CBR values of treated soil with a different mix-ratio of SHA-lime is full fill the specification as a subgrade material.

The increment of lime and mixture of SHA-lime may be attributed to the chemical and cementatious effects of lime on structural composition of soils is more significant than to that of SHA, since both lime and SHA have cementatious material which bonding between clay particles, lime and SHA becomes soils strong, and the load bearing capacity has been increased.

Even though both SHA and lime have cementation materials, cementitious alone doesn't improve strength properties of clay materials. From the reviewed literature, it can be seen that oxide amount in SHA is less than oxide amount in lime. Hence flocculation and hydration are the primary mechanisms to improve the strength of clay soils.

4.3.6 The effect of addition of SHA-Lime on CBR Swell Test

The soil samples with lime and SHA-lime additive mixtures compacted in CBR molds at Optimum moisture content and maximum dry density gauged for swelling properties before and after soaking for four days to evaluate the percent of swell. The CBR swell shows a decrease as the content of lime and SHA-lime mixture contents are increases for both HMK and KF soil samples collected from the study areas. The test result at different mix-ratio for both HMK and WYR soil samples was plotted in table 4.14, table 4.15, and figure 4.13.

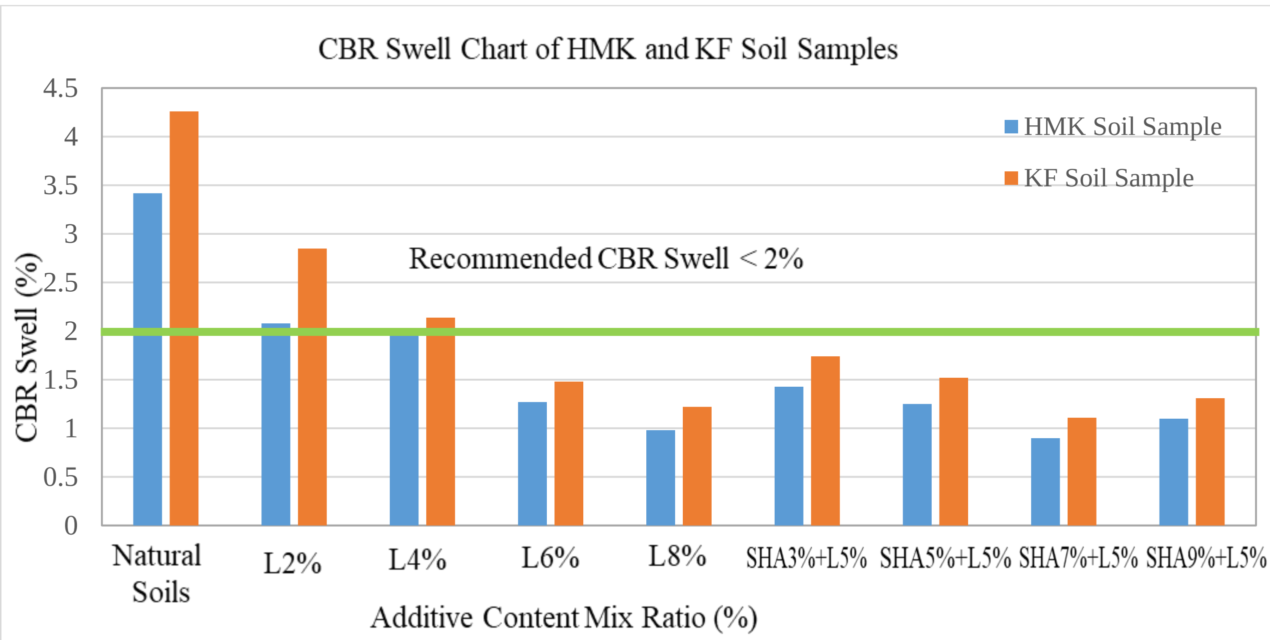

Figure 4.13 Summary of CBR swell results of HMK and KF soil samples

Figure 4.13, shows both HMK and KF untreated soil samples with CBR swell of 3.42% and 4.26% respectively, have the properties of swelling and potentially expansive soil. CBR swell showed significant reduction with the addition of lime and SHA-lime mixture contents. CBR swell of HMK and KF soil samples treated with 8% lime yields 0.98 % and 1.22% swelling respectively. On the other hand, the CBR swell of HMK and KF soil sample treated with SHA7%+L5% yields 0.90% and 1.11% swelling respectively. Though, when SHA and lime was added with different mix-ratio the CBR swell value reduces. However, the CBR Swell shows a decrease as the content of lime and SHA-lime mixture content is increases for both soil samples collected from the study areas. But the decrease in the CBR swell is achieved by adding a higher ratio of lime content in the soil and this is not promising result. These reduced swell characteristics are generally attributed to decreased affinity for water of the calcium saturated clay and the formation of a cementitious matrix that resists volumetric expansions. Using both the stabilizers improves the stability and strength of the subgrade soils and the strength of the subgrade is the principal factor in determining the thickness of the pavement, but deterioration due to frost action must also be taken into account.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

Based on the test results obtained from the investigation of the selected soil treated with lime and SHA-lime mixture material the following conclusions can be drawn. In the conclusion part each treated clay material is compared with that of the pure expansive clay soil (untreated state) and hence, all figures are expressed in percentage to show clearly the extent of SHA-lime Stabilization.

- The chemical composition of Sorghum husk ash test result indicates the combined percent composition of main oxides (SiO_2 + Al_2O_3 + Fe_2O_3) was 77.30% which is above the minimum of (70%) specified by ASTM (C618). which is acceptable as a good Pozzolana with specific gravity of 2.27.
- The soil types were highly expansive and had high degree of expansion, high plastic index and poor strength. According to USCS and AASHTO classification system, HMK soil sample was categorized as CH and A-7-5 (62.11) and KF soil sample was categorized as CH and A-7-5 (79.28) respectively. Thus, the natural soil was very poor in strength to be used as a subgrade material as per ERA (2013) specification. The engineering properties of the studied expansive soil revealed that it was not suitable to use as a sub-grade material unless its undesirable properties are improved.
- Atterberg limit shows reduction as the ratio of SHA-lime increases in the mechanical stabilization process. When treated SHA-lime mixture (SHA7%+L5%) for both soil samples, the liquid limit is reduced by 34.14% (from 92.96 to 58.82%) for HMK soil sample and by 44.27% (from 105.10% to 60.83%) for KF soil sample. The plastic index also reduced by 46.11% (from 54.34% to 8.23%) for HMK soil sample and by 56.60% (from 68.80% to 12.20%) for KF soil sample as the mix-ratio of SHA7%+L5%.
- The linear shrinkage of the HMK soil samples is reduced by 14.59% (from 18.86% to 4.27%) and by 16.10% (from 21.07% to 4.97%) for KF soil sample at the mix-ratio of SHA7%+L5%. However, as the linear shrinkage test result of the stabilized expansive clay soil is compared with appendix B (Altmeyer Method of classification of expansive soil) for both HMK and KF soil samples fall in critical and degree of expansion.

- The free swell test for both soil samples shows a decrease in the range, for HMK soil sample is reduced by 71.20% (from 91.70% to 20.50%) and for KF soil sample is reduced by 79.5% (from 111% to 31.50%) at the mix-ratio of SHA7%+L5%. Hence, this indicates that the addition of SHA-lime material in expansive clay soil reduces the heaving potential of the soil.
- The MDD shows a slight decrease and OMC shows an increase in the treatment of weak subgrade soil with SHA-lime additive agents. For HMK soil sample, MDD decreases from 1.389 g/cm^3 to 1.315 g/cm^3 and OMC increases from 30.961% to 35.082%. For KF soil sample, MDD decreases from 1.409 g/cm^3 to 1.331 g/cm^3 and OMC increases from 29.748% to 35.664% at optimum mix- ratio of SHA7%+L5%. Generally, when increasing the percentage of lime and SHA-limet mix-ratio led increase in the maximum dry density and decrease optimum moisture content rather than SHA.
- Laboratory test was carried out to determine the CBR value for soil samples collected from HMK and KF Test pits. Accordingly, the test result shows more significant of CBR value for both soil samples collected from the corresponding areas which were treated with different incremental percentage of SHA-lime material because curing allows pozzolanic reactions. Hence, combination of SHA and lime can strongly improve the strength of the expansive soil samples. As observed from the test result performed under this study, the maximum value of CBR for both HMK and KF soil samples were achieved at SHA7% +L5% with CBR value of 8.76% and 8.40%, respectively.
- On the other hand CBR-swell value for both soil samples shows a significant reduction as the ratio of SHA-lime material increase. The CBR-Swell for HMK soil sample reduced by 2.52% (from 3.42% to 0.90%) and that of the KF soil sample reduced by 3.15% (from 4.26% to 1.11%) when soil samples treated with SHA7%+L5%. This result indicates that blending of SHA-lime material to expansive clay soil minimize the heaving tendency which occurs due to seasonal moisture variations.

Generally, the most parameters of ERA (2013) specification requirement were achieved and the physical and engineering properties of expansive soil were improved by SHA combined with lime in different mix-proportion. The optimum amount for adequate stabilization were determined to be 6% lime only and a mixture of SHA7%+L5%.

5.2 Recommendations

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

In the light of the study discussed, sorghum husk ash can be made commercially available in its pure form or as SHA-lime blends and promoted as a stabilizing agent for soils in pavement construction. This would help in alleviating extreme poverty among the rural poor, enhance agro-waste management reduce net CO_2 contribution of the construction industry to the environment and reduce the cost of stabilizing soils for pavement construction.

For further study the following pointes are recommended:-

- This study was done for specific area and specific stabilizers, it is recommended as more investigation shall be performed on different parts of the country by mixing with other stabilizers such as cement.
- As stabilization of expansive soil with SHA and lime mixture is a relatively new concept and are scanty in the literature, chemical interactions and mechanisms involved in SHA, lime, water and expansive soil shall be studied.
- This study was conducted by mixing of Sorghum husk ash with hydrated lime at different proportion of mixing ratio. It is recommended to the next researcher to conducting tests at different percentages of sorghum husk ash alone in different parts of the country.
- The present study was conducted by taking limited parameter such as Atterberg limit, linear shrinkage, free swell index, moisture density relation, CBR and CBR swell potential on stabilization by SHA and lime. It is recommended to test additional parameter like unconfined compressive strength and mineralogical tests should also be performed to have more realistic test results.

Finally, the results and findings of this research work may be considered as indicative only for further studies as these findings are based on limited parameters and a small number of samples. More elaborate sampling and testing of expansive soils from different origins are recommended before concluding the performance of sorghum husk ash and lime as a stabilizing agent for expansive soil.

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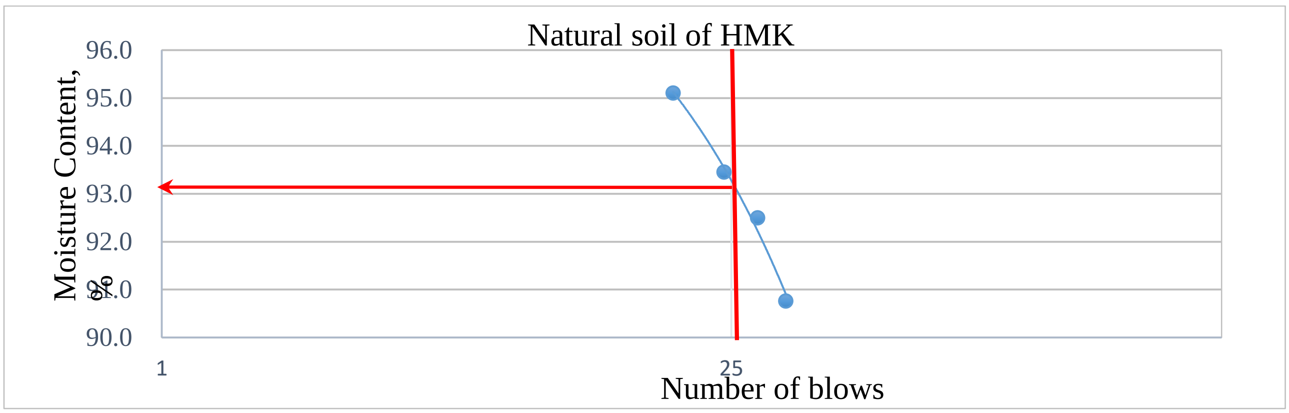
APPENDIX

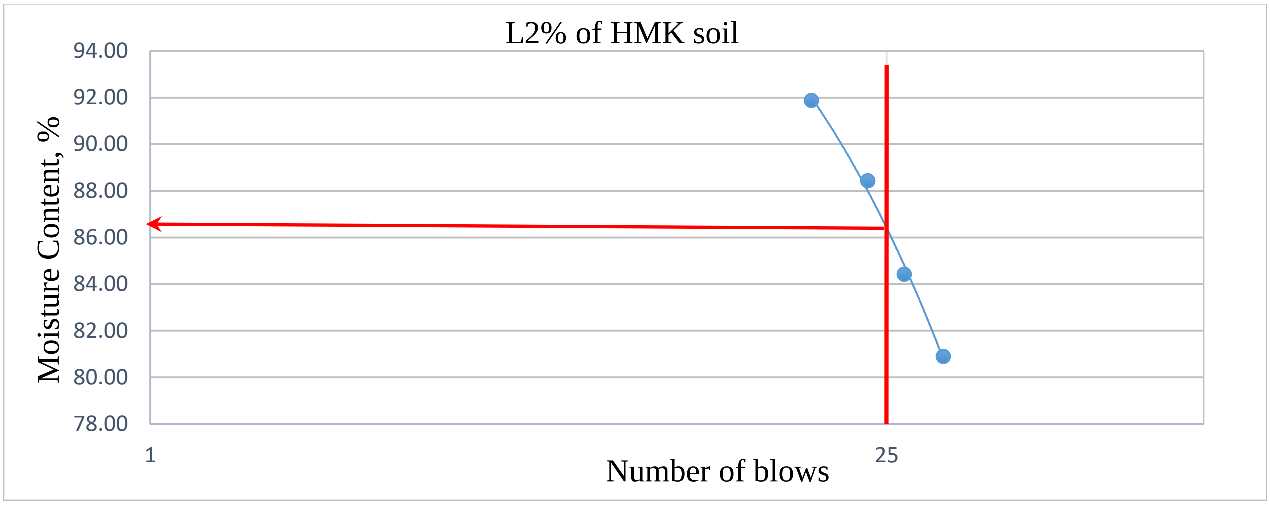
APPENDIX A: Atterberg Limit Test Analysis Data

I. Atterberg limit of HMK Soil Sample

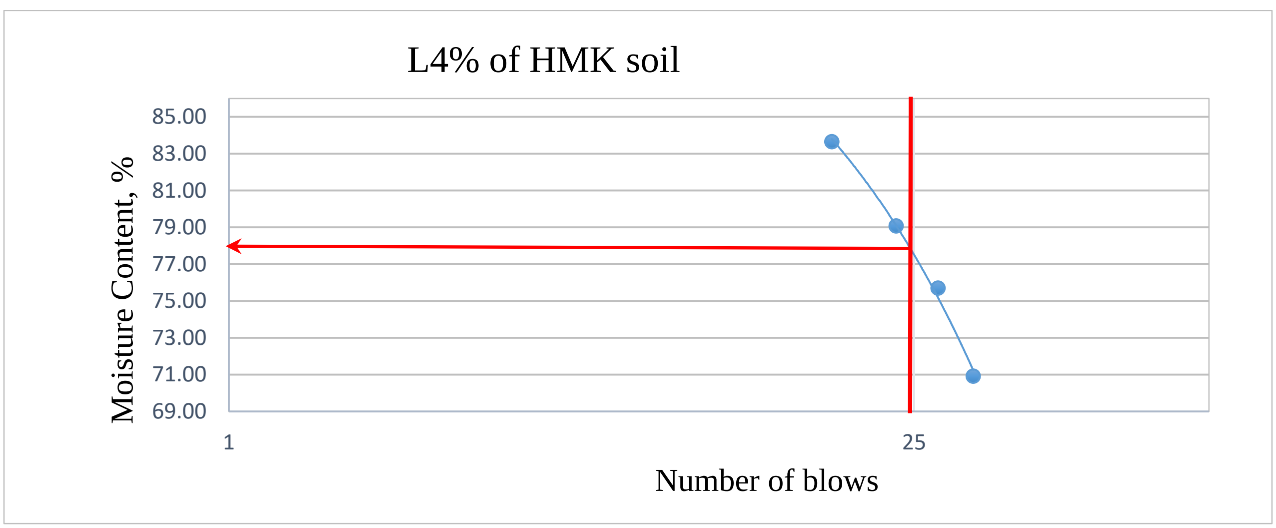
Sample Location: HMK	Natural Soil					
Determination	**Liquid Limit**				**Plastic Limit**	
Number of blows	34	29	24	18	----	----
Test No	1	2	3	4	1	2
Container No	F5	A17	B8	3L	K1	T4
Wt. of container + wet soil, g	58.05	56.16	40.30	41.51	22.26	24.17
Wt. of container + dry soil, g	39.08	38.77	29.88	30.83	21.15	22.01
Wt. of container, g	18.18	19.97	18.73	19.60	17.96	16.92
Wt. of water, g	18.97	17.39	10.42	10.68	1.11	2.16
Wt. of dry soil, g	20.90	18.80	11.15	11.23	3.19	5.09
Moisture content, %	90.8	92.5	93.5	95.1	34.80	42.44
Average	92.96				38.62	
Plasticity Index	54.34					



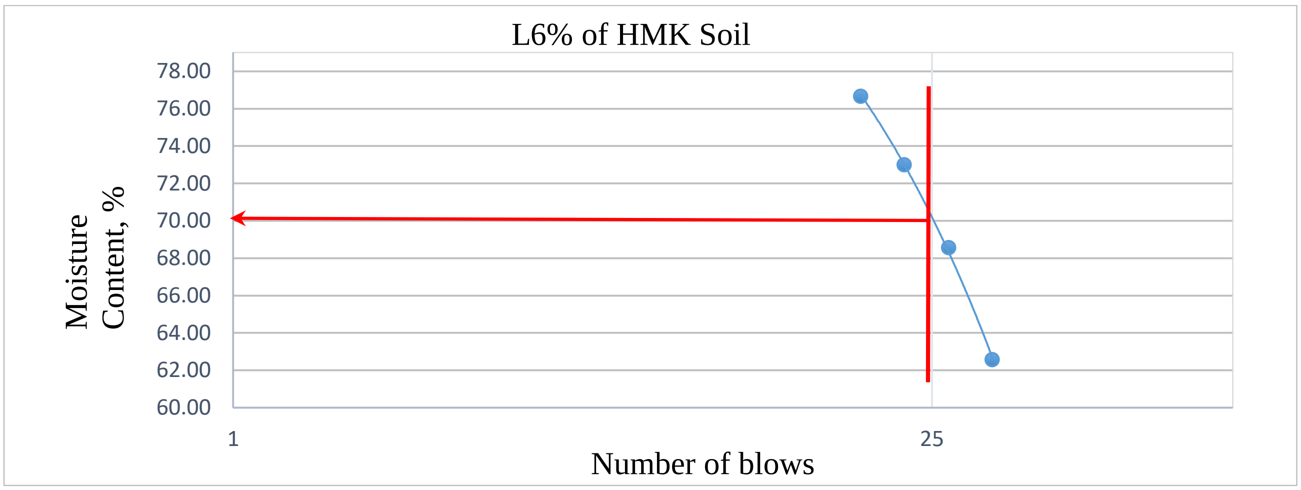
Sample Location: HMK	Additive Content: L2%					
Determination	**Liquid Limit**				**Plastic Limit**	
Number of blows	32	27	23	18	----	----
Test No	1	2	3	4	1	2
Container No	3L	F5	A17	B8	J7	A4
Wt. of container + wet soil, g	38.25	38.89	35.59	37.17	28.42	26.91
Wt. of container + dry soil, g	29.91	29.41	29.17	28.35	24.38	25.32
Wt. of container, g	19.60	18.18	21.91	18.75	17.96	16.78
Wt. of water, g	8.34	9.48	6.42	8.82	4.04	1.59
Wt. of dry soil, g	10.31	11.23	7.26	9.60	6.42	8.54
Moisture content, %	80.89	84.42	88.43	91.88	62.93	18.6
Average	86.40				40.77	
Plasticity Index	45.63					



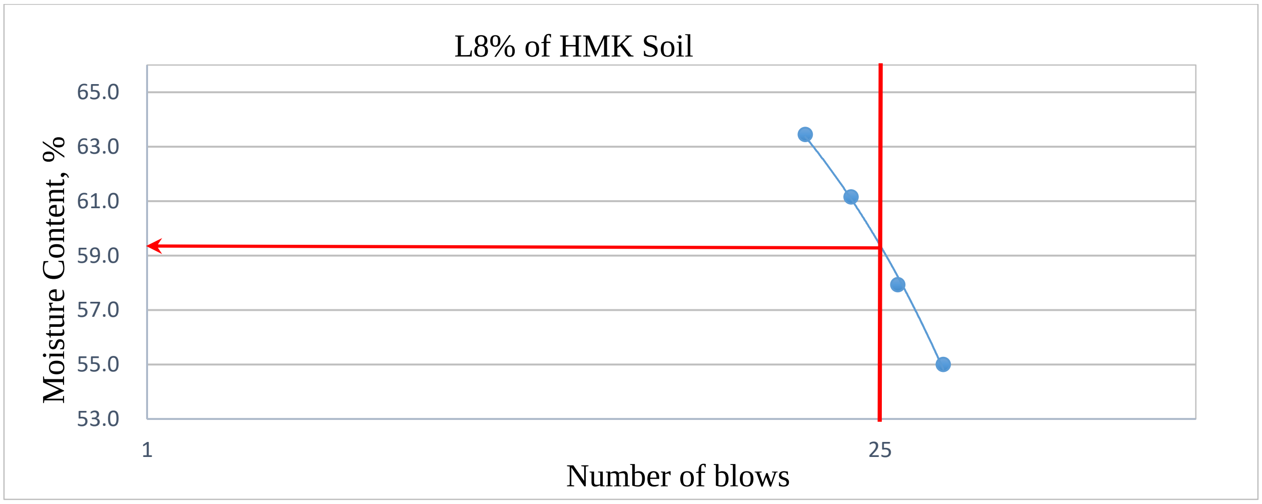
Sample Location: HMK	Additive Content: L4%					
Determination	**Liquid Limit**				**Plastic Limit**	
Number of blows	33	28	23	17	----	----
Test No	1	2	3	4	1	2
Container No	3L	F5	A17	B8	J7	A4
Wt. of container + wet soil, g	37.22	37.91	34.91	36.38	27.92	27.85
Wt. of container + dry soil, g	29.91	29.41	29.17	28.35	24.38	25.32
Wt. of container, g	19.60	18.18	21.91	18.75	17.96	16.78
Wt. of water, g	7.90	8.50	5.74	8.03	3.54	2.53
Wt. of dry soil, g	10.31	11.23	7.26	9.60	6.42	8.54
Moisture content, %	70.90	75.69	79.06	83.65	55.14	29.6
Average	77.33				42.38	
Plasticity Index	34.95					



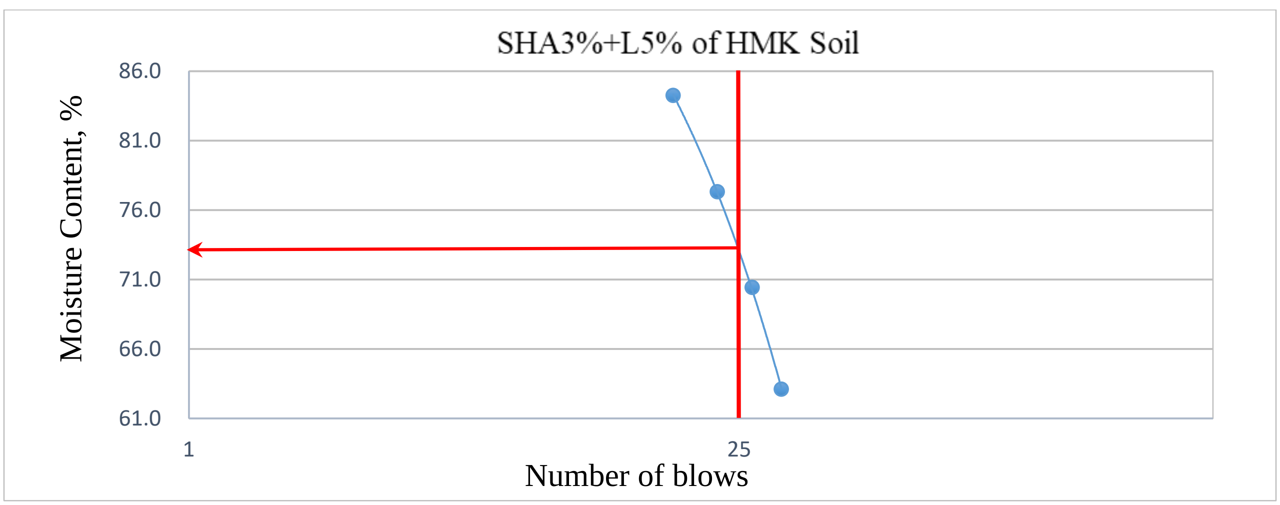
Sample Location: HMK	**Additive Content: L6%**					
Determination	**Liquid Limit**				**Plastic Limit**	
Number of blows	33	27	22	18	----	----
Test No	1	2	3	4	1	2
Container No	3L	F5	A17	B8	J7	A4
Wt. of container + wet soil, g	36.36	37.11	34.47	35.71	28.51	27.42
Wt. of container + dry soil, g	29.91	29.41	29.17	28.35	24.38	25.32
Wt. of container, g	19.60	18.18	21.91	18.75	17.96	16.78
Wt. of water, g	6.45	7.70	5.30	7.36	4.13	2.10
Wt. of dry soil, g	10.31	11.23	7.26	9.60	6.42	8.54
Moisture content, %	62.56	68.57	73.00	76.67	64.33	24.6
Average	70.20				44.46	
Plasticity Index	25.74					



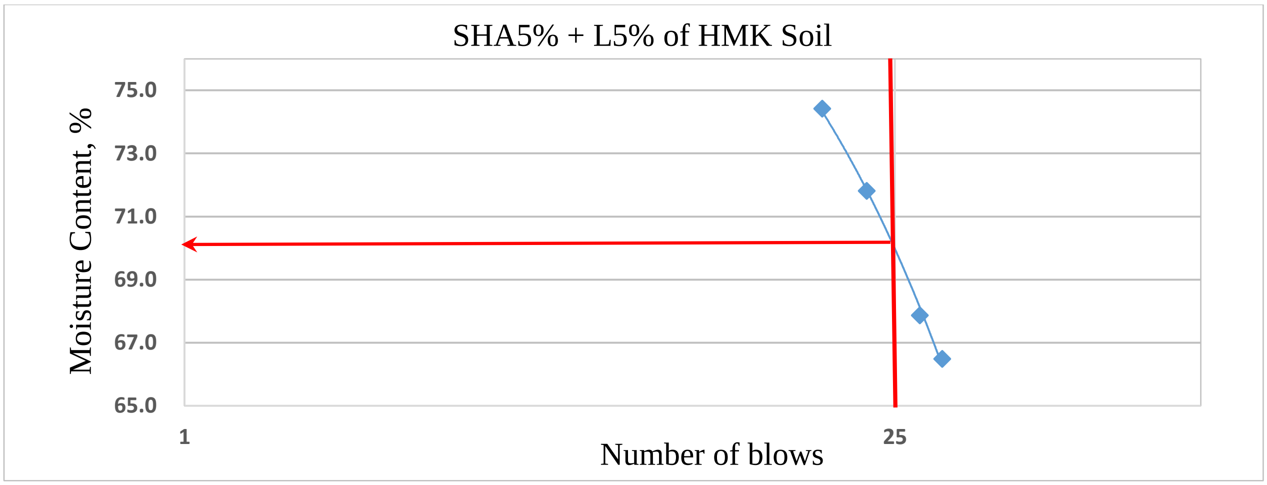
Sample Location: HMK	**Additive Content: L8%**					
Determination	**Liquid Limit**				**Plastic Limit**	
Number of blows	33	27	22	18	----	----
Test No	1	2	3	4	1	2
Container No	1-3	A-16	2	C9	R4	S
Wt. of container + wet soil, g	39.91	35.08	34.65	36.31	13.17	12.88
Wt. of container + dry soil, g	32.54	28.54	28.70	28.81	10.49	11.11
Wt. of container, g	19.14	17.25	18.97	16.99	6.44	6.01
Wt. of water, g	7.37	6.54	5.95	7.50	2.68	1.77
Wt. of dry soil, g	13.40	11.29	9.73	11.82	4.05	5.10
Moisture content, %	55.0	57.9	61.2	63.5	66.17	34.7
Average	59.38				50.44	
Plasticity Index	8.94					



