JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULITY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

COMBINED EFFECTS OF LIME AND MARBLE DUST ON THE PROPERTIES OF EXPANSIVE SUBGRADE SOIL IN JIMMA TOWN

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

By

Nurala Abera

March, 2018

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Nurala Abera

Advisor: Prof. Emer T. Quezon

Co-Advisor: Engr. Anteneh Geremew, MSc.

March, 2018

Jimma, Ethiopia

DECLARATION

I, the undersigned, declare that this thesis entitled: **"Combined effects of lime and marble dust on the properties of expansive subgrade soil in Jimma town.**" is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for these have been duly acknowledged.

Candidate:

Nurala Abera

Signature______________________________

ABSTRACT

The expansive soil is one of the most problematic grounds which cause extensive damage in civil engineering structure; mainly on the building, shallow foundation or other lightly loaded structure including roads, airport pavement, pipelines. This type of soil occurs in many parts of the world, Ethiopia is one of those countries. Some land areas in Jimma town is covered with expansive soil. The problematic nature of such lands can be improved by employing chemical stabilization techniques such as lime, cement and enzyme stabilization. However, as these methods are expensive to develop, countries such as Ethiopia, locally available low-cost materials such as marble dust can be used as a full or partial replacement of those elements to improve the engineering properties of expansive soils. Since, marble dust up to 30% alone has not shown significant improvement on properties highly expansive grounds of Jimma town especially on bearing capacity, it may not suitable and meet the minimum requirements of ERA pavement manual specification for use as a sub-grade material in road construction.

Relative to this, this research work is aimed to investigate combined effect lime and marble dust on expansive clay soils of Jimma town. The study is carried out on highly expansive soils of the study area. To achieve the objectives of the research, first field investigation work involved during dry season to identify the area of expansive soils and based on the properties that described under field investigations, five places (samples) with different location was determined. Free swell test was carried out for each sample, two samples with high free swell value had been selected, and then various laboratory tests were carried out on both two samples to classify the soil. The result from laboratory tests showed that both soil sample belonged to A-7-6 class according to AASHTO and CH (fat clay) according to ASTM soil classification system and rated as poor (unsuitable) subgrade materials. The soil was stabilized with a combination of lime and marble dust, (1-3%) Fixed percentage of lime blended with a different portion of marble dust (5-30%) by weight of soil. The laboratory tests carried out to evaluate the stabilized soil sample were; Atterberg limits, free swell, compaction and CBR tests.

The result indicated that the addition of marble dust with small percentage dosage of lime showed significant improvement on the geotechnical properties of both selected expansive soil samples. It reduces plasticity index, swelling, and OMC with an increase in MDD and CBR values with all combinations. The maximum improvement achieved at a combination 3% lime and 30% marble dust for both soil samples. Comparison of the results obtained with some specifications showed that the improvements obtained from this stabilization, and it was satisfied ERA Standard Specification for subgrade materials hence, Combination of lime and marble dust is an effective soil stabilization agent based on the results observed and described in this thesis. It is recommended that it can be considered for use in the stabilization of soil for sub-grade materials.

Keywords: *Atterberg limits, CBR, expansive soil, lime, marble dust, MDD and OMC*

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ACROMYMS

AACRA	Addis Ababa City Road Authority
AASHTO	American Association of State Highway and Transportation Organization
AL_2O_3	Aluminum Oxide
AC	Activity
ASTM	American Society for Testing Materials
CBR	Californian Bearing Ratio
Cao	Calcium Oxide
$CaCO_3$	Calcium Carbonate
CEC	Cation Exchange Capacity
CH	High plastic clay (fat clay) soil
DD	Dry Density
DFS	Differential free swell
ERA	Ethiopian Road Authority
Fe_2O_3	Iron Oxide
Fs	Free swell
LL	Liquid limit
MD	Marble Dust
MgO	Magnesium oxide
MH	Elastic silt soil
OMC	Optimum Moisture Content
PI	Plasticity index

PL	Plastic limit
S1	Sample one or Subgrade class one
S2	Sample two or Subgrade class two
S3	Subgrade class three
SI	Shrinkage index
SL	Shrinkage limit
SP	Swelling potential
U.S.B.R	United state Bureau of reclamation
USCS	Unified Soil Classification System
UCS	Unconfined Compressive Strength
Vi	Initial Volume
Vf	Final Volume

CHAPTER ONE

INTRODUCTION

1.1 Background

Developing countries like Ethiopia focus their attention on the development of infrastructures like railways, roadways, Airways and housing facilities**.** The stability of the structures to be built on the soil depends entirely on the balance of the land at which it rests so that Soil is the basis for any construction, it supports the substructure of any structure, and it is the subgrade which endorses the sub-base/base in the pavement. There are several soils that pose a threat to the stability of the structures because of the existing land at a particular location may not be suitable for the construction due to inadequate bearing capacity and higher compressibility or even sometimes excessive swelling in case of expansive soils. This type of land is posed severe problem on construction activities; which can lead to expensive design, construction cost, mitigation measure as well as repeated and costly maintenance cost (Fekerte, 2006)

Expansive soil cover a significant portion of Ethiopia; It's about 40% of the country land is covered by black cotton (vertisols) soil (Ehitabezahu N., and Abebe D., 2014). Especially Jimma zone is mainly covered with expansive and black clay soils which have surface and subsurface water which mostly encloses the flat area. For this reason, constructions could be sensitive for structural failure as a result of excessive consolidation settlement. For the expansive soils, because of change in moisture conditions, there could be a significant volume change problem at different seasons. This could affect the stability of lightweight structures as a result of cyclic swell-shrink process (Jemal, J., 2014)

The improvement of problematic soil at a site is indispensable due to rising cost of the land, and there is a huge demand for road construction. There is a need to concentrate on improving properties of soils using cost-effective practices like treating it with low cost and readily available material.

There are several treatment methods for improving properties of problematic soil; among this Stabilization is one of the most common ways. Soil stabilization is the process of altering the properties of soil by applying some modifiers to meet specified Engineering requirements of road pavement layers. It can be taken as an alternate to borrow selected materials, and it has the advantage that the effect to the environment is reduced, and in areas where selected/granular materials are scarce, it has a comparative economic advantage.

Soil stabilization is carried out by various methods, and one of them is mixing with the Stabilizing Additives such as lime and cement. The demand of lime and cement has been increasing in the construction industry which causes increasing their cost. Efforts, therefore, have been carried out since a long time to use the materials as admixtures which are obtained as waste from the manufacturing processes.

The number of research has been done in Ethiopia in the direction of utilizing of industrial waste into the soil stabilization technique such as Bagasse Ash by Meron Wubshet 2013, marble dust by Tagel mada 2016, and Rice Husk Ash Nitshit Tedla 2016.

In this study, industrial wastes like marble dust had been used with small percentage of lime to improve geotechnical properties of a soil. Waste marble dust is obtained by different methods of cutting marble in manufacturing companies. However, environmental damage can occur from the uncontrolled spill of these waste materials in natural habitats, so reusing of marble dust may improve soil properties and also it will reduce their damage on environments.

1.2 Statement of problem

Every Civil Engineering structure is to be founded on the soil. The soil on which the composition is to be built should be capable of withstanding the load to be imposed on it. However, naturally, there exist problematic grounds to be used as a foundation or subgrade materials, such as soil with poor bearing capacity and higher compressibility or even sometimes excessive swelling in case of expansive soils whose engineering characteristics are mainly affected by the fluctuation of moisture content. Many damages occur each year and roads constructed on such lands exhibit severe problems including increased cost of construction and maintenance.

Expansive soils occur in many parts of the world. However, the problem of expansion and shrinkage is associated with high moisture changes. Hence, it is restricted in areas where the seasonal variation in climatic condition is high. The significant volume change with the periodic cycle of wetting and drying can cause extensive damages in civil engineering infrastructures; mainly on small buildings, shallow foundation and other lightly loaded structures including roads and airport pavements, pipelines, etc. (Chen, F.H., 1988).

A significant portion of Ethiopian land is covered with expansive soil. It's about 40% of the country land is covered by black cotton soil (Ehitabezahu N., and Abebe D., 2014). Especially the subgrade property of Jimma town is inferior which is commonly included with this expansive ground; it will pose several problems on in infrastructure that was going to be built on the city. The traditional practice to solve the problematic nature of lands in areas with expansive soils is to remove the problematic soil to the required depth and replace it with selected materials. The excavation and replacement of the problematic soil may lead to increase in project cost and time as it needs excavation of the unsettled land, production, and transportation of the selected material and compaction to the required specification. In addition to the above, to get selected materials, additional borrow areas need to be excavated, and that contribute a lot for environmental degradation.

Current studies indicate that the possibilities of using different industrial waste such as marble dust as a stabilizing agent or as partial replacement of others common addictive materials such as lime and cement to increase the bearing capacity of this low strength subgrade soil and reducing their swelling potential. In addition, utilizing such industrial waste as stabilization has two purpose; it decreases the signs of industrial waste on the environment and improving the properties of poor strength soil to make it capable of carrying the load with low cost. However From the revised literature the conducted researches in Ethiopia on the suitability of marble dust for soil stabilization has been found that the marble dust up to 30% has not shown significant improvement of engineering properties of the expansive subgrade soil to meet specification requirements for road subgrade material(Tagel M., 2016). This is the reason why the concept has been considered to study the combined effect of marble dust and lime on expansive subgrade soil of Jimma.

1.3 Research question

1. Where is the location of highly expansive soil in Jimma town?
2. What are the engineering properties of selected expansive subgrade soils of the study area?
3. What are the change in properties of expansive soil when stabilized with lime and marble dust?
4. How can compare laboratory test result with standard and specifications of subgrade materials?

1.4 Objective

1.4.1. General objective

The general objective of the study is to investigate the combined effect of marble dust and lime on selected expansive subgrade soil for road construction

1.4.2. Specific objective

1. To identify the locations of highly expansive soils in Jimma town
2. To determine existing engineering properties of the selected expansive subgrade soil.
3. To analyze the change in properties of expansive soil when stabilized with marble dust and lime
4. To compare laboratory test result with standard and specifications of subgrade materials

1.5. Significance of study

This study is to investigate the combined effect of marble dust, and lime on selected expansive subgrade soil of Jimma town. Benefit from the studies are cost saving because marble dust is typically by far cheaper than traditional stabilizers such as cement and lime, the study will provide lessons that will help the concerned body to come up with appropriate measures to address problems resulting from loose subgrade soil with cost-effective. On the other hand, other researchers will use the findings as a reference for further research on stabilization of subgrade soil.

1.6. Scope and limitation of the study

The study covered stabilization of selected expansive soil in Jimma town. It has been supported by different source of literatures and a series of laboratory experiments. The relevant laboratory tests have been done by researcher was; grain size distribution (gradation), standard Proctor compaction, CBR, swelling potential (free swell trial), and Atterberg limit taste (includes Liquid Limit (LL), Plasticity Index (PI), Optimum Moisture Content (OMC)). However, the finding of the research was limited on selected expansive soil in Jimma town.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Soils to be used as road subgrade material may have different characteristics such as soils with excellent load bearing capacity which is suitable for the use of subgrade material and on the other hand soils which are unsuitable to be used as subgrade material such as highly expansive soils.

Expansive soil refers to a land that has the potential for swelling and shrinking due to changing moisture condition. Expansive soils cause more damage to structures particularly pavements and light buildings than any other natural hazard, including earthquakes and floods. It has been reported that the damage caused by these soils contribute significantly to the burden that the inherent risk pose on the economy of countries where the occurrence of these lands is significant (Nelson, D.J., and Miller, J.D., 1992)

There are many improvement methods of problematic soil, of them. Soil stabilization is one of the most improved ways of expansive soil.

2.2 Origin, Distribution, and Characteristics of Expansive Soil

2.2.1 Origin of Expansive Soil

The origin of expansive soils is related to a combination of conditions and processes that result in the formation of clay minerals having a particular chemical makeup which, when in contact with water, expands. Variations in the terms and methods may also form other clay minerals, most of which are non-expansive. The conditions or processes, which determine the clay mineralogy, include the composition of the parent material and degree of physical and chemical weathering to which the elements are subjected.

A. Parent Material

The constituents of the parent material during the early and intermediate stages of the weathering process determine the type of clay formed. The nature of the parent material is much more critical during these stages than after intense weathering for long periods of time (Chen, F.H., 1988). The parent materials that can be associated with expansive soils are classified into two groups. The first team comprises the basic igneous rocks and the second team includes the sedimentary rocks that contain Montomorillonite as a constituent (Chen, F.H., 1988). The basic volcanic rocks are comparatively low in silica, generally about 45 to 52 percent. Rocks that are rich in the metallic base such as the pyroxenes, amphiboles, biotite and olivine fall within this category. Such rocks include the gabbros, basalts and volcanic glasses (Chen, F.H., 1988). The sedimentary rocks that contain Montomorillonite as constituent include shale and clay stones. Limestone and marls rich in magnesium can also weather to clay. These parent materials contain varying amounts of volcanic ash and glass, which can subsequently be weathered to Montomorillonite. The volcanic eruptions sent up clouds of ash, which fell on the continents and sea. Some of the fine-grained sediments which accumulated to form these rocks also contain Montomorillonite derived from weathering of continental igneous rocks and from ash, which fell on the continental areas (Chen, F.H., 1988)

B. Weathering and Climate

The weathering process by which clay is formed includes physical, biological and chemical means. The essential weathering process responsible for the formation of Montomorillonite is the chemical weathering of parent rock mineral. The parent material consists of Ferro magnesium mineral, calcic feldspars, volcanic glass, volcanic rocks and volcanic ash. The formation is aided in an alkaline environment, the presence of magnesium ion and lack of leaching. Such condition is favorable in semi-arid regions with relatively low rainfall or moderate seasonal rainfall, particularly where evaporation exceeds precipitation. Under these circumstances, enough water is available for the alteration process, but the accumulated cautions will not be removed by rainwater (Chen, F.H., 1988).

2.2.2. Distribution of Expansive Soil

Expansive soils are mostly found in the arid and semi-arid regions, and it covers a huge part of the world the problem of expansive soils is widespread throughout the world. Same of The countries that are facing issues with expansive soils are Australia, the United States, Canada, China, Israel, India(Murthy, V. N.S, 1994) and, most of the African countries such as South Africa, Ethiopia, Kenya, Mozambique, Morocco, Ghana, Nigeria etc (Teferra, A., and Leikun, M., 1999)

In Ethiopia the aerial coverage of expansive soils is estimated to be 24.7 million acres (Lyon associates, 1971; as cited by Nebro, D., 2002), according to ERA 2011 "road sector development program, 13 years performance" it's about 40% of the country land are covered with this expansive soil. They are widely spread in the central part of Ethiopia following the significant truck roads like Addis-Ambo, Addis-Wolliso, Addis– Debrebirhan, Addis-Gohatsion, and Addis-Modjo are covered by expansive soils. Also, areas like Mekele and Gambella are covered by expansive soil. The distributions are shown in

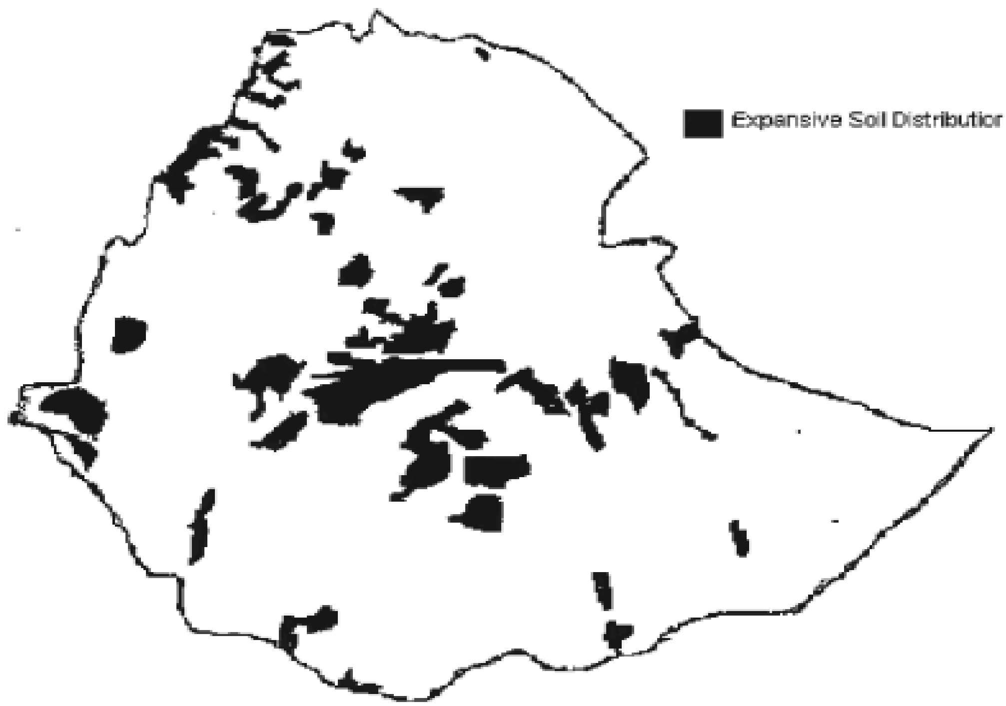

Figure 2.1: Distribution of expansive soil in Ethiopia. Source; (Tilahun, D., 2004)

2.2.3. Characteristics of Expansive Soil

Expansive soils are residual deposits formed from basaltic and sedimentary rocks. Expansive soils of different origin and location have common features such as high clay content with appreciable plasticity, dark or gray color and tendency to expand as result of moisture increase and shrink due to loss of moisture (Chen, F.H., 1988).

