ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
SCHOOL OF GRADUATE STUDIES

SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE

STABILIZATION OF EXPANSIVE SUB GRADE SOIL BY WHEAT HUSK ASH AND LIME

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A THESIS SUBMITTED TO

SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILLMENT OF THE
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A Thesis Submitted to School of Graduate Studies of Adama Science and Technology University in Partial Fulfillment of the Requirements for The Degree of

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LIST OF SYMBOLS AND ABBREVIATIONS

AASHTO	American Association High way and Transportation Officials;
Ac	Activity;
ASTM	American Society for Testing Materials;
C	Percentage of clay size finer than 0.002mm;
CAH	Calcium aluminate;
Ca(OH)2	Calcium hydro oxide;
CaO	Calcium oxide;
CBR	California bearing ratio;
CH	In organic clay of high plasticity;
CL	In organic clay of low plasticity;
CSH	Calcium silicate;
F	Percentage passing;
FSI	Free swell Index;
GC	Clayey gravel;
GM	Silty gravel;
GP	poor graded gravel;
GW	Well graded gravel;
H2O	Water;
K	Factor for clay content;
LL	Liquid limit;
MDD	Maximum dry density;
MH	In organic silts of high compressibility;
MI	In organic silts of low to medium plasticity;
ML	In organic silts of none low to plasticity;
OH	Organic clay of low to high plasticity;
OL	Organic silts of low plasticity;

OMC	Optimum moisture content;
PI	Plasticity Index;
PL	Plastic Limit;
S	Swelling Potential;
SC	Clayey sand;
SM	Silty sand;
SP	Poor graded sand;
SW	Well graded sand;
UCS	Unconfined compressive strength;
USCS	Unified soil classification system;
Vk	Volume of kerosene;
Vw	Volume of water and
WHA	Wheat Husk Ash;

Units

cc	Centimeter cube;
cm3	Centimeter cube;
gm	Gram;
kg	Kilogram;
km	Kilometer;
kN	Kilo Newton;
kN/m2	Kilo Newton per meter square;
mm	millimeter;
g/cm3	Gram per centimeter cube;
µm	micrometer and
^{o}C	Degree Centigrade.

ABSTRACT

Expansive soil is very sensitive to variation in moisture content and exhibit large volume change. This behavior is attributed to the presence of montmorillonite mineral. Extensive spread of the black cotton soil has posed challenges and causes more damage to light building and pavements than any natural hazard. To encounter with it, there are various methods to improve the strength of the soil, such as mechanical compaction, dewatering and earth reinforcement. And other methods like stabilization using admixtures are more advantageous. In addition to this, the innovative and nontraditional research on waste utilization is gaining importance now days before resting any structure on expansive soil. Some of soil improvements using admixtures are rice husk ash, wheat husk ash, lime, cement, blast furnace slag, fly ash etc. The main objective of this study is to introduce an alternative method of stabilization of expansive soil and to evaluate the effects or performance of soil using wheat husk ash and lime as soil stabilizing materials. The samples of lime taken from Zuway lime factory, the expansive soil collected from Welenchity and Wheat Husk Ash from Arsi region. A number of trial mix of laboratory test has been conducted on using soil mixed with lime as 0%, 2%, 4%, 6%, 8% and 10% blended with Wheat Husk Ash in 0%, 3%, 6% 9% and 12% by weight of dry soil. The laboratory test results show that a significant increase in CBR and UCS strength. The Soaked CBR values increases from 3.25% to 27.86% and UCS improved from 87kN/m2 to 802.94kN/m2.The free swell of the expansive soil is reduced by 29.8% with increase in Wheat Husk Ash content from 0% to 6%. From this investigation it can be concluded that the combination of lime and Wheat Husk Ash has a potential to improve the engineering performance of expansive sub grade soil.

CHAPTER ONE

INTRODUCTION

1.1. General

Soil used for foundation beds must be strong which requires better soil properties for safety of civil engineering structures. Expansive soils are soils that have a characteristic of volume change or swell-shrink during wet and dry season(Nelson and Miller, 1992). The recent studies predict that Ethiopia is one of the countries in the world where the expansive and the non-expansive residual soil cover more of the country's land area. The expansive soils have a colour of black or gray. The expansive soil contains active clay mineral called montmorillonite which have a tendency to expand. The continuous shrink-swell behavior of expansive soil is worldwide stability problem that causes extensive damage to civil engineering structures like light building, pavements, retaining walls, canal beds and lining etc. built on them. Because of such light weight structures can't exert the necessary counter load to overcome the swelling. The studies reported in the literature show that the damages happen to civil engineering structures are so severe that, it is estimated to be $1000 million in USA and £150 in UK (Nelson, J.D. and Miller, D.J., 1992).There is no exact damage cost record in Ethiopia like USA and Uk, but the evidence shows that some structure constructed in areas of expansive soils are damaged; and as a result the country is spending millions of birr for maintenance per year. These damages are characterized by cracks on building and high on road construction.

There are several methods of improvement techniques for inadequate stability of expansive soil (William Powrie, 1997). Such as: removal and replacement method, preloading, pore water pressure reduction, Mechanical and chemical stabilization. Most of the time in Ethiopia, the highway practice in resolving expansive soil problem was using method of removal and replacement. This removal and replacement method causes high costs of investment per year. So, to reduce cost of investment, the soil stabilization is preferable. Soil stabilization is a process by which certain materials are added to soil to improve its engineering properties. Chemical stabilization is one of the methods used to improve the engineering properties of soil.

Many investigators have been used natural and fabricated additives materials to improve geotechnical properties of expansive soil. Soil stabilization using agricultural and industrial wastes is one of the efficient and cost effective methods. Recent research works in the area of geotechnical engineering and construction materials focuses more on the search for cheaper and locally available materials, agricultural and industrial wastes, for use in construction industry. These materials may be classified as pozzolanic (fly ash, rice husk ash, wheat husk ash etc.), binder (lime, cement, cement kiln dust, lime sludge etc.) and inert (quarry dust, sand, ceramic dust etc.) are added to soil individually or combinedly (Akshaya Kumar Sabat,2014).

The objective of the this study is focused on using agricultural product wheat husk ash and lime materials as one of alternative stabilization techniques to improve the engineering properties of expansive sub grade soils and to evaluate the effect of two stabilizers on the expansive soil. Wheat ash has been considered waste traditionally, but it can be put in to use for in various chemical synthesis, partial replacement of cement and soil stabilization. As an agricultural product, wheat straw contains considerable amounts of SiO2: When WHA burned under controlled conditions can generates amorphous silica which has tremendous significant and good market value. When burned it leaves an ash very rich in SiO2 that has a pozzolanic character (Hasan Biricik et al.1999).

In addition to having pozzolanic properties, also have some self-cementing properties in the presence of water (Amardeep B. et.al, 2015). Another additives produced from lime manufacturing factory is lime and its main constituent is CaO. Wheat Ash as a pozzolanic material and lime as a binder can be utilized to stabilize expansive soil. In present investigation, an attempt has been made to evaluate the changes of properties of the stabilized soil studied were, Atterberg's limits, linear shrinkage, free swell, maximum dry density (MDD), optimum moisture content (OMC), unconfined compressive strength (UCS), un soaked CBR and soaked California bearing ratio (CBR) of soil. From the study, the optimum percentage of WHA and lime for stabilization of soil was found to be 6% and 6% respectively.

1.2. Statement of the Problem

The extensive spread of expansive soils has pose challenges and causes problem on different engineering structures. Such as appeared as cracking and break-up pavements, high way embankments, road ways, rail ways, building foundations, slab on grade members channel and reservoir linings, irrigation systems, water lines, sewer lines etc. Expansive soils are soils which swell when come in contact with water and shrink when the water squeezes out. This cyclic swell-shrink characteristic of expansive soil affects the engineering structures. In Ethiopia a number of road route constructed on expansive soil. For example, the route constructed on expansive soil from Gedo-Nekemet has cracks on asphalt layers and some settlements. To encounter the impact of this problematic soil, the study on treatment of expansive soil is essential work in order to stabilize or improve its engineering strength. The performance of soil with volume change, low strength and poor workability can be improved by using chemical stabilizers.

1.3. Objectives

1.3.1. General objective

The objective of this study is to evaluate the performance selected stabilizers and an alternative methods of soil stabilization technique by introducing the Wheat husk ash which are an abundantly available agriculture waste in wheat rising areas, and lime to improve the strength of expansive sub grade soil. To accomplish the research successfully an integrated method of literature review, physical observation, soil sampling, laboratory testing, analysis and interpretation of the test results were conducted.

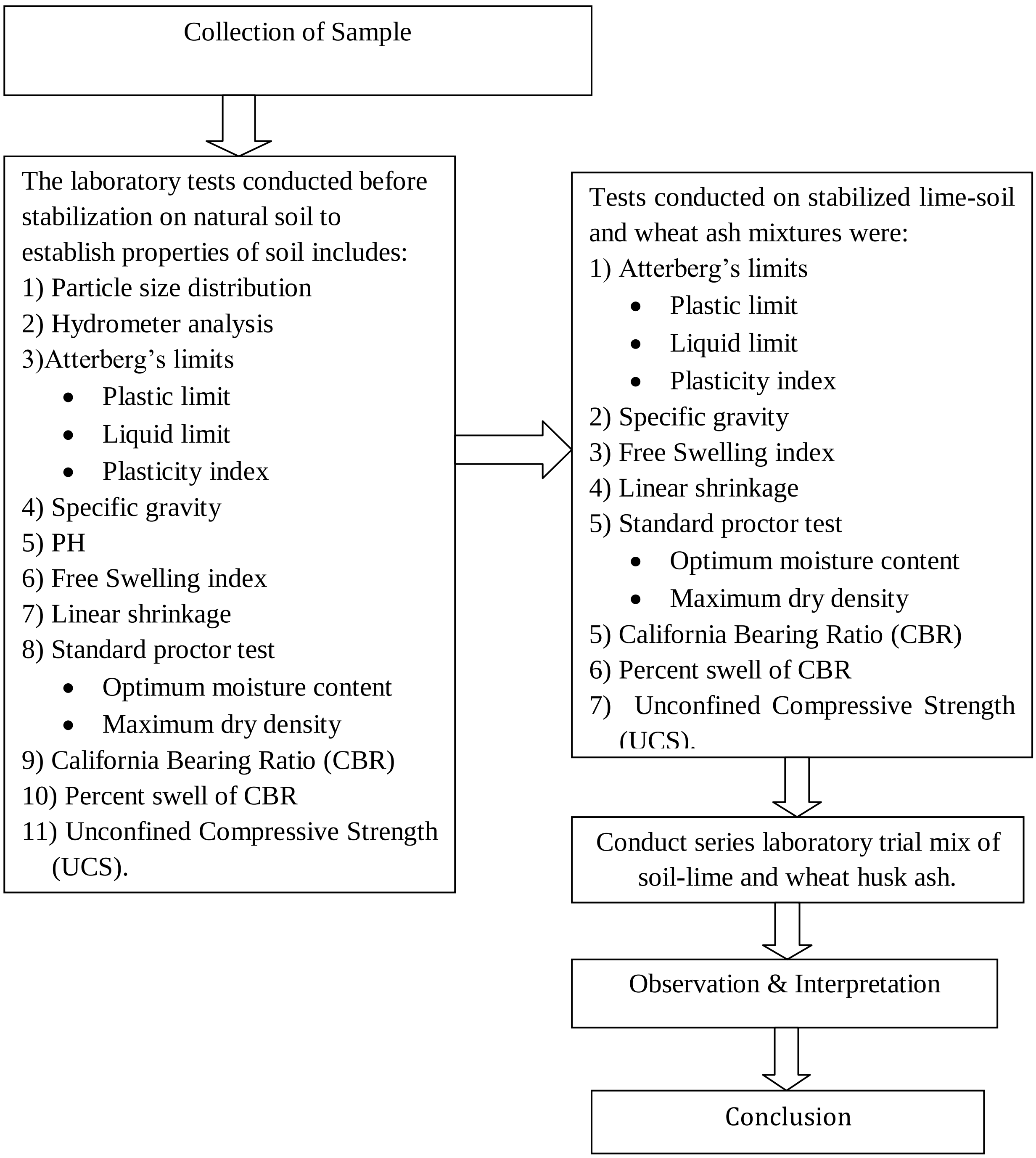
1.3.2. Specific objectives or Scope of the study

- To investigate and evaluate the effects and performance of selected chemical stabilizing agents on expansive sub-grade soil.
- To study the index and compaction properties of expansive soil with addition of various percentage of lime and wheat husk ash to reach the optimum percentage and also intended to compare the change in geotechnical properties of natural soils.
- To study the strength parameters such as UCS and CBR value of the natural soil as well as Stabilized soil and the performance of these additives on strength of expansive soil.
- To study the strength behavior of expansive soil treated with optimum percentage of wheat husk ash and lime at various curing periods.

- To develop the rational approaches for the use of Lime and wheat husk ash for geotechnical purposes. Thus, enhancing the rate of utilizing the agricultural product for construction purpose and to reduce the disposal problem and minimize the environmental hazards in Ethiopia.

1.4. Methodology of the Study

The research was conducted using review of literature on behavior of expansive soils, problems caused by such soil and assessing the availability of literature review in the study area, field observations, collection of samples for laboratory testing and analysis of the laboratory test results. A soil sample was collected from Northern part of Welenchit town which is found around 115km from Adama town. And the wheat ash was collected from wheat rising areas of Arsi region. Primarily emphasis was given to review previous works on treatment of expansive sub grade soils particularly on chemical stabilization methods. During present study the source of literature used includes: books, research paper, journals and on-line materials available on internet. Field observation and identification soil were made before taking samples to laboratory tests. Four samples were taken from different location and laboratory tests carried on atterberg limits and free swell and grain sizes analysis to select one location. After fixing a location and identifying the soil as expansive, one representative sample was collected for detailed laboratory testing. Laboratory tests were carried on soil samples before and after mixing with selected chemical additives. Laboratory test was conducted to characterize the expansive soil and study the effects and performance of chemical stabilization on this soil.



Different trial tests have been made on different mix proportion of hydrated lime was taken as 0%, 2%,4%,6% ,8% and 10% and for wheat husk ash taken as 0%, 3% ,6%,9% and 12% to fix one best optimum. The strength parameters with different percentage of soil, lime and wheat husk ash mix were tested after stabilization for 0days, 3days, 4days and 7days of curing periods. The test results are evaluated by primarily considering the effects of the stabilizers on engineering properties of the expansive soil and compared with un treated soil. Moreover, the analysis and interpretation results have been made on improvements of engineering properties of expansive soil. Finally, the analyzed and interpreted data was compiled and also based on results obtained from the study appropriate conclusion and recommendations have been made.

1.5. Significance of the Research

The research was conducted to study an alternative stabilization methods and to evaluate the effects of chemical stabilizers on expansive sub grade soil. This study introduces the knowledge of chemical stabilization particularly in agricultural wastes in the county for proper treatment of expansive sub-grade soils. Additionally it helps to improve susceptibility problem of expansive sub grade soil to water, increase stability and durability of pavement. The research work improves the knowledge of expansive soils in the country and will be an indicative method of improving such soils using combination of industrial and agricultural wastes in the country.

1.6. Limitations of the Study

The Research is carried out on soil sample specified in methodology for laboratory testing and analysis. All tests conducted were made for the purpose of this research work and has some limitations. Laboratory tests were conducted on small number of samples and one region of soil. Therefore, the results are indicative rather than definitive. In addition to this, only selected tests which are very important to achieve the objectives of the research have been included. Due to lack of sufficient laboratory equipment, skilled personnel at laboratory, finance, time and transportation facilities, a limited number of samples was conducted in laboratory for analysis. As results of this, the mineralogy of soil and wheat ash were not conducted for this study.

1.7. Structure of thesis

The Thesis has six chapters.

Chapter 1 comprises the introduction part, which includes the problem statement, objectives of the study, methodology, scope of the study, significance of the research, limitations and structure of thesis.

Chapter 2 deals with the literature review about origin, mineralogy, identification of expansive soil, classification of expansive soil and problems associated with expansive soils and improvement methods of expansive sub-grade soil.

Chapter 3 presents the literature review on soil stabilization. It contains the introduction, type of stabilization, stabilizing agents and earlier works relevant to the present research.

Chapter 4 presents the materials and methodology. It presents the chemical composition, gradation, plasticity index, moisture content and dry density characteristics, strength and percent swell and over all characterization of the sub-grade soil.

Chapter 5 presents the interpretation and discussion of the test results and comparison with other similar test results

Chapter 6 presents the conclusions and recommendations based on results of the present research work.

CHAPTER TWO

LETRATURE REVIEW

2.1. Introduction

2.1.1. Expansive soil in general

The expansive soil is defined as the plastic clay of which commonly called black cotton soil that changes in volume in relation to changes in water content. The expansive soils are found extensively in tropical areas. Before resting any structure on expansive soil, we need to have a proper knowledge about their properties and the factors that affect the behavior. The key element which shows swelling characteristics to any ordinary non-swelling soil is a clay mineral. The clay minerals present in expansive soil can absorb more water and expand when in contact with water and leaving large voids in soils when they are dried and shrink. It has cracks in during dry season. In organic clays of high plasticity, generally those with liquid limits exceeding 50 percent and plasticity index over 30; usually have high inherent swelling capacity. Expansive soils are a worldwide problem, causing extensive damage to civil engineering structures because of its cyclic swell - shrink behavior and low strength.

Figure2.1 The surface cracks of expansive soil during dry season.

During the present study exhaustive literature review was under taken in order to provide a framework and understanding regarding origin, mineralogy, identification, classification of expansive soils, problems associated with such sub-grade soils and treatment methods that allow to overcome the adverse effects of these soils. Attention was given to the review of previous works on treatment methods of expansive sub-grade soils with particularly concern to chemical stabilization techniques. For the present study, different literature sources were used. These include books, journals and on-line materials available on the internet. Previous studies and practical works conducted in Ethiopia that are of similar nature to the present research were assessed and included as part of the literature review.

2.2. Origin of Expansive soil

The origin of expansive soil is from parent materials. The constituent of this parent material during the early and intermediate stages of the weathering process determine the types of clay formed. Variation in the conditions and process may also form clay minerals of which both expansive and non-expansive soils. The condition and process which determine the clay material and degree of physical and chemical weathering to which the materials are subjected. Chen (1988) has described that the origin of expansive soil is related to a complex combination of conditions and process that result in the formation of clay mineral having a particular chemical makeup. These clay particles results from the alteration of parent rock material (Chen 1988).Alteration takes place by several processes which include weathering, diagenesis, hydrothermal action and post depositional alteration.

2.2.1. Parent Materials

The formation of soils commences by chemical alteration and physical disintegration of rocks at their exposed surface. These rocks are termed the parent material. The parent material has the greatest influence on the incipient soils in the early stages of soil formation and in the drier regions (Birkeland,1984). There are a variety of parent materials as there are a variety of rock types with different mineral phases and chemical composition. Rocks have been divided into three main types based upon by their method of formation, such as igneous rocks, sedimentary rocks and metamorphic rocks. Each group contains a wide variety of rock types that differ from one another by either the chemical composition, texture or both. Among those parent materials for which the expansive soil can be formed are classified into two groups. The first group contain the basic igneous rock and the second group comprises the sedimentary rocks that contains montmorillonite as constituent(Chen1988). According to his study the basic igneous rocks rich in the basic materials pyroxene, amphibolites, biotite and volcanic glass. The rock contains semctite (montmorillonite) as constituent and breaks down physically to form expansive soil. Chen (1988) stated that smectite (montmorillonite) is one of the main sources of clay minerals that form expansive soils.

2.2.2. Weathering and climate

The formation of expansive soil is due to weathering process such as physical, chemical and biological process that lead to disintegration of mass rock. Weathering converts the rock mass into soil. The most important factor for formation of montmorillonite is the chemical weathering process of parent rock mineral. The parent material is generally consists of ferro magnesium mineral, calcic feldspars, volcanic glass, volcanic rocks and volcanic ash. The formation is aided in alkaline environment, availability of magnesium ion and lack of leaching. Such condition is favorable in semi-arid regions with relatively low rain fall or seasonal moderate rain fall particularly where evaporation exceeds precipitation. Under this condition enough water is available for the alteration process but the accumulation cations will not be removed by rain water (Chen 1988).

2.3. Mineralogy of Expansive soil

The availability of clay mineralogy in the soil is a fundamental factor to show the expansivity of soil. Clay has a particle size of 0.002mm or less. According to the investigation of Chen (1988), the grain size alone does not determine clay minerals. He focused on determination of the most important property of fine grained soils by their mineralogical composition. The presence of clay minerals in soil shows the shrinkage and swelling characteristics of soils. For the use of engineering study, the most important clay minerals can be divided into three general groups on the basis of their crystalline arrangements (Chen 1988, Nelson 2010) such as:

- kaolinite group
- Illite group
- Montmorillonite group(also called the smectite group)

2.3.1. Kaolinite Minerals

Tropical decomposition tends to favor formation of the clay mineral kaolinite. It is the most clay mineral in tropical residual soil. Kaolinite is usually non-expansive due to the availability of strong hydrogen bond that holds the individual particles together. Since hydrogen bonds are comparatively strong than alkinline crystals consists of many sheet stacking that are difficult to dislodge. Kaolinite is a typical two-layer mineral having a tetrahedral and an octahedral sheet joined to form a 1-1 layer structure held by strong hydrogen bond. When it come in contact with water , it does not absorb and expand(Nelson 2010).He described that kaolinite is formed by weathering or hydrothermal alteration of rocks rich in feldspar in low ph condition to favor the leaching out of ions like sodium, potassium, calcium ,magnesium and iron. Therefore, this mineral is stable and water cannot enter between the sheets to expand the unity cells. Kaolinite is electrically neutral.

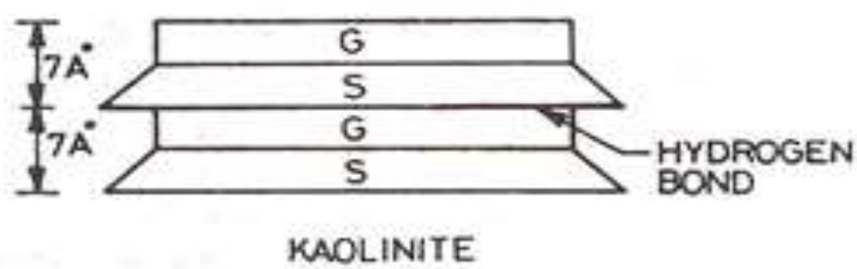


Figure 2.2 Kaolinite mineral (Arora K.R, 2004)**.**

2.3.2. Illite mineral

Illites have moderate degree of expansion soil. It contains weaker potassium bond that that allow limited expansion. The availability of potassium as the bonding material between units makes the illite minerals swell less. According to their structural arrangement, these minerals fall between the kaolinite and mantimorillonite group. It does not create significant effect on engineering structures. The space between different structural units much less than montmorillonite, as potassium ions fit in between silica sheet surfaces. The property of illite is intermediate between kaolinite and montmorillonite. The bond between non exchangeable K^+ ions through stronger than that in montmorillonite.

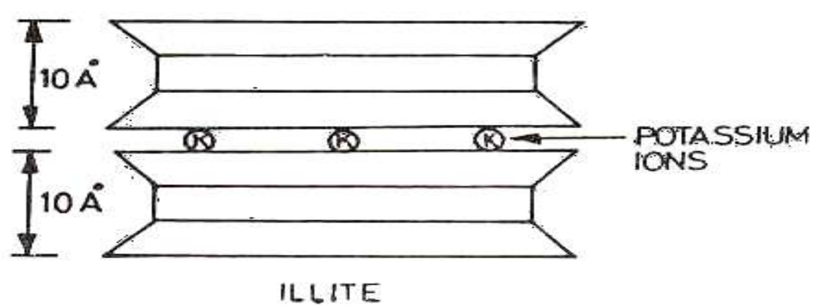


Figure 2.3 Illite mineral (Arora K.R, 2004***).***

2.3.3. Montmorillonite minerals

The particles are highly expansive soils create the major engineering problems. The structures are bonded together by weak Vander Waals force and the water can easily enter between the bonds and create swelling. montmorillonite or smectite is usually predominant clay minerals in residual soils from basalts, dolerites , norites, kimerlites, mud rock and shales. The montmorillonite group clays have a 2-1 layer structure formed by an octahedron and winched between two tetrahedrons. This group of clay can have significant amounts of magnesium and iron substituting into the octahedron layers. The most important aspect of the montmorillonite group is the ability to absorb water between the layers, causing volume of minerals to increase when they come in contact with water (Nelson 2010).The negatively charged surfaces of the silica sheet attract the water in the space between the structural units. This results in an expansion of clay mineral. It may also cause dissociation of clay mineral into individual structural units of thickness $10A^0$.The soil containing large amount of the mineral montmorillonite exhibits large shrinkage and high swelling characteristics.

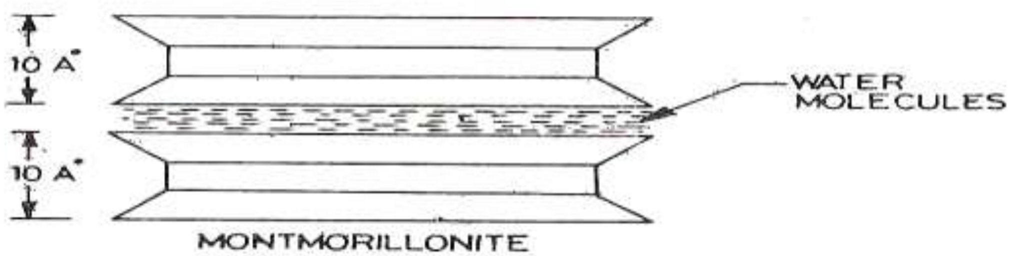


Figure2.4 Montmorillonite minerals (Arora, 2004)

2.4. Identification of expansive soil

Soil type and mineral type can be identified by simple laboratory tests and field observations. Engineering investigation of expansive soil have consists of two phases. The first is recognition and identification of expansive soils and the second is sampling and testing of material properties to be used as the basis for design predictions. In engineering practice, the common identification schemes are based on standard classification, such as grain size analysis and Atterberg limits. However, other tests used in identifying potentially swelling soils are available and are used routinely by agricultural and geological survey laboratories. Engineering identification of soils is generally based on simple to determine field and laboratory identification and classification tests. The purpose of this topic is to discuss different ways of commonly used to identify expansive soils.

2.4.1. Field identification

It is the primary task in which the expansive soil deposit can be recognized in the field through visual inspections. Some of the important points that help to recognize the expansive soil through field observation (Chen 1988, Nelson, D.J, and Miller, J.D., 1992) include:

- Have colour black or gray
- Shiny appearance or have glazed cut surfaces
- Open or closed fissures (joint or similar discontinuities) or shattered conditions or obvious structural damage caused by such soils to existing buildings.
- Spacing and width of wide or deep shrinkage cracks
- High dry strength and low wet strength
- Arid and semi-arid areas are particular trouble spots as a result of large variations in rain fall and temperature.
- Stickiness and low traffic when wet.

2.4.2. Laboratory identification

Generally there are three different methods are proposed in literature for identifying expansive soils in laboratory. Such as: (i) Mineralogical Identification, (ii) Direct measurement, and (iii) Indirect methods.

2.4.2.1. Mineralogical identification

Determination of mineralogy is used to characterize the crystal dimensions, characteristic reaction to heat treatment size and shape of clay particles. Type of clay mineral is a fundamental factor, which determines the expansive behavior of a soil. Mineralogical test is used to identify clay minerals, but it is impractical and uneconomical for practicing engineers. There are different types of techniques, which are used to identify the clay mineralogy. According to (Chen, F.H. ,1988) the common types techniques are:

- Microscopic examination
- X-ray diffraction
- Differential thermal analysis
- Dye adsorption analysis
- Chemical analysis

These methods are not suitable for routine tests because of the following reason:

- They are time -consuming
- Results can only interpreted by special trained technicians and
- Requires the special skills and expensive test equipments.

For this reason most laboratories tests are preferred to use simple identification procedures based on physical properties of the soils.

2.4.2.2. Direct method

This test is used to determine the swelling potential and swelling pressure of expansive clay. And also directly measures the swelling pressure that a swelling soil exerts on any structure resting on it. It is a convenient and more reliable test because it directly tells the likely in-situ response of the soil for moisture variations. The test can be done by the use of a conventional one-dimensional consolidometer which is available in most soil mechanics laboratories.

2.4.3. Indirect Methods

This method is used to determine the swelling potential of a soil by examining other parameters, which indirectly give information about the soil property. These include Index Property tests and Potential Volume Change (PVC) test. Some of the index property tests are grain Size analysis, Atterberg Limit, shrinkage index and free swell tests. The grain size analysis helps to determine the amount of colloidal sized particles existing in a soil. According to (Chen1998), single index method is one of the tools in evaluating the swelling potential of expansive soil, and the tests are easy to form and used as routine test. There are various tests under these methods are:

- Atterberg limit tests
- Linear shrinkage tests
- Free swell tests and
- Colloid content determination
- Soil classifications

i. Atterberg Limit tests

The Atterberg limit tests are conducted for identification of all engineering soils. In addition, when they are combined with other tests they can be used to classify the expansive soils. The plastic index and liquid limits are important indices for identification of swelling potential of expansive soils.

According to Seed at al., (1962), the swelling potential is given as a function of the plasticity index by the formula:

$$S = 60K(PI)^{2.44} \tag{2.1}$$

Where, S= Swell potential in percent

PI = plasticity index in percent

K = 3.6 X10-5, a factor for clay content 8 and 65 percent (Chen, 1998).

This equation has a limitation, and is only applicable for soils with clay content ranging from 8 to 65%. Chen (1988) demonstrated that the relationship between plasticity index and the swelling potential of expansive soils. The relation between plasticity index, PI and swelling potential of clays is shown in Table 2.1

Table 2.1 Relation between swelling potential of clays and the plasticity index

Swelling Potential	Plasticity index
Low	0 -15
Medium	10 - 35
High	20 - 55
Very high	35 and above

It may be true that the high swelling soil will shows the high index property, the reverse is not true (Chen, F.H., 1988).According to Wiesman et al., the index properties is used to identify expansive soils and tabulated in table below.

Table 2.2 Atterberg Limits results and Degree of expansion

Index tests	Usually non problematic	Always problematic
Plastic index	< 20	> 32
Shrinkage Limit	> 13	< 10
Free Swell	< 50	> 100

ii. Linear shrinkage

Linear shrinkage is the change in length of a sample as it dries to the shrinkage limit expressed as a percentage of the original length. It is combined with other tests used to classify the expansive soil.

Altimeyer(1955) has demonstrated a guide for determination of potential of expansiveness based on shrinkage limit and linear shrinkage.

Table 2.3 Relation between swelling potential, shrinkage limits and linear shrinkage.

Shrinkage limit %	**Linear shrinkage %**	**Degree of expansion**
< 10	> 8	Critical
10 – 12	5 - 8	Marginal
> 12	0 - 5	No critical

iii. Free Swell tests

The free swell test is the measure of volume change in clay upon saturation and the most commonly used simple test to determine the swelling potential of expansive soil. This test is conducted by slowly pouring 10cc of dry soil passing through 425µm sieve into two 100cc graduated cylinder one filled with kerosene and other with distilled water. Therefore, recording the swelled volume of the soil after it come to rest (after 24hrs) the free swell values are calculated in percentage. The Amer, A., and Mattheus, F.A. 2006) have developed the equation of free well test determination.

$$\text{Free swell Indix} = \frac{\text{Vw} - \text{Vk}}{\text{Vk}} \text{x100} \qquad (2.2)$$

Where, Vw = final volume in water

Vk = final volume in kerosene

iv. Free swell Ratio

According to Sidharan and Prakash (2004) investigation, they have been developing the free swell ratio method to determine the swell property of the swelling of soils. Free swell ratio is the ratio of the sediments volume as 10cc oven dried soil passing through 425µm sieve in distilled water to that of kerosene equation (2.3).

$$\text{Free swell ratio} = \frac{\text{Vw}}{\text{Vk}} \text{x100} \qquad (2.3)$$

The relation between the differential free swell ratio and degree of expansion is given in Table 2.4

Table 2.4 Classification of soils based on free swell ratio (Sridharan and Prakash, 2004)

Free Swell Ratio	Soil expansivity	Clay type
< 1	Negligible	Non swelling
1.0 _1.5	Low	Mixture of non-swelling and swelling
1.5 -2.0	Moderate	Swelling
2.0 -4.0	High	Swelling
>4.0	Very High	Swelling

2.5. Classification of expansive soils

Engineering classification of soils is generally based on simple to determine field and laboratory identification and classification tests. The methods that are used for classifying soils are based on one or the other of the following two broad systems:

1. A textural system which is based only on grain size distribution.
2. The systems that are based on grain size distribution and limits of soil.

Many systems are in uses that are based on grain size distribution and limits of soil. Once a soil is identified as expansive, it has to be classified according to the property it exhibits. Soil related CL or CH by USC, and A6 or A7 by AASHTO, may be considered potentially expansive soils.

2.5.1. Classification using general methods

Most commonly used engineering classification systems namely Unified Soil Classification System (USC), and American Association of State Highway Transportation Officials (AASHTO) American Society of Testing Materials (ASTM).

i. AASHTO Classification system

To determine a soil classification in the AASHTO system, one first determines the relative proportions of gravel, coarse sand, fine sand, and silt-clay. The system is based on particle -size distribution, liquid limit and plasticity index (Arora K.R, 2004). Furthermore, a group index may be calculated to quantify a soil expected performance within a group. As shown in Table 2.5 soil ranks from A-6 or A-7 by AASHTO can be considered potentially expansive (Nelson, D.J., and Miller, J.D., 1992). To classify a soil according to Table 2.5, one must apply the test data from left to right. By process of elimination, the first group from the left into which the test data, it is the correct classification.

Table 2.5 AASHTO Classification Chart (Arora K.R, 2004)

General Classification	**Granular materials (35 percent or less of total sample passing No.200)**							**Silty- clay Materials (More than 35 percent of total passing No.200)**			
Group classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve analysis percent passing											
No.10	50 max										
No.40	30 max	50 max	51 min								
No.200	15 max	25 max	10 min	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
(Characterstics of fraction passing No.40)											
Liquid limit				40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity Index	6 max	N.P.		10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min
Usual tpyes of Significant constituent materials	Stone fragments - gravel and		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
Greral rating as sub grade	Excellent to good					Fair to poor					

To further evaluate the relative quality and supporting value of a soil as a highway sub-grade material, one may calculate or incorporate a number called the group index (GI) with the groups and subgroups of the soil.

$$\text{Group index } = (\mathrm{F}-35)\ [0.2]\ + 0.005(\mathrm{F}-35)\ (\mathrm{LL}-40)] + \ 0.01(\mathrm{F}-15)(\mathrm{PI}-10) \qquad (2.4)$$

Where, F, percentage passing through the No. 200 sieve

LL, liquid limit

PI, plasticity index

ii. Unified soil classification system (USCS)

USCS is based on the air field classification system developed by Casa Grande during World War II with some modification. Now a day it is widely used by engineers (ASTM designation D-2481). In order to use this classification system; the following points should be considered.

a. The classification is based on material passing No.200 sieve.

b. Course fraction percent retain above No.200 sieve

The USCS is based on the identification of type and mainly considering the grain size, gradation, plasticity and compressibility. According to USCS, the soil is classified into three major categories: such as coarse grain soils, fine grained soils and highly organic soils.

Field identifications conducted by visual examination of the coarse grain soils and a few simple hand tests for fine grained soils. For fine-grained soils and organic soils, classification in the unified system is based on Atterberg limits determined by the fraction passing the No. 40 sieve. The liquid limit and plasticity index are determined and plotted on the plasticity chart.

The vertical line at LL = 50 separates high-plasticity soils from low-plasticity soils. The A-line separates clay from silt. The equation of the A-line is

$$\mathrm{PI} = 0.73(\mathrm{LL} - 20) \tag{2.5}$$

Inorganic soils with liquid limits below 50 that plot above the A-line and have PI values greater than 7 are lean clays and are designated CL; those with liquid limits above 50 that plot above the A-line are fat clays and are designated CH.

The above classification system can be summarized as follows:

a. All clayey gravels and sands and silts exhibit moderate volume changes.

b. All clay soils and organic soils exhibit high volume change

c. All sands and gravels exhibit little or no expansion.

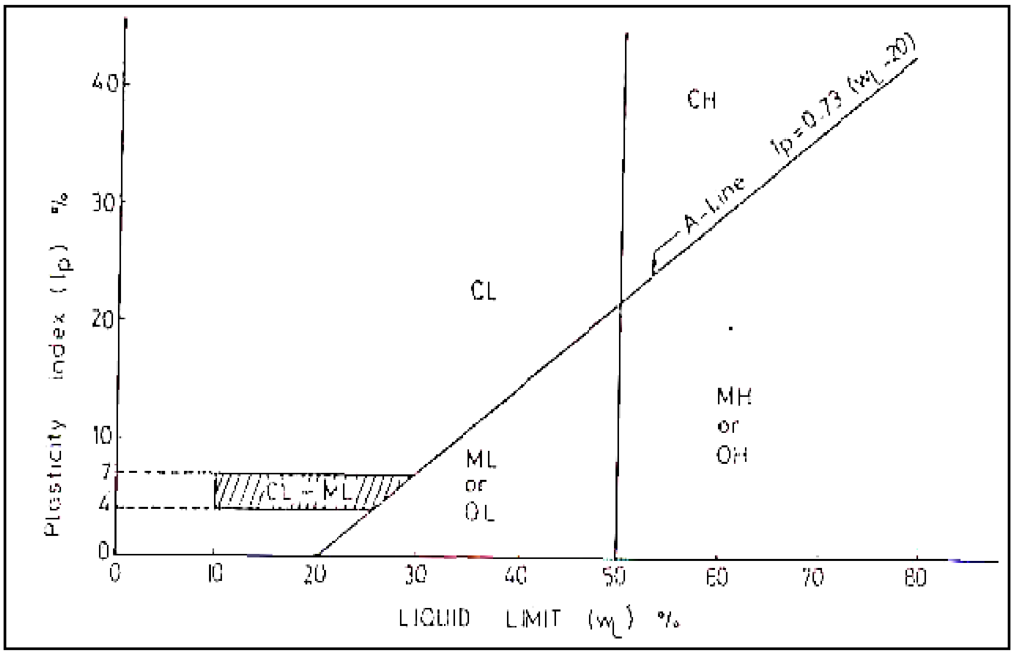


Figure 2.5 Plasticity chart of USCS (Arora K.R, 2004)

Table 2.6 Shows the approximate equivalence between AASHTO and USC System (Arora K.R,2004)

AASHTO System	USC System(most probable)
A-1-a	GW,GP
A-1-b	SW, SM, GM, SP
A-2-4	GM, SM
A-2-5	GM , SM
A-2-6	GC, SC
A-2-7	GM , GC, SM, SC
A-3	SP
A-4	ML, OL, MH, OH
A-5	MH, OH, ML,OH
A-6	CL
A-7-5	OH, MH, CL, CH
A-7-6	CH,CL, OH

iii. Textural soil classification

The boundaries between the various soil fractions of these systems are given in Table 2.7.

Table 2.7 Soil Fraction as per U.S. Department of Agriculture

Soil fraction	Diameter in mm
Gravel	> 2.00
Sand	2 -0.05
Silt	0.05 - 0.002
Clay	< 0.002

2.6. Problems associated with expansive sub grade soils

The problems associated with expansive soil are related to bearing capacity and cracking, breaking up of pavements, and various other building foundation problems. In expansive soils, major problem is large ground deformations in and around the structures due to swelling and shrinking of soil on wetting and drying. These excessive movements can damage structures and utilities also. The problems have tremendous negative impact on the structure or sub grade performance in terms of time and cost.

These soils have low CBR value in range of 2% to 4% and they have low strength to support the leads transferred from the pavement structure which results in excessive deformation beyond permissible limits (Rao,2007; Seehra, 2008). The problem rises due to insufficient identification of expansive soil during the site investigation and testing stages on many projects. According to ERA(2002), the highly expansive clays are exposed to erosion.

2.7. Improvement of expansive sub-grade soils

Requirement of pavement construction on expansive sub-grade soils calls for improvement of geotechnical behavior of the sub-grade prior to the construction. The main purpose of soil improvements are:

- An increase in the bearing capacity
- A reduction in the amount of settlement and time in which it occurs
- an acceleration in the rate at which drainage occurs
- elimination of the possibility of liquefaction
- An increase in the stability of slope vertical cut or of underground opening.

The following are some of treatment methods of expansive soils:

a. Mechanical modification/improvements

b. Hydraulic modification

c. Physical and chemical modification

d. Modification by inclusions and confinement

e. Stabilization by means of chemical admixtures.

According to Little and Nair (2009), the improvement of these problematic soil is achieved by physical or chemical stabilization or modification. A chemical stabilizer is another alternative soil improvement method to improve the performance of soil properties. Some of such stabilizers includes: Lime, cement, wheat husk ash, rice husk ash, fly ash, granulated blast furnace steel slug, marble dusts etc. Lime is most widely used stabilizing materials. Lime may be used alone or in combination with fly ash, cement or other pozzolanic materials like wheat husk ash. Some investigators have carried out research in the areas for last few years in areas of wheat.

Attom and Shatnawi (2005) had investigated the stabilizing effects of wheat husk on expansive soil in increase in shear strength and decrease in Potential swelling in expansive soil by stabilization with wheat husk. Santosh and Vishwanath (2015) were conducted investigation on stabilization of expansive soil by wheat husk ash and granulated blast furnace slag, and they concluded that the result of using these materials reduces the water content and increase the strength.

CHAPTER THREE

REVIEW OF SOIL STABLIZATION

3.1. Introduction

Soil stabilization is a process by which we can improve the soil characteristics & its economy. Stabilization, in a broad sense, incorporates the various methods implement for modifying the properties of a soil and improves the engineering properties and performance of soil. The performance of any geotechnical structures depends on the soundness of the underlying soils. Expansive soils can create significant problems for pavements or on any structures. The main purpose of soil stabilization is to improve the performance of the soil by increasing its density, shear strength, bearing capacity and stiffness and also decrease water sensitivity. Soil stabilization can be achieved by pulverizing the natural soil or borrow material, mixing in a chemical additive, and thoroughly compacting the mixture.

3.2. Types of Soil Stabilization

The two commonly used soil stabilization are physical or mechanical stabilization (such as compaction) and chemical stabilization (such as mixing with cement, fly ash, lime, and lime by-Products, etc).

3.2.1.Mechanical stabilization

It is a process of improving the engineering properties of soil to make stable without altering the chemical properties of the soil. In mechanical stabilization, soil stabilization can be achieved through physical process by altering the physical nature of native soil particles. This is done by applying compaction, mixing or blending two or more gradations geo-reinforcement (such as barriers and nailing). According to Little and Nair (2009) investigation, the mechanical stabilization, or compaction, results in the densification of soil by application of mechanical energy.

Mechanical stabilization is not the main subject of this review and will not be further discussed.

3.2.2. Chemical stabilization

Chemical stabilization involves mixing chemical additives (binding agents) with natural soils to remove moisture and improve strength properties of the soil. A chemical stabilization method is the fundamental of this review. Chemical (Additive) soil stabilization is achieved by the addition of proper percentages of cement, lime, fly ash, bitumen, or combinations of these materials to the soil.

The selection of the type and the determination of the percentage of the additive to be used are dependent upon the soil classification and the degree of improvement in soil quality desired. In general, smaller amounts of additives are required when it is simply desired to modify soil properties such as gradation, workability, and plasticity. When it is desired to improve the strength and durability significantly, larger quantities of additive are used. After the additive has been mixed with soil, spreading and compaction are achieved by conventional means (U.S. Army, Air Force & Navy, 2005).

Generally, the role of the stabilizing agent in the treatment process is either reinforcing of the bounds between the particles or filling of the pore spaces. Among these stabilizers, starting from past, the most common used chemical additives in soil stabilization are lime and cement. The main advantage of chemical stabilization is that setting time and curing time can be controlled.

During selection of an additive for effectiveness of stabilization, described by Little and Nair (2009) depends on:

- Soil consistency and gradation
- Soil mineralogy and composition
- Desired engineering properties
- Purpose of treatment
- Mechanisms of stabilization
- Environmental conditions and engineering economics.

For a successful stabilization, a laboratory tests followed by field tests may be required in order to determine the engineering and environmental properties. Laboratory tests although may produce higher strength than corresponding material from the field, but will help to assess the effectiveness of stabilized materials in the field. Results from the laboratory tests, will enhance the knowledge on the choice of binders and amounts (Euro Soil Stab, 2002).

3.3. Stabilizing Agents

These are hydraulic (primary binders) or non-hydraulic (secondary binders) materials that when in contact with water or in the presence of pozzolanic minerals reacts with water to form cementitious composite materials. The commonly used binders are:

- Lime
- Cement
- Fly ash

- Blast furnace slag
- Rice husk ash
- Wheat husk ash, etc.

3.3.1. Lime Stabilization

Lime is in organic chemical compound which is produced by burning of lime stone in kilns. Lime is widely used as a soil modification agent to improve the performance of sub grade soils and also reduce volume change. Lime provides an economical way of soil stabilization which is alone or combination with cement, fly ash for better result and economic stabilization; and the most effective and widely used chemical additive for expansive soils. Effective mixing of lime and soil is critical to ensuring that the expected improvements occur throughout the soil mass. Lime also decreases the apparent amount of fines in a soil by causing flocculation and agglomeration of the clay particles (Little 1995). Lime stabilization helps in increasing the strength, durability and also minimizes the swelling, moisture variations in the soil and lime must be well compacted for obtaining sufficient strength and durability by maintaining OMC. Lime improves the low load bearing capacity of poor sub-grade soil and lower the plasticity index and percent swell of highly expansive sub-grade soil (Chen,1988).In lime stabilization, the liquid limit of the soil generally decreases but the plastic limit increases. As a consequence, the plasticity index of soil decreases.

Lime stabilization may refer to pozzolanic reaction in which pozzolana materials reacts with lime in presence of water to produce cementitious compounds (Sherwood, 1993, Euro Soil Stab, 2002).Soil improvement by means of lime stabilization can be grouped into three chemical reactions; cation exchange, flocculation-agglomeration and pozzolanic reactions.

According to Sherwood (1993) investigation, lime modification results an increase in strength brought by cation exchange capacity rather than cementing effect brought by pozzolanic reaction. It is useful for stabilization of clayey soils. When lime reacts with soil, there is exchange of cations in the adsorbed water layer and decrease in plasticity of soils. The resulting material is more friable than the original clays and it is more suitable as sub grade.

Cation Exchange: The excess of ions of opposite charge (to that of the surface) over those of like charge present in the diffuse double layer are called exchangeable ions. These ions can be replaced by a group of different ions having the same total charge by altering the chemical composition of the equilibrium electrolyte solution. Negatively charged clay particles adsorb cations of specific type and amount.

Floc1culation and Agglomeration: Cation exchange reactions result in the flocculation and agglomeration of the soil particles with consequent reduction in the amount of clay-size materials and hence the soil surface area, which inevitably accounts for the reduction in plasticity (Terzaghi and Peck, 1967). Due to change in texture, a significant reduction in the swelling of the soil occurs.

Pozzolanic Reactions: Time depending pozzolanic reactions play a major role in the stabilization of the soil, since they are responsible for the improvement in the various soil properties (Show et al., 2003). Pozzolanic constituents produces calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH).