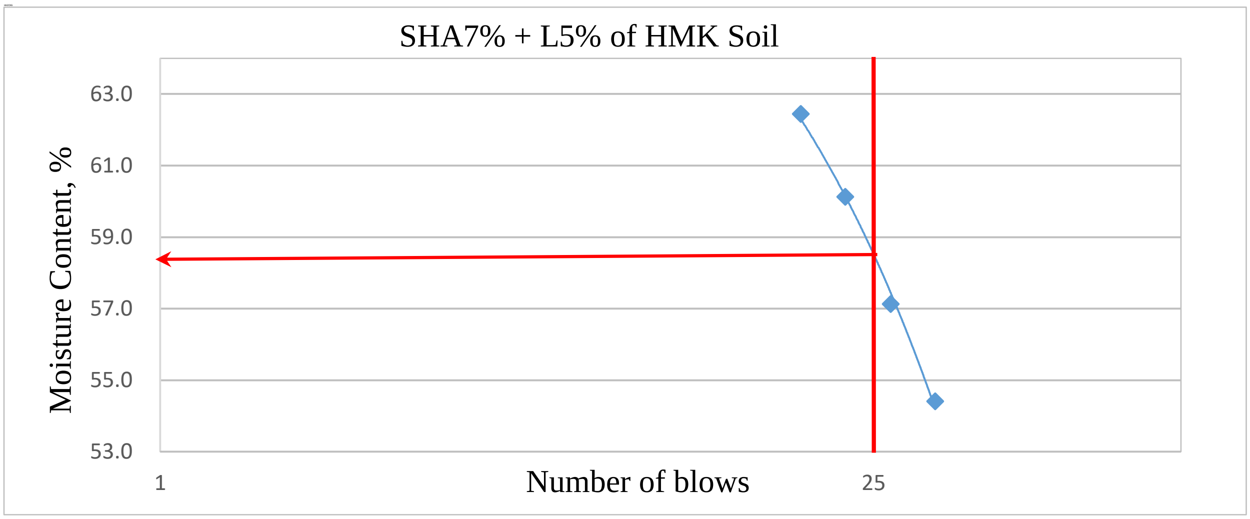
Sample Location: HMK	Additive Content: SHA3%+L5%					
Determination	Liquid Limit				Plastic Limit	
Number of blows	32	27	22	17	----	----
Test No	1	2	3	4	1	2
Container No	F5	A17	B8	3L	J7	A4
Wt. of container + wet soil, g	38.68	41.21	38.57	39.11	24.11	24.91
Wt. of container + dry soil, g	30.75	33.26	29.92	30.19	21.69	23.11
Wt. of container, g	18.18	21.97	18.73	19.60	17.96	16.92
Wt. of water, g	7.93	7.95	8.65	8.92	2.42	1.80
Wt. of dry soil, g	12.57	11.29	11.19	10.59	3.73	6.19
Moisture content, %	63.1	70.4	77.3	84.2	64.88	29.1
Average	73.76				46.98	
Plasticity Index	26.78					



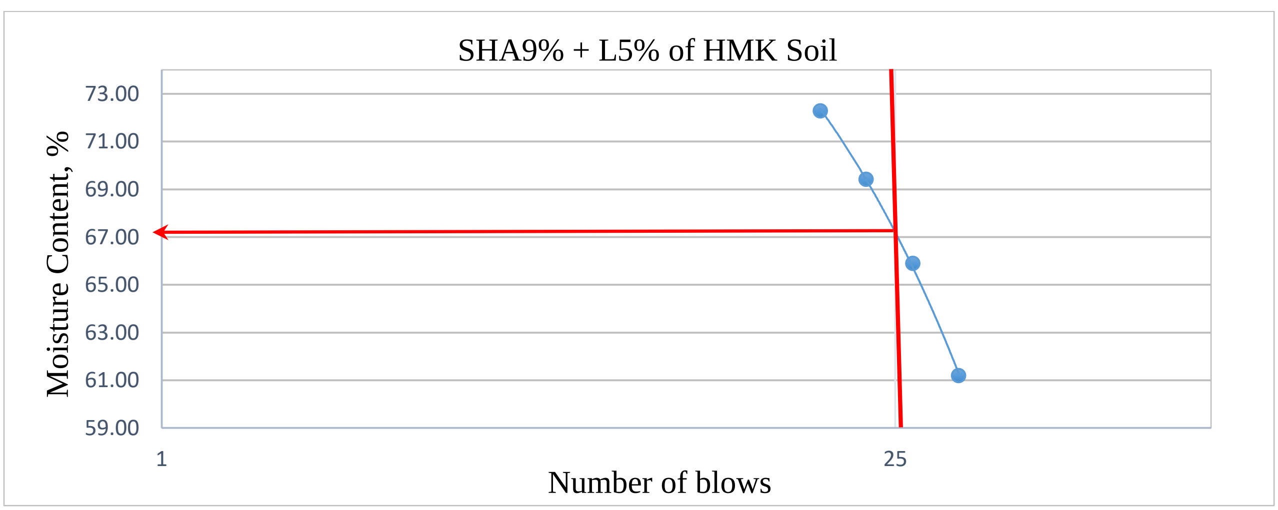
Sample Location: HMK	Additive Content: SHA5%+L5%					
Determination	Liquid Limit				Plastic Limit	
Number of blows	31	28	22	18	----	----
Test No	1	2	3	4	1	2
Container No	4	3	B9	G8	A7	C1
Wt. of container + wet soil, g	34.67	37.18	37.95	38.97	25.95	26.84
Wt. of container + dry soil, g	27.63	30.76	30.31	30.71	21.82	26.81
Wt. of container, g	17.04	21.30	19.67	19.61	17.51	20.94
Wt. of water, g	7.04	6.42	7.64	8.26	4.13	0.03
Wt. of dry soil, g	10.59	9.46	10.64	11.10	4.31	5.87
Moisture content, %	66.5	67.9	71.8	74.4	95.82	0.5
Average	70.14				48.17	
Plasticity Index	21.97					



Sample Location: HMK	Additive Content: SHA7%+L5%					
Determination	Liquid Limit				Plastic Limit	
Number of blows	33	27	22	18	----	----
Test No	1	2	3	4	1	2
Container No	13	A-16	2	C9	R4	S
Wt. of container + wet soil, g	39.83	34.99	34.55	36.19	13.19	12.84
Wt. of container + dry soil, g	32.54	28.54	28.70	28.81	10.49	11.11
Wt. of container, g	19.14	17.25	18.97	16.99	6.44	6.01
Wt. of water, g	7.29	6.45	5.85	7.38	2.70	1.73
Wt. of dry soil, g	13.40	11.29	9.73	11.82	4.05	5.10
Moisture content, %	54.4	57.1	60.1	62.4	66.67	33.9
Average	58.52				50.29	
Plasticity Index	8.23					

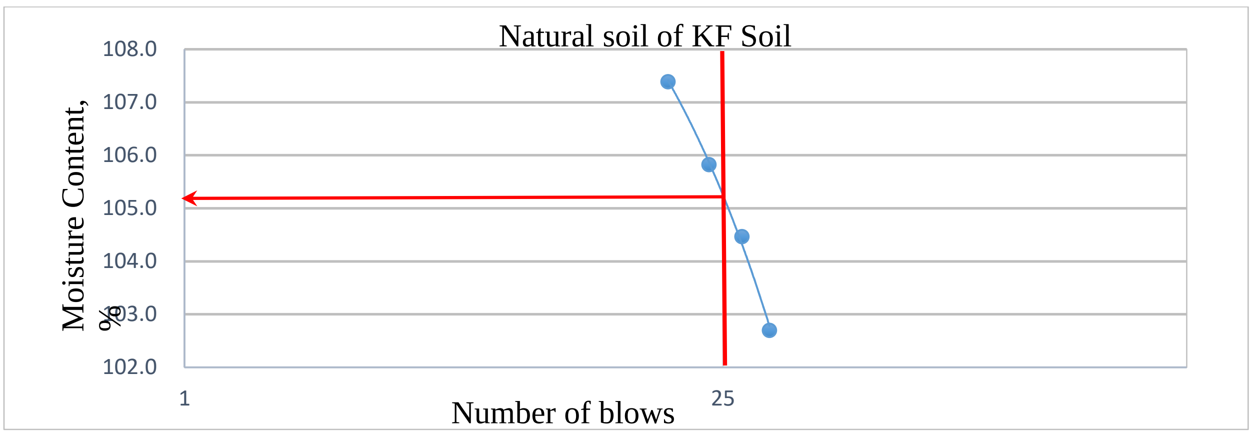


Sample Location: HMK	Additive Content: SHA9%+L5%					
Determination	**Liquid Limit**				**Plastic Limit**	
Number of blows	33	27	22	18	----	----
Test No	1	2	3	4	1	2
Container No	3L	F5	A17	B8	J7	A4
Wt. of container + wet soil, g	36.22	36.81	34.21	35.29	28.94	28.19
Wt. of container + dry soil, g	29.91	29.41	29.17	28.35	24.38	25.32
Wt. of container, g	19.60	18.18	21.91	18.75	17.96	16.78
Wt. of water, g	6.31	7.40	5.04	6.94	4.56	2.87
Wt. of dry soil, g	10.31	11.23	7.26	9.60	6.42	8.54
Moisture content, %	61.20	65.89	69.42	72.29	71.03	33.6
Average	67.20				52.32	
Plasticity Index	14.88					

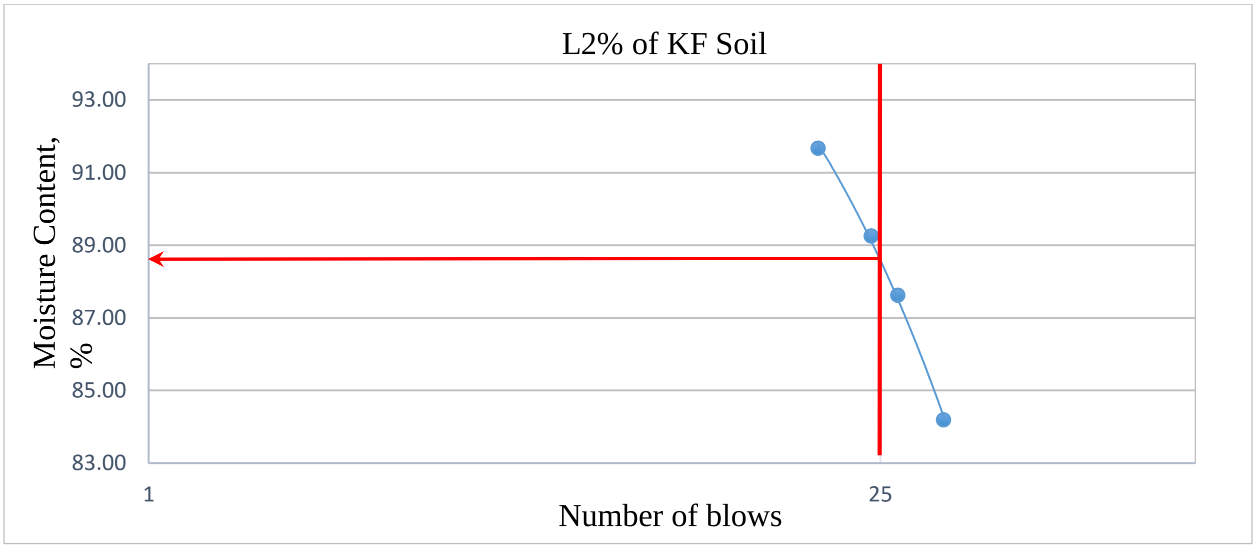


II. Atterberg limit of KF Soil Sample

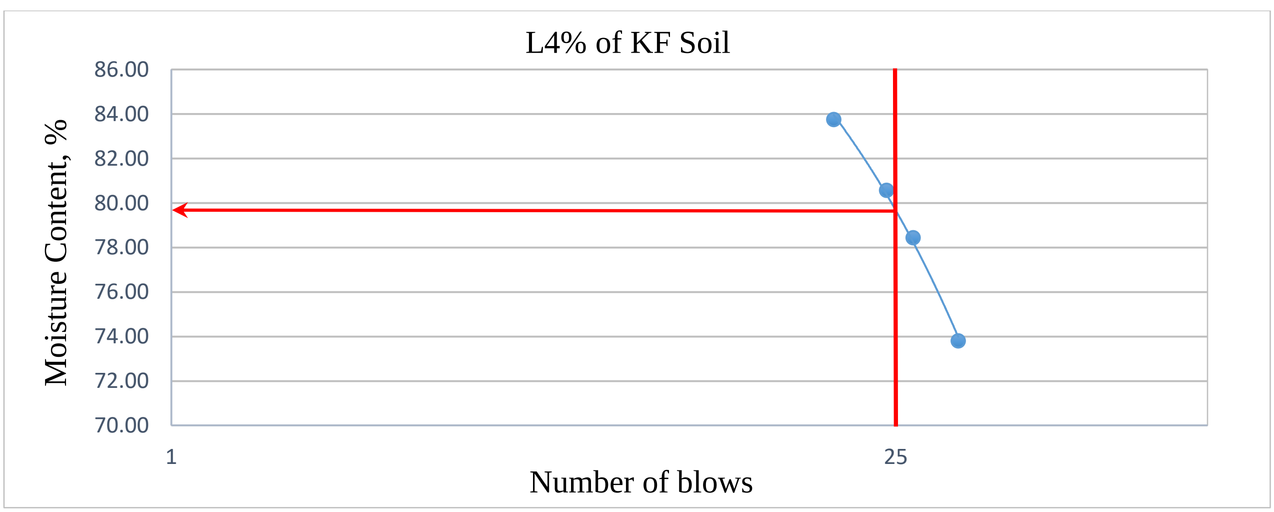
Sample Location: KF	**Natural Soil**					
Determination	**Liquid Limit**				**Plastic Limit**	
Number of blows	33	28	23	18	----	----
Test No	1	2	3	4	1	2
Container No	F5	A17	B8	3L	K1	T4
Wt. of container + wet soil, g	62.45	58.39	41.68	42.89	22.15	24.11
Wt. of container + dry soil, g	40.02	38.76	29.88	30.83	21.15	22.01
Wt. of container, g	18.18	19.97	18.73	19.60	17.96	16.92
Wt. of water, g	22.43	19.63	11.80	12.06	1.00	2.10
Wt. of dry soil, g	21.84	18.79	11.15	11.23	3.19	5.09
Moisture content, %	102.7	104.5	105.8	107.4	31.35	41.26
Average	105.10				36.30	
Plasticity Index	68.80					



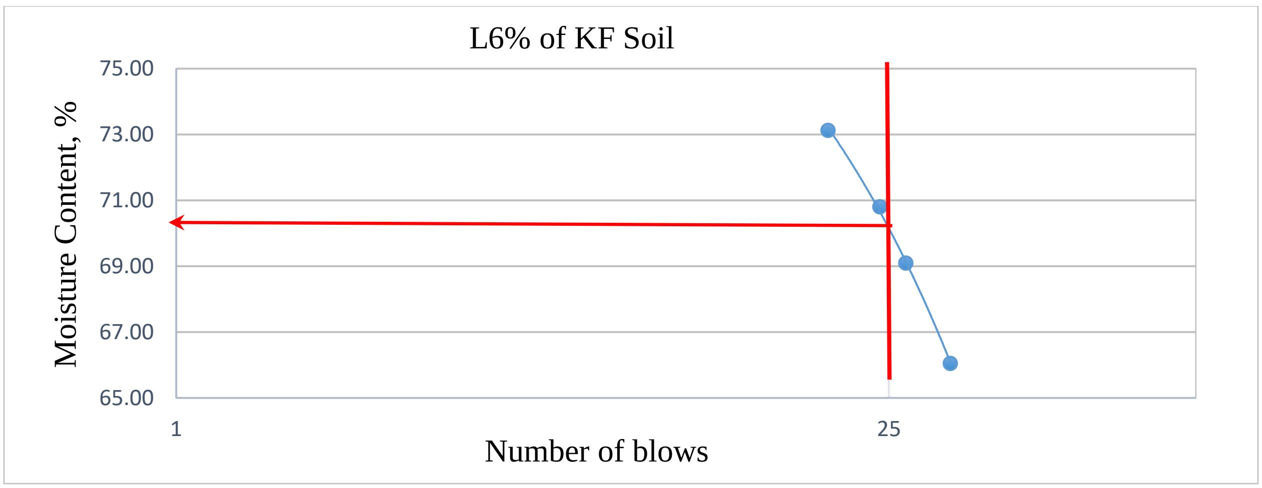
Sample Location: KF	**Additive Content: L2%**					
Determination	**Liquid Limit**				**Plastic Limit**	
Number of blows	33	27	24	19	----	----
Test No	1	2	3	4	1	2
Container No	3L	F5	A17	B8	J7	A4
Wt. of container + wet soil, g	38.59	39.25	35.65	37.15	28.27	26.89
Wt. of container + dry soil, g	29.91	29.41	29.17	28.35	24.37	25.39
Wt. of container, g	19.60	18.18	21.91	18.75	17.96	16.78
Wt. of water, g	8.68	9.84	6.48	8.80	3.90	1.50
Wt. of dry soil, g	10.31	11.23	7.26	9.60	6.41	8.61
Moisture content, %	84.19	87.62	89.26	91.67	60.84	17.4
Average	88.18				39.13	
Plasticity Index	49.05					



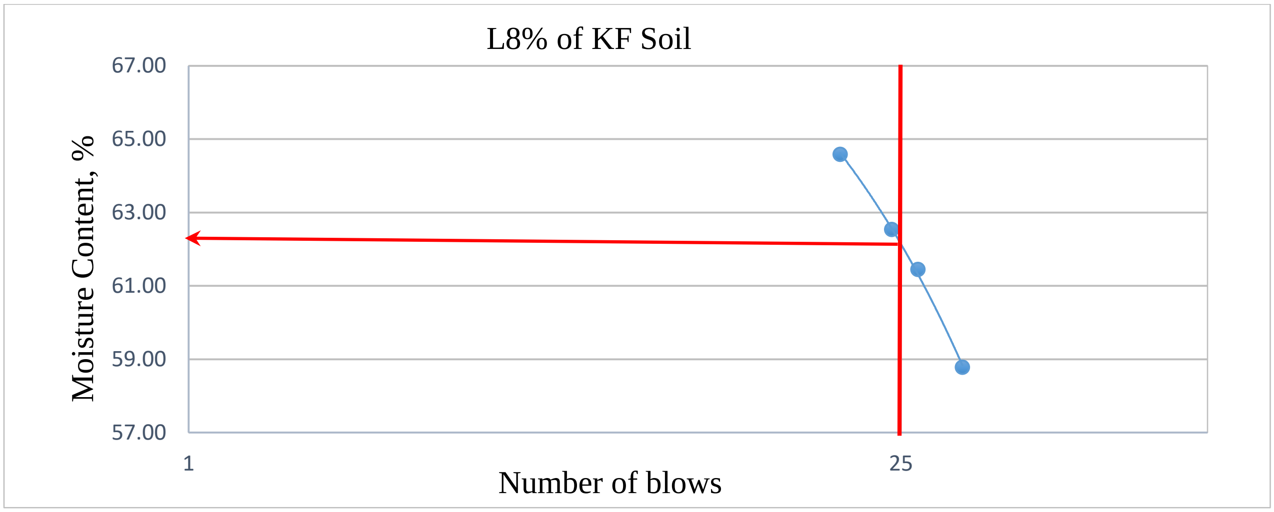
Sample Location: KF	Additive Content: L4%					
Determination	**Liquid Limit**				**Plastic Limit**	
Number of blows	33	27	24	19	----	----
Test No	1	2	3	4	1	2
Container No	3L	F5	A17	B8	J7	A4
Wt. of container + wet soil, g	37.52	38.22	35.02	36.39	28.57	26.89
Wt. of container + dry soil, g	29.91	29.41	29.17	28.35	24.37	25.39
Wt. of container, g	19.60	18.18	21.91	18.75	17.96	16.78
Wt. of water, g	7.61	8.81	5.85	8.04	4.20	1.50
Wt. of dry soil, g	10.31	11.23	7.26	9.60	6.41	8.61
Moisture content, %	73.81	78.45	80.58	83.75	65.52	17.4
Average	79.15				41.47	
Plasticity Index	37.68					



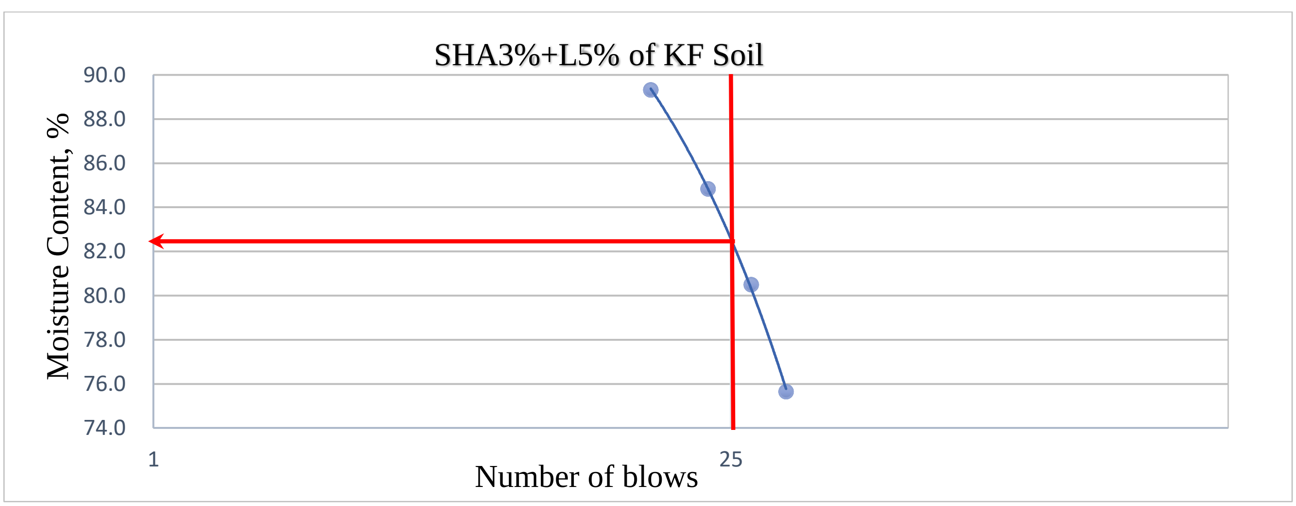
Sample Location: KF	Additive Content: L6%					
Determination	**Liquid Limit**				**Plastic Limit**	
Number of blows	33	27	24	19	----	----
Test No	1	2	3	4	1	2
Container No	3L	F5	A17	B8	J7	A4
Wt. of container + wet soil, g	36.72	37.17	34.31	35.37	28.77	26.97
Wt. of container + dry soil, g	29.91	29.41	29.17	28.35	24.37	25.39
Wt. of container, g	19.60	18.18	21.91	18.75	17.96	16.78
Wt. of water, g	6.81	7.76	5.14	7.02	4.40	1.58
Wt. of dry soil, g	10.31	11.23	7.26	9.60	6.41	8.61
Moisture content, %	66.05	69.10	70.80	73.13	68.64	18.4
Average	69.77				43.50	
Plasticity Index	26.27					



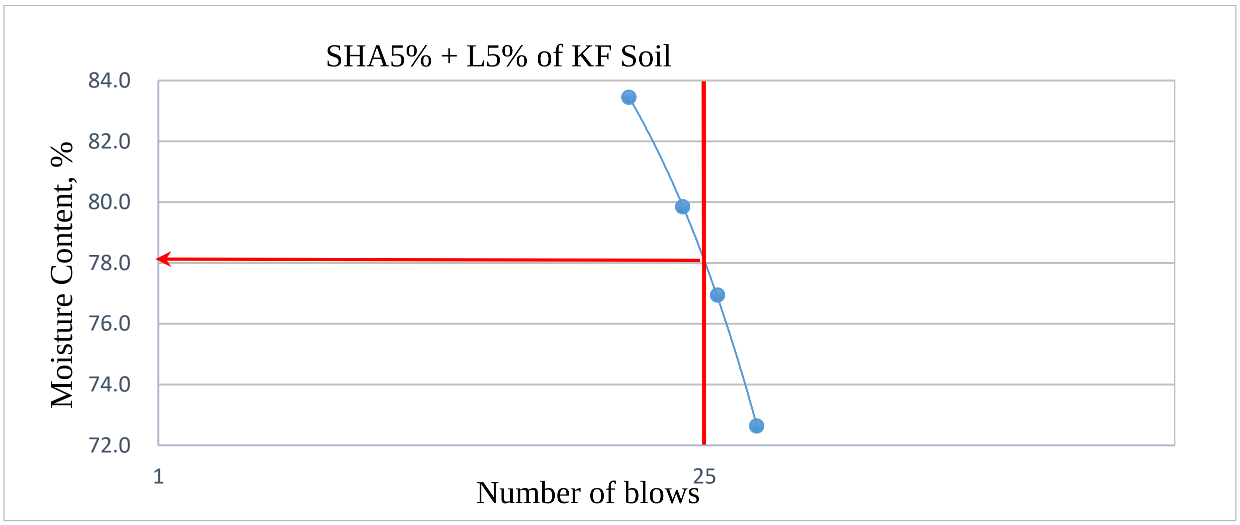
Sample Location: KF	Additive Content: L8%					
Determination	**Liquid Limit**				**Plastic Limit**	
Number of blows	33	27	24	19	----	----
Test No	1	2	3	4	1	2
Container No	3L	F5	A17	B8	J7	A4
Wt. of container + wet soil, g	35.97	36.31	33.71	34.55	28.87	27.69
Wt. of container + dry soil, g	29.91	29.41	29.17	28.35	24.37	25.39
Wt. of container, g	19.60	18.18	21.91	18.75	17.96	16.78
Wt. of water, g	6.06	6.90	4.54	6.20	4.50	2.30
Wt. of dry soil, g	10.31	11.23	7.26	9.60	6.41	8.61
Moisture content, %	58.78	61.44	62.53	64.58	70.20	26.7
Average	61.83				48.46	
Plasticity Index	13.37					