Expansive soils absorb water slowly, swell, become soft and lose strength. These soils are easily compressible when wet and possess a tendency to heave during damp condition and shrink in volume and develop cracks during dry seasons of a year, and they show extreme hardness and breaks when they are in the dry state. The seasonal change in the number of expansive soils is manifested by both horizontal and vertical movements; the smooth flow leads to fissure opening during dry seasons and closing during wet seasons whereas the vertical movement leads to cyclic changes in levels. The magnitude of this action decreases with depth where there are no seasonal moisture changes (Chen, F.H., 1988).

2.3. Mineralogy of Expansive Soils

The parent materials of expansive soils may be classified into two groups. The first group Comprises the basic igneous rocks such as basalt, dolerite sills and dykes, gabbros, etc., where feldspar and pyroxene minerals of the parent rocks decompose to form Montomorillonite – the predominant mineral of expansive soil – and other secondary minerals The second group comprises sedimentary rocks that contain Montomorillonite, and break down physically to build expansive soils. There are indications that confirm that the expansive soils of Ethiopia are derived from both groups (Jemal, J., 2014).

There are three common types of clay minerals; Kaolinite, Illite and Montomorillonite, and these common groups of clay minerals are most important in engineering studies. Kaolinite is a standard two layered mineral having a tetrahedral and an octahedral sheet joined to form 1 to 1 layer structure held by a relatively stable hydrogen bond. Kaolinite does not absorb water and hence does not expand when it comes in contact with water. The Montomorillonite groups of clay minerals have 2 to 1 layer structure formed by an octahedron sandwich between two tetra hadrons (Nelson, 2010). These clay groups have a significant amount of magnesium and iron sandwiched into the octahedral layers. The most important aspect of the Montomorillonite clay mineralogy group is the ability for water molecules to be absorbed between the layers, causing the volume of the minerals to increase when they come in contact with water. The Illite clay minerals have a structure similar to that of kaolinite, but are typically deficient in alkalis, with less aluminum substitution for silicon, magnesium, and calcium can also sometimes substitute for potassium and Illite are the non-expanding type of clay minerals(Craig, 1997).

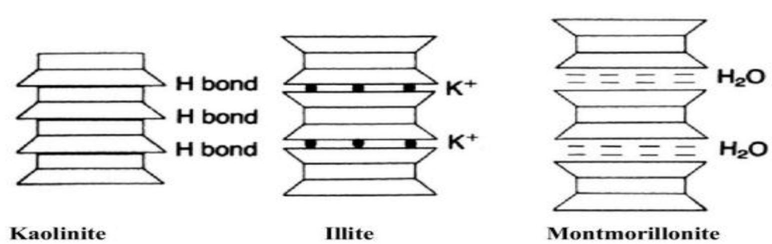

Figure 2.2: Schematic representation of clay minerals (Craig, 1997)

2.4. Classification of expansive soil

A soil classification system is an arrangement of different soils into groups having similar properties. The purpose of soil classification is to make possible the estimation of soil properties by association with soils of the same class whose properties are known and to provide the engineer with an accurate method of soils description (Teferra A. and M. Leikun., 1999).

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

2.4.1. Classification Using General Methods

Soils are classified in the general schemes: Unified Soil Classification System (USCS) and the American Association of State High way and Transportation Officials (AASHTO) method according to index properties.

2.4.1.2. Unified Soil Classification System

In this classification system, a correlation is made between swell potential and unified soil classification as follows. The USC system includes common soil names with the classification system. Soils that are intermediate between two groups may be identified symbolically by combined notation such as SM-ML and SC-C

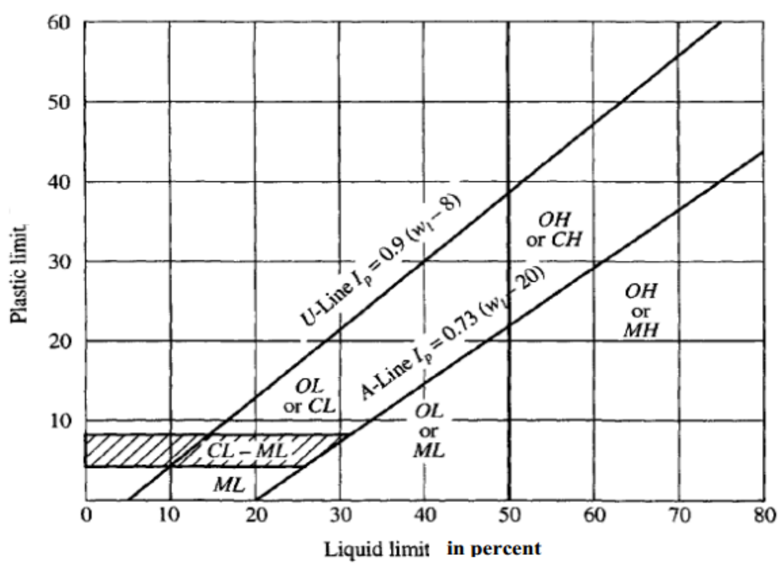

Figure 2.3: Plasticity chart for classification of fine-grained soils (ASTM, 1996)

2.4.1.1 AASHTO Classification

From AASHTO soil classification chart, soils rated A-6 or A-7 can be considered potentially expansive soils (Nelson, D.J., and Miller, J.D., 1992)

General classification	Granular Materials (35 percent or less of total sample passing No. 200)							Silt-clay Materials (More than 35 percent of total sample 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 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics 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 max	10 max	10 max	11 min	11 min
Usual types of significant constituent materials	Stone fragments—gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good					Fair to poor					

Figure 2.4: AASHTO Classification chart (Nelson, D.J., and Miller, J.D., 1992)

2.4.2 ERA Sub grade Classifications

ERA pavement design manual classify subgrade soil based their design CBR value. According to ERA manual 2013, the subgrade strength for design is assigned to one of six strength classes reflecting the sensitivity of thickness design to subgrade strength. The classes are defined in Table 2.1. For subgrades with CBRs less than 2, special treatment is required. (ERA, 2013)

Table 2. 1: ERA Sub grade strength class (ERA, 2013)

Class	CBR Range in %
S1	<3
S2	3,4
S3	5,6,7
S4	8_15
S5	15-30
S6	>30

2.4.3. Classification Specific to Expansive Soil

I. Method of Chen

Chen, F.H 1998, presented a single index method for identifying expansive soils using only plasticity index as it is shown in the following table

Table 2.2: Expansive soil classification based on plasticity index (Chen, F.H 1998)

Swelling potential(SP)	Plasticity Index (PI)
Low	0-15
Medium	15-35
High	20-55
Very High	>55

II. Method of Daksanamurthy and Raman (1973)

Daksanamurthy and Raman (1973) presented a single index method for identifying expansive soils using only liquid limit as it is shown in following table

Table 2.3: Expansive soil classification based on liquid limit (Amer, A., and Mattheus, F.A., 2006).

Swelling potential	Liquid limit
Low	$20 < LL \leq 35$
Medium	$35 < LL \leq 50$
High	$50 < LL \leq 70$
Very high	$LL > 70$

III. Method of Skempton

Skempton is identifying expansive soil based on their activity; the method is developed, by combining Atterberg limits and clay content into a single parameter called Activity. Activity is defined as:

$$AC = \frac{PI}{\text{Percentage by weight finer than } 2\mu m}$$

Where AC= Activity and PI= Plasticity index

Table 2.4: Expansive soil classification based their activity (Jemal, J., 2014).

Activity	Potential for expansion
$Ac < 0.75$	Low (inactive)
$.75 < Ac < 1.25$	Medium(normal)
$Ac > 1.25$	High(active)

VI. Method of Seed et al

After an extensive study on swelling characteristics of remolded, artificially prepared and compacted clays, Seed et al. (Chen, F.H., 1988) have developed a chart based on activity and percent clay sizes as shown in Figure 2.2. The activity here is defined as:

$$AC = \frac{PI}{C-10}$$

Where AC= Activity, PI= Plasticity index and C= percentage of clay-size finer than 0.002mm

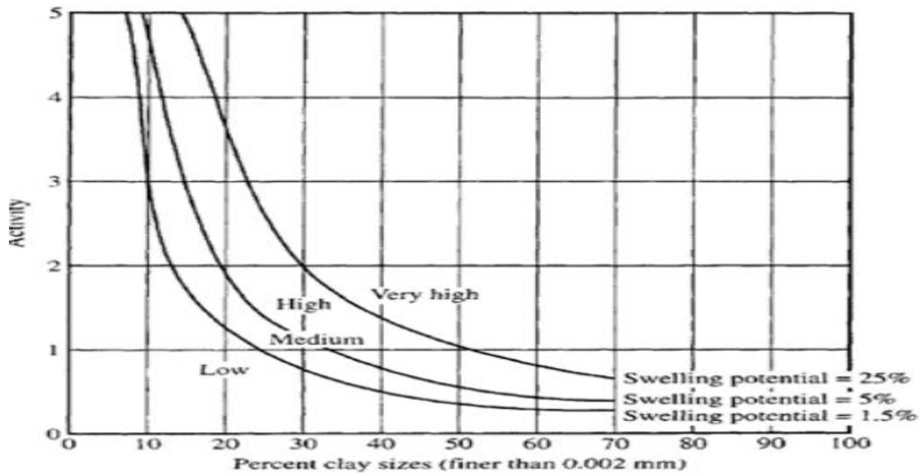

Figure 2.5: Classification Chart for swelling potential Seed et al. 1962(Chen, F.H., 1988)

2.5 Identification of expansive soil

Several different methods and techniques are developed by soil scientist and geotechnical engineers since a long time to obtain information on physical, chemical and mineralogical properties of expansive soil. That is used in the construction industry before design and construction of any structure; to identifying and characterizing this soil, to estimate the magnitude of damage that might be faced and providing necessary measurement to alleviate the damage that it might be encountered. Field and laboratory identifications are the standard and mostly used technics and method. Chen (1988) and Nelson and Miller (1992) are widely discussed on laboratory identification methods of expansive soils, and they grouped the process into three categories namely;

- ✓ Mineralogical identification
- ✓ Indirect measurements (index properties)
- ✓ Direct measurements

2.5.1 Field identifications

In the field, expansive soils can be identified by applying several identification techniques. Some of the critical field identification methods used to indicate the potential of the expansiveness of soils includes (Chen, F.H., 1988; Nelson, D.J., and Miller, J.D., 1992 and AACRA-2004):

- ✓ Usually, have a color of black or grey.
- ✓ The polygonal pattern of surface cracks during the dry season. Cracks 205cm wide and over 1m depth and cracks close after rainy season
- ✓ A shiny surface when partly dray piece of the soil is polished with fingers
- ✓ High dry strength and low wet strength.
- ✓ Stickiness and low traffic ability when wet.
- ✓ Cracks are observed on nearby lightweight structures such as houses and fences

Figure 2.6: Wet expansive soil Figure 2.7: Dry expansive soil (Tagel, M.2016)

Figure 2.8: Polygonal cracks on the ground surface during dry season of expansive soil (Tagel, M., 2016)

2.5.2 Laboratory identification

Laboratory identification of expansive soils can be categorized into mineralogical, indirect and direct methods. Chen, F.H., 1988; Nelson, D.J., and Miller, J.D., 1992):

2.5.2.1 Mineralogical identification

Clay mineralogy is a fundamental factor controlling expansive soil behaviors, and it can be identified in the laboratory by applying tests such as;

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

The above methods are essential in examining the fundamental clay properties in laboratories, but they are time-consuming, require expensive test equipment, and hence they are not commonly used in soil geotechnical laboratories (Chen, F.H., 1988)

2.5.2.2 Indirect methods

These are simple and more practical methods used in engineering work for classification of expansive soil and evaluation of their swelling potential. The same laboratories tests included under these plans are Atterberg limits (plastic limit, liquid limit, and plastic index), free swell test, free swell ratio, free swell index, etc (Chen, F.H., 1988; Day, 2001 Nelson, D.J., and Miller, J.D., 1992):

A. Atterberg limit

In this method, measurement of the Atterberg limits of the soil is conducted for identification of all soils and provides a wide acceptable means of rating. Especially when they are combined with other tests they can be used to classify expansive soils. The relation between the swelling potential of clays and the plasticity index is shown in Table 2.1 below.

Table 2.5: Relation of the swelling potential of clays and the plasticity index (Chen, F.H., 1988)

Swelling potential	Plasticity index
Low	0-15
Medium	10-35
High	20-55
Very high	$\geq$55

According to (Nelson, D.J., and Miller, J.D., 1992) the relation between Atterberg limit, expansion potential, and type of clay mineral in the soil are shown in table 5.2

Table 2.6: relationship between Atterberg limit, expansion potential, and type of clay mineral, (Nelson, D.J., and Miller, J.D., 1992)

Clay mineral type	Atterberg limits%			expansion potential
	LL	PL	SL	
Kaolinite	10-20	30-100	25-29	Low
Illite	60-120	35-60	15-17	Moderate
Montomorillonite	100-900	50-100	8.5-15	High

B. Free Swell Tests

Free swell tests are known to indicate the presence of swelling clay in soil (Head, K.H., 1980), it is one of the most common and simple analyses to estimate the swelling potential of expansive clay soil sample without being loaded.

Experiments indicated that a good grade of high swelling commercial bentonite would have a free swell of from 1200 to 2000 percent. Soils having a free swell value as low as 100 percent can cause considerable damage to lightly loaded structures, and soils are having an open swell value below 50 percent seldom exhibit appreciable volume change even under very light loadings. The free swell percentage can be computed using Equation (2.1) from the relationship between initial and swelled volume. (Chen, F.H., 1988; Nelson, D.J., and Miller, J.D., 1992; Teferra, A., and Leikun, M., 1999 as cited by Meron, W.,)

$$\text{Free swell (\%)} = \frac{Vf - Vi}{Vi} \quad \text{……………………. Equation, 2.1}$$

Where: Vf= final volume, Vi= initial volume

C. Free Swell Index

The free swell index is also one of the most commonly used simple tests to estimate the swelling potential of expansive clay; the free swell index is calculated using Equation (2.2). (Amer, A., and Mattheus, F.A., 2006). The relation between the degree of expansion and differential free swell index is shown in Table 2.2

Free swell index = $\frac{Vw-Vk}{Vk}$ x 100………………. Equation, 2.2

Where Vw= final volume in water, Vk= final volume in kerosene

Table 2.7: Degree of expansion and differential free swell index (Ranjan, G., and Rao, A.S.R., 2002)

Free swell index	Degree of expansiveness
< 20	Low
20-35	Moderate
35-50	High
>50	Very High

Note; the relation between Degree of expansion and differential free swell index shown in the above table is normal to quantify 10cc as the volume occupied by 10g of soil. This does not account for variations of density (Amer, A., and Mattheus, F.A., 2006).