$Ca^{++} + 2(OH)^- + SiO_2$ (Silica from Clay & WHA) $\longrightarrow$ CSH

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

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

3.3.1.1. Types of Lime

There are different forms of lime that have been used as soil stabilizing agents. There are generally 5 types of limes:

a) High calcium, quick lime (CaO)

b) Hydrated high calcium lime [$Ca(OH)_2$]

c) Dolomite lime ($CaO + MgO$)

d) Normal Hydrated dolomitic lime [$Ca(OH)_2 + MgO$]

e) Pressure, hydrated dolomitic lime [$Ca(OH)_2 + MgO_2$]

The engineering properties of heavy clay soils or granular soils with silt- clay fractions can be improved by Quick limes or hydrated limes. Quick lime is more effective as stabilizer than the hydrated lime, but the hydrated lime is more safe and convenient to handle. Usually, hydrated lime is used and is also known as slacked lime. The higher the magnesium content of the lime, the less is the affinity for water and the less is the heat generated during mixing. The amount of lime required for stabilization varies between 2 to 10% of the soil. Lime treatment is not recommended for sandy soils with no fine fraction and not effective with silt-loam soils. The effect can be brought by either quicklime, CaO or hydrated lime, $Ca(OH)_2$. Their soil-stabilizing ability is roughly equal. Quicklime is occasionally used to stabilize heavy clays. Quicklime is a strong caustic and requires the use of goggles and protective clothing.

3.3.1.2. Chemical and physical changes in lime stabilization

Lime decreases soil density and increases soil modulus of elasticity, strength; and cause a decrease in tendency of attraction of water. And also increase in the unconfined compressive strength is some times as high as 60 times. Lime reacts with medium, moderately fine, and fine-grained soils to produce decreased plasticity, increased workability, and increased strength.

A. Chemical Properties

Strength gain is primarily due to the chemical reactions that occur between the lime and soil particles (Little, 1995).When lime reacts with wet soil, it alters the nature of the adsorbed layer by base exchange. Calcium ions replace the sodium or hydrated ions. Lime reacts chemically with available silica and alumina in soils. The quicklime is vulnerable to water; even the moisture in the air produces a destabilizing effect by air slaking. Hydrated lime is more stable since water does not cause a change in its composition. Lime is chemically known as Calcium oxide (CaO). Quick lime is a white, caustic, alkaline crystal solid at room temperature. On hydration, quick lime forms slaked lime or lime water. When water is added to lime it becomes hot and cracks to form a white powder. This is called slaking of lime.

$$CaO + H2O \longrightarrow \underset{\text{Slaked lime}}{Ca(OH)2} \tag{3.1}$$

B. Properties of lime

- Lime is a white amorphous solid.
- It has a high melting point of 2600^{o}C.
- It is highly stable and even fusion cannot decompose it.

Physically, quicklime is white of varying degrees of intensity, depending on its chemical purity. The colour of lime depends on the presence of impurities within the lime and results in a grayish or yellowish appearance. Hydrated limes reflect as similar relationship between purity and Whiteness (Dallas N.Little, 1995). He described that the most important physical properties of limes related to soil stabilization are specific gravity, bulk density, Heat of solution and Solubility. Annual worldwide production of quicklime is around 283 million metric tons. China is by far the world's largest producer, with a total of around 170 million metric tons per year. The United States is the next largest with around 20 million metric tons per year.

Currently in Ethiopia, there are some factories that producing lime as a source for local market. Such as: Dire Dawa Cement and Lime Factory, Ethio Lime Factory of Senkele, the Caustic Soda lime unit, Zuway lime factory and the Wonji Shoa Sugar Estates supplemented with small quantity of imports.

3.3.1.3. Curing Conditions

Increasing temperature and time improve the gain strength for lime stabilization of soils.

3.3.2. Cement

Cement is one of the oldest chemical binding agents to improve soil engineering properties as well as mechanical characteristics of soil like degree of compaction. It is similar to that of lime and produces similar results. These include a reduction of liquid limit, shear strength, plasticity index, potential volume change and increase in the shrinkage limit. Cement treated soils can exhibit higher strength gains than lime treated soils. It is stated in Euro Soil Stab 2002, as cement reaction is not dependent on soil minerals, and the major role is its reaction with water that may available in any soil. This can be the reason why cement is used to stabilize a wide range of soils. Hydration process is a process under which cement reaction takes place. The process starts when cement is mixed with water and other components for required application resulting into hardening phenomena. The hardening (setting) of cement will enclose soil as glue, but it will not change the structure of soil (Euro Soil Stab, 2002).

3.3.3. Wheat Husk Ash (WHA)

As an agricultural product, wheat straw contains considerable amounts of SiO_2: When burned it leaves an ash very rich in SiO_2 that has a pozzolanic character. The WHA was completely burned in controlled conditions for 5 hours at 570 and 670°C.The ash is cooled suddenly. The ash obtained has pozzolanic activity and reactive. In some research Article, the constituent of SiO_2 in WHA is 74.23% and in RHA 90.11%. Biricik et al. (1999) stated that wheat straw ash produced from combustion at 670°C for 5 h had a higher pozzolanic activity than that from 570°C combustion. Combustion at temperatures below 600°C gives the highest silica extraction by producing the most alkaline solutions, preventing calcium solubility and maintaining silica in more reactive form.

3.3.3.1. Chemical properties of WHA

The study was made on an investigation using a test on chemical properties of wheat husk ash which reveals that WHA has similar oxides to those of cement and other supplementary cementing materials which implies that it can be used as a cement replacement material if used in the right proportion(Amardeep B.Dehane et al., 2015).

Table 3.1 Chemical Properties WHA (Amardeep B.Dehane et al., 2015)

Oxides	Percentage
CaO	10.16
SiO2	50.7
Al2O3	0.48
MgO	2.20
Alkalies (K2O, Na2O)	K2O -0.07 Na2O -5.41
SiO3	6.13

3.3.4. Fly–Ash

Fly ash is a byproduct of coal fired electric power generation facilities; it has little cementitious properties compared to lime and cement. Most of the fly ashes belong to secondary binders; these binders cannot produce the desired effect on their own. However, in the presence of a small amount of activator, it can react chemically to form cementitious compound that contributes to improved strength of soft soil.

A researcher called Pandian et al. (2001) had added fly ash (class- F) up to 100% to black cotton soil at an increment of 10% and found that California bearing ratio (CBR) values of black cotton soil increased up to 20% addition of fly ash beyond it, CBR decreased. It again increased and attained an optimum value when the percentage of fly ash was 70%.

3.3.5. Blast Furnace Slag

These are the by-product in pig iron production. The chemical compositions are similar to that of cement. It is however, not cementitious compound by itself, but it possesses latent hydraulic properties which upon addition of lime or alkaline material the hydraulic properties can develop (Sherwood, 1993).

3.3.6. Rice Husk Ash

A number of researches were conducted on rice as stabilizing material for expansive soil. The Rice Husk Ash would appear to be an inert material with the silica in the crystalline form suggested by the structure of the particles, it is very unlikely that it would react with lime to form calcium silicates. It is also unlikely that it would be as reactive as Rice Husk Ash, which is more finely divided. So Rice Husk Ash would give great results when it used as a stabilizing material.

3.4. Earlier Works

In Ethiopia, there was no such earlier practical experience and studies based on chemical stabilization of expansive soil for engineering application. As an example, some of the earlier works as a practical experience mentioned in Ethiopia are:

A pilot road project constructed from Ambo-Gedo on expansive sub-grade soil of highly plastic granular material using lime and cement stabilization.

Some of the followings were the related studies to the present work that was conducted in the past for academic purposes:

The works of Reshid Musema (2014), Aksum Tesfaye (2001), Daniel Nebro (2002) and Beniam Alemue (2010) are among the literatures referred during the present study.

- **Reshid Musema (2014)** was conducted on stabilization of expansive soils with lime (A case study on the Adura-Burbey DS6 road segment). For this study samples were collected from Gambela region. The laboratory tests conducted to attain the objective of the study were Atterberg limits, Proctor tests, free swell, UCS and CBR. Based on laboratory studies results, he has drawn the following conclusions:
  - ✓ Addition of lime decreases Liquid limit, increases limits, shrinkage limit and decreases plasticity index and free swell.
  - ✓ Increasing UCS and Improving CBR and hence, 12% lime is taken as optimum value.
  - ✓ The CBR improves from 1.46% to 8.92% and the value UCS is 791.7kN/m2
- **Akxum Tesfaye(2001)**has made studied on improvement of expansive soil by addition of lime and cement on black cotton soil. For the study soil sample was collected from different parts of Addis Ababa. During the study, the laboratory tests carried were attereberg limits, moisture-density relation and free swell and swell pressure of soil-lime mixture. He was concluded the following points:
  - ➢ The swelling potential of expansive soil with 6% lime falls within low limit and15% cement falls within medium degree of expansion; but the swelling pressure was still higher.
  - ➢ Swelling pressure decreases within increasing lime or cement and molding water.

Daniel Nebro (2002) was made research on stabilization of potentially expansive sub-grade soil using lime and Con-Aid on samples taken from Addis Ababa-Jimma road section. The laboratory tests conducted to evaluate effects of these chemical additives were Atterberg limits, moisture-density relations and CBR. From the results, has was drawn the following conclusions:

- ✓ Addition of lime reduced maximum dry density and increased the optimum moisture content.
- ✓ Addition of 4% lime effectively increases the CBR and UCS and therefore, 4% lime taken as the optimum value.
- ✓ Addition of lime reduces the swelling potential .But addition of Con-Aid had no effect on the soaked CBR and CBR swell of the treated soil.

- **Beniam Alemue (2010)**has made investigation on stabilization of granular sub base material using Lime on Ambo-Gedo road Project. During the study, he has conducted Atterberg limits, UCS tests and determined the initial requirement of lime by PH test method. From the results, he concluded that addition of lime decreases the PI and increase the strength and overall effectively stabilized the granular sub base material.

Some of international Journals referred during Present study were:

- **B. Suneel Kumar and T.v. Preethi (2014)** were conducted a research on behavior of Clayey stabilization with RHA and Lime.
  - They concluded that using 6% lime +10% RHA is effective or optimum value and increase the strength.
  - The CBR values is improved from 5.48% to 29.66%
- **S. Chakraborty, et.al, (2014)** were made study on Improvement of Sub Grade by Lime and Rice Husk Ash Admixtures. They conducted tests on Atterber limits, Proctor test, and CBR tests.
  - From result, it was concluded that using 6% Lime and 6% RHA is the optimum value in improvement of sub grade soil.
  - The CBR increases from 3.5% to 29.82%
- **Monica Malhotra and Sanjeev Naval (2013)** were made research on Stabilization of Expansive Soils Using Low Cost Materials. Tests conducted were Compaction test, Atterberg limits and free swell index.
  - They concluded that 5%Lime+25% (Fly Ash + Black cotton soil) are effective.

CHAPTR FOUR

MATERIALS AND METHODS

4.1. Introduction

The research was conducted using different literature review on expansive soils, field observations, collection of samples for laboratory testing and analysis of test results. Laboratory tests were conducted on natural soil samples before and after mixing with lime and wheat husk ash. The laboratory tests were carried out on soil samples to observe the effects and performance of selected chemical stabilizers on the expansive sub-grades soil. In this chapter, the materials used and the methods to perform the intended research work are described with respect to their source.

4.2. Materials

The materials used for the intended research were Expansive soil, Wheat husk ash and Lime. The physical properties of these materials are summarized in the following sections.

A. Expansive Soil

For the present study, considering the expansion of Adama town, the expansive soil sample was collected from rural area of Welenchit town in Northern direction at coordinate x=537702 and y=962506 from one test pit. The soil is black in colour and highly plastic clay. A soil sample was collected from test pit at a depth of 1.5m or below in order to avoid the inclusion of organic matter. The test pit is shown in Figure 4.1. The geotechnical property of expansive soil is presented in Table5.1.

Figure 4.1 An overview of the test pit

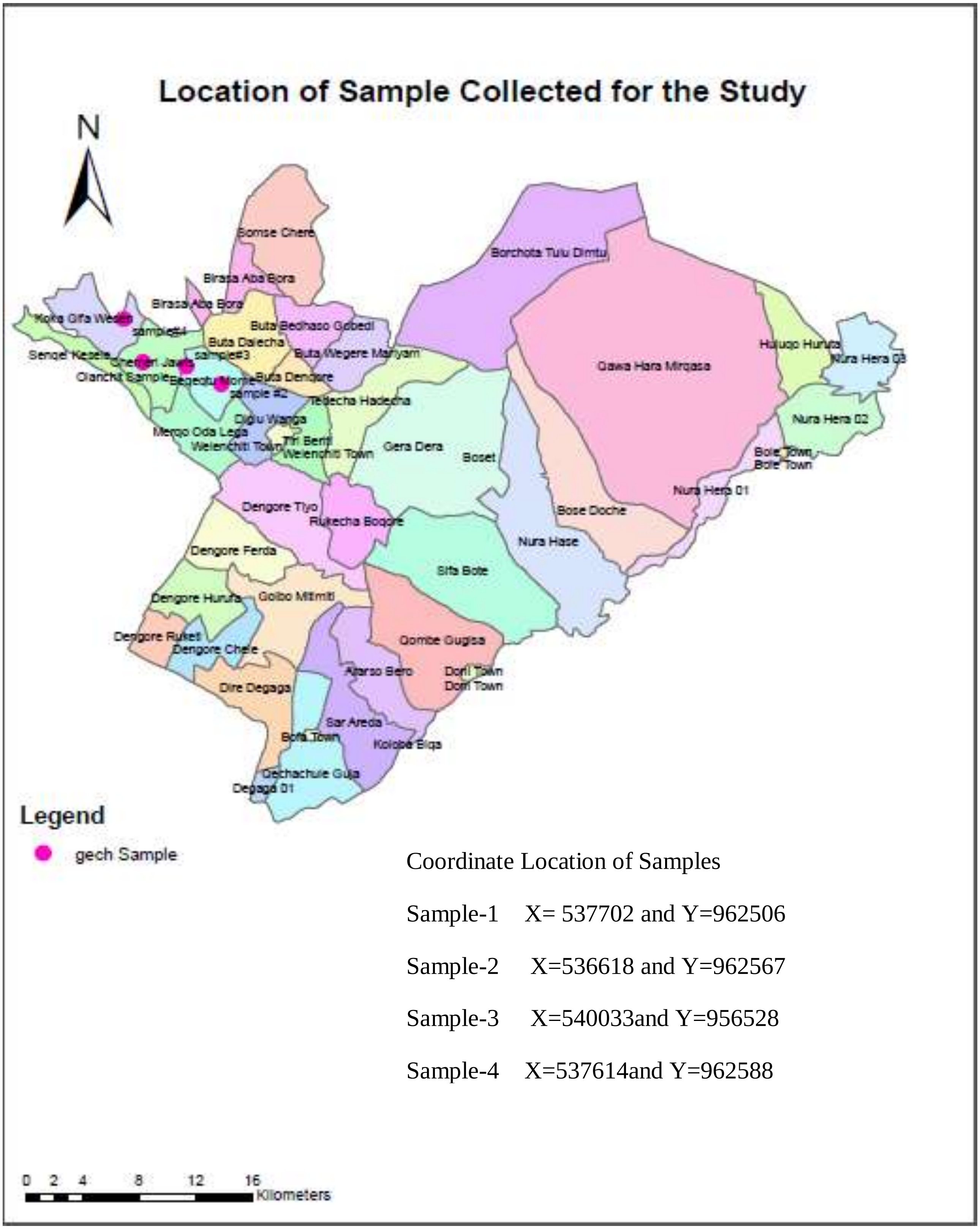


Figure 4.2 Location of Sample collection

B. Wheat Husk Ash

For present study, locally available wheat ash was obtained from wheat rising areas of Arsi region and which is located in the Eastern part of Ethiopia in Oromiya Regional State as shown in Figure 4.2.The physical properties are determined and presented in Table 5.2.1. For this research, the ash was burned under controlled condition in prepared pit of dimension 1.50m x 1.50m x 0.6m using stone and cooled in air by applying small quantity of water. Finally, it is properly packed in sacks and transported to the laboratory for testing.

Figure 4.3 Wheat husk ash from Arsi Chole.

1. **Physical properties of wheat husk ash**

- Light in weight
- Have a colour of white to blue
- High burning ratio

2. **Chemical properties of WHA**

The chemical properties of WHA for this study was referred from literature review and indicated in Table 3.1.

C. Lime

The lime used in this study was obtained from the Zuway lime factory. The hydrated lime is used for this works. The constituent of hydrated lime with percentage by weight is shown in Table 4.1.

Table 4.1 Chemical Properties Hydrated lime

Oxides	Percentage
CaO	70
SiO2	2.5
Al2O3	0.81
MgO	1.41
Fe2O3	0.48

4.3. Methods

To classify soil as expansive soil, the laboratory tests were conducted on natural soil before going to treat with selected stabilizing materials. Such tests were Atterberg limits, particle size distribution and free swell tests. The laboratory tests were conducted on four samples on which were collected from different location. After classifying expansive soil one sample location was selected for the present study. After classification, the detail laboratory tests were carried out on Atterberg limits, free swell, specific gravity, linear shrinkage, Standard proctor tests, UCS, CBR and percent swell of CBR by using different percentages of lime taken as 0%, 2%, 4%, 6%, 8%, 10% and Wheat husk ash taken as 0%, 3%, 6%, 9%, 12% are mixed with soil to attain the objectives of the research. To observe the effects of lime and wheat husk ash on the properties of natural soil, different trial mix proportions were made in laboratory. Among different trial mix tests, one best optimum value was selected.

4.3.1. Preparation of Sample

Before going to carried out tests and treatment, the sample was prepared in accordance with AASHTO T87-86 methods of sample preparations. The procedure for sample preparation during the study includes:

- Air drying of samples or oven drying at 60ºC or less;
- Disintegrating the soil aggregates by rubber covered mallet.
- After disintegration of soil aggregate, sieve analysis is performed on dried soil samples for preparation two separate samples. The first sample was prepared uniformly for Atterberg limits, Specific gravity, linear shrinkage and free swell index tests. And the second sample for standard proctor test, unconfined compressive strength and California bearing ratio tests.

- ❖ After completion of sample preparation, soil with lime and soil with wheat husk ash mix trial was prepared manually to attain uniform mix test.
- ❖ At last, for different trial of soil, lime and wheat ash is mixed by hand to obtain uniform mix ratio for each trial test.

a. air drying

b. Disintegrating soil aggregates.

c. prepared sample during test

Figure 4.4 Samples preparation

4.3.2. Grain Size Distribution

Grain size distribution is one of the parameters used for engineering classification of soils.
The analysis of grain size is done for:

- Mechanical sieve and
- Hydrometer analysis

a. Sieve Analysis

To classify soil as expansive soil, sieve analysis was carried out to determine the grain size distribution. Accordingly, wet sieve analysis was employed for the study to determine the grain size distribution of expansive soil samples in accordance with AASHTOT-88 Test Method of Particle-size analysis of soils.

A nest of sieves is prepared by stacking test sieves one above the other with the largest opening at the top followed by sieves of successively smaller openings and a catch pan at the bottom. Then, a sample of oven dry soil is poured onto the top sieve, the nest is covered, and it is then shaken by hand until each particle has dropped to a sieve with openings too small to pass, and the particle is retained. The cumulative weight of all material larger than each sieve size is determined and divided by the total sample weight to obtain the percent retained for that sieve size, and this value is subtracted from 100% to obtain the percent passing that sieve size.

Finally, results are displayed by plotting the percent passing (on a linear scale) against the sieve opening size (on a log scale) and connecting the plotted points with a smooth curve referred to as a grain-size distribution curve.

Figure 4.5 Laboratory wet sieve analysis test

b. Hydrometer analysis

The hydrometer analysis test was conducted on sample to know the silt and clay fractions in accordance with ASTM D422standard testing procedure for particle size analysis. Taking the fine soil from the bottom pan of the sieve set, place into a beaker ,and add 125ml of the dispersant agent (sodium hexametaphosphate) (40g/L) solution. Then the mixture is stirred until the soil gets thoroughly wet or soaks for at least for ten minutes. After soaking, add 125ml of dispersant agent into the control cylinder and fill it with distilled water up to 1000ml mark. Finally, the reading was taken at the top of the meniscus formed by hydrometer system.

Figure 4.6 Hydrometer reading for expansive soil

4.3.3. Soil classification

For classification and characterization of the soil, the laboratory tests were conducted on Liquid Limit, Plasticity index, free swell, Grain size and Hydrometer tests. The most widely used for soil classification systems are the American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS).The AASHTO classification system, the soils are divided into 7 types , designated as A-1 to A-7. The classification system is based on particle-size distribution, liquid limit and plasticity index of the soil. The AASHTO system classifies a soil into coarse-grained and fine- grained soils. The granular material is further divided into three groups which are called A-1, A-2 and A-3. The silt-clay material is in turn divided into four groups namely, A-4, A-5, A-6 and A-7. According to this system the soil of the study area falls in the region of A-7-5. This means the soil under interest is plastic clay which has a high volume change capacity between wet and dry states.

The second classification system is the Unified Soil Classification System which is based on gradation, Liquid Limit and Plasticity Index of a soil. The system is most popular for use in all types of engineering problems involving soils. The "A-line" is expressed by equation, PI = 0.73*(LL-20) which is used to separate the soil designation of 'MH or OH' and the 'CH or OH'. According to this classification system, the soil of the study area fall in region of CH group and this shows that the soil is potentially expansive soil as shown in Figure 4.7.

Field identification the soil deposits can be recognized through visual observation of color (usually black),deep shrinkage cracks, high dry strength but low wet strength, shiny appearance at cut section and sticky behavior when wet. And also few simple hand tests for the fine-grained soils.

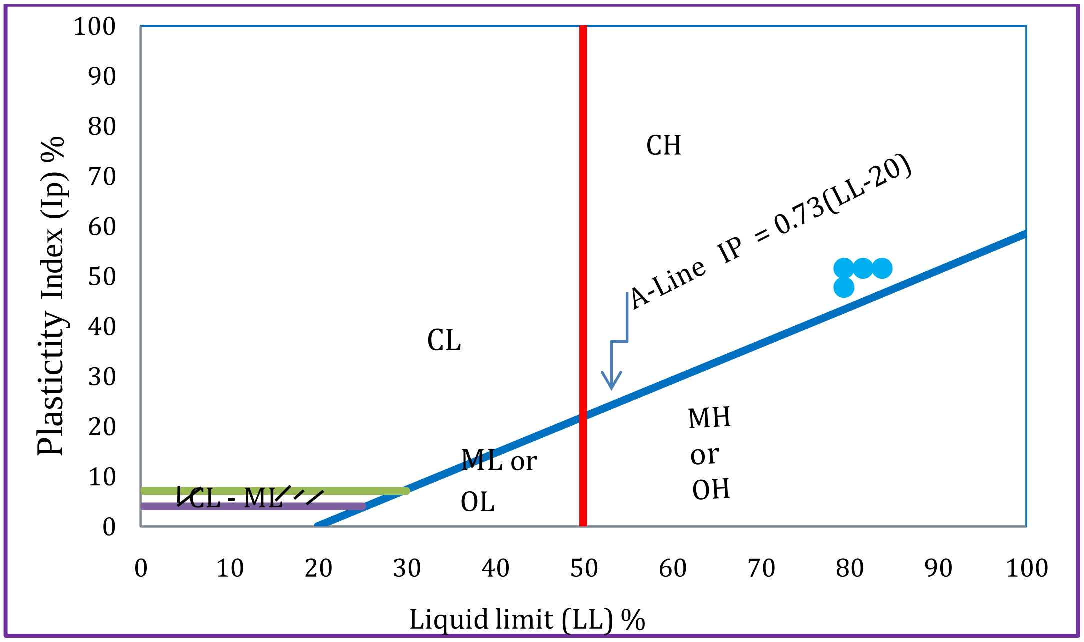


Figure 4.7 **USCS classification chart**

The test results analysis in general shows that the soil can be classified as A-7-5 (20) according to AASHTO and CH according to USCS soil classification system.

4.3.4.Specific Gravity

Specific gravity which is the measure of heaviness of the soil particles. The specific gravity of untreated and treated soil was determined as per IS: 2720-part 3-sect.1980, standard testing procedure by water pycnometer. The oven dry sample of 10gm which is passing No.10 (425μm) sieve size was used.

4.3.5.Liquid limit

The Liquid Limit is defined as the water content at which the groove cup into the soil will close over a distance of 12.5mm following 25 blows. The Liquid Limit is the moisture content at which a specific soil moves from a plastic to a liquid state. The liquid limit was determined in the laboratory by the help of standard liquid limit apparatus. The laboratory test of liquid limit was conducted both for soil and soil with different percentage of lime and wheat ash mixtures as per AASHTO T89-90. For liquid limit determination, 300gm of sample which is passing the 425μm sieve size was taken.

A dry powder dry of soil as well as soil with additives are mixed with distilled water into a paste and placed in the cup to a thickness of about 12.5mm.The soil surface is smoothed and groove is cut into the soil using a standard grooving tool. A brass cup was raised and allowed to fall on a rubber base; and the number of blows required to close the groove over a length of 12.5mm ranging from 15 to 40blows is counted and recorded. Four tests at different water contents were conducted. The test results are plotted using water content on ordinate axis (arithmetic scale) versus number of blows on abscissa, logarithmic scale as shown in Figure 4.8.The liquid limit is read from the graph as the water content on the liquid state line corresponds to 25 blows.

Figure 4.8 Determination of liquid limit.

4.3.6. Plastic limit

The laboratory test of plastic limit was conducted for natural expansive soil and treated soil with different percentage of lime and wheat ash as per AASHTO T 90-96. The plastic limit is determined by rolling a small soil sample as well as mixture of additives into threads and finding the water content at which threads approximately 3mm in diameter with just start to crumble. Two determinations are made and the average water content is taken as plastic limit.

4.3.7. Plasticity index

The range of moisture contents at which a soil is considered to be plastic are those which fall between the Liquid Limit and the Plastic Limit. This range is identified as an engineering property by the Plasticity Index (PI). The Plasticity Index is a calculated value derived by subtracting the Plastic Limit from the Liquid Limit.

$$PI = LL - PL \tag{4.1}$$

The Plasticity Index is an indicator of the suitability of the clay fraction of a soil or soil aggregate for use in highway construction.

4.3.8. Linear shrinkage

The test was conducted in accordance with IS: 460 (part-1)-1978. The sample was prepared using the sieve size of 425µm and 150gm of specimen was taken from prepared for soil and soil-lime - wheat ash mix for each test. The shrinkage dish and distilled water is used during test and sample is taken into shrinkage dish (at18 blows).Linear shrinkage is expressed by the equation:

$$LS = \left(1 - \frac{\text{Oven dry length}}{\text{Initial length}}\right)x100 \tag{4.2}$$

a. During sample mixing b. Linear shrinkage of untreated soil c. Linear shrinkage of treated soil

Figure 4.9 Linear shrinkage test

4.3.9. Compaction

In practice, the effect of addition of binder to the density of soil is of significant importance. Stabilized mixture has lower maximum dry density than that of unstabilized soil for a given degree of compaction. The optimum moisture content increases with increasing binders (Sherwood, 1993).In stabilized soils, enough moisture content is essential not only for hydration process to proceed but also for efficient compaction. The test is performed for determination of the maximum dry density and the optimum moisture content of the natural soil and the soil-lime-wheat husk ash mixture. The tests were conducted for both natural soil and soil, lime and wheat husk ash mix in accordance with ASTM testing procedures.

4.3.9.1. Maximum dry density and Optimum moisture content

After removing impurities like vegetation, stones etc. the soil was mixed with wheat husk ash and lime in varying proportion by volume. The Mixing was thoroughly carried out manually and the tests were conducted as per standard procedures. The maximum dry density and optimum moisture content of soil was conducted with various percentage of lime taken as (0%, 2%, 4%, 6%, 8%, 10%), and wheat husk ash taken as (0%, 3%, 6%, 9%, 12%). The test was conducted by performing the “standard proctor test” as per ASTM D 698 testing procedures.

The standard proctor tests was done using a dry soil as well as soil with selected additives, mixed with water and compacted in cylindrical mold of volume 944cm3 by repeated blows from mass of hammer 2.5kg, falling from a height of 31cm.The sample was compacted in three layers each of which 25 blows per layer in the standard mold by varying moisture content.. The blows are uniformly distributed over the surface of each layer. The collar is then removed and the compacted sample leveled off at the top of the mold with a straight edge. The mold containing the leveled sample is then weighed. From the middle of compacted soil, small representative sample is taken for the determination of moisture content. The same procedure is repeated for four to five sets of samples. The dry density is determined and plotted against water content to find OMC and corresponding maximum dry density.

4.3.10. Free swell

The free swell test was determined as per IS: 2720 (part-40) testing procedures. The free swell for natural soil as well as soil, lime taken as (2%, 4%, 6%, 8%, 10%), and wheat husk ash taken as (3%, 6%, 9%, 12%) was mixed uniformly for each tests. The test was conducted by taking two 10gm of dried samples for both soil and soil-lime and wheat husk ash mixture of each passing through 425μm sieve size and each samples were slowly pouring in a separately two 100ml graduated cylinders. Distilled water was filled in one cylinder and kerosene in the other cylinder up to 100ml mark. The final volume of soil was read after 24 hours to calculate free swell index.

$$\mathrm{FSI} = \left(\frac{\mathrm{Vw} - \mathrm{Vk}}{\mathrm{Vk}}\right) \mathrm{x}100 \qquad (4.3)$$

Where, Vw = final volume of distilled water

Vk = final volume of kerosene

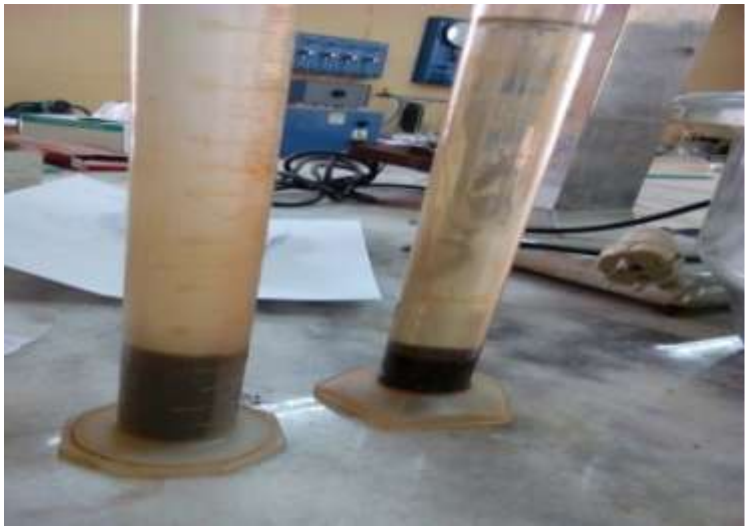


Figure 4.10 Determination of free swell test for expansive soil

4.3.11. Unconfined Compressive Strength (UCS)

The unconfined compression test is by far the most popular method of soil shear testing because it is one of the fastest and cheapest methods of measuring shear strength. The unconfined compressive strength tests are conducted on expansive soil, expansive soil with lime ,expansive soil with wheat husk ash and expansive soil, lime and wheat husk ash mixtures as per IS: 2720 part 10 (1973). The sample sizes were of 38mm diameter and 76mm length. All the samples are prepared by static compaction using split mould at optimum moisture content (OMC) and maximum dry density (MDD) to maintain same initial dry density and water content. The samples of expansive soil and additive mixes were cured for 0 days, 3 days and 7daysand at the end of each curing period, three samples for each mix were tested.

Picture 4.11 UCS test for untreated soil

4.3.12. California Bearing Ratio (CBR) test

California Bearing Ratio (CBR) test is a compressive nature penetration test.CBR value is a method to evaluate the quality of stabilized material for subgrade material (Bowles, 1992).CBR-value is a familiar indicator test used to evaluate the strength of soils for these applications (Nicholson et al., 1994).California Bearing Ratio (CBR) is actually an indirect measure which represents comparison of the strength of sub grade, sub-base and base-course material to the strength of standard crushed rock quoted in percentage values. The test is specifically used to determine the mechanical strength as well as the potential strength of road sub grades and base courses materials including the recycled material generally used for road and airfield pavements. The CBR tests are conducted in accordance with AASHTO T193-93 for the natural soils and soil- lime- wheat husk ash mixtures of different percentages. The tests are conducted using the Optimum Moisture Content (OMC) value by different mixtures of lime and wheat husk ash, and the tests were conducted at time intervals of curing for 0days and 4days of curing at optimum moisture content. The 5.0kg of the natural soil and the soil-wheat ash mixture are mixed at their respective optimum moisture contents in 2124 cubic centimeters mould. The samples are compacted in three layers with 56 blows from the 2.5kg rammer.

Figure 4.12 Laboratory CBR Reading.

CHAPTER FIVE

TEST RESULTS AND DISCUSSIONS

5.1. Introduction

In this chapter a total of 30 different laboratory tests have been done and representative parametric studies are presented. The laboratory tests conducted to evaluate the effects of this chemical stabilizing agents using alone and blended together with soil. The important engineering property of the soil is evaluated both for natural and stabilized soil samples separately. The soil was initially air dried prior to the testing. The tests were conducted to study the behavior of expansive soil, when it was untreated, treated with Lime and wheat ash for the sub grade soil. The following tests were conducted:

A. LABORATORY TEST RESULTS

The laboratory test results for different parameters of Soil-Lime-WHA mixture are presented in table 5.1

Table-5.1 Laboratory Test Result for Index properties, Compaction Characteristics, CBR, CBR swell and UCS of soil -Lime- WHA mixtures.

Mix No	Soil (%)	Lime (%)	WHA (%)	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	MDD(k kg/m3)	OMC (%)	CBR (Unsoaked) (%)	CBR (soaked) (%)	CBR Swell (%)	0 days Uncured condition(kN/m2)	3 days cured condition(kN/m2)	7 days cured condition (kN/m2)
1	100	0	0	84.25	39.25	45	1227.44	33.43	4.49	3.25	10.62	87.14	0.00	0
2	98	2	0	84.38	43.25	41.13	1222.25	34.86	12.78	9.60	2.57	109.07	189.66	182.09
3	96	4	0	71.62	45.71	25.91	1212.48	35.07	12.91	12.23	1.08	141.54	263.53	304.67
4	94	6	0	66.03	47.43	18.6	1201.32	35.97	18.08	21.71	0.73	145.79	404.71	675.52
5	92	8	0	59.78	48.09	11.69	1181.89	38.45	19.92	21.00	0.43	102.2	397.76	671.63
6	90	10	0	58.11	48.81	9.3	1167.13	39.05	19.24	19.24	0.5	105.07	392.29	596.38
7	97	0	3	82.26	42.89	39.37	1223.96	34.84	9.24	13.05	2.07	122.9	170.76	295.75
8	94	0	6	81.24	46.25	34.99	1208.85	34.95	12.19	14.34	1.19	146.37	220.52	309.64
9	91	0	9	79.45	47.08	32.37	1190.29	36.34	13.96	15.45	0.41	130.18	157.40	209.57
10	88	0	12	77.86	48.57	29.29	1147.43	38.11	10.98	12.33	0.17	123.79	133.09	189.91
11	95	2	3	82.57	45.09	37.48	1221.05	36.50	13.86	10.06	3.68	258.37	268.36	286.14
12	92	2	6	81.83	48.09	33.74	1168.19	38.38	16.58	15.63	1.01	260.75	327.30	335.83
13	89	2	9	79.32	49.36	29.96	1147.15	39.50	17.8	14.26	2.5	233.55	317.38	328.59
14	86	2	12	77.05	51.21	25.83	1106.17	41.54	16.12	13.96	2.6	177.21	177.21	247.09
15	93	4	3	71.18	46.34	24.83	1194.62	37.00	20.63	22.97	0.47	143.07	245.00	317.36
16	90	4	6	69.02	48.27	20.75	1165.58	38.33	20.81	23.85	0.3	229.09	235.47	509.97
17	87	4	9	68.14	50.53	17.61	1136.47	39.07	22.15	24.39	0.44	199.98	274.26	447.52
18	84	4	12	65.82	53.48	12.33	1082.56	41.30	18.29	22.22	0.46	175.46	260.03	242.57
19	91	6	3	66.14	49.56	16.58	1187.61	38.97	25.2	24.87	0.26	181.72	409.70	443.4
20	88	6	6	63.37	53.52	9.85	1147.47	39.77	24.33	27.86	0.043	236.75	586.86	802.94
21	85	6	9	63.05	53.18	9.86	1114.56	41.24	25.74	26.56	0.17	216.86	469.60	719.92
22	82	6	12	60.86	55.67	5.19	1074.99	43.08	23.24	24.46	0.29	115.14	340.77	551.47
23	89	8	3	63.67	50.58	13.09	1181.10	39.00	19.51	21.14	0.35	167.78	540.37	789.8
24	86	8	6	62.95	52.21	10.74	1142.49	40.56	21.98	24.94	0.32	256.75	587.67	800.72
25	83	8	9	61.11	53.09	8.02	1112.60	41.48	22.76	23.71	0.22	263.2	595.28	803.34
26	80	8	12	59.98	55.53	4.45	1072.99	43.00	19.98	18.89	0.37	258.73	391.74	752.35
27	87	10	3	60.15	48.49	11.66	1160.52	40.00	18.97	19.78	0.52	188.37	378.20	721.11
28	84	10	6	58.87	50.01	8.86	1127.15	41.00	18.97	21.41	0.47	188.63	447.61	782.48
29	81	10	9	57.75	51.58	6.17	1103.79	41.50	20.19	19.92	0.38	196.33	473.36	755.8
30	78	10	12	55.86	53.43	2.43	1057.97	44.00	18.29	16.94	0.34	191.2	293.69	573.82

5.1.1. Natural soil

a. **Properties of soil**

i. The grain size distribution

ii. Index properties –Liquid Limit, Plastic Limit, Linear shrinkage

iii. Swell Tests- Differential Free swell

iv. Strength tests- California bearing ratio and unconfined compressive strength tests.

b. Visual characteristics of soil

The following properties were observed from visual classification in dry condition.

- Colour -- Black colour
- Texture --- Fine to medium grained
- Dry strength -- High
- Appearance -- shiny
- Plasticity -----Highly plastic
- Classification -- Highly plastic clay (CH)

The laboratory tests were conducted for identification of properties of natural soil before mixing with lime and wheat ash and the results are presented in table 5.2.

Table 5.2 Geotechnical Properties of natural Soil.

S.No	**Basic Properties of soil**	**Test results**	**S.No**	**Basic Properties of soil**	**Test results**
1	Colour	Black	11	AASHTO soil classification	A-7-5
2	Liquid limit (%)	84.25	12	USCS classification	CH
3	Plastic Limit (%)	39.25	13	Free Swell (%)	138.9
4	Plastic Index (%)	45	14	Linear Shrinkage Index (%)	16.07
5	Specific Gravity	2.479	15	Optimum moisture content (%)	33.43
6	Percent passing No.200 sieve	89.51	16	Maximum Dry density(kg/m3)	1227
7	Gravel (%)	1.92	17	UCS (kN/m2)	87.14
8	Sand (%)	8.57	18	(%) CBR un Soaked	3.25
9	Silt (%)	43.11	19	(%) CBR Soaked	4.49
10	Clay (%)	46.4			

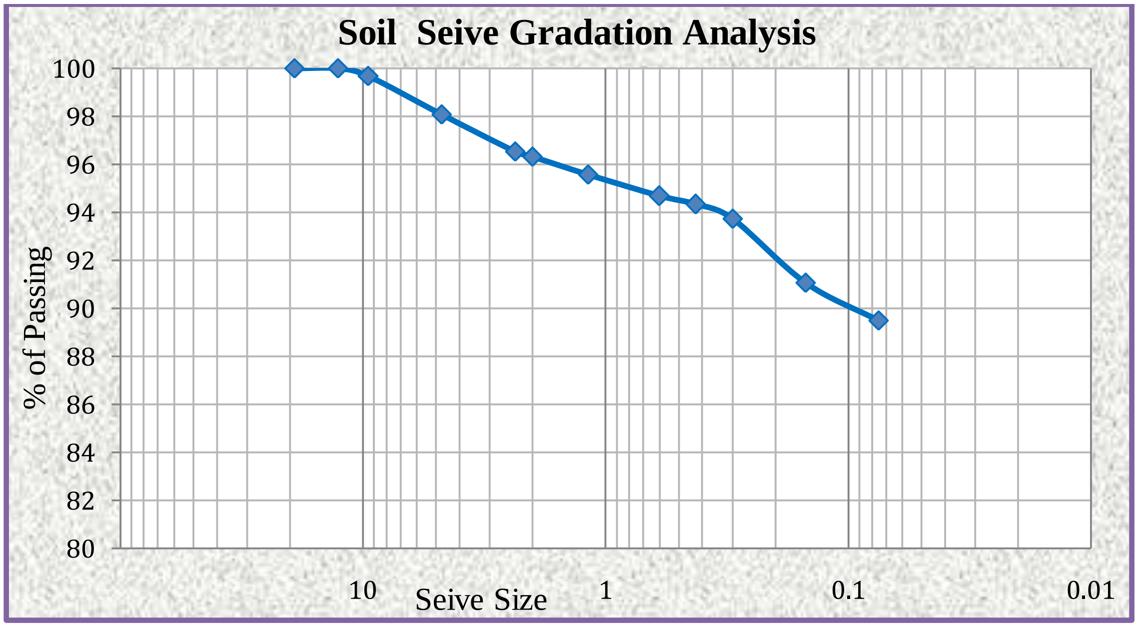


Figure 5.1 Particle size distribution curve of the expansive

Test results from particle size distribution graph shown in figure 5.1 the percentage of soil passing No.200 sieve size is 89.51%. From Table 5.2, a liquid limit of 84.25%, a plastic limit of 39.25% and plasticity index of 45.0%.

According to Chen (1988) soil having plasticity index greater than 35% is highly expansive soil. Accordingly the soil falls under the A-7-5 soil class based on AASHTO soil classification system. Soils under this class are generally classified as a material of poor engineering property to be used as a sub-grade material. Results that are related to swelling characteristics of the soil are also indicate that the soil is highly expansive clay with a free swell of about 138.9%. The soil has a maximum dry density of 1.227g/cm3; optimum moisture content of 33.48%, unsoaked CBR value of 4.49% and soaked CBR value of 3.25%.

5.1.2. Wheat Husk Ash

The chemical composition of wheat ash was not carried out due to unfunction of X-ray diffraction equipment. But the chemical properties of wheat husk ash was referred for this study from literature review and presented in Table 3.1 in chapter four. The results indicate pozzolanicity of the wheat husk ash.

Table 5.3 Physical properties of wheat husk ash

S. No	PROPERTY		VALUE
1	Grain size distribution (percent finer than)	4.75 mm	100.00
		2.36mm	99.77
		2.0 mm	99.68
		1.18mm	99.07
		0.6 mm	96.18
		0.425 mm	93.28
		0.3 mm	87.05
		0.15mm	23.00
		0.075 mm	3.39
2	SPECIFIC GRAVITY		2.33

5.2. Atterberg limit

The result of Atterberg limit tests on the expansive soil with different percentage of lime and WHA are shown in Table 5.1. The results of liquid limit tests on expansive soil treated with different percentage of lime and wheat husk ash are shown in Figure 5.2. From figure it can be seen that with increasing in percentage of lime the liquid limit of soil goes on decreasing for particular percent of wheat husk ash.

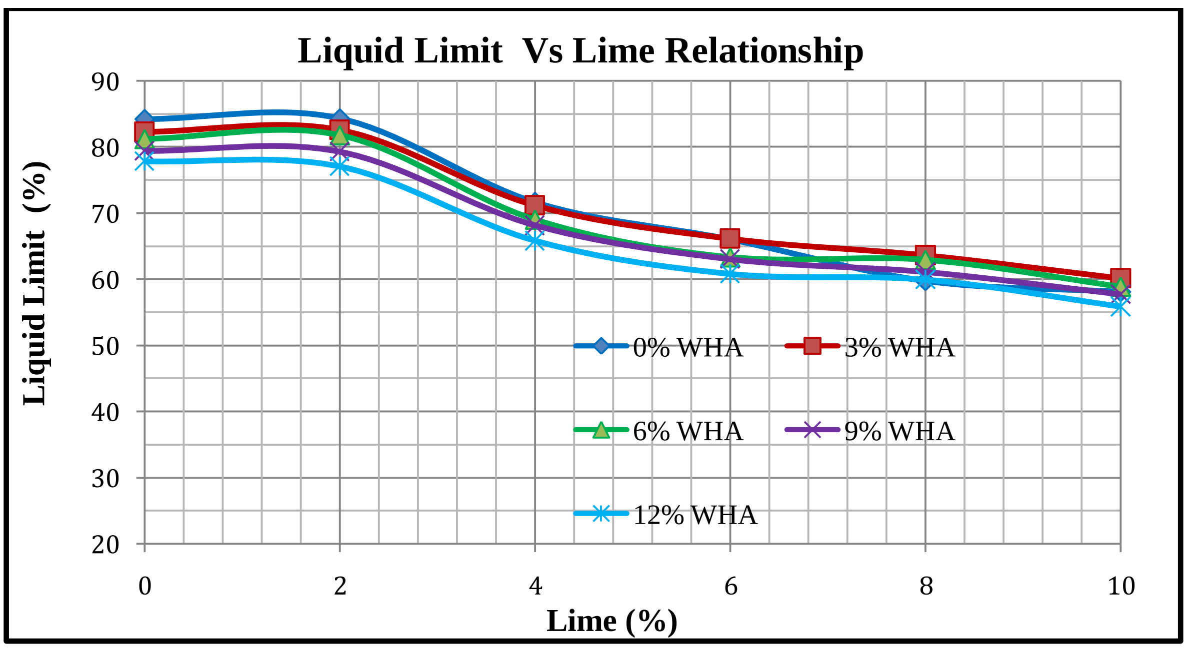


Figure 5.2 Liquid Limit with different percentage of Lime and WHA combinations

5.3. Plastic limit

The result of plastic tests on expansive soil treated with different percentage of Lime and WHA are as shown in Figure 5.3.The figure shows a general trend of increase of plastic limit with the increase of lime percent up to 6 % and beyond that it is decreasing in nature for all wheat husk ash contents. The plastic limit increases from 39.425% to 53.52% when lime increased from 0 to 6%. This is attributed to the fact that the Wheat Husk Ash has pozzolanic reaction with the lime compound possessing cementing properties of calcium silicate cement with soil particles. The result determined and presented in table 5.1.