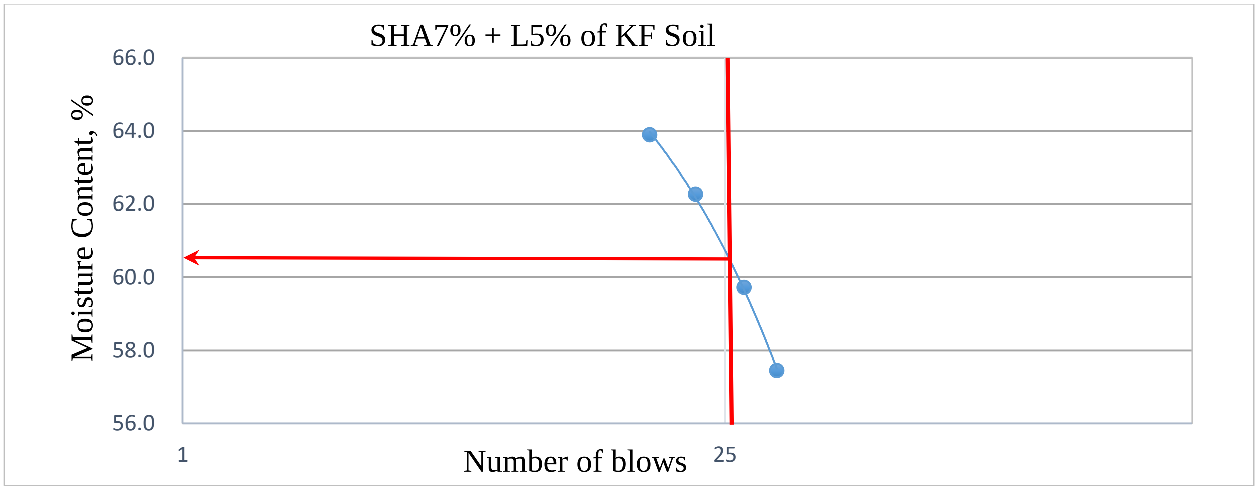
Sample Location: KF	Additive Content: SHA3%+L5%					
Determination	**Liquid Limit**				**Plastic Limit**	
Number of blows	34	28	22	16	----	----
Test No	1	2	3	4	1	2
Container No	F5	A17	B8	3L	K1	T4
Wt. of container + wet soil, g	42.49	43.25	39.32	40.86	23.25	23.44
Wt. of container + dry soil, g	32.02	33.76	29.87	30.83	21.15	22.31
Wt. of container, g	18.18	21.97	18.73	19.60	17.96	16.92
Wt. of water, g	10.47	9.49	9.45	10.03	2.10	1.13
Wt. of dry soil, g	13.84	11.79	11.14	11.23	3.19	5.39
Moisture content, %	75.7	80.5	84.8	89.3	65.83	21.0
Average	82.57				43.40	
Plasticity Index	39.17					



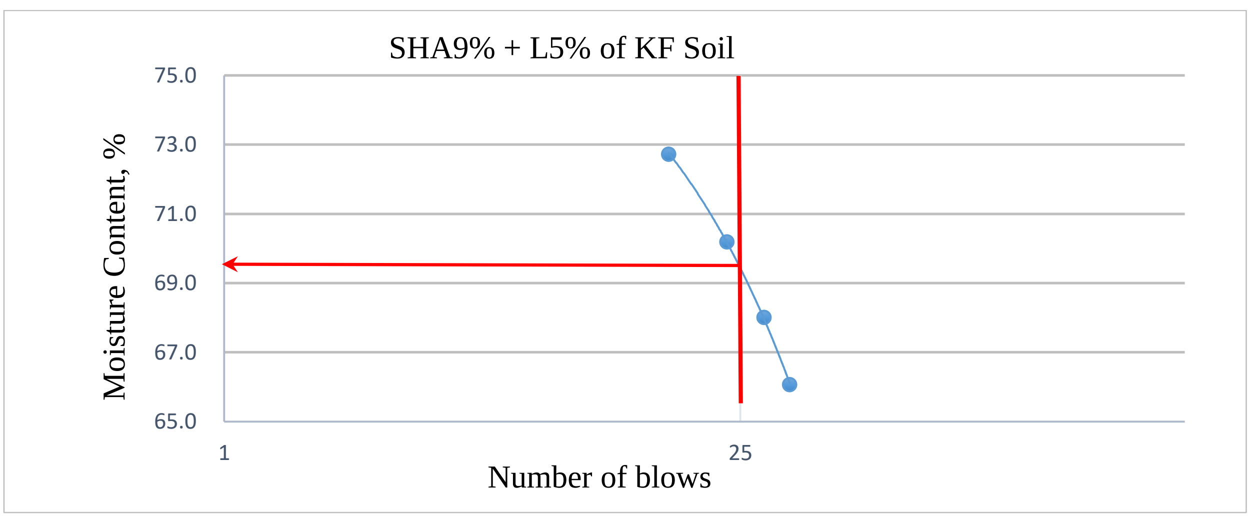
Sample Location: KF	**Additive Content: SHA5%+L5%**					
Determination	**Liquid Limit**				**Plastic Limit**	
Number of blows	34	27	22	16	----	----
Test No	1	2	3	4	1	2
Container No	F5	A17	B8	3L	Z-E	G3T2
Wt. of container + wet soil, g	44.37	42.16	39.27	42.11	24.11	24.21
Wt. of container + dry soil, g	33.35	33.38	30.15	31.87	22.82	21.35
Wt. of container, g	18.18	21.97	18.73	19.60	17.96	16.92
Wt. of water, g	11.02	8.78	9.12	10.24	1.29	2.86
Wt. of dry soil, g	15.17	11.41	11.42	12.27	4.86	4.43
Moisture content, %	72.6	77.0	79.9	83.5	26.54	64.6
Average	78.23				45.55	
Plasticity Index	32.68					



Sample Location: KF	**Additive Content: SHA7%+L5%**					
Determination	**Liquid Limit**				**Plastic Limit**	
Number of blows	34	28	21	16	----	----
Test No	1	2	3	4	1	2
Container No	F5	A17	B8	3L	Z-E	G3T2
Wt. of container + wet soil, g	41.97	42.27	42.68	44.79	22.88	23.47
Wt. of container + dry soil, g	33.29	34.68	33.49	34.97	20.82	22.15
Wt. of container, g	18.18	21.97	18.73	19.60	17.96	16.92
Wt. of water, g	8.68	7.59	9.19	9.82	2.06	1.32
Wt. of dry soil, g	15.11	12.71	14.76	15.37	2.86	5.23
Moisture content, %	57.4	59.7	62.3	63.9	72.03	25.24
Average	60.83				48.63	
Plasticity Index	12.20					



Sample Location: KF	Additive Content: SHA9%+L5%					
Determination	Liquid Limit				Plastic Limit	
Number of blows	34	29	23	16	----	----
Test No	1	2	3	4	1	2
Container No	F5	A17	B8	3L	Z-E	G3T2
Wt. of container + wet soil, g	41.28	42.45	44.91	44.74	24.87	23.97
Wt. of container + dry soil, g	32.09	34.16	34.10	34.13	22.82	21.35
Wt. of container, g	18.18	21.97	18.70	19.54	17.96	16.92
Wt. of water, g	9.19	8.29	10.81	10.61	2.05	2.62
Wt. of dry soil, g	13.91	12.19	15.40	14.59	4.86	4.43
Moisture content, %	66.1	68.0	70.2	72.7	42.18	59.1
Average	69.25				50.66	
Plasticity Index	18.59					



APPENDIX B: Linear Shrinkage Analysis Data

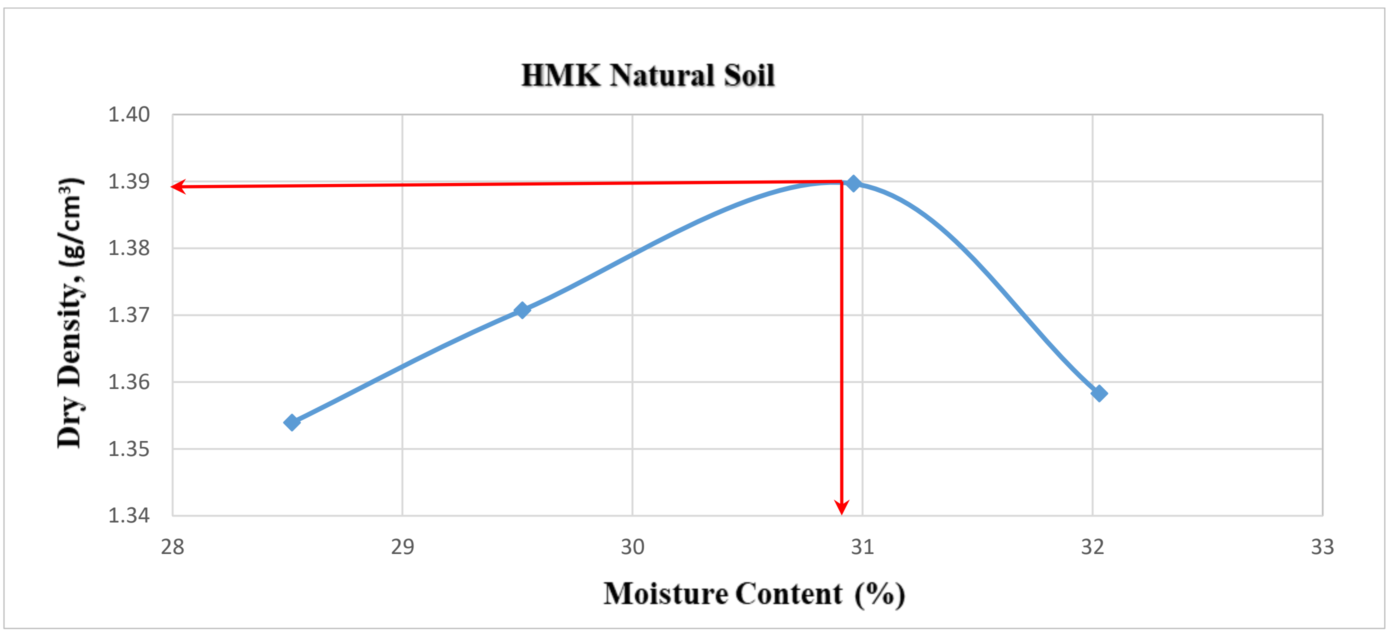
Sample Location			HMK Soil Sample	
Additives	**Length of Mold (cm)**	**length of dry specimen (cm)**	**Linear Shrinkage (%)**	**Degree of Expansion**
Natural Soil	14.00	11.36	18.86	Critical
L2%	14.00	11.91	14.93	Critical
L4%	14.00	12.71	9.21	Critical
L6%	14.00	13.22	5.57	Marginal
L8%	14.00	13.34	4.71	Non-critical
SHA 3% + 5% L	14.00	12.85	8.21	Critical
SHA 5% + 5% L	14.00	13.12	6.29	Marginal
SHA 7% + 5% L	14.00	13.41	4.21	Non-critical
SHA 9% + 5% L	14.00	13.21	5.64	Marginal

Sample Location			KF Soil Sample	
Additives	**Length of Mold (cm)**	**length of dry specimen (cm)**	**Linear Shrinkage (%)**	**Degree of Expansion**
Natural Soil	14.00	11.05	21.07	Critical
L2%	14.00	11.71	16.36	Critical
L4%	14.00	12.47	10.93	Critical
L6%	14.00	13.05	6.79	Marginal
L8%	14.00	13.28	5.14	Marginal
SHA 3% + 5% L	14.00	12.81	8.50	Critical
SHA 5% + 5% L	14.00	12.96	7.43	Marginal
SHA 7% + 5% L	14.00	13.31	4.93	Non-critical
SHA 9% + 5% L	14.00	13.14	6.14	Marginal

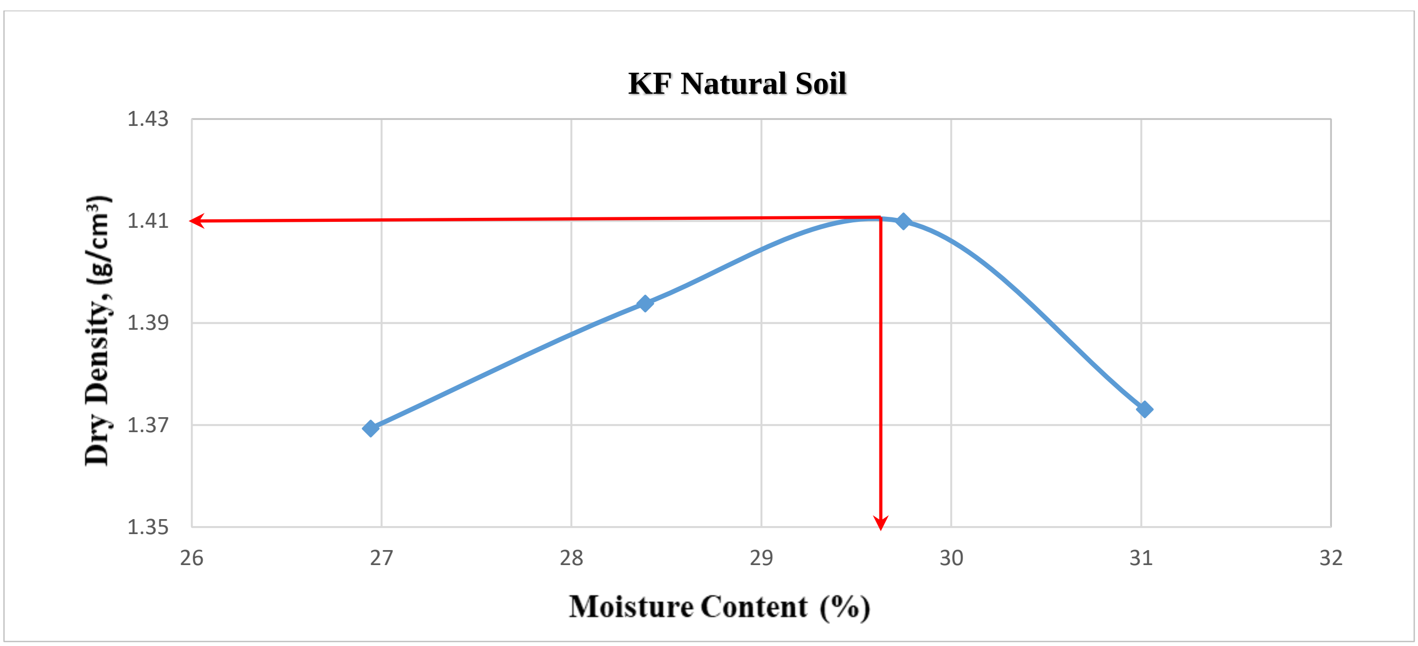
APPENDIX C: Compaction Test Analysis Data

I. Compaction test results of HMK and KF untreated soil samples

Sample Location: HMK			**Natural Soil of HMK**					
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6416		6491		6574		6529	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3695.9		3770.9		3865.5		3808.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.74		1.78		1.82		1.79	
Moisture Content Determination								
Container Code.	A2	ZE	T1	E-12	G	2	P65	P15
Mass of Wet soil + Container (g)	156.21	153.4	124.9	128.55	164.31	162.18	133	134
Mass of dry soil + container (g)	128.69	125.5	104.4	107.65	133.19	130.43	108	111
Mass of container (gm)	28.12	31.59	37.63	33.49	25.11	34.59	36.43	33.5
Mass of moisture (gm)	27.52	27.88	20.59	20.9	31.12	31.75	24.97	22.7
Mass of Dry soil (gm)	100.57	93.95	66.72	74.16	108.08	95.84	71.44	77.8
Moisture content (%)	27.36	29.68	30.86	28.18	28.79	33.13	34.95	29.11
Av. moisture content (%)	28.519		29.521		30.961		32.029	
Dry Density (gm/cm^3)	1.354		1.371		1.389		1.358	
OMC (%)	30.961			**MDD (g/cm^3)**		1.389		

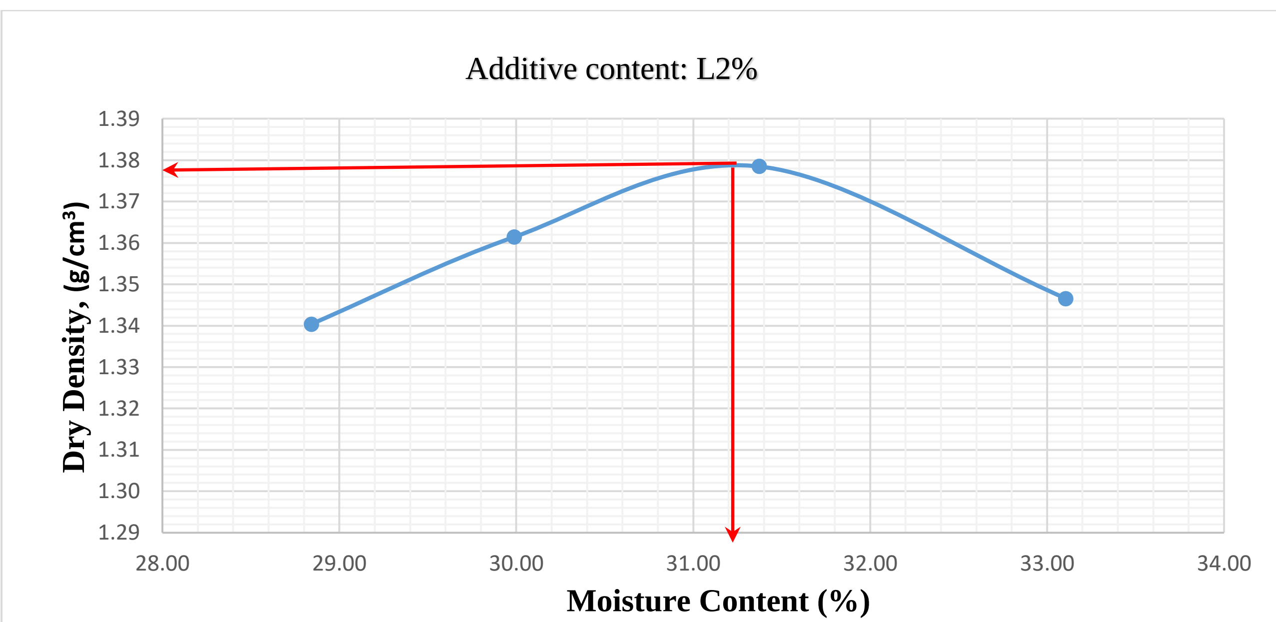


Sample Location: KF			**Natural Soil of KF**					
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6412.1		6521		6594		6541	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3692		3800.9		3885.5		3820.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.74		1.79		1.83		1.80	
Moisture Content Determination								
Container Code.	A2	ZE	T1	E-12	G	2	P65	P15
Mass of Wet soil + Container (gm)	158.22	155.12	128.12	130.09	164.21	162.13	131.14	133.46
Mass of dry soil + container (gm)	130.81	128.71	107.88	108.98	133.61	131.73	108.05	110.51
Mass of container (gm)	28.12	31.59	37.63	33.49	25.11	34.59	36.43	33.49
Mass of moisture (gm)	27.41	26.41	20.24	21.11	30.6	30.4	23.09	22.95
Mass of Dry soil (gm)	102.69	97.12	70.25	75.49	108.5	97.14	71.62	77.02
Moisture content (%)	26.69	27.19	28.81	27.96	28.20	31.30	32.24	29.80
Av. moisture content (%)	26.942		28.388		29.749		31.019	
Dry Density (gm/cm^3)	1.369		1.394		1.409		1.373	
OMC (%)	29.749			**MDD (g/cm^3)**		1.409		

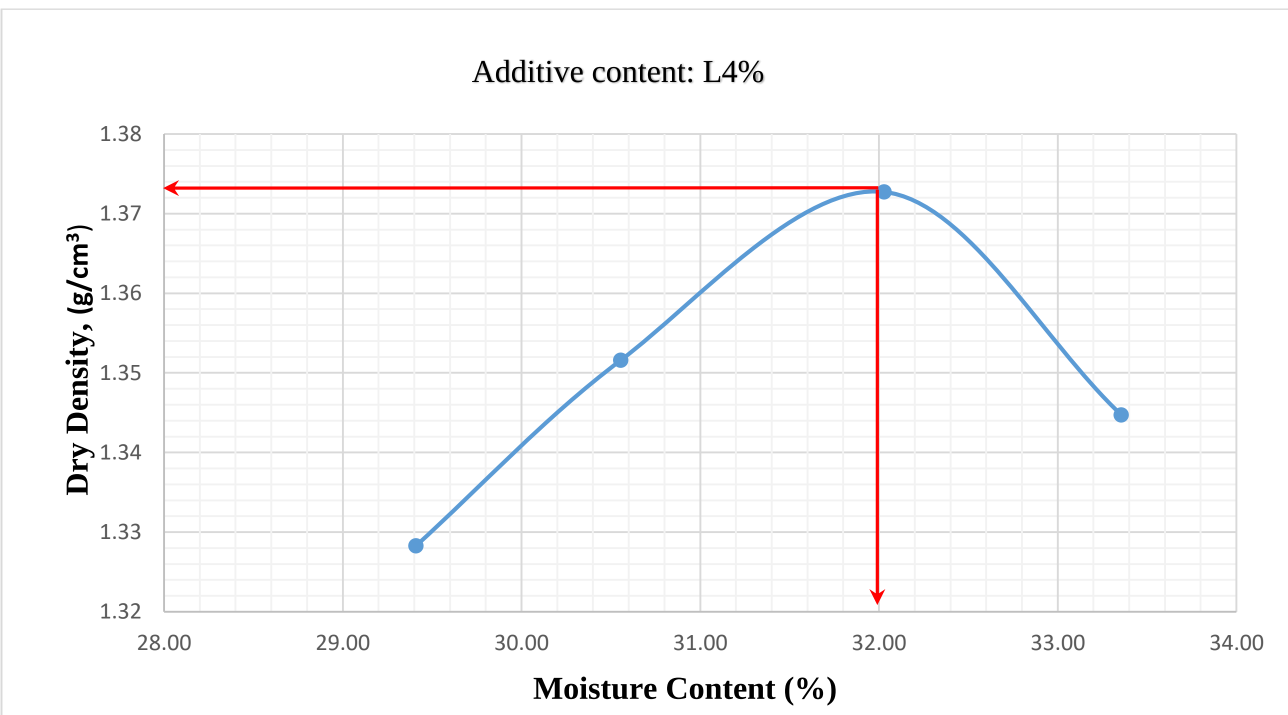


II. Compaction test results of HMK treated soil sample

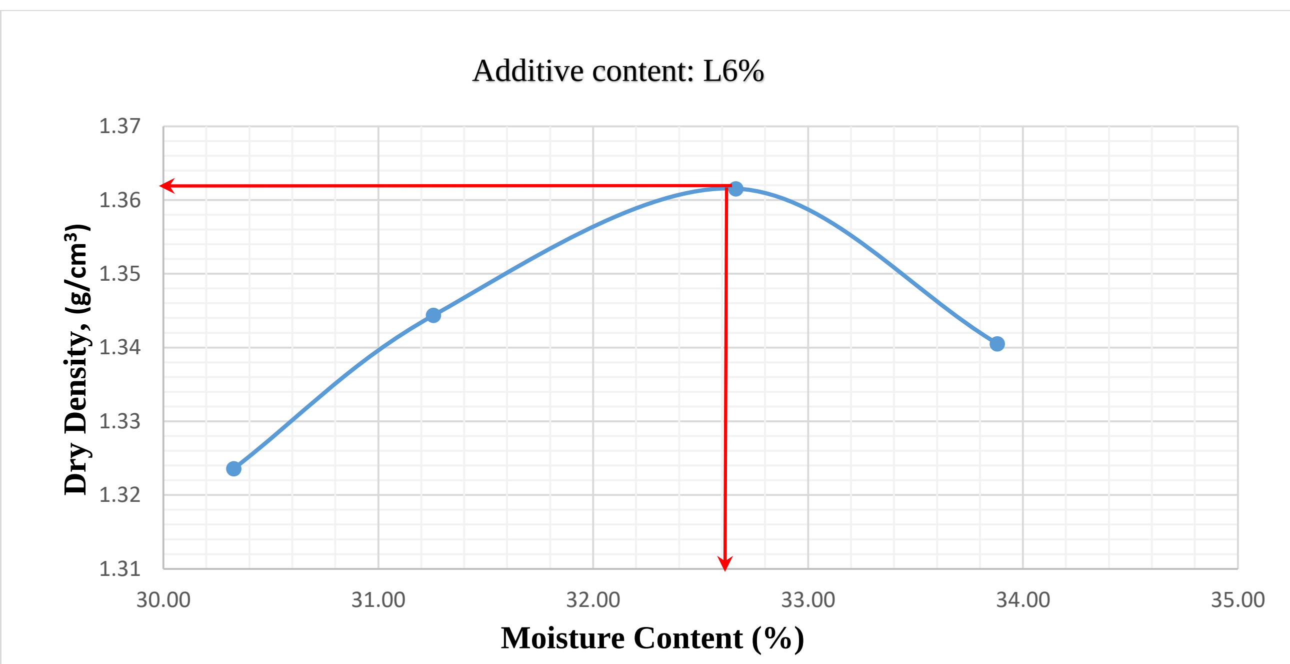
Sample Location: HMK				**Additive Content: L2%**				
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6388.1		6479		6555		6527	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3668		3758.9		3846.5		3806.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.73		1.77		1.81		1.79	
Moisture Content Determination								
Container Code.	A2	ZE	T1	E-12	G	2	P65	P15
Mass of Wet soil + Container (gm)	161.64	159.6	129.7	130.39	165.12	166.11	133	134
Mass of dry soil + container (gm)	137.19	126.2	107.9	108.72	132.19	134.23	108	110
Mass of container (gm)	28.12	31.59	37.63	33.49	25.11	34.59	36.4	33.5
Mass of moisture (gm)	24.45	33.38	21.89	21.67	32.93	31.88	24.9	24
Mass of Dry soil (gm)	109.07	94.65	70.22	75.23	107.08	99.64	71.7	76.3
Moisture content (%)	22.42	35.27	31.17	28.80	30.75	32.00	34.76	31.45
Av. moisture content (%)	28.842		29.989		31.374		33.105	
Dry Density (gm/cm^3)	1.340		1.361		1.378		1.347	
OMC (%)	31.374			**MDD (g/cm^3)**	1.378			



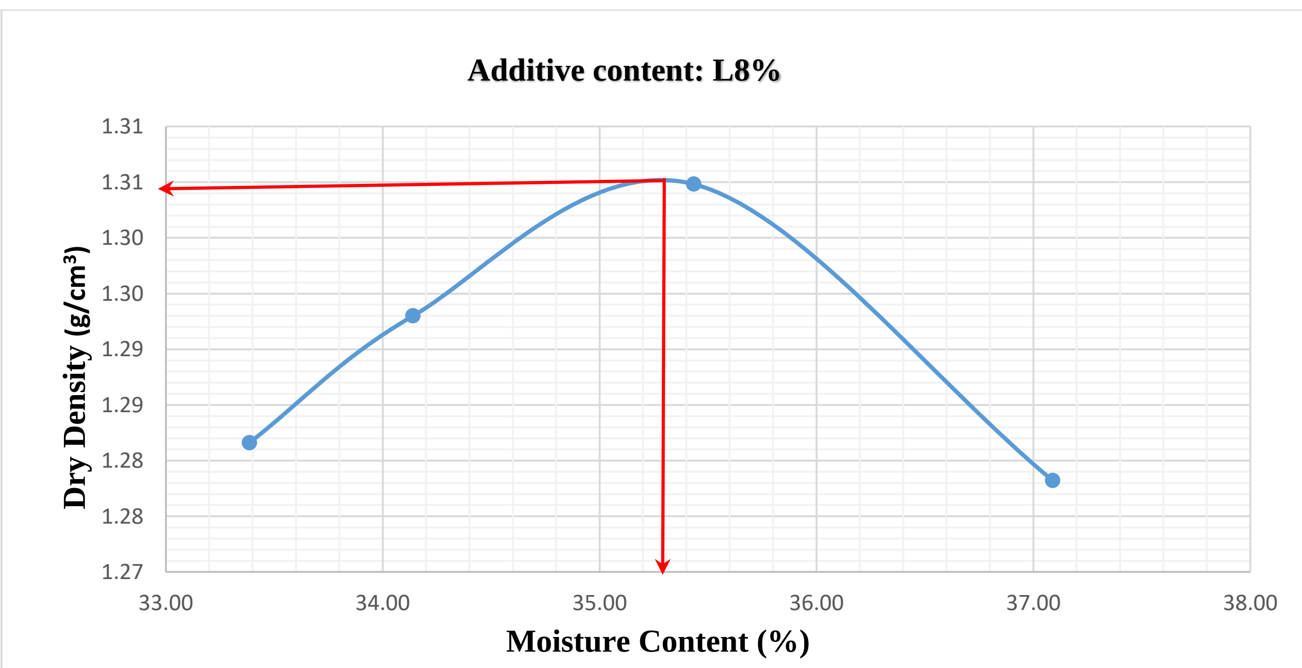
Sample Location: HMK					**Additive Content: L4%**			
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6371		6468		6558		6529	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3650.9		3747.9		3849.5		3808.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.72		1.76		1.81		1.79	
Moisture Content Determination								
Container Cod.	A2	ZE	T1	E-12	G	2	P65	P15
Mass of Wet soil + Container (gm)	161.64	159.6	129.7	130.39	165.20	166.11	133	134
Mass of dry soil + container (gm)	136.19	126.2	107.3	108.72	131.19	134.23	108	110
Mass of container (gm)	28.12	31.59	37.63	33.49	25.11	34.59	36.4	33.5
Mass of moisture (gm)	25.45	33.38	22.49	21.67	34.01	31.88	25	24.4
Mass of Dry soil (gm)	108.07	94.65	69.62	75.23	106.08	99.64	71.7	76.3
Moisture content (%)	23.55	35.27	32.30	28.80	32.06	32.00	34.81	31.91
Av. moisture content (%)	29.408		30.554		32.028		33.356	
Dry Density (gm/cm^3)	1.328		1.351579969		1.373		1.345	
OMC (%)	32.028			**MDD (g/cm^3)**		1.373		