D. Free Swell Ratio test

To determine the swell property, Sridharan and Prakash proposed the free swell ratio method of characterizing the soil swelling. Free swell ratio is defined as the ratio of sediments volume of 10cc oven dried soil passing through 425µm sieve in distilled water to that of Kerosene, to calculate free swell ratio Sridharan and Prakash are developed Equation (2.3.) The relation between the degree of expansion and differential free swell rate is given in Table 2.3.

Free swell ratio = $\frac{Vw-Vk}{Vk}$ x 100………………. Equation, 2.3

Where Vw= final volume in water, Vk= final volume in kerosene

Table 2.8: Classification of Soils based on free swell rate; (Sridharan and Prakash 2004)

Free swell ratio	Soil expansivity	Clay type
<1	Negligible	Non swelling
1.0-1.5	Low	Mixing of non-swelling and swelling
1.5-2.0	Moderate	Swelling
2.0-4.0	High	Swelling
>4.0	Very high	Swelling

E. Cation Exchange Capacity (CEC)

Cation exchange capacity of the soil is a measure of easily exchangeable cation in the soil; and is greatly influenced by mineralogical content and specific surface area of soil grains (Chen, F.H., 1988). This test is used to obtain information about the soil fertility in agricultural applications; it indicates potential expansive properties of soil in engineering application (Fekerte. 2006.)

High Cation Exchange Capacity (CEC) values indicate a high surface activity. In general, swell potential increases as the CEC increases. Typical CEC values of essential clay minerals are shown by (Nelson, D.J., and Miller, J.D., 1992) after (Mitchell, 1976) are given in Table 2.4

Table 2.9: Typical CEC values of essential clay minerals (Nelson, D.J., and Miller, J.D., 1992)

Clay Mineral	CEC(meq/100gm	Expansion potential
Kaolinite	3-15	Low
Illite	10-40	Moderate
Montomorillonite	80-150	High

2.5.2.3 Direct methods

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

2.6. Problem associated with expansive soil

Most of the issues related to comprehensive soils arise mostly from the nature of the soil itself and drainage facilities provided. As a result of their low CBR and strength, expansive soils fail to support the loads transmitted from the pavement structure and cause excessive deformation beyond permissible limits. The common problems associated with expansive soils are described below (ERA, 2002).

A. Volume changes:

Expansive soils tend to shrink and crack when they dry out and swell when they get wet. The cracks allow water to penetrate deep into the soil, hence causing considerable expansion. This results in deformation of the road surface since the development and the subsequent heave are never uniform. Furthermore, these volume changes may produce lateral displacements ("creep") of the expansive clay, if the side slopes are not gentle enough. Seasonal wetting causes the road edges to wet and dry at a different rate than those under the surfacing. This mechanism, in turn, causes differential movements over the cross-section of the road and associated crack developments, first occurring in the shoulder area, and subsequently developing in the carriageway.

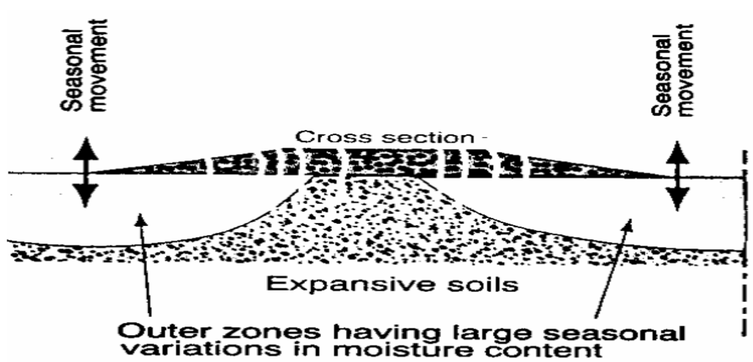

Figure 2.9: Moisture Content in Expansion Source: (ERA, 2002).

B. Bearing capacity:

When the moisture content increases, expansion occurs, and the bearing capacity of the soil decreases dramatically. As moisture content increase, the soils became fully saturated hence the CBR value may be reduced to less than two (2%) which makes such soils unsuitable to be used as road subgrade material.

C. Susceptibility to erosion:

When they are or become dry, expansive soils may present sand-like texture. In this state, they are prone to corrosion to a much greater extent than that anticipated from their plasticity and clay content.

2.7. Design and construction considerations in the area of expansive soils

To mitigate or overcome the problem of expansive soils, the design engineer may consider the following four main approaches; (ERA, 2002).

- ✓ Avoid expansive soils areas by realignment
- ✓ Excavate the expansive soils and replace them with suitable material (backfilling)
- ✓ Treat the expansive clays (with lime or materials)
- ✓ Minimize moisture changes and potential swelling in the expansive soils.

2.8. Mitigation measures on expansive soils

The following mitigation measures are recommended by ERA, 2002

A. Realignment:

This solution is possible only if the areas covered with expansive clays are of limited extent. It is still possible to consider at this stage of design.

B. Excavation and replacement:

This is a simple method that effectively eliminates the problems of expansive soils, and hence it is recommended as much as possible. However, backfill materials are to be obtained from borrow pits, thereby increasing the need for such investigations. The investigations should focus on minimizing haulage of the materials, and this method will be economically viable only if suitable backfill material is available in the vicinity of the road.

It is usually considered sufficient to excavate the expansive soil to a depth of about 1 m (even if some expansive soil remains under the backfill material, it will be confined and protected from moisture changes). This may consequently be used for preliminary estimates of the required quantity of backfill material. Such backfill material should exhibit strength (CBR) characteristics similar to those of the overlying embankment materials (preferably at least CBR on the order of 5, i.e., subgrade strength class S3) and should not be too previous in order not to act as a drain.

C. Treatment with lime

Treatment of expansive soils with hydrated lime can give good results. The addition of 4 to 6% of lime is usually required and provides the following improvements: -

- Reduction of the plasticity index to less than 20
- Considerable increase of the shrinkage limit
- Modification of the swell to negligible values - Increase of the CBR to a minimum of 10 (after seven days cure) and 15 (after 28 days cure), with the corresponding improvement of the subgrade strength class.
- Modification of the particle size distribution (by agglomeration of the clay particles), the final grading being similar to that of silt.

This treatment is, however, costly, in particular, because it is necessary to treat a substantial thickness of soil (minimum 30 cm compacted thickness). Lime treatment would, therefore, be considered advantageous only where investigations failed to locate suitable backfill or improved subgrade material, and when pavement savings can be made by taking advantage of the enhanced strength of the treated clay.

D. Minimizing Moisture Changes and Consequent Movements

If the above methods cannot be utilized, because of excessive costs or the absence of suitable fill or replacement material, expansive clays may be used for fill and subgrade. Particular practices are then necessary to avoid detrimental moisture and volume changes in the swelling soils, as follows:

- Confining expansive clays under improved subgrade and protective blankets
- Surcharging expansive soils
- Limiting the compaction of expansive soils
- Placing expansive clays at equilibrium moisture
- Preventing moisture changes under the pavement

2.10. Soil stabilization

One of the most improved methods of expansive soil is soil stabilization. Soil stabilization is the alteration of one or more soil properties, by mechanical or chemical means, to create an improved soil material possessing the desired engineering properties. The process may include blending of soils to achieve a desired gradation or mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil (Guyer. J.P., 2011).

2.10.1 Uses of stabilization

Pavement design is based on the premise that minimum specified structural quality will be achieved for each layer of material in the pavement system. Each layer must resist shearing, avoid excessive deflections that cause fatigue cracking within the coating or in overlying layers, and prevent excessive permanent deformation. As the quality of a soil layer is increased, the ability of that layer to distribute the load over a greater area increases so that a reduction in the required thickness of the soil and surface layers may be permitted. Commonly, improvement attained from soil stabilization can be summarized as (Guyer. J.P, 2011)

- ✓ ***Quality improvement****:* the most common enhancements achieved through stabilization include reduction of plasticity index or swelling potential and increases in durability and strength with a better soil gradation. In wet weather, stabilization may also be used to provide a working platform for construction operations.
- ✓ ***Thickness reduction****:* the strength and stiffness of a soil layer can be improved through the use of additives to permit a reduction in design thickness of the stabilized material compared with an unstabilized or unbound material. The design thickness can be reduced if the strength, stability and durability requirement of a base or subbase course is indicated to suitable by further analysis

2.10.2 Types of Soil Stabilization

A. Stabilization by Compaction

Loose materials can be made more stable only by the application of compaction. Though compaction cannot be considered as stabilization process, it plays a fundamental role in the properties of stabilized materials.

B. Mechanical Stabilization

Mechanical stabilization is a process by which the gradation of soil is improved by the incorporation of another material which affects only the physical properties of the soil. In the case of mechanical stabilization, unlike other stabilizing agents, the proportion of the stabilizing material exceeds 10% and may be as high as 50%.

C. Stabilization using stabilizing agents

Application of maintaining agents such as lime, cement and chemical stabilizers in low amount causes significant improvement in engineering properties of expansive soils.

D. Chemical Stabilization

Chemical stabilization of soil is mixing of soil with one or a combination of admixtures of powder, slurry, or liquid for the general objective of improving or controlling its volume stability, strength and stress-strain behavior, permanently and durability (Winterkorn and Pamukcu, 1990).

Soil improvement using chemical stabilization can be grouped into three chemical reactions; cation exchange, flocculation – agglomeration, pozzolanic reactions.

i. 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 (Winterkorn and Pamukcu, 1990).

Negatively charged clay particles absorb cations of specific type and amount. The ease of replacement or exchange of cations depends on several factors, primarily the valence of the cation. Higher valence cations easily replace cations of lower valence. For ions of the same valence, the size of the hydrated ions becomes important; the larger the ion the grater the replacement power. If other conditions are equal, trivalent cations are held more tightly than divalent and divalent cations are held more tightly than monovalent cations (Mitchell and Soga, 2005).Typical replicability serious is;

$Na^+ < Li^+ < K^+ < Rb^+ < Cs^+ < Mg^{2+} < Ca^{2+} < Ba^{2+} < Cu^{2+} < Al^{3+} < Fe^{3+} < Th^{4+}$

The exchangeable cations may be present in the surrounding water or be gained from the stabilizers. An example of cation exchange (Sivapullah, 2006)

$Ca^{2+} + Na^+ - Clay \rightarrow Ca^{2+}\ Clay + (Na^+)$

ii. Flocculation – Agglomeration

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

iii. Pozzolanic Reaction

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. Pozzolanic constituents produces calcium silicate hydrate (CSH), and calcium aluminate hydrate (CAH) Show et al., 2003).

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

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

The calcium silicate gel formed coats initially and binds lumps of clay together. The gel then crystalizes to form an interlocking structure thus, strength of the soils increases (Hadi et al., 2006; Sivapullaiah, 2006)

2.11. Lime Stabilization

Lime is one of the oldest and still famous additives used to improve fine-grained soils. Lime, either alone or in combination with other materials, can be used to treat a range of soil types. Lime treatment of soil facilitates the construction activity in three ways. First, a decrease in the liquid limit and an increase in the plastic limit results in a significant reduction in plasticity index. Reduction in plasticity index facilitates higher workability of the treated soil. Second, as a result of chemical reaction between soil and lime, a decrease in water content occurs. This facilitates compaction of very wet soils. Further, lime addition increases the optimum water content but decreases the maximum dry density and finally immediate increase in strength and results in a stable platform that facilitates the mobility of equipment (Teferra, A**.** and .Leikun, M., 1999).

2.11.1 Previous Studies

• Tesfaye, A., (2001) studied improvement of expansive soil by addition of lime and cement on black cotton soil from different parts of Addis Ababa. Index properties, compaction characteristics and swelling pressure of soil-cement and soil-lime were determined using Atterberg limit test, moisture-density relations, free swell and swelling pressure tests. The conclusions and findings drawn from the study are;

- Expansive soil becomes moderately active to inactive based on the amount of lime and cement added.
- Swelling pressure of expansive soil decreases with increasing lime, cement and molding water content.
- 4-6% of lime and 9-12% of cement yielded significant improvement on plasticity and swelling properties of expansive soils.

• Nebro, D., (2002)evaluated lime and liquid stabilizer called Con-Aid for stabilization of potentially expansive subgrade soil on samples collected form Addis-Jimma road which had indicated different pavement damages exacerbated by the presence of expansive soils. The experimental study involved Atterberg limit test, moisture-density relation, UCS, CBR and CBR swell. The findings and conclusions of the study can be summarized as follows:

- Addition of lime reduced maximum dry density and increased the optimum moisture content.
- 4% of lime by dry weight of the soil was optimum lime content to stabilize the soil even though the increased quantity of lime led to increased strength.
- Addition of lime reduces the swelling potential, but no significant improvement in the engineering properties of the soil was attained by addition of Con-Aid.

• Argu, Y., (2008**)** studied stabilization of light grey and red clay subgrade soil collected from Addis Ababa using SA-44/LS-40 chemical and lime. The experimental study involved Atterberg limit, moisture-density relation, swelling pressure and CBR tests. The conclusions and findings drawn from the study are;

- 8% lime yielded significant improvement on plasticity, swelling and strength properties of expansive soils.
- The applications of SA-44/LS-40 chemical alone are ineffective in improving the soaked CBR value of the red clay and light grey soils.

- The application of 0.30lit/m3 of SA-44/LS-40 chemical and 2% lime is an excellent proportion in increasing the soaked CBR value and reducing the swelling pressure of the light grey clay soil.
- The application of 0.08lit/m3 of SA-44/LS-40 chemical and 4% lime is an optimum proportion in increasing the soaked CBR value of the red clay soil

Nigussie, E., (2011) evaluated the effect of sodium silicate and its combination with cement/lime for soil stabilization collected from Addis Ababa. The experimental study involved Atterberg limit, moisture-density relation, and CBR tests. The conclusions and findings drawn from the study are;

- 6% lime yielded significant improvement on plasticity and strength properties of expansive soils.
- No significant improvement in the engineering properties of the soil was attained by

However, the stabilizing agents used so far are not economical as most of them are factory products. For instance, cement and lime treatment is costly as the substantial thickness of soil (at least 30cm compacted width) has to be prepared. This procedure can be considered advantageous only if it is difficult to get selected backfill material nearby the project and when pavement savings can be made by taking advantage of the enhanced strength of the treated clay addition of sodium silicate.

2.4 Industrial Waste as a Soil Stabilizing Material

Recent research works in the field of civil engineering focus more on the search for cheaper and locally available materials, agricultural and industrial wastes, for use in construction industry.

The use of different industrial and agricultural wastes has become a common practice in the construction industry. Fly ash, sugarcane bagasse ash, coconut husk ash, rice husk, cement ash, wood ash and marble dust can be cited as an example. Those by-products are increasingly playing a part in road construction and concrete technology, hence minimizing the problem of resource depletion, environmental degradation, and energy consumption.

This research will focus on the potential utilization of marble dust with small percentage of lime in soil stabilization, specifically expansive soil.

2.4.1. Marble dust as soil stabilization material

Marble is a metamorphic rock resulting from the transformation of pure limestone. The purity of the marble is responsible for its color and appearance: it is white if the limestone is composed solely of calcite (100% CaCO3) (Dietrich, R.V., and Sklinner, B.J. 1979). Marble is used for construction and decoration; marble is durable, has a noble appearance, and is consequently in high demand.

These days sustainability plays the significant role in every aspect of human activities. Many technologies came to an end because they were not in harmony with the idea of sustainable development. Sustainability is concerned about the world we will be leaving behind for future generations. It focuses on the social, environmental and economic issues of human activities. Therefore it requires every event to be environmentally friendly, economical and safe for the social.