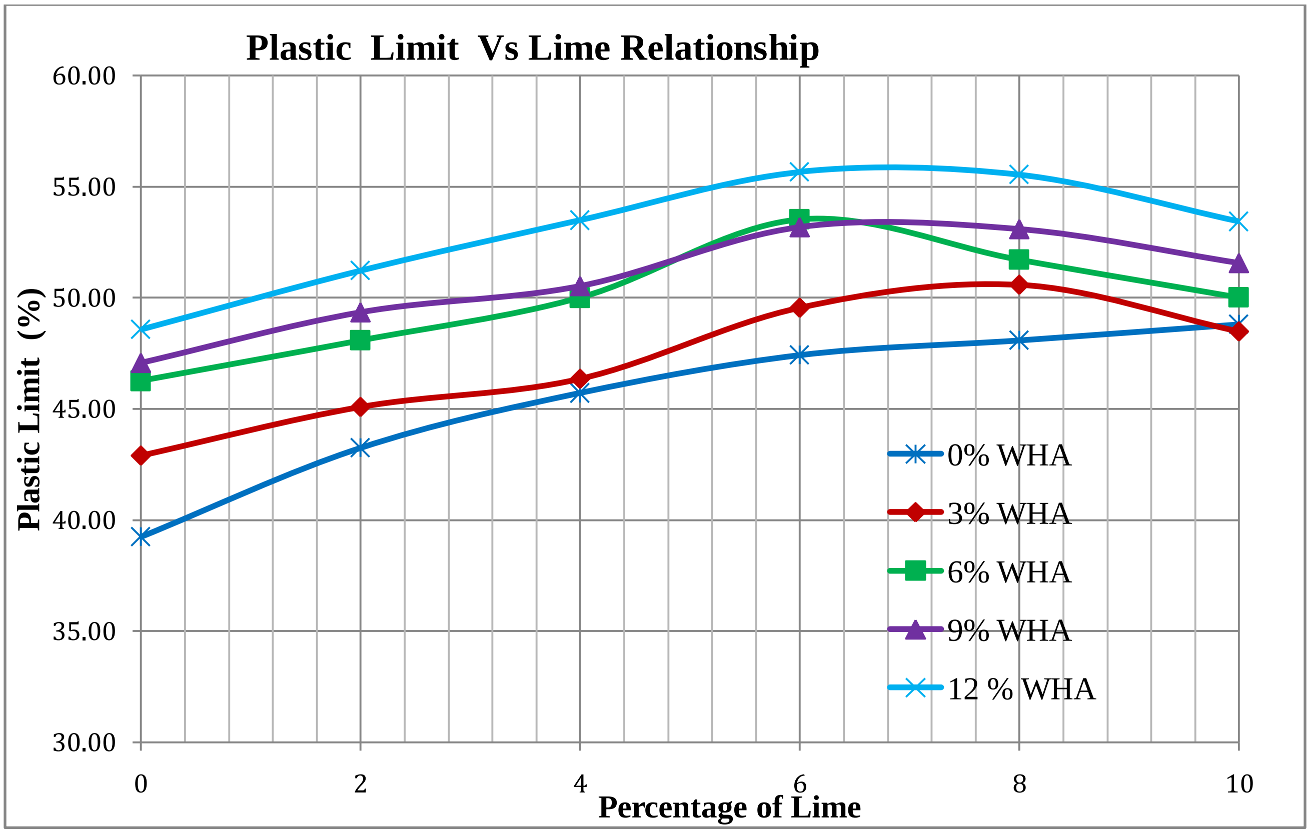


Figure 5.3 Variation of plastic limit with percentage of Lime and WHA combinations

The variation of plasticity index with percentage of lime and WHA are shown in Figure 5.4. From the figure it can be observed that the plasticity index goes on decreasing with addition additives up to 6% lime and 6% WHA beyond that it is slightly increasing. The decrease in plasticity index indicates an improvement in the workability of the soil. The plasticity index decreases from 45% to 9.85% when lime and WHA are increased from 0% to 6%.

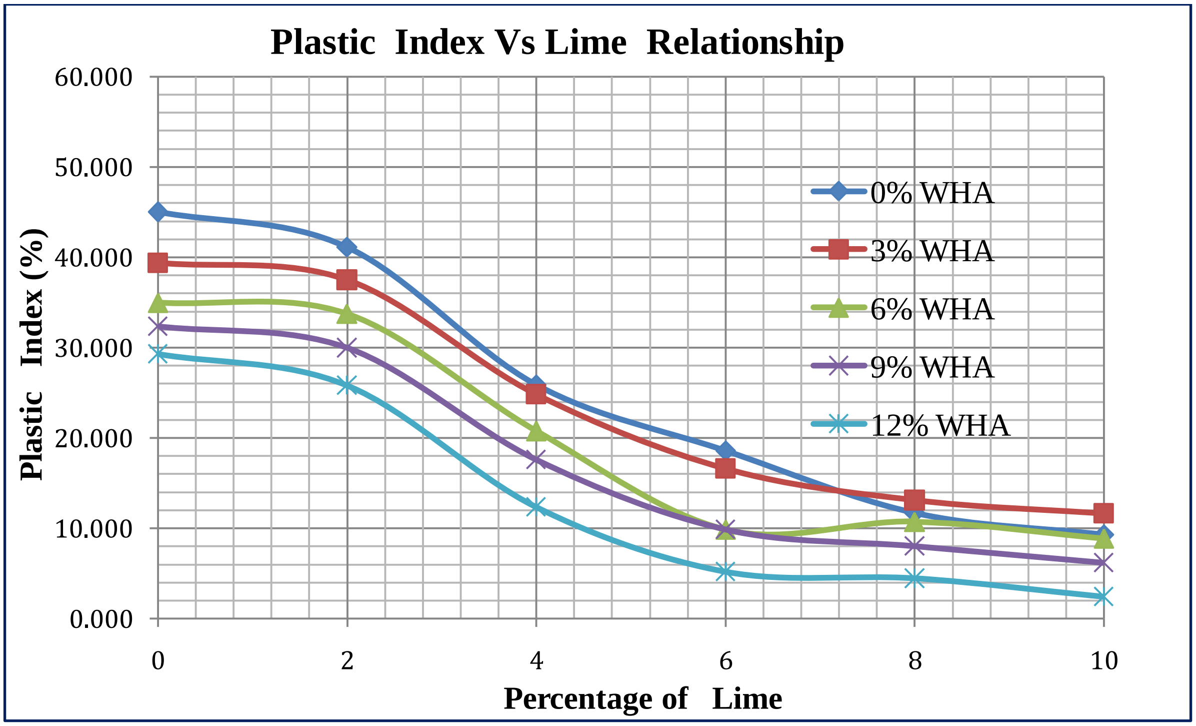


Figure5.4 Variation of Plasticity Index with percentage of Lime and WHA Combinations

The reduction in plasticity index associated with a lime is as a result of more calcium is available for cation exchange to take place and also this effect could be attributed to the combined action of partial replacement of plastic soil particles with non-plastic particles of minerals of the soil. These led to flocculation and agglomeration of the clay particles which in turn reduces the plasticity of the treated soil.

5.4. Compaction

The test includes the determination of the maximum dry density and the optimum moisture content for the natural soil and the soil-lime-wheat husk ash mixture.

5.4.1. Maximum Dry Density and Optimum moisture content

The results of standard proctor tests on expansive soil treated with different percentage of lime and wheat husk ash are shown of Figure 5.5 and 5.6 respectively. Figure 5.11 shows the variation of MDD with percentage of lime and WHA. The MDD values are decreasing with increasing percentages of lime and wheat husk ash added to soil. The MDD decreases from 1.227kg/m3 to 1.147kg/m3 when lime and wheat husk ash are increased from 0 to 6%. The reason of such behavior is due to cationic exchange of lime which induces flocculation and agglomeration of the clay particles. The above graph shows, as the water content increases the dry density increases up to a limit afterwards decreases. The optimum moisture content and the maximum dry density is calculated from graph.

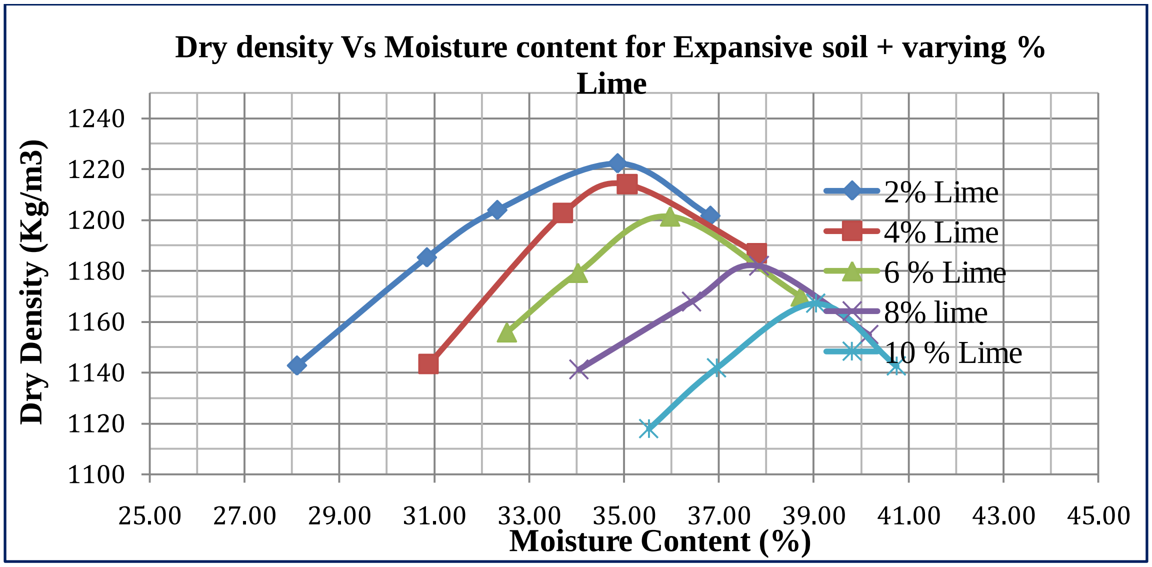


Figure 5.5 Compaction affects varying percent of lime on maximum dry density

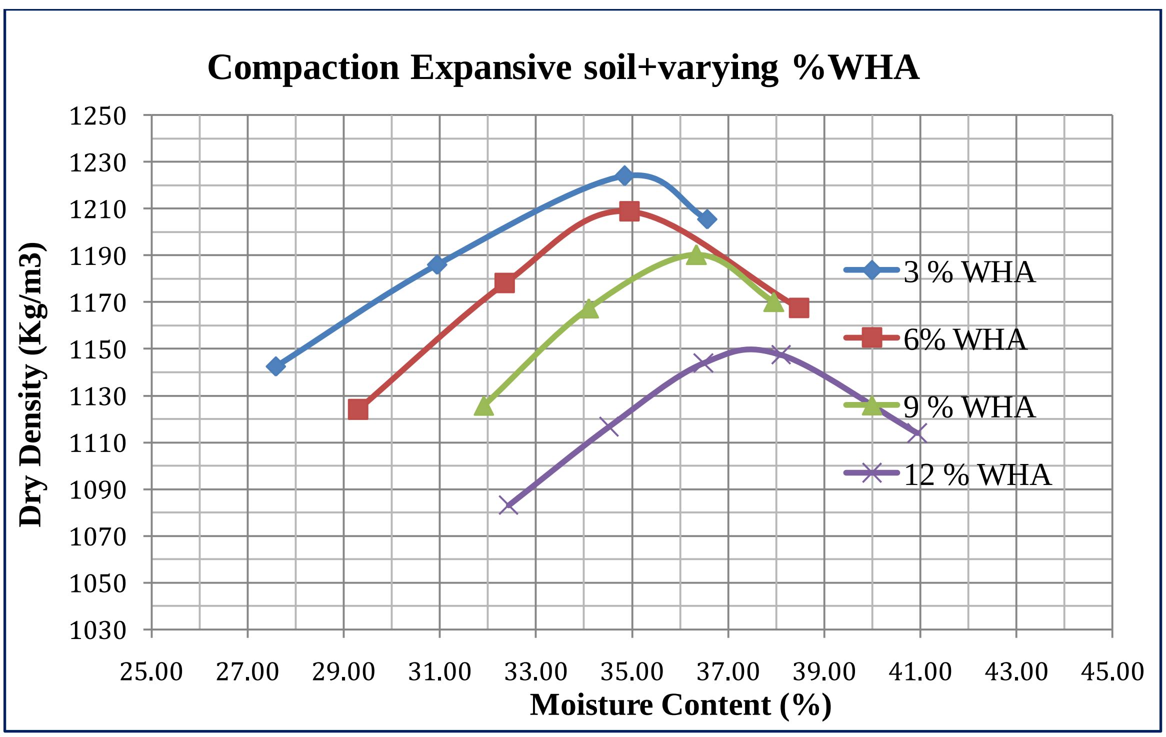


Figure5.6 Compaction with varying percentage of wheat husk ash

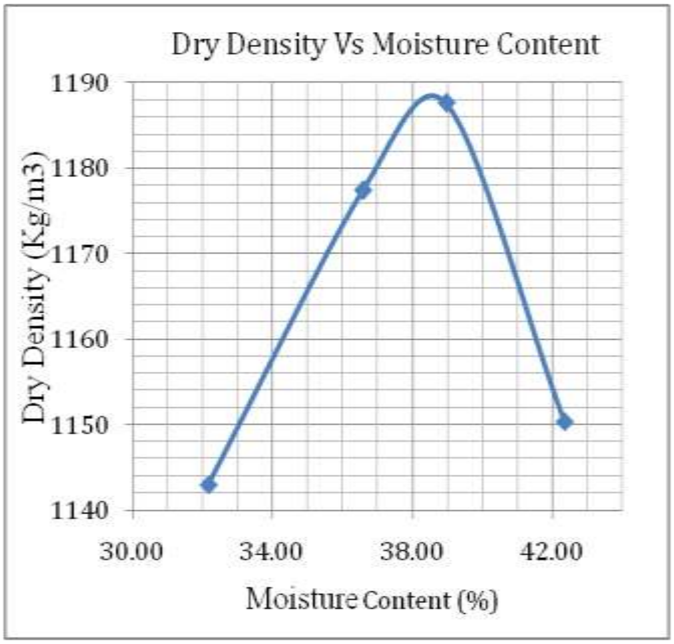


Figure 5.7 Soil sample +6%lime +3%WHA

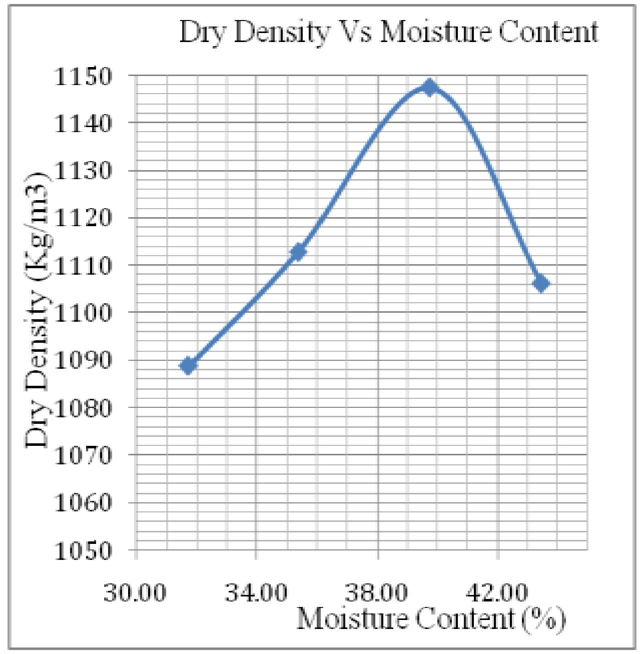


Figure 5.8 Soil sample +6%lime +6%WHA

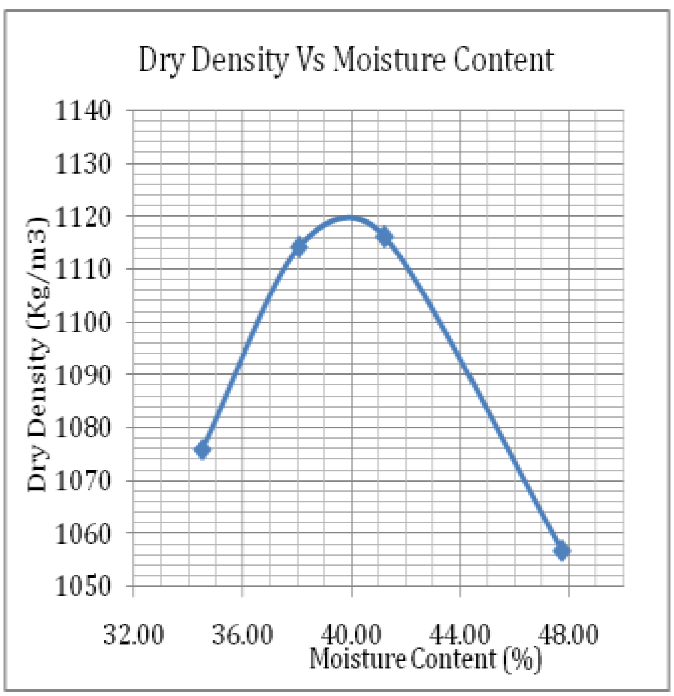


Figure 5.9 Soil sample +6%lime +9% WHA

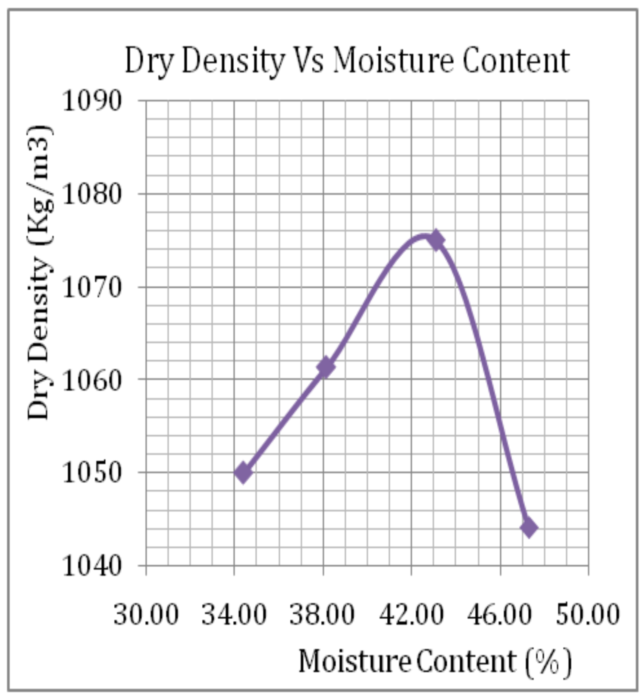


Figure 5.10 Soil sample +6% lime +12% WHA

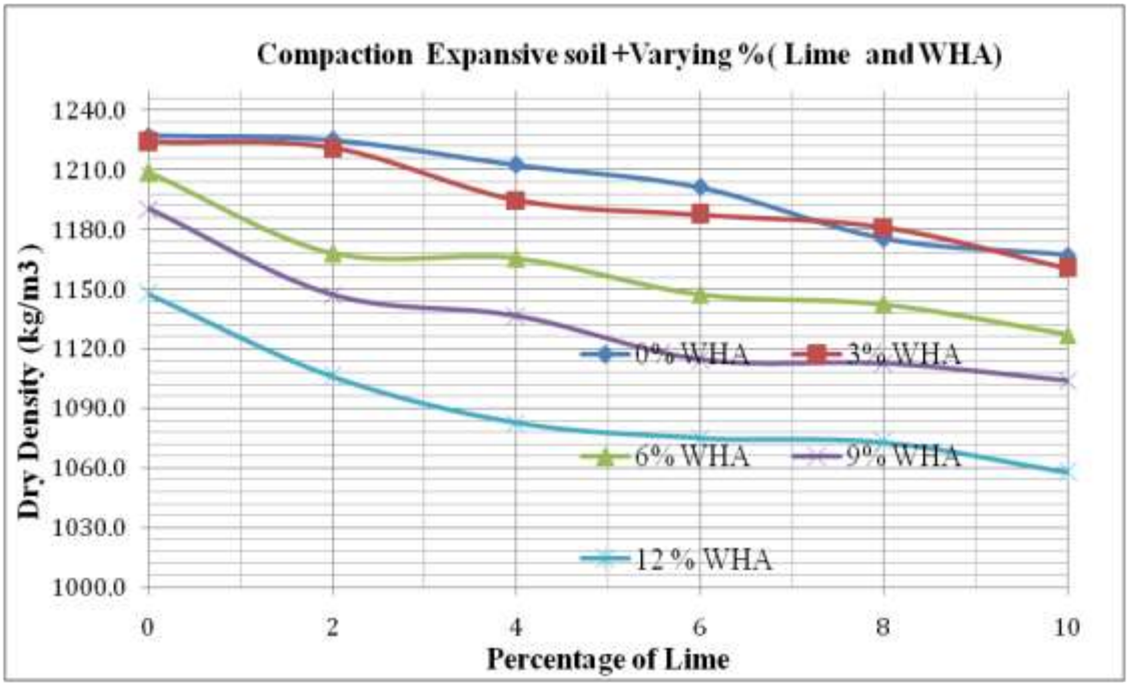


Figure 5.11 Variation of MDD with Lime and WHA combinations

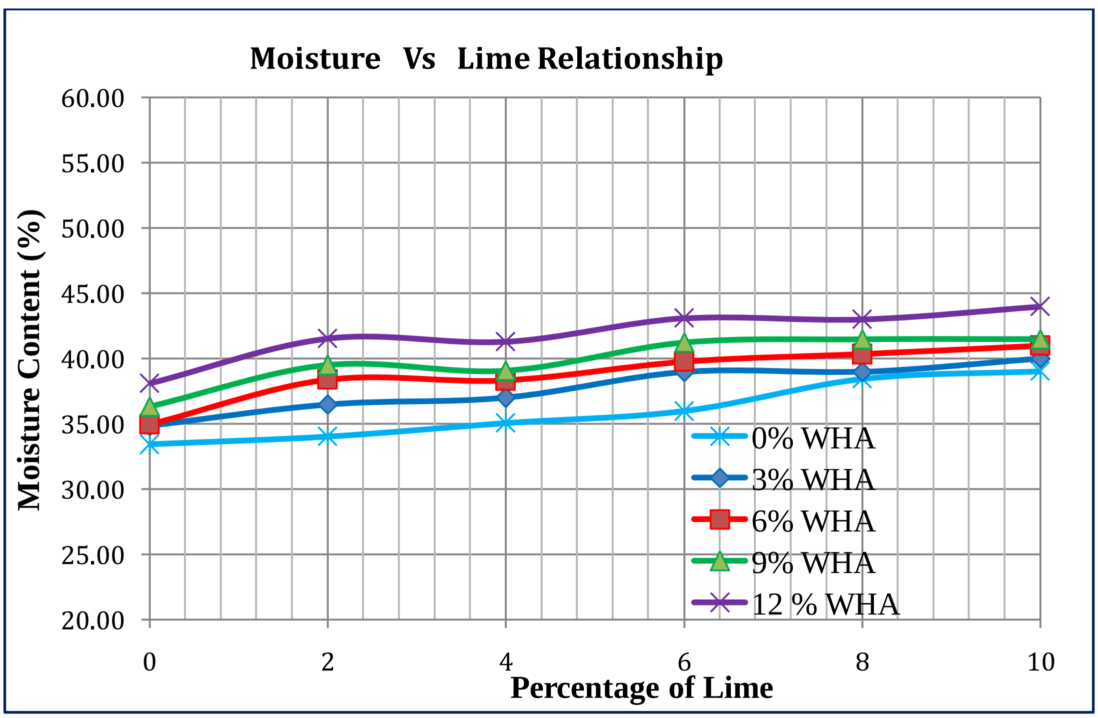


Figure5.12 Variation of OMC with Lime and WHA combinations.

As it can be observed from Figure 5.12, the OMC values are increasing with increasing percentages of lime added to soil. This is due to fines present in lime particles fills the voids of the coarse grained particles of soil. The OMC values are increasing with increasing percentages of wheat ash added to soil. This is due to increase in fine content of wheat ash causes in increase in finer content of soil in the WHA–soil mix. The increase in OMC is due to the addition of fine contents, which requires more water in addition to the free lime that needed more water for pozzalanic reactions. These occur in reducing the surface area caused by Flocculation. The OMC increases from 33.43% to 39.77% when the lime and wheat husk ash are increased from 0 to 6%.

5.5. Specific gravity

The results of specific gravity with different percentage of lime and WHA alone mixed with soil as shown in Figure 5.13 and figure 5.14 respectively. The general summaries of specific gravity for different concentration of lime -soil and WHA have been presented in Appendix. From figure 5.13 and 5.14, it can be seen that increasing the percentage of lime and WHA, the specific gravity tends to decrease.

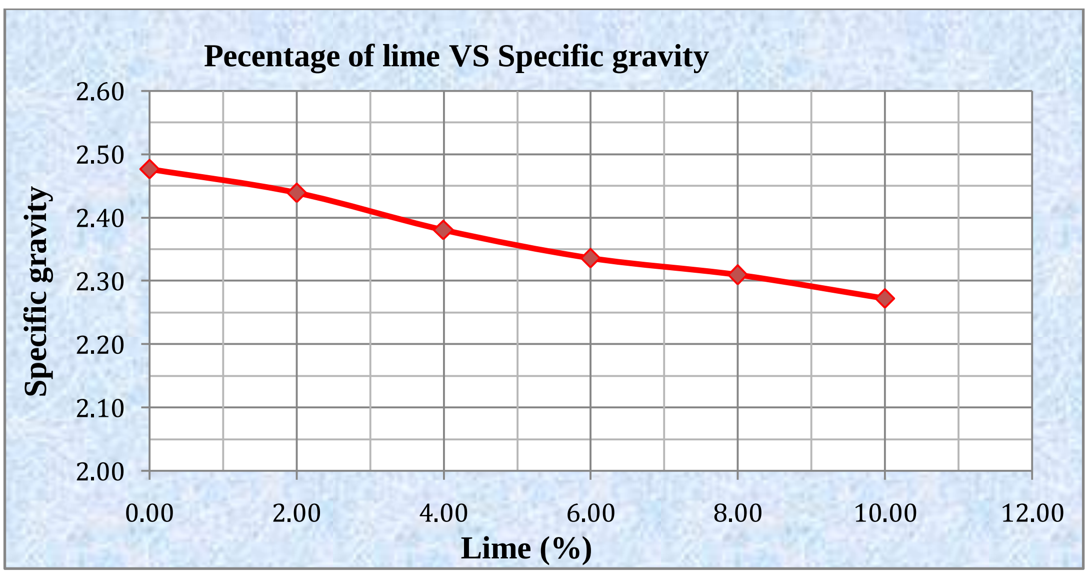


Figure5.13 Determination of specific gravity for different percentage of lime

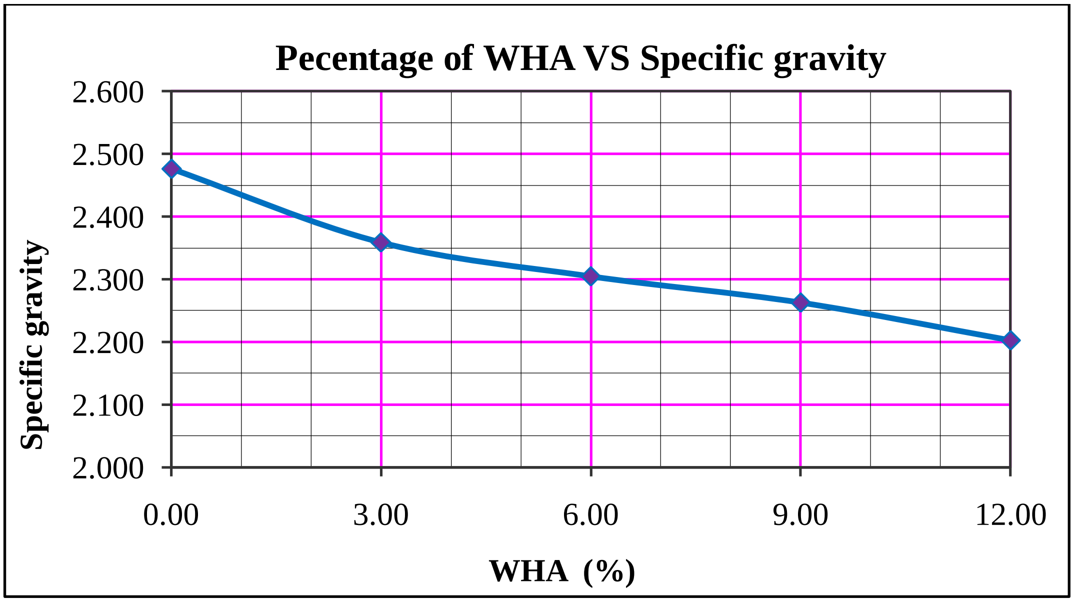


Figure 5.14 Specific gravity for different percentage of WHA

5.6. Linear shrinkage

The results of linear shrinkage tests on expansive soil treated with different percentage of lime and wheat husk ash are tabulated in Table form in the Appendix. With increasing in percentage of lime and wheat husk ash, the linear shrinkage of soil goes to decreasing up to 6% lime and wheat husk ash.

5.7. Free Swell

The results of free swell on expansive soil treated with different percentage of wheat husk ash as shown in Figure 5.15. From Figure it can be observed that with increasing in percentage of WHA, the free swell of soil goes to decreasing up to 6% WHA and beyond that it was increasing. The highest reduction in free swell is attained when the expansive soil is treated with 6% wheat husk ash which is 26.38% reduction compared to untreated soil. The effects of soil- lime and soil-lime and WHA mixes on free swell of expansive soil are shown in Figure 5.16 and Figure 5.17 respectively.

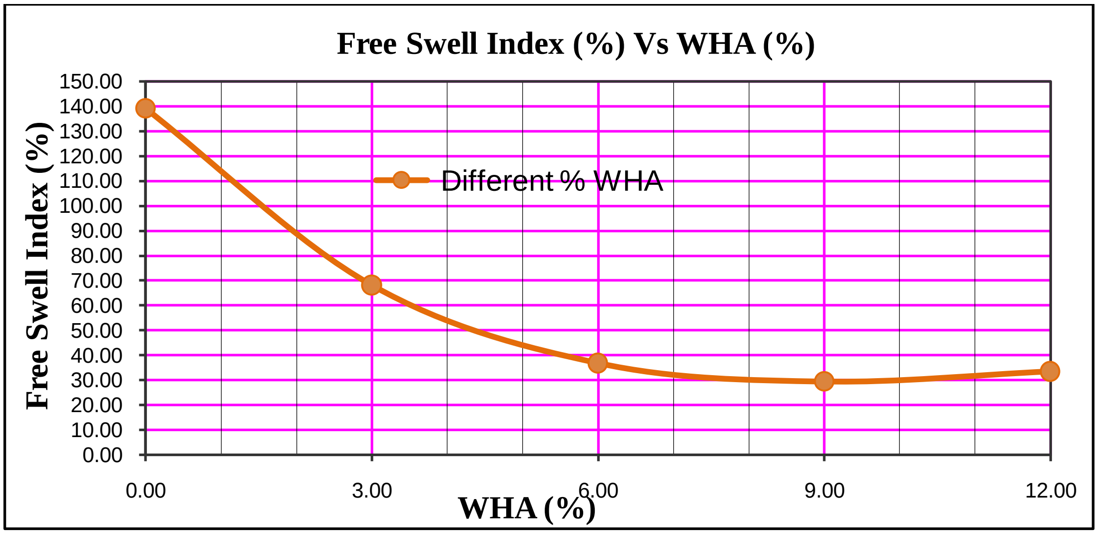


Figure5.15 Free Swell for different % wheat husk ash.

Figure 5.16 shows variation of free swell with percentage of lime. With increasing percentage of lime, the free swell tends to decrease up to 6% Lime and beyond 6% lime the free swell goes on increasing.

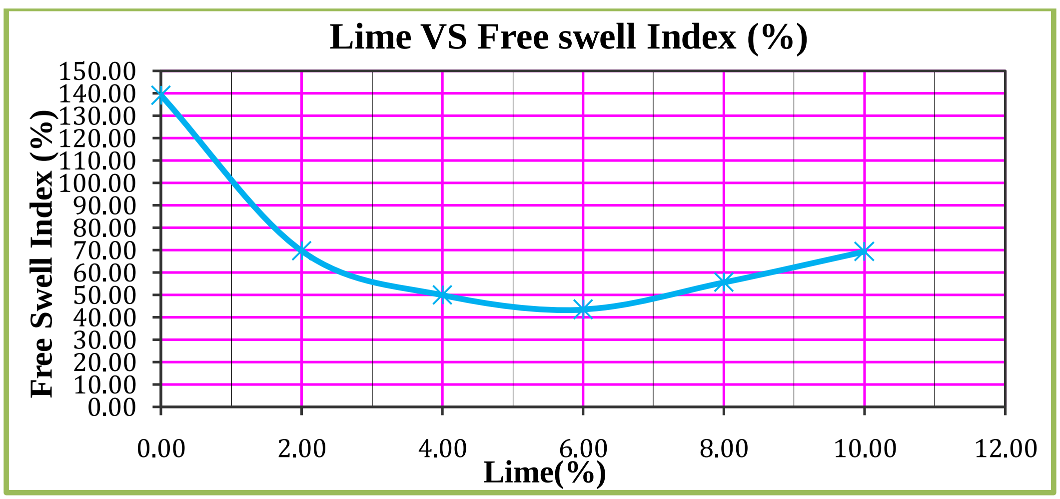


Figure5-16 Free swell for different percentage of lime

From figure 5.17: it can be seen that as percentage of lime and WHA blended with soil increases up to 6% lime and 6% WHA, the free swell goes to decrease and beyond 6% of lime and WHA ,it tends to increases. From figure it can be seen that the free swell decreases from 139% to 41.38% when treated with 6% lime and 6% WHA mixed with soil

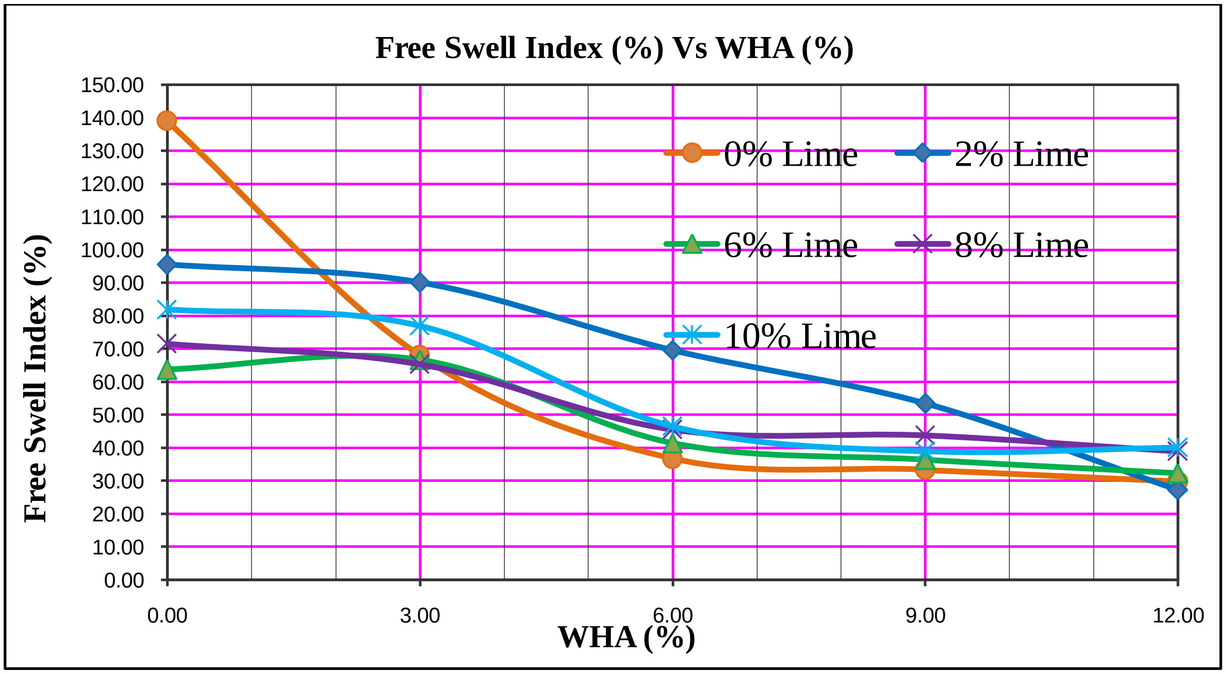


Figure5.17 Determination of frees well for soil -lime and WHA combinations

5.8. Unconfined Compressive Strength (UCS)

The test results of the UCS on expansive soil as shown in Figure 5.18.The variation of UCs for different percent of lime and wheat husk ash is shown in Figure 5.19 and 5.20 respectively. The laboratory test results of the UCS on expansive soil treated with different percentage of lime and wheat husk ash is shown in Figure 5-21. From the figure it can be observed that with addition of different percentage of lime and wheat husk ash increase up to 6% lime beyond that goes to and decrease. The UCS increase from 87.14kN/m2 to 802.94kN/m2 when lime and wheat husk ash are increased from 0 to 6%. The effect of curing days on unconfined compressive strength by varying percentage of WHA and lime is shown in figure 5.22 and 5.23 respectively. From figure it is observed that as no of curing days increases, the unconfined compressive strength goes to increases. This is effective for 6% lime and 6% WHA.

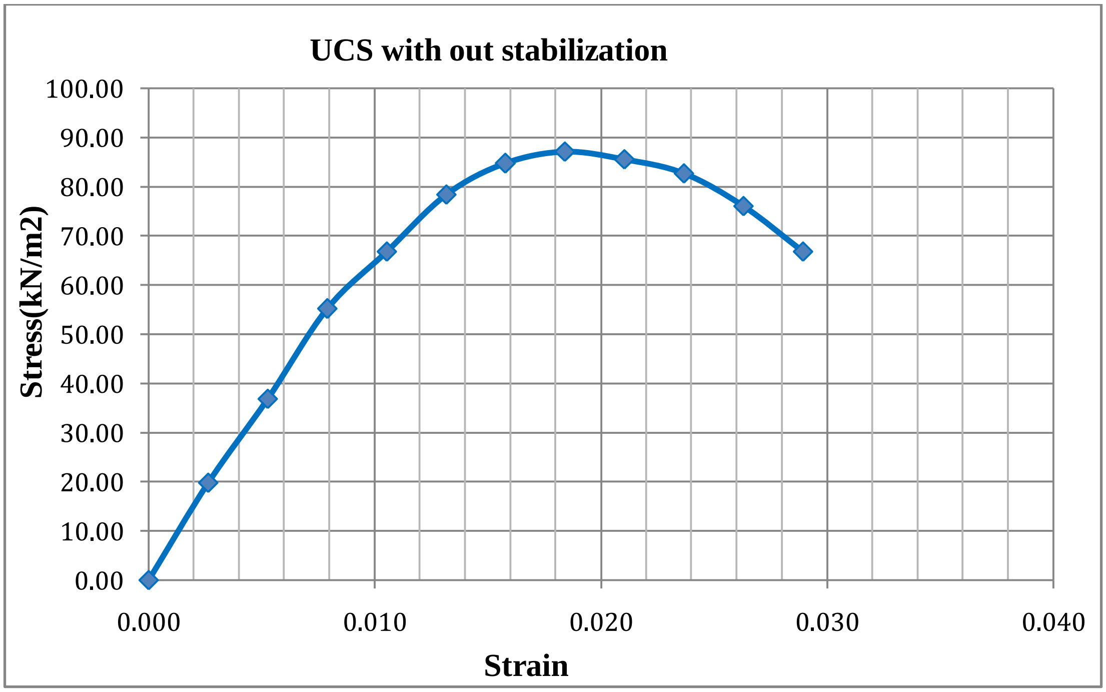


Figure5.18 Determination of UCS for expansive soil

From figure 5.18, the value obtained for the UCS for expansive soil without stabilizer is 87.14 kN/m2

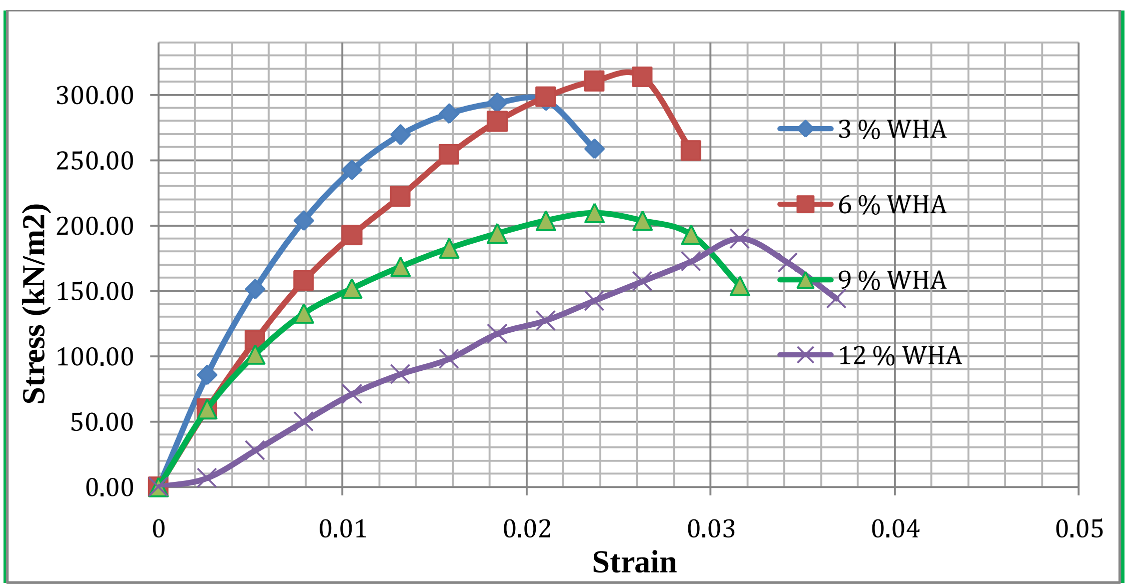


Figure 5.19 Effects of wheat husk ash on unconfined compressive strength of expansive soil

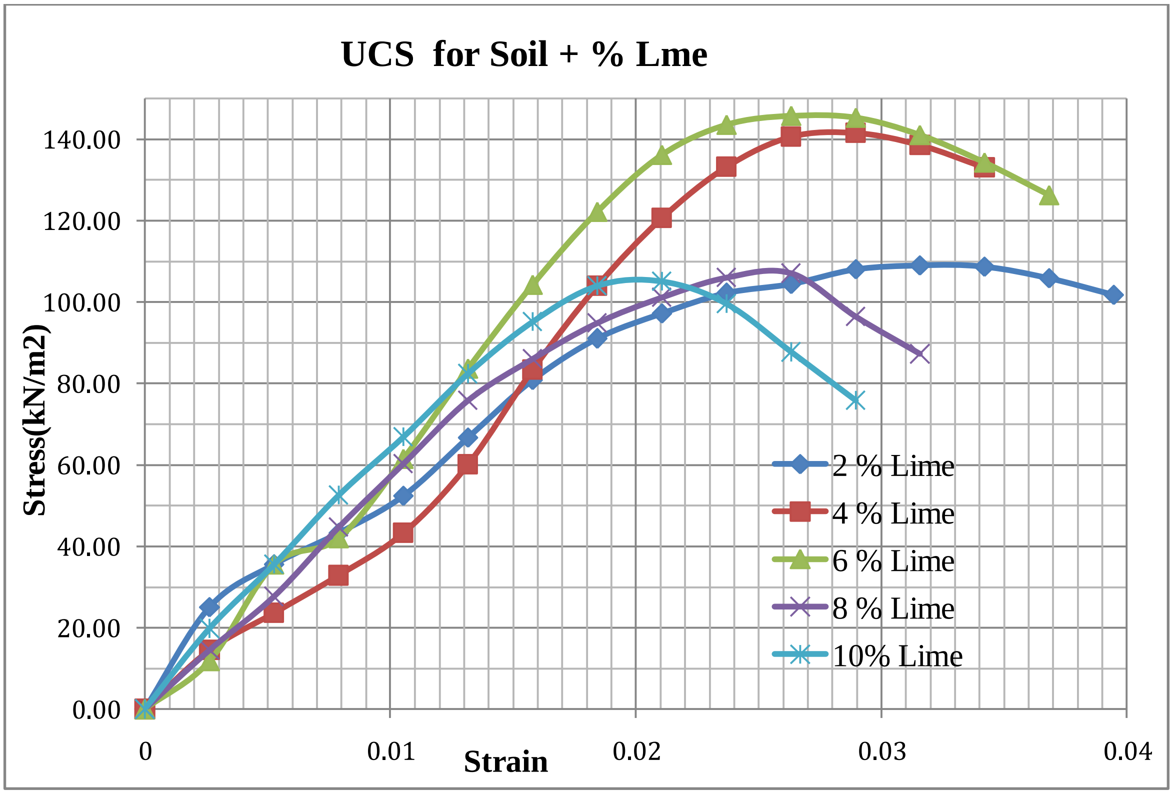


Figure5.20 Effects of lime on unconfined compressive strength of expansive soil

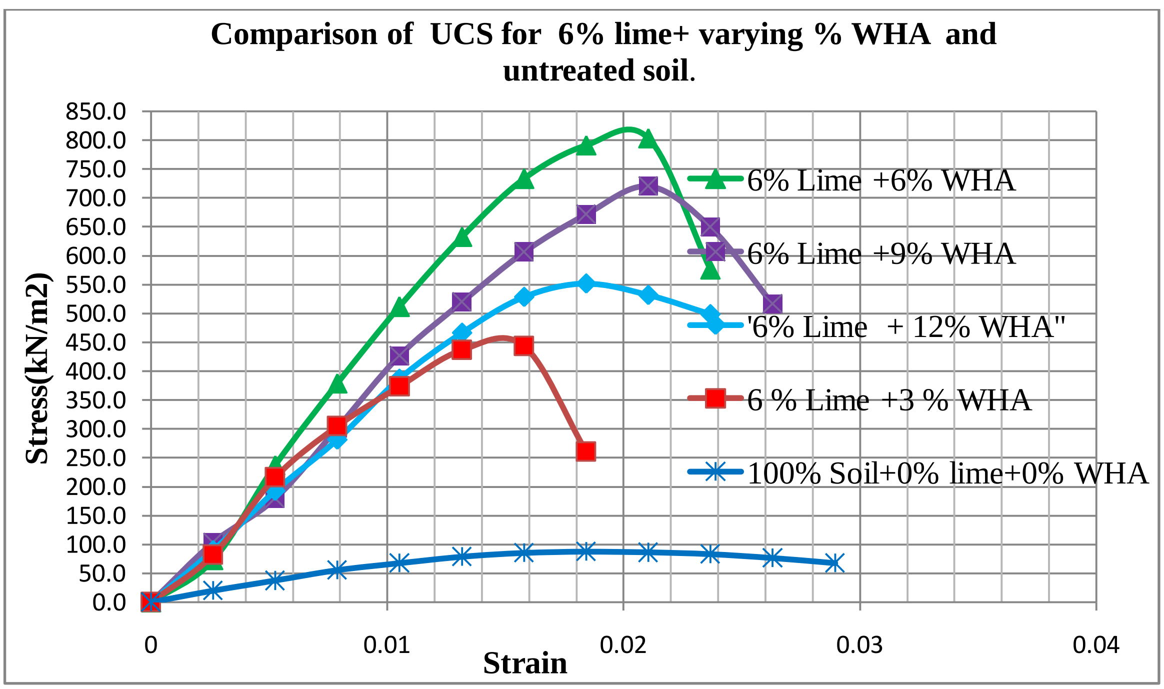


Figure5.21 Typical comparison of UCS for untreated soil and treated soil

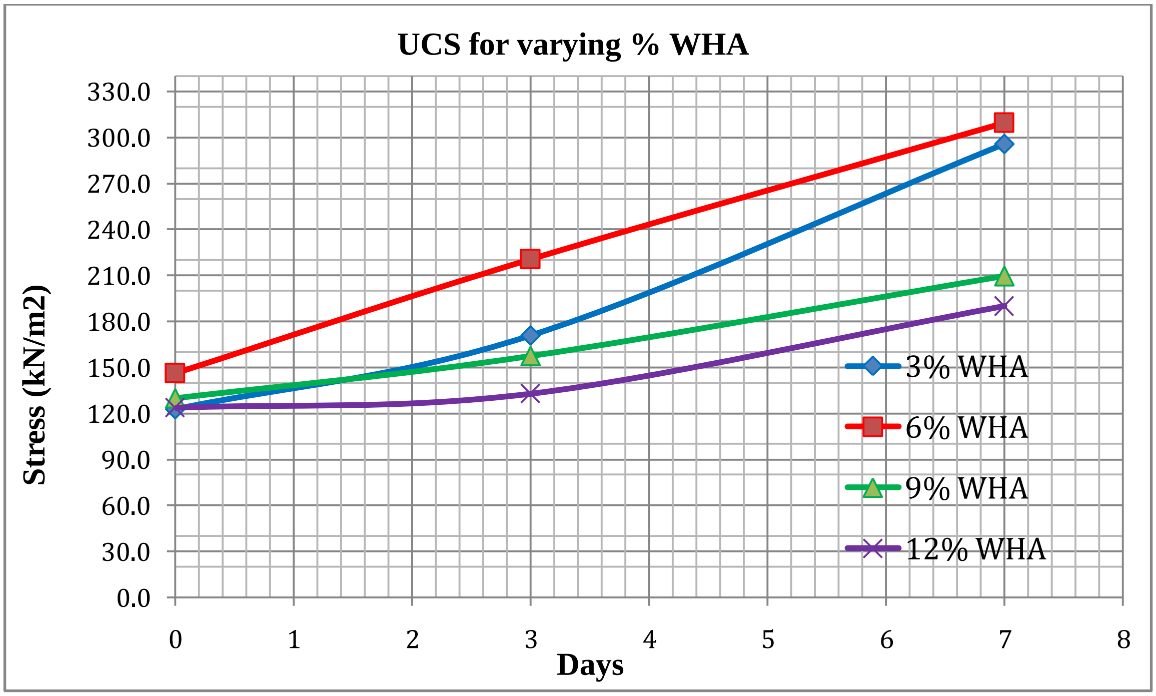


Figure 5.22 Graph stress against no of days for different % of WHA

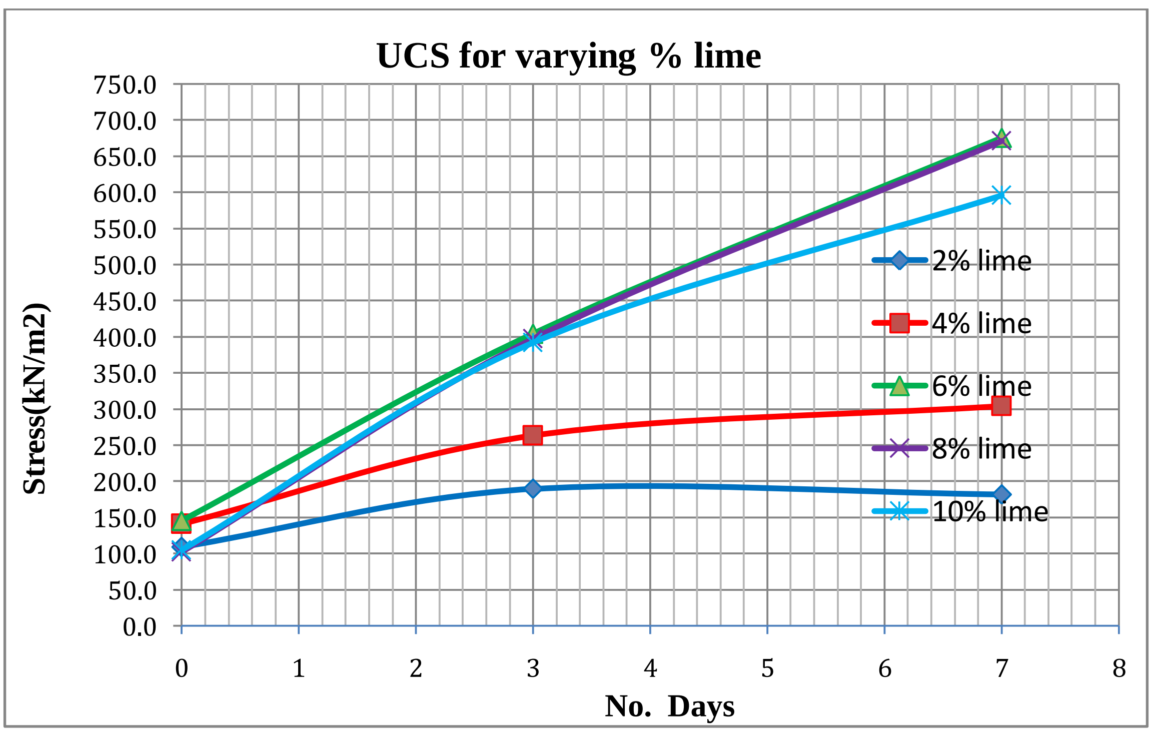


Figure5.23 Graph stress against no of days for different % of lime

5.9. California Bearing Ratio (CBR) and CBR swell test

5.9.1. CBR values

From results presented in Figure 5.25, Figure 5.26 and figure 5.27 shows that Soaked CBR of all treated soil increases with different percent of soil-WHA, soil- lime and Soil-WHA-lime mix. Results of curing shows that increases the strength development of expansive soil treated with lime and lime plus wheat husk ash but curing has an insignificant change when expansive soil is treated with wheat husk ash alone. As shown in the figure 5.25 and 5.26, the soaked CBR value increases for all mixes from a natural soil value of 3.25% to 13.86 %, and 3.25 to 21.35% with the addition of 6% lime, and 6%wheat husk ash respectively. The test result of soaked CBR tests on expansive soil treated with different percentage of lime and wheat husk ash are shown in Figure5.27. From the figure it can be observed that with increase in percentage of lime and WHA, the soaked CBR of soil goes on increasing up to 6% of WHA and lime. The soaked CBR of soil increases from 3.25% to 27.86% when lime and wheat husk ash are increased from 0 to 6% for 4 days curing period. Detailed test results are given in Table 5.1.