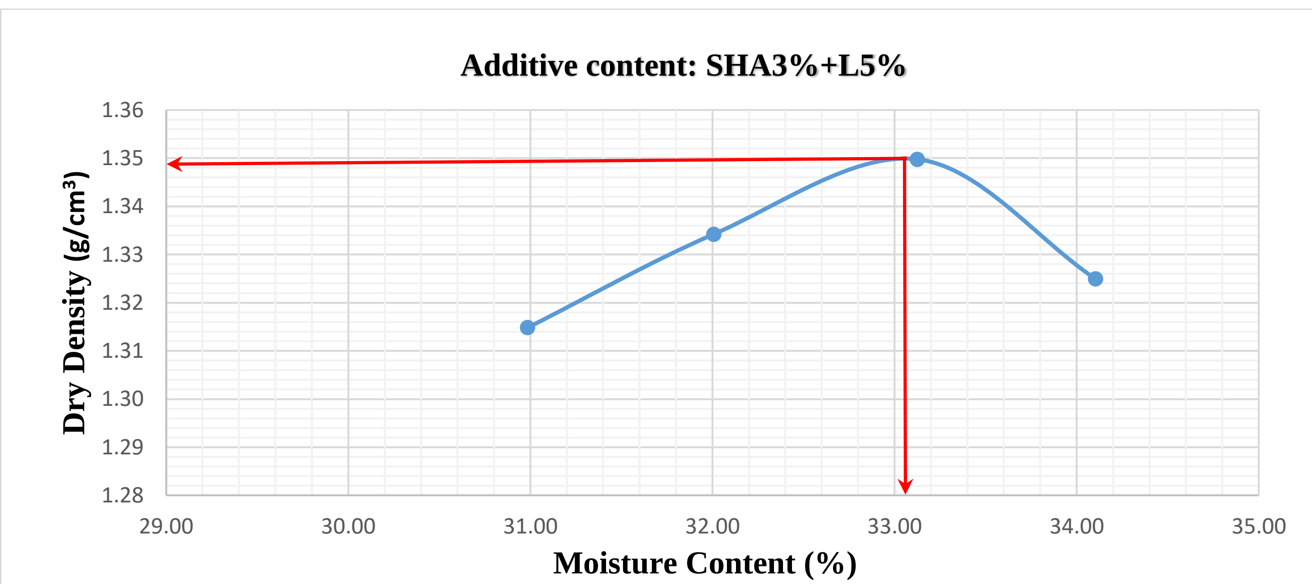
Sample Location: HMK			**Additive Content: L6%**					
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6384		6468		6545		6532	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3663.9		3747.9		3836.5		3811.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.73		1.76		1.81		1.79	
Moisture Content Determination								
Container Code.	A2	ZE	T1	E-12	G	2	P65	P15
Mass of Wet soil + Container (gm)	161.94	159.1	129.8	130.99	165.79	166.94	134	136
Mass of dry soil + container (gm)	131.58	128.7	107.5	108.12	132.71	132.93	108	111
Mass of container (gm)	28.12	31.59	37.63	33.49	25.11	34.59	36.4	33.5
Mass of moisture (gm)	30.36	30.41	22.27	22.87	33.08	34.01	25.4	25.1
Mass of Dry soil (gm)	103.46	97.12	69.88	74.63	107.6	98.34	71.7	77.3
Moisture content (%)	29.34	31.31	31.87	30.64	30.74	34.58	35.36	32.40
Av. moisture content (%)	30.328		31.257		32.664		33.881	
Dry Density (gm/cm3)	1.324		1.344		1.362		1.341	
OMC (%)	32.664			**MDD (g/cm^3)**		1.362		



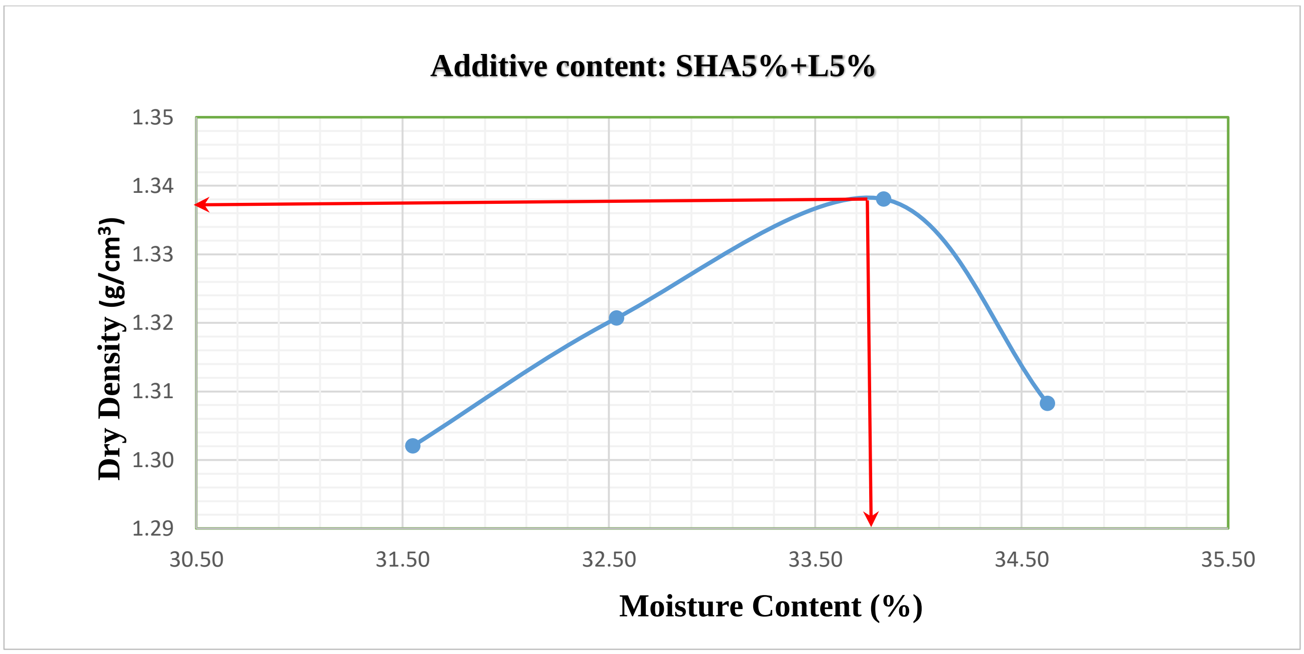
Sample Location: HMK					**Additive Content: L8%**			
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6351		6404		6462		6442	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3630.9		3683.9		3753.5		3721.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.71		1.73		1.77		1.75	
Moisture Content Determination								
Container Code.	A2	ZE	T1	E-12	G	2	P65	P15
Mass of Wet soil + Container (gm)	163.79	160.8	129.9	131.89	165.9	166.94	133.94	136.86
Mass of dry soil + container (gm)	130.22	128.1	106.10	107.22	129.2	132.17	107.17	109.31
Mass of container (gm)	28.12	31.59	37.63	33.49	25.11	34.59	36.43	33.49
Mass of moisture (gm)	33.57	32.71	23.84	24.67	36.68	34.77	26.77	27.55
Mass of Dry soil (gm)	102.1	96.52	68.47	73.73	104.1	97.58	70.74	75.82
Moisture content (%)	32.88	33.89	34.82	33.46	35.24	35.63	37.84	36.34
Av. moisture content (%)	33.384		34.139		35.434		37.089	
Dry Density (gm/cm^3)	1.282		1.293		1.305		1.278	
OMC (%)	35.434			**MDD (g/cm^3)**		1.305		



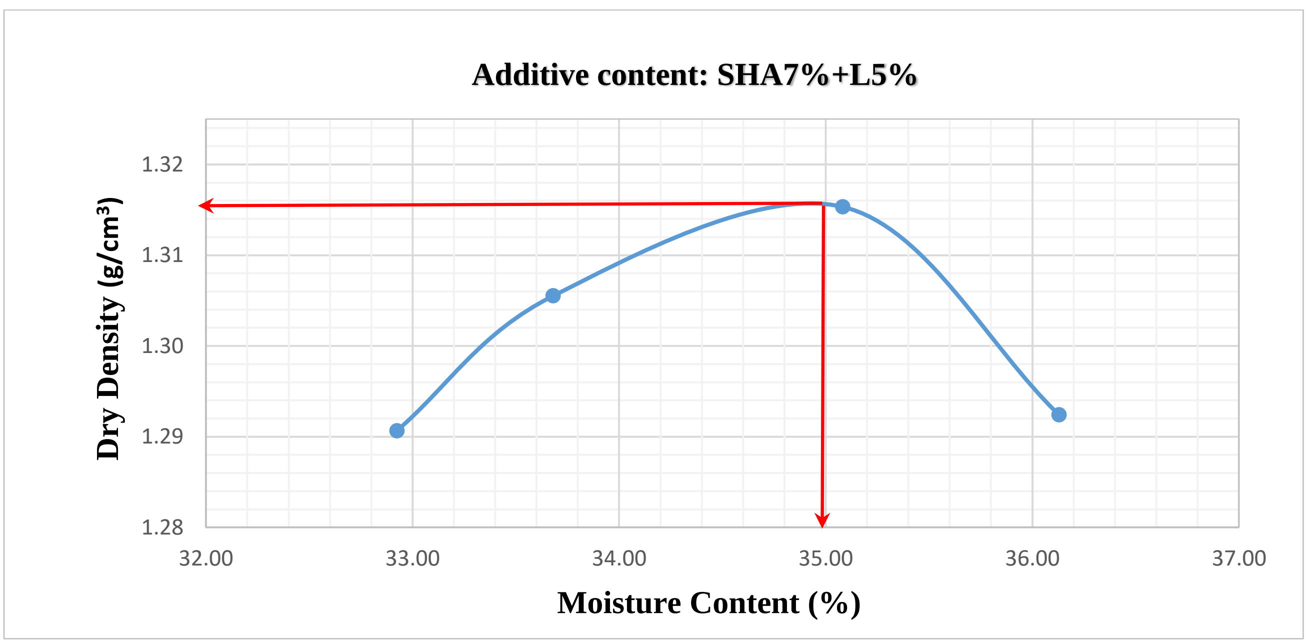
Sample Location: HMK				**Additive Content: SHA3%+L5%**				
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6378.1		6461		6525		6494	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3658		3740.9		3816.5		3773.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.72		1.76		1.80		1.78	
Moisture Content Determination								
Container Code.	A2	ZE	T1	E-12	G	2	P65	P15
Mass of Wet soil + Container (gm)	158	155.8	126	127.89	166.28	164.31	132.38	134.19
Mass of dry soil + container (gm)	127.8	125.9	103	106.75	133.19	130.23	107.39	109.21
Mass of container (gm)	28.12	31.59	37.6	33.49	25.11	34.59	36.43	33.49
Mass of moisture (gm)	30.18	29.88	22.9	21.14	33.09	34.08	24.99	24.98
Mass of Dry soil (gm)	99.67	94.29	65.2	73.26	108.08	95.64	70.96	75.72
Moisture content (%)	30.28	31.69	35.16	28.86	30.62	35.63	35.22	32.99
Av.moisture content (%)	30.985		32.007		33.125		34.103	
Dry Density (gm/cm^3)	1.315		1.334		1.349		1.325	
OMC (%)	33.125			**MDD (g/cm^3)**		1.349		



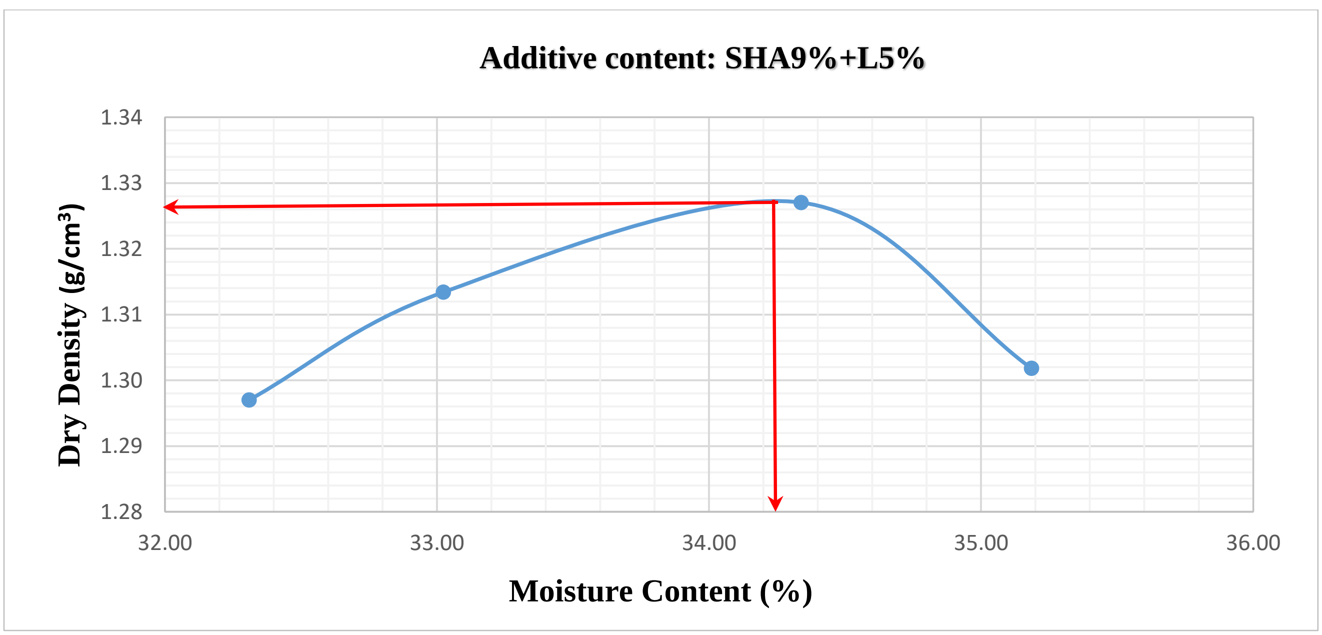
Sample Location: HMK					Additive Content: SHA5%+L5%			
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6358.1		6438		6512		6461	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3638		3717.9		3803.5		3740.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.71		1.75		1.79		1.76	
Moisture Content Determination								
Container Code.	A2	ZE	T1	E-12	G	2	P65	P15
Mass of Wet soil + Container (gm)	161.1	158.3	128	130.39	165.31	164.18	132.54	134.49
Mass of dry soil + container (gm)	129.4	127.8	106	106.78	131.19	130.23	107.17	109.21
Mass of container (gm)	28.12	31.59	37.6	33.49	25.11	34.59	36.43	33.49
Mass of moisture (gm)	31.71	30.57	22.4	23.61	34.12	33.95	25.37	25.28
Mass of Dry soil (gm)	101.3	96.16	68.3	73.29	106.08	95.64	70.74	75.72
Moisture content (%)	31.31	31.79	32.86	32.21	32.16	35.50	35.86	33.39
Av. moisture content (%)	31.548		32.537		33.831		34.625	
Dry Density (gm/cm^3)	1.302		1.321		1.338		1.3083	
OMC (%)	33.831			**MDD (g/cm^3)**		1.338		



Sample Location: HMK					**Additive Content: SHA7%+L5%**			
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil(gm)	6364		6427		6494		6457	
Mass of Mold (gm)	2720.1		2720.1		2720.1		2720.1	
Mass of Wet Soil (gm)	3643.9		3706.9		3773.9		3736.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.72		1.75		1.78		1.76	
Moisture Content Determination								
Container Code.	A2	ZE	T1	E-12	G	2	P65	P15
Mass of Wet soil + Container (gm)	158.1	156.3	129	130.67	166.03	163.11	132.14	134.56
Mass of dry soil + container (gm)	128.2	123.3	105	106.92	131.11	128.25	105.75	108.81
Mass of container (gm)	28.12	31.59	37.6	33.49	25.11	34.59	36.43	33.49
Mass of moisture (gm)	29.89	33.01	23.6	23.75	34.92	34.86	26.39	25.75
Mass of Dry soil (gm)	100.1	91.72	67.5	73.43	106	93.66	69.32	75.32
Moisture content (%)	29.86	35.99	35.02	32.34	32.94	37.22	38.07	34.19
Av. moisture content (%)	32.924		33.681		35.082		36.129	
Dry Density (gm/cm^3)	1.291		1.306		1.315		1.292	
OMC (%)	35.082			**MDD (g/cm^3)**		1.315		

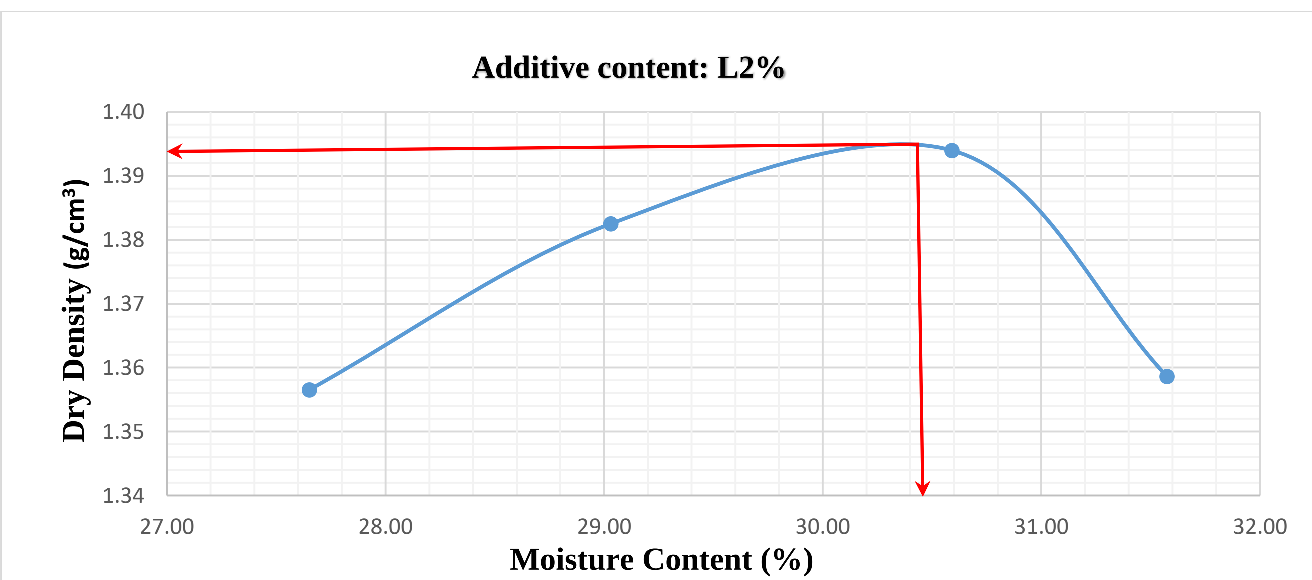


Sample Location: HMK				**Additive Content: SHA9%+L5%**				
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6365		6431		6495		6458	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3644.9		3710.9		3786.5		3737.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.72		1.75		1.78		1.76	
Moisture Content Determination								
Container Code.	A2	ZE	T1	E-12	G	2	P65	P15
Mass of Wet soil + Container (gm)	160.5	157.6	129	130.12	165.35	163.72	134.14	135.16
Mass of dry soil + container (gm)	131.1	124.2	106	106.21	131.28	129.13	107.67	109.81
Mass of container (gm)	28.12	31.59	37.6	33.49	25.11	34.59	36.43	33.49
Mass of moisture (gm)	29.4	33.41	22.7	23.91	34.07	34.59	26.47	25.35
Mass of Dry soil (gm)	103	92.62	68.3	72.72	106.17	94.54	71.24	76.32
Moisture content (%)	28.55	36.07	33.17	32.88	32.09	36.59	37.16	33.22
Av. moisture content (%)	32.309		33.023		34.339		35.186	
Dry Density (gm/cm^3)	1.297		1.313		1.327		1.302	
OMC (%)	34.339			**MDD (g/cm^3)**		1.327		

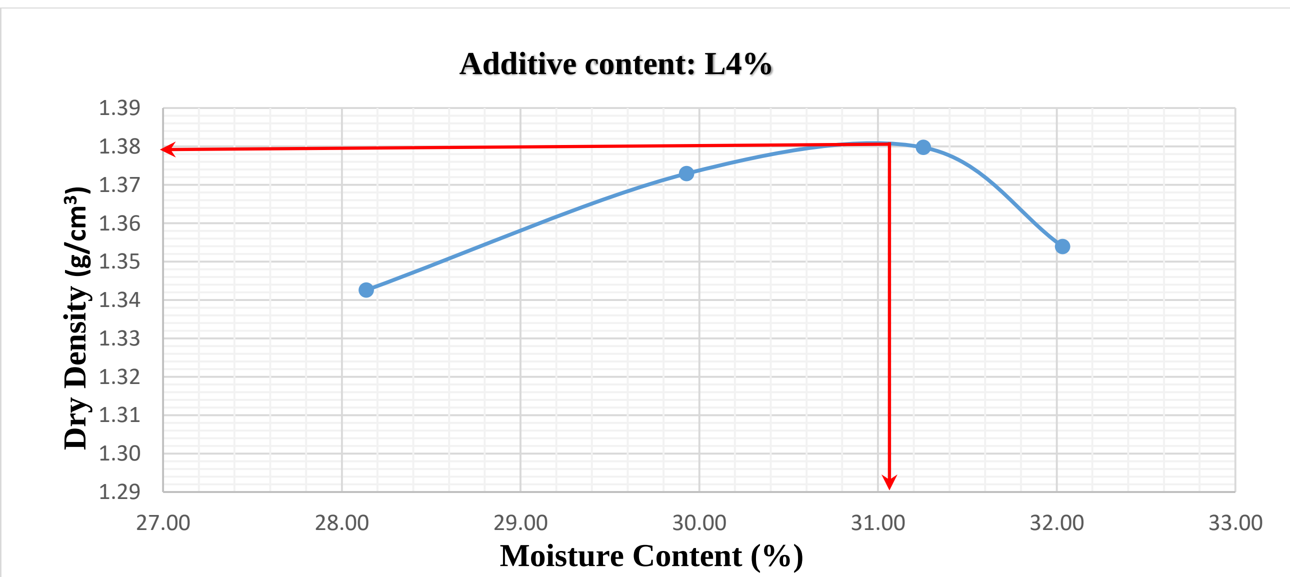


III. Compaction test results of KF treated soil sample

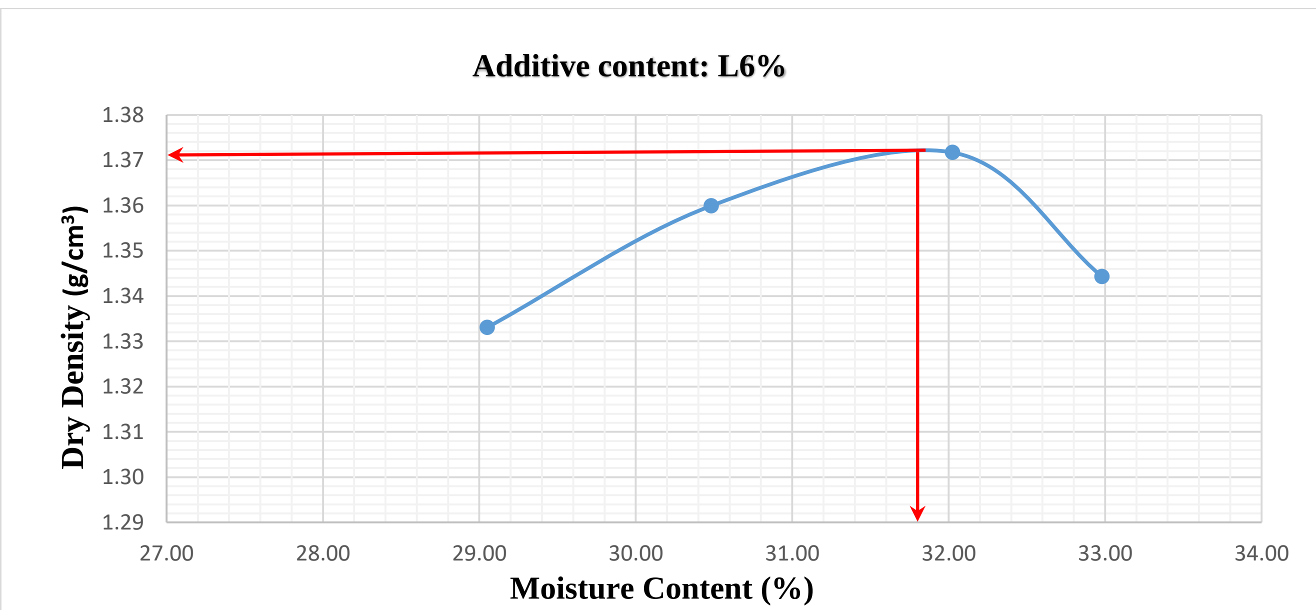
Sample Location: KF			**Additive Content: L2%**					
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6398.1		6509		6575		6517	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3678		3788.9		3866.5		3796.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.73		1.78		1.82		1.79	
Moisture Content Determination								
Container Code.	A2	ZE	T1	E-12	G	2	P65	P15
Mass of Wet soil + Container (gm)	161.24	159.12	129.24	130.19	165.54	166.61	132.73	133.81
Mass of dry soil + container (gm)	137.89	126.74	107.45	109.72	133.24	135.13	109.17	110.21
Mass of container (gm)	28.12	31.59	37.63	33.49	25.11	34.59	36.43	33.49
Mass of moisture (gm)	23.35	32.38	21.79	20.47	32.3	31.48	23.56	23.6
Mass of Dry soil (gm)	109.77	95.15	69.82	76.23	108.13	100.54	72.74	76.72
Moisture content (%)	21.27	34.03	31.21	26.85	29.87	31.31	32.39	30.76
Av. moisture content (%)	27.651		29.031		30.591		31.575	
Dry Density (gm/cm^3)	1.357		1.382		1.394		1.359	
OMC (%)	30.591			**MDD (g/cm^3)**		1.394		