Marble Dust is the wastes generated during marble cutting and polishing. The research is done Indian shows that it is a chemical composition of Cao 40.45%, Al_2O_3 3.42%, SiO_2 28.35%, Fe2O3 9.70% and MgO 16.25% (Pramanic, T. and Kumar, K.S. 2016), but the chemical composition of marble dust is different from place to place. It's evident that Marble dust is containing a significant amount of Cao which is similar with the lime component. Literature shows that the need for marble products is increasing from time to time, marble production amount was 21.7 million tons in the year 1986in the world; however in the year 1998 this amount rose to 51 million tons showing 135% increment within 12 years (Baser, O.. 2009) Increasing demand for marble production rises the generation of waste marble material. The output of marble discharged as waste during block production at the quarries is equal to 40-60% of the overall production volume (Celik, T. 1996). Large pieces of marble waste can be used as embankment or pavement material, and the waste marble dust is used in cement and paper industries.

2.4.1.1. Previous Studies

In our country, Ethiopia a little study is done on the performance of marble dust to improve the engineering properties of expansive soils. However, experiences of other countries such as India shows that marble dust has significant effect to improve the engineering properties of expansive soils.

According to the International Journal of Earth Science and Engineering -2011, the addition of marble dust to expansive clay reduces clay content, increases the percentage of coarser particles, reduces LL, raises the SL, decrease PI, activity and swelling potential. As the percentage of the stabilizer increases, swelling percentage, free swell ratio, and rate of swell decrease. Samples having marble dust reached 50% of the total swelling earlier. By curing the samples, the rate of swell and swelling percentage decreased.

•BASER (2009) conducted the major laboratory tests on the natural soil, and marble dust blended sample (5% to 30%) and came up with the following conclusions;

- Addition of marble dust decreases liquid limit (LL), plasticity index (PI), Activity and shrinkage index (SI) and increases plastic limit (PL) and shrinkage limit (SL)
- Free swell decrease with increasing percentage of marble dust
- By addition of marble dust, the swelling percentage of the soil decrease considerably
- For increase percentage of stabilizer, the t_{50} values were decreased (i.e., samples having more stabilizers reached the 50% of total swell quickly)
- Swelling percentage and rate of swell of samples decrease by curing

Parte Shyam Singh, Yadav R.K. (2014) “Effect of Marble Dust on Engineering Characteristics of Black Cotton Soil. The experimental study involved; moisture-density relation, differential free swell (DFS), unconfined compressive Strength (UCS) and CBR tests. The conclusions and findings drawn from the study are;

- addition of marble dust in expansive soil vary from 10% to 30% of dry weight of clay showed an increase in maximum dry density (MDD) from 1.72 g/cc to 1.86 g/cc
- decrease in optimum moisture content (OMC) from 20.5% to 14.2%,
- differential free swell (DFS) of black-cotton soil is reduced from 66.6% to 20%
- a significant increase in soaked California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) values

Jagmohan Mishra, R K Yadav and A K Singhai (2014), Studied the effect of granite dust on the index properties of Black Cotton Soil stabilized with 5% lime and the test results showed;

- liquid limit and plasticity index decreases from 37% to 28% and 17.45% to 4.80%, respectively if Black Cotton Soil is blended with 5% lime and granite dust from 0% to 30% by weight of Black Cotton Soil

- With the increase in the granite dust percentage, the liquid limit values decrease from 57% to 28%,
- With the increase in the granite dust percentage the liquid limit values decrease from 57% to 28%, plasticity index values decrease from 37.2% to 3.7%, differential
- Free swell decreased drastically from 56.6% to 4.1%, shrinkage limit values increases from 8.15% to 18% with the increase in granite dust.

Tagel M. (2016) Application of Marble Dust to Improve the Engineering Properties of Expansive Soils to be used as Road Bedding Material in Addis Ababa city. The experimental study involved Atterberg limit, moisture-density relation, swelling pressure and CBR tests. The conclusions and findings drawn from the study are;

- With the application of 30% marble dust, the properties of the natural subgrade soil of the subject project section are changed from (LL=88%, PI=52%, CBR=1% and swell 83.6%) to (LL =63%, PI= 34%, CBR= 2.25% and Swell = 5.3%)

From the revised literature the conducted researches in Ethiopia on the suitability of marble dust for soil stabilization has been found that the marble dust up to 30% has not shown significant improvement of engineering properties of the expansive subgrade soil to meet specification requirements for road subgrade material. Previous similar works indicate that other stabilizing agents such as lime have practical results in improving the engineering properties of expansive soils. Lime stabilization is found to be useful for more than 4% of the lime. But using lime more than 4% is cost and using marble as stabilization more than 30% is impossible. So the researcher is motivated to blend marble dust and with small percentage of lime. Thus the study was investigated on the combined effect of marble dust and lime on expansive subgrade soil in Jimma town

CHAPTER THREE

MATERIALS AND RESEARCH METHODOLOGY

3.1 study area

The study was conducted in Jimma town, southwestern Ethiopia which is located 335km by road southwest of Addis Ababa. Its geographical coordinates are between 7° 13'- 8° 56N latitude and 35°49'-38°38'E longitude with an estimated area of 19,506.24. The town is found in an area of average altitude, of about 5400 ft. (1780 m) above sea level. It lies in the climatic zone locally known as Woynā Dagā which is considered ideal for agriculture as well as human settlement. It is mainly covered with black, gray and red colored plastic clay soils.

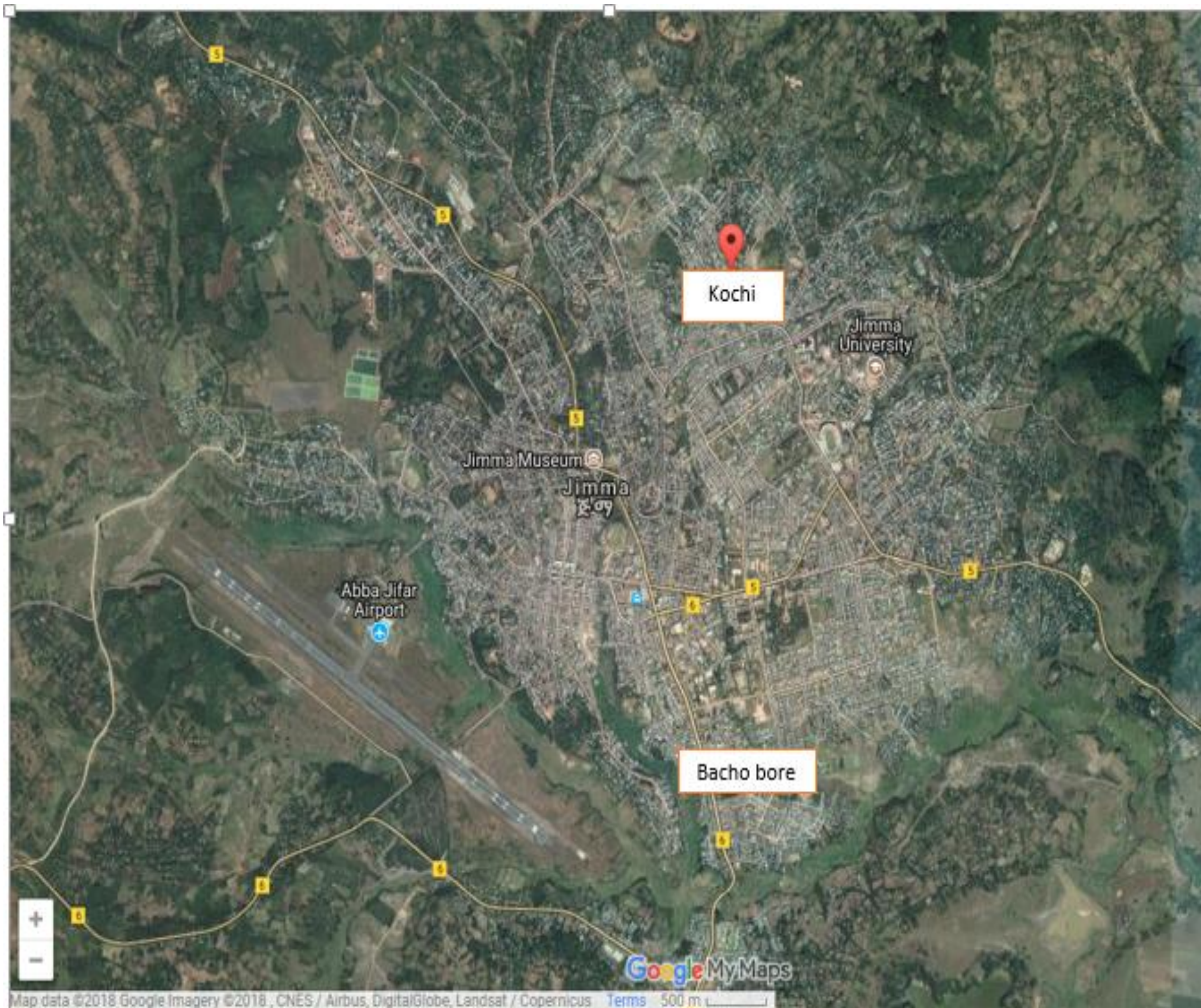

Figure 3.1: Study area and location of sample test pits (source Google map; 2018)

3.2 Study design

To meet the objective of this research, generally the study design are divided in 5 main stage; (1) organizing literature review of different previous published researches and gathering as much as information as possible on the study subject and study area; (2) field identification; (3) sampling and data collection; (4) laboratories tests and analyzing the result from tests (5) conclusion and recommendation.

Field identification were conducted on the study area to identify the properties of expansive soils that are good indicator of their extensive potential, these was done for sampling during the time of highly dry season where expansive soils can be identified visually The conducted Field investigations are including identification of soil based on observation of color, soil texture and lithological position.

The samples were collected by following purposive soil sample, five test pits having expansive soil from different location have been selected, among this test pits a representative soil sample from two test pits were taken depending upon the value of their free swell tests. Disturbed soil samples were taken at a depth of 1.5m. After careful sampling, samples are transported to the laboratory.

For laboratory tests; the sample preparation and the tests procedure was conducted according AASHTO and ASTM code of practice and then the tests were performed on natural and stabilized sample soil to investigate; the engineering parameters of natural soil sample and the effect of proposed stabilizing agent on their properties by fixing different percentage of lime (1%-3%) and blending it with varying percentage of marble dust (5%-30%). The laboratory test conducted on selected natural subgrade soil and stabilized subgrade soil are; natural moisture content, grain size analysis, hydrometer, free swell tests, Atterberg limit, standard Proctor test and California bearing ratio (CBR).

After obtaining the results from laboratory test, it has been analyzed and discussed thoroughly. Then the output from analysis had been compared with standard specification of subgrade materials and categorized according to their test results.

Finally, the obtained output gives conclusion and recommendation

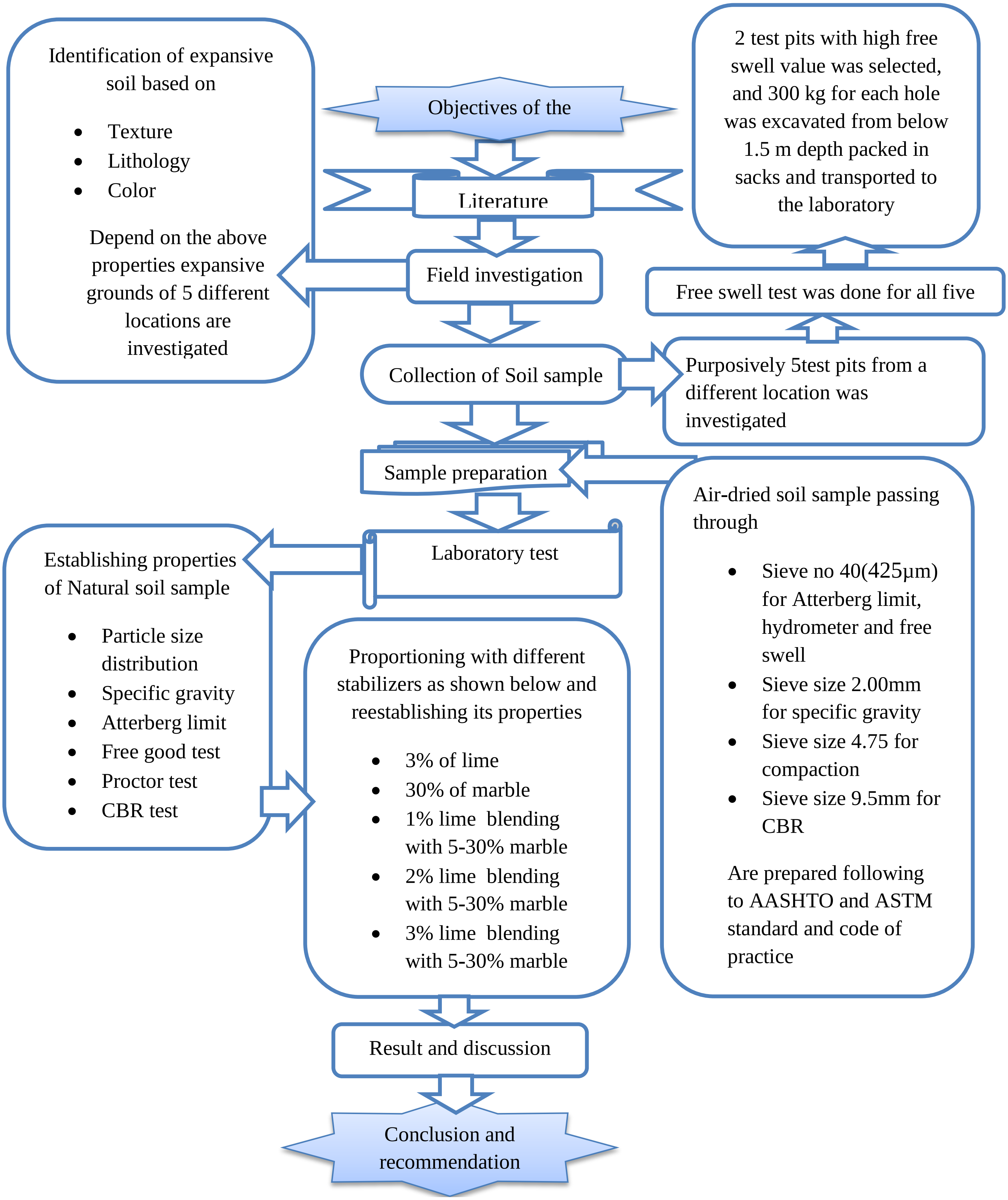

Figure 3.2: Research design diagram

3.3 Sample Technique

The representative and purposive sampling techniques were used by selecting particular parameters to make it sure that the settings have specific characteristics as indicated for this study. It is projected the specified at appropriate geotechnical parameters.

3.4 Sample size

For this study, five soil samples from a different location, (merkato, technic sefer, kittofurdisa, Kebele 05(Kochi) and Bachobore) which can be well represented expansive soils found in Jimma town are purposively selected, and for each sample, the free swell test was conducted on the disturbed wet soil sample. Thus, from five samples, the two soil samples (Kebele 05(Kochi) and Bachobore) with high free swell value were selected, and all tests are performed for it in both natural and stabilized condition.

3.5 Study variable

- Independent variables: Engineering properties of expansive soils and
  Locations of expansive soil
- Dependent variable: combined effects of Lime and Marble dust on expansive subgrade soils

3.6. Data source and collection

Data were collected from the primary and secondary source. Primary data were obtained by laboratory tests and field investigation; secondary data's are literature and materials used for this research from different source.

3.6.1. Field Investigation

In the field, expansive soils can be identified by applying several techniques. In this study the method listed under (Chen F 1988 and Nelson D.J.,) was used to identify expansive soils of the study area during dry season. According to this method expansive soils have the following properties;

- Have a color of black and gray
- Polygon pattern of surface Crack during dry season
- A shiny surface when partly dry piece of soil is polished with finger
- High dry strength and low wet strength
- Sickness and low traffic ability when wet

Based on the above methods expansive soils of five different location where identified

3.6.2. Material source

3.6.2.1 Expansive Soil

The soil used in this study was an expansive soil, which is collected from Jimma town. The soil sample with represents an expansive soil of Jimma town was obtained from two pits, Kebele 5 (Kochi) and Bachobore where expansive soils highly occur. A disturbed sample is collected from the hole at a depth of 1.5 m from ground level to avoid the inclusion of organic matter. The Index & Engineering properties of expansive soil are going to be determined as per AASHTO and ASTM code of practice and briefly discussed in chapter four.