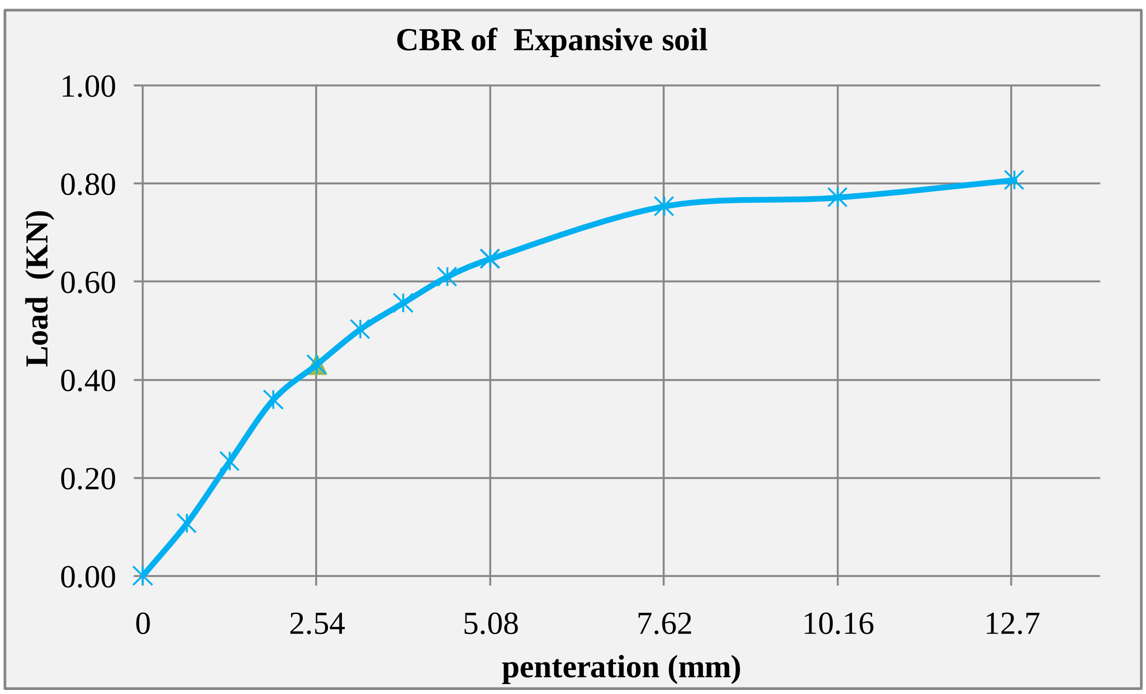


Figure 5.24 Soaked CBR of Untreated expansive soil

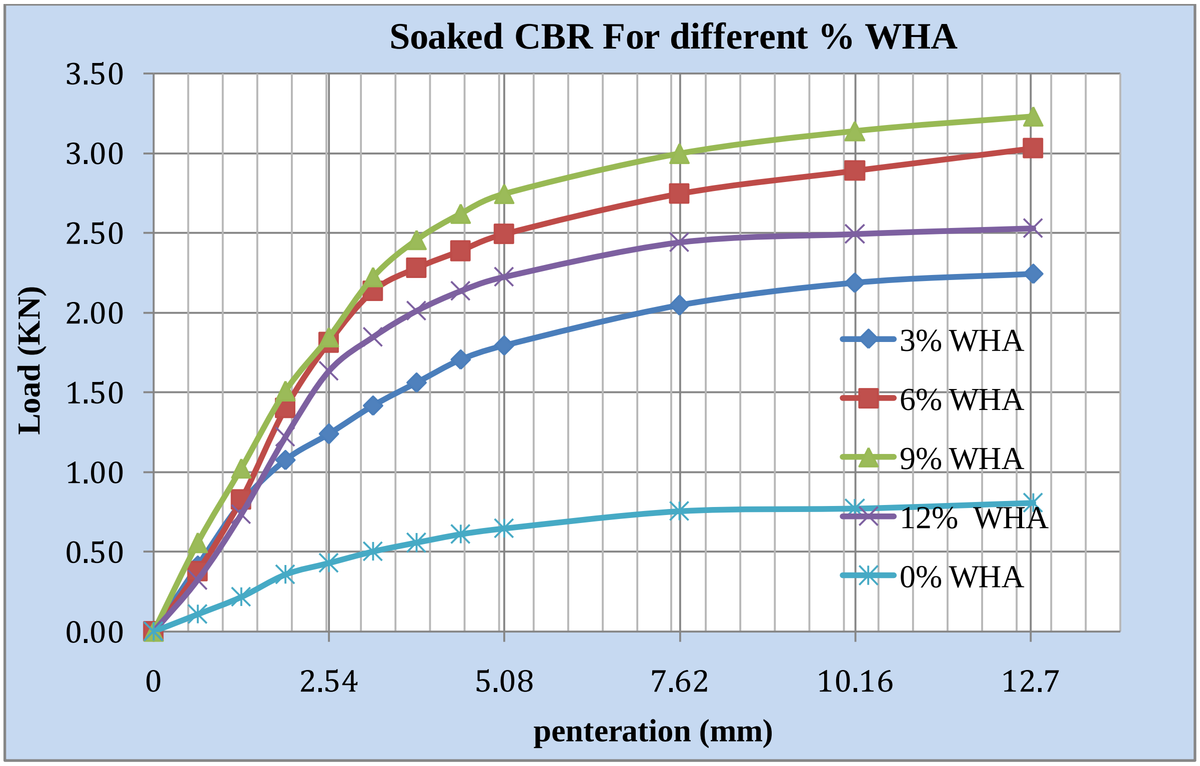


Figure 5.25 Soaked CBR for different % of WHA

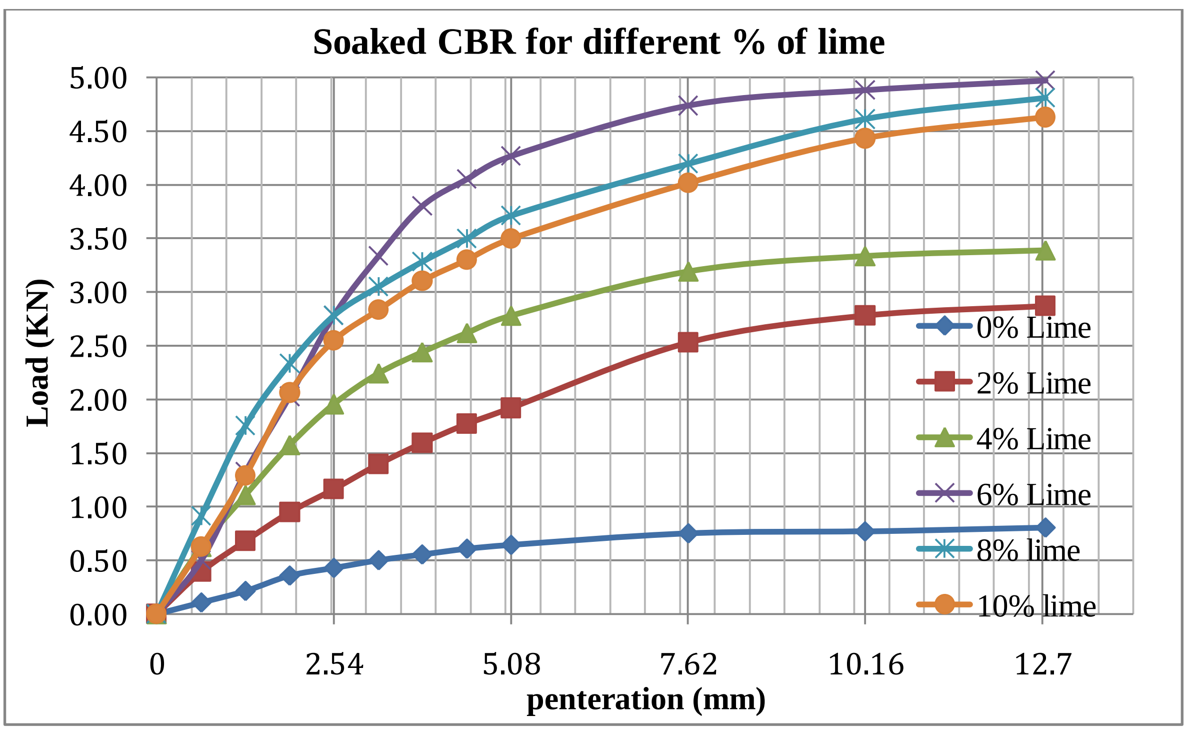


Figure 5.26 Soaked CBR for different % lime with soil mix

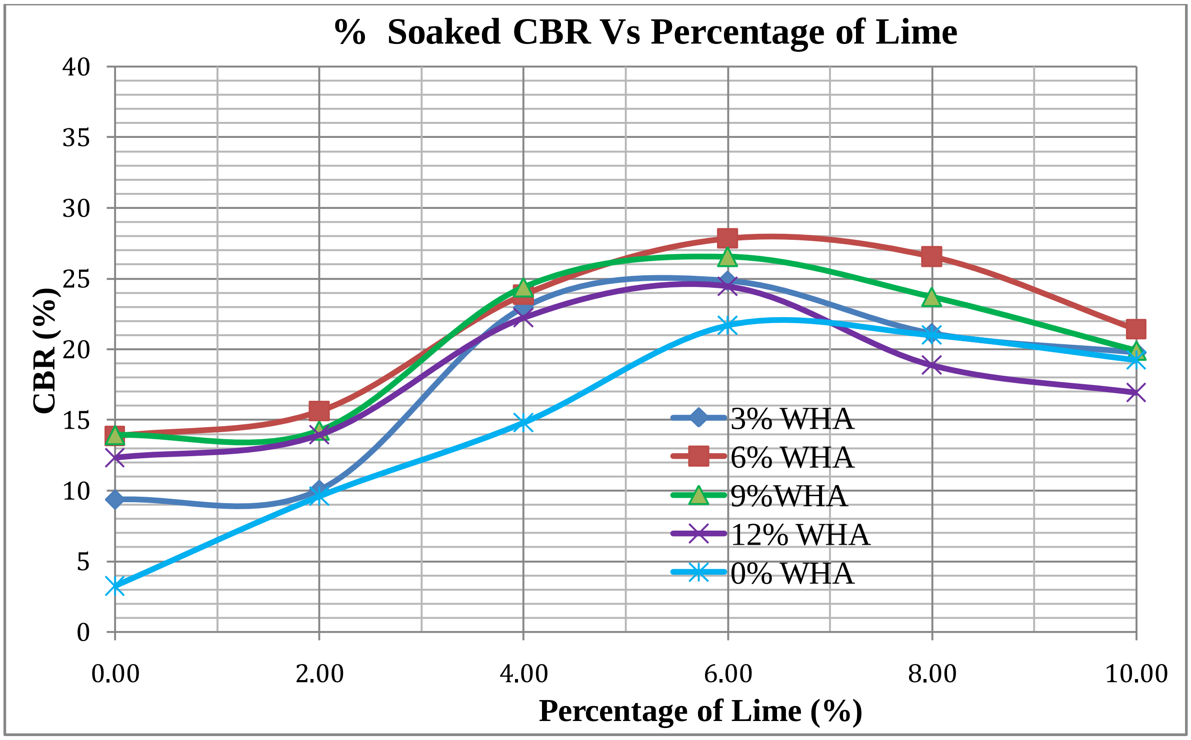


Figure 5.27 Variation of Soaked CBR with percentage of lime

5.9.2. CBR swelling percent

The CBR swell percentage shows as the percentage of lime and wheat husk ash mixtures increases, it decreases up to 6% WHA and then increases beyond 6%. From the test result the CBR swell percent decrease from 10.62% to 0.043%, when lime and WHA increases from 0 to 6%.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1. Conclusion

In this study, the sample of expansive soil was collected from Welechity, and stabilized with lime-wheat ash mix. The laboratory test were divided into two steps; Firstly, untreated or static tests which consists of basic geotechnical test such as; Atterberg limit, standard proctor, linear shrinkage, free swelling, unconfined compressive test(UCS),California bearing Ratio(CBR) tests have been carried out. Secondly, different trial laboratory tests were conducted to study the stabilizing effects of lime and wheat husk on liquid limit, plastic limit, plasticity index, maximum dry density(MDD), optimum moisture content (OMC), linear shrinkage, free swell, UCS, CBR and Percent swell. The result from present study has been compared with available data. This chapter contains conclusions drawn from the present experimental investigation. Last section is the scope of the further study.

Based on laboratory test of test results, the following conclusions are drawn:

1) From the findings of this study, the use of lime and wheat husk ash as stabilizing material is one of best alternative to be implemented in area of expansive soil encountered along the route in road construction.
2) The WHA can utilize as an alternative or a partial replacement of lime in stabilizing the expansive soil which is reduces the construction cost particularly in Ethiopia.
3) The maximum dry density and optimum moisture content determined for each mix. Based on the maximum UCS values the percent of soil, lime and wheat husk ash that gives the optimum mix is 88%, 6% and 6% respectively(Soil+6 Lime +6WHA).
4) The liquid limit values of soil- lime and WHA mix decreases with increasing percentage of lime and wheat ash up to 6% beyond that it is increasing pattern. The value decreases from 84.25% to 63.37%.
5) The test results of plastic limit increases up to 6% and beyond that it is decreasing in nature for all wheat ash contents. The value increases from 39.25 % to 53.52%, the plasticity index of the soil lime wheat ash mixture decreases up to 6% ,and beyond this it is slightly increases. The result decreases from 45.25% to 9.85% which is reduced by 78.16% on addition of 6% wheat husk Ash and 6% lime.

6) It is observed that the free swell of treated soil is decreasing up to 6% lime and beyond this it goes on increasing. The value decreases from 139.8% to 41.38%,and linear shrinkage decreases from 16.7% to 4.5% from virgin soil to the stabilized expansive soil of the optimum mix.
7) With the increase in wheat husk ash and lime percentage, the Optimum moisture content increases from 33.43% to 39.77% and Maximum dry density decreases from 1.227kg/m3 to 1.147kg/m3 for 6% lime and 6% wheat husk ash mixtures .
8) There is significant increase in the values of California bearing ratio. Unsoaked California bearing ratio increases from 4.49 % to 24.254% and soaked CBR value increases from 3.25% to 27.78% for 6% lime and 6% WHA mix with soil. For 4 days curing period, the CBR-swell decreased from natural soil value of 10.63% to 0.043% with addition of 6% lime and 6% wheat husk ash. This shows that the swelling capacity of the expansive soil decreased considerably with wheat husk ash and lime treatment and curing has also a significant effect on the CBR-swell values.
9) The unconfined compressive strength (UCS) value increases from 87 kN/m2 to 802 kN/m2 for 7 days of curing periods.

   After different laboratory test result have been made, the conclusion is drawn as the trial mix of 6% Lime and 6% WHA combination is effective for improving the engineering properties of expansive soil.

6.2. Recommendations

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

- ❖ For present study the expansive soil sample was collected from Welenchity by considering the expansion of Adama town to Welechity. But the study is continued for different type of soil and different region of soil; and also further study is continued for different percentage of mix proportion for selected material with expansive soil, lime and WHA mixtures.
- ❖ The present research work is conducted by taking limited soil samples and parameters on stabilized soil-lime and WHA mixtures. It is recommended that additional parameters of swelling pressure and consolidation settlement tests should also be performed to have more realistic results.
- ❖ From the result of this research, using chemical additives (Lime & WHA),have provided promising results in improving the engineering properties of the expansive soil and using 6%

of each chemicals is effective to stabilize the expansive sub-grade soil. But the laboratory test results obtained from the study should be verified by field tests for its long term durability. Hence, it is recommended to conduct the long term durability tests during wet and dry season to evaluate the strength of these stabilized materials.

- Determination of mineralogy of expansive soil is important to understand the behavior of chemical additives when mixed with soil. Since mineralogy has a great effect on the stabilization of expansive soil with chemical additives. Therefore, it is recommended to study mineralogy of representative soil samples of the different expansive soils found in Welenchity area and other region of Ethiopia; and also study continued for the mineralogy of WHA.
- From this study, the WHA can be used as soil improvement. Therefore, the awareness creation should be done from side of concerning bodies for farmers during harvesting and stoking to avoid waste of wheat straw. Because of the farmers can gain additional revenue by selling wheat husk ash.
- For more practicability and visibility, it is recommended to use for light weight building foundation by further study the swelling pressure and consolidation settlement tests and also included as part of this document.

Finally, the results and findings of the present study, it may be considered as indicative only as a result of these studies is based on limited parameters and on small number of samples. To be more realistic, conducting more elaborate sampling and testing would be mandatory before implementation of results. Thus, the present finding has provide overall methodology to carry out similar studies on stabilization of expansive sub-grade soils using agricultural products for design of pavements.

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APPENDIX

Appendix A: Details of the Laboratory Test Results

GRAIN SIZE DISTRIBUTION OF EXPANSIVE SOIL

Table 6: Mechanical Wet sieve Analysis of natural soil

	Sieve size (mm)	Weight retained	% Retained	Cumulative % Retained	%passing
GRAIN SIZE ANALYSIS	12.70	0.0	0.0	0.0	100.00
	9.5	2.98	0.312	0.312	99.69
	4.75	15.34	1.608	1.920	98.08
	2.36	14.65	1.536	3.456	96.54
	2.00	2.10	0.220	3.676	96.32
	1.18	7.12	0.746	4.422	95.58
	0.6	8.48	0.889	5.311	94.69
	0.425	3.31	0.347	5.658	94.34
	0.3	5.71	0.599	6.257	93.74
	0.15	25.57	2.680	8.937	91.06
	0.075	14.85	1.5566	10.494	89.51
	Pan	853.89	89.506	100.000	00
	Total Weight of dry soil before washing = 954gm				

Table7: Hydrometer Reading for expansive soil.

Time	Elapsed Time (min)	Temp. (oC)	Actual hydrometer Reading Rh	Reading in dispersant Ro	Modified hydrometer reading, Rd = Rh-Ro	Effective depth, L(mm)	Coefficient K	Particle / Grain size / diameter, D(mm)	Percentage finer than D, p (%)
3.40	0	20							
3.42	2	20	37.0	5.00	32.00	10.2	0.01431	0.03232	64.0
3.45	5	20	36.5	5.00	31.50	10.3	0.01431	0.02054	63.0
3.55	15	20	36.0	5.00	31.00	10.4	0.01431	0.01192	62.0
4.10	30	20	34.0	5.00	29.00	10.7	0.01431	0.00855	58.0
5.10	60	20	31.0	5.00	26.00	11.2	0.01431	0.00618	52.0
8.05	240	22	30.0	5.00	25.00	11.4	0.01397	0.00304	50.0
	1440	20	26.0	5.00	21.00	12.0	0.01431	0.00131	42.0

<u>GRAIN SIZE DISTRIBUTION OF WHEAT HUSK ASH</u>

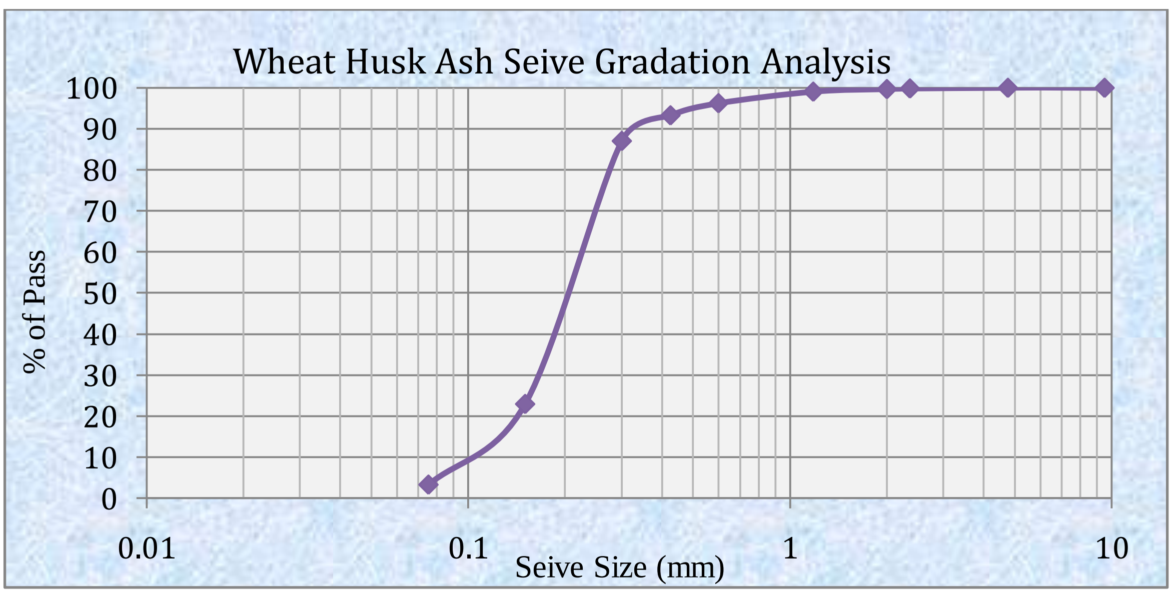


Figure6: Presents the Particle size distribution of WHA

Table-8: Determination of PH value

S.No	Materials	PH Value
1	Natural soil	7.46
2	Wheat Husk Ash(WHA)	10.58
3	Lime	12.49

SPECIFIC GRAVITY

Table-9: Specific Gravity Reading for expansive soil.

No	Observation	Sample-1
	Bottle No	4
A	Wt of oven dry sample (g)	10.00
B	Wt of bottle filled with water (g)	72.800
C	Wt of bottle filled with water and sample (g)	78.765
D	Wt of bottle	25.300
	Specific gravity(G)=A/B+A-C	2.478

Table-10: Specific gravity of expansive soil+ vary%lime + vary % WHA

Mix No	Type of mix			Specific gravity
	Soil (%)	Lime (%)	WHA (%)	
1	100	0	0	2.48
2	98	2	0	2.44
3	96	4	0	2.38
4	94	6	0	2.34
5	92	8	0	2.31
6	90	10	0	2.27
7	97	0	3	2.36
8	94	0	6	2.30
9	91	0	9	2.26
10	88	0	12	2.20
11	95	2	3	2.44
12	92	2	6	2.38
13	89	2	9	2.33
14	86	2	12	2.27
15	93	4	3	2.39
16	90	4	6	2.33
17	87	4	9	2.27
18	84	4	12	2.22
19	91	6	3	2.37
20	88	6	6	2.33
21	85	6	9	2.27
22	82	6	12	2.22
23	89	8	3	2.29
24	86	8	6	2.24
25	83	8	9	2.20
26	80	8	12	2.17
27	87	10	3	2.27
28	84	10	6	2.22
29	81	10	9	2.17
30	78	10	12	2.13

FREE SWELL INDEX TEST

Table-11:Free swell index test of swelling soil with diff conc. of wheat-ash and Lime

S. No	Type of mix.	Soil sample in(g), (A)	Height measured in water (ml), A	Height measured in kerosene (ml) , B	Difference (C)= B-A	Swelling Index (%) =(C/A)*100
1	100% Soil+0%Lime+0% WHA	10.00	23.90	10.00	13.90	139.00
2	98% Soil+2% Lime+0% WHA	10.00	21.50	11.00	10.50	95.45
3	96% Soil+4% Lime+0% WHA	10.00	20.00	11.00	9.00	81.82
4	94% Soil+6% Lime+0% WHA	10.00	18.00	11.00	7.00	63.64
5	92% Soil+8% Lime+0% WHA	10.00	18.00	10.50	7.50	71.43
6	90% Soil+10% Lime+0%WHA	10.00	20.00	11.00	9.00	81.82
7	97% Soil+0% Lime+3% WHA	10.00	21.00	12.50	8.50	68.00
8	94% Soil+0% Lime+6% WHA	10.00	20.50	15.00	5.50	36.67
9	91% Soil+0% Lime+9% WHA	10.00	22.00	16.50	5.50	33.33
10	88% Soil+0% Lime+12%WHA	10.00	24.00	17.00	7.00	41.18
11	95% Soil+2% Lime+3% WHA	10.00	19.00	10.00	9.00	90.00
12	92% Soil+2% Lime+6% WHA	10.00	19.50	11.50	8.00	69.57
13	89% Soil+2% Lime+9% WHA	10.00	23.00	15.00	8.00	53.33
14	86% Soil+2% Lime+12%WHA	10.00	28.00	22.00	6.00	27.27
15	93% Soil+4% Lime+3% WHA	10.00	19.00	10.50	8.50	80.95
16	90% Soil+4% Lime+6% WHA	10.00	20.50	13.00	7.50	57.69
17	87% Soil+4% Lme+9% WHA	10.00	20.50	14.00	6.50	46.43
18	84% Soil+4% Lime+12%WHA	10.00	22.00	17.00	5.00	29.41
19	91% Soil+6% Lime+3% WHA	10.00	20.00	12.00	8.00	66.67
20	88% Soil+6% Lime+6% WHA	10.00	20.50	14.50	6.00	41.38
21	85% Soil+6% Lime+9% WHA	10.00	22.50	16.50	6.00	36.36
22	82% Soil+6% Lime+12%WHA	10.00	20.50	15.50	5.00	32.26
23	89% Soil+8% Lime+3% WHA	10.00	19.00	11.50	7.50	65.22
24	86% Soil+8% Lime+6% WHA	10.00	24.00	16.50	7.50	45.45

25	83% Soil+8% Lime+9% WHA	10.00	23.00	16.00	7.00	43.75
26	80% Soil+8%Lime+12%WHA	10.00	25.00	18.00	7.00	38.89
27	87% Soil+10%Lime+3%WHA	10.00	23.00	13.00	10.00	76.92
28	84% Soil+10%Lime+6%WHA	10.00	20.50	14.00	6.50	46.43
29	81% Soil+10%Lime+9%WHA	10.00	25.00	18.00	7.00	38.89
30	78%Soil+10%Lime+12%WHA	10.00	24.50	17.50	7.00	40.00

LINEAR SHRINKAGE TEST

Table 12: Linear shrinkage test of swelling soil with diff conc. of wheat-ash and Lime

S.No	Type of mix.	Apparatus No.	Initial Length, Lo (cm)	Final /Oven Dry /Length ,Lf (cm)	Difference (cm)	Linear Shrinkage (%) =(1-Lf/Lo)*100
1	95% Soil+0% Lime+0% WHA	1.00	14.00	11.75	2.25	16.07
2	95% Soil+2% Lime+3% WHA	3.00	14.00	11.70	2.30	16.43
3	92% Soil+2% Lime+6% WHA	4.00	14.00	12.20	1.80	12.86
4	89% Soil+2% Lime+9% WHA	1.00	14.00	12.50	1.50	10.71
5	86% Soil+2% Lime+12% WHA	2.00	14.00	12.70	1.30	9.29
6	93% Soil+4% Lime+3% WHA	3.00	14.00	11.80	2.20	15.71
7	90% Soil+4%Lime +6% WHA	4.00	14.00	12.10	1.90	13.57
8	87% Soil+4% Lime +9% WHA	1.00	14.00	12.45	1.55	11.07
9	84% Soil+4% Lime+12% WHA	2.00	14.00	12.50	1.50	10.71
10	91% Soil+6% Lime +3% WHA	2.00	14.00	13.00	1.00	7.14
11	88% Soil+6% Lime +6% WHA	3.00	14.00	13.37	0.63	4.50
12	85% Soil+6% Lime +9% WHA	4.00	14.00	13.30	0.70	5.00
13	82% Soil+6% Lime+12% WHA	1.00	14.00	13.20	0.80	5.71
14	89% Soil+8% Lime +3% WHA	1.00	14.00	13.25	0.75	5.36
15	86% Soil+8% Lime +6% WHA	2.00	14.00	13.35	0.65	4.64
16	83% Soil+8% Lime+9% WHA	3.00	14.00	13.30	0.70	5.00

17	80% Soil+8% Lime+12% WHA	4.00	14.00	13.35	0.65	4.64
18	87% Soil+10% Lime+3% WHA	2.00	14.00	13.26	0.74	5.29
19	84% Soil+10% Lime+6% WHA	1.00	14.00	13.35	0.65	4.64
20	81% Soil+10% lime +9% WHA	3.00	14.00	13.30	0.70	5.00
21	78% Soil+10% Lime+12% WHA	4.00	14.00	13.25	0.75	5.36

ATTERBERG LIMITS

Table 13.1 Atterberg limit determination for natural(virgin) expansive soil only

	1 LIQUID LIMIT				2 PLASTIC LIMIT		
No of blows	37	29	23	17			
Container no	33	28	24	15	4	2	3
Wt of container + wet soil	42.29	38.65	39.8	41.54	49.95	24.9	21.7
Wt of container + dry soil	33.42	31.68	31.6	32.13	49.34	24.4	21.2
Wt of container	22.69	23.3	21.8	21.3	47.9	23	19.9
Wt of water	8.87	6.97	8.24	9.41	0.606	0.52	0.5
Wt of dry soil	10.73	8.38	9.78	10.83	1.44	1.39	1.3
Moisture content %	82.67	83.17	84.25	86.89	42.08	37.09	38.57
LL at 25 blows &Avg. PL =84.25	84.29				39.25		
3 Plasticity index, PI=LL-PL = 84.25-39.25 =45 %							

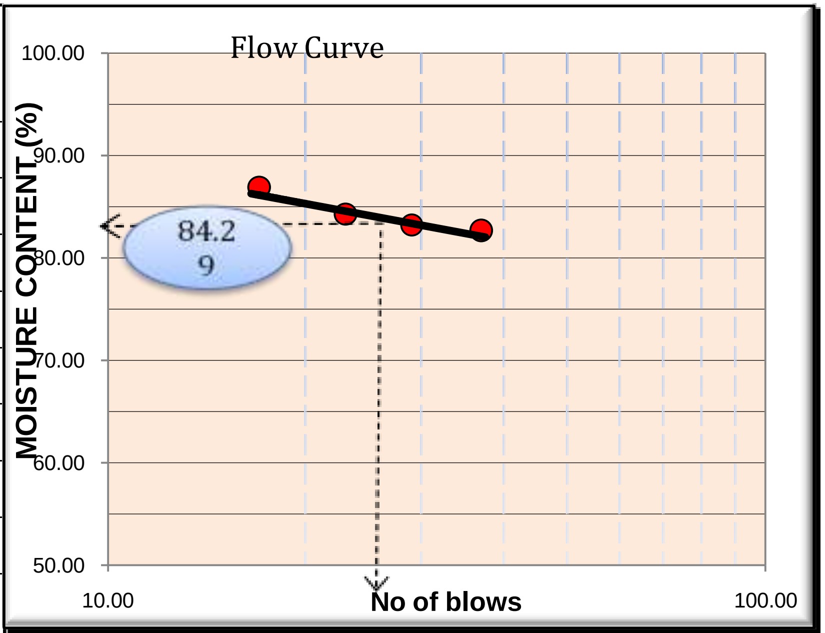


Table-13.2 Liquid limit of 95% Soil+2% Lime +3% WHA

LIQUID LIMIT					PLASTIC LIMIT		
No of blows	36	28	23	18			
container no	314	27	24	346	31	301	306
Wt of container + wet soil	45.7	45.45	44.17	42.78	28.98	26.9	28.82
Wt of container + dry soil	35.51	35.31	34.21	33.56	27.28	25.11	26.98
Wt of container	22.69	22.73	22.39	22.83	23.48	21.1	23.0
Wt of water	10.19	10.14	9.96	9.22	1.7	1.79	1.84
Wt of dry soil	12.82	12.58	11.82	10.73	3.8	3.99	4.0
Moisture content %	79.49	80.60	84.26	85.93	44.74	44.86	45.66
	LL=82.57				Av.PL=45.09		

Table-13.3 Liquid limit and Plastic limit of 92 Soil+2% lime+6% WHA

LIQUID LIMIT					PLASTIC LIMIT		
No of blows	35	28	22	18			
Container no	301	31	306	369	47	336	370
Wt of container + wet soil	48.01	44.24	43.04	44.47	36.21	36.06	35.85
Wt of container + dry soil	37.21	33.92	33.87	33.98	31.73	31.78	31.52
Wt of container	23.5	21.1	22.95	21.5	22.5	22.8	22.5
Wt of water	10.8	10.32	9.17	10.49	4.48	4.28	4.33
Wt of dry soil	13.71	12.82	10.92	12.48	9.23	8.97	9.02
Moisture content %	78.77	80.50	83.97	84.05	48.54	47.71	48.00
	LL=81.83				Av.PL=48.09		

Table-13.4 Liquid and plastic limit of 89% Soil+2% Lime +9% WHA

LIQUID LIMIT					PLASTIC LIMIT		
No of blows	35	28	23	16			
container no	301	47	370	314	364	346	
Wt of container + wet soil	48.88	41.11	47.11	42.29	33.12	32.75	
Wt of container + dry soil	37.89	32.999	36.12	32.73	29.87	29.46	
Wt of container	23.54	22.5	22.35	21.3	23.3	22.8	
Wt of water	10.99	8.111	10.99	9.56	3.25	3.29	
Wt of dry soil	14.35	10.499	13.77	11.43	6.57	6.68	
Moisture content %	76.59	77.25	79.81	83.64	49.47	49.25	
	LL=79.32				Av.PL=49.36		

Table-13.5 Liquid and plastic limit of 86% Soil+2% Lime +12% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	35	28	23	16		
container no	301	47	370	314	364	346
Wt of container + wet soil	48.67	41.08	46.82	41.69	33.16	32.82
Wt of container + dry soil	37.89	32.999	36.12	32.73	29.83	29.41
Wt of container	23.54	22.5	22.35	21.3	23.3	22.8
Wt of water	10.78	8.081	10.7	8.96	3.33	3.41
Wt of dry soil	14.35	10.499	13.77	11.43	6.53	6.63
Moisture content %	75.12	76.97	77.71	78.39	51.00	51.43
	LL=77.05				Av.PL=51.21	

Table-13.6 Liquid and plastic limit of 93% Soil+4% Lime +3% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	31	27	23	18		
container no	132	349	301	311	336	27
Wt of container + wet soil	39.74	37.86	36.08	35.69	29.8	30.51
Wt of container + dry soil	32.61	31.27	30.6	30.35	27.27	28.16
Wt of container	22.3	21.8	23.01	23.11	21.81	23.1
Wt of water	7.13	6.59	5.48	5.34	2.53	2.35
Wt of dry soil	10.31	9.47	7.59	7.24	5.46	5.07
Moisture content %	69.16	69.59	72.20	73.76	46.34	46.35
	LL=77.17				Av.PL=46.34	

Table-13.7 Liquid and plastic limit of 90% Soil+4% Lime +6% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	33	28	23	18		
container no	24	41	340	306	47	364
Wt of container + wet soil	43.82	43.65	41.93	40.59	30.36	30.23
Wt of container + dry soil	35.26	35.22	34.2	33.22	27.8	27.91
Wt of container	22.39	22.9	23	23	22.5	23.1
Wt of water	8.56	8.43	7.73	7.37	2.56	2.32
Wt of dry soil	12.87	12.32	11.2	10.22	5.3	4.81
Moisture content %	66.51	68.43	69.02	72.11	48.30	48.23
LL=69.017					Av.PL=48.27	

Table-13.8 Liquid and plastic limit of 87% Soil+4% Lime +9% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	33	29	23	18		
container no	314	366	145	G	369	129
Wt of container + wet soil	44.52	41.4	42.09	40.85	32.35	32.29
Wt of container + dry soil	35.31	33.62	33.75	33.03	28.69	29.02
Wt of container	21.3	21.8	21.6	22.22	21.5	22.5
Wt of water	9.21	7.78	8.34	7.82	3.66	3.27
Wt of dry soil	14.01	11.82	12.15	10.81	7.19	6.52
Moisture content %	65.74	65.82	68.64	72.34	50.90	50.15
	LL=68.14				Av.PL=50.53	

Table-13.9 Liquid and plastic limit of 84% Soil+4% Lime +12% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	36	28	23	15		
container no	32	144	349	145	324	336
Wt of container + wet soil	45.77	41.07	41.06	41.47	35.81	34.88
Wt of container + dry soil	36.69	33.59	33.38	33.47	31.26	30.29
Wt of container	22.6	22.1	21.8	21.6	22.69	21.8
Wt of water	9.08	7.48	7.68	8	4.55	4.59
Wt of dry soil	14.09	11.49	11.58	11.87	8.57	8.52
Moisture content %	64.44	65.10	66.32	67.40	53.09	53.87
	LL=65.82				Av.PL=53.48	

Table-13.10 Liquid and plastic limit of 91% Soil+6% Lime +3% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	33	28	23	18		
container no	319	144	31	346	389	346
Wt of container + wet soil	41.22	40.76	41.83	48.92	29.83	29.06
Wt of container + dry soil	34.03	33.38	33.35	38.42	27.54	26.88
Wt of container	23	22.1	20.6	22.85	22.9	22.5
Wt of water	7.19	7.38	8.48	10.5	2.29	2.18
Wt of dry soil	11.03	11.28	12.75	15.57	4.64	4.38
Moisture content %	65.19	65.43	66.51	67.44	49.35	49.77
	LL=66.14				Av.PL=49.56	

Table-13.11 Liquid and plastic limit of 88% Soil+6% Lime +6% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	32	27	23	16		
container no	2	350	7	315	36	4
Wt of container + wet soil	47.06	40.07	50.46	43.18	33.62	32.7
Wt of container + dry soil	39.32	33.29	41.29	35.11	31.25	29.01
Wt of container	26.87	22.6	26.94	22.5	26.8	22.2
Wt of water	7.74	6.78	9.17	8.07	2.37	3.69
Wt of dry soil	12.45	10.69	14.35	12.61	4.45	6.86
Moisture content %	62.17	63.42	63.90	64.00	53.26	53.79
	LL=63.37				Av.PL=53.52	

Table-13.12 Liquid and plastic limit of 85% Soil+6% Lime +9% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	33	28	23	17		
container no	47	24	306	336	41	349
Wt of container + wet soil	41	42.69	43.47	35.14	35.94	35.83
Wt of container + dry soil	34.08	34.82	36.98	30.06	31.29	31.36
Wt of container	22.8	22.22	26.8	22.2	22.5	23.0
Wt of water	6.92	7.87	6.49	5.08	4.65	4.47
Wt of dry soil	11.28	12.6	10.18	7.86	8.79	8.36
Moisture content %	61.35	62.46	63.75	64.63	52.90	53.47
	LL=63.048				Av.PL=53.18	

Table-13.13 Liquid and plastic limit of 82% Soil+6% Lime +12% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	32	27	23	17		
container no	3	340	8	324	311	301
Wt of container + wet soil	50.83	45.02	44.2	45.55	27.62	28.72
Wt of container + dry soil	40.28	36.39	35.86	38.45	26.01	26.85
Wt of container	22.73	22.23	22.2	26.87	23.11	23.5
Wt of water	10.55	8.63	8.34	7.1	1.61	1.87
Wt of dry soil	17.55	14.16	13.66	11.58	2.9	3.35
Moisture content %	60.11	60.95	61.05	61.31	55.52	55.82
	LL=60.86				Av.PL=55.67	

Table-13.14 Liquid and plastic limit of 89% Soil+8% Lime +3% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	32	28	23	17		
container no	331	32	369	145	370	1
Wt of container + wet soil	41.66	39.33	38.33	41.32	31.42	31.47
Wt of container + dry soil	34.41	32.85	31.72	33.56	28.42	28.37
Wt of container	22.7	22.6	21.5	21.6	22.5	22.2
Wt of water	7.25	6.48	6.61	7.76	3	3.1
Wt of dry soil	11.71	10.25	10.22	11.96	5.92	6.14
Moisture content %	61.91	63.22	64.68	64.88	50.68	50.49
	LL=63.67				Av.PL=50.58	

Table-13.15 Liquid and plastic limit of 86% Soil+8% Lime +6% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	32	27	23	18		
container no	318	31	144	346	389	319
Wt of container + wet soil	37	37.1	40.24	41.45	31.92	32.49
Wt of container + dry soil	30.76	30.92	33.19	34.18	28.85	29.21
Wt of container	20.6	21.1	22.1	22.8	22.9	23.0
Wt of water	6.24	6.18	7.05	7.27	3.07	3.28
Wt of dry soil	10.16	9.82	11.09	11.38	5.95	6.21
Moisture content %	61.42	62.93	63.57	63.88	51.60	52.82
	LL=62.95				Av.PL=52.21	

Table-13.16 Liquid and plastic limit of 83% Soil+8% Lime +9% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	35	28	22	17		
container no	129	5	36	314	29	30
Wt of container + wet soil	45.21	39.72	47.39	48.86	34.15	33.78
Wt of container + dry soil	38.45	33.38	38.03	38.84	30.14	29.35
Wt of container	26.98	22.69	23.11	23.05	22.5	21.1
Wt of water	6.76	6.34	9.36	10.02	4.01	4.43
Wt of dry soil	11.47	10.69	14.92	15.79	7.64	8.25
Moisture content %	58.94	59.31	62.73	63.46	52.49	53.70
	LL=61.11				Av.PL=53.09	

Table-13.17 Liquid and plastic limit of 80% Soil+8% Lime +12% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	32	28	23	18		
container no	340	2	315	354	306	311
Wt of container + wet soil	38.84	37.36	39.04	34.97	36.65	37.23
Wt of container + dry soil	33.18	31.84	32.78	29.89	33.1	32.12
Wt of container	23.5	22.5	22.44	21.67	26.72	22.9
Wt of water	5.66	5.52	6.26	5.08	3.55	5.11
Wt of dry soil	9.68	9.34	10.34	8.22	6.38	9.22
Moisture content %	58.47	59.10	60.54	61.80	55.64	55.42
	LL=59.98				Av.PL=55.53	

Table-13.18 Liquid and plastic limit of 87% Soil+10% Lime +3% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	34	27	23	16		
container no	366	336	4	3	24	41
Wt of container + wet soil	42.62	37.9	37.87	46.22	31.69	33.09
Wt of container + dry soil	34.92	31.92	31.92	38.75	28.68	29.69
Wt of container	21.8	21.77	22.15	26.72	22.36	22.8
Wt of water	7.7	5.98	5.95	7.47	3.01	3.4
Wt of dry soil	13.12	10.15	9.77	12.03	6.32	6.89
Moisture content %	58.69	58.92	60.90	62.09	47.63	49.35
	LL=60.15				Av.PL=48.49	