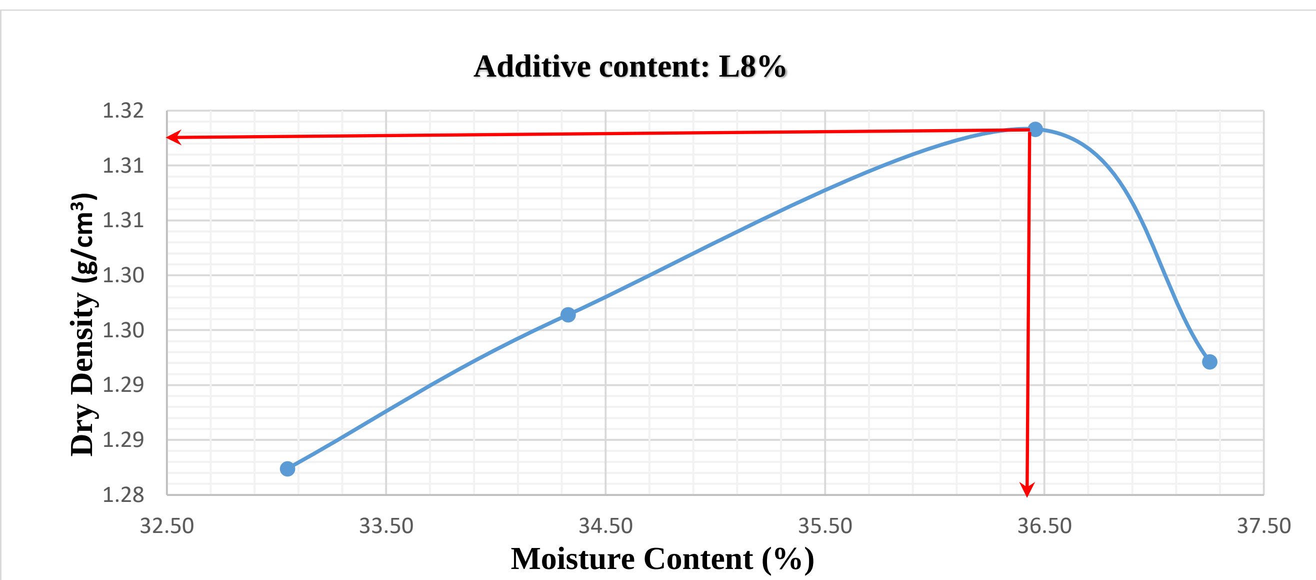
Sample Location: KF					**Additive Content: L4%**			
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6374.1		6509		6555		6517	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3654		3788.9		3846.5		3796.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.72		1.78		1.81		1.79	
Moisture Content Determination								
Container Code.	G1	P65	T1	G3T2	G	E	P65	P15
Mass of Wet soil + Container (gm)	161.14	159.32	129.74	130.58	165.44	166.71	132.73	133.81
Mass of dry soil + container (gm)	137.89	126.14	107.15	109.72	133.24	134.13	108.67	110.21
Mass of container (gm)	28.12	31.59	37.63	33.49	25.11	34.59	36.43	33.49
Mass of moisture (gm)	23.25	33.18	22.59	20.86	32.2	32.58	24.06	23.6
Mass of Dry soil (gm)	109.77	94.55	69.52	76.23	108.13	99.54	72.24	76.72
Moisture content (%)	21.18	35.09	32.49	27.36	29.78	32.73	33.31	30.76
Av. moisture content (%)	28.137		29.929		31.255		32.033	
Dry Density (gm/cm^3)	1.343		1.373		1.379		1.354	
OMC (%)	31.255			**MDD (g/cm^3)**		1.379		



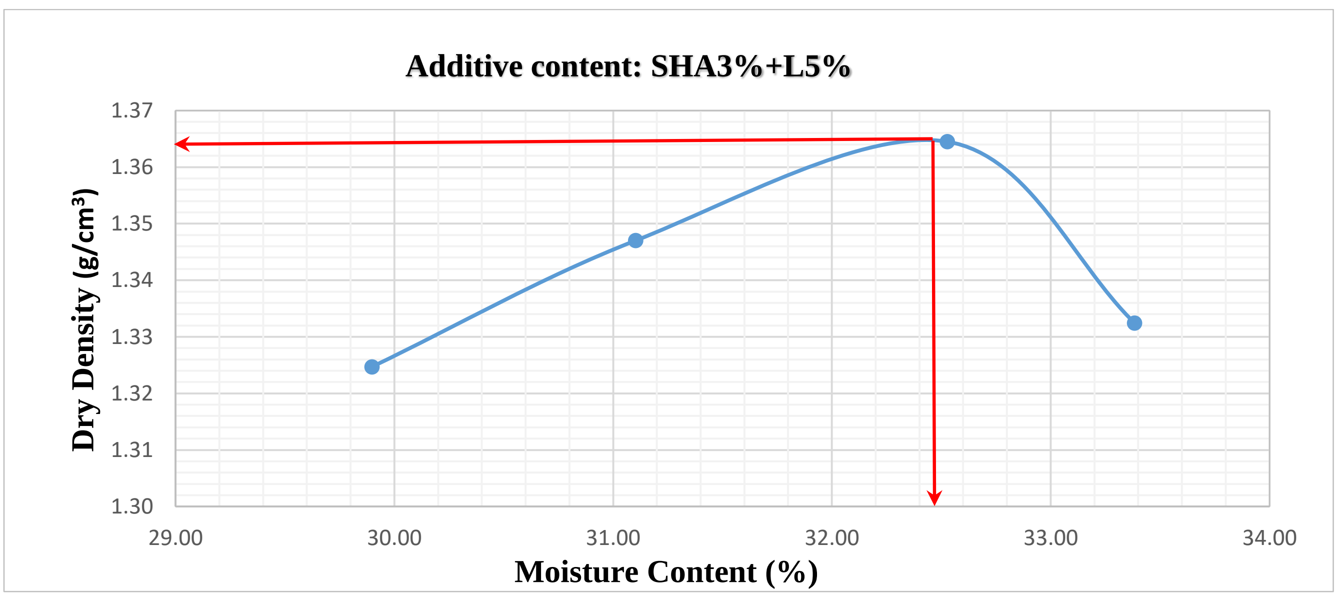
Sample Location: KF				**Additive Content: L6%**				
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6374.1		6489		6555		6517	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3654		3768.9		3846.5		3796.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.72		1.77		1.81		1.79	
Moisture Content Determination								
Container Code.	P15	E-12	G3T2	ZE	T4	Z	P65	A2
Mass of Wet soil + Container (gm)	161.14	159.12	129.74	130.78	165.84	166.91	132.93	133.81
Mass of dry soil + container (gm)	134.85	127.14	107.15	109.22	132.44	134.13	108.17	109.81
Mass of container (gm)	28.12	31.59	37.63	33.49	25.11	34.59	36.43	33.49
Mass of moisture (gm)	26.29	31.98	22.59	21.56	33.4	32.78	24.76	24
Mass of Dry soil (gm)	106.73	95.55	69.52	75.73	107.33	99.54	71.74	76.32
Moisture content (%)	24.63	33.47	32.49	28.47	31.12	32.93	34.51	31.45
Av. moisture content (%)	29.051		30.482		32.025		32.980	
Dry Density (gm/cm^3)	1.333		1.359		1.372		1.344	
OMC (%)	32.025			**MDD (g/cm^3)**		1.372		



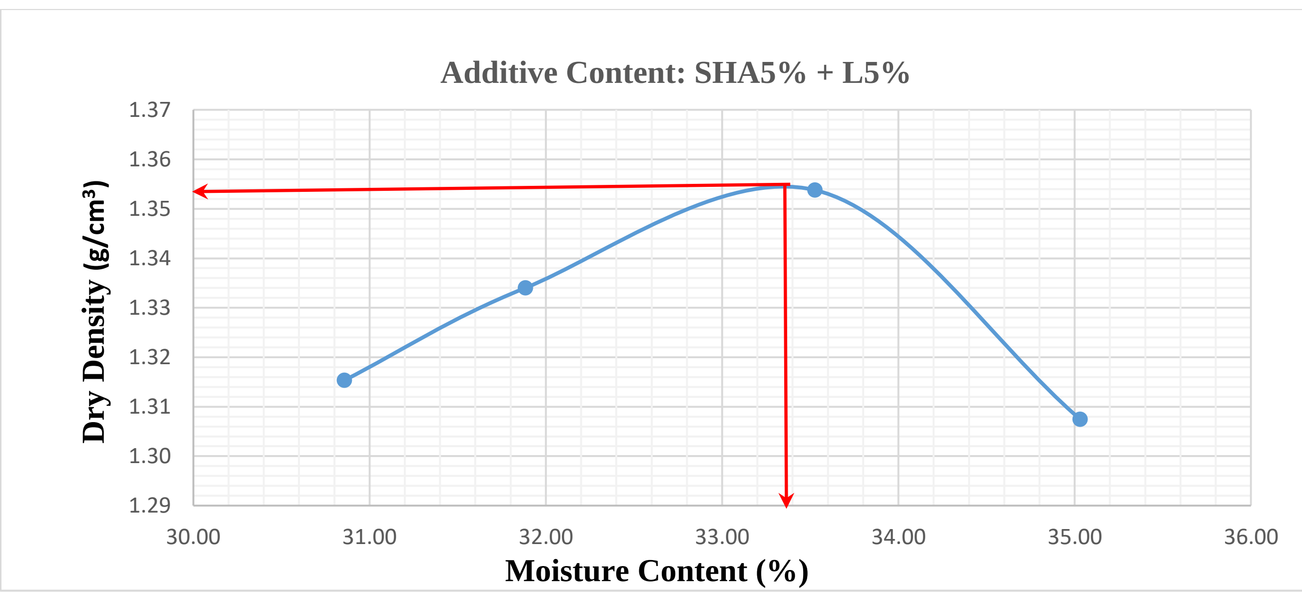
Sample Location: KF				**Additive Content: L8%**				
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6344.1		6419		6515		6487	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3624		3698.9		3806.5		3766.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.71		1.74		1.79		1.77	
Moisture Content Determination								
Container Code.	G	P15	E	Y7	E	2	ZE	N9
Mass of Wet soil + Container (gm)	163.19	162.57	132.34	134.28	167.89	170.68	135.73	136.81
Mass of dry soil + container (gm)	132.81	127.14	107.41	109.31	131.12	133.04	108.17	109.41
Mass of container (gm)	28.12	31.59	37.63	33.49	25.11	34.59	36.43	33.49
Mass of moisture (gm)	30.38	35.43	24.93	24.97	36.77	37.64	27.56	27.4
Mass of Dry soil (gm)	104.69	95.55	69.78	75.82	106.01	98.45	71.74	75.92
Moisture content (%)	29.02	37.08	35.73	32.93	34.69	38.23	38.42	36.09
Av. moisture content (%)	33.049		34.329		36.459		37.254	
Dry Density (gm/cm^3)	1.282		1.296		1.313		1.292	
OMC (%)	36.459			**MDD (g/cm^3)**	1.313			



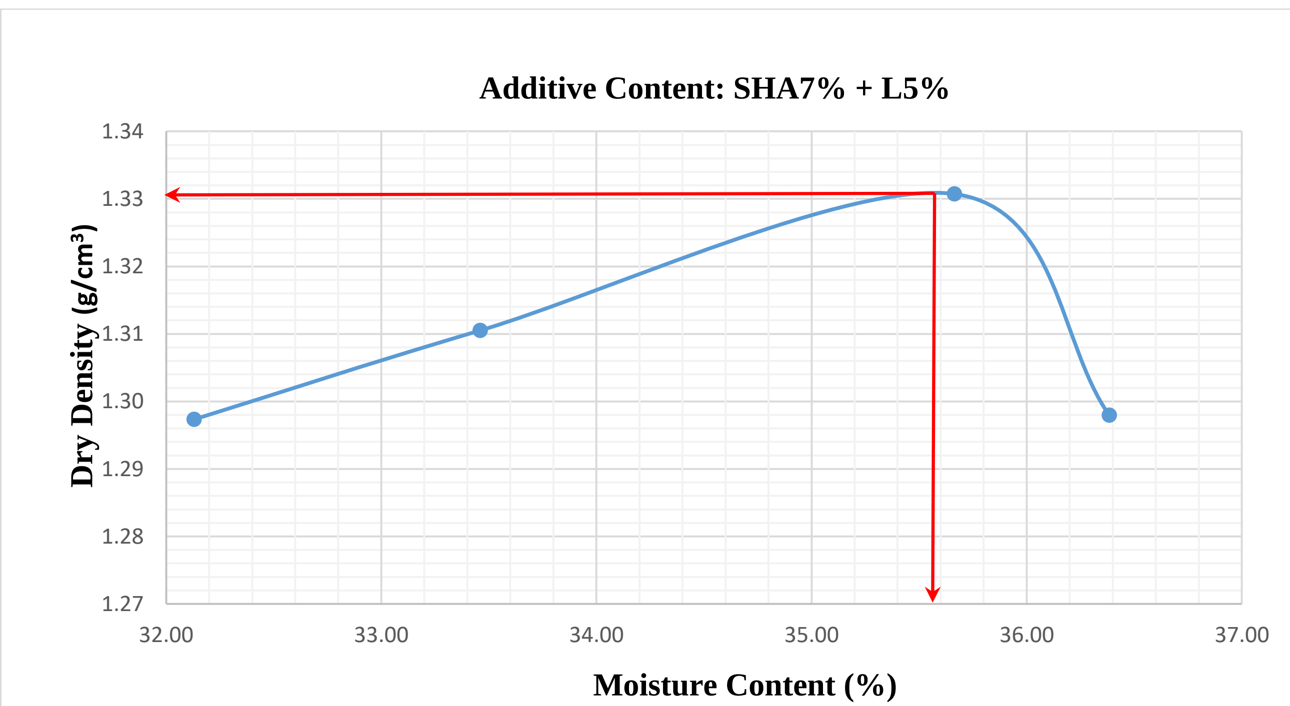
Sample Location: KF					Additive Content: SHA3%+L5%			
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6375		6471		6561		6495	
Mass of Mold (gm)	2720.1		2720.1		2720.1		2720.1	
Mass of Wet Soil (gm)	3654.9		3750.9		3840.9		3774.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.72		1.77		1.81		1.78	
Moisture Content Determination								
Container Code.	E-12	Y4	T1	P15	G3T2	2	P65	C1
Mass of Wet soil + Container (gm)	160.61	158.1	128.74	130.39	166.11	164.18	132.44	134.3
Mass of dry soil + container (gm)	130.45	128.7	105.78	108.89	132.89	131.13	107.15	110.4
Mass of container (gm)	28.12	31.59	37.63	33.49	25.11	34.59	36.43	33.49
Mass of moisture (gm)	30.16	29.44	22.96	21.5	33.22	33.05	25.29	23.85
Mass of Dry soil (gm)	102.33	97.09	68.15	75.4	107.78	96.54	70.72	76.92
Moisture content (%)	29.47	30.32	33.69	28.51	30.82	34.23	35.76	31.01
Av. moisture content (%)	29.898		31.102		32.528		33.383	
Dry Density (gm/cm^3)	1.325		1.347		1.364		1.332	
OMC (%)	32.528			**MDD (g/cm^3)**	1.364			



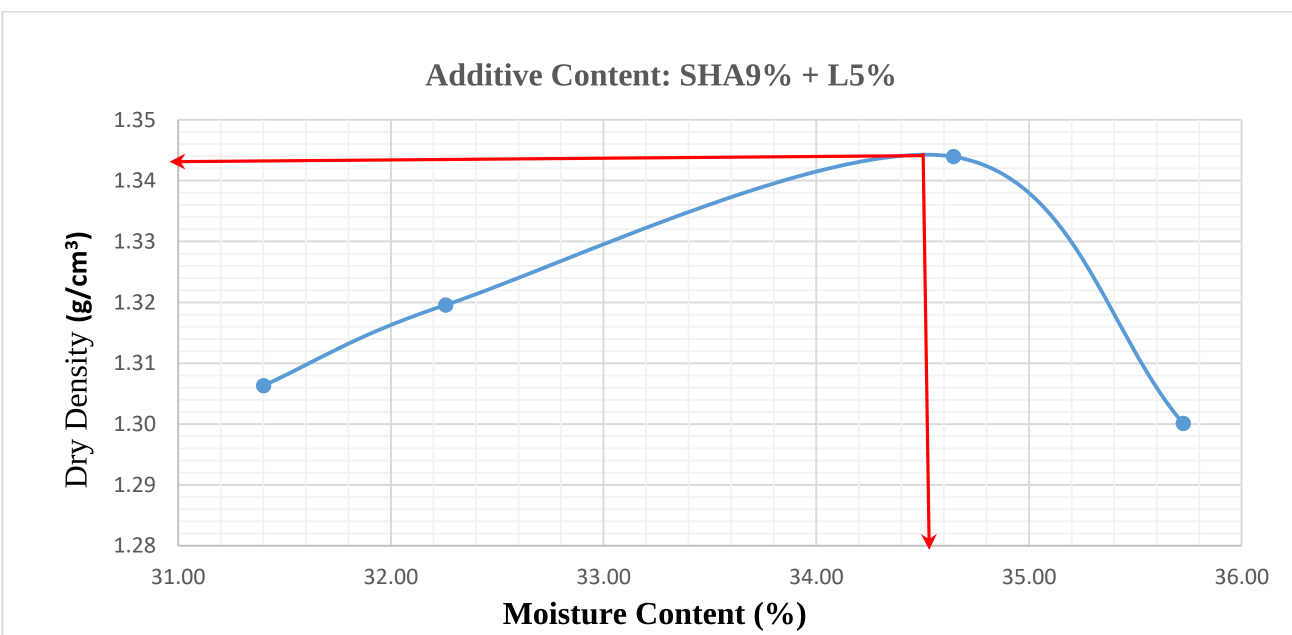
Sample Location: KF				**Additive Content: SHA5%+L5%**				
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6376		6457		6548		6470	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3655.9		3736.9		3839.5		3749.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.72		1.76		1.81		1.77	
Moisture Content Determination								
Container Code.	A2	ZE	T1	E-12	G	2	P65	P15
Mass of Wet soil + Container (gm)	156.6	154.1	126.72	128.61	164.61	162.78	132.74	134.9
Mass of dry soil + container (gm)	126.85	124.7	104.15	106.75	132.41	128.13	107.15	109.2
Mass of container (gm)	28.12	31.59	37.63	33.49	25.11	34.59	36.43	33.49
Mass of moisture (gm)	29.75	29.41	22.57	21.86	32.2	34.65	25.59	25.65
Mass of Dry soil (gm)	98.73	93.12	66.52	73.26	107.3	93.54	70.72	75.72
Moisture content (%)	30.13	31.58	33.93	29.84	30.01	37.04	36.18	33.87
Av. moisture content (%)	30.858		31.884		33.526		35.029	
Dry Density (gm/cm^3)	1.315		1.334		1.354		1.3075	
OMC (%)	33.526			**MDD (g/cm^3)**		1.354		



Sample Location: KF				**Additive Content: SHA7%+L5%**				
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6361		6435		6543		6480	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3640.9		3714.9		3834.5		3759.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.71		1.75		1.81		1.77	
Moisture Content Determination								
Container Code.	A2	ZE	T1	E-12	G	2	P65	P15
Mass of Wet soil + Container (gm)	157.45	155.2	126.81	124.72	166.61	164.71	132.14	134.5
Mass of dry soil + container (gm)	126.05	125.1	103.62	102.72	131.18	128.93	106.06	108.1
Mass of container (gm)	28.12	31.59	37.63	33.49	25.11	34.59	36.43	33.49
Mass of moisture (gm)	31.4	30.11	23.19	22	35.43	35.78	26.08	26.35
Mass of Dry soil (gm)	97.93	93.52	65.99	69.23	106.07	94.34	69.63	74.62
Moisture content (%)	32.06	32.20	35.14	31.78	33.40	37.93	37.46	35.31
Av. moisture content (%)	32.130		33.459		35.665		36.384	
Dry Density (gm/cm^3)	1.297		1.311		1.331		1.298	
OMC (%)	35.665			**MDD (g/cm^3)**		1.331		



Sample Location: KF			**Additive Content: SHA9%+L5%**					
Density Determination								
Test No.	1		2		3		4	
Mass of Mold + Wet soil (gm)	6366		6427		6552		6468	
Mass of Mold (gm)	2720.1		2720.1		2708.5		2720.1	
Mass of Wet Soil (gm)	3645.9		3706.9		3843.5		3747.9	
Volume of Mold (cm^3)	2124		2124		2124		2124	
Bulk Density (gm/cm^3)	1.72		1.75		1.81		1.76	
Moisture Content Determination								
Container Code.	A2	ZE	T1	E-12	P65	G3T2	C1	P15
Mass of Wet soil + Container (gm)	155.25	153.5	124.78	127.13	163.97	162.78	132.44	134.8
Mass of dry soil + container (gm)	125.05	124.2	103.23	104.61	130.11	128.13	106.15	109.2
Mass of container (gm)	28.12	31.59	37.63	33.49	25.11	34.59	36.43	33.49
Mass of moisture (gm)	30.2	29.31	21.55	22.52	33.86	34.65	26.29	25.55
Mass of Dry soil (gm)	96.93	92.62	65.6	71.12	105	93.54	69.72	75.72
Moisture content (%)	31.16	31.65	32.85	31.66	32.25	37.04	37.71	33.74
Av. moisture content (%)	31.401		32.258		34.645		35.725	
Dry Density (gm/cm^3)	1.306		1.319		1.344		1.300	
OMC (%)	34.645			**MDD (g/cm^3)**		1.344		



APPENDIX D: Specific Gravity Test Analysis Data

Sample Location		HMK		
Trial Number		1	2	3
Mass of dry, clean Calibrated Pycnometer, Mp, (g)		28.57	29.13	27.98
A. Mass of oven dry sample (g)		25	25	25
B. Mass of Pycnometer + water (g)		107.79	105.65	110.85
C. Mass of Pycnometer + water + sample (g)		123.53	121.11	126.88
Observed temperature of water, Ti		25	25	25
Temperature, Tx, (°c)		24	24	24
Temperature Correction factor, K for Tx		0.9991	0.9991	0.9991
Specific gravity at 20°c, Gs	Gs = A*K/(A+B-C)	2.70	2.62	2.78
Average Specific gravity at 20°c, Gs		2.70		

Sample Location		KF		
Trial Number		1	2	3
Mass of dry, clean Calibrated pycnometer, Mp, (g)		27.95	30.23	28.56
A. Mass of oven dry sample (g)		25	25	25
B. Mass of Pycnometer + water (g)		104.72	107.36	108.78
C. Mass of Pycnometer + water + sample (g)		120.28	122.45	124.76
Observed temperature of water,Ti		25	25	25
Temperature, Tx, °c		24	24	24
Temperature Correction factor, K for Tx		0.9991	0.9991	0.9991
Specific gravity at 20°c, Gs	Gs = A*K/(A+B-C)	2.65	2.52	2.77
Average Specific gravity at 20°c, Gs		2.65		

Material Type		Sorghum Husk Ash		
Trial Number		1	2	3
Mass of dry, clean Calibrated pycnometer, Mp, (g)		28.75	29.13	27.98
A. Mass of oven dry sample (g)		20	20	20
B. Mass of Pycnometer + water (g)		80.72	87.91	79.71
C. Mass of Pycnometer + water + sample (g)		94.98	98.89	89.71
Observed temperature of water,Ti		25	25	25
Temperature, Tx, °c		24	24	24
Temperature Correction factor, K for Tx		0.9991	0.9991	0.9991
Specific gravity at 20°c, Gs	Gs = A*K/(A+B-C)	2.58	2.22	2.00
Average Specific gravity at 20°c, Gs		2.27		

APPENDIX E: Grain Size Distribution Test Analysis Data

I. Wet Sieve analysis

HMK Soil Sample				
Sieve size (mm)	**Mass of retain on each sieve (g)**	**Percentage of retained soil**	**Cumulative % of retain soil**	**Percentage of passing particle**
9.5	0.00	0.00	0.00	100.00
4.75	2.91	0.29	0.29	99.71
2.36	4.82	0.48	0.77	99.23
2	3.73	0.37	1.15	98.85
1.18	4.96	0.50	1.64	98.36
0.85	5.92	0.59	2.23	97.77
0.6	6.89	0.69	2.92	97.08
0.425	7.79	0.78	3.70	96.30
0.3	8.81	0.88	4.58	95.42
0.15	7.89	0.79	5.37	94.63
0.075	9.76	0.98	6.35	93.65
pan	936.52	93.65	100.00	0.00
Sum	1000.0			

KF Soil Sample				
Sieve size (mm)	**Mass of retain on each sieve (g)**	**Percentage of retained soil**	**Cumulative % of retain soil**	**Percentage of passing particle**
9.5	0.00	0.00	0.00	100.00
4.75	1.61	0.16	0.16	99.84
2.36	3.32	0.33	0.49	99.51
2	2.54	0.25	0.75	99.25
1.18	3.16	0.32	1.06	98.94
0.85	4.71	0.47	1.53	98.47
0.6	5.27	0.53	2.06	97.94
0.425	7.44	0.74	2.81	97.20
0.3	6.25	0.63	3.43	96.57
0.15	4.13	0.41	3.84	96.16
0.075	5.16	0.52	4.36	95.64
pan	956.41	95.64	100.00	0.00
Sum	1000.0			

II. Hydrometer analysis

HMK soil sample											
Time	Elapsed time (min)	Temperature	Actual hyd. reading	Effective Depth, L (cm)	K	Grain size, D (mm)	Temp. corr., CT	a	Corrected hyd. Reading (Rc)	Percentage of finer %	corrected (Pa)
8:35	1	24	47	7.9	0.013	0.037	1	1	44.5	94	88.03
8:36	2	24	44	8.3	0.013	0.027	1	1	41.5	88.00	82.41
8:39	5	24	42	8.6	0.013	0.017	1	1	39.5	84.00	78.67
8:59	15	24	40	9.1	0.013	0.01	1	1	37.5	80.00	74.92
9:14	30	24	37	9.7	0.013	0.007	1	1	34.5	74.00	69.3
10:44	60	24	35	10.1	0.013	0.005	1	1	32.5	70.00	65.56
11:44	120	24	33	10.4	0.013	0.004	1	1	30.5	66.00	61.81
13:44	240	23	31	10.7	0.013	0.003	0.7	1	28.8	62.00	58.06
15:44	480	23	27	11.2	0.013	0.002	0.7	1	24.8	54.00	50.57
8:00	1440	22	25	11.9	0.013	0.001	0.4	1	23.1	50.00	46.83

KF soil sample											
Time	Elapsed time (min)	Temperature	Actual hyd. reading	Effective Depth, L (cm)	K	Grain size, D (mm)	Temp. corr., CT	a	Corrected hyd. Reading (Rc)	Percentage of finer %	corrected (Pa)
8:32	1	24	48	8.6	0.01282	0.0376	1	0.99	45.5	95.04	90.9
8:33	2	24	46	9.1	0.01282	0.0273	1	0.99	43.5	91.08	87.11
8:38	5	24	44	9.4	0.01282	0.0176	1	0.99	41.5	87.12	83.32
8:48	15	24	42	9.7	0.01282	0.0103	1	0.99	39.5	83.16	79.54
9:03	30	24	40	10.2	0.01282	0.0075	1	0.99	37.5	79.20	75.75
9:33	60	24	38	10.6	0.01282	0.0054	1	0.99	35.5	75.24	71.96
10:33	120	24	36	10.9	0.01282	0.0039	1	0.99	33.5	71.28	68.17
12:33	240	23	34	11.2	0.01297	0.0028	0.7	0.99	31.8	67.32	64.39
14:33	480	23	31	11.9	0.01297	0.002	0.7	0.99	28.8	61.38	58.7
8:00	1440	22	27	12.2	0.01312	0.0012	0.4	0.99	25.1	53.46	51.13

III. Combined wet sieve analysis and hydrometer analysis

Combined wet sieve analysis and hydrometer analysis		
Sieve opening	KF	HMK
	Percent passing	Percent passing
9.5	100.00	100.00
4.75	99.84	99.71
2.36	99.51	99.23
2.00	99.25	98.85
0.18	98.94	98.36
0.85	98.47	97.77
0.60	97.94	97.08
0.425	97.20	96.30
0.25	96.57	95.42
0.15	96.16	94.63
0.075	95.64	93.65
0.038	90.9	88.03
0.027	87.11	82.41
0.017	83.32	78.67
0.010	79.54	74.92
0.007	75.75	69.3
0.005	71.96	65.56
0.004	68.17	61.81
0.003	64.39	58.06
0.002	58.7	50.57
0.001	51.13	46.83