Figure 3.3: An overview of test pits (photo captured by sadiq A).

3.6.2.2 Marble Dust

Marble dust used in this research was obtained from Ethiopian marble industry which is located in the capital Addis Ababa Gulale sub-city. Marble dust from the sector is appropriately packed in sacks and transported to the laboratory.

Figure 3.4: Marble Dust (photo captured by Nurala A.)

3.6.2.3 Limes

The lime used in this study is hydrated lime from Senkelle lime factory Ethiopia, Oromia regional state which located in the west Shoa around Ambo city. Chemical compositions of Senkelle hydrated lime are studied by Solomon H. (2011) using X-ray Fluorescence analysis is presented in chapter 4

Figure 3.5: Senkelle hydrated lime (photo captured by Nurala A.)

3.7. Sample preparation

3.7.1 Preparations of Natural soil for laboratory tests

Before treatment and testing, the sample was prepared by the method described in AASHTO T87-86. This process involves:

- Air drying of samples and oven drying at 105±5ºC.
- Breaking up the soil aggregates by a rubber covered mallet and adequately pulverized.
- Then sieve analysis are conducted on properly pulverize natural soil. Sieves are conducted into three groups. The first team are soil samples passing #40 (4.25mm) sieve for Atterberg limits and free swell, 2.00mm sieve for specific gravity and the third group are soil samples passing # 4 (4.75mm) for compaction and California bearing ratio

Figure 3.6: Sample preparation procedure (photo captured by Sadiq A.)

3.7.2 Mixing procedure

- Additive was first added to the pulverized, sieved and air-dried soil sample and dry mixed thoroughly
- When lime and marble dust where applied in combination the soil sample was dry blended with lime first, and marble dust was added after that
- Finally, wet mixing was done by sprinkling measured amount of water followed by a thorough mixing until a uniform soil-additive matrix was obtained

Figure 3.7: Mixing procedure (photo captured by Sadiq A.)

3.8. Laboratory tests

3.8.1 Moisture content

Moisture content test was conducted for natural subgrade soil according to the standard test procedure of AASHTO T265 the following process is used to determine moisture content of the tested soil

- Disturbed small representative soil sample covered with plastic was taken from the site
- Obtained soil sample was weighed and kept in oven dried for at least for 16 hours

The sample was then reweighed, and the weight of dry soil divided the difference in weight is giving moisture content of the soil

Figure 3.8: Determination of Natural Moisture content

3.8.2 Atterberg limit test

Atterberg limit test where conducted for natural and stabilized soil sample (with marble dust and lime alloy) according to the standard test procedure of AASHTO specification.

3.8.2.1 Liquid limit (LL)

Liquid limit test where conducted according to the standard test procedure of AASHTO T89, the test are performed by the following process

- 250 g of air-dried soil sample passing through sieve no 40 (aperture 425μm) was obtained soaked at least for 16 hr, to ensure that the soil grained had absorbed water and soften through
- Then the mixed soil paste was placed on the Casagrande cup and grooved by standard grooving tool
- Then the cup is lifted up and dropped by turning the crank until the two parts of the soil come into contact at the bottom of the groove.
- For one test point, it needs three trials by increasing 1-3 % of its moisture content
- The number of blows at which that occurred was recorded, and a little quantity of the soil was taken and its moisture content determined.
- The values of the moisture content (determined) and the corresponding number of blows is then plotted on a semi-logarithmic graph, and the liquid limit is identified as the moisture content corresponding to 25 blows.

The same procedure is also carried out for the treated soil with increment lime and marble dust content.

3.8.2.2 Plastic limit (PL)

Plastic limit test was conducted according to the standard test procedure of AASHTO T90, and the test is performed by the following process

- A portion of the natural soil and the soil with lime and marble mixture used for the liquid limit test is retained for the determination of plastic limit.
- Retained soil sample paste was remolded and rolled into the threads on glass plate until the threads started to crack at a diameter of about 3 mm
- The moisture content at which the soil sample begins to crumble at the specified width was recorded as plastic limit

3.8.2.3 Plastic index (PI)

Plastic index of the natural soil as well as for stabilized soil sample was calculated by subtracting the result of plastic limit from liquid limit

$PI = LL - PL$…..equation 3.1

Figure 3.9: Determination Atterberg's limit tests(photo captured by Sadiq A.)

3.8.3 CBR test

CBR test was carried out for both natural and stabilized soil using the procedure outlined in AASHTO T193-93 or ASTM D1883-73, the difference between this twos standard is only in the sample preparation

- 5 kg of aired dry soil sample passing through no 9.5 sieve size was obtained
- Optimum moisture content determined from the standard compaction test is used for mixing of prepared soil sample for CBR test(ASTM D698-70)
- The uniformly mixed soil at optimum moisture content is compacted in 15.2 cm diameter mold by 24.4 N hammer in 5 layers with 56 no of blows for each layer(ASTM D1572-2)
- The mold with compacted soil was soaking for a period of 96hour with a surcharge weight not less than 4.54 Kg
- Swell reading is taken during the period of arbitrarily selected time
- At the end of soaking period(after 96 hrs.) the CBR penetration test was made to obtain CBR value for the soil in saturated condition

After penetration testing accomplished in compression machine using a strain rated of 1.27/reading, reading vs. penetration are taken at each 0.5 mm of penetration to include the value of 5.08 mm and then at 2.54 increment after that until the total penetration include is 12.7mm and then CBR and CBR swell value were calculated using the flowing equations.

$$CBR\% = \frac{\text{test load on the sample}}{\text{standard load on the crushed stone}} * 100\% \text{..................equation. 3.2}$$

$$CBR\ Swell = \frac{\text{Change in Length in mm during Soaking}}{116.3\text{mm}} * 100\ \% \text{.....equation.3.3}$$

Figure 3.10: CBR test Procedure (photo captured by Nisar M.)

3.8.4 Grain Size Distribution

This test is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the more exceptional particles. (ASTM D 422)

3.8.4.1 Wet sieve analysis

Wet sieve analysis test was carried for natural soil sample, and the test is conducted by the following procedure

- 500 gm of the natural subgrade soil is taken and washed on sieve size of 75µm

- After removed the soil sample, the retained soil on sieve size of 75µm was taken and oven dried over the night
- Recording the weight of the dried soil sample
- Cleaning all the sieves and assemble them in the ascending order of sieve numbers (#4 sieves at the top and #200 sieves at the bottom) Place the pan below #200 sieves. Carefully pour the dried soil sample into the top sieve and place the cap over it.
- Place the sieve stack in the mechanical shaker and shake it, after 10 minutes Remove the stack from the shaker and finally record the weight of the soil retained on each sieve.

Figure 3.11: Sieve analysis (photo captured by Dakebi G.)

3.8.4.2 Hydrometer test

To determine the distribution of fine particles (silt and clay) 50g of air-dried soil sample passing sieve 75 µm is used. The soil sample is socked in 125 ml (40g/lit) chemical solution (Sodium hexa-meta phosphate) for 24 hours, and then hydrometer readings were taken after elapsed time of 2 and 5, 8, 15, 30, 60 minutes and 24 hours

Figure 3.12: Determinations of Hydrometer test (photo captured by Bona A.)

3.8.5 Specific gravity

Specific gravity test was carried for natural soil sample; the test is conducted by AASHTO T100-93 testing procedure. It's determined by the method of pycnometer method using a soil sample passing No. 10 sieve (2mm sieve size) and oven dried at 105-degree centigrade.

Figure 3.13: Determinations of specific Gravity (photo captured by Bona A.)

3.8.6 Free Swell Tests

The test included the determination of the free swell for the natural soil and stabilized soil sample this analysis has not yet been standardized by AASHTO and ASTM. The method was suggested by Holtz and Gibbs, (1956) to measure the expansive potential of cohesive soils. The free swell test gives a fair approximation of the degree of the expansiveness of the soil sample. The procedure consists of pouring very slowly of 10 cubic centimeters of that part of the dry soil passing No. 40 sieve into a 100 cubic centimeters graduated measuring cylinder and letting the content stand for approximately 24 hours until all the soil ultimately settles on the bottom of the graduating cylinder. Then the final volume of the soil is noted. Finally, the free swell value is calculated using Equation (2.1).

$$\text{Free swell (\%)} = \frac{Vf-Vi}{Vi} \times 100 \text{.......equation 3.4}$$

Where Vi= initial reading and Vf= final reading after 24 hours

Figure 3.14: Free swell test Procedure (photo captured by Dekebi G.)

The analysis was carried for natural and stabilized soil; the test is conducted by AASHTO T99-94 testing procedures

- 2.5 kg of air-dried soil sample passing through sieve size #'s were obtained (for stabilized soil the percentage of marble dust and lime are converted into kg and subtracting from the weight of soil)
- Mixing the prepared soil sample by varying the different amount of water
- The mixed sample is then compacted into the 944 cubic centimeters mold (of mass m1); in three layers of approximately equal mass with each layer receiving 25 blows. The blows are uniformly distributed over the surface of each layer
- The compacted sample is leveled off at the top of the mold with a straight edge.
- The mold containing the leveled sample is then weighed to the nearest 1g, and recording as m_2.
- At least three small representative samples are then taken from the compacted soil for the determination of moisture content (W).

The same procedure is repeated at least five times for one sample by varying different amount of water until the increment weight of soil sample compacted in the mold shows decrement to minimum of 40gm

The bulk density (ρ) and dry density (ρ_d) are respectively calculated by following formula

$$\rho = \frac{m1-m2}{944} \text{.............................equation 3.5}$$

$$\rho_{d=}\frac{100*\rho}{(100+W)} \text{.............................equation 3.6}$$

The values of the dry densities as gained from equation above are plotted against their respective moisture contents and the dry densities; MDD is deduced as the maximum point on the resulting curves, and the corresponding value of moisture contents at maximum dry densities from the graph of dry density against moisture content gives optimum moisture content

Figure 3.15: Compaction test Procedure (photo captured by sadik A.)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Introduction

This chapter presented; the result of laboratory tests on natural soil sample as well as stabilized soil sample and discussion to the result of the laboratory tests. Laboratory tests are included natural moisture content, specific gravity, standard Proctor(compaction) test, Atterberg's limit tests(liquid limit, plastic limit, and plastic index), free swell, hydrometer, wet sieve analysis and California bearing ratio(CBR).

4.2. Identification of expansive soils in Jimma town

From field identification, expansive soils of five place from different place in Jimma town where selected and to identify whether it's highly expansive or not, free swell test was conducted on each sample by following the methods of Holz and Gibbs (1996).

U.S.B.R classification method (the method developed by Holz and Gibbs1996) are classify expansive soil based on their free swell value and their classification are shown in the table 4.1

Table 4. 1: U.S.B.R classification method of expansive soil (Alemayehu T. and Mesfin L. 1999)

Degree of expansion or Swell	Free swell value(FS)
High	>100%
Medium	50-100%
Low	<50%

Then the free swell values of five samples from different place in Jimma town and their classification according to U.S.B.R methods are shown in the following table

Table 4. 2: classification of Jimma expansive soil

Ser.No.	Location	Color	Free swell (%)	U.S.B.R classification
1	Merkato	Black	95	Medium
2	Technic sefer	Black	105	Highly Expansive
3	Bachobore	Gray	105	Highly Expansive
4	Kitto furdisa	Gray	95	Medium
5	Kochi	Black	110	Highly expansive

Based on their free swell value, **Technic sefer, Bachobore** and **Kochi** expansive soil were classified under **highly expansive soil**. From this three expansive soil **Bachobore** and **Kochi** soil sample were selected and the laboratory test was conducted for both this soil samples on natural soils and on stabilized conditions.

4.3 Properties of Material Used in the Study

4.3.2 Natural soil

The results of the tests conducted for determination of properties of the natural soil sample are shown in table 4.3. The soil sample used in this study were identified and taken from two pits Bachobore (Sample1), and Kochi (Sample2), the color of soil samples are black and gray respectively.

From sieve analysis tests, percentage of passing through sieve No. 200 (0.075mm sieve size) of Samlpe1 and Sample2 is 96.63% and 95.718 % respectively. While from the Atterberg's limit test results, the soil sample contains a liquid limit of 105.6 and 98%, a plastic limit of 40.12% and 38.5%, and plasticity index of 65.48% and 59.5%, respectively.

According to (Whitlow, R., 1995), Liquid limit less than 35% indicates low plasticity, between 35% and 50% intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity. Hence, these values indicate that both soil samples are highly plastic clay.

According to AASHTO soil classification system, the soil falls under the A-7-6 soil and CH (fat clay) according to ASTM soil class. Soils under this category are classified as a material of reduced engineering property to be used as a sub-grade material.

The Results from free swell test indicated that the soil is highly expansive clay with a free swell of about 105 and 110 for sample1 and sample2 respectively. The soil samples have a maximum dry density of 1.230g/cm3 and 1.245 g/cm3, the optimum moisture content of 37.1 and 36.5 natural moisture content of 65.8 and 40, and soaked CBR value of 0.93% and 1.1% for sample 1 and sample 2.

Bowles, J., 1992 also establish a general relationship between CBR values and the quality of the subgrade soils used in pavement applications. It indicated in Table 4.3.

Table 4.3: Classification of subgrade soil according to Bowles, J., 1992

CBR value	Quality of sub grade
0-3	Very poor
3-7	Poor
7-20	Poor to fair
20-50	Fair
20-50	Good
>50	Excellent

Hence, the soil was found to be highly plastic expansive clay with low bearing capacity and high swelling potential which fell below the standard recommendations for most highway construction. According to ERA 2013, pavement design, a material with CBR value less than three are challenging to work and subgrade would lead to uneconomical pavement structures, it is recommended to cover with selected material or treating it with other stabilizing material. Therefore, the soil requires first modification and stabilization to improve its workability and engineering property.

Table 4.4: Geotechnical properties of the natural soil sample

Sample	1 (Bachobore	2 (Kochi)
Percentage passing through sieve No 200	96.63%	95.718%
Liquid limit	105.6	98
Plastic limit	40.12	38.5
Plastic index	65.48	59.5
AASHTO specification	A-7-5	A-7-5
ASTM D 2487 (USCS)	Fat clay, (CH)	Fat clay, (CH)
Specific gravity	2.64	2.70
Free Swell	105	110
Natural Moisture content	43	61
Maximum dry density g/cm3	1.230	1.245
Optimum moisture content	37.1	36.5
CBR value	1.1%	0.93%
CBR-swell	9.8	10.4
ERA subgrade class	S1	S1
Color	Gray	Black

4.3.2. Marble Dust

Typical properties of marble dust; (Sachin N. Bhavsar and Ankit J. Patel, 2014)

- ✓ Less reactive
- ✓ Better acid resistance
- ✓ Increase flow rates because of its higher bulk density and sp. Gravity
- ✓ Higher production rates
- ✓ Fewer plastic materials

Physical properties of marble dust used in this study

The researcher conducted physical properties of marble dust used in this study it has shown in the following table

Table 4.5: Physical properties of marble dust used in this study

Physical properties of marble dust used in this study	
Liquid limits	22
Plastic limits	18.68
Plastic index	3.32
Specific gravity	2.82

4.3.3. Lime

Chemical composition of Senkelle hydrated lime are studied by (Solomon H. 2011) using X-ray Fluorescence analysis is presented in the following table

Table 4.6: Chemical composition of Senkelle hydrated lime

Constituent	Percentage (%)
SiO2	6.21
AL2O3	2.18
Fe2O3	3.57
CaO	59.47
MgO	3.91
Na2O	0.61
K2O	0.79
TiO2	0.3286
P2O5	0.208
MnO	0.2785
SO3	0.58

4.4. Effect of stabilizers on engineering properties of expansive soils of the study area

As per literature review of different papers (Baser., O 2009, Parte Shyam Singh and Yadav R.K. 2014, Jagmohan Mishra, R K Yadav and A K Singhai 2014, Tagel. M 2016),the percentage of marble dust used to stabilize expansive soils are maximum up to 30% with intervals of 5% and also 10% interval used in same papers. So based on literature reviews, maximum 30% of marble dust with interval of 5% was used in this study to stabilize highly expansive sub grade soils of Jimma town.