Table-13.19 : Liquid and plastic limit of 84% Soil+10% Lime +6% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	32	28	23	18		
container no	349	27	364	350	47	301
Wt of container + wet soil	36.15	43.09	41.61	39.12	31.82	35.45
Wt of container + dry soil	30.94	35.47	34.66	32.85	28.71	31.47
Wt of container	21.8	22.23	23.05	22.58	22.5	23.5
Wt of water	5.21	7.62	6.95	6.27	3.11	3.98
Wt of dry soil	9.14	13.24	11.61	10.27	6.21	7.97
Moisture content %	57.00	57.55	59.86	61.05	50.08	49.94
	LL=58.87				Av.PL=50.01	

Table-13.20 Liquid and plastic limit of 81% Soil+10% Lime +9% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	33	28	22	18		
container no	370	332	319	144	G	145
Wt of container + wet soil	45.24	43.27	42.56	42.21	32.59	31.16
Wt of container + dry soil	36.97	35.99	35.38	34.79	29.08	27.89
Wt of container	22.5	23.3	23	22.1	22.22	21.6
Wt of water	8.27	7.28	7.18	7.42	3.51	3.27
Wt of dry soil	14.47	12.69	12.38	12.69	6.86	6.29
Moisture content %	57.15	57.37	58.00	58.47	51.17	51.99
	LL=57.75				Av.PL=51.58	

Table-13.21 Liquid and plastic limit of 78% Soil+10% Lime +12% WHA

LIQUID LIMIT					PLASTIC LIMIT	
No of blows	34	28	23	18		
container no	318	32	369	346	331	129
Wt of container + wet soil	37.87	43.42	39.26	35.14	27.5	28.1
Wt of container + dry soil	31.78	35.99	32.88	30.64	25.82	26.16
Wt of container	20.6	22.6	21.5	22.8	22.7	22.5
Wt of water	6.09	7.43	6.38	4.5	1.68	1.94
Wt of dry soil	11.18	13.39	11.38	7.84	3.12	3.66
Moisture content %	54.47	55.49	56.06	57.40	53.85	53.01
	LL=55.86				Av.PL=53.43	

STANDARD PROCTOR TEST (ASTM D 698)

Table 14.1: Maximum dry density and Optimum moisture content for un treated expansive soil

1.Determination of Maximum Dry Density(MDD) and optimum moisture content (OMC) for untreated soil (ASTM D 698)							
Trial No	1	2	3	4	5	6	
Mass mould+ wet soil(gm) (A)	5120	5198	5258	5298	5340	5334	
Mass of mould(gm) (B)	3794	3794	3794	3794	3794	3794	
Mass of wet soil (gm) (A-B=(C)	1326	1404	1464	1504	1546	1540	
Volume of mould cm3 (D)	944	944	944	944	944	944	
Bulk density gm/cm3 =(E)	1405	1487	1551	1593	1638	1631	
Container No	B4	A3	K1	A2	B	14	NMC
Mass of wet soil + Container (gm) (F)	140.46	114.15	118.58	112.16	125.68	156.24	128.36
Mass of dry soil + Container (gm) (G)	118.8	95.39	97.08	90.28	98.98	119.52	121.66
Mass of container (gm) (H)	18.05	18.7	18.8	18.46	19.1	18.85	18.21
Mass of water (gm) F-G =(I)	21.66	18.76	21.50	21.88	26.70	36.72	6.70
Mass of dry soil (gm) G-H=(J)	100.75	76.69	78.28	71.82	79.88	100.67	103.45
Moisture content % (I/J)*100 =K	21.50	24.46	27.47	30.47	33.43	36.48	6.48
Dry density gm/cm3 E/((100+K)*100)	1156	1195	1217	1221	1227	1195	

From the compaction curve: MDD = 1.227 g/cm3 and OMC = 33.4 %

STANDARD PROCTOR TEST

The degree of compaction of a soil is measured in terms of its dry density. The degree of compaction mainly depends upon its moisture content, compaction energy and type of soil. For a given compaction energy every soil attains the maximum dry density at a particular water content which is known as optimum moisture content. The readings for standard proctor compaction test results of soil with different percentage of lime and wheat husk ash are as below:

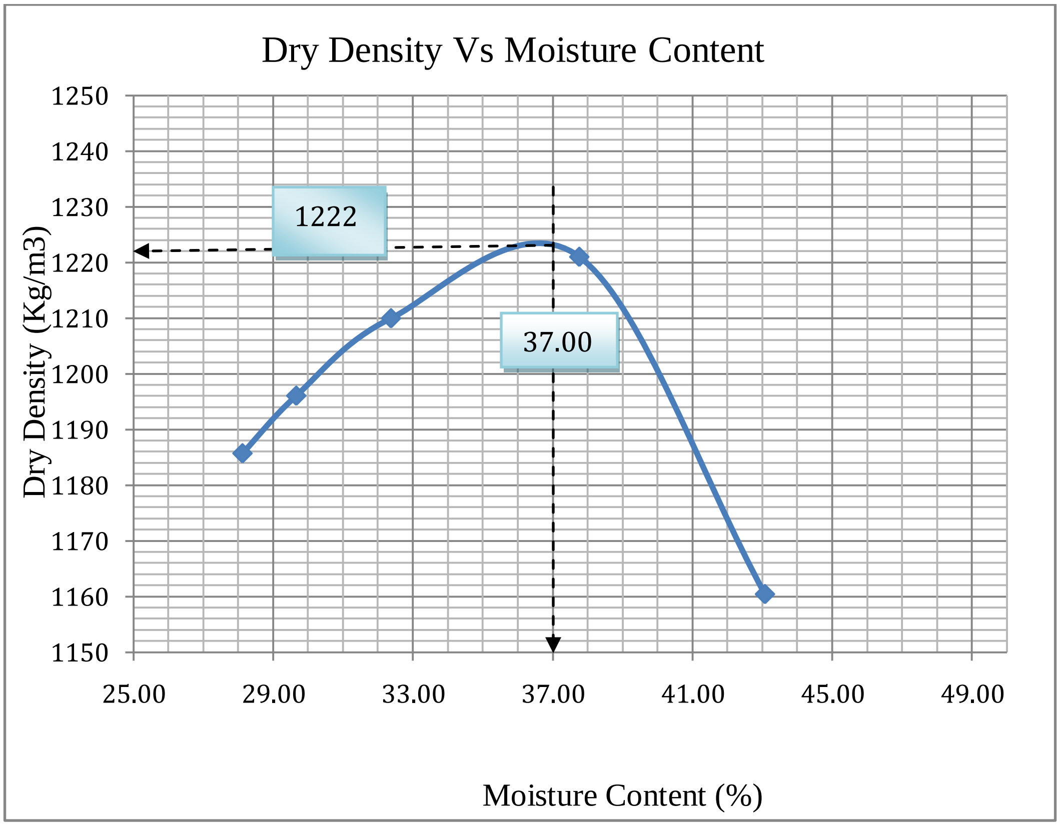


Figure-7.1 Soil sample+2% Lime +3% WHA

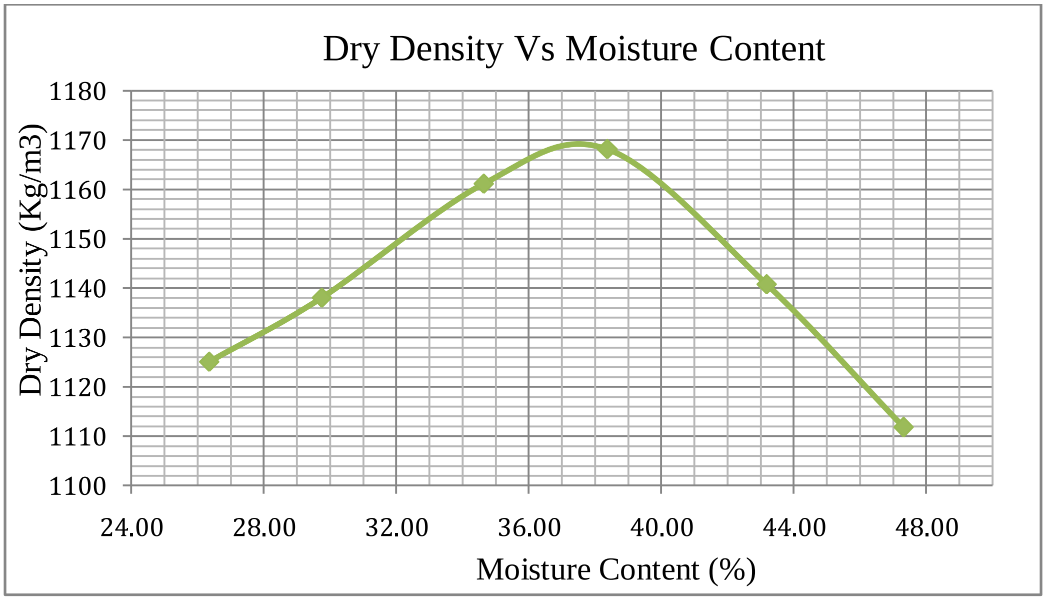


Figure-7.2 Soil sample +2% Lime +6% WHA

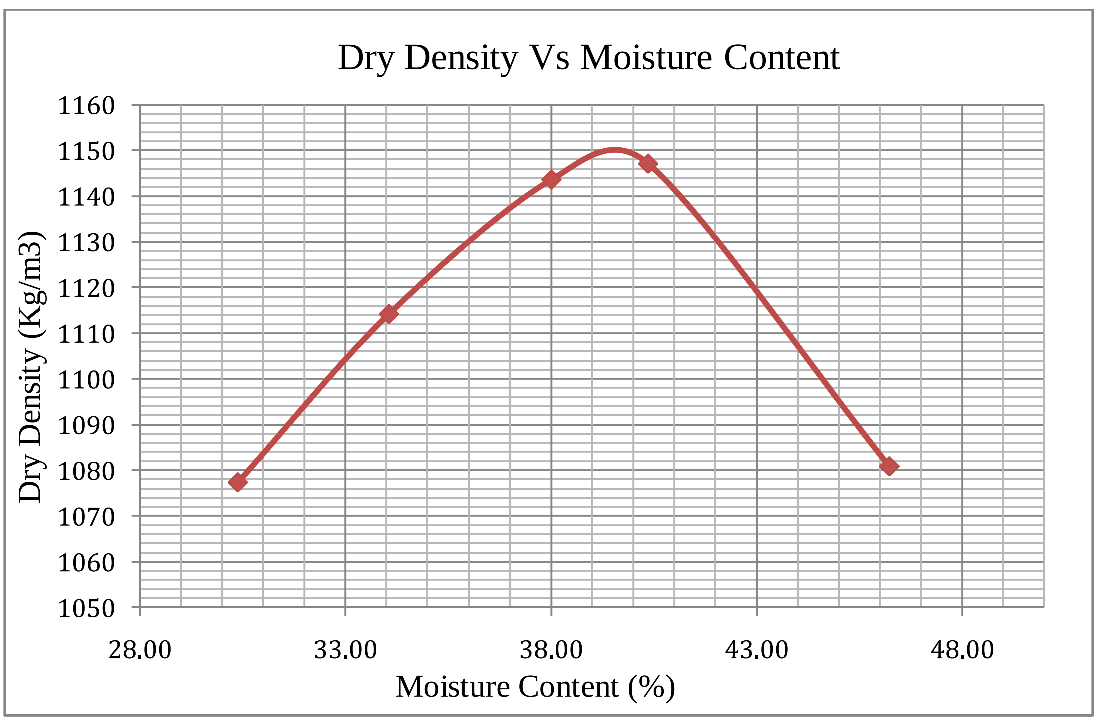


Figure-7.3 Soil sample + 2% lime+ 9% WHA

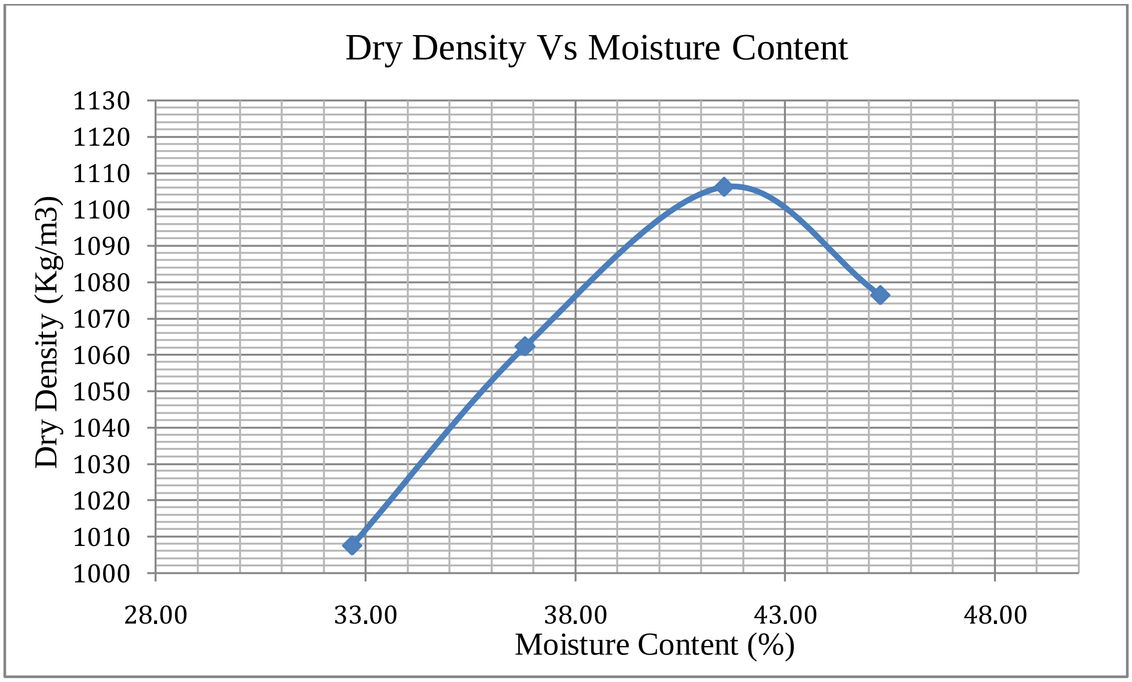


Figure-7.4 Soil sample + 2% lime+ 12% WHA

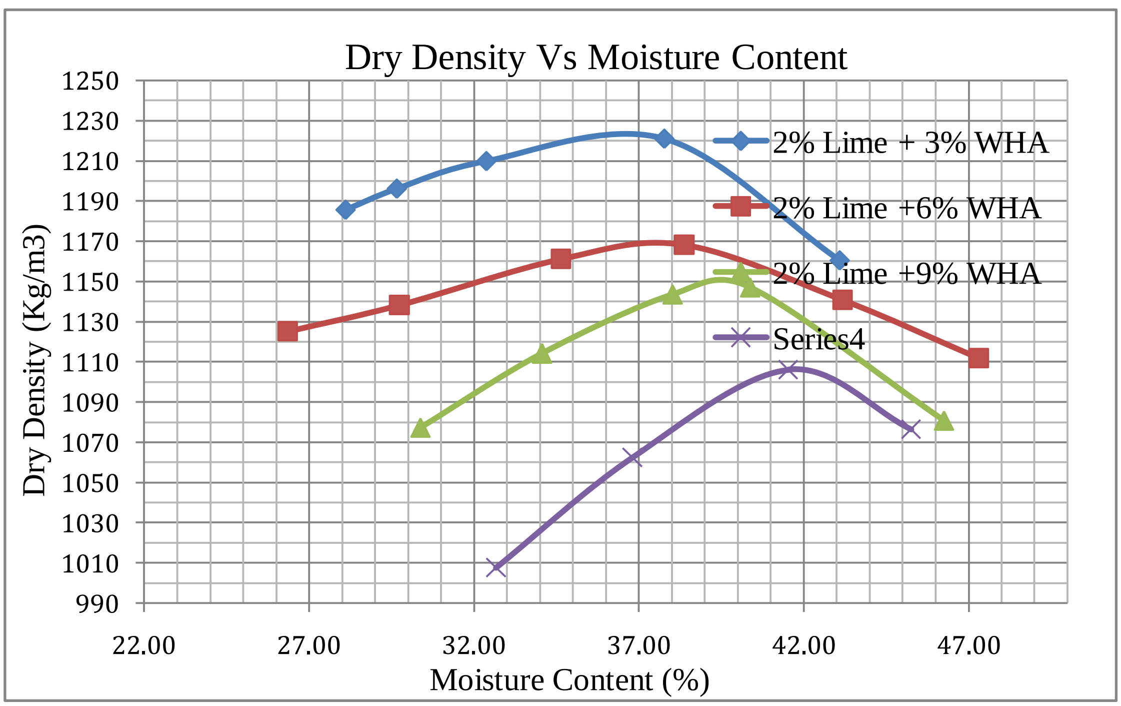


Figure-7.5 Soil sample + 2% lime + varying percent of WHA

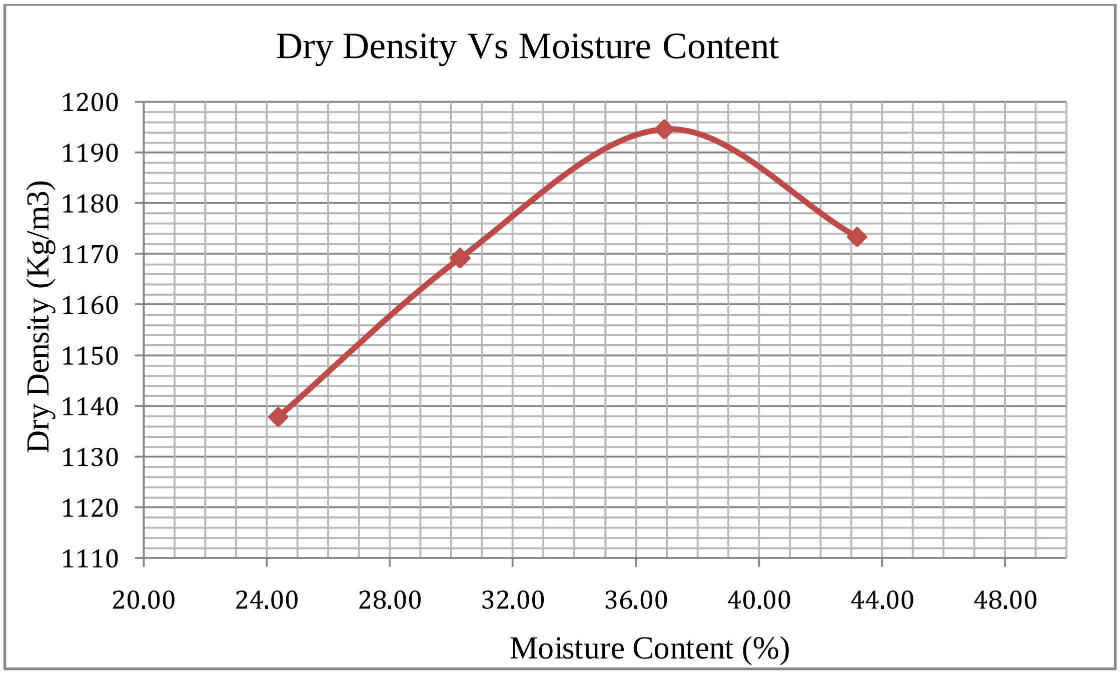


Figure-7.6 Soil sample + 4% lime+ 3% WHA

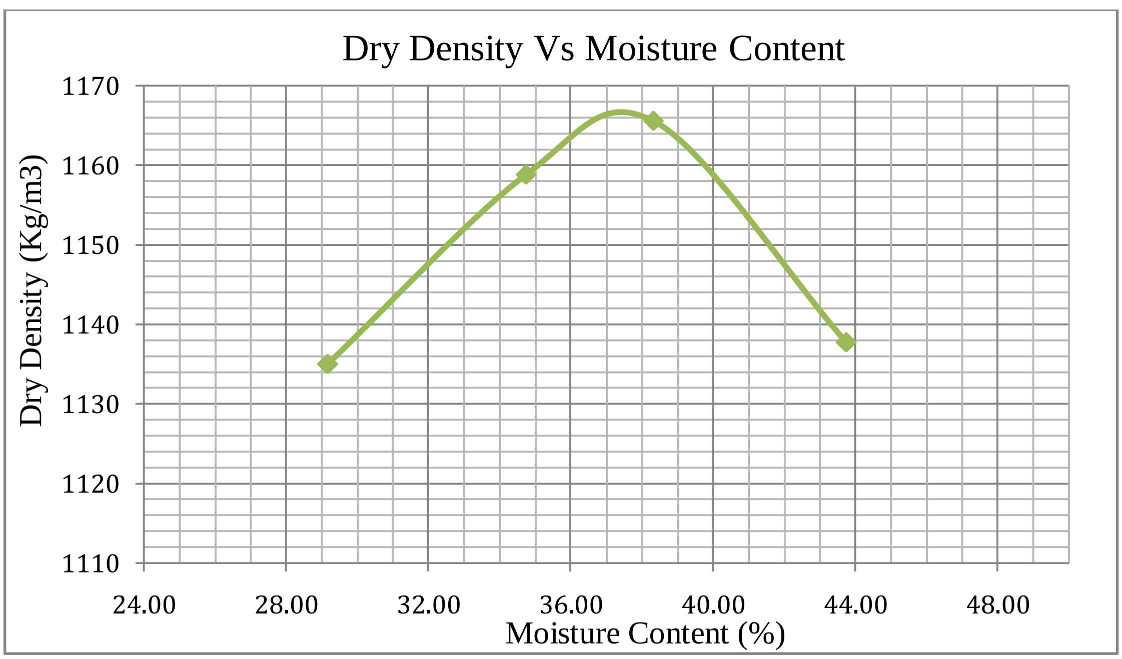


Figure-7.7 Soil sample +4% Lime +6% WHA

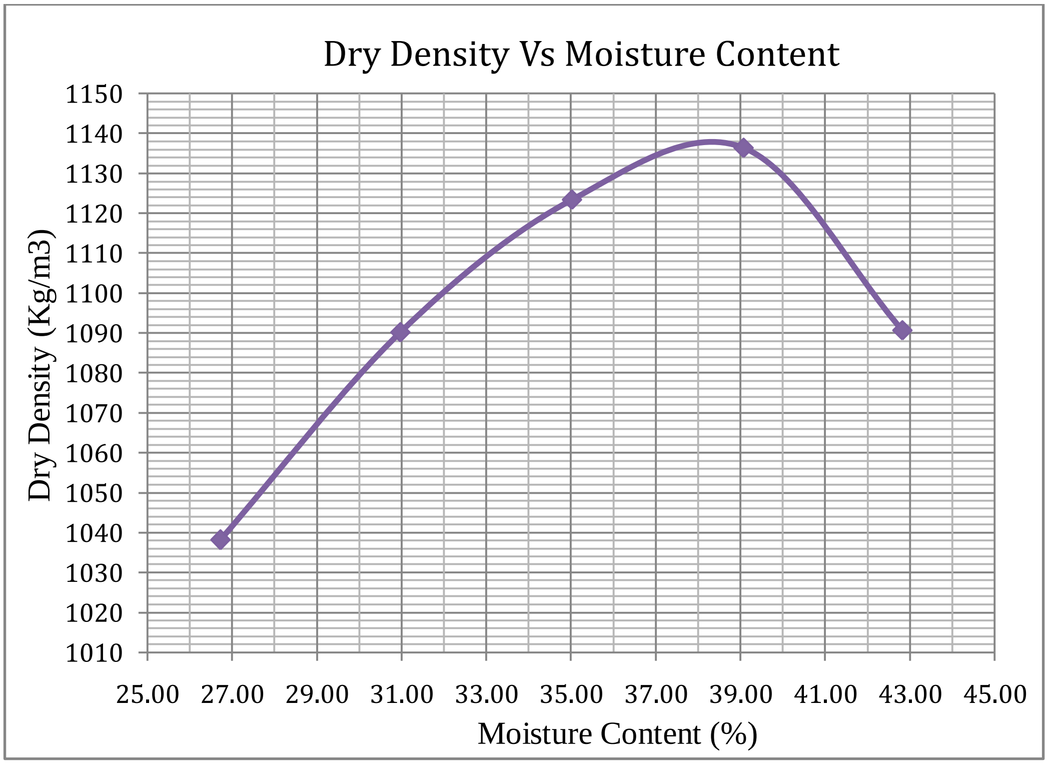


Figure-7.8 Soil sample + 4% lime+9% WHA

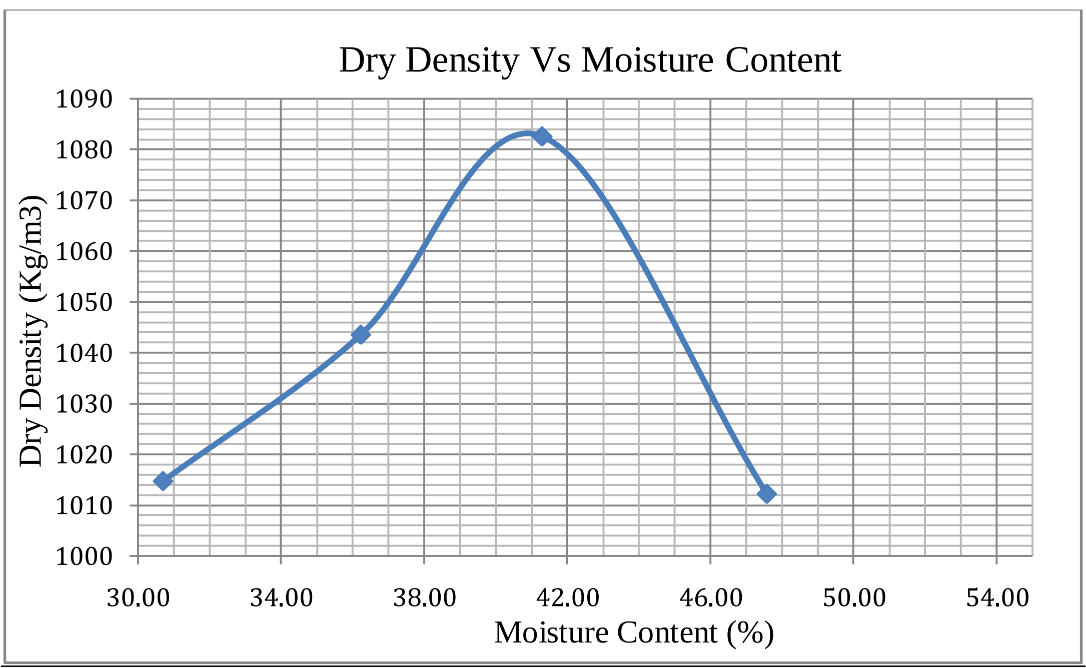


Figure-7.9 Soil sample + 4% lime+12% WHA

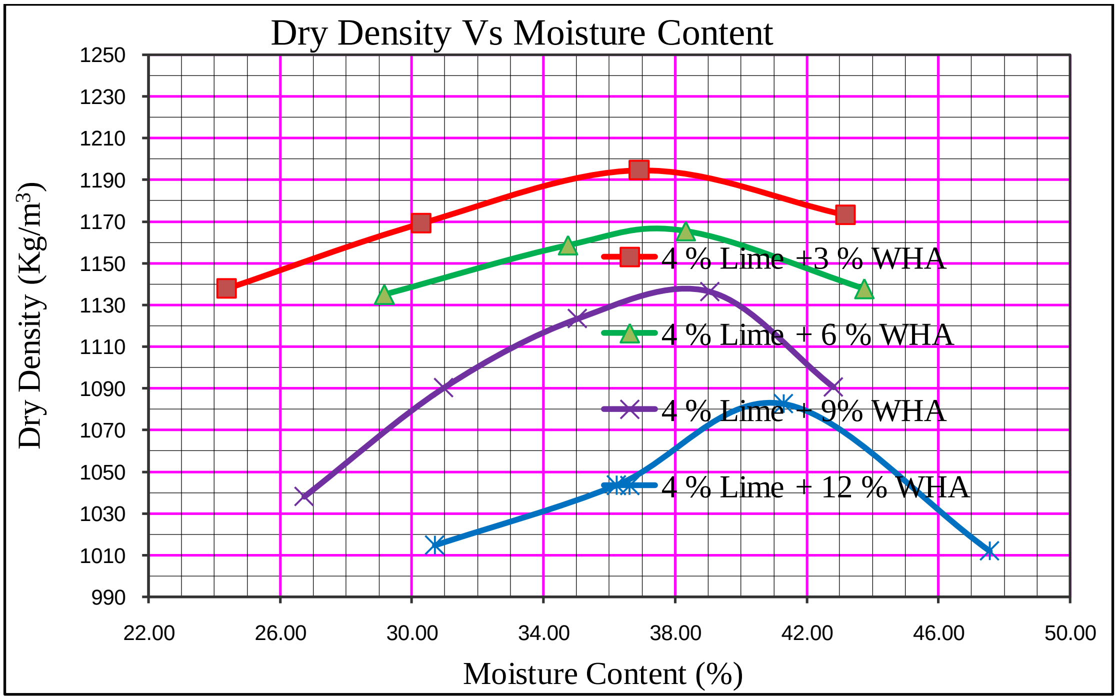


Figure-7.10 Soil sample + 4% lime+ varying percent WHA

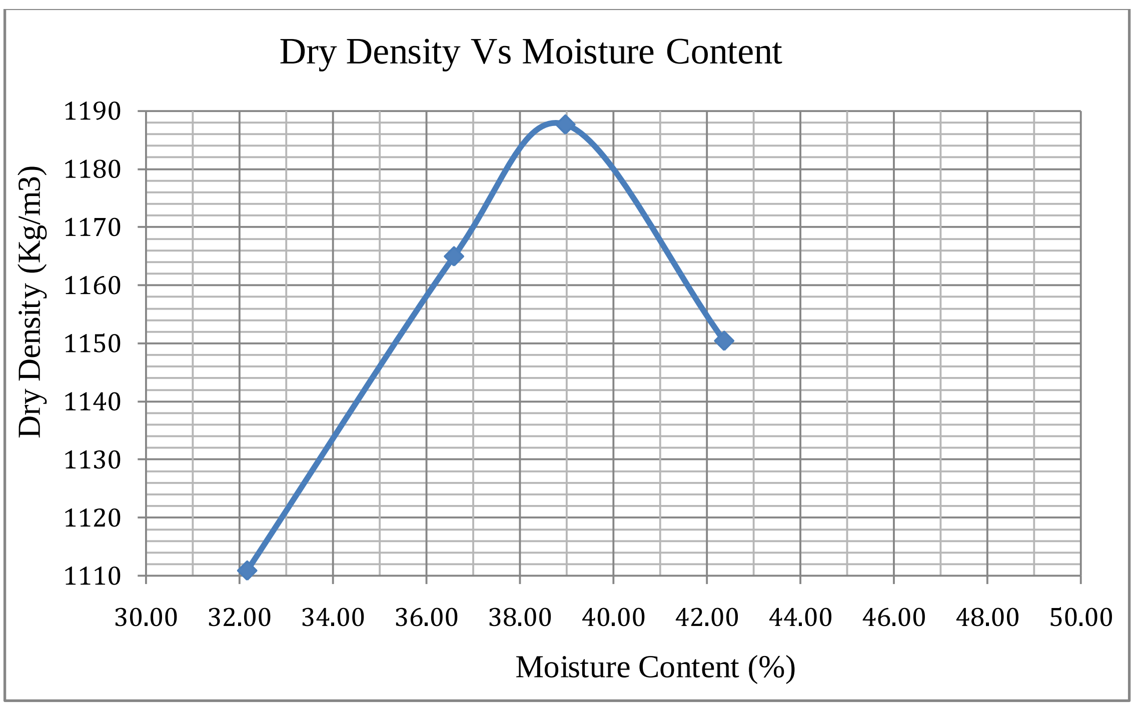


Figure-7.11 Soil sample + 6% lime+ 3% WHA

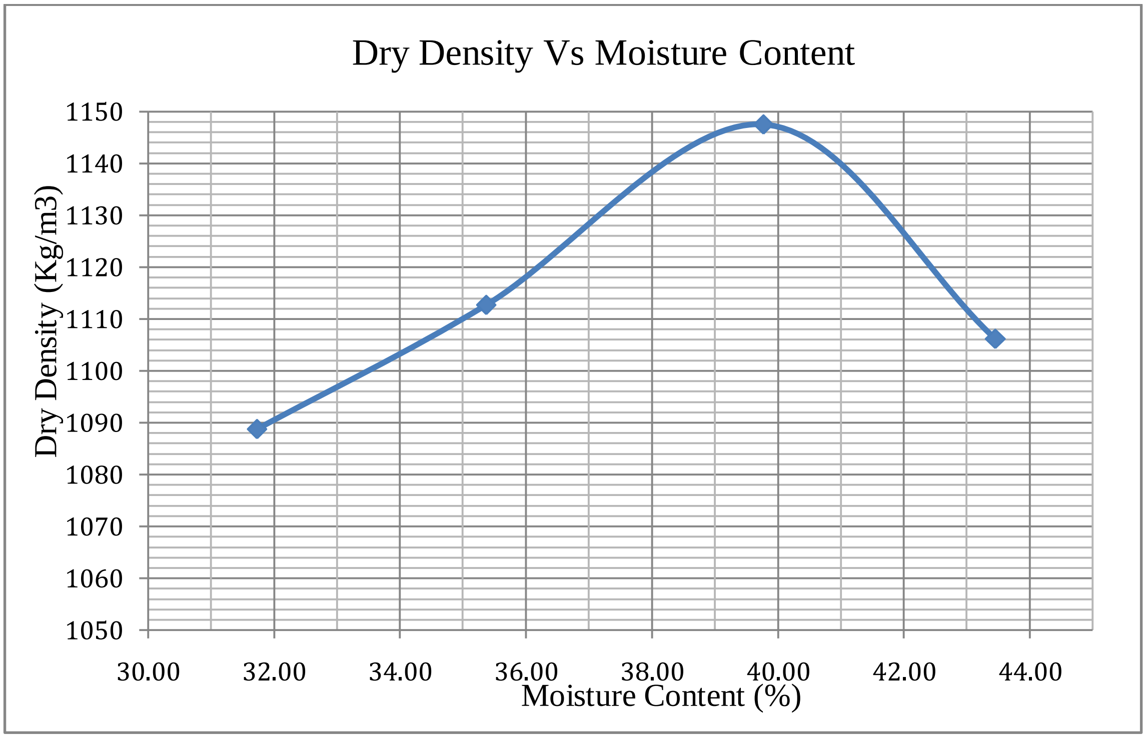


Figure-7.12 Soil sample+ 6% lime+ 6%WHA

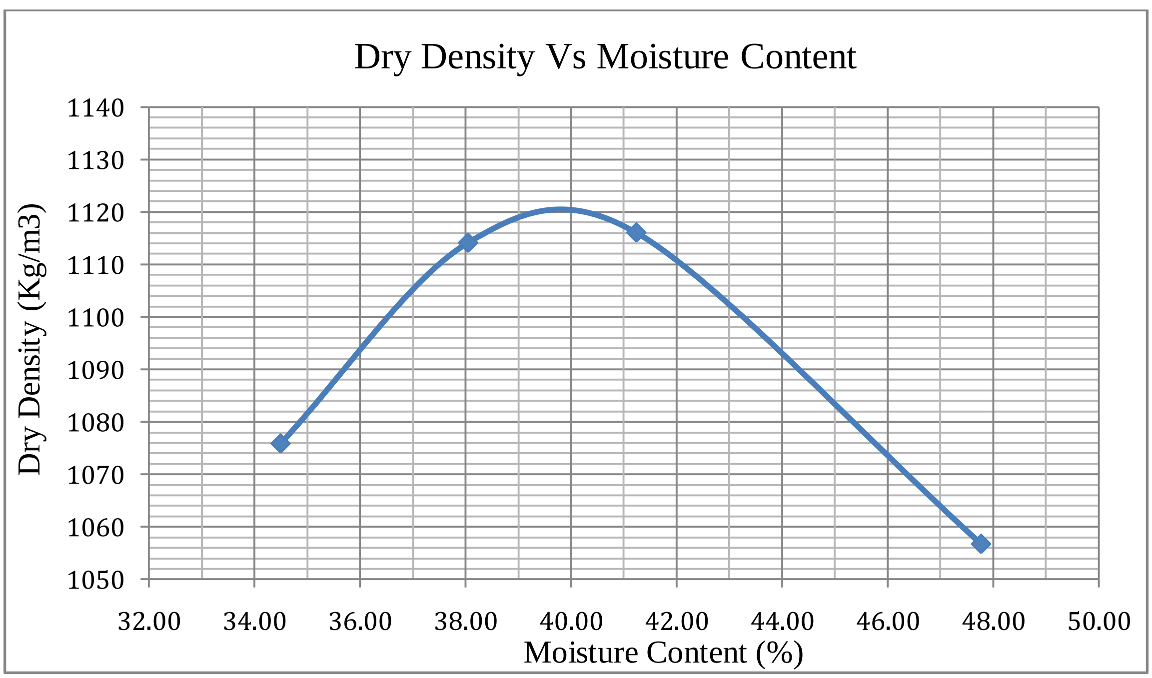


Figure-7.13 Soil saple+6% lime+9% WHA

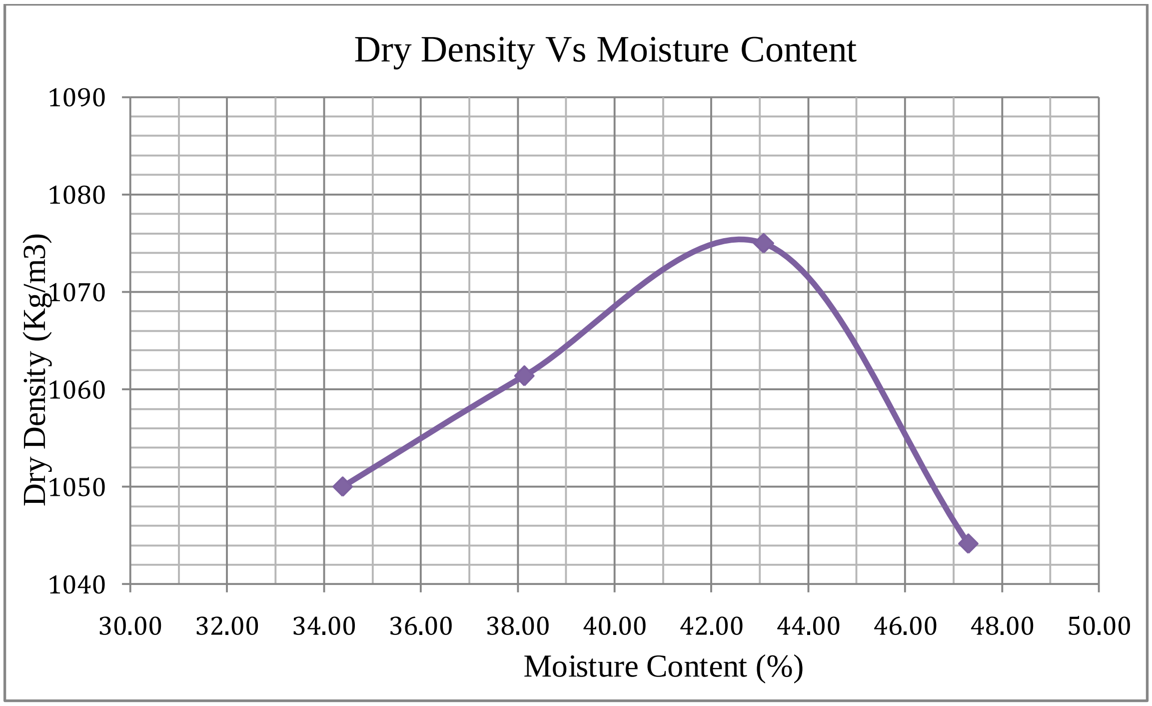


Figure-7.14 Soil sample+6% lime+12% WHA

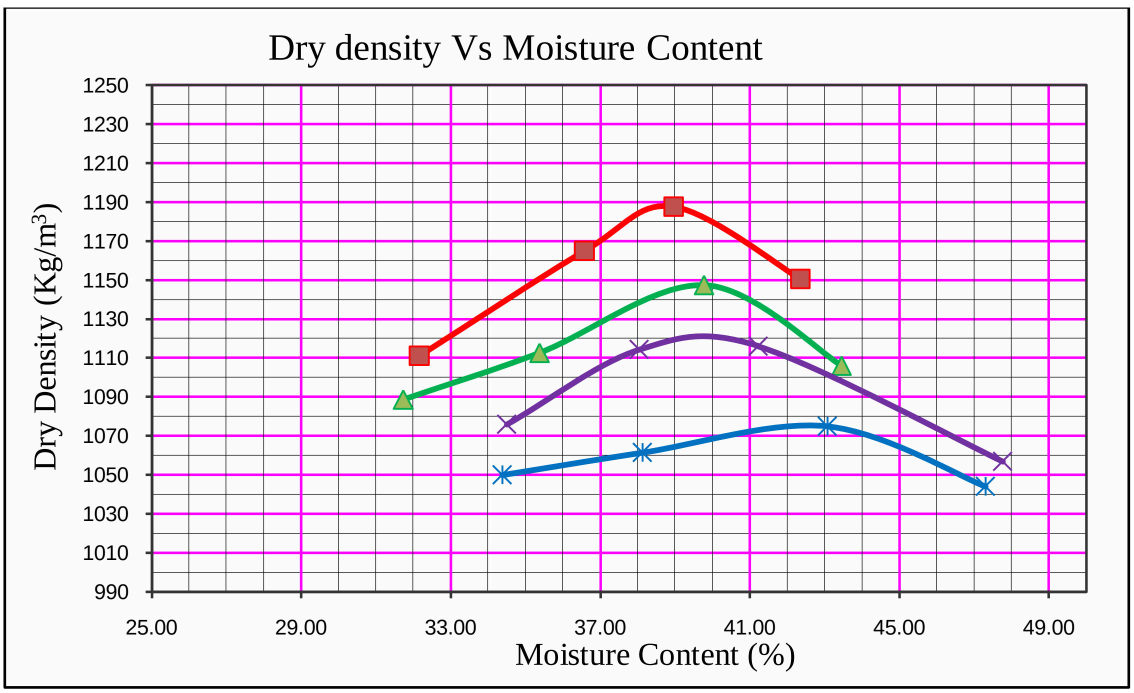


Figure-7.15 Summary of compaction of soil-6% lime+ Var. % WHA

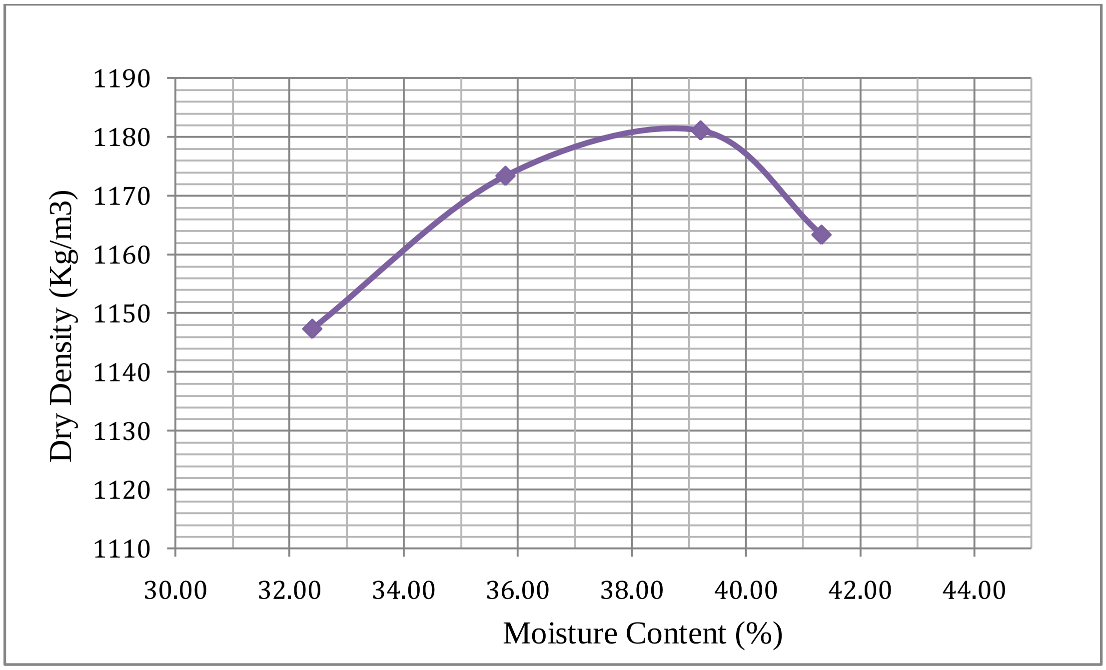


Figure-7.16 Soil sample+8% lime+3% WHA

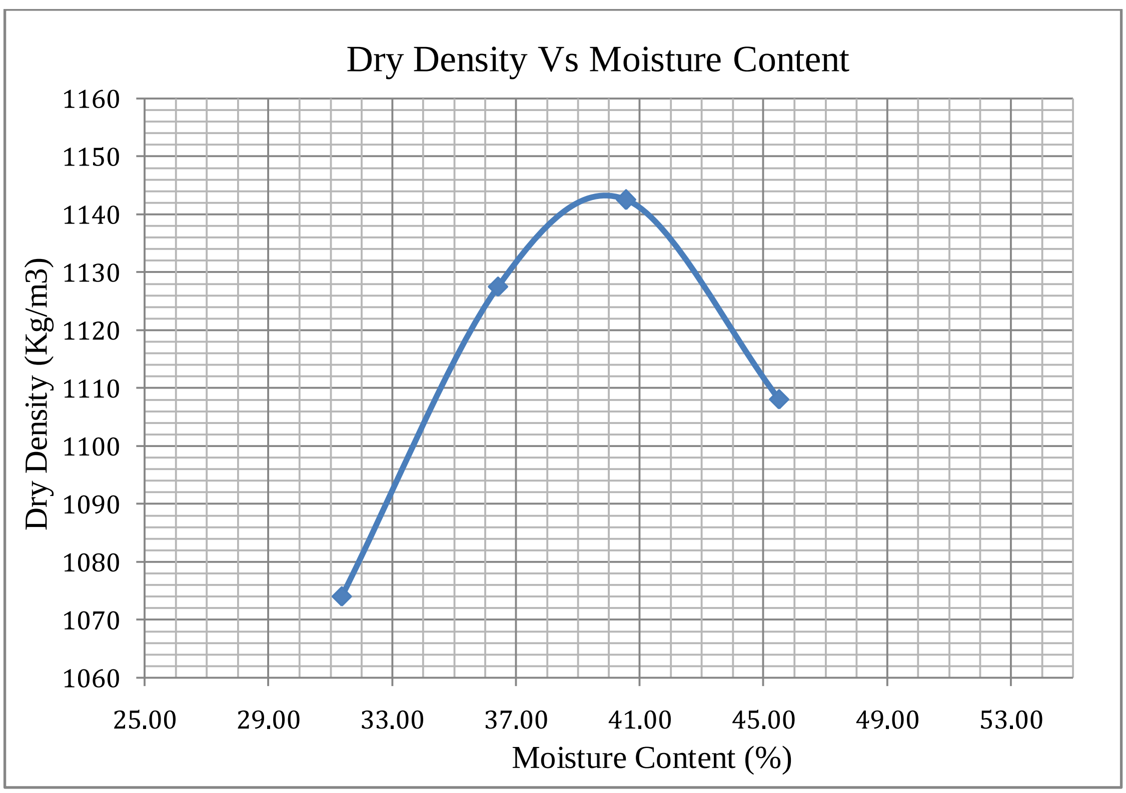


Figure-7.17 Soil sample+8% lime+6% WHA

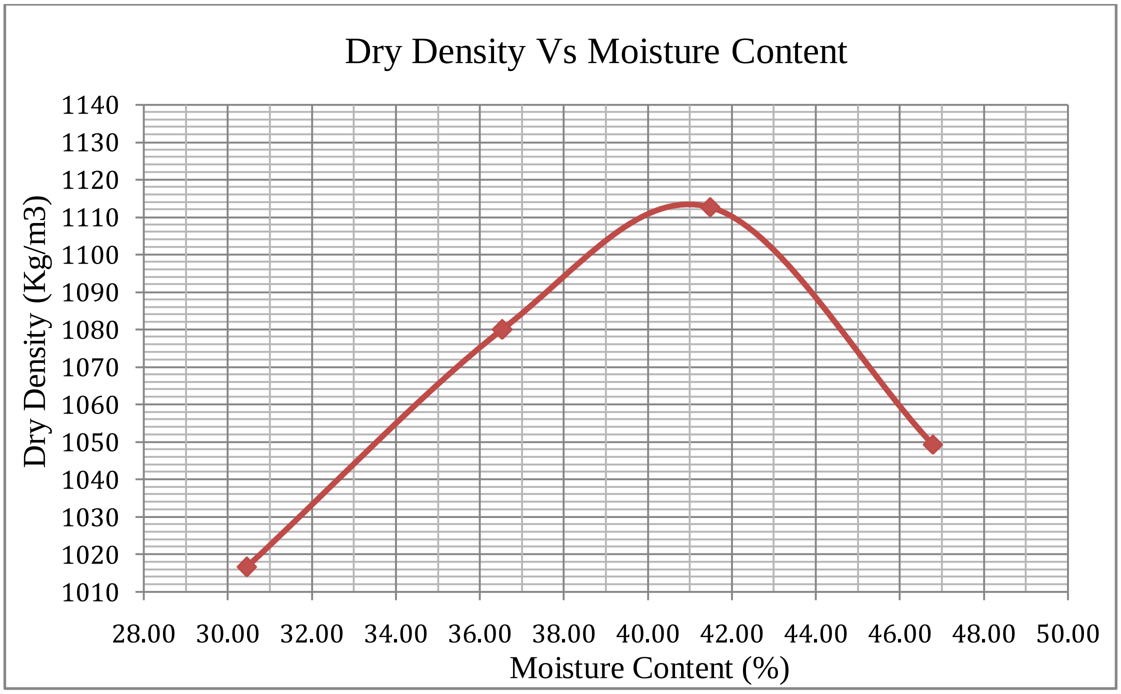


Figure-7.18 Soil sample+8% lime+9% WHA

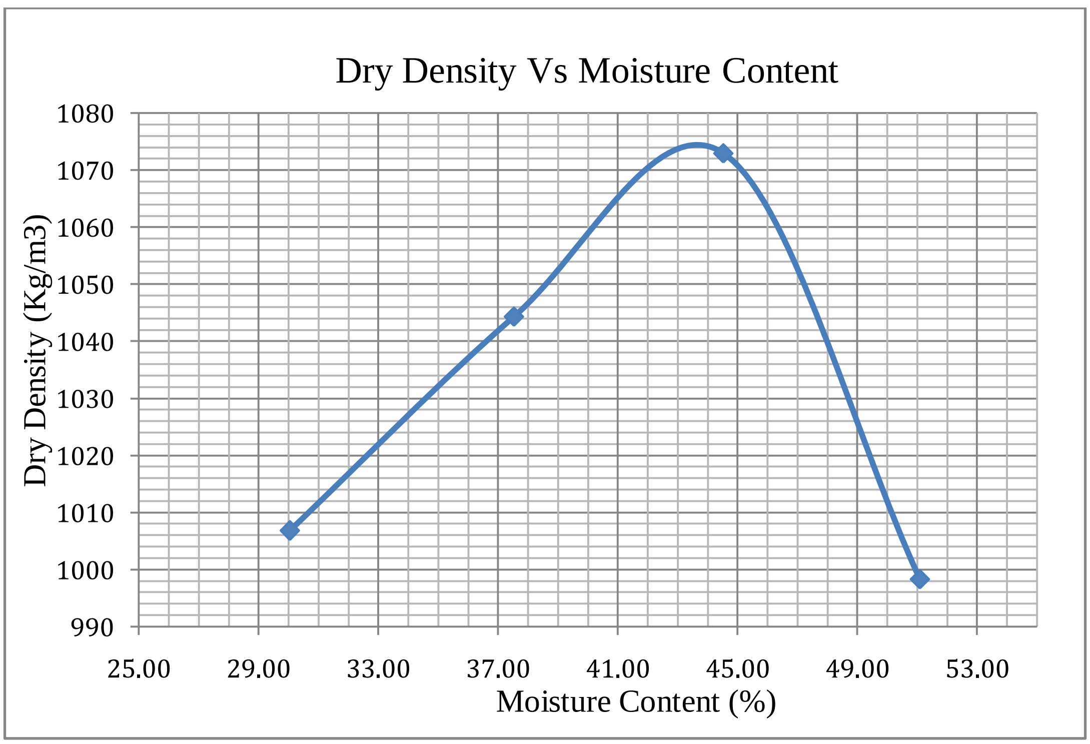


Figure-7.19 Soil sample + 8% lime+12% WHA

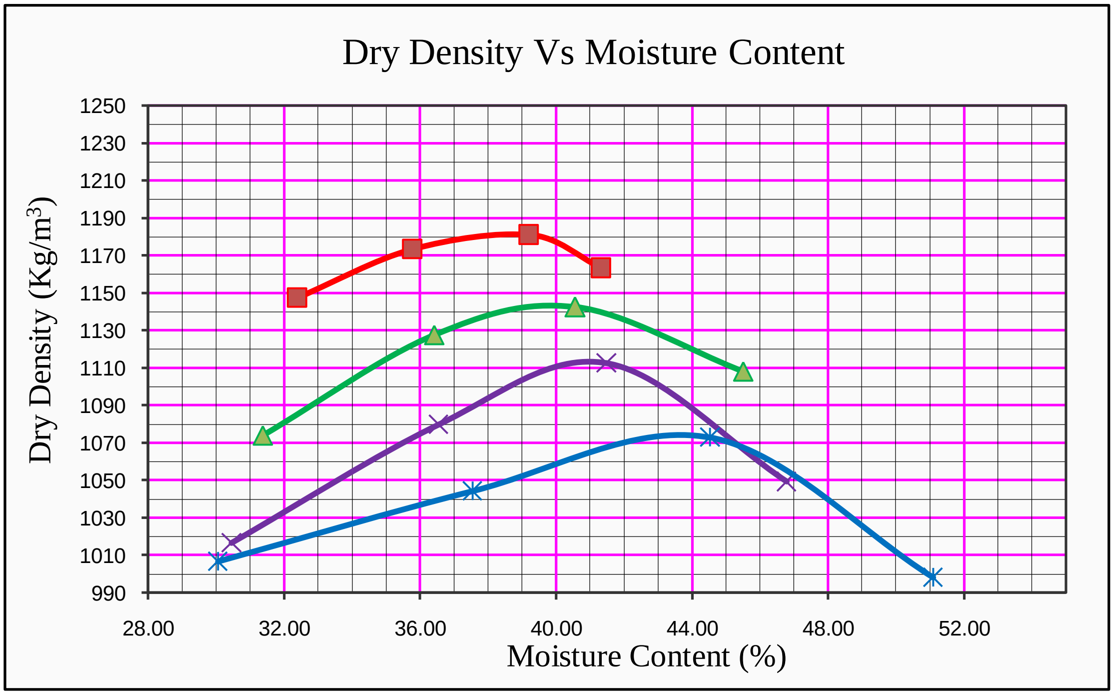


Figure-7.20 Soil sample + 8% lime + varying% WHA

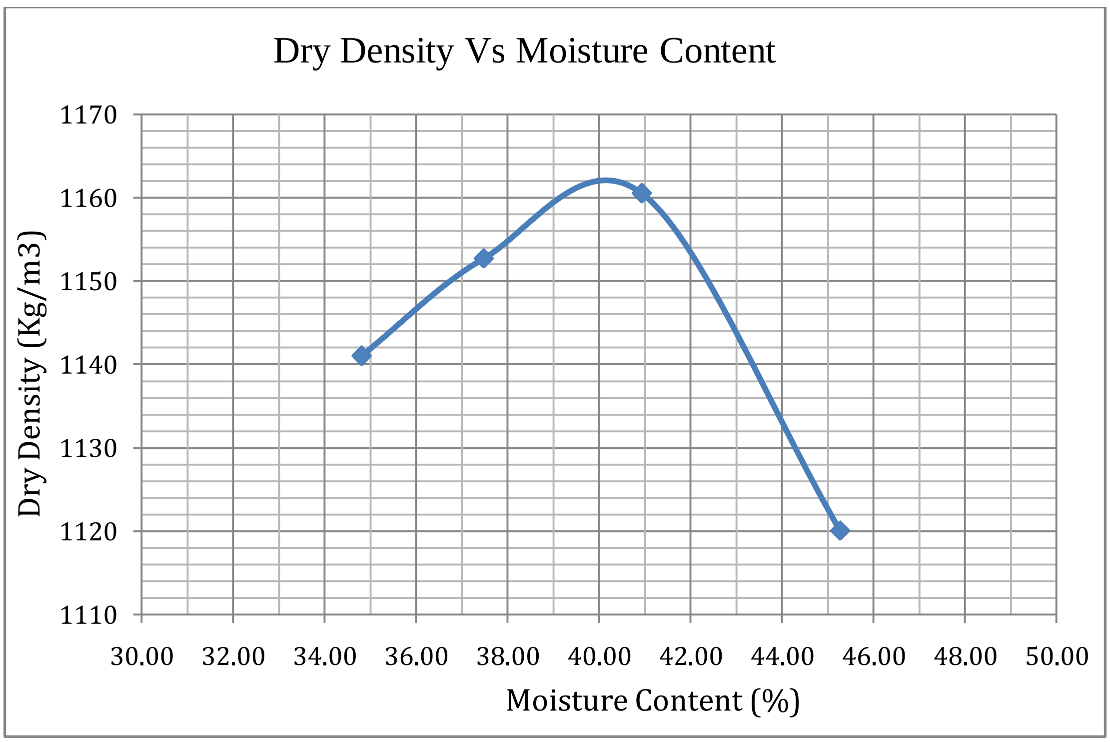


Figure-7.21 Soil sample +10% lime+ 3% WHA

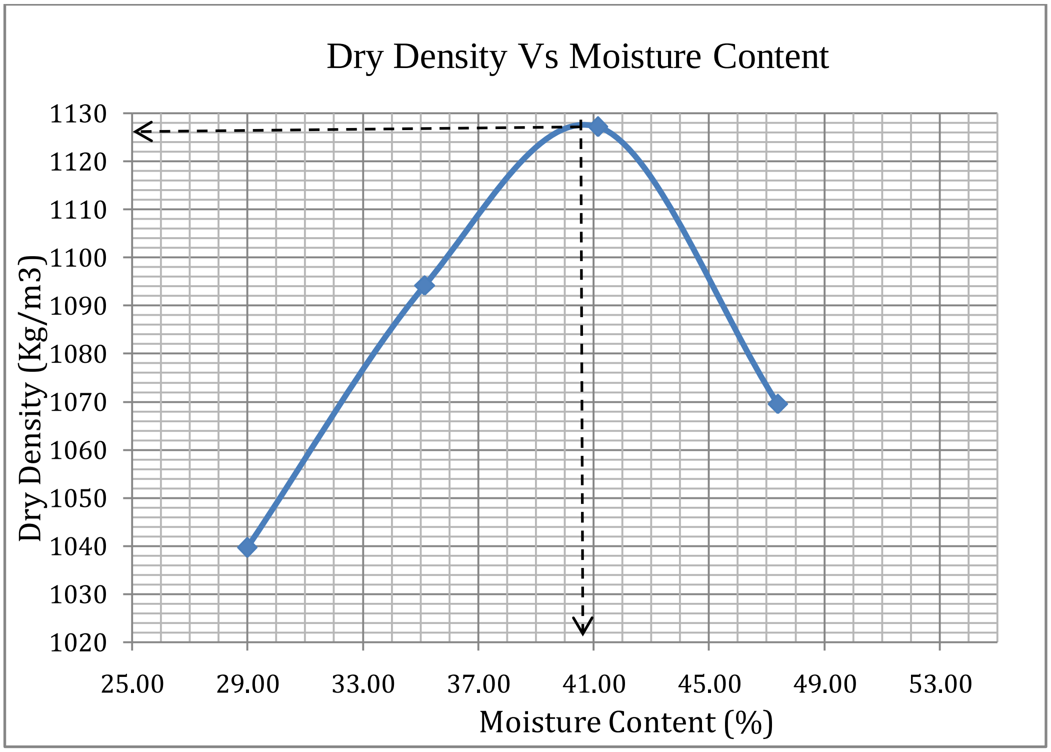


Figure-7.22 Soil sample+10% lime+ 6% WHA

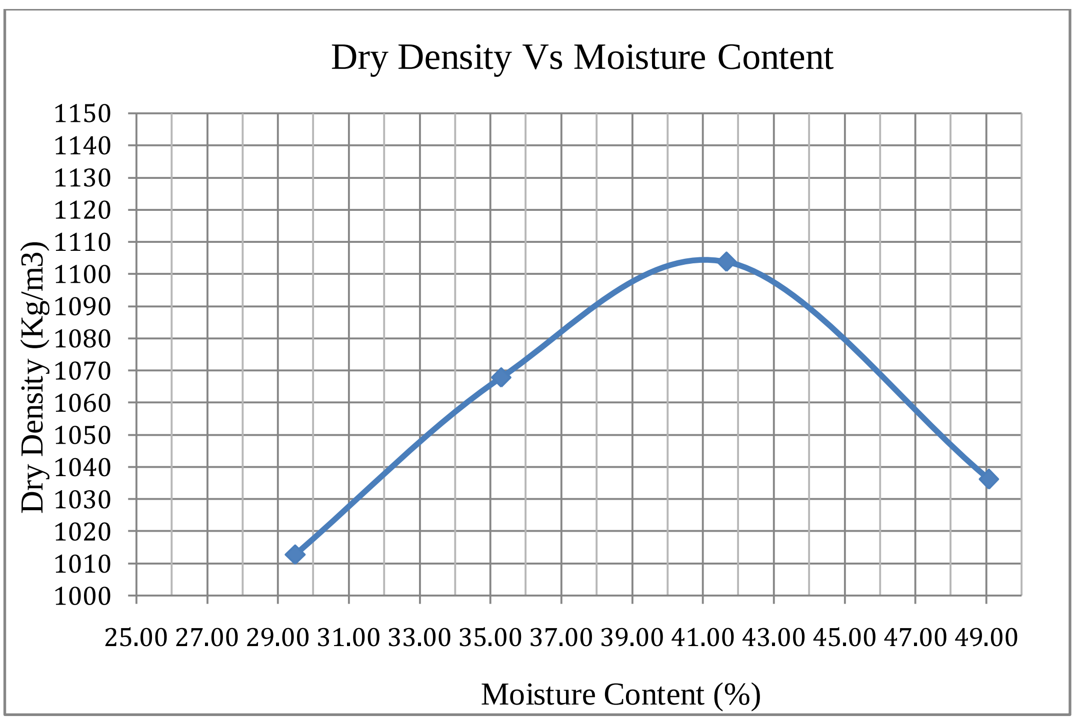


Figure-7.23 Soil sample + 10% lime+ 9% WHA

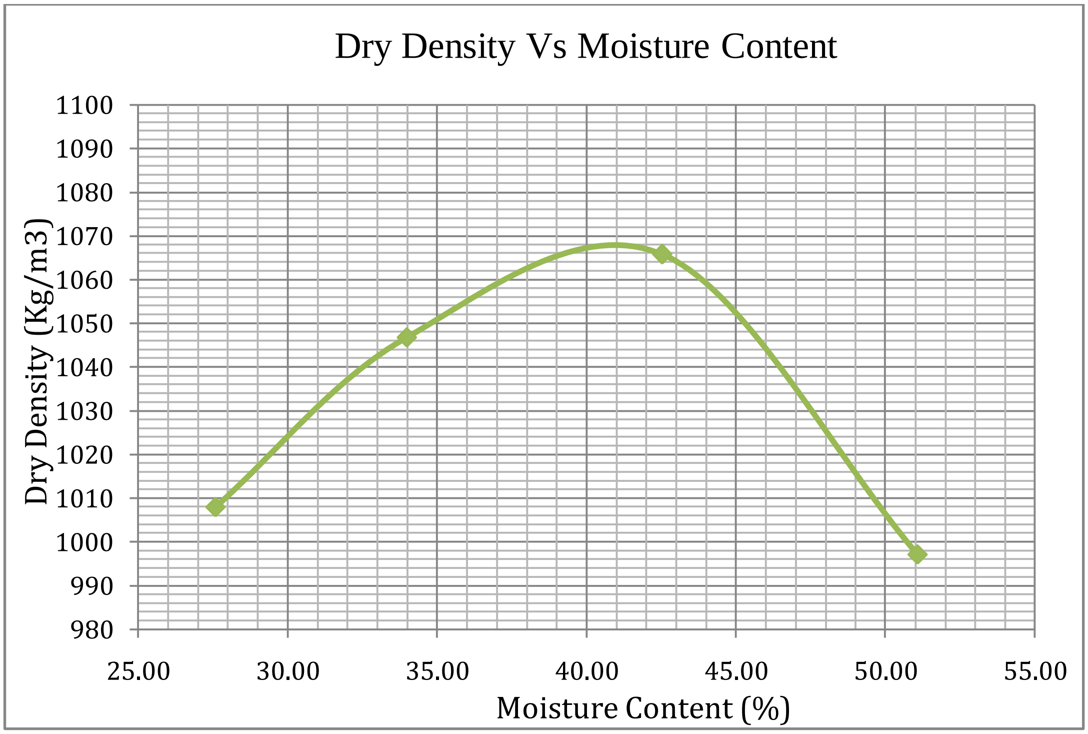


Figure-7.24 Soil sample + 10% lime+ 12% WHA

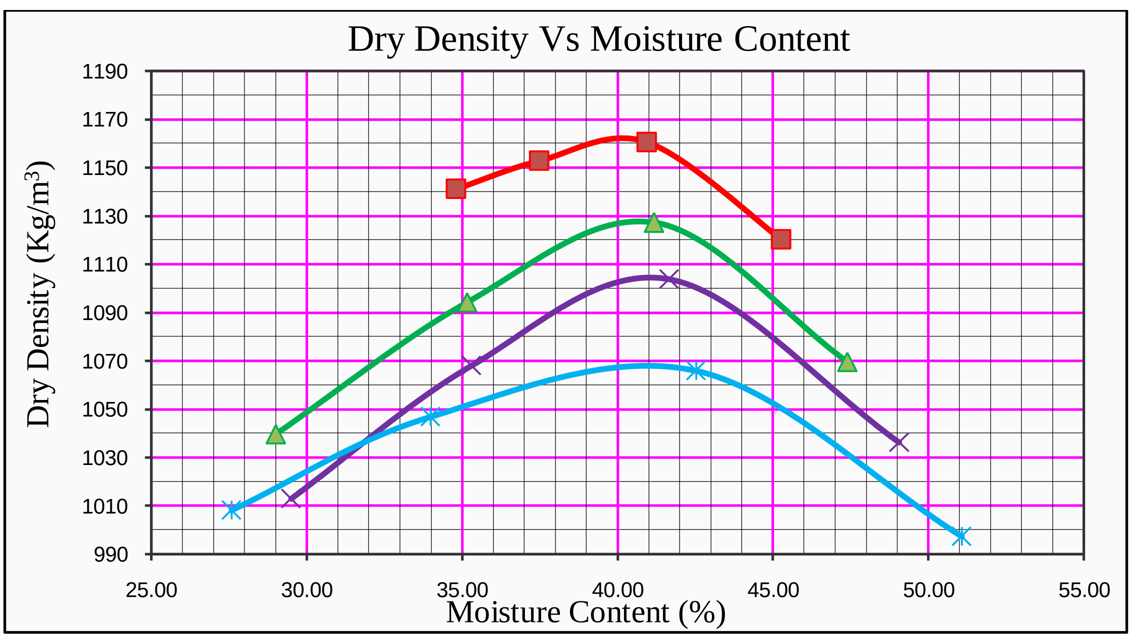


Figure-7.25 Soil sample + 10% lime+ varying % WHA

UNCONFINED COMPRESSIVE STRENGTH TEST

A) UNSOAKED (0) DAYS UNCONFINED COMPRESSIVE STRENGTH

Table-15.1: **Unconfined compressive strength test of expansive soil**

SL No	OBSERVATION				CALCULATION				
	Dial Gauge		Proving ring						
	Reading	Deformation ΔL(mm) , Lc =0.001mm	Dial Reading	Load (kN)	Strain(ε) =ΔL/Lo	% Strain	Area(Ao) ,m2	Corrected Area =Ao/(1-ε)	Stress, σ= P/A, (kN/m2)
1	0.0	0.000	0.0	0.00	0.000	0.00	0.001	0.0011	0.00
2	20	0.200	15	0.02	0.003	0.26	0.001	0.0011	19.82
3	40	0.400	28	0.04	0.005	0.53	0.001	0.0011	36.91
4	60	0.600	42	0.06	0.008	0.79	0.001	0.0011	55.21
5	80	0.800	51	0.08	0.011	1.05	0.001	0.0012	66.87
6	100	1.000	60	0.09	0.013	1.32	0.001	0.0012	78.46
7	120	1.200	65	0.10	0.016	1.58	0.001	0.0012	84.77
8	140	1.400	67	0.10	0.018	1.84	0.001	0.0012	87.14
9	160	1.600	66	0.10	0.021	2.11	0.001	0.0012	85.61
10	180	1.800	64	0.1	0.024	2.37	0.001	0.0012	82.79
11	200	2.000	59	0.09	0.026	2.63	0.001	0.0012	76.12
12	220	2.200	52	0.08	0.029	2.89	0.001	0.0012	66.91

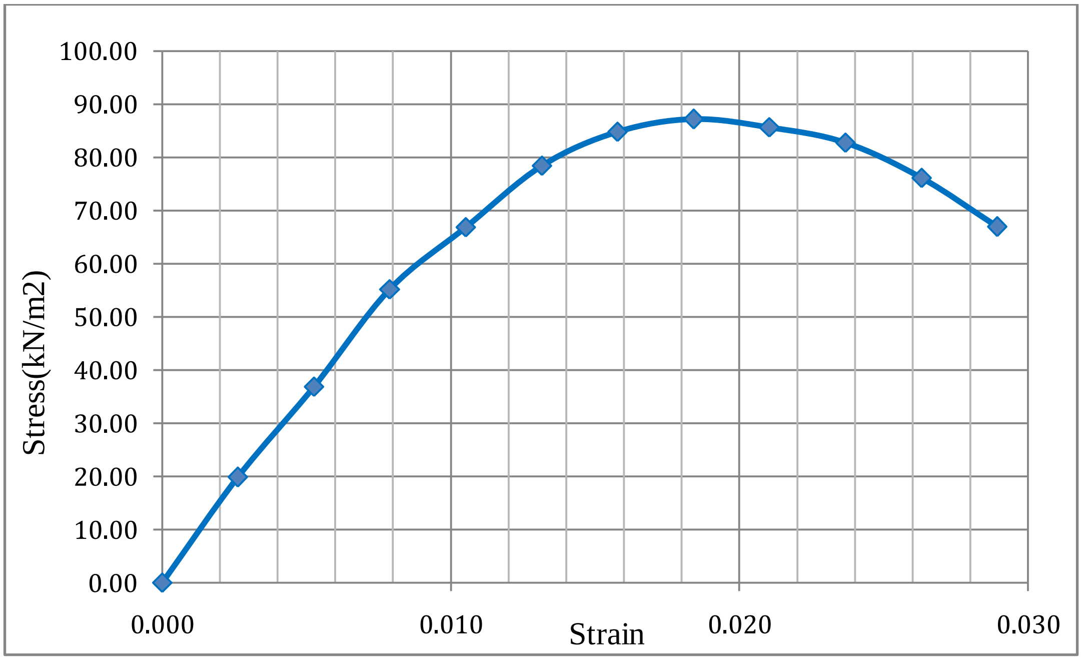


Figure-8.1: UCS for expansive soil only

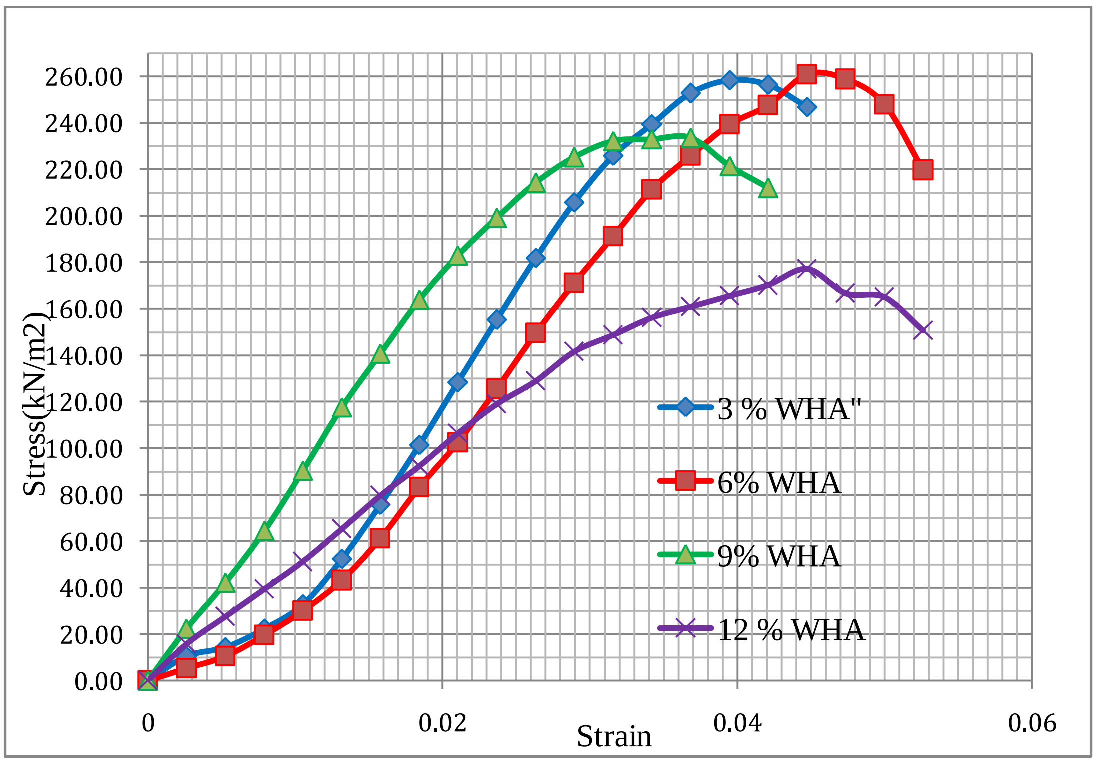


Figure-8.2: UCS for soil-2% lime + varying % WHA

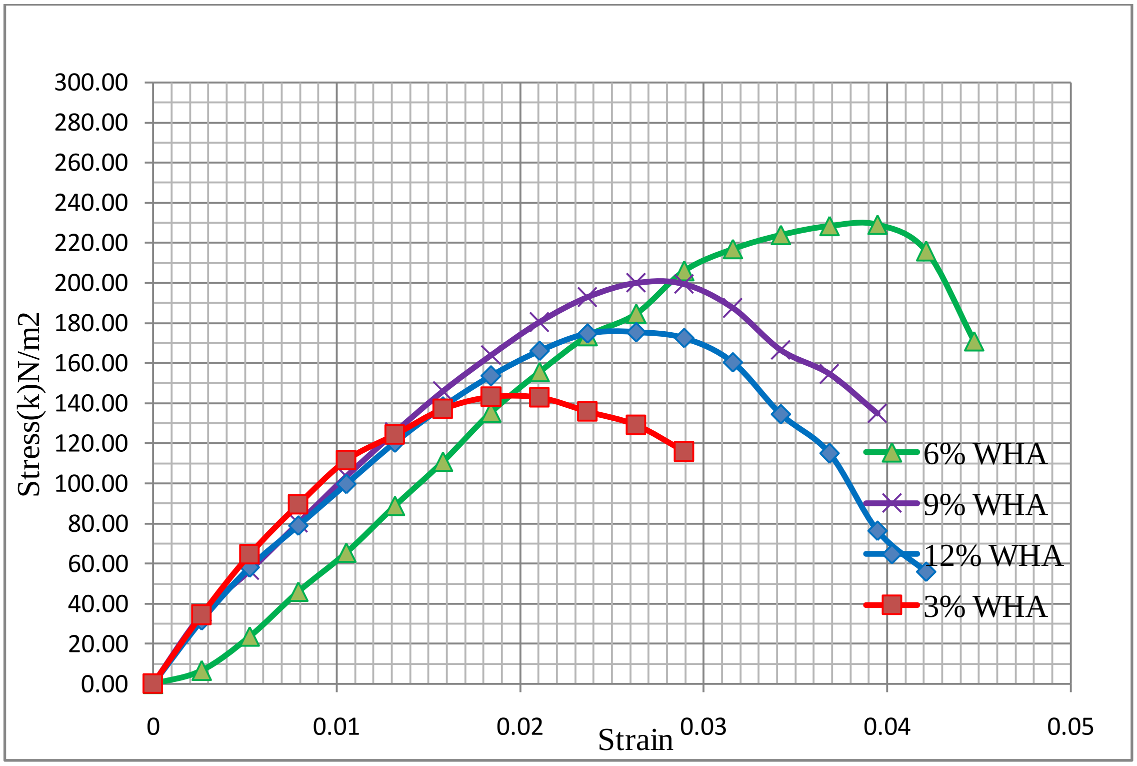


Figure-8.3: Days UCS for soil-4% lime and varying % WHA

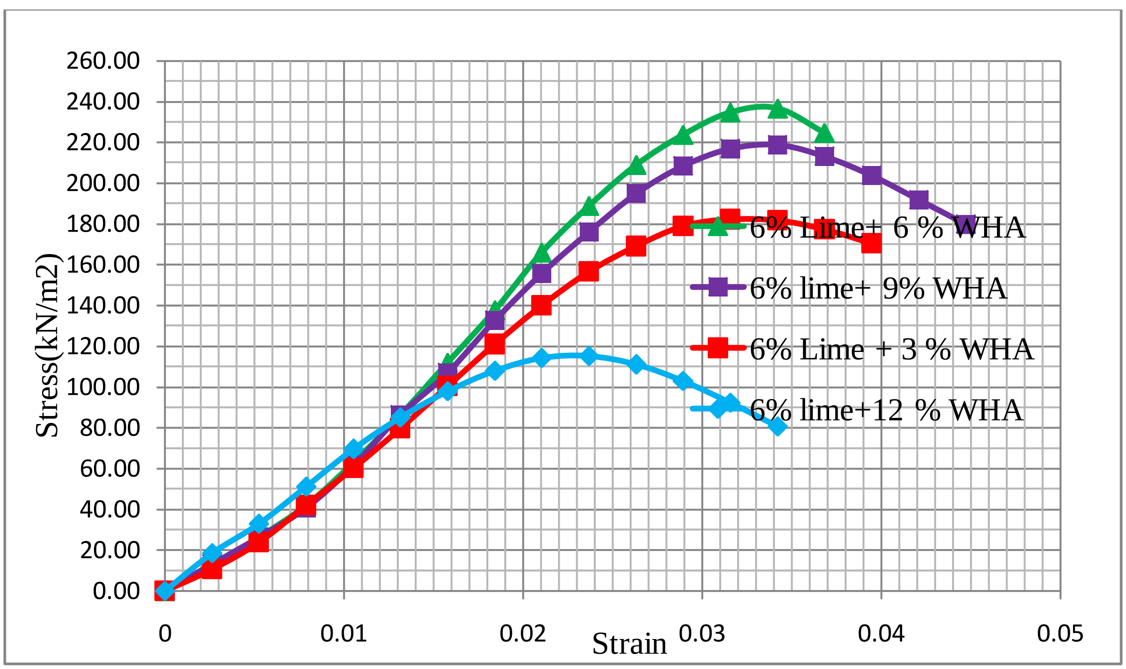


Figure-8.4: Uncured conditions of UCS for soil+ 6% Lime +varying % WHA

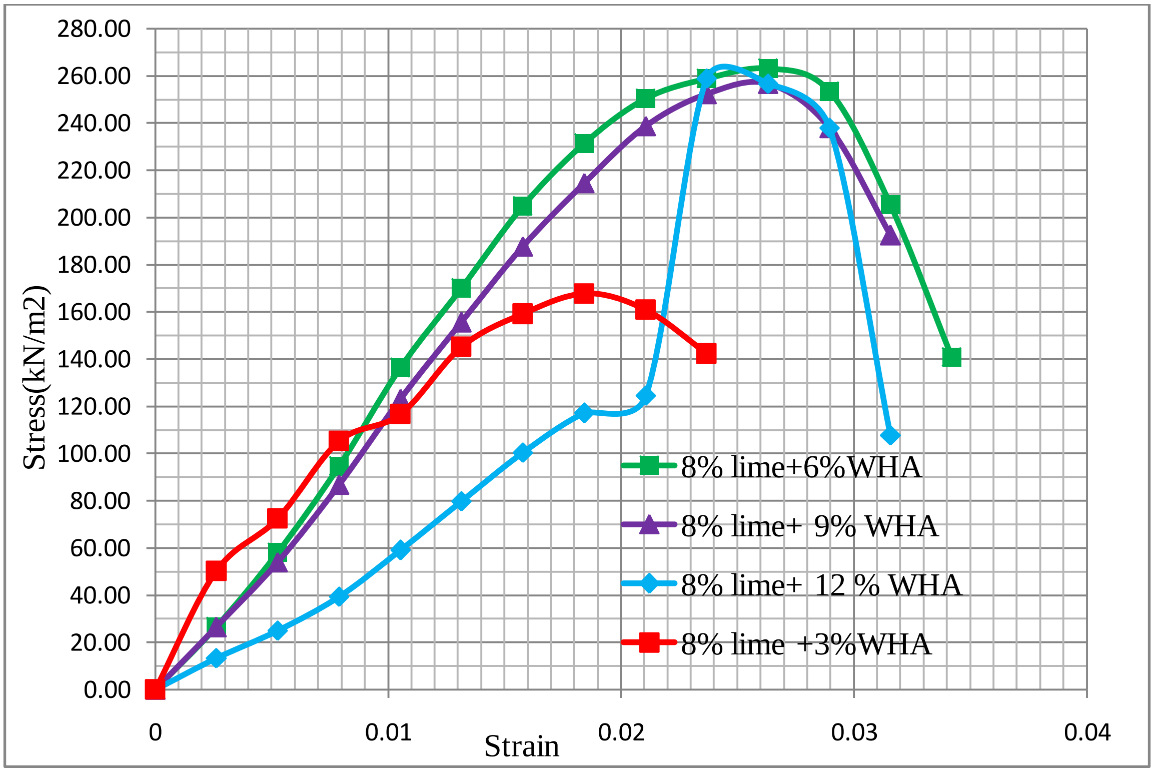


Figure-8.5: Uncured conditions of UCS for soil+ 8% Lime +varying% WHA

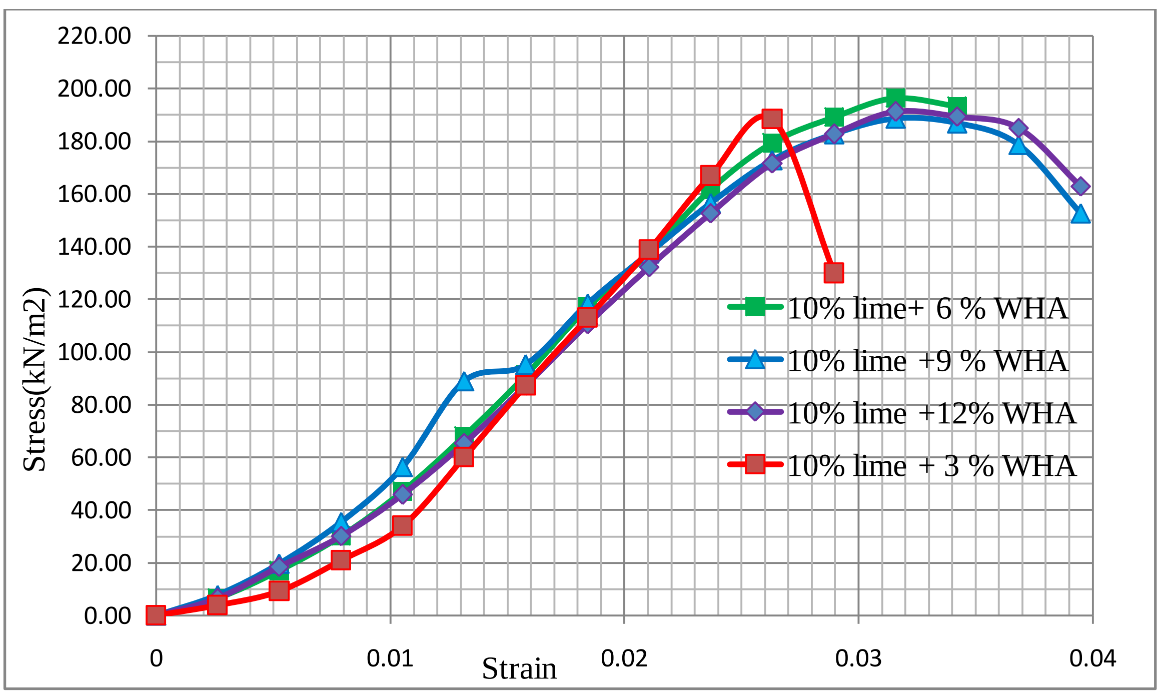


Figure-8.6: 0 Days UCS for soil + 10% lime and Varying % WHA

B) 3 DAYS SOAKED UNCONFINED COMPRESSIVE STRENGTH

Table-16.1: Unconfined compressive strength test of soil+2% lime+3%WHA

S.NO	OBSERVATION				CALCULATION				
	Dial Gauge		Proving ring						
	Deformation Dial Reading	Sample Deformation L (mm)	Load Dial Reading	Load (kN)	Strain, e =ΔL/Lo	% Strain	Area, Ao (m2)	Corrected Area, Ac =(Ao/(1-e))	Stress, σ =P/Ac
1	0	0	0	0.00	0	0	0.000	0	0.00
2	20	0.2	23	0.03	0.003	0.263	0.001	0.0011	30.40
3	40	0.4	39	0.06	0.005	0.526	0.001	0.0011	51.41
4	60	0.6	50	0.08	0.008	0.789	0.001	0.0011	65.73
5	80	0.8	63	0.09	0.011	1.053	0.001	0.0011	82.60
6	100	1	89	0.13	0.013	1.316	0.001	0.0011	116.38
7	120	1.2	120	0.18	0.016	1.579	0.001	0.0012	156.50
8	140	1.4	151	0.23	0.018	1.842	0.001	0.0012	196.40
9	160	1.6	178	0.27	0.021	2.105	0.001	0.0012	230.89
10	180	1.8	198	0.30	0.024	2.368	0.001	0.0012	256.15
11	200	2	208	0.31	0.026	2.632	0.001	0.0012	268.36
12	220	2.2	203	0.30	0.029	2.895	0.001	0.0012	261.20
13	240	2.4	195	0.29	0.032	3.158	0.001	0.0012	250.23

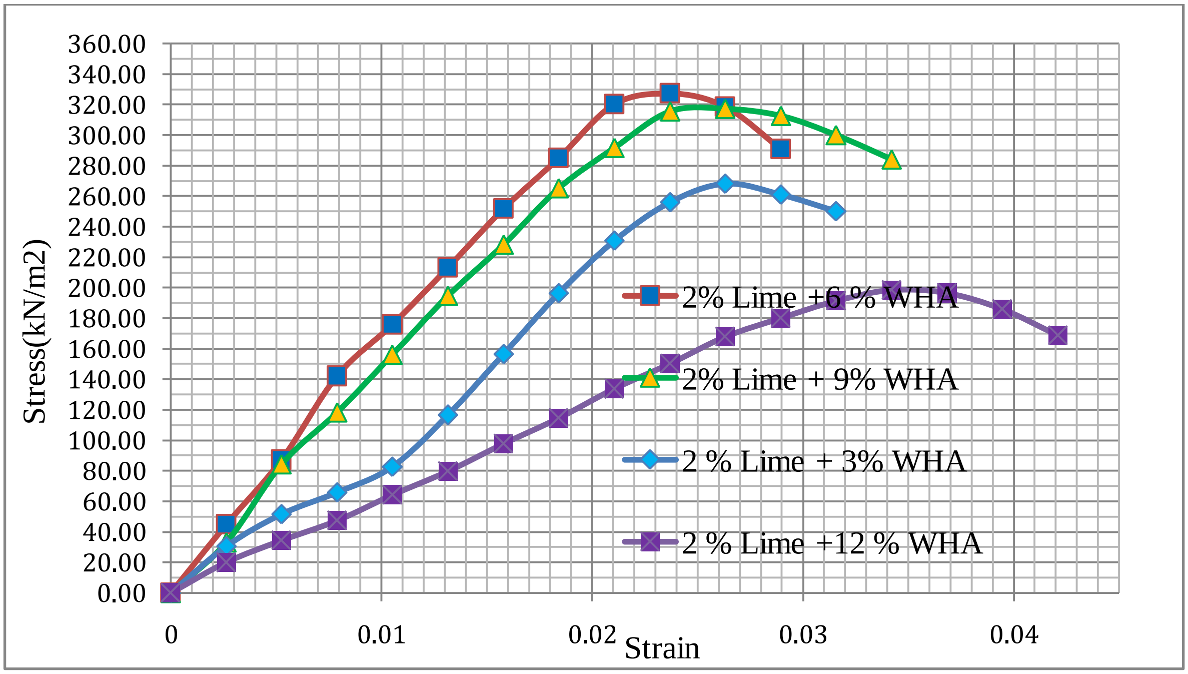


Figure-9.1: 3Days UCS for soil-2% lime and varying % WHA

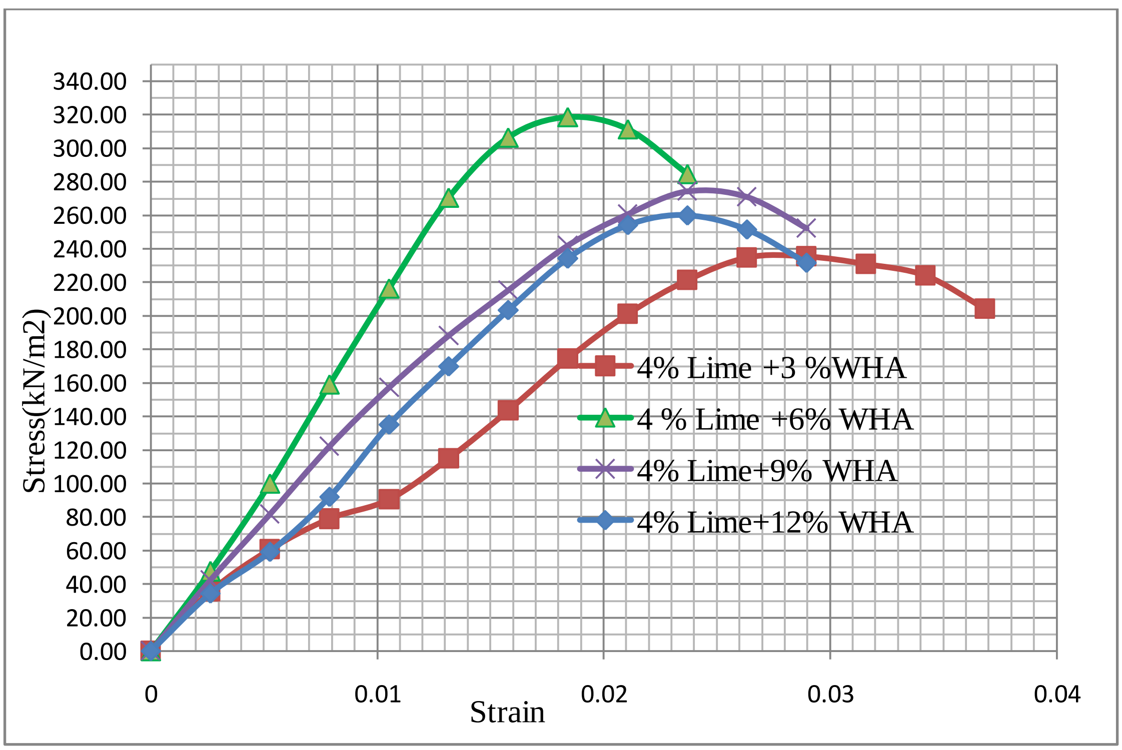


Figure-9.2: 3Days UCS for soil-4% lime and varying % WHA

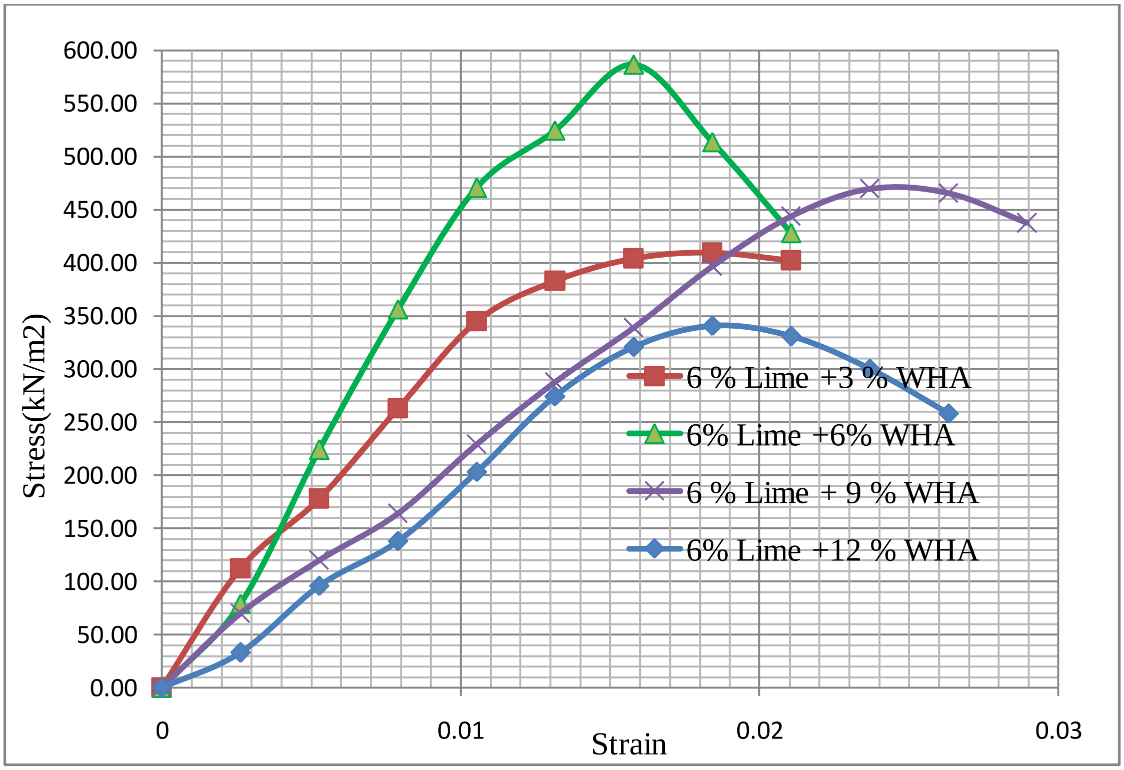


Figure-9.3: 3Days UCS for soil-6% lime and varying % WHA

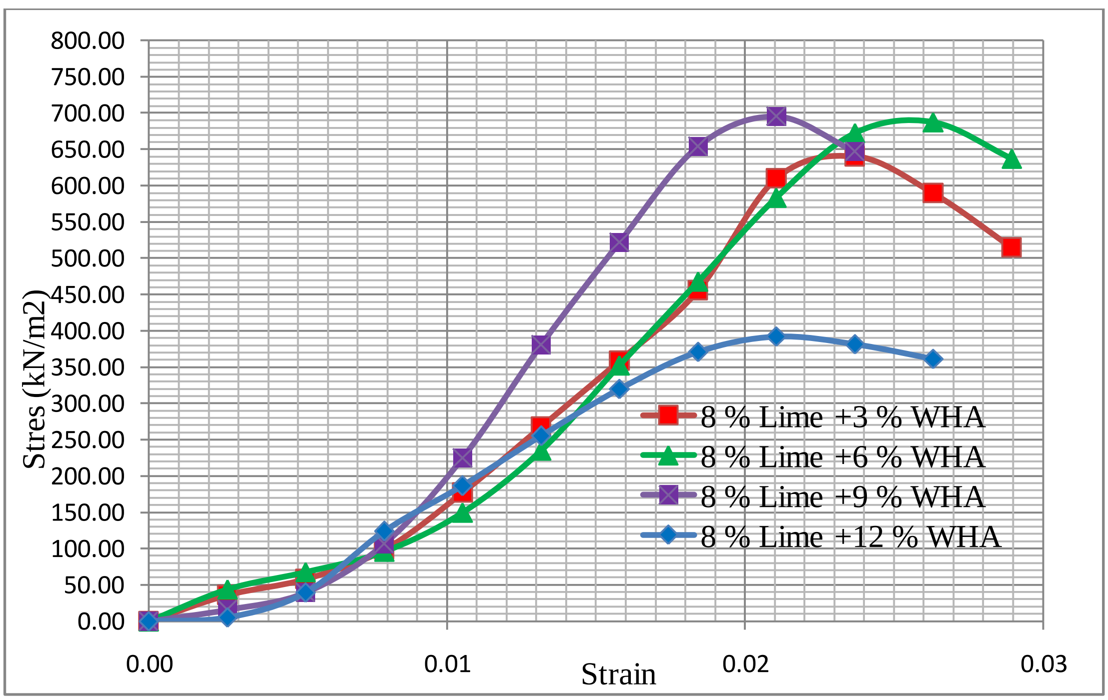


Figure-9.4: 3Days UCS for soil-8% lime and varying % WHA

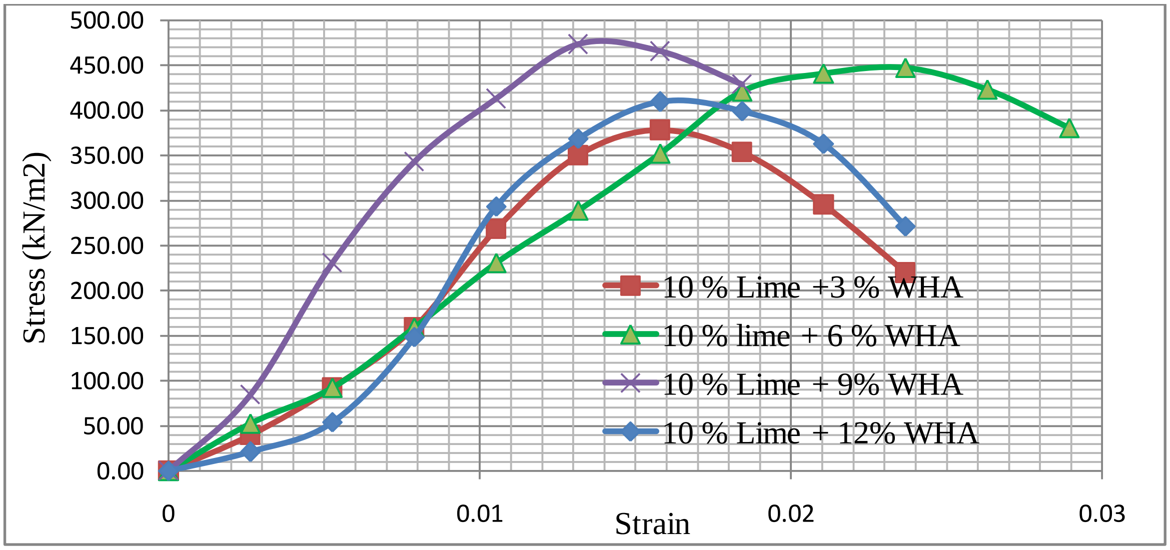


Figure-9.5: 3Days UCS expansive soil+10% lime+ varying percent WHA

C). 7DAYS SOAKED UNCONFINED COMPRESSIVE STRENGTH TESTS

Table-17.1: Unconfined compressive strength test of expansive soil+2% lime+3%Wheat husk ash