APPENDIX F: Free Swell Index Test Analysis Data

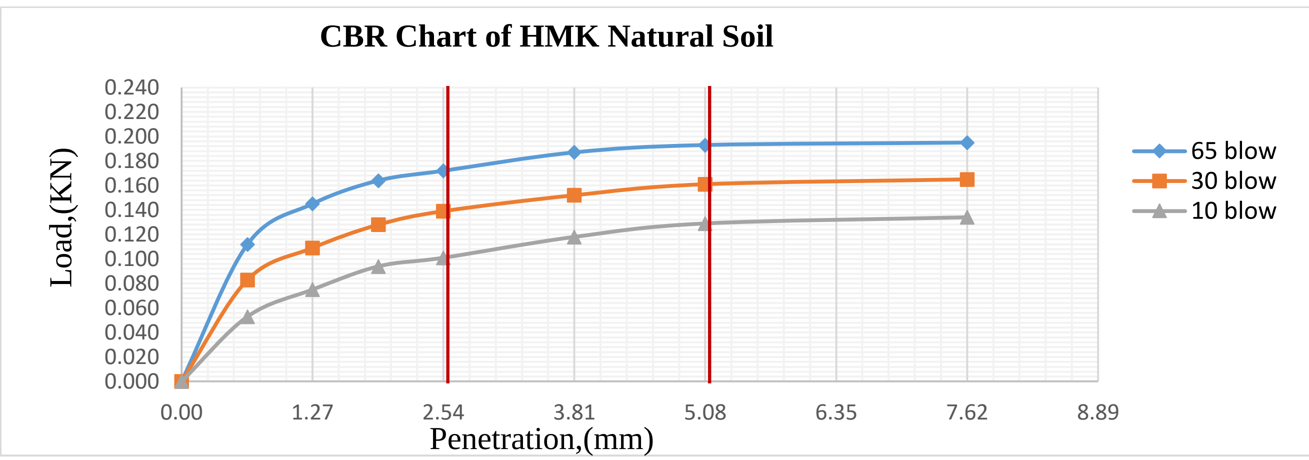
Sample location	Mix-Proportion of Additives (%)		FSI (%)	Percentage of reduction (%)	IS 1498 requirement	Test Result Status
	SHA%	L%				
HMK	Natural Soil		91.70	0	FSI < 50%	Control
	0	2	67.52	24.18		Poor
	0	4	44.91	46.79		In rage
	0	6	31.78	59.92		Satisfied
	0	8	18.91	72.79		Satisfied
	3	5	53.30	38.40		In rage
	5		43.40	48.30		In rage
	7		20.50	71.20		Satisfied
	9		33.10	58.60		Satisfied

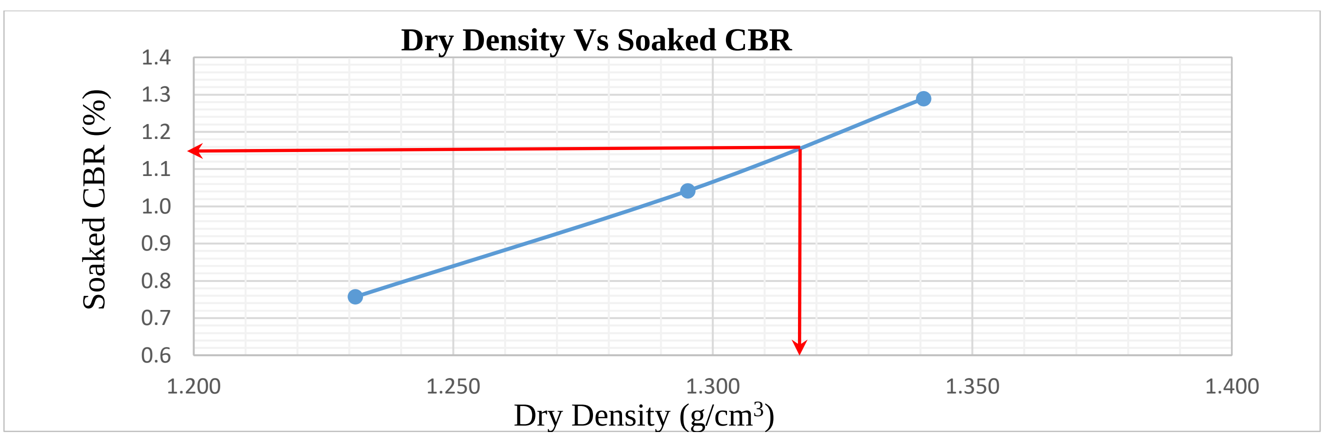
Sample location	Mix-Proportion of Additives (%)		FSI (%)	Percentage of reduction (%)	IS 1498 requirement	Test Result Status
	SHA%	L%				
KF	Natural Soil		111.00	0.00	FSI < 50%	Control
	0	2	75.41	35.59		Poor
	0	4	52.64	58.36		In rage
	0	6	38.57	72.43		Satisfied
	0	8	28.35	82.65		Satisfied
	3	5	63.90	47.10		Poor
	5		50.20	60.80		In rage
	7		31.50	79.50		Satisfied
	9		46.10	64.90		Satisfied

APPENDIX G: California Bearing Ratio (CBR) Test Analysis Data

I. CBR test results of HMK soil sample

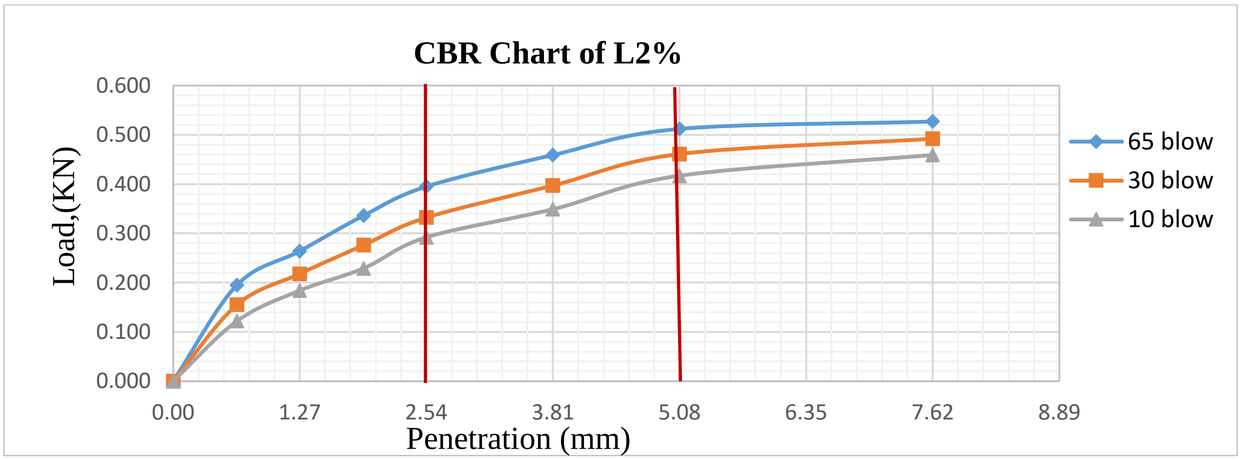
PENETRATION AND LOAD DETERMINATION OF UNTREATED SOIL @ HMK						
Penetration Data After 96-hours Soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	1.290	9.67	0.139	1.04	0.101	0.76
5.08	0.970	4.85	0.161	0.81	0.129	0.65
CBR RESULT SUMMARY OF UNTREATED SOIL @ JIT						
MMDD	1.389					
Dry Density at 95% of MDD	1.320					
No of Blows	65	30	10			
CBR Values (%)	9.67	1.04	0.76			
DDBS g/cc	1.341	1.295	1.231			
CBR at 95% MDD	1.17					

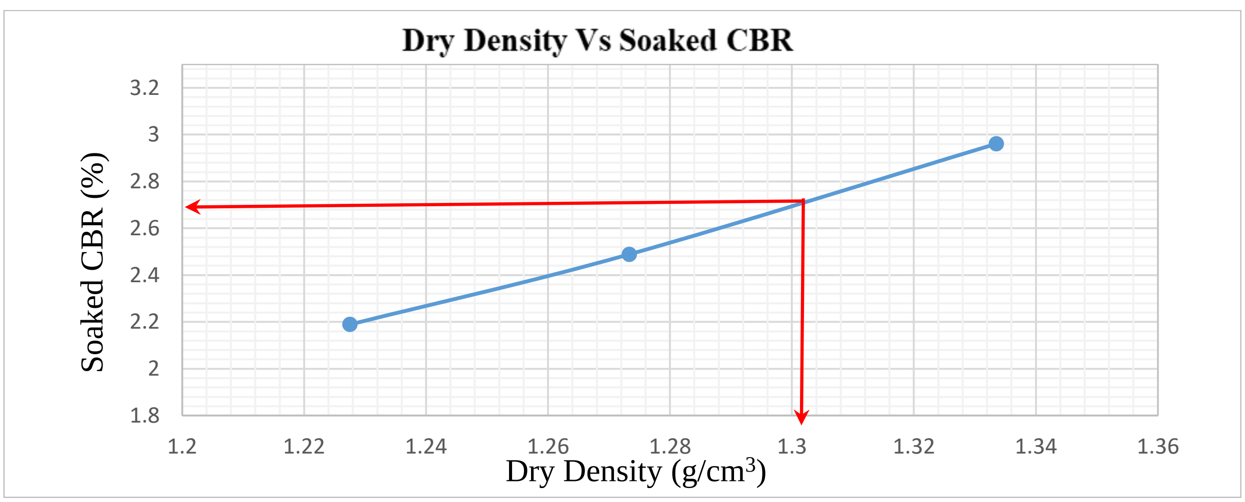




PENETRATION AND LOAD DETERMINATION OF L2% @ HMK						
Penetration Data After 96-hours Soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.395	2.96	0.332	2.49	0.292	2.19
5.08	0.512	2.56	0.461	2.31	0.417	2.09

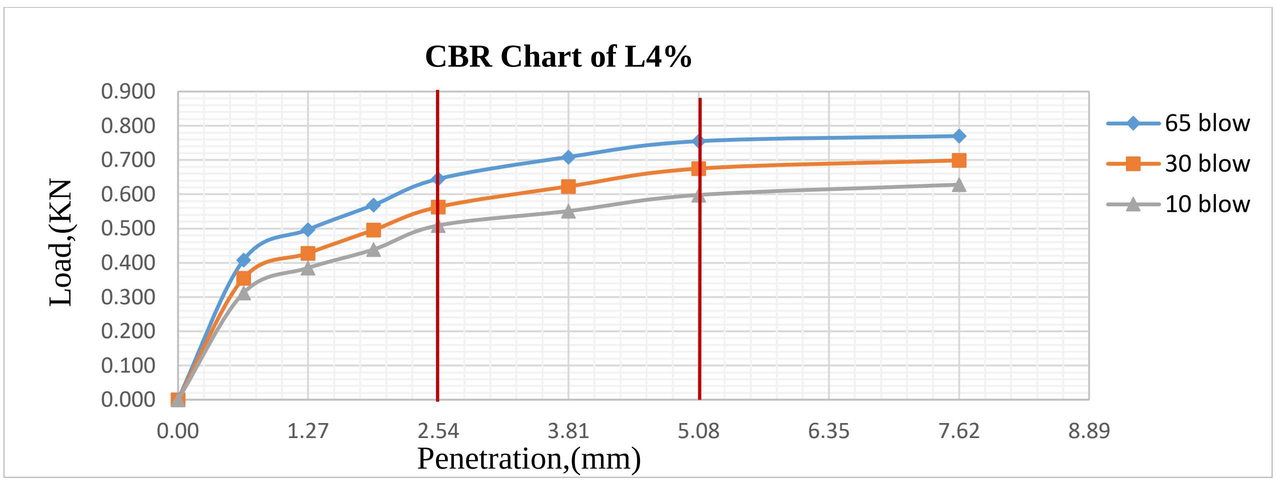
CBR RESULT SUMMARY OF L2% @ HMK			
MMDD	1.378		
Dry Density at 95% of MDD	1.309		
No of Blows	65	30	10
CBR Values (%)	2.96	0.332	2.49
DDBS g/cc	1.334	1.273	1.228
CBR at 95% MDD	2.77%		

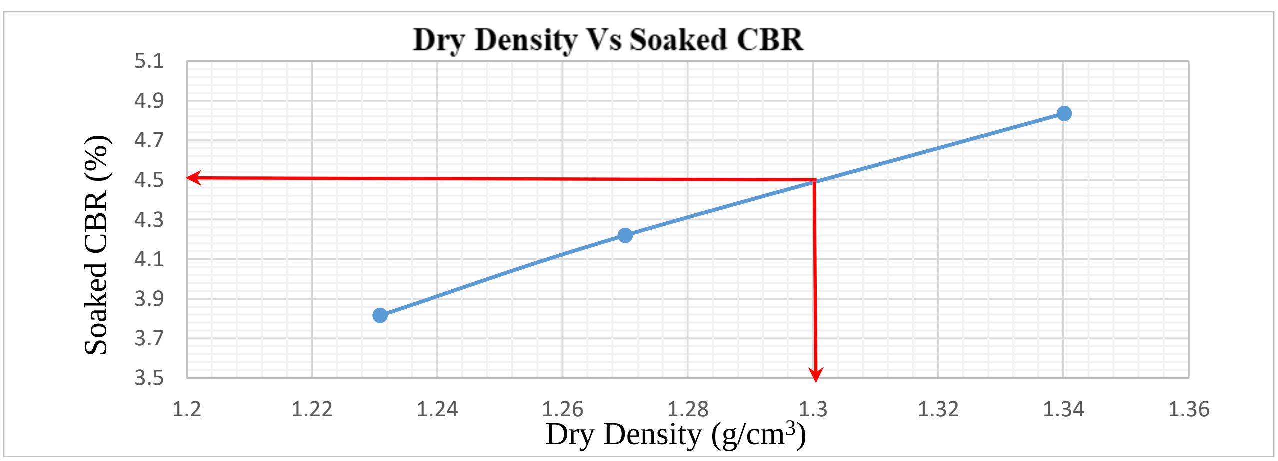




PENETRATION AND LOAD DETERMINATION OF L4% @ HMK						
Penetration Data After 96-hours Soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.645	4.84	0.563	4.22	0.509	3.82
5.08	0.755	3.78	0.675	3.38	0.598	2.99

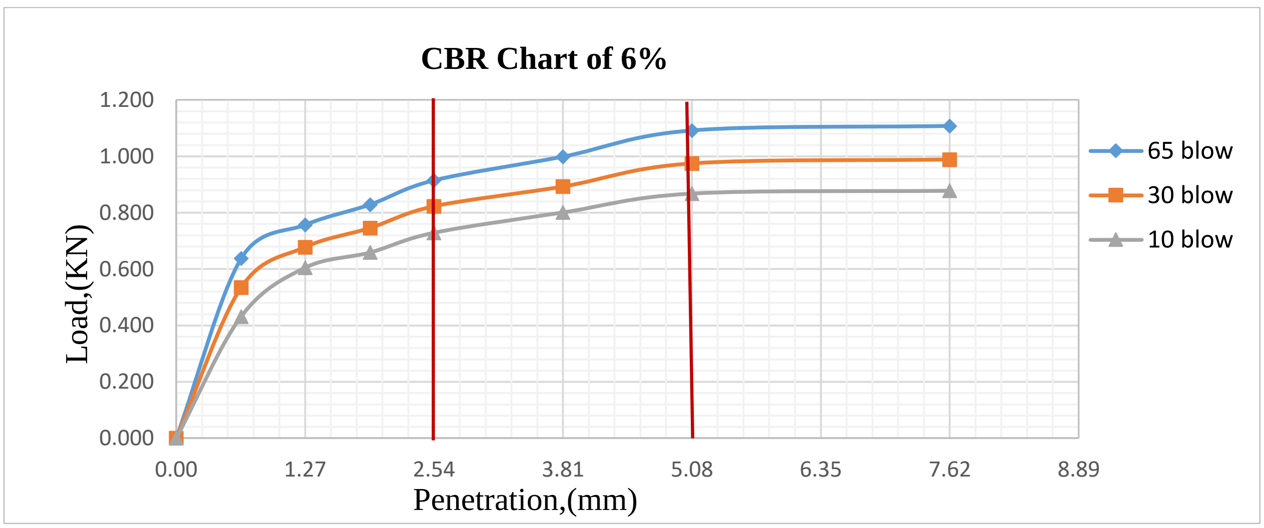
CBR RESULT SUMMARY OF L4% @ HMK			
MMDD	1.373		
Dry Density at 95% of MDD	1.304		
No of Blows	65	30	10
CBR Values (%)	4.84	0.563	4.22
DDBS g/cc	1.340	1.270	1.231
CBR at 95% MDD	4.52%		

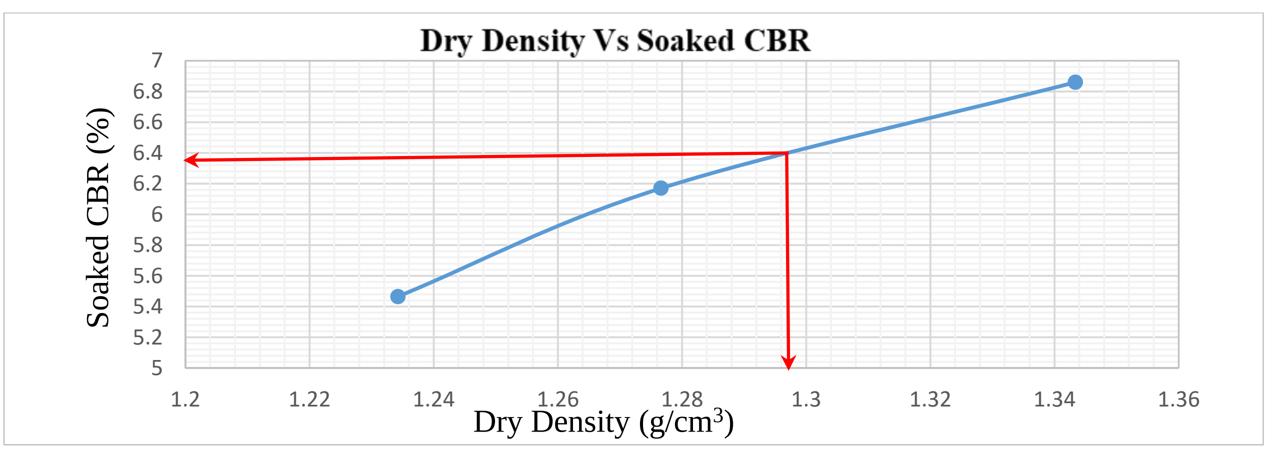




PENETRATION AND LOAD DETERMINATION OF L6% @ HMK						
Penetration Data After 96-hours Soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.915	6.86	0.823	6.17	0.729	5.46
5.08	1.092	5.46	0.975	4.88	0.868	4.34

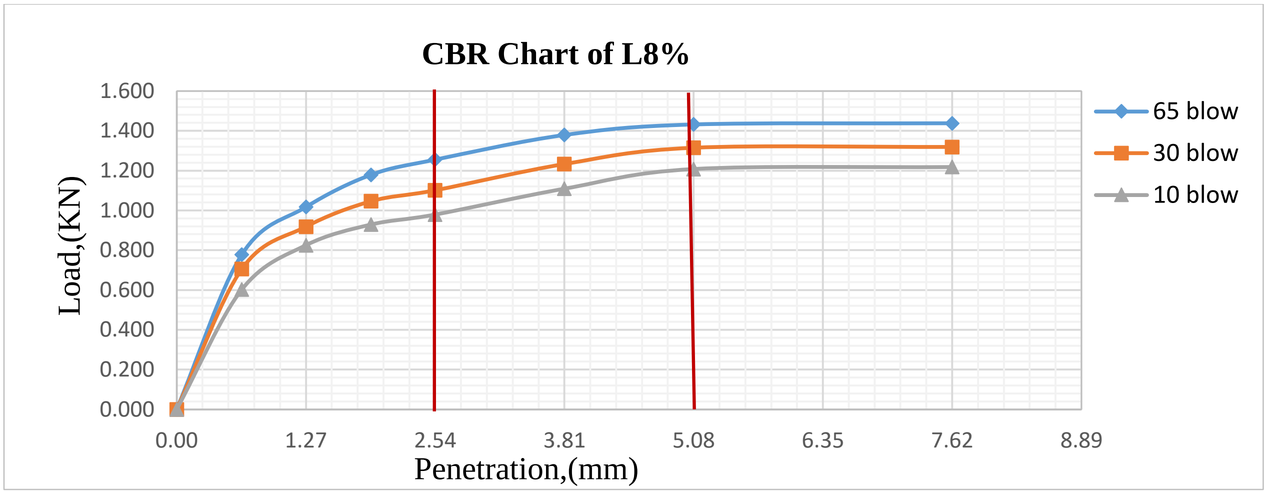
CBR RESULT SUMMARY OF L6% @ HMK			
MMDD	1.362		
Dry Density at 95% of MDD	1.294		
No of Blows	65	30	10
CBR Values (%)	6.86	0.823	6.17
DDBS g/cc	1.343	1.277	1.234
CBR at 95% MDD	6.35%		

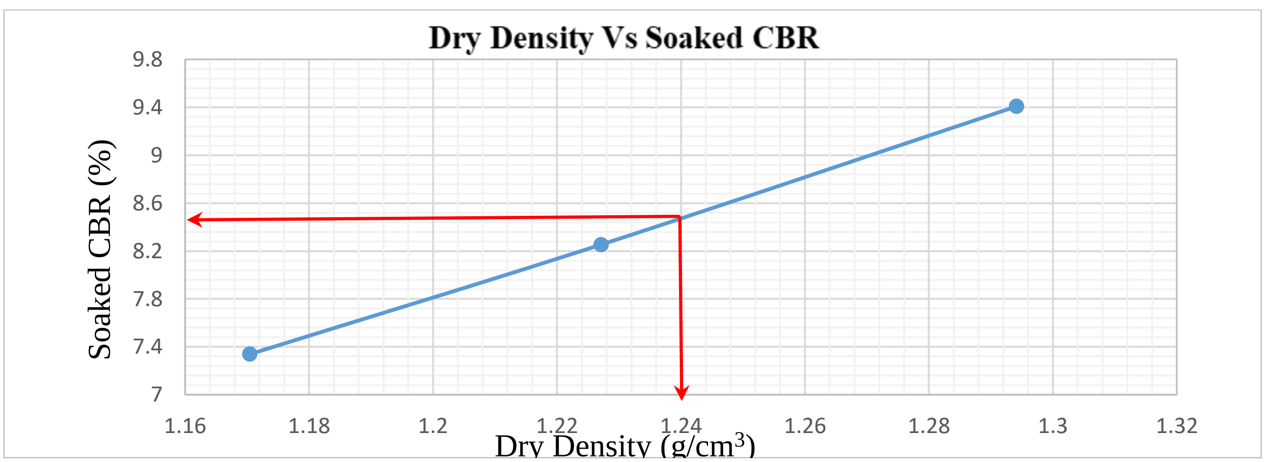




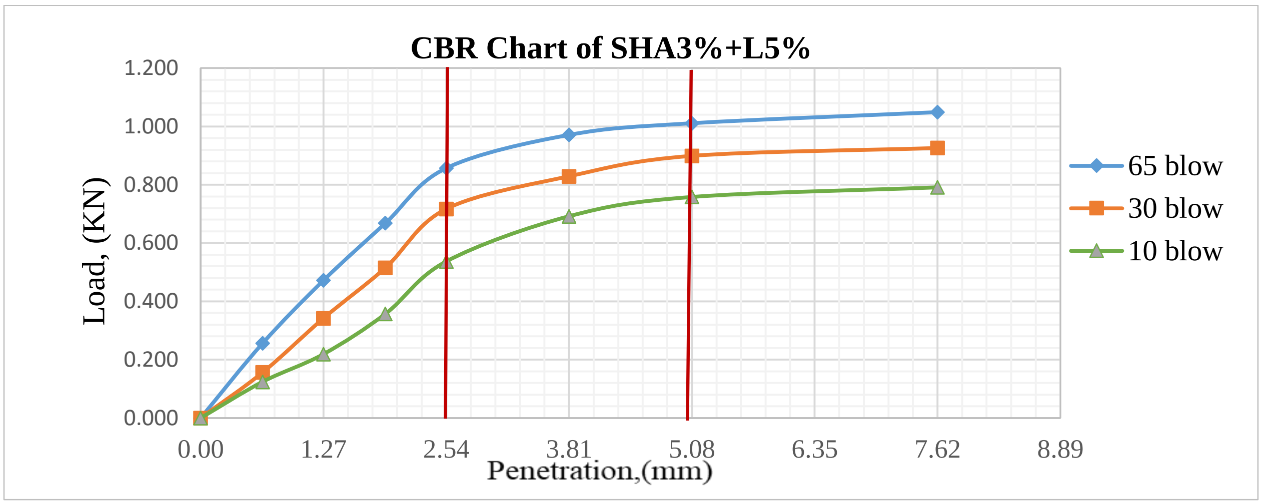
PENETRATION AND LOAD DETERMINATION OF L8% @ HMK						
Penetration Data After 96-hours Soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	1.255	9.41	1.101	8.25	0.979	7.34
5.08	1.432	7.16	1.315	6.58	1.208	6.04

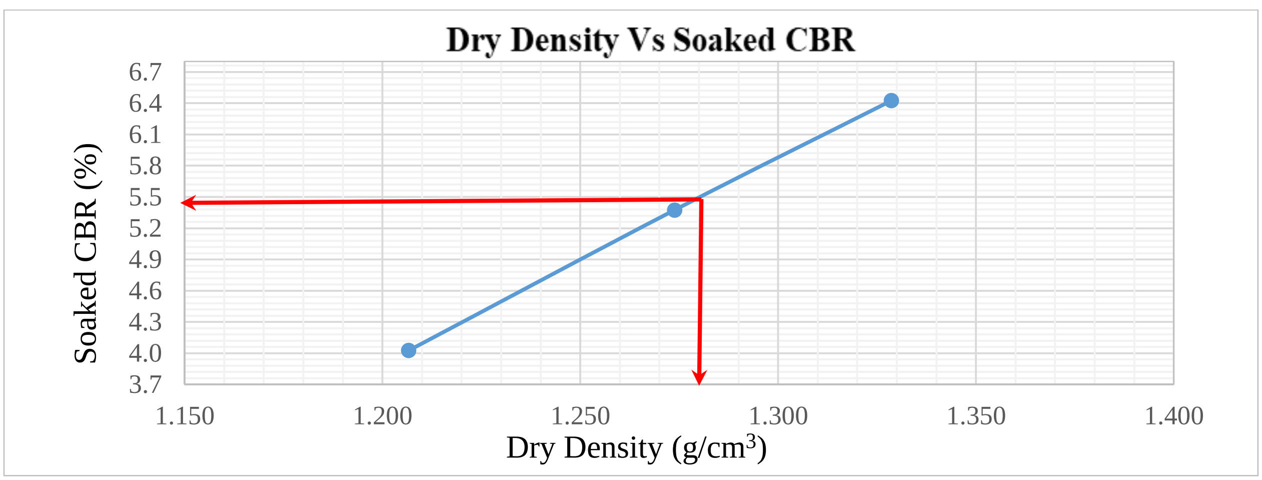
CBR RESULT SUMMARY OF L8% @ HMK			
MMDD	1.305		
Dry Density at 95% of MDD	1.240		
No of Blows	65	30	10
CBR Values (%)	9.41	1.101	8.25
DDBS g/cc	1.294	1.227	1.170
CBR at 95% MDD	8.47%		