As per literature review, for addictive material which has low pozzolanic reaction to improve the soil properties, half optimum percentage of common addictive material such as lime and cement are recommended to activate the pozzolanic reaction of those poor addictive materials(Veisi, M., et al., 2010 and Meron, W.,2013), research done in Jimma town shows lime has become optimum percentage to improve expansive soil for 6-8% lime hence, 3% of lime are recommended to activate pozzolanic reaction of marble dust-soil mix.

4.4.1 Effects of maximum percentage of marble dust (30%) on Atterberg, compaction, CBR and free swell tests

a) On Atterberg limits Tests

The first approach was to test the effect of an assumed maximum percentage of marbles dust (30%) on liquid limit, plastic limits and plastic index was conducted on both sample1 and sample2. In table 4.7, from laboratory test results, it has been noted that by addition of 30 % marble dust, the liquid limit and plastic index decreased. However, some increment on plastic limit has been observed. Therefore, the next tests should be lower in percentage of dosage. These are shown in succeeding discussions.

Table 4.7: Effect of marble dust on Atterberg limit values

		LL	PL	PI
Sample1 (Bachobore)	Natural	105.6	40.12	65.48
	with 30% marble dust	80	43.9	36.1
Sample2 (Kochi)	Natural	98	38.5	59.5
	with 30% marble dust	75.5	41.72	33.78

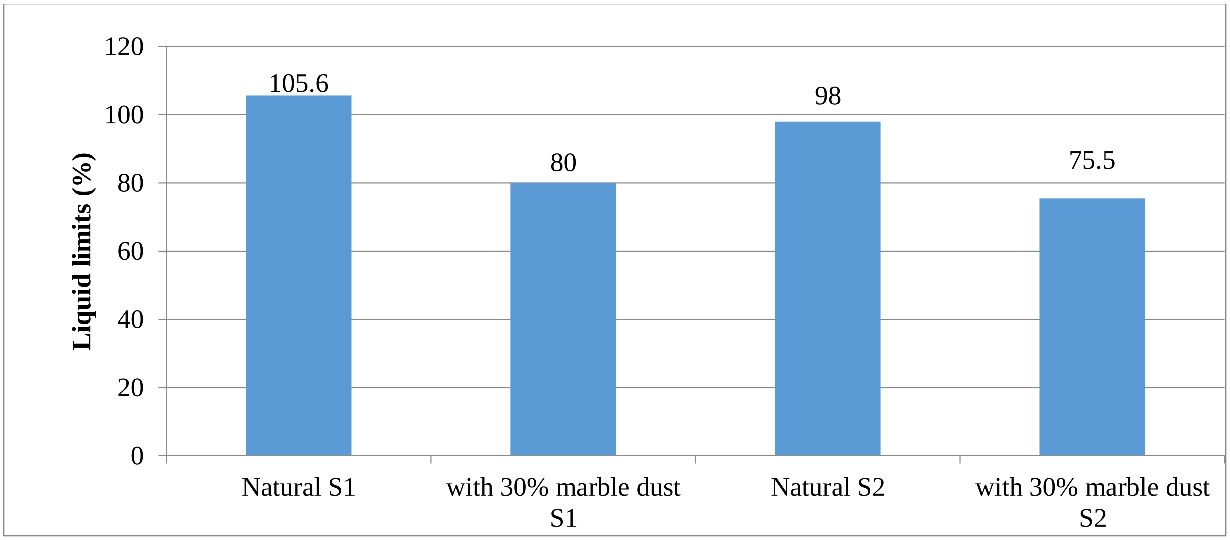

Figure 4.1: Effects of 30% marble dust on liquid limits

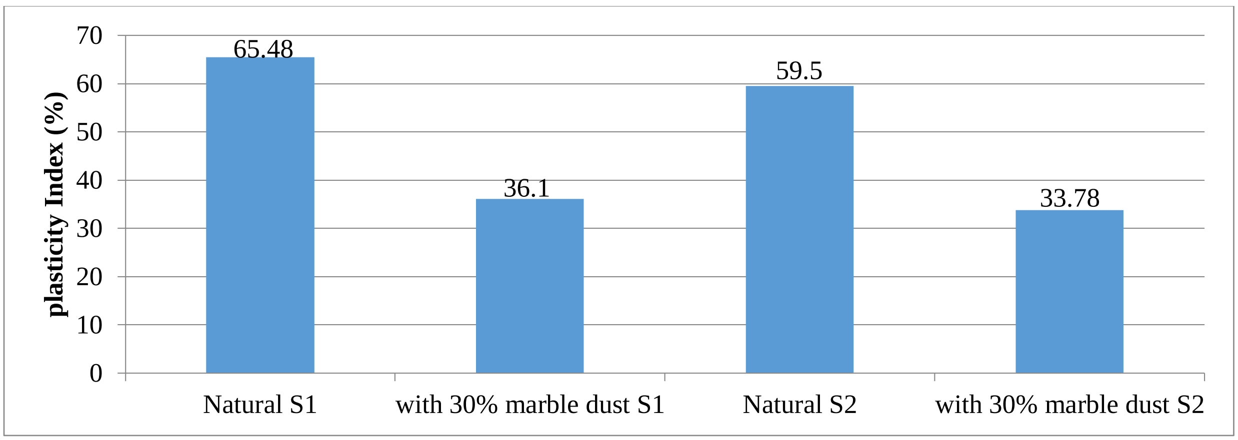

Figure 4.2: Effects of 30% marble dust on Plasticity index

In general, the results agree with (BASER. O., 2009) the plastic index and liquid limits of soil sample the decrease with increment of partial replacement of marble dust in soil. It means that Marble dust is non-plastic material and when it's blending with expansive clay soils, flocculation, and agglomeration of clay particles caused by cation exchange will happened.

b) On Compaction and Moisture relationship

Effects maximum percentage marbles dust (30%) on compaction and moisture content ware conducted on both sample1 and sample2, and shown on fig 4.3. From moisture and compaction relationship diagram (fig 4.3), it was observed that with addition of 30% of marble dust, optimum moisture content of both sample1 and sample2, it decreases from37.1% and 36.5% to

28.5% and 24% respectively. While, the maximum dry density of both soil sample was increased from 1.23 g/cm3 and 1.245 g/cm3 to 1.405 g/cm3 and 1.45g/cm3 respectively.

Table 4.8: Effect of 30% marble dust on Compaction and Moisture relationship

sample 1	maximum dry density g/cm3	Natural condition	1.23
		with 30% marble	1.405
	optimum Moisture content %	Natural condition	37.1
		with 30% marble	28.5
sample 2	maximum dry density g/cm3	Natural condition	1.245
		with 30% marble	1.45
	optimum Moisture content %	Natural condition	36.5
		with 30% marble	24

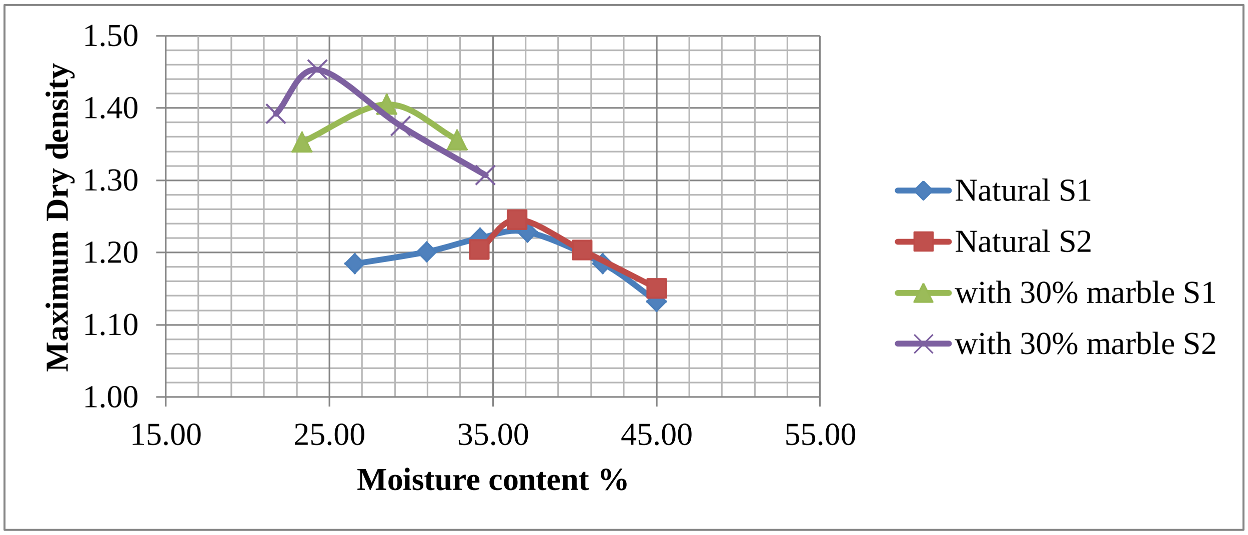

Figure 4. 3: Effects of 30% marble on compaction and moisture relationship

The increment of maximum dry density was due to marble dust high specific gravity than the natural soil sample, and it has a high frequency.

This behavior of the soil may be attributed to the non-plastic behavior of the marble powder added in the highly plastic clay soil, facilitating the compaction at lower OMC and resulting in higher corresponding maximum dry density

c) On free swell value

Effects of maximum percentage marbles dust (30%) on free swell value was conducted on both sample1 and sample2. From the laboratory test result, it has been observed that with addition of

30% marble dust in soil, free swell value of both sample1 and sample2 decreased from 105% and 110% to 70% and 60% respectively.

Table 4.9: Effect of 30% marble dust on free swell value

Sample type		Sample one	Remark	Sample two	Remark
Free swell %	Natural condition	105	Highly expansive	110	Highly expansive
	With 30% of Lime	70	Medium	60	Medium

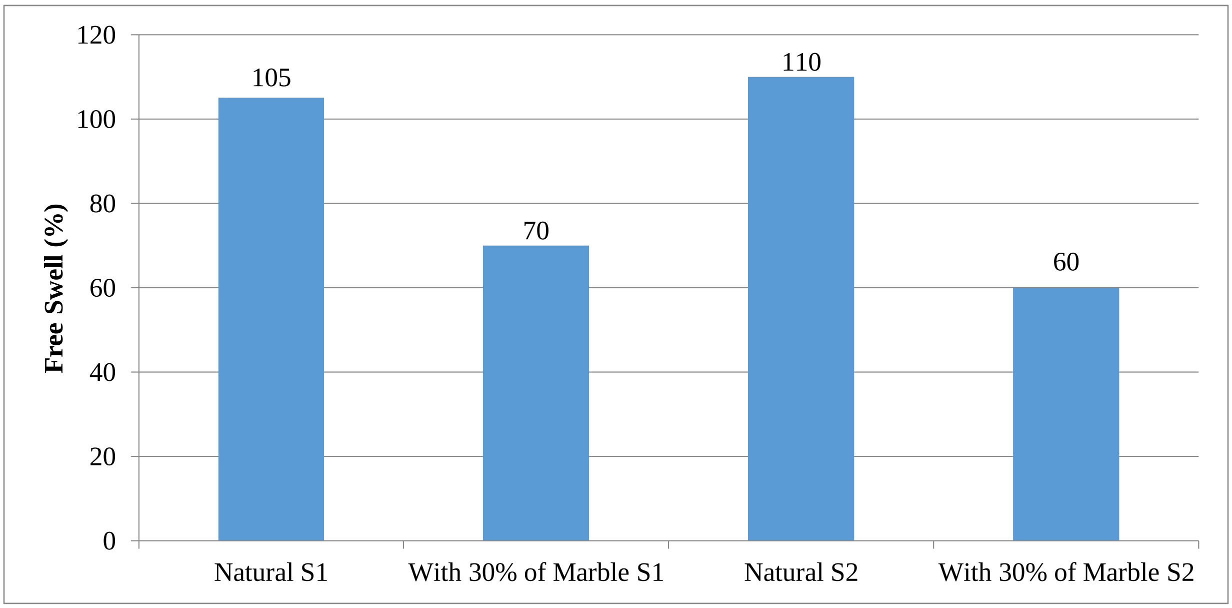

Figure 4.4: Effects of 30% marble dust on free swell value

According to U.S.B.R classification Method (the method developed Holz and Gibbs) the free swell amount of natural soil sample is lying high swelling soil, hence by addition 30% of marble dust; the soil sample became medium expansive soil. This shows that, marble dust decrease the large potential of clay soil due to cation exchange between marble dust and soil when blends.

d) On CBR

Effects of maximum percentage marbles dust (30%) on CBR value was conducted on both sample1 and sample2. From the laboratory test result it has been observed that with addition of

30% marble dust in soil, CBR value of both sample1 and sample2 was increased from 1.196% and 0.92% to 2.063% and 1.839% respectively.

Table 4.10: Effect of 30% marble dust on CBR value

Sample type		Sample one	ERA subgrade class	Sample two	ERA subgrade class	Bowels subgrade classification
CBR %	Natural condition	1.196	Blow required	0.92	Blow required	V. poor
	With 30% of Marble Dust	2.063	Blow required	1.839	Blow required	V. poor

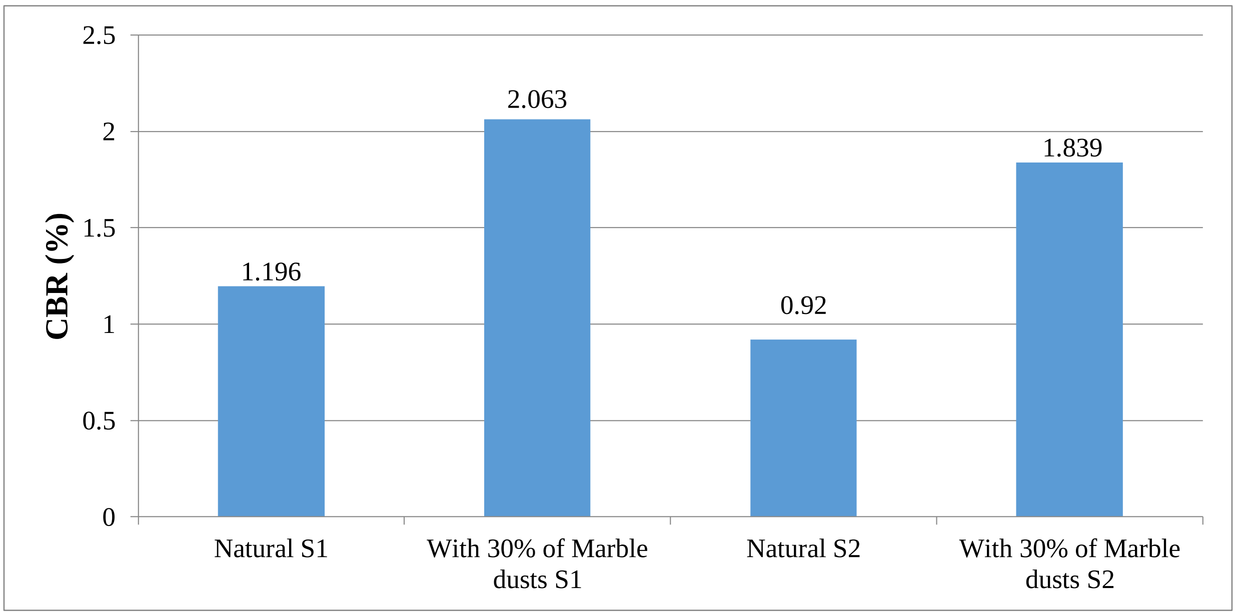

Figure 4.5: Effects of 30% marble dust on CBR value

From the above table and figure, with additions of 30% marble dust on natural subgrades soils of both sample1 and sample2, the CBR values of both samples increased, but still it is below the ERA specification requirements for road subgrade material. According to ERA manuals, the CBR values required for subgrade materials could not less than 3% hence marble dust alone, it could not use to stabilize expansive subgrade soils of Jimma town. However, it could be used in admixture stabilization with more potent stabilizers such as lime and cement, in order to reduce the cost of stabilization.