S.NO	OBSERVATION				CALCULATION				
	Dial Gauge		Proving ring						
	Deformation Dial Reading	Sample Deformation L (mm)	Load Dial Reading	Load (kN)	Strain, e =ΔL/Lo	% Strain	Area, Ao (m2)	Corrected Area, Ac =(Ao/(1-e))	Stress, σ =P/Ac
1	0	0	0	0.00	0	0	0.000	0	0.00
2	20	0.2	15	0.02	0.0026	0.2632	0.001	0.0011	19.82
3	40	0.4	47	0.07	0.0053	0.5263	0.001	0.0011	61.95
4	60	0.6	96	0.14	0.0079	0.7895	0.001	0.0011	126.20
5	80	0.8	147	0.22	0.0105	1.0526	0.001	0.0011	192.73
6	100	1	186	0.28	0.0132	1.3158	0.001	0.0011	243.22
7	120	1.2	207	0.31	0.0158	1.5789	0.001	0.0012	269.96
8	140	1.4	220	0.33	0.0184	1.8421	0.001	0.0012	286.14
9	160	1.6	215	0.32	0.0211	2.1053	0.001	0.0012	278.89
10	180	1.8	202	0.30	0.0237	2.3684	0.001	0.0012	261.32
11	200	2	180	0.27	0.0263	2.6316	0.001	0.0012	232.23

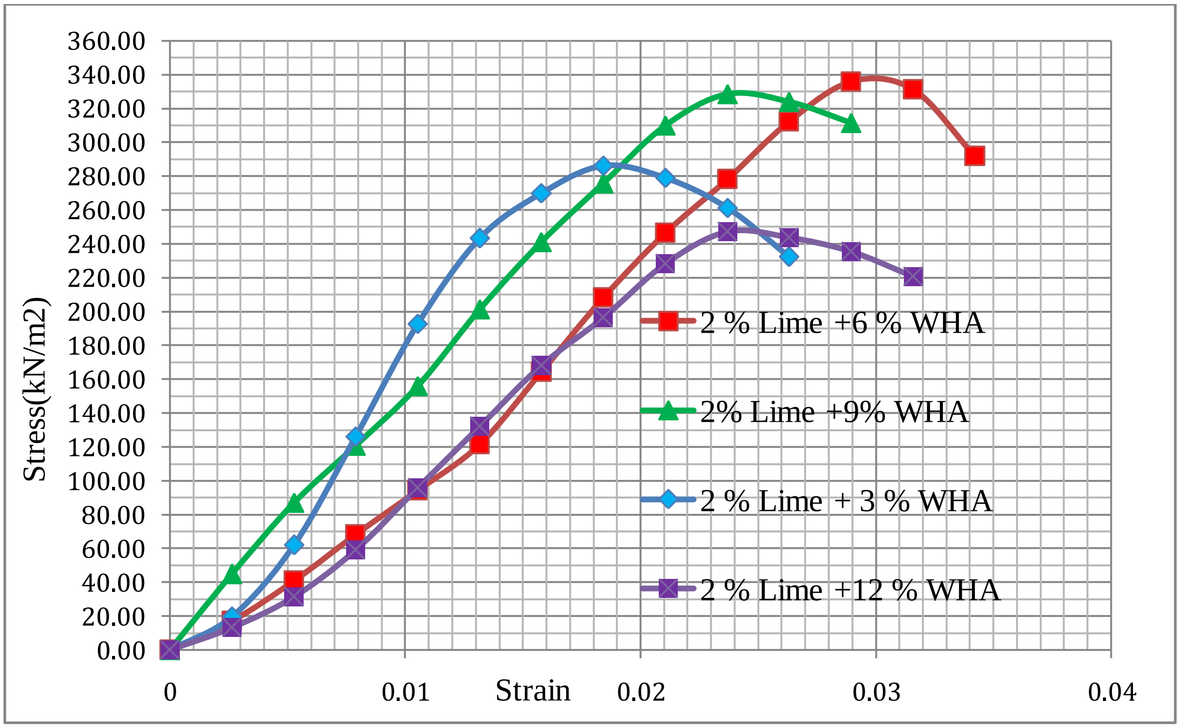


Figure-10.1: 7days UCS for Soil + 2% lime+ Varying % WHA

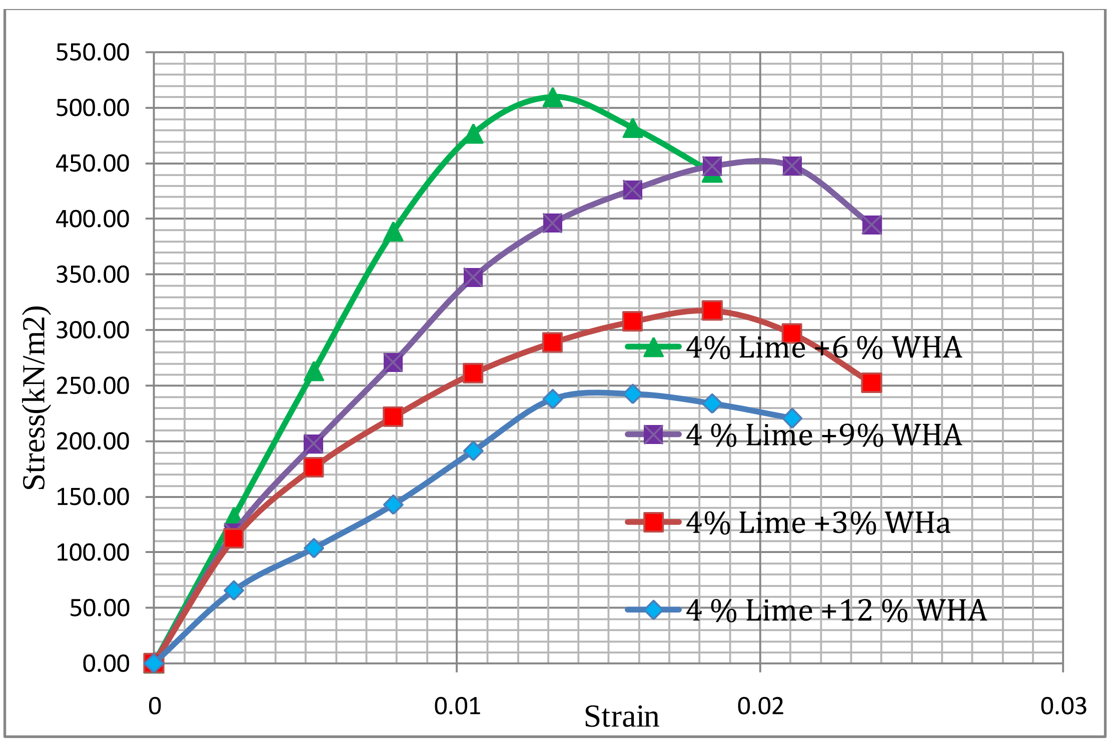


Figure-10.2: 7days UCS for Soil + 4% lime+varying % WHA

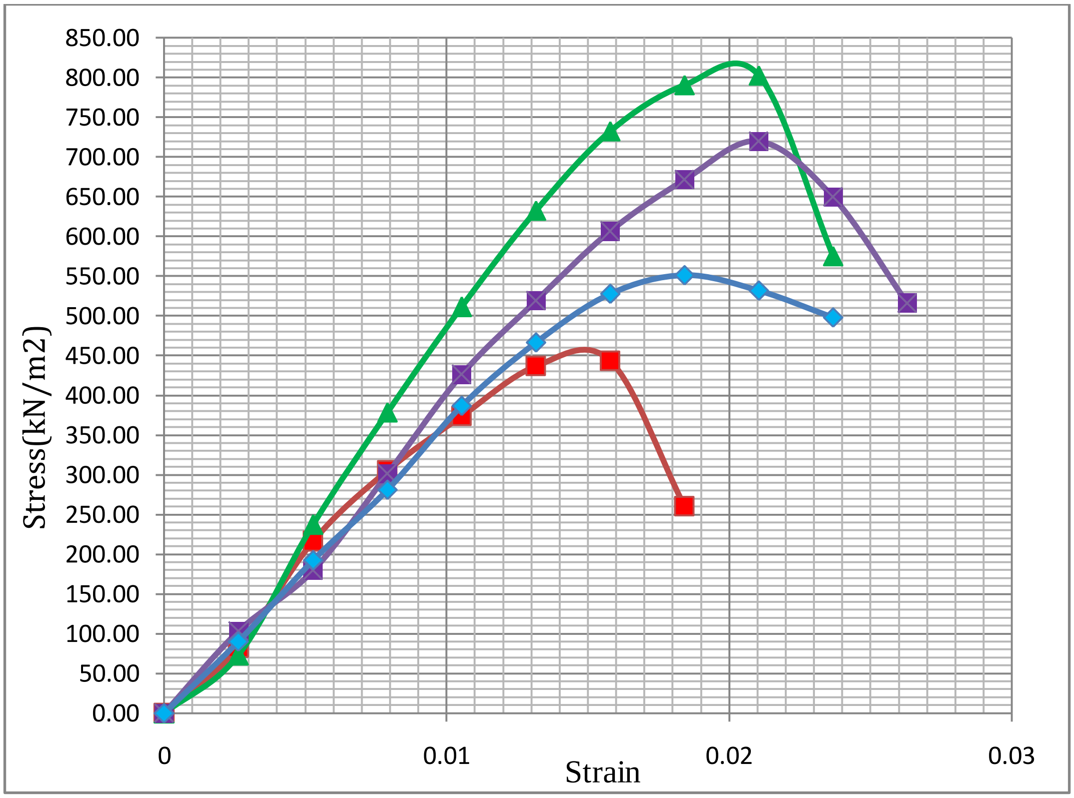


Figure-10.3: 7days UCS for Soil +6% lime+ varying % WHA

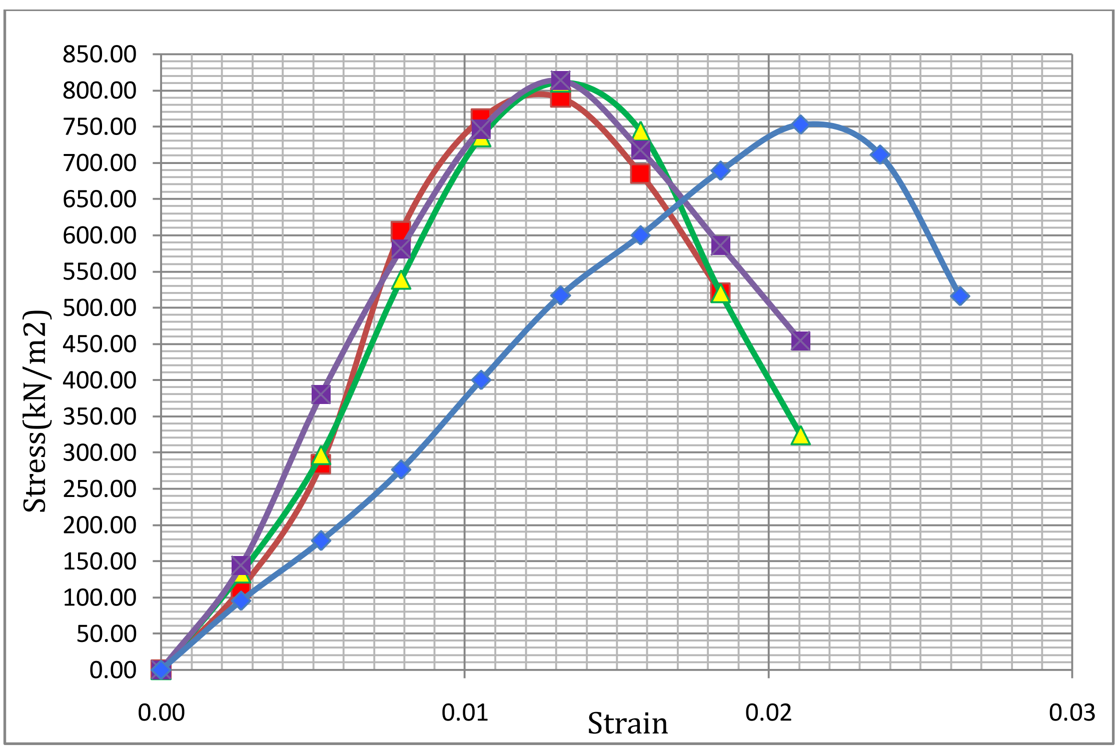


Figure-10.4: 7days UCS for Soil+ 8% lime+ varying % WHA

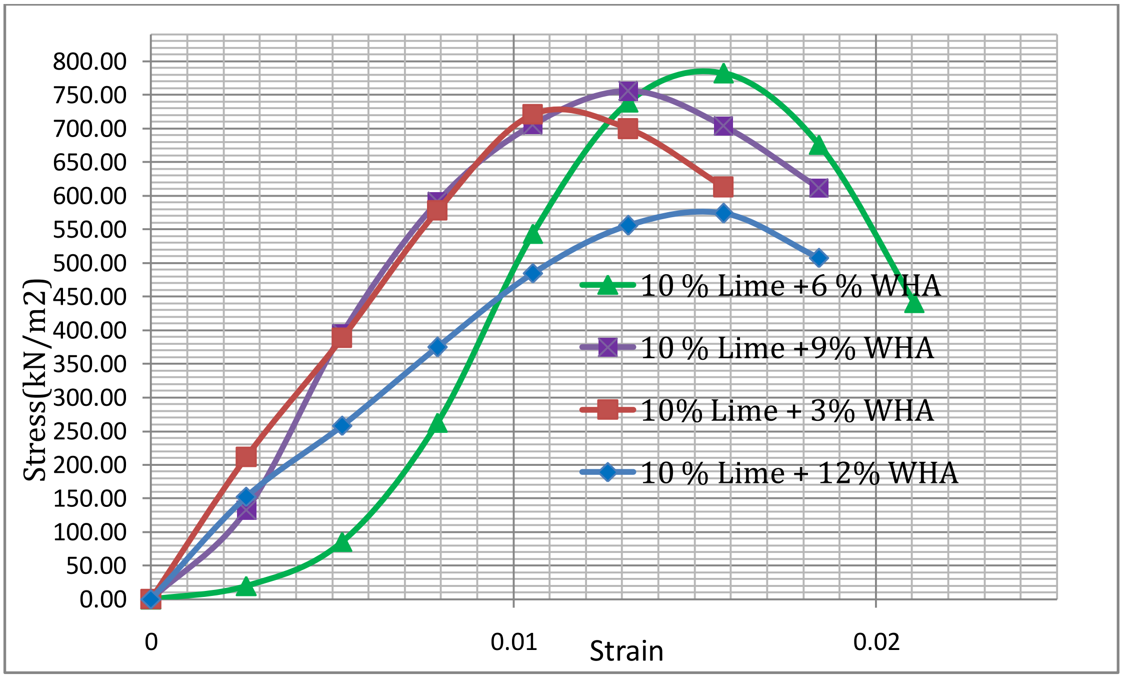


Figure-10.5: 7 Days UCS for Soil + 10% lime+ varying % WH

UN SOAKED CALIFORNIA BEARING RATIO TEST

Table 15: Un Soaked CBR Value at Standard Loads and CBR Test Summary

Mix No	Material type	No. of blows	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
			2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54mm	5.08 mm	
1	100% Soil+0% lime+0% WHA	56	0.595	0.85	13.24	20	4.493	4.25	4.49396
2	98% Soil+2% lime+0% WHA	56	1.686	2.439	13.24	20	12.775	12.1992	12.775
3	96% Soil+4% lime+0% WHA	56	1.704	2.529	13.24	20	12.91	12.65	12.91
4	94% Soil+6% lime+0% WHA	56	2.386	3.480	13.24	20	18.076	17.402	18.076
5	92% Soil+8% lime+0% WHA	56	2.529	3.659	13.24	20	19.105	18.299	19.105
6	90% Soil+10% lime+0% WHA	56	2.296	3.372	13.24	20	17.344	16.864	17.344
7	98% Soil+0% lime+3% WHA	56	1.219	1.758	13.24	20	9.242	8.7906	9.242
8	94% Soil+0% lime+6% WHA	56	1.614	2.314	13.24	20	12.19	11.57	12.19
9	91% Soil+0% lime+9% WHA	56	1.847	2.421	13.24	20	13.956	12.110	13.956
10	88% Soil+0% lime+12% WHA	56	1.453	2.081	13.24	20	10.975	10.405	10.975
11	95% Soil+2% lime+3% WHA	56	1.830	2.565	13.24	20	13.821	12.827	13.821
12	92% Soil+2% lime+6% WHA	56	2.189	3.229	13.24	20	16.531	16.146	16.531
13	89% Soil+2% lime+9% WHA	56	2.350	3.175	13.24	20	17.750	15.877	17.750
14	86% Soil+2% lime+12% WHA	56	2.135	2.978	13.24	20	16.124	14.890	16.124
15	93% Soil+4% lime+3% WHA	56	2.332	4.001	13.24	20	17.615	20.003	20.003

16	90% Soil+4% lime+6% WHA	56	2.870	4.126	13.24	20	21.680	20.631	21.680
17	87% Soil+4% lime+9% WHA	56	2.924	4.270	13.24	20	22.086	21.349	22.086
18	84% Soil+4% lime+12% WHA	56	2.781	4.126	13.24	20	21.002	20.631	21.002
19	91% Soil+6% lime+3% WHA	56	3.157	4.126	13.24	20	23.848	20.631	23.848
20	88% Soil+6% lime+6% WHA	56	3.211	4.646	13.24	20	24.254	23.232	24.254
21	85% Soil+6% lime+9% WHA	56	3.409	4.664	13.24	20	25.745	23.322	25.745
22	82% Soil+6% lime+12% WHA	56	3.068	4.485	13.24	20	23.170	22.425	23.170
23	89% Soil+8% lime+3% WHA	56	2.583	3.552	13.24	20	19.512	17.761	19.512
24	86% Soil+8% lime+6% WHA	56	2.691	4.395	13.24	20	20.325	21.977	21.977
25	83% Soil+8% lime+9% WHA	56	3.014	4.306	13.24	20	22.764	21.528	22.764
26	80% Soil+8% lime+12% WHA	56	2.637	3.947	13.24	20	19.918	19.734	19.918
27	87% Soil+10% lime+3% WHA	56	2.332	3.480	13.24	20	17.615	17.402	17.615
28	84% Soil+10% lime+6% WHA	56	2.512	3.767	13.24	20	18.970	18.837	18.970
29	81% Soil+10% lime+9% WHA	56	2.673	3.911	13.24	20	20.189	19.555	20.189
30	78% Soil+10% lime+12% WHA	56	2.422	3.498	13.24	20	18.292	17.492	18.292

SOAKED CALIFORNIA BEARING RATIO TEST

Table 16: Soaked CBR Value at Standard Loads and CBR Test Summary

Mix No	Material type	No. of Blows	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR-Swell (%)
			2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
1	100% Soil+0% lime+0% WHA	56	0.43056	0.64584	13.24	20	3.2519	3.2292	3.2519
2	98% Soil+2% lime+0% WHA	56	1.1661	1.91958	13.24	20	8.807	9.5979	9.5979
3	96% Soil+4% lime+0% WHA	56	1.6146	2.36808	13.24	20	12.23	11.84	12.23
4	94% Soil+6% lime+0% WHA	56	2.7807	4.34148	13.24	20	21.066	21.707	21.066
5	92% Soil+8% lime+0% WHA	56	2.7807	3.71358	13.24	20	21.002	18.568	21.002
6	90% Soil+10% lime+0% WHA	56	2.54748	3.4983	13.24	20	19.241	17.492	19.241
7	97% Soil+0% lime+3% WHA	56	1.23786	1.794	13.24	20	9.378	8.97	9.378
8	94% Soil+0% lime+6% WHA	56	1.82988	2.49366	13.24	20	13.86	12.47	13.86
9	91% Soil+0% lime+9% WHA	56	1.9734	2.74482	13.24	20	14.905	13.724	14.905
10	88% Soil+0% lime+12% WHA	56	1.63254	2.22456	13.24	20	12.330	11.123	12.330
11	95% Soil+2% lime+3% WHA	56	1.328	1.884	13.24	20	10.027	9.419	10.027
12	92% Soil+2% lime+6% WHA	56	2.063	2.781	13.24	20	15.582	13.904	15.582
13	89% Soil+2% lime+9% WHA	56	1.866	2.852	13.24	20	14.092	14.262	14.262

14	86% Soil+2% lime+12%WHA	56	1.848	2.781	13.24	20	13.956	13.904	13.956
15	93% Soil+4% lime+3% WHA	56	2.835	4.126	13.24	20	21.409	20.631	21.409
16	90% Soil+4% lime+6% WHA	56	3.157	4.557	13.24	20	23.848	22.784	23.848
17	87% Soil+4% lime+9% WHA	56	3.229	4.772	13.24	20	24.390	23.860	24.390
18	84% Soil+4% lime+12%WHA	56	2.942	4.037	13.24	20	22.222	20.183	22.222
19	91% Soil+6% lime+3% WHA	56	3.283	4.736	13.24	20	24.796	23.681	24.796
20	88% Soil+6% lime+6% WHA	56	3.678	5.221	13.24	20	27.777	26.103	27.777
21	85% Soil+6% lime+9% WHA	56	3.480	5.185	13.24	20	26.287	25.923	26.287
22	82% Soil+6% lime+12% WHA	56	3.229	4.862	13.24	20	24.390	24.309	24.390
23	89% Soil+8% lime+3% WHA	56	2.799	4.144	13.24	20	21.138	20.721	21.138
24	86% Soil+8% lime+6% WHA	56	3.229	4.987	13.24	20	24.390	24.937	24.937
25	83% Soil+8% lime+9% WHA	56	3.140	4.736	13.24	20	23.712	23.681	23.712
26	80% Soil+8% lime+12%WHA	56	2.494	3.767	13.24	20	18.834	18.837	18.837
27	87% Soil+10% lime+3%WHA	56	2.619	3.947	13.24	20	19.783	19.734	19.783
28	84% Soil+10% lime+6%WHA	56	2.835	4.270	13.24	20	21.409	21.349	21.409
29	81% Soil+10% lime+9%WHA	56	2.637	3.929	13.24	20	19.918	19.644	19.918
30	78% Soil+10% lime+12%WHA	56	2.243	3.319	13.24	20	16.937	16.595	16.937

UN SOAKED CALIFORNIA BEARING RATIO TEST

Ring Factor = 0.01794 kN/Div, Penetration Rate =1.27mm/min, and Area of plunger =1985mm2

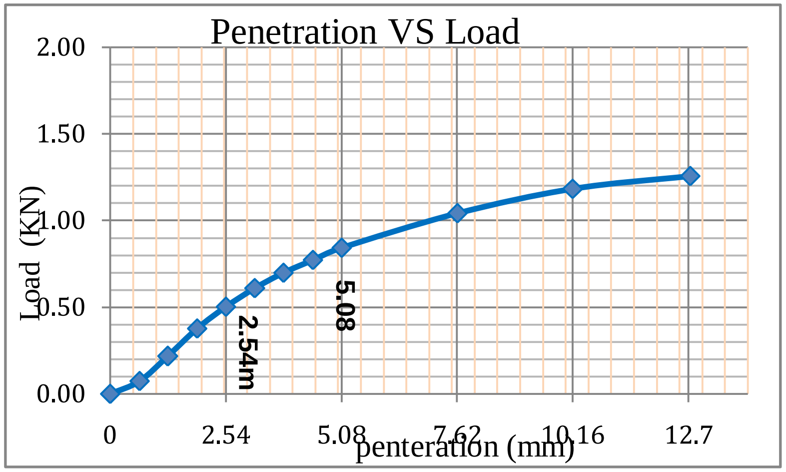


Figure 11.1: Unsoaked CBR for expansive soil only

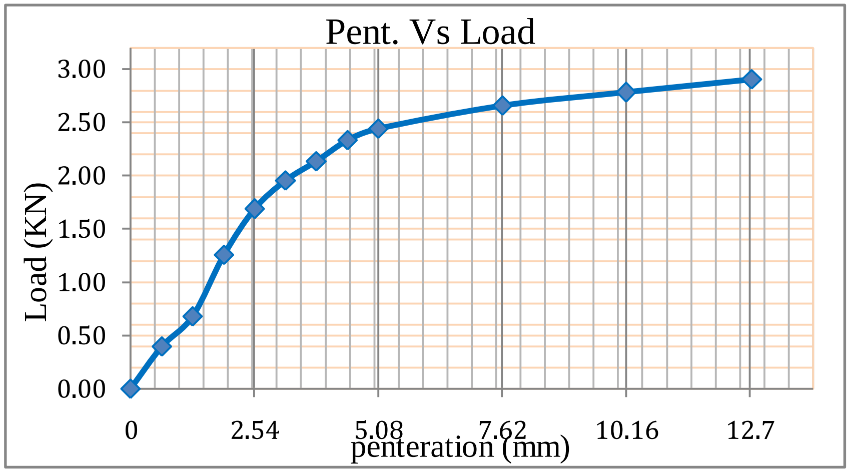


Figure-11.2: Unsoaked CBRfor soil+2% lime

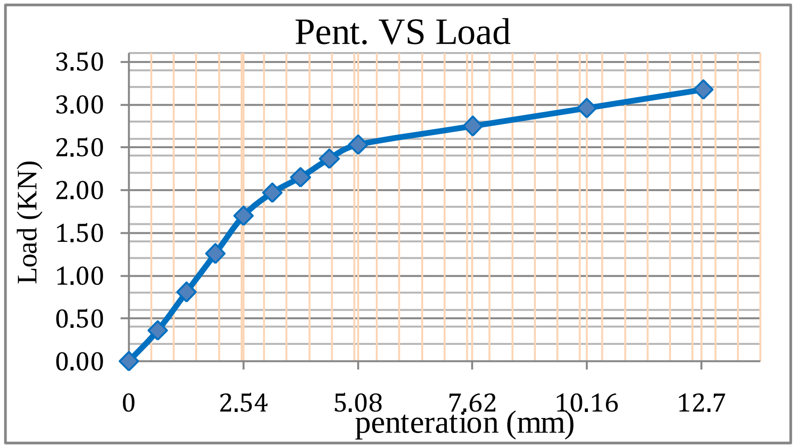


Figure-11.3: Unsoaked CBR for Soil+4% lime

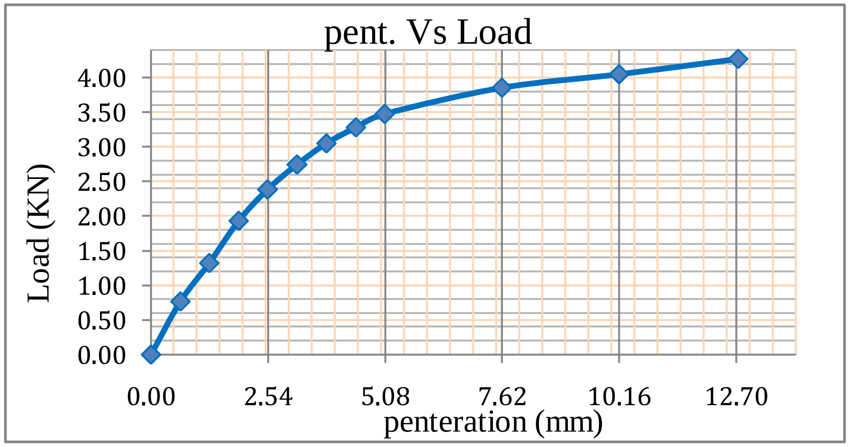


Figure-11.4: Unsoaked CBR for Soil+6% lime

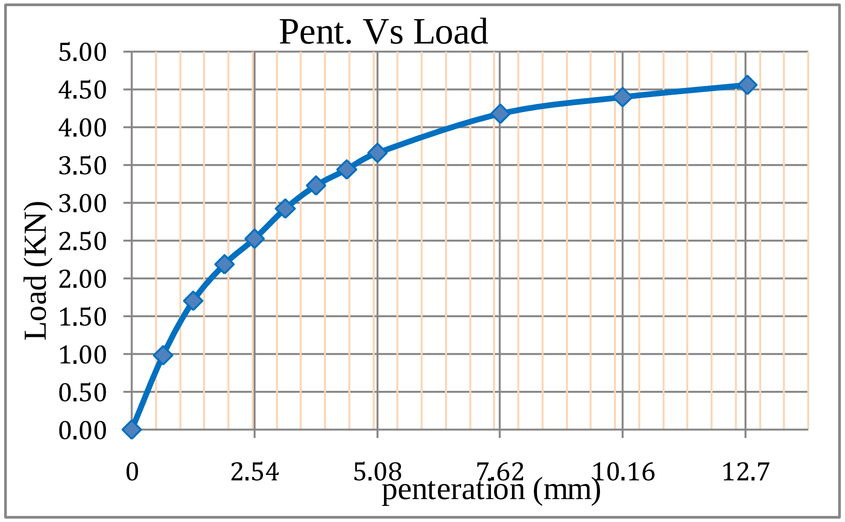


Figure-11.5: Unsoaked CBR for Soil+8% lime

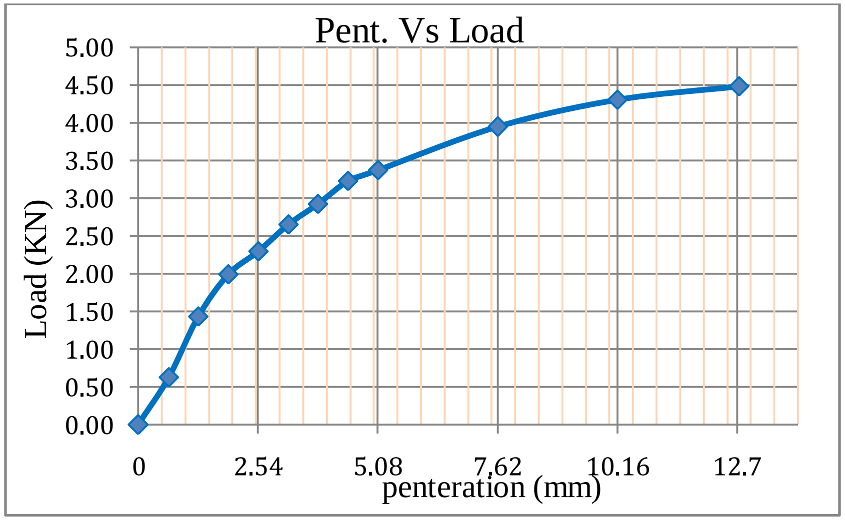


Figure-11.6: Unsoaked CBR for Soil+10% lime

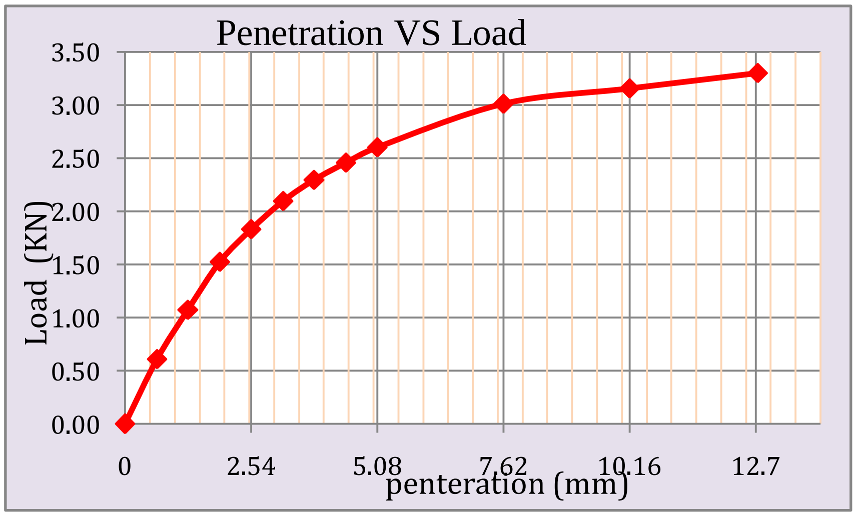


Figure-11.7: Unsoaked CBR test for soil+2% lime+3%WHA

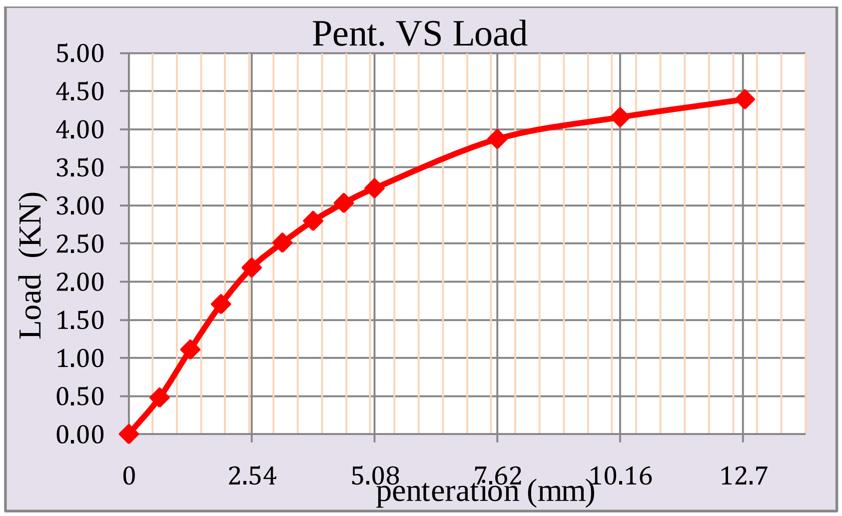
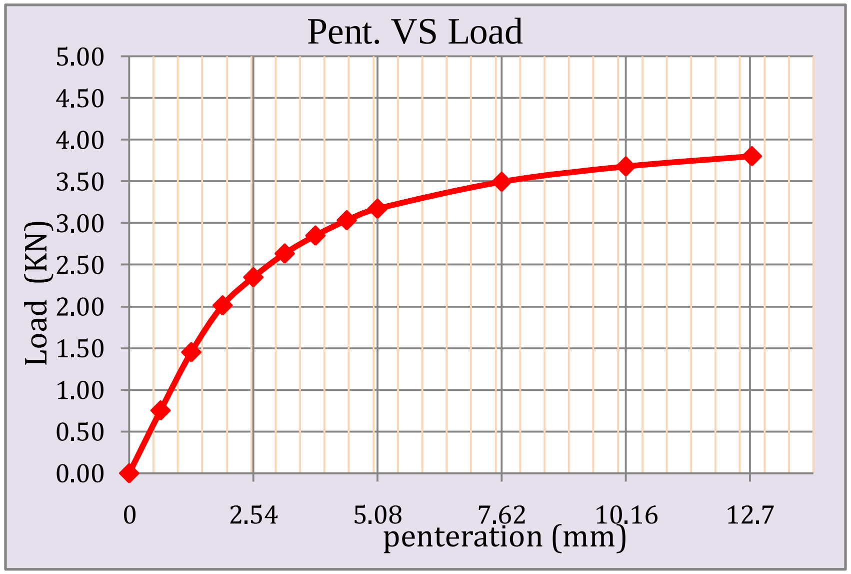


Figure-11.8: Unsoaked CBR test for soil+2% lime+6%WHA



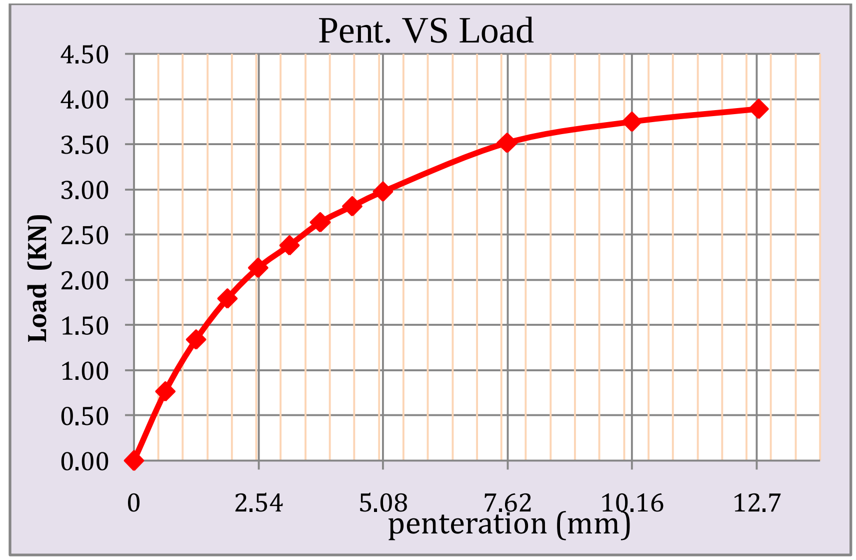
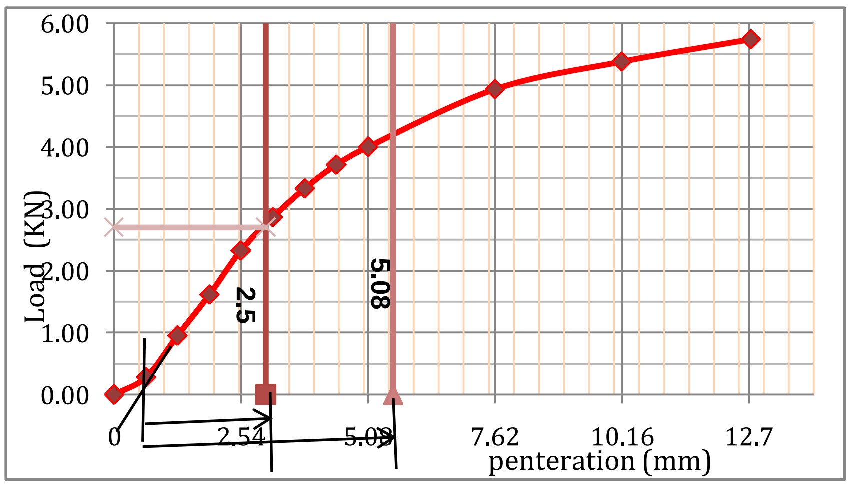