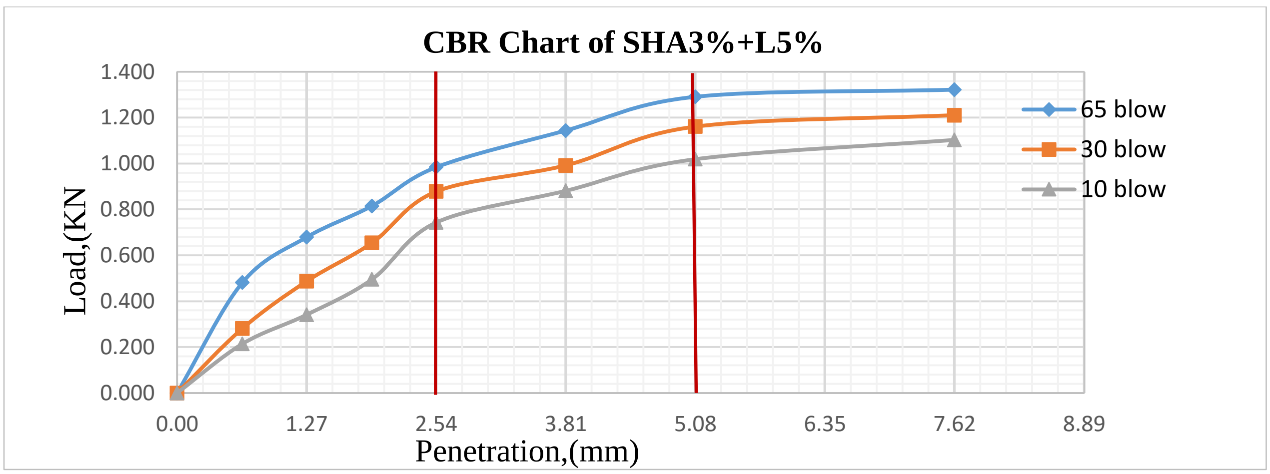
PENETRATION AND LOAD DETERMINATION OF SHA3%+L5% @ HMK						
Penetration Data After 96-hours Soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.857	6.42	0.717	5.37	0.537	4.03
5.08	1.011	5.06	0.899	4.50	0.758	3.79
CBR RESULT SUMMARY OF SHA3%+L5% @ HMK						
MMDD	1.349					
Dry Density at 95% of MDD	1.282					
No of Blows	65		30		10	
CBR Values (%)	6.42		0.717		5.37	
DDBS g/cc	1.329		1.274		1.207	
CBR at 95% MDD	5.52%					

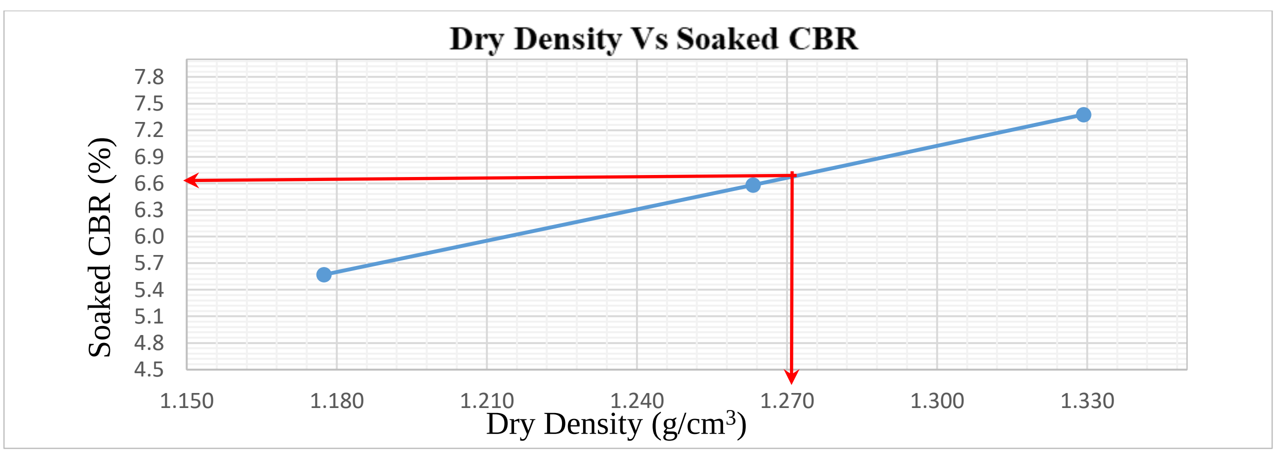




PENETRATION AND LOAD DETERMINATION OF SHA5%+L5% @ HMK						
Penetration Data After 96-hours Soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.984	7.38	0.878	6.58	0.743	5.57
5.08	1.291	6.46	1.161	5.81	1.019	5.1

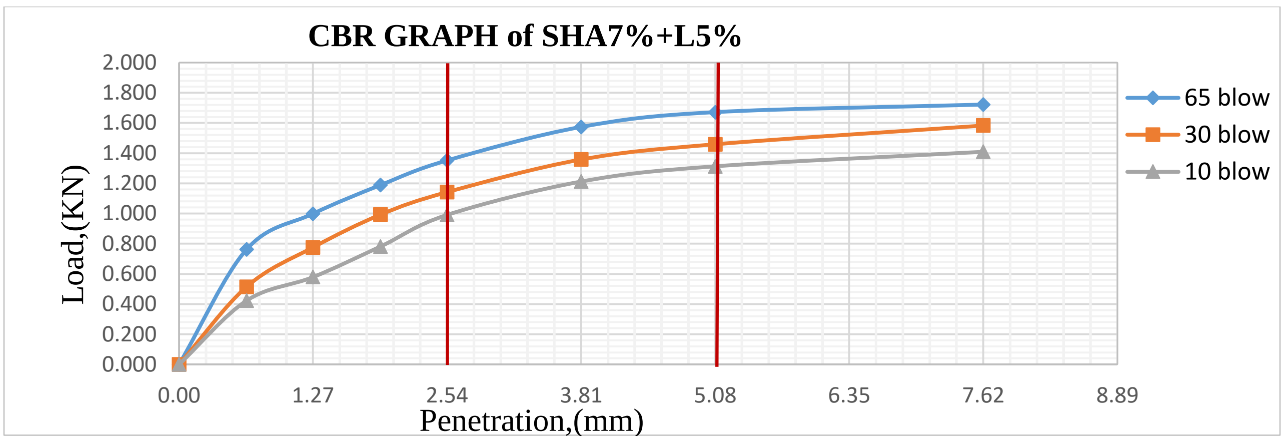
CBR RESULT SUMMARY OF SHA5%+L5% @ JIT			
MMDD	1.338		
Dry Density at 95% of MDD	1.271		
No of Blows	65	30	10
CBR Values (%)	7.38	6.58	5.57
DDBS g/cc	1.329	1.263	1.177
CBR at 95% MDD	6.68%		

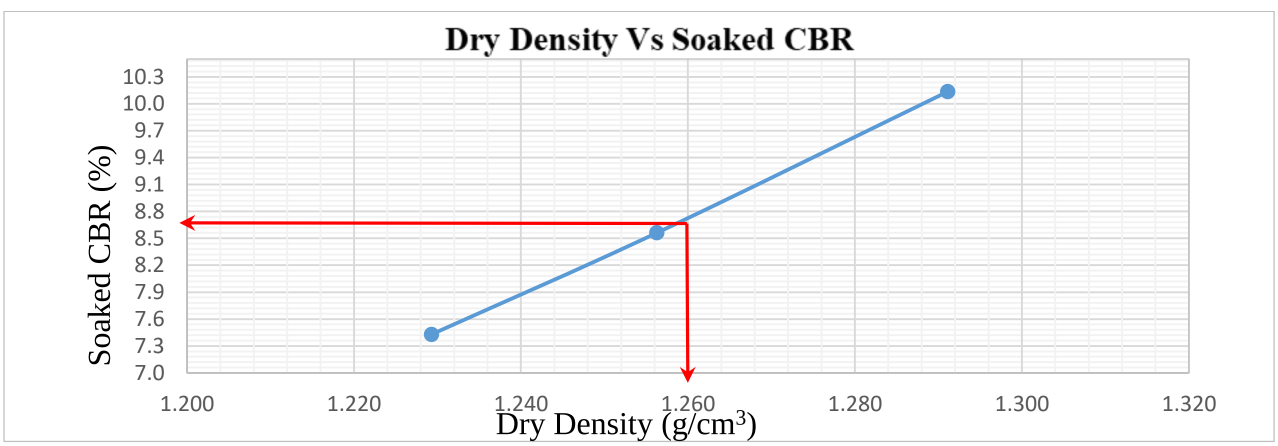




PENETRATION AND LOAD DETERMINATION OF SHA7%+L5% @ HMK						
Penetration Data After 96-hours Soaking						
Penetration (mm)	**65-Blows**		**30-Blows**		**10-Blows**	
	Load (KN)	**CBR (%)**	**Load (KN)**	**CBR (%)**	**Load (KN)**	**CBR (%)**
2.54	1.351	10.13	1.142	8.56	0.991	7.43
5.08	1.672	8.36	1.459	7.30	1.313	6.57

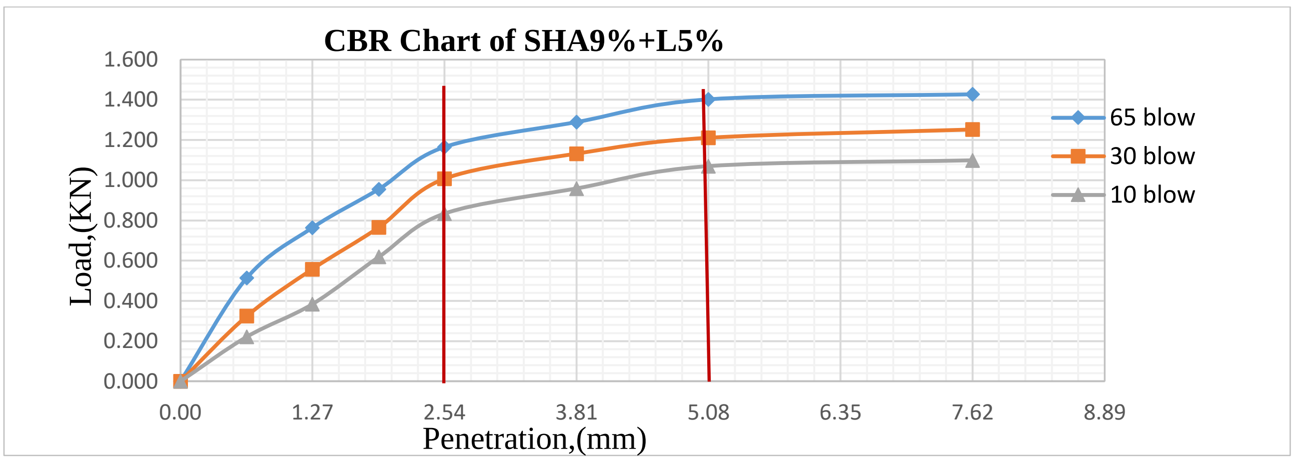
CBR RESULT SUMMARY OF SHA7%+L5% @ JIT			
MMDD	1.327		
Dry Density at 95% of MDD	1.261		
No of Blows	65	30	10
CBR Values (%)	10.13	8.56	7.43
DDBS g/cc	1.291	1.256	1.229
CBR at 95% MDD	8.76%		

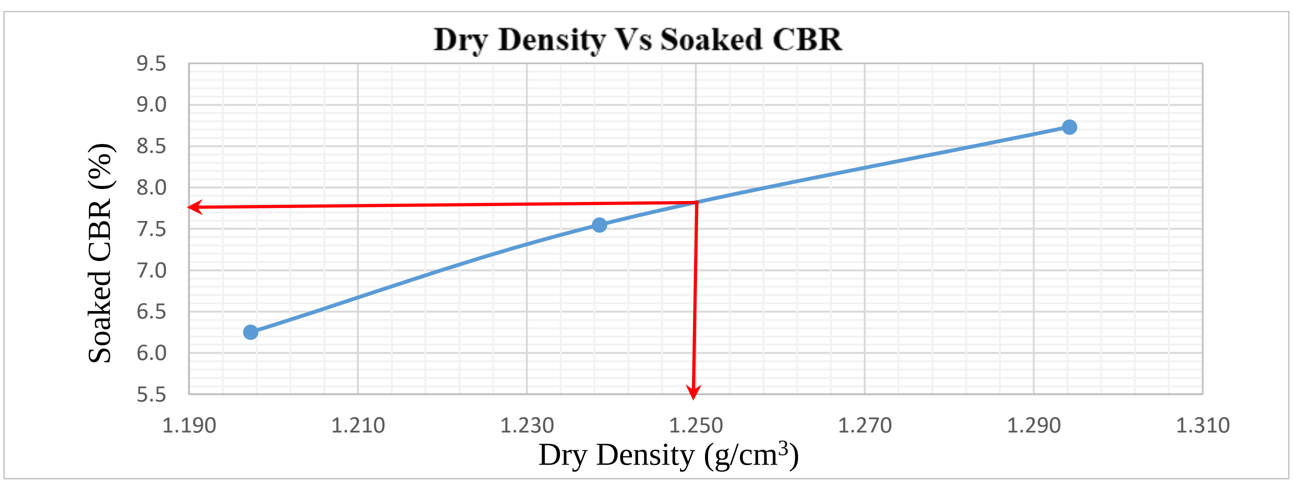




PENETRATION AND LOAD DETERMINATION OF SHA9%+L5% @ HMK						
Penetration Data After 96-hours Soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	1.165	8.73	1.007	7.55	0.834	6.25
5.08	1.402	7.01	1.211	6.06	1.07	5.35

CBR RESULT SUMMARY OF SHA9%+L5% @ HMK			
MMDD	1.315		
Dry Density at 95% of MDD	1.249		
No of Blows	65	30	10
CBR Values (%)	8.73	7.55	6.25
DDBS g/cc	1.294	1.239	1.197
CBR at 95% MDD	7.78%		

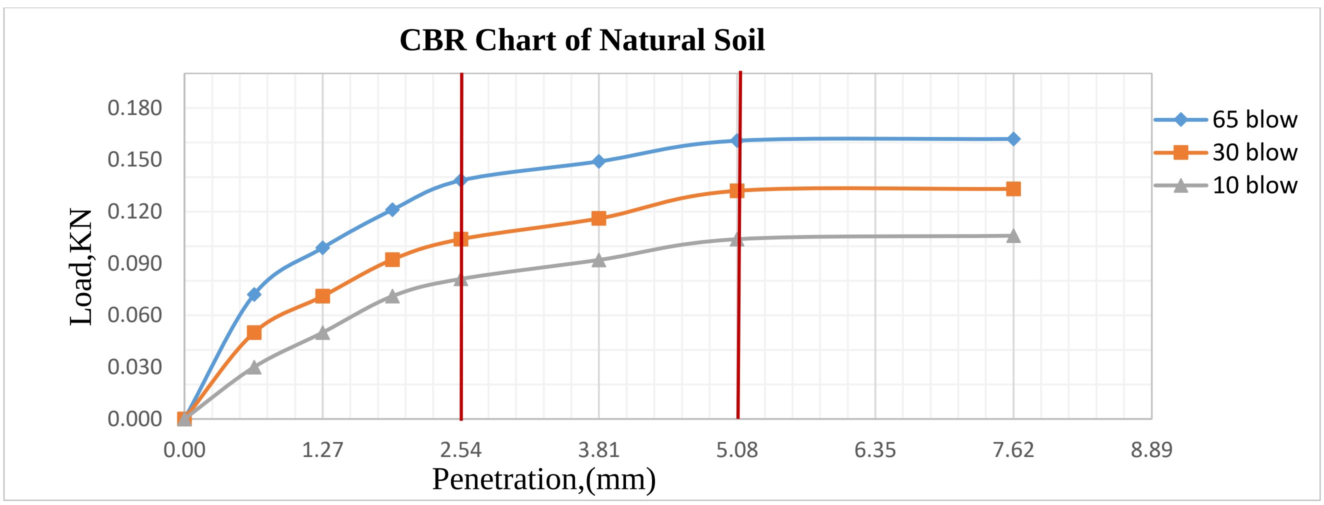


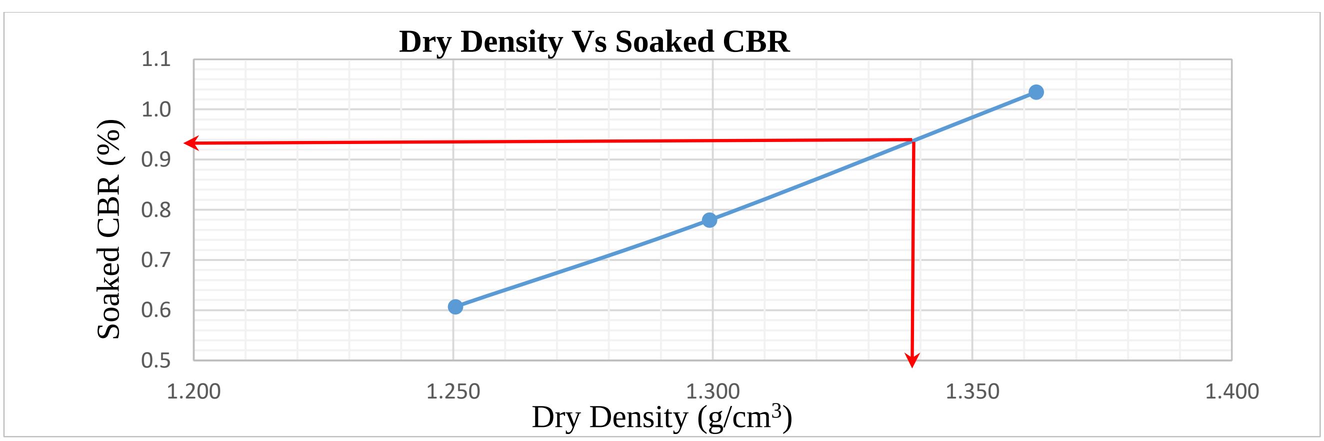


II. CBR test results of KF soil sample

PENETRATION AND LOAD DETERMINATION OF UNTREATED SOIL @ KF						
Penetration Data After 96-hours Soaking						
Penetration (mm)	**65-Blows**		**30-Blows**		**10-Blows**	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.138	1.03	0.104	0.78	0.081	0.61
5.08	0.161	0.81	0.132	0.66	0.104	0.52

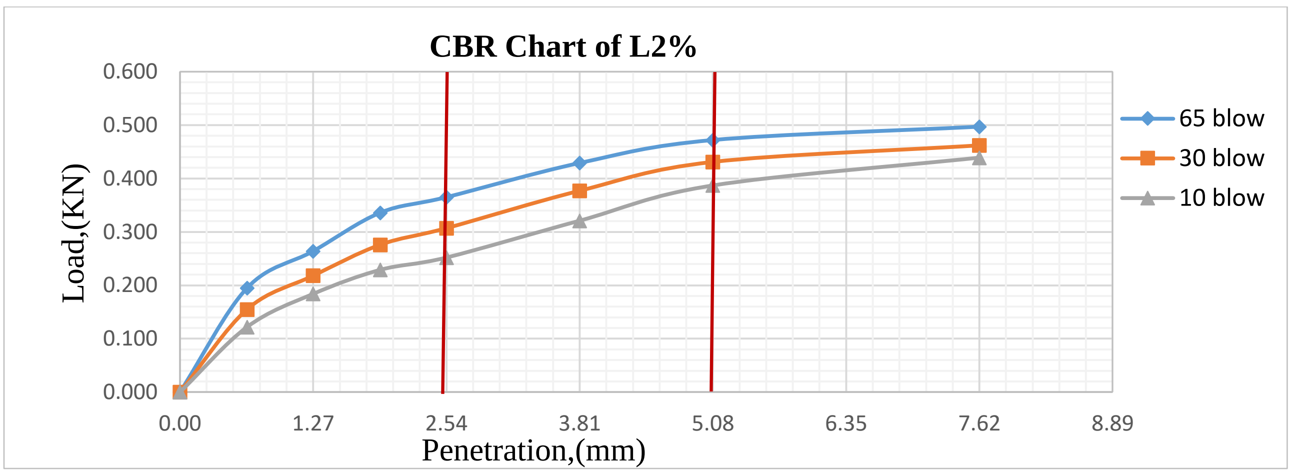
CBR RESULT SUMMARY OF UNTREATED SOIL @ KF			
MMDD	1.409		
Dry Density at 95% of MDD	1.339		
No of Blows	65	30	10
CBR Values (%)	1.03	0.78	0.61
DDBS g/cc	1.362	1.299	1.250
CBR at 95% MDD	0.94		

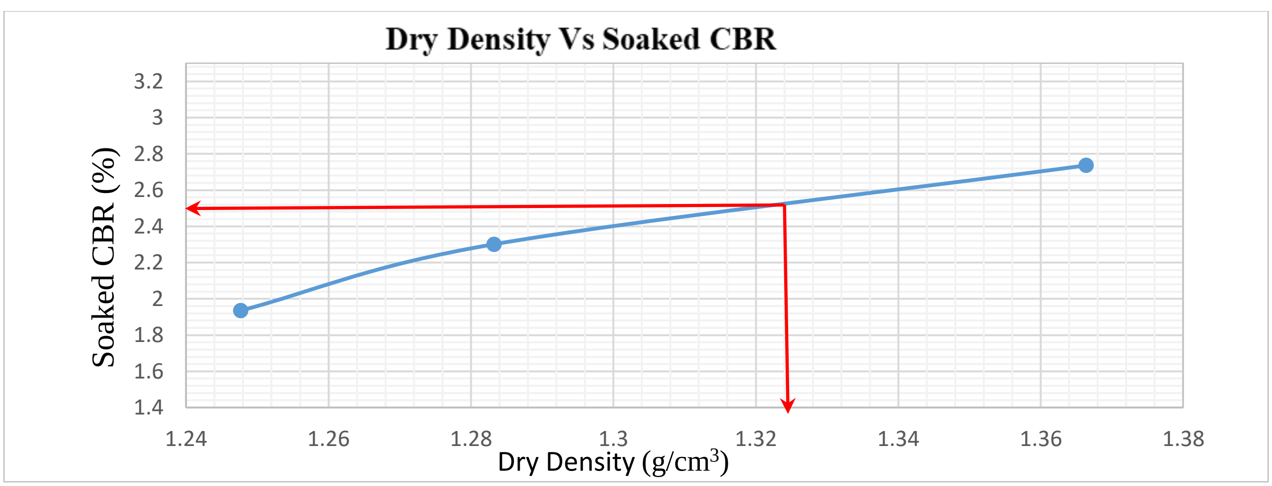




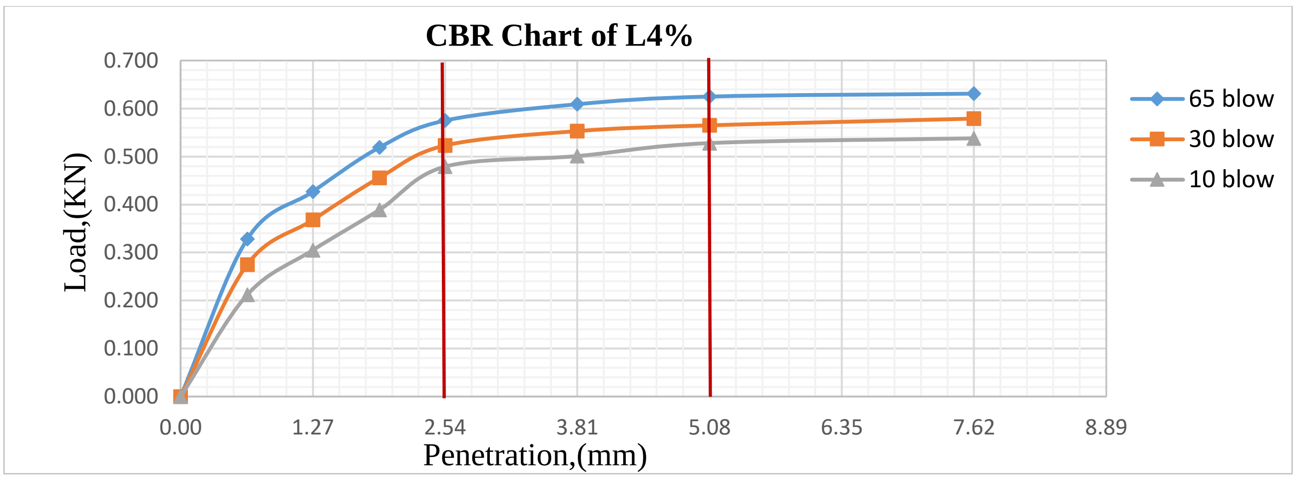
PENETRATION AND LOAD DETERMINATION OF L2% @ KF						
Penetration Data After 96-hours Soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.365	2.74	0.307	2.30	0.252	1.89
5.08	0.472	2.36	0.431	2.16	0.387	1.94

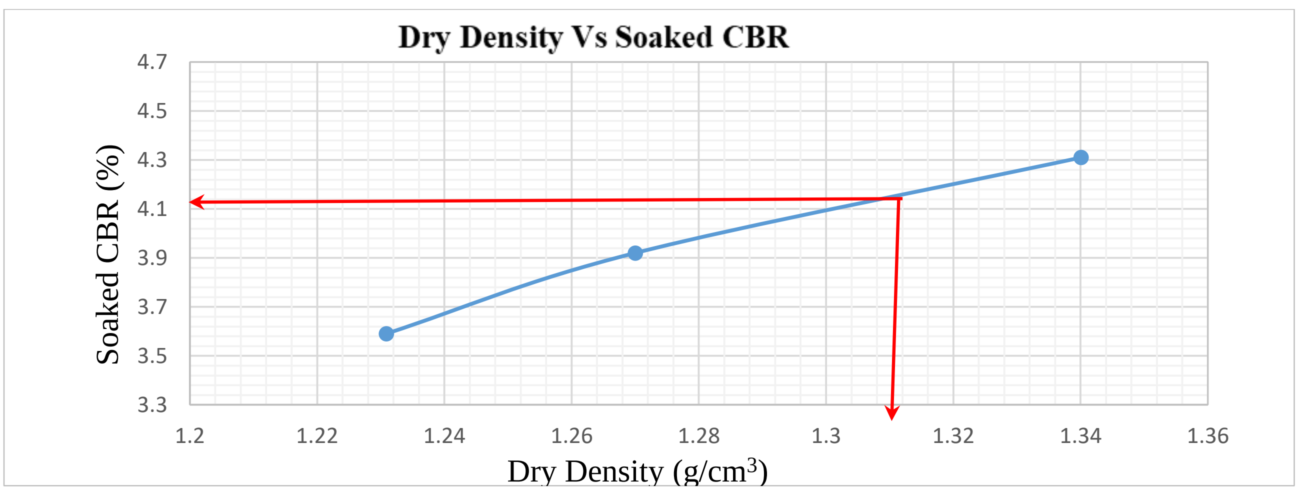
CBR RESULT SUMMARY OF L2% @ KF			
MMDD	1.394		
Dry Density at 95% of MDD	1.3243		
No of Blows	65	30	10
CBR Values (%)	2.74	0.307	2.3
DDBS g/cc	1.366	1.283	1.248
CBR at 95% MDD	2.52%		