In discussions below, a series of laboratory test were conducted to investigate combined effect of lime and marble dust on expansive subgrade soils of Jimma town and the results of the test are shown in section 4.4.2 and 4.4.3.

4.4.2 Effect of 3% lime on Atterberg, compaction and moisture relationship, free swell value and CBR value

A. on Atterberg limits

The effects of 3% of lime on Atterberg limits are conducted on both soil samples. It was observed that with addition of 3% of lime on natural soil sample, the values of liquid limit of natural soils of both sample 1 and sample 2 where changed from 105.6% and 98% to 96.5% and 88% respectively. While the plastic index is changed from 65.48% and 59.5% to 59.11% and 50.22%, it was summarized and shown on the following table.

Table 4.11: Effect of 3% lime on Atterberg limits

Sample types		Sample 1	Sample 2
Liquid limits %	Natural condition	105.6	98
	With addition 3% of lime	96.5	88
Plastic limits %	Natural condition	40.12	38.5
	Also 3% of lime	37.39	37.78
Plastic index %	Natural condition	65.48	59.5
	With addition 3% of lime	59.11	50.22

B. on Compaction and moisture relationship

The effect of 3% of lime on compaction and moisture relationship are conducted on both soil samples, and the result from laboratory tests are summarized and shown on the following table. It was observed that with addition of 3% lime on natural soil samples, maximum dry density of sample 1, stayed the same, while the optimum moisture contents were decreased. Likewise, the maximum dry density of sample 2 was reduced, while the optimum moisture content was increased.

Table 4.12: Effect of 3% lime on compaction and moisture relationship

sample1	Maximum dry density g/cm3	Natural soil	1.23
		with 3% lime	1.23
	Optimum Moisture content%	Natural soil	36.5
		with 3% lime	35.6
sample2	Maximum dry density g/cm3	Natural soil	1.245
		with 3% lime	1.24
	Optimum Moisture content%	Natural soil	37.1
		with 3% lime	37.8

C. On free swell value

The effects of 3% of lime on the free swell index are conducted on both soil samples, and the result from laboratory tests are summarized and shown on the following table.

Table 4.13: Effect of 3% lime on free swell value

Sample type		Sample one	Remark	Sample two	Remark
Free swell index %	Natural condition	105	Highly expansive	110	Highly expansive
	With 3% of Lime	80	Marginal	80	Marginal

From the above table, it was observed that with the addition of 3% of lime on expansive subgrade soil sample, both soil samples are changed from highly extensive to the marginal soil.

D. On CBR value

Effect of 3% of lime CBR and CBR swell value is conducted on both soil samples, and the result from laboratory tests are summarized and shown on the following table.

Table 4.14: Effect of 3% lime CBR value

Sample type		Sample one	ERA subgrade class	Sample two	ERA subgrade class	Bowels J. subgrade classification
CBR %	Natural condition	1.196	Blow S1	0.92	Blow S1	V. poor
	With 3% of lime	2.391	Blow S1	2.851	Blow S1	V. poor

4.4.3. Combined Effects of Lime and Marble on Atterberg limit, compaction and moisture relationship, free swell value and CBR value

4.4.3.1 Combined Effect of lime and marble dust on Atterberg's limit

Combined Effects of lime and marble dust on Atterberg limit tests are conducted on both sample 1 & 2. The results from laboratory tests was summarized and shown in the table 4.15 and table 4.16. From the laboratory test results, it has been noted that the value of liquid limits and plastic index's decrease as a fixed percentage of lime that blended with a different rate of marble dust increases. It summarized and shown in figure below detail of each percentage lime with different portion of marble dust are demonstrated on Appendix2. As seen from the figure the maximum improvement on liquid limit and plastic index of both samples, it observed at combinations of 3% lime and 30% marble, with this combination plasticity index decreased from a natural soil value of 65.48% to 26.11% for sample1 and 59.5% to 23.58% for sample2. It was almost above 50% decrement on both samples and liquid limit decreased from 106% to 68.2% for sample 1 and 99% to 69% for sample 2.

Table 4.15: Combined Effect of lime and marble dust on Atterberg limit of sample one

Sample 1 (Bachobore)				
Lime (%)	**Marble dust (%)**	**LL**	**PL**	**PI**
1	5	101.2	38.49	62.71
	10	97.6	40.91	56.69
	15	89.3	41.44	47.86
	20	84.8	41.03	43.77
	25	80.5	42.81	37.69
	30	77.5	42.87	34.63
2	5	96.5	41.01	55.49
	10	93.3	42.10	51.20
	15	86	42.95	43.05
	20	80.6	42.30	38.30
	25	77	42.91	34.09
	30	73.6	43.35	30.25
3	5	91.2	42.90	48.30
	10	85.8	43.18	42.62
	15	81	42.91	38.09
	20	74.2	43.03	31.17
	25	72.8	42.94	29.86
	30	68.2	42.09	26.11

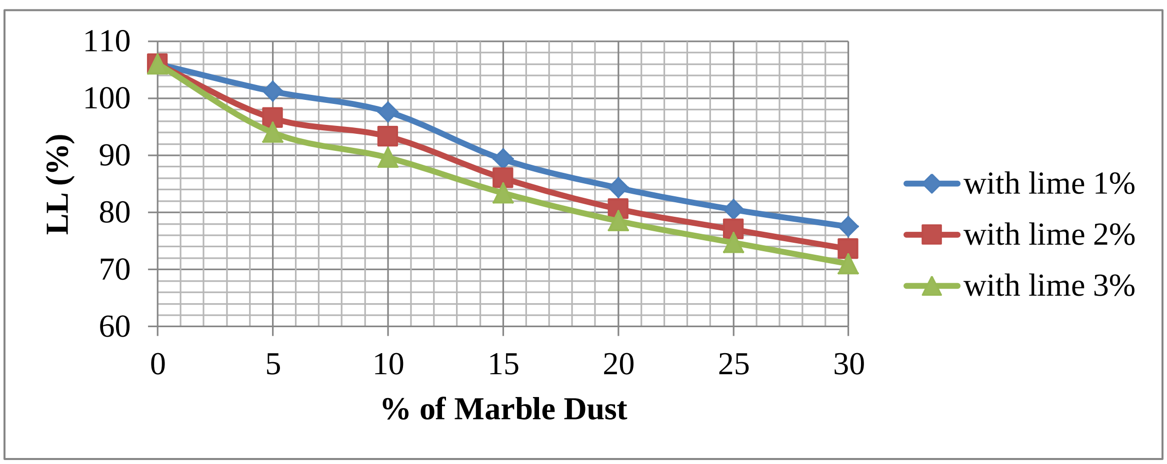

Figure 4.6: Combined effects of lime and marble dust on liquid limits of sample 1

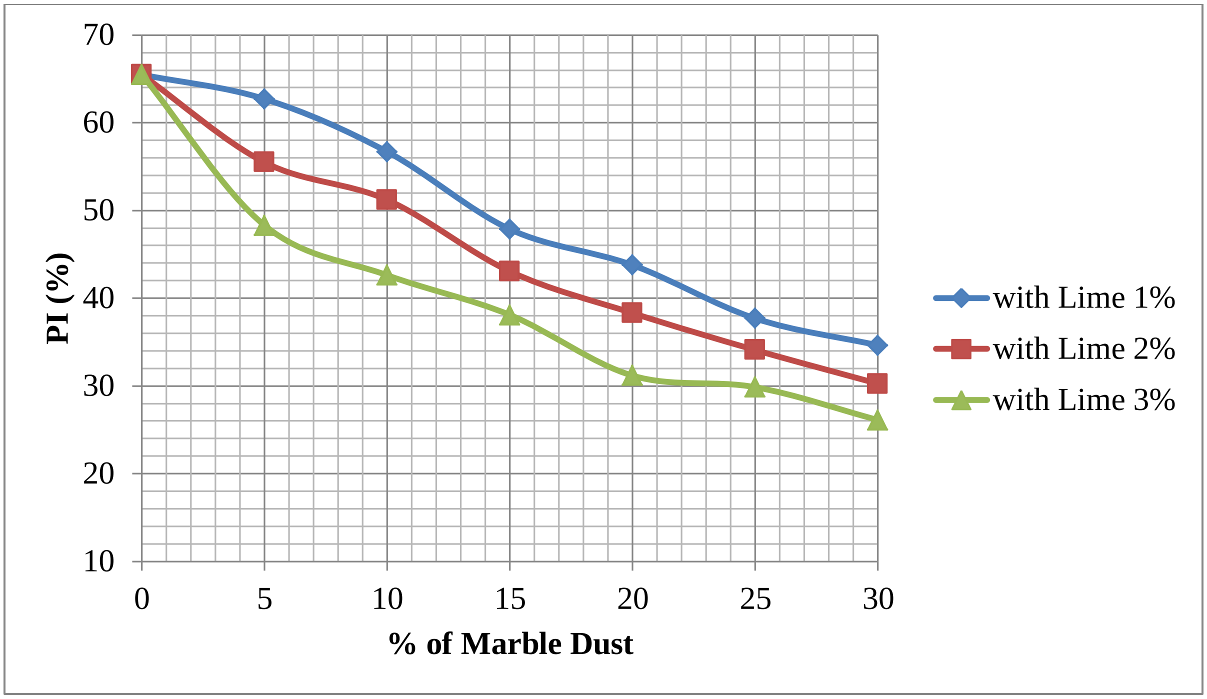

Figure 4. 7: Combined effects of lime and marble dust on plasticity index of sample 1

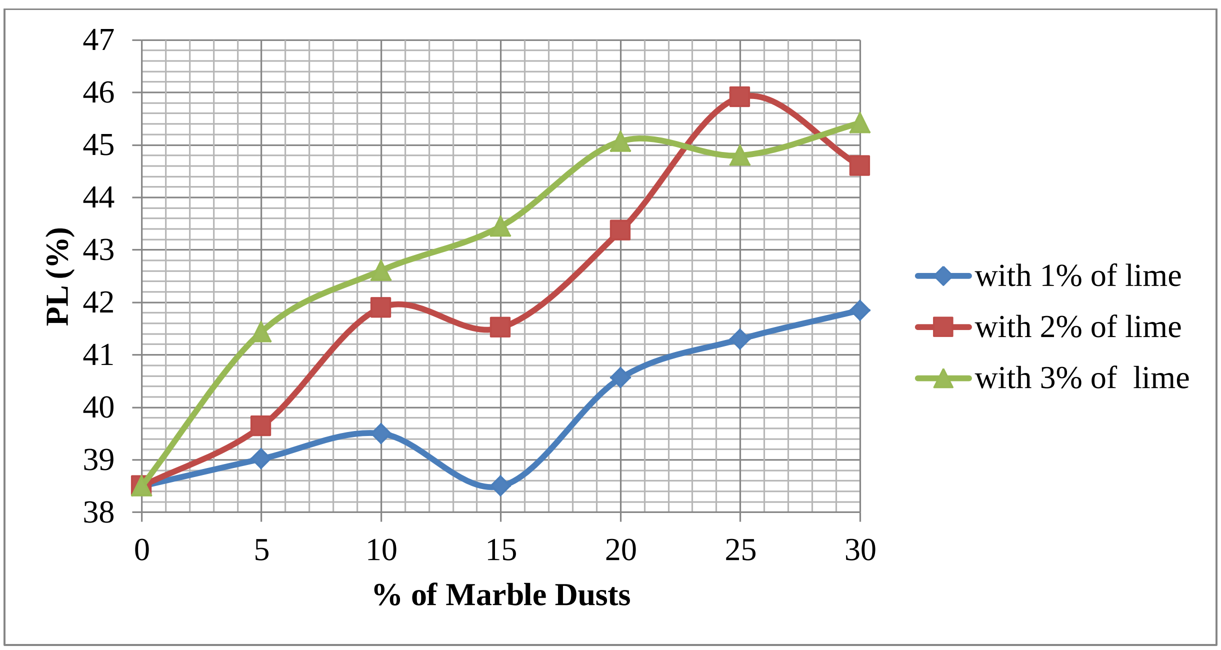

Figure 4. 8: Combined effects of lime and marble dust on plastic limit of sample 1

Table 4.16: Combined Effects of lime and marble dust on Atterberg limit of sample 2

Results of Atterberg limit tests Sample2 (Kochi)				
Lime (%)	**Marble Dust (%)**	**LL**	**PL**	**PI**
1	5	97	39.02	57.98
	10	92.5	39.50	53.00
	15	89	38.50	50.50
	20	85.2	40.56	44.64
	25	77.8	41.30	36.50
	30	71.6	41.85	29.75
2	5	94.2	39.64	54.56
	10	91	41.90	49.10
	15	85	41.52	43.48
	20	82	43.37	38.63
	25	76	45.91	30.09
	30	73	44.60	28.40
3	5	90	41.44	48.56
	10	86.5	42.61	43.89
	15	83	43.45	39.55
	20	79	45.07	33.93
	25	74.3	44.80	29.50
	30	69	45.42	23.58

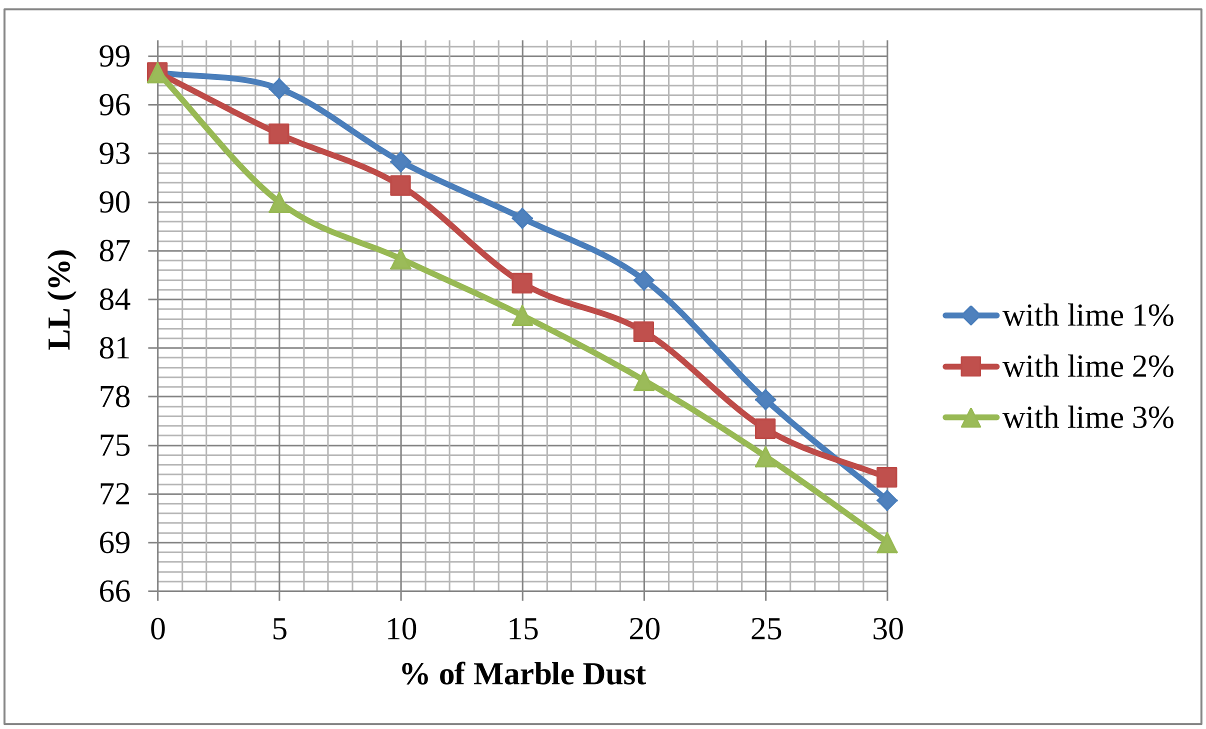

Figure 4. 9: Combined effects of lime and marble dust on Liquid limit of sample 2