Figure-11.9: Unsoaked CBR test for soil+2% lime+9%WHA

Figure-11.10: Unsoaked CBR test for soil+2% lime+12% WHA



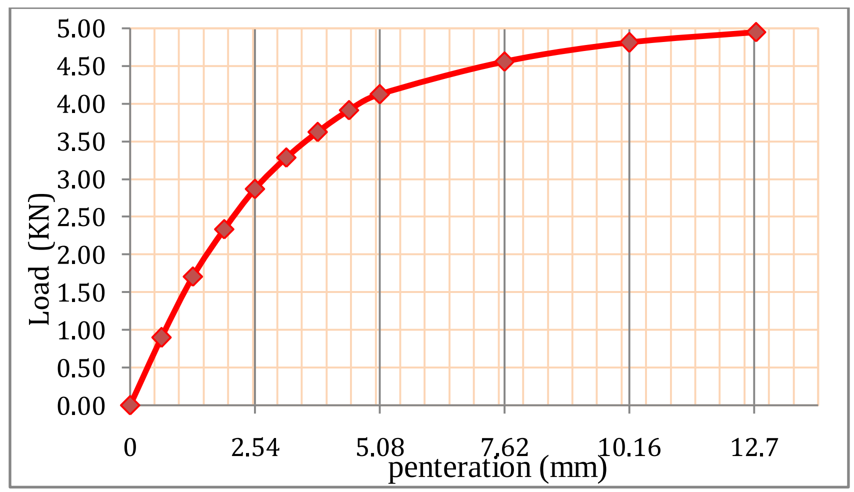


Figure-11.11: Unsoaked CBR for soil+4%lime+3% WHA

Figure-11.12: Unsoaked CBR for soil+4%lime+6% WHA

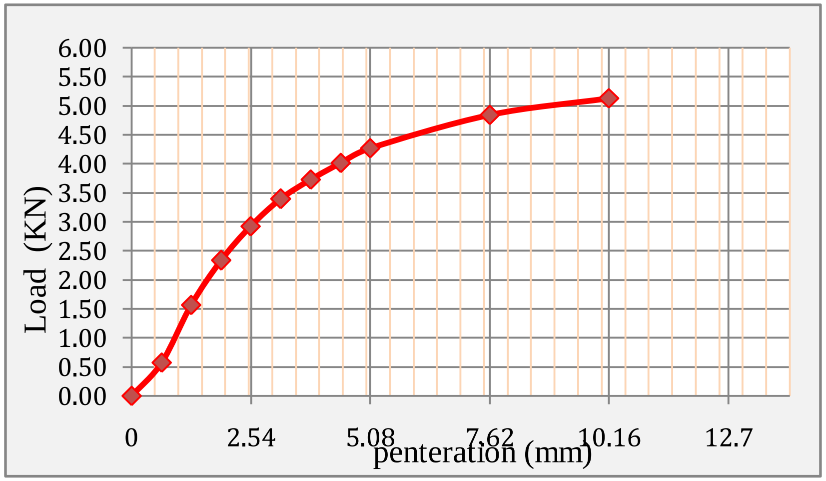


Figure-11.13: Unsoaked CBR test for soil+4%lime+9% WHA

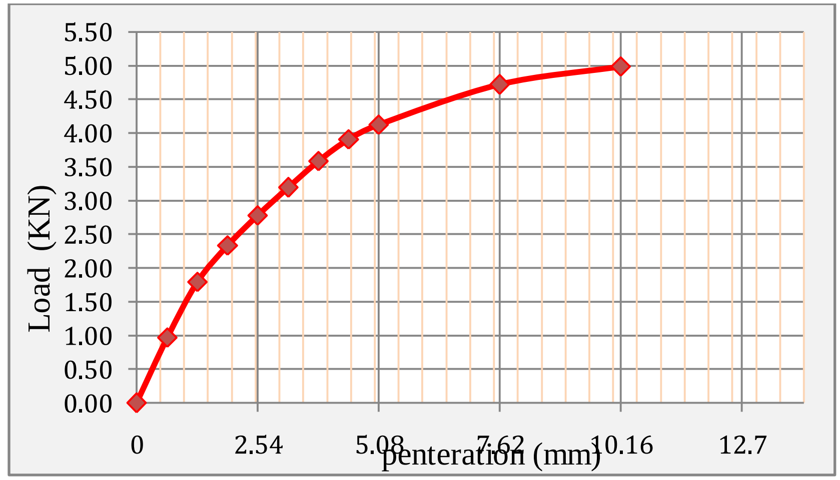


Figure-11.14: Unsoaked CBR test for soil+4%lime+12%WHA

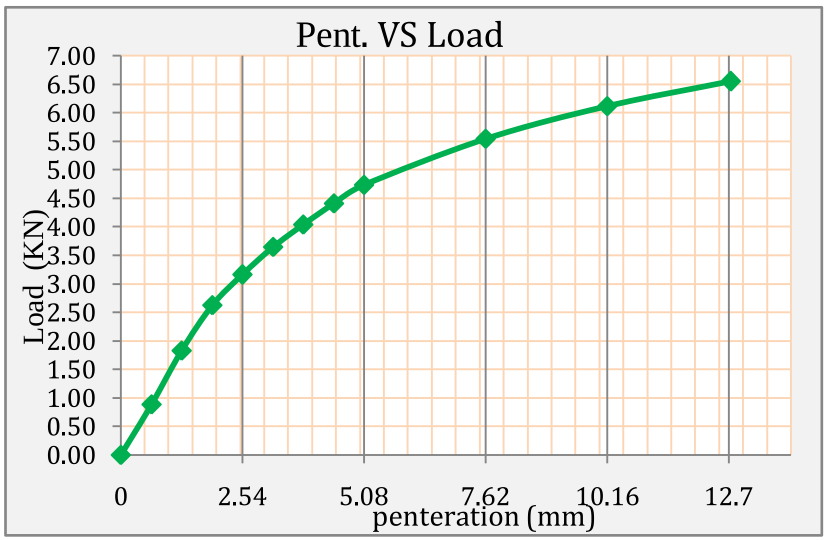


Figure-11.15: Unsoaked CBR test for soil+6%lime+3%WHA

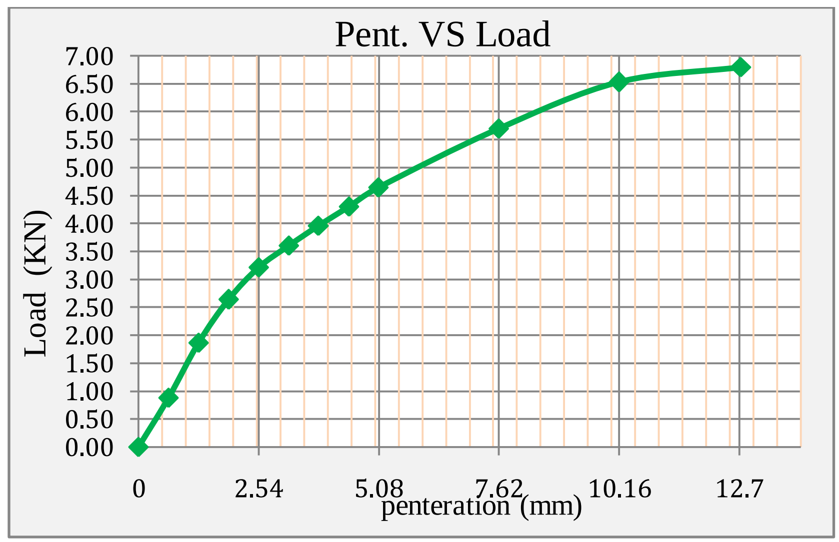


Figure-11.16: Unsoaked CBR for soil+6%lime+6%WHA

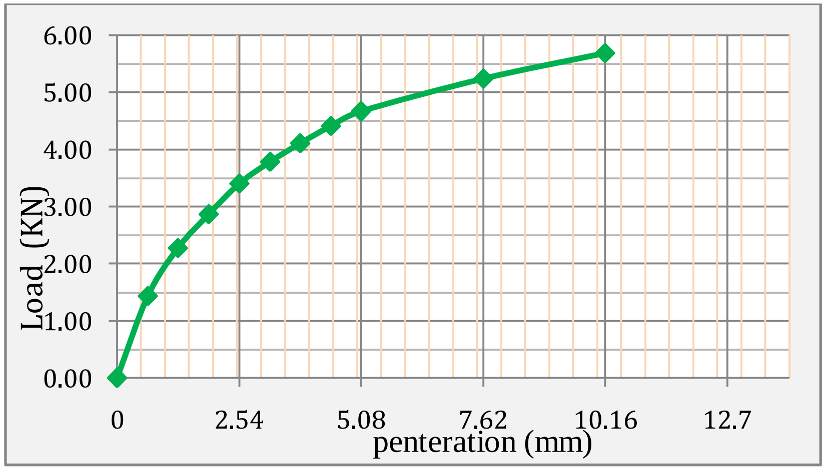


Figure-11.17: Unsoaked CBR test for soil+6%lime+9%WHA

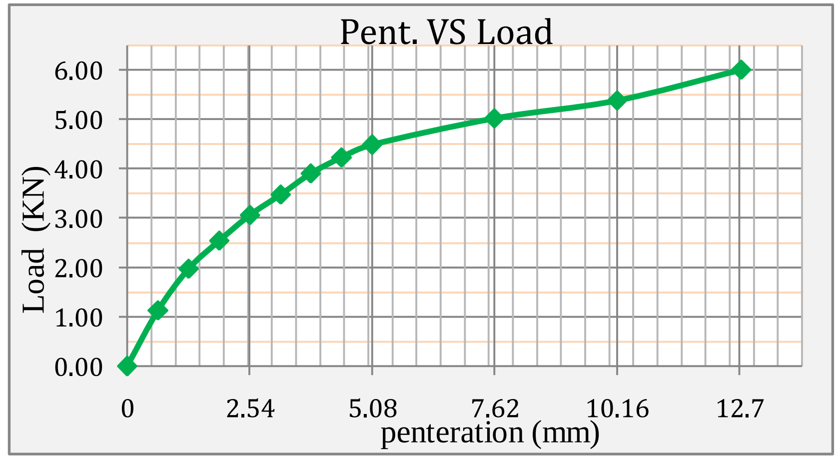


Figure-11.18: Unsoaked CBR test for soil+6%lime+12%WHA

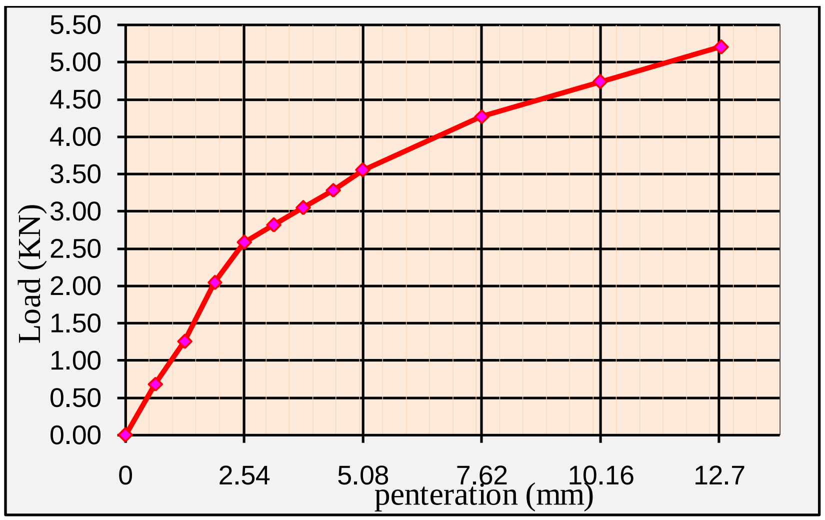


Figure-11.19: Unsoaked CBR test for soil+8%lime+3%WHA

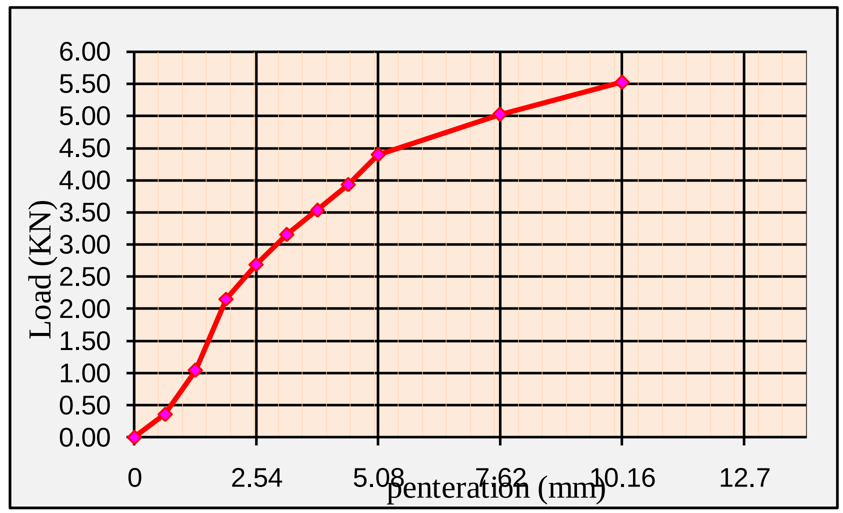


Figure-11.20: Unsoaked CBR test for soil+8%lime+6%WHA

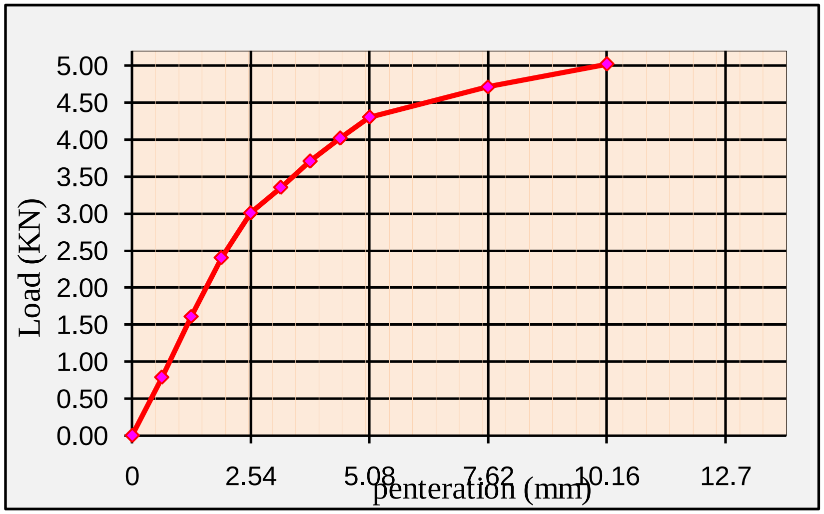


Figure-11.21: Unsoaked CBR test for soil+8%lime+9%WHA

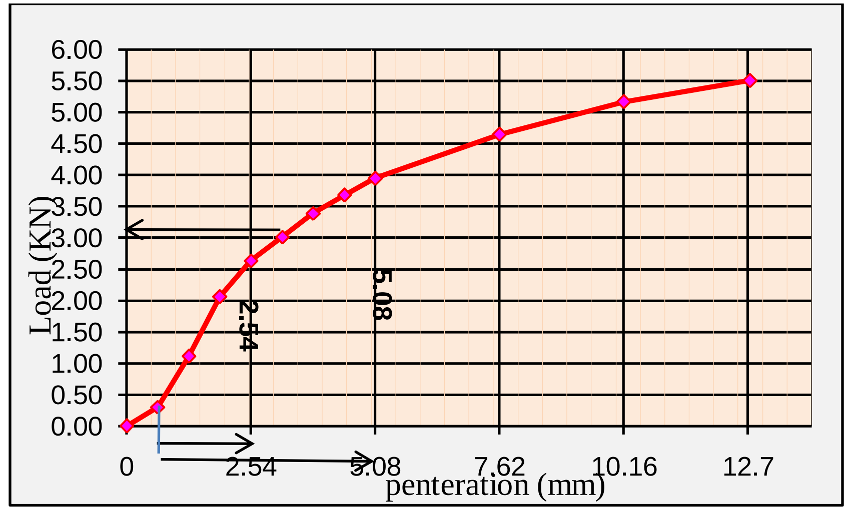


Figure-11.22: Unsoaked CBR test for soil+8%lime+12%WHA

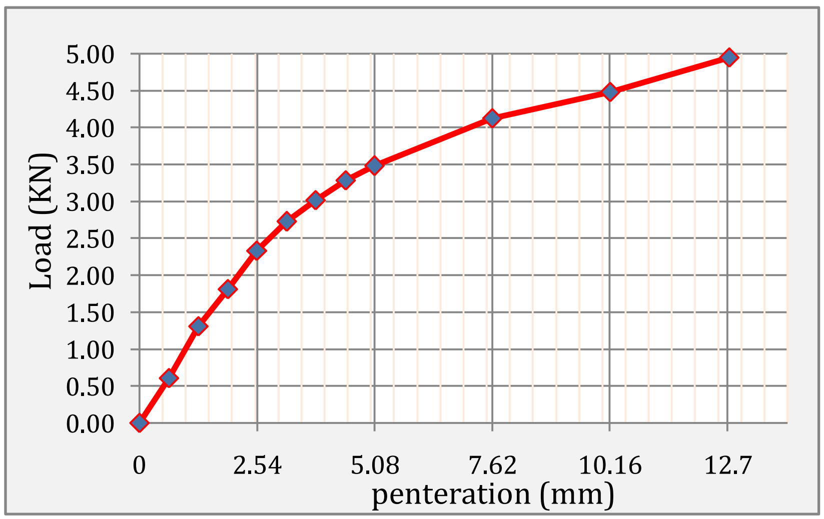


Figure-11.23: Unsoaked CBR for soil+10%lime+3%WHA

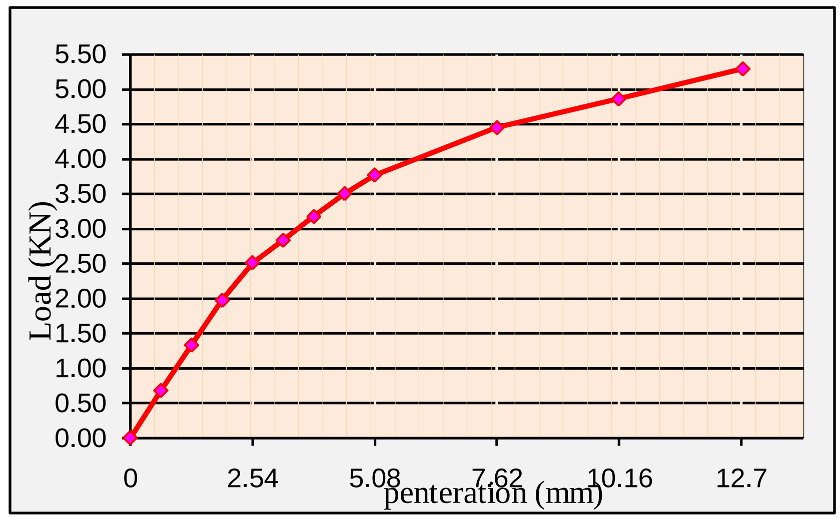


Figure-11.24: Unsoaked CBR for soil+10%lime+6%WHA

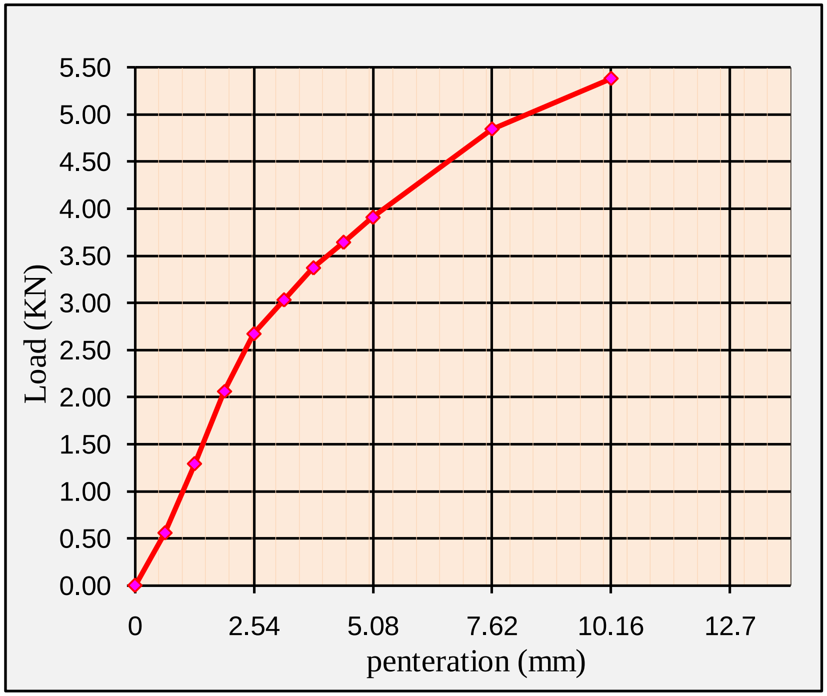


Figure-11.25 : Un soaked CBR test for soil+10%lime+9%WHA

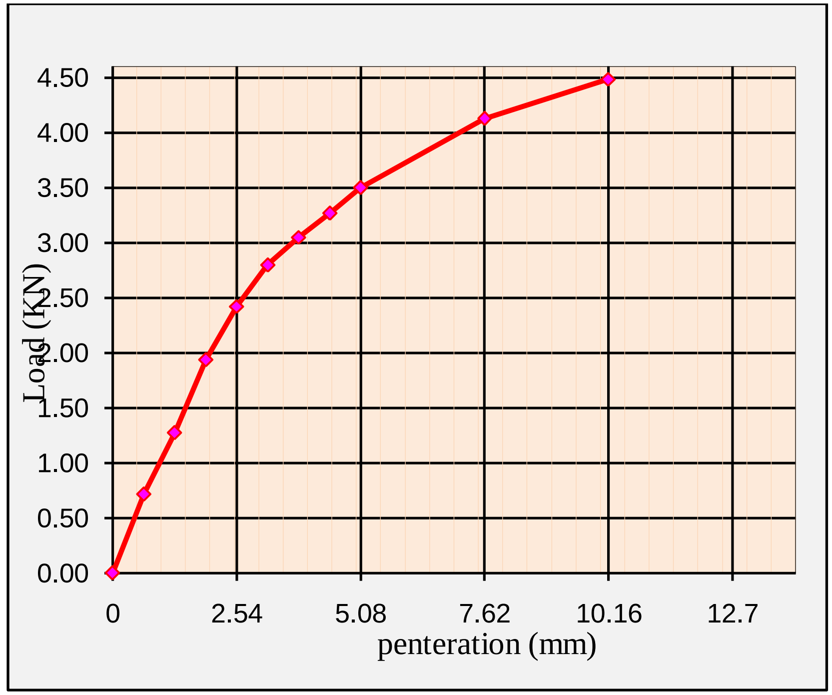


Figure-11.26: Unsoaked CBR test for soil+10%lime+12%WHA

SOAKED CALIFORNIA BEARING RATIO TEST

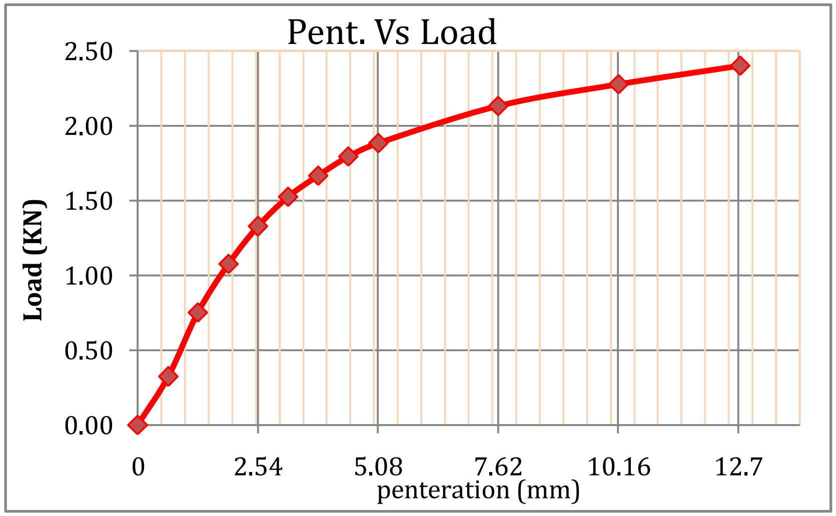


Figure-12.1: Soaked CBR test for soil+2% Lime +3% WHA

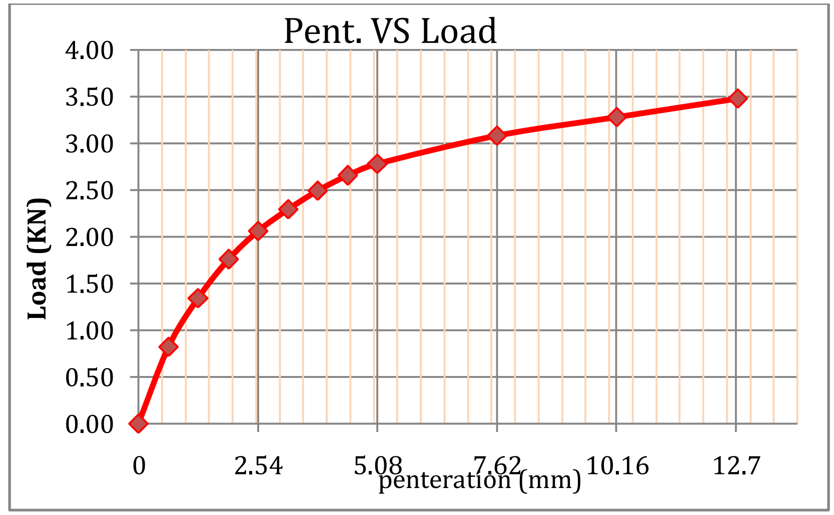


Figure-12.2: Soaked CBR test for soil+2% Lime +6%WHA

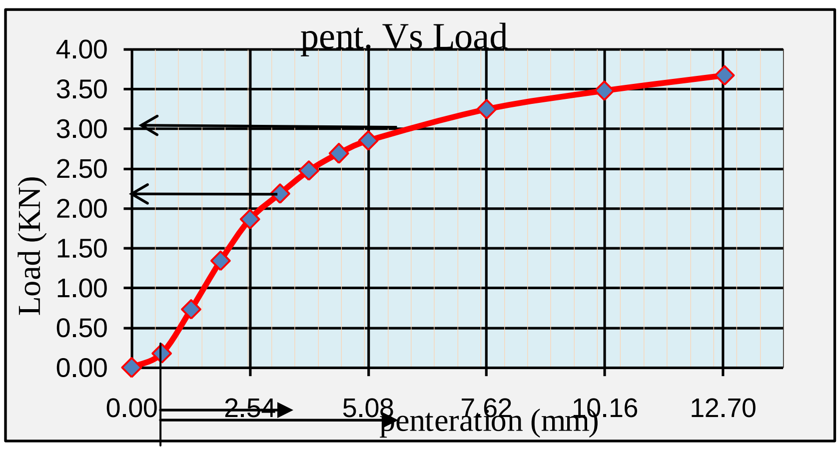


Figure-12.3: Soaked CBR test for soil+2% Lime +9%WHA

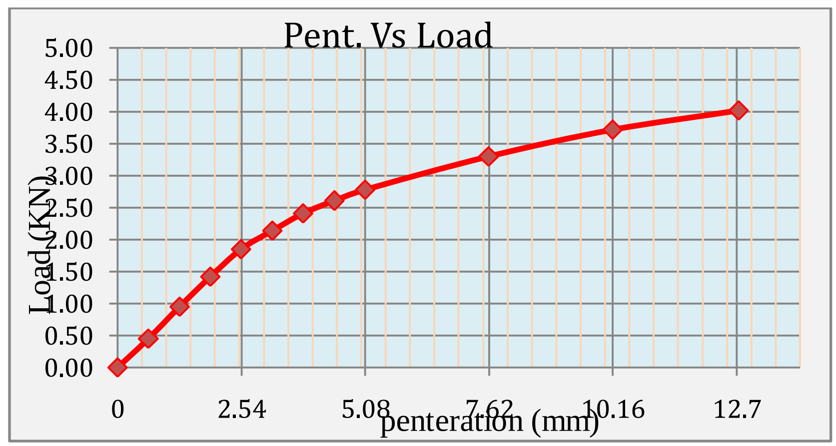


Figure-12.4: Soaked CBR test for soil+2% Lime +12%WHA

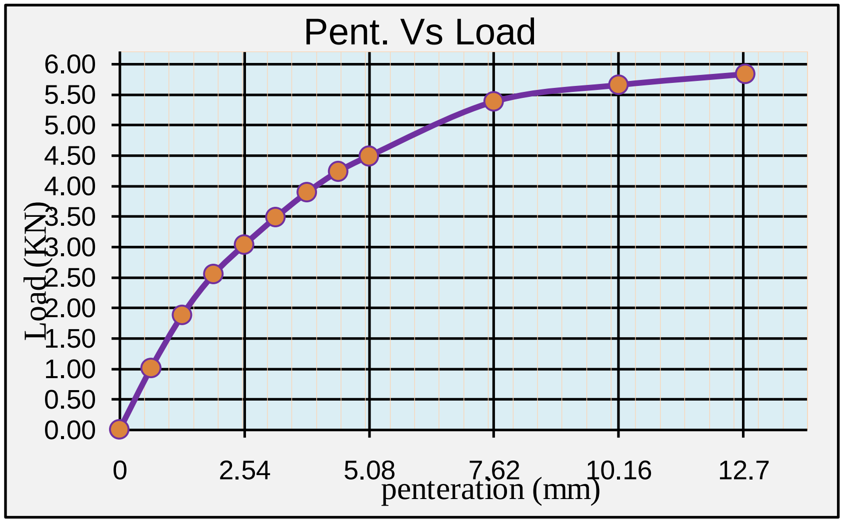


Figure-12.5: Soaked CBR test for soil+4% Lime +3%WHA

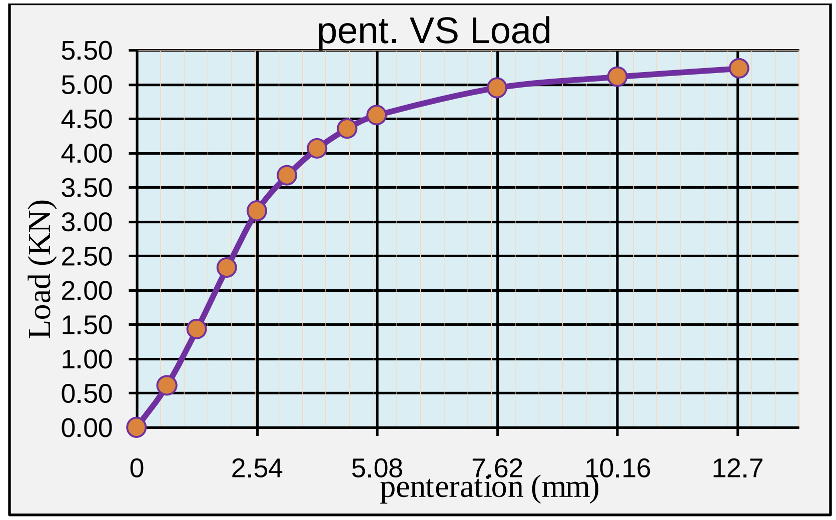


Figure-12.6: Soaked CBR test for soil+4% Lime +6%WHA

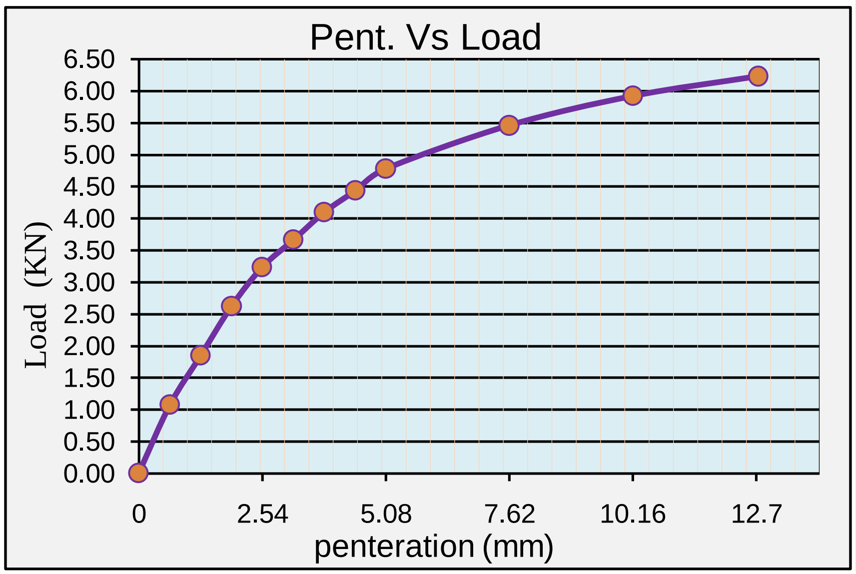


Figure-12.7: Soaked CBR test for soil+4% Lime +9%WHA

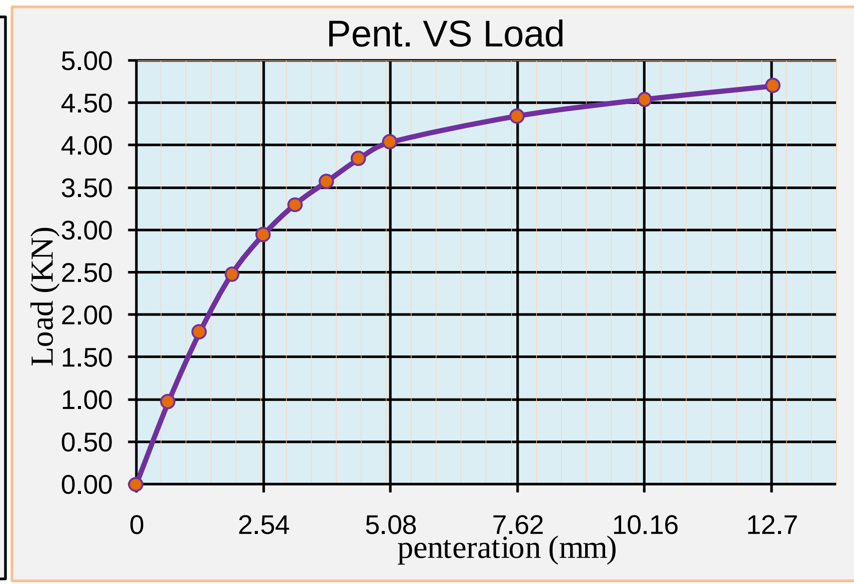


Figure-12.9 : Soaked CBR test for soil+4% Lime +12%WHA

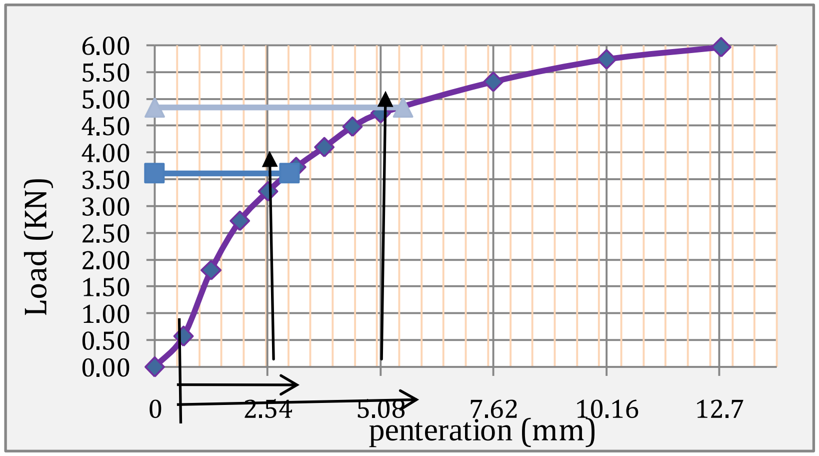


Figure-12.10: Soaked CBR test for soil+6% Lime +3%WH

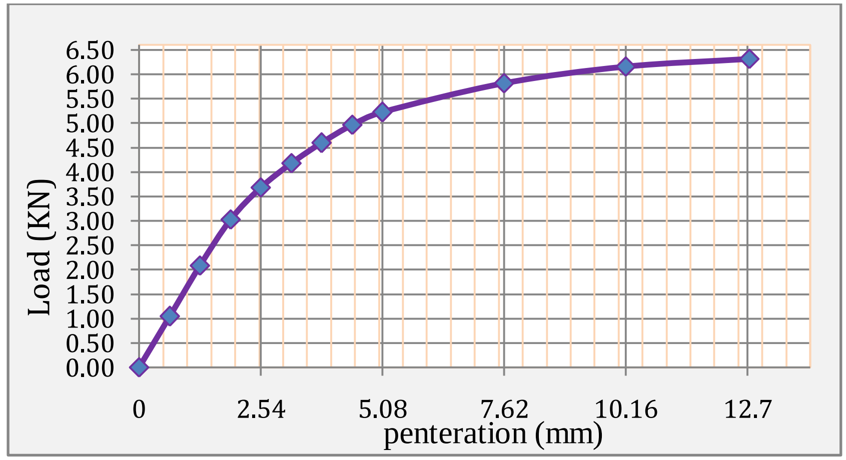


Figure-12.11: Soaked CBR for soil+6% Lime +6%WHA

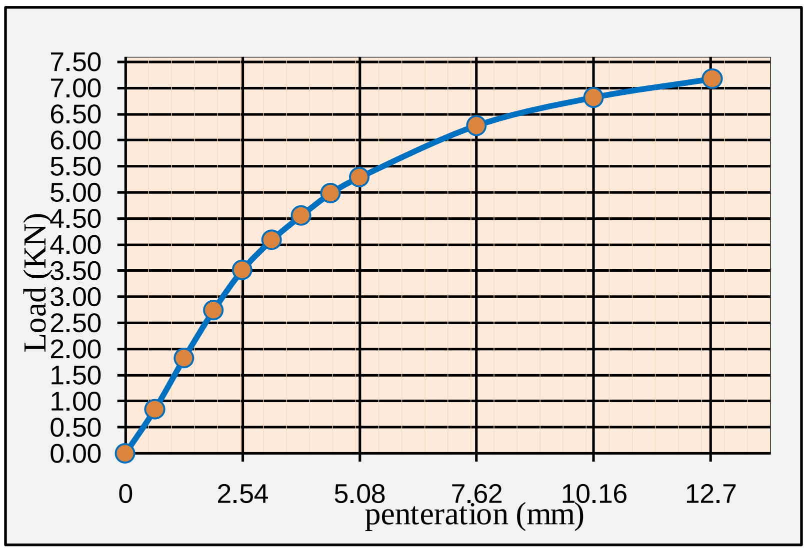


Figure-12.12: Soaked CBR test for soil+6% Lime +9%WHA

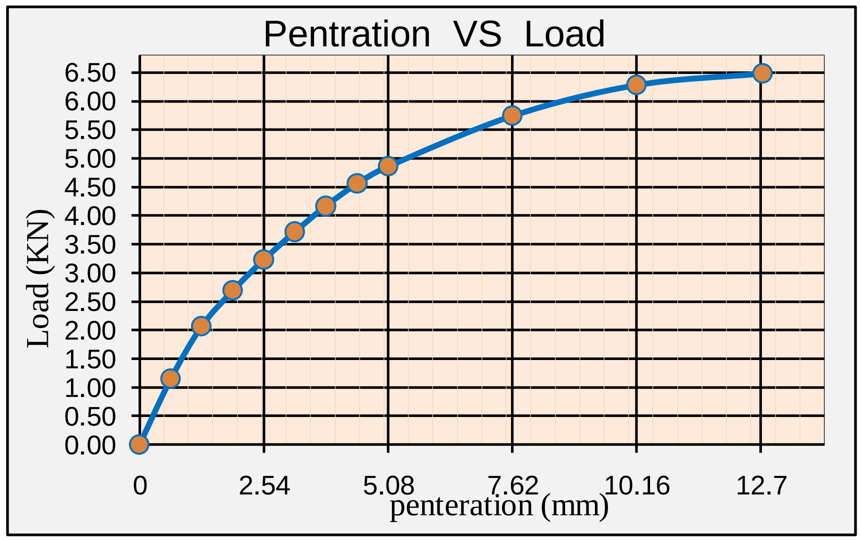
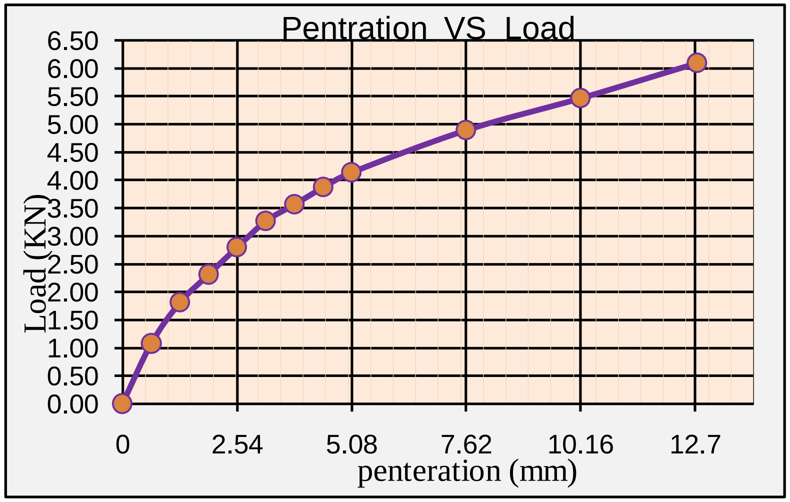


Figure-12.13: Soaked CBR test for soil+6% Lime +12%WHA



Figuree-12.14: Soaked CBR test for soil+8% Lime +3%WHA

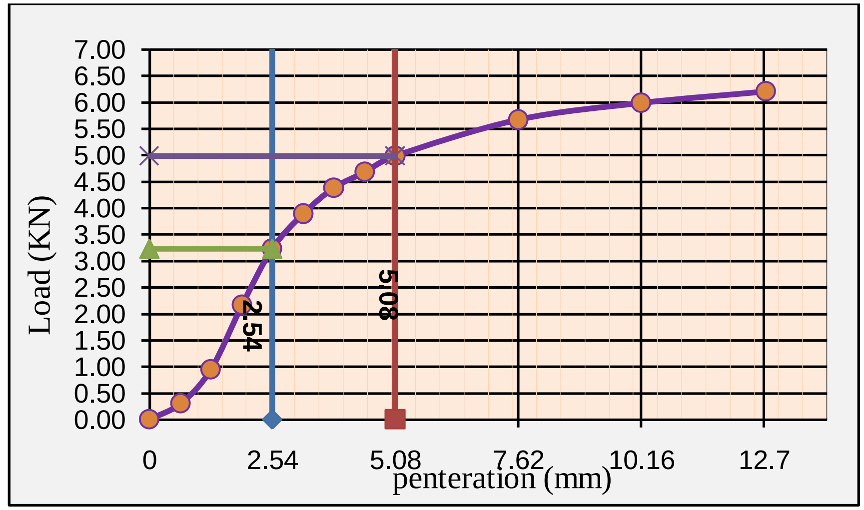


Figure-12.15: Soaked CBR test for soil+8% Lime +6%WHA

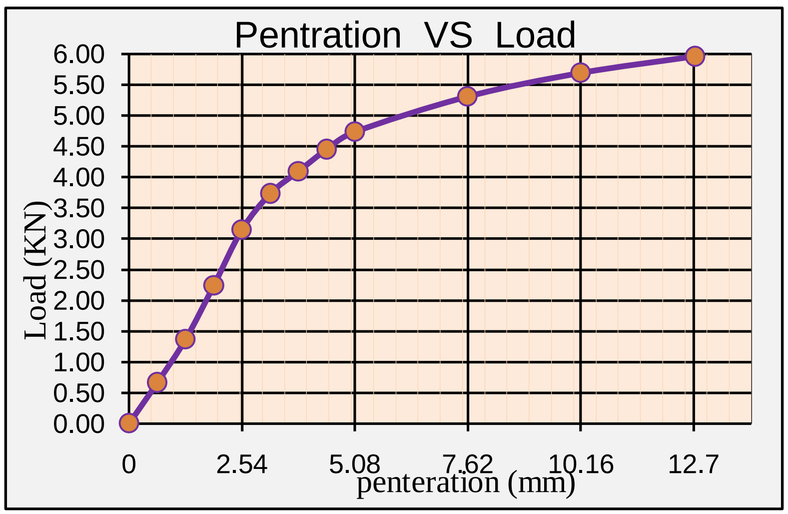


Figure-12.16: Soaked CBR test for soil+8% Lime +9%WHA

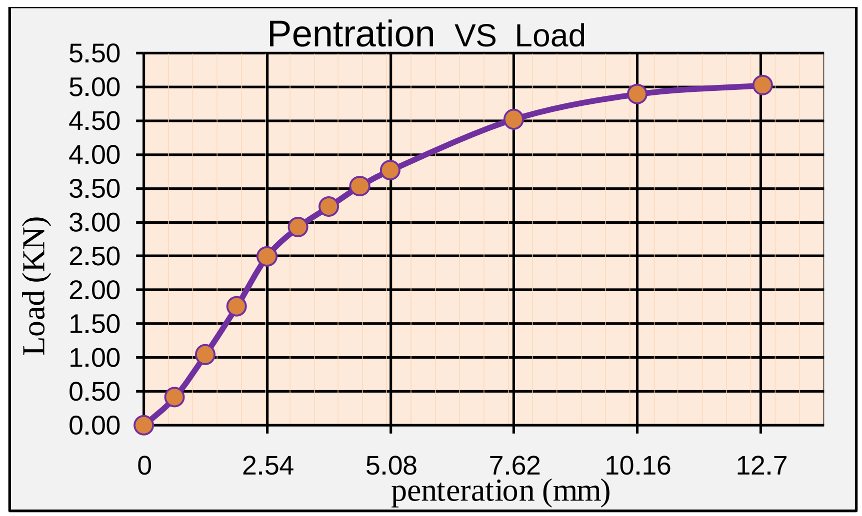


Figure-12.17: Soaked CBR test for soil+8% Lime +12%WHA

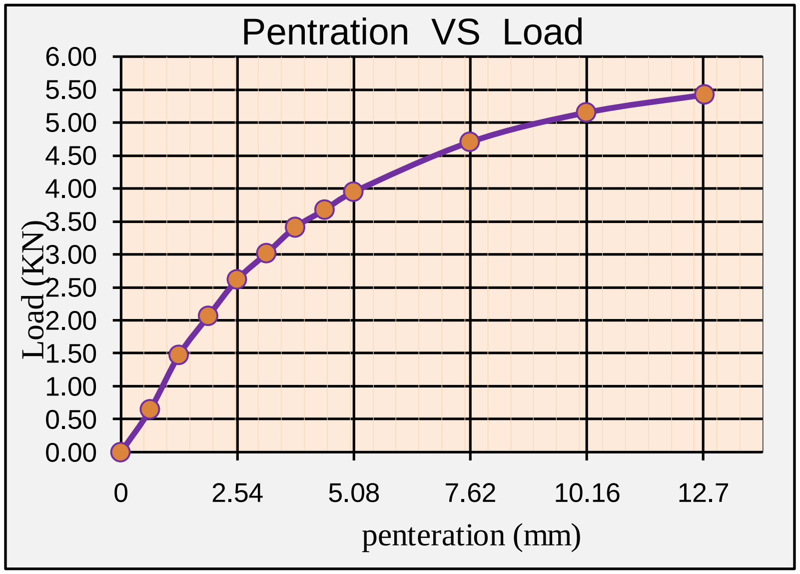


Figure-12.18: Soaked CBR test for soil+10% Lime +3%WHA

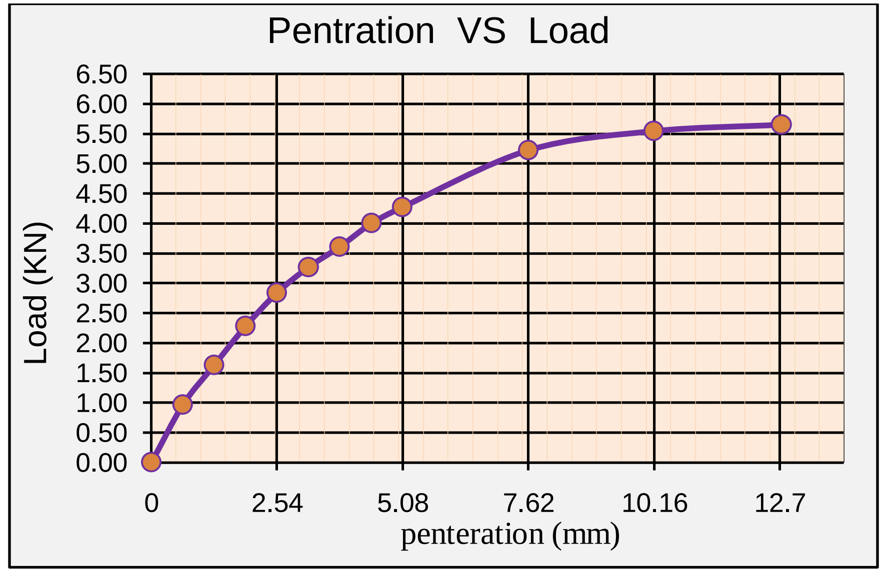


Figure-12.19: Soaked CBR test for soil+10% Lime +6%WHA

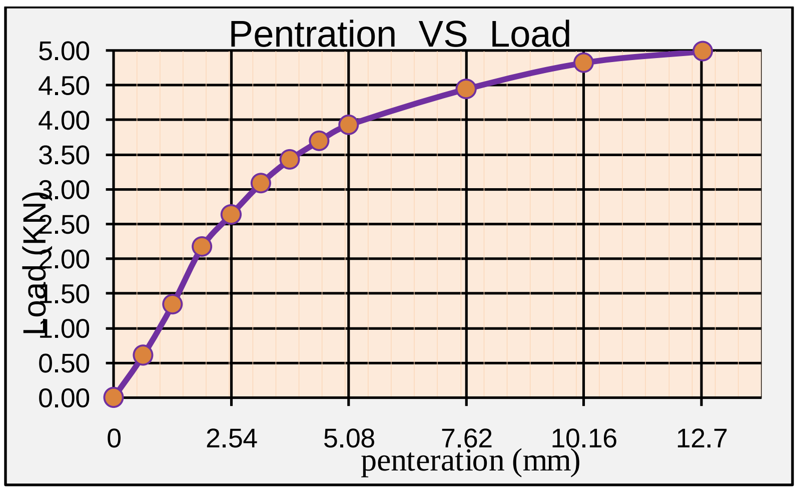


Figure-12.20: Soaked CBR test for soil+10% Lime +9%WHA

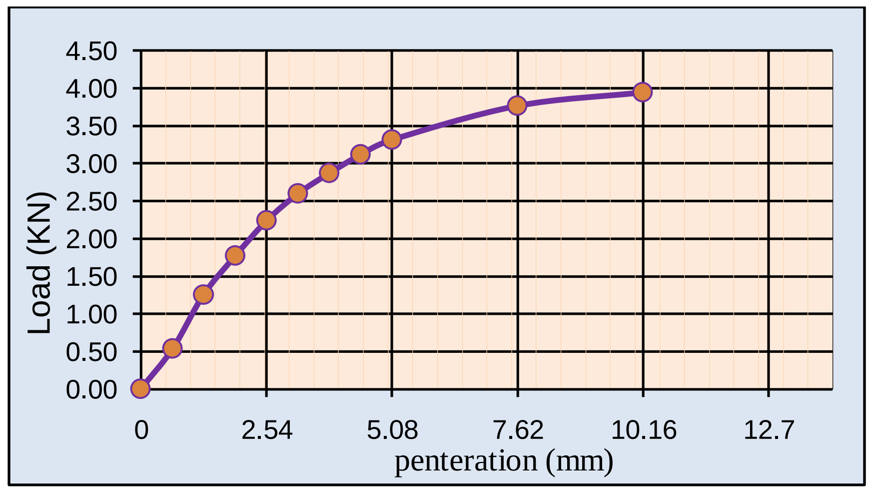


Figure-12.21: Soaked CBR test for soil+10% Lime +12%WHA