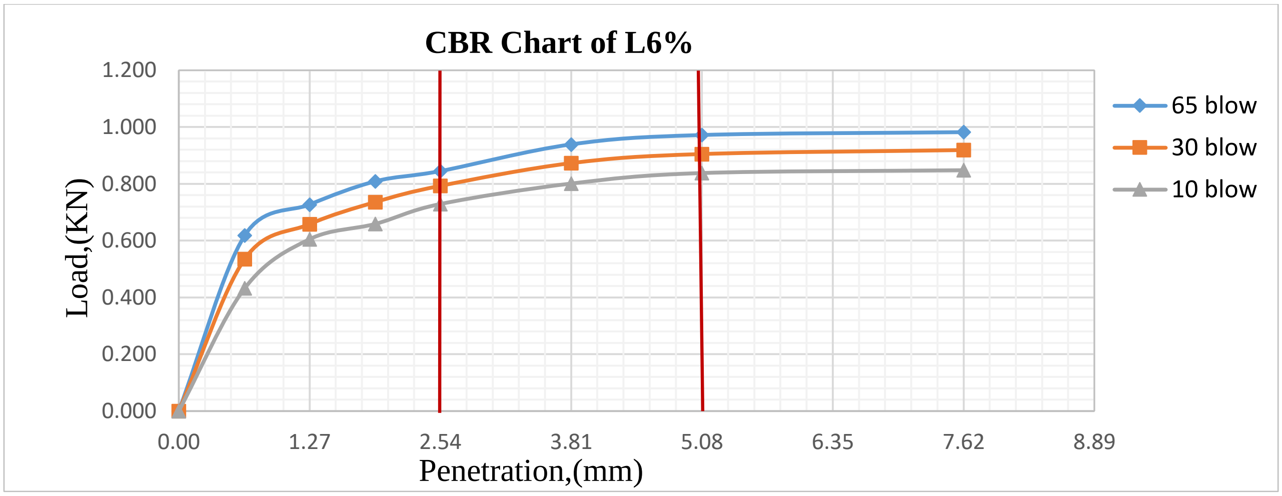
PENETRATION AND LOAD DETERMINATION OF L4% @ KF						
Penetration Data After 96-hours Soaking						
Penetration (mm)	**65-Blows**		**30-Blows**		**10-Blows**	
	Load (KN)	**CBR (%)**	**Load (KN)**	**CBR (%)**	**Load (KN)**	**CBR (%)**
2.54	0.575	4.31	0.523	3.92	0.479	3.59
5.08	0.625	3.13	0.565	2.83	0.528	2.64
CBR RESULT SUMMARY OF L4% @ KF						
MMDD			1.379			
Dry Density at 95% of MDD			1.31005			
No of Blows			65	30	10	
CBR Values (%)			4.31	0.523	3.92	
DDBS g/cc			1.340	1.270	1.231	
CBR at 95% MDD			4.14%			

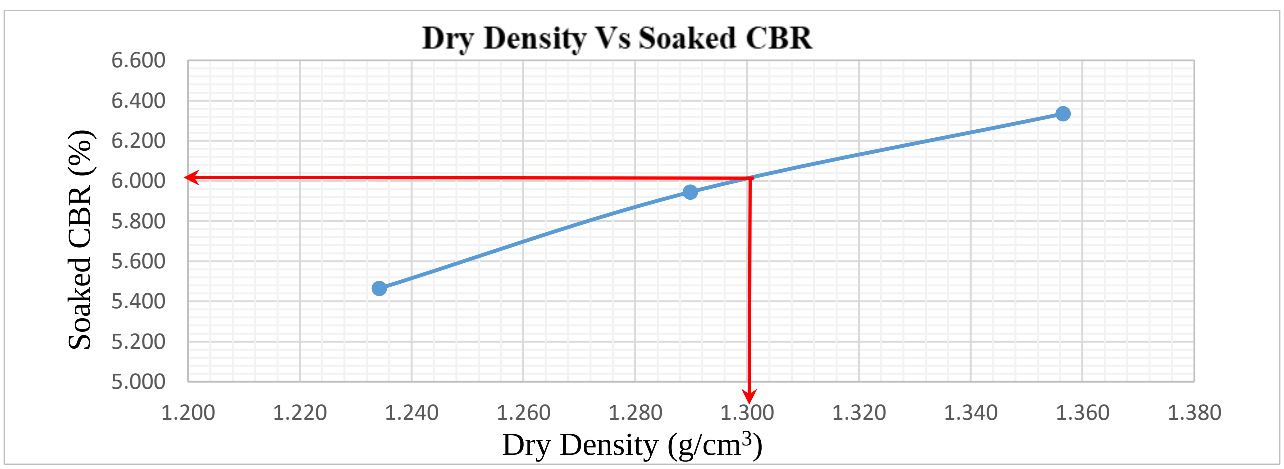




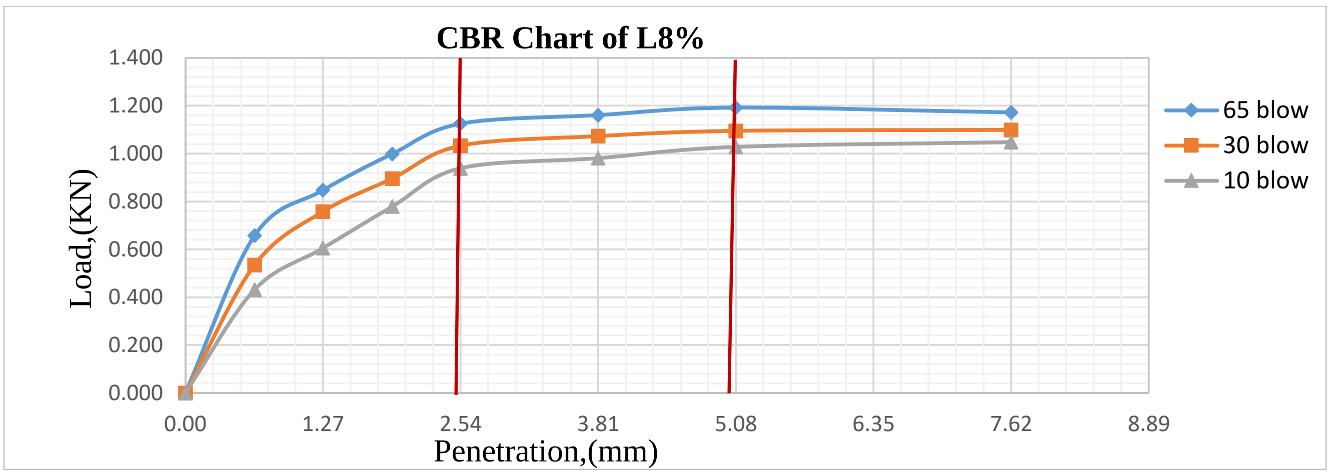
PENETRATION AND LOAD DETERMINATION OF L6% @ KF						
Penetration Data After 96-hours Soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.845	6.33	0.793	5.94	0.729	5.46
5.08	0.972	4.86	0.905	4.53	0.838	4.19

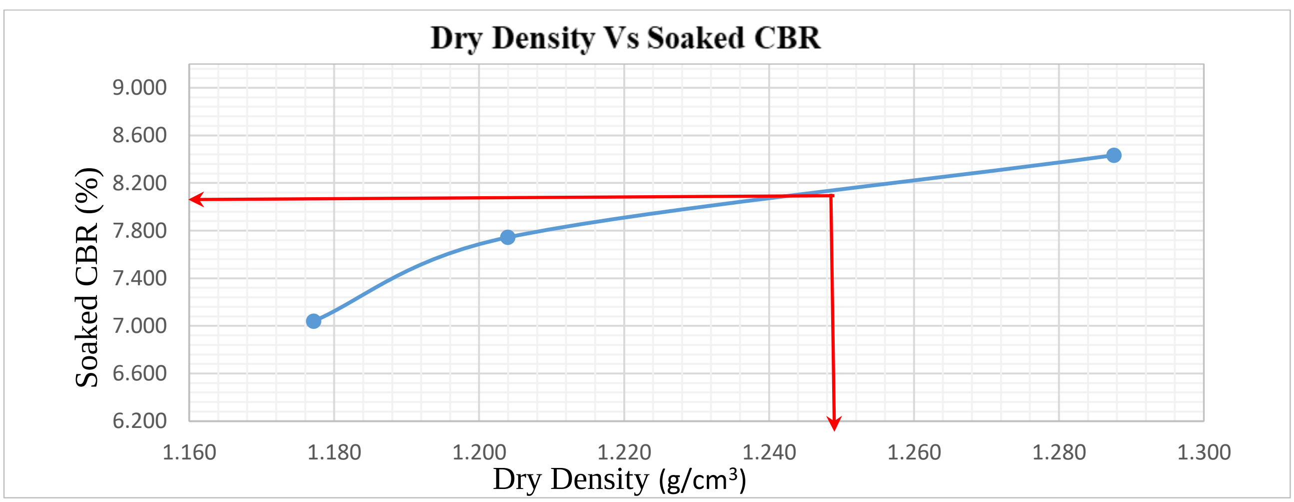
CBR RESULT SUMMARY OF L6% @ KF			
MMDD	1.372		
Dry Density at 95% of MDD	1.3034		
No of Blows	65	30	10
CBR Values (%)	6.33	0.793	5.94
DDBS g/cc	1.357	1.290	1.234
CBR at 95% MDD	6.02%		





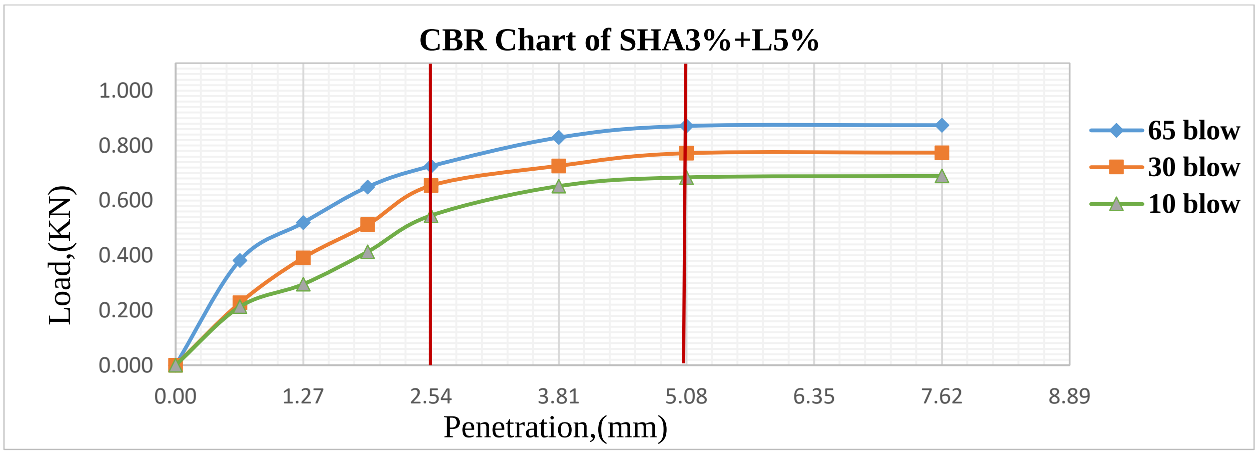
PENETRATION AND LOAD DETERMINATION OF L8% @ KF						
Penetration Data After 96-hours Soaking						
Penetration (mm)	**65-Blows**		**30-Blows**		**10-Blows**	
	Load (KN)	**CBR (%)**	**Load (KN)**	**CBR (%)**	**Load (KN)**	**CBR (%)**
2.54	1.125	8.43	1.033	7.74	0.939	7.04
5.08	1.192	5.96	1.095	5.48	1.028	5.14
CBR RESULT SUMMARY OF L8% @ KF						
MMDD	1.313					
Dry Density at 95% of MDD	1.24735					
No of Blows	65	30	10			
CBR Values (%)	8.43	1.033	7.74			
DDBS g/cc	1.288	1.204	1.177			
CBR at 95% MDD	8.10%					

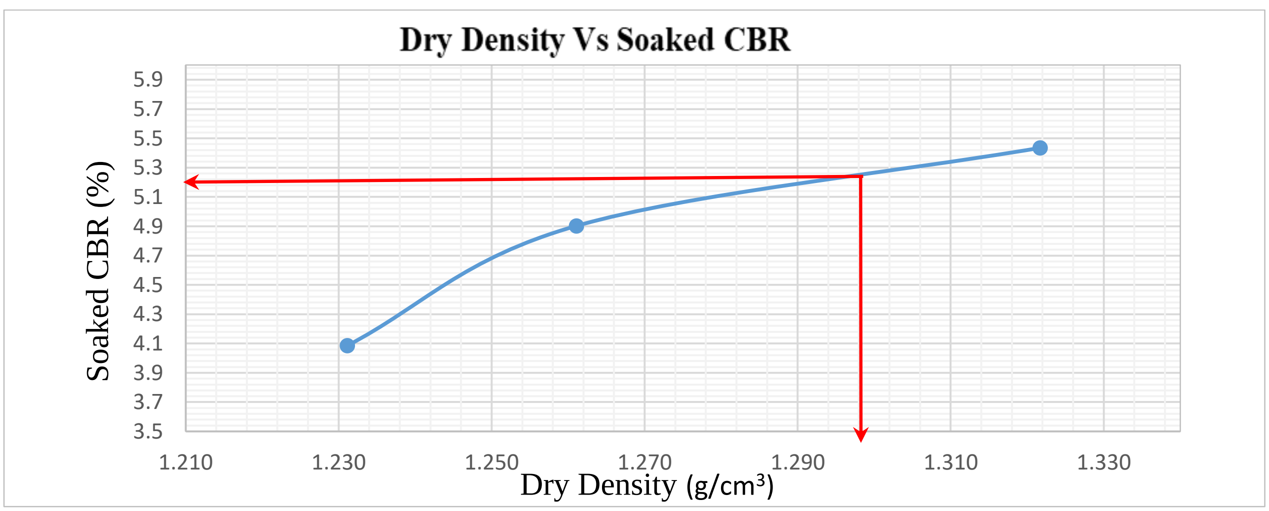




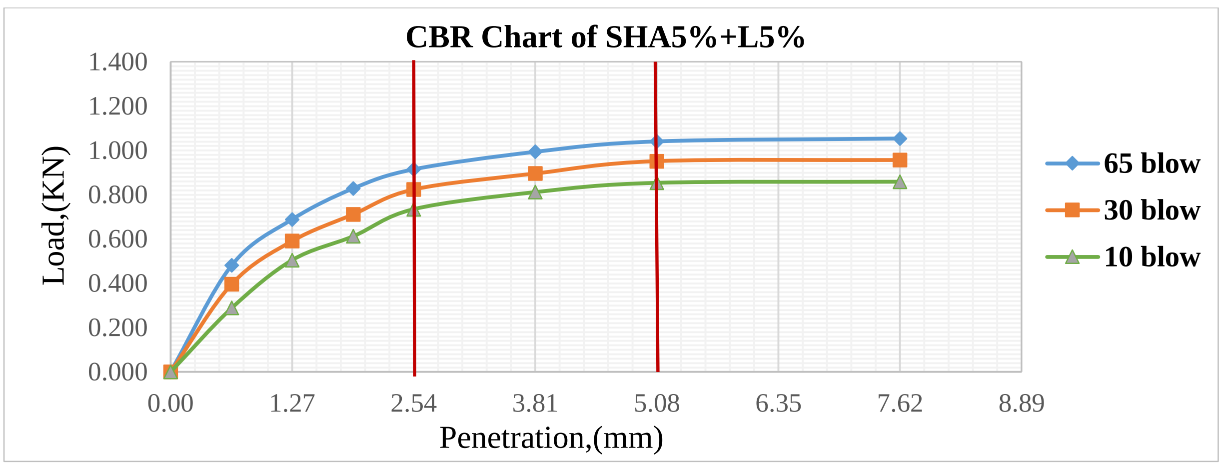
PENETRATION AND LOAD DETERMINATION OF SHA3%+L5% @ KF						
Penetration Data After 96-hours Soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.725	5.43	0.654	4.90	0.545	4.09
5.08	0.871	4.36	0.772	3.86	0.684	3.42

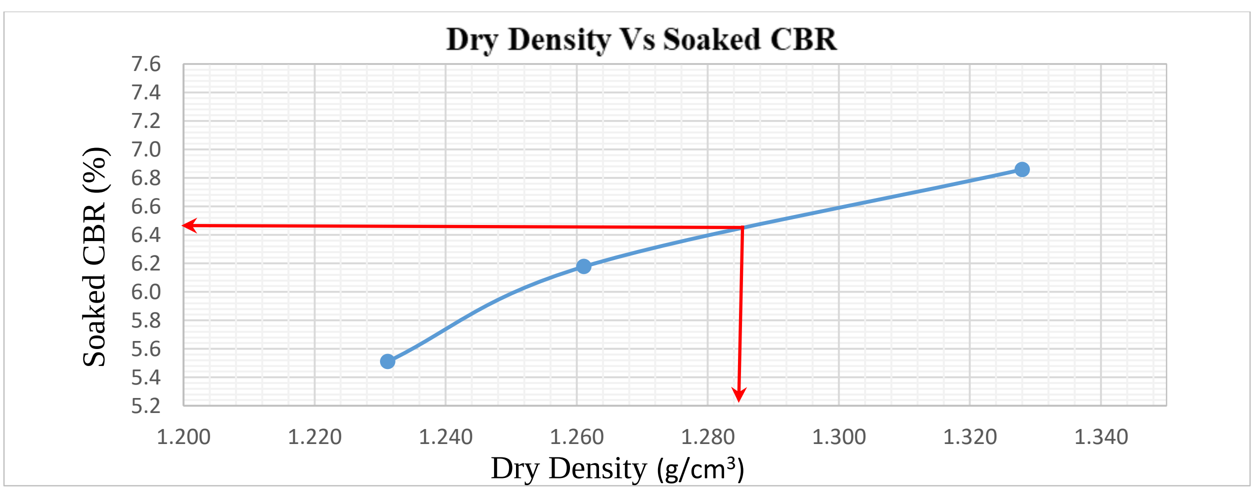
CBR RESULT SUMMARY OF SHA3%+L5% @ KF			
MMDD	1.364		
Dry Density at 95% of MDD	1.296		
No of Blows	65	30	10
CBR Values (%)	5.43	4.90	4.09
DDBS g/cc	1.322	1.261	1.231
CBR at 95% MDD	5.21%		



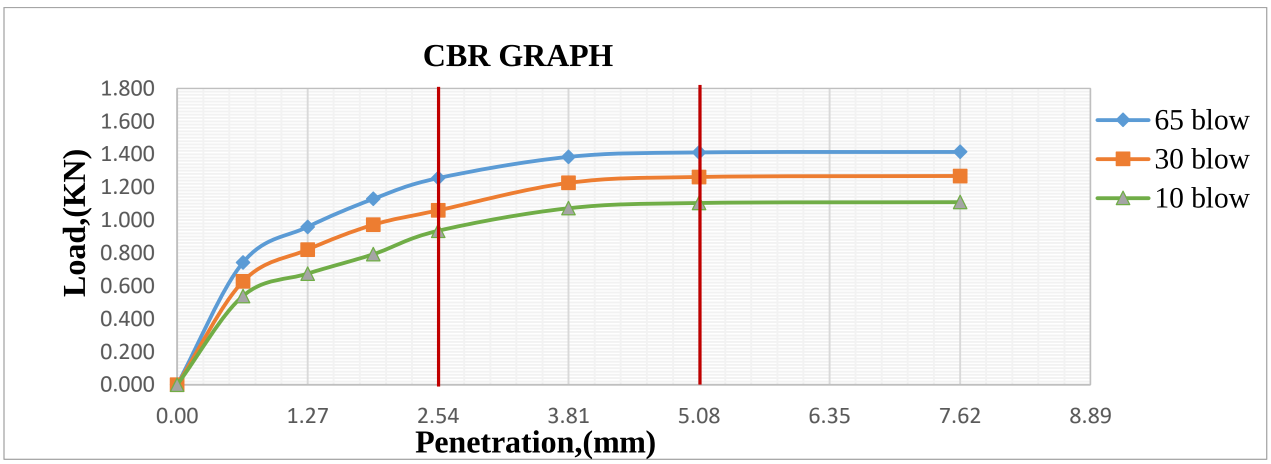


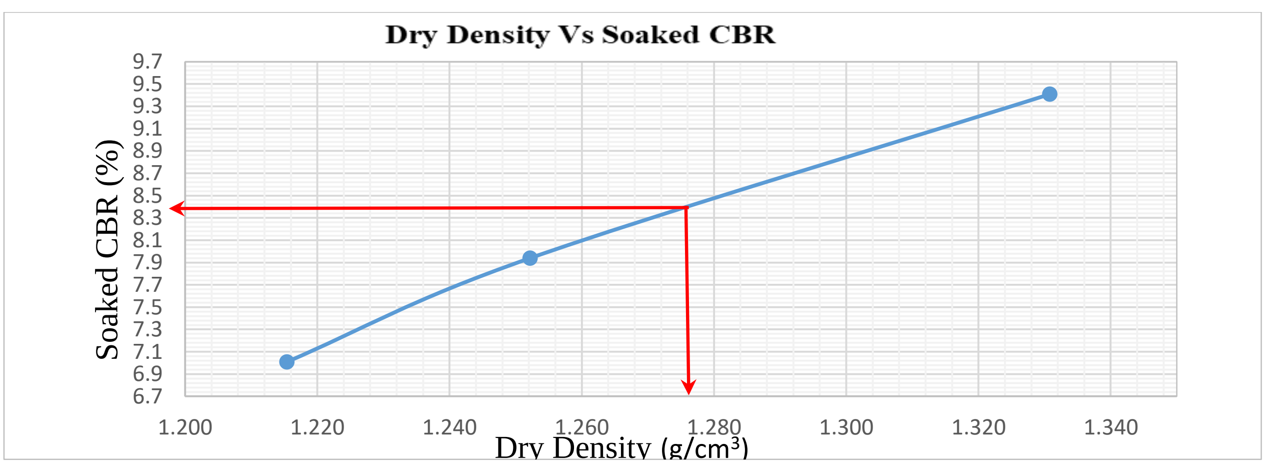
PENETRATION AND LOAD DETERMINATION OF SHA5%+L5% @ KF						
Penetration Data After 96-hours Soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.915	6.86	0.824	6.18	0.735	5.51
5.08	1.041	5.21	0.952	4.76	0.854	4.27
CBR RESULT SUMMARY OF SHA5%+L5% @ KF						
MMDD			1.354			
Dry Density at 95% of MDD			1.286			
No of Blows			65	30	10	
CBR Values (%)			6.86	6.18	5.51	
DDBS g/cc			1.328	1.261	1.231	
CBR at 95% MDD			6.43%			





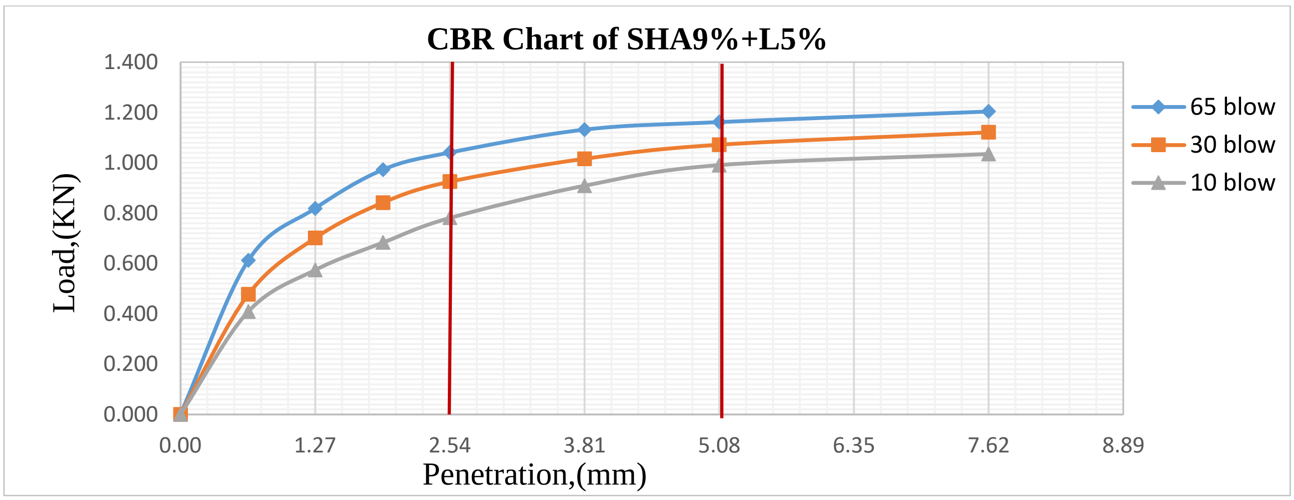
PENETRATION AND LOAD DETERMINATION OF SHA7%+L5% @ KF						
Penetration Data After 96-hours Soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	1.255	9.41	1.059	7.94	0.935	7.01
5.08	1.411	7.06	1.262	6.31	1.104	5.52
CBR RESULT SUMMARY OF SHA7%+L5% @ KF						
MMDD			1.344			
Dry Density at 95% of MDD			1.277			
No of Blows			65	30	10	
CBR Values (%)			9.41	7.94	7.01	
DDBS g/cc			1.331	1.252	1.215	
CBR at 95% MDD			8.40%			

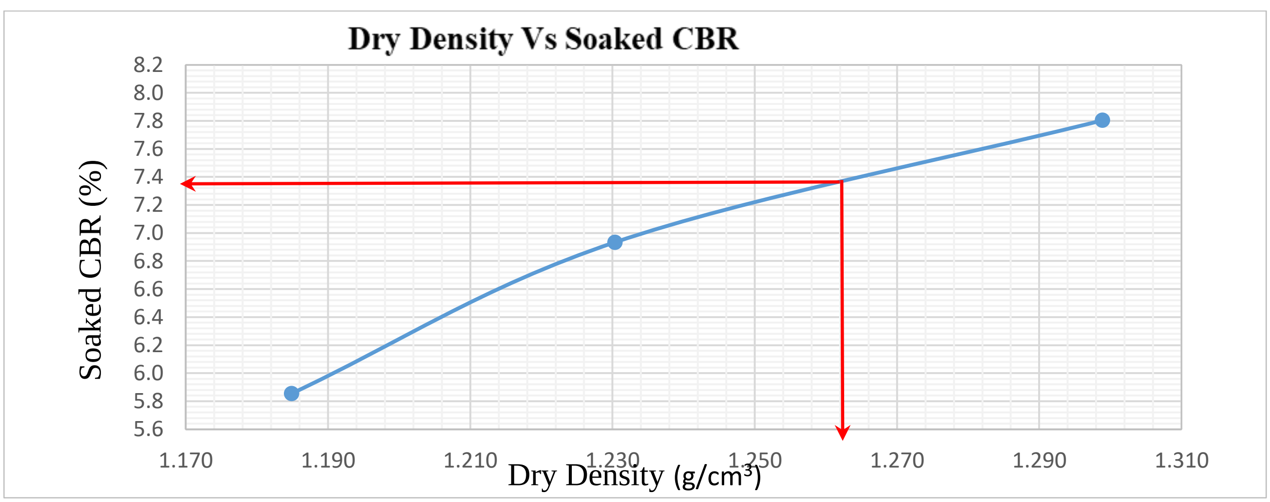




PENETRATION AND LOAD DETERMINATION OF SHA9%+L5% @ KF						
Penetration Data After 96-hours Soaking						
Penetration (mm)	**65-Blows**		**30-Blows**		**10-Blows**	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	1.041	7.80	0.925	6.93	0.781	5.85
5.08	1.162	5.81	1.072	5.36	0.991	4.96

CBR RESULT SUMMARY OF SHA9%+L5% @ KF			
MMDD	1.331		
Dry Density at 95% of MDD	1.264		
No of Blows	65	30	10
CBR Values (%)	7.80	6.93	5.85
DDBS g/cc	1.299	1.230	1.185
CBR at 95% MDD	7.37%		





APPENDIX H: Natural Moisture Content

Sample Location	HMK		
Trial Number	1	2	3
Can number	S1	G19	E3
Mass of can (Mc), g	20.17	17.48	19.56
Mass of can + moist soil (Mcms), g	81.89	78.95	74.75
Mass of can + mass of oven dried soil (Mcds), g	64.78	59.41	58.37
Mass of water (Mw), g	17.11	19.54	16.38
Mass of dry soil (Ms), g	44.61	41.93	38.81
Water Content (w), %	38.35	46.6	42.21
Average water content (w), %	42.39		

Sample Location	KF		
Trial Number	1	2	3
Can number	A17	F5	B8
Mass of can (Mc), g	21.97	18.18	18.7
Mass of can + moist soil (Mcms), g	79.68	74.89	76.55
Mass of can + mass of oven dried soil (Mcds), g	62.78	55.41	58.37
Mass of water (Mw), g	16.9	19.48	18.18
Mass of dry soil (Ms), g	40.81	37.23	39.67
Water Content (w), %	41.41	52.32	45.83
Average water content (w), %	46.52		