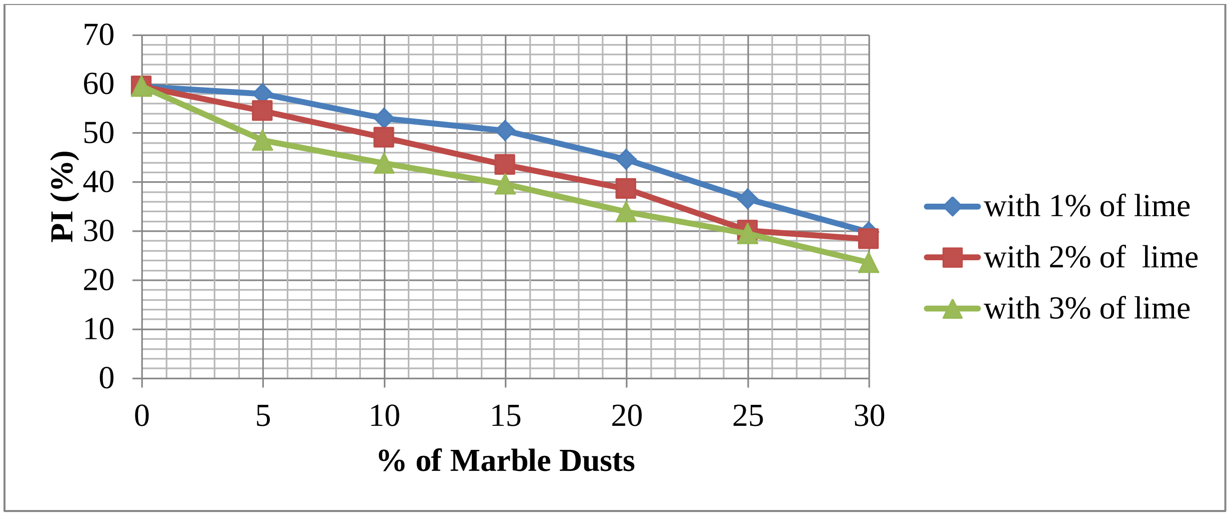

Figure 4. 10: Combined effects of lime and marble dust on plasticity index of sample 2

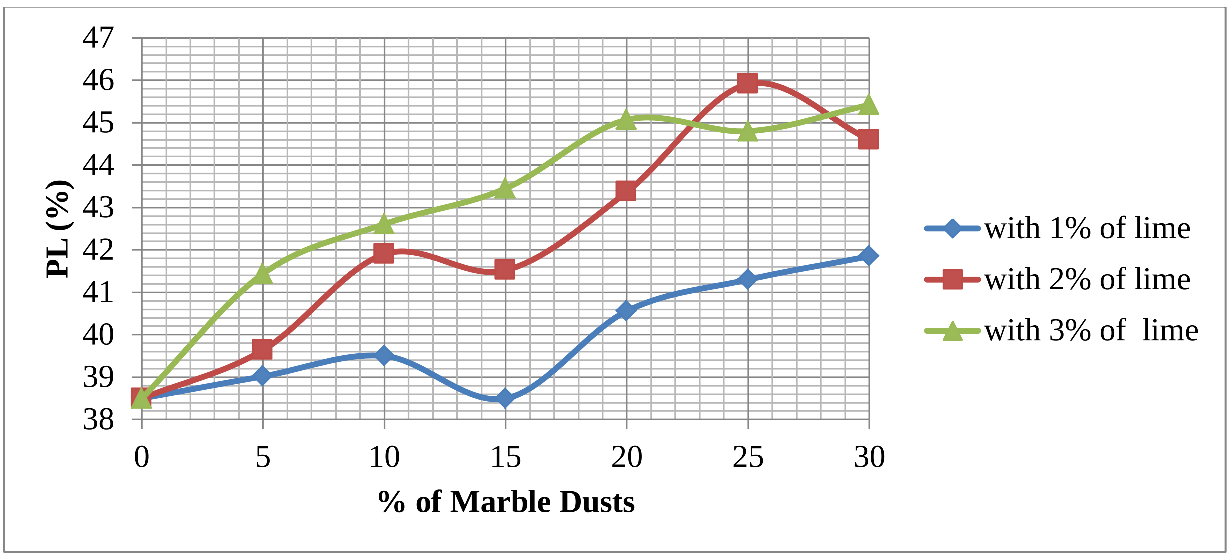

Figure 4. 11: Combined effects of lime and marble dust on plastic limit of sample 2

In general, the combination of lime and marble dusts effectively improve the plasticity of expansive soil. This is shown by the fact that plasticity index of treated soil decreased with increasing additive content. These effects probably due to the partial replacement of plastic soil particles with both non-plastic materials(lime and marble dust)and flocculation and agglomeration of clay particles caused by cation exchange. However, plastic limit diagrams of both sample 1 and sample 2 treated with combinations of different percentage of lime and marble dust results unusual variations from which it was difficult to decide whether increment or decrement on plastic limit values.

4.4.3.2. Combined Effect s of lime and marble Dust on free swell

The combined Effects of lime and marble dust on free swell tests are conducted on both sample one and sample two. The results from laboratory tests are summarized and shown in the table 4.17 and table 4.18. From the laboratory test results, both soil samples are highly expansive soil with a free swell value of 105% and 110% respectively for sample 1 and sample 2. Hence, the increment of lime and marble dust that blended with soil samples, the value of free swell is significantly decreased. Free swell values of both soil samples are decreased to 20% and 30%, when blended with 1-3% of lime and 5-30% of marble dust on both sample 1 and sample 2, respectively. According to U.S.B.R classification Method (the method developed Holz and Gibbs) the soil sample which is initially lies under, highly expansive was shifted to low expansive soil with maximum percentage of stabilizer would be observable.

Table 4.17: Combined Effects of lime and marble dust on free swell values of sample 1

Free swell test				
Sample type: Bachobore (sample1)				
Mix proportion		**Initial volume(ml)**	**Final volume(ml)**	**Free swell Value (%)**
Natural	0%	10	20.5	105
0% lime+	30% marble	10	17	70
3% lime+	0% marble	10	18	80
1% lime+	5% marble	10	19.5	95
	10% marble	10	17	70
	15% marble	10	15	50
	20% marble	10	15	50
	25% marble	10	14.5	45
	30% marble	10	15	50
2% lime+	5% marble	10	17	70
	10% marble	10	16.5	65
	15% marble	10	16	60
	20% marble	10	15	50
	25% marble	10	14	40
	30% marble	10	14	40
3% lime+	5% marble	10	16	60
	10% marble	10	14.5	45
	15% marble	10	13	30
	20% marble	10	13	30
	25% marble	10	13	30
	30% marble	10	12	20

Table 4.18: Combined Effects of lime and marble dust on free swell values of sample 2

Free swell test				
Sample type: Kochi (sample2)				
Mix proportion		**Initial volume(ml)**	**Final volume(ml)**	**Free swell (%)**
Natural	0%	10	21	110
0% lime+	30% marble	10	16	60
3% lime+	0% marble	10	18	80
1% lime+	5% marble	10	20	100
	10% marble	10	18.5	85
	15% marble	10	17	70
	20% marble	10	16	60
	25% marble	10	15	50
	30% marble	10	15	50
2% lime+	5% marble	10	16	60
	10% marble	10	16	60
	15% marble	10	15.5	55
	20% marble	10	15	50
	25% marble	10	15	50
	30% marble	10	14	40
3% lime+	5% marble	10	16	60
	10% marble	10	15	50
	15% marble	10	14	40
	20% marble	10	13	30
	25% marble	10	13	30
	30% marble	10	13	30

From the above tables as fixed percentage of lime that blended with deferent rate of marble dust on soil sample increases the value of free swell index is significantly decreased, and it has shown on the following figure.

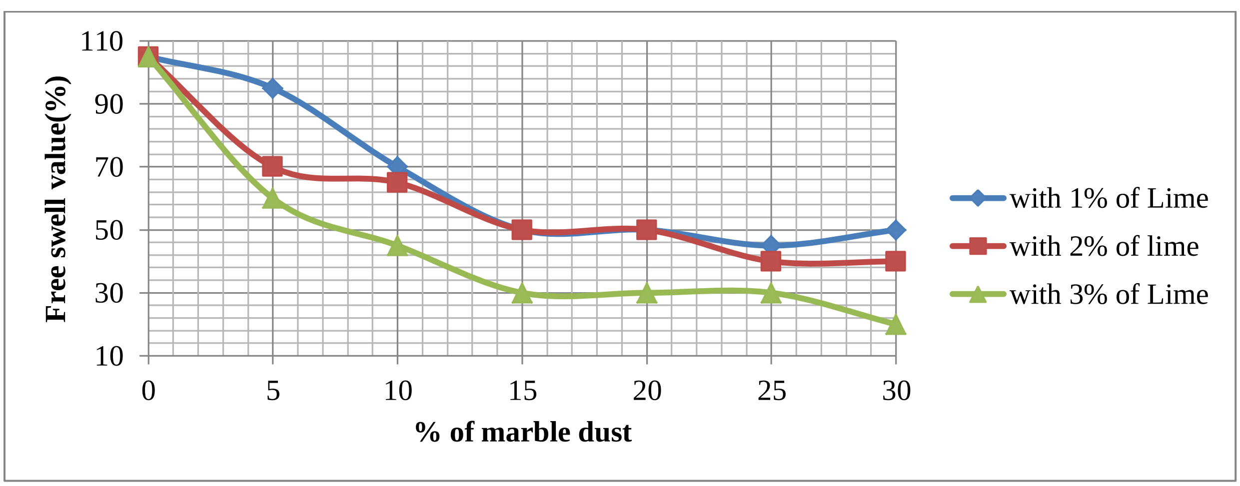

Figure 4. 12: Combined Effects of lime and marble dust on free swell values of sample 1

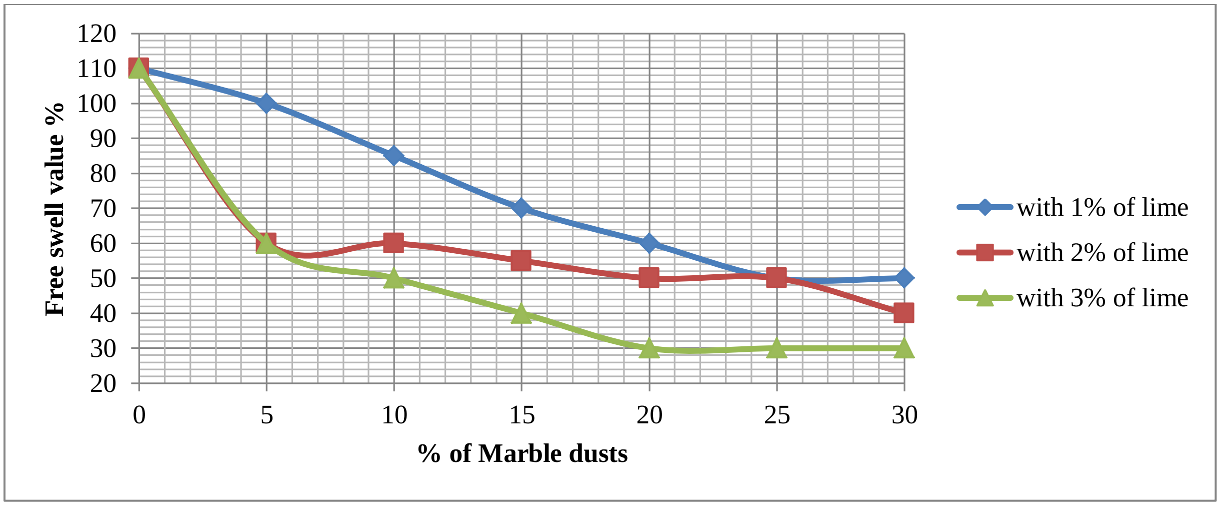

Figure 4. 13: Combined Effects of lime and marble dust alloy on free swell values of sample 2

As is shown in the above figure, the reduction in free swell value is directly proportional to the quantity of admixture (lime and marble dust). The highest reduction in free swell value is attained when the expansive soil is treated with 3% lime and 30% marble dust which is 75% and 70% reduction when compared to the untreated soil for sample one and sample two respectively. The decline in percentage is mainly due to the reason may be due to cation exchange in the combination of lime and marble with soil mix.

4.4.3.3. Combined Effects of lime and marble compaction and moisture characteristics

4.4.3.3.1 Maximum Dry Density

The combined effect of marble dust and lime on the maximum dry density of both sample1 and sample2 by fixing percentage lime from 1%-3% and blending it with different percentage of marble dust from (5%-30%) as shown in the table 4.19 and 4.20. from this result, it was observed that maximum dry density increase with increasing percentage of both lime and marble dust

Table 4.19: Combined Effects of lime and marble dust on Maximum dry density of sample 1

Sample 1(Bachobore) Maximum Dry Density								
Lime 1%	Marble dust (%)	0	5	10	15	20	25	30
	Maxumum Dry density (g/cm3)	1.230	1.235	1.260	1.312	1.355	1.409	1.424
Lime 2%	Marble dust (%)	0	5	10	15	20	25	30
	Maxumum Dry density (g/cm3)	1.230	1.249	1.265	1.316	1.369	1.416	1.434
Lime 3%	Marble dust (%)	0	5	10	15	20	25	30
	Maxumum Dry density(g/cm3)	1.230	1.254	1.270	1.335	1.370	1.425	1.444

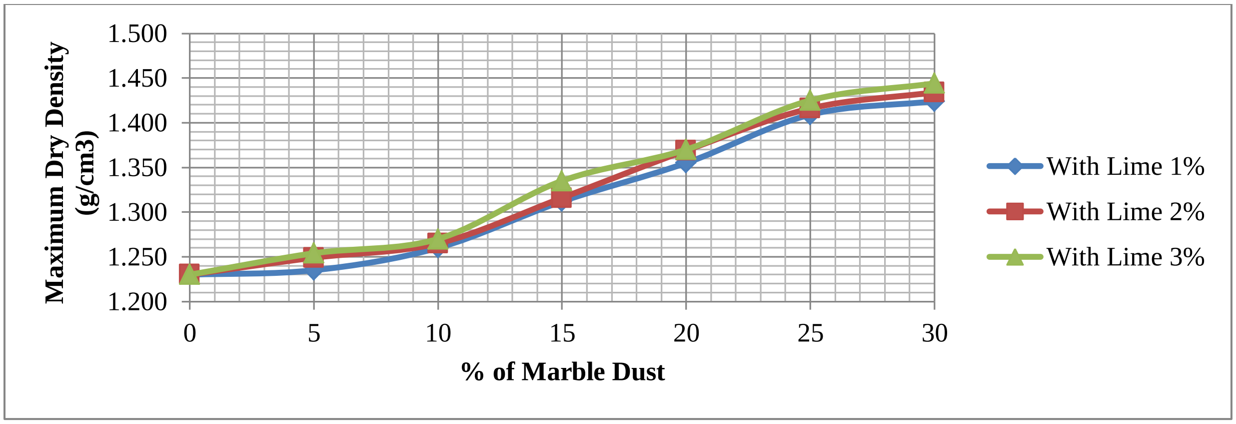

Figure 4. 14: Combined Effect of lime and marble dust on Maximum dry density of sample 1

Table 4.20: Combined Effects of lime and marble dust on Maximum dry density of sample 2

Sample 2(Kochi) Maximum Dry Density								
Lime 1%	Marble dust (%)	0	5	10	15	20	25	30
	Maxumum Dry density (g/cm3)	1.245	1.315	1.405	1.421	1.423	1.450	1.462
Lime 2%	Marble dust (%)	0	5	10	15	20	25	30
	Maxumum Dry density (g/cm3)	1.245	1.320	1.415	1.424	1.438	1.456	1.471
Lime 3%	Marble dust (%)	0	5	10	15	20	25	30
	Maxumum Dry density(g/cm3)	1.245	1.323	1.420	1.426	1.441	1.459	1.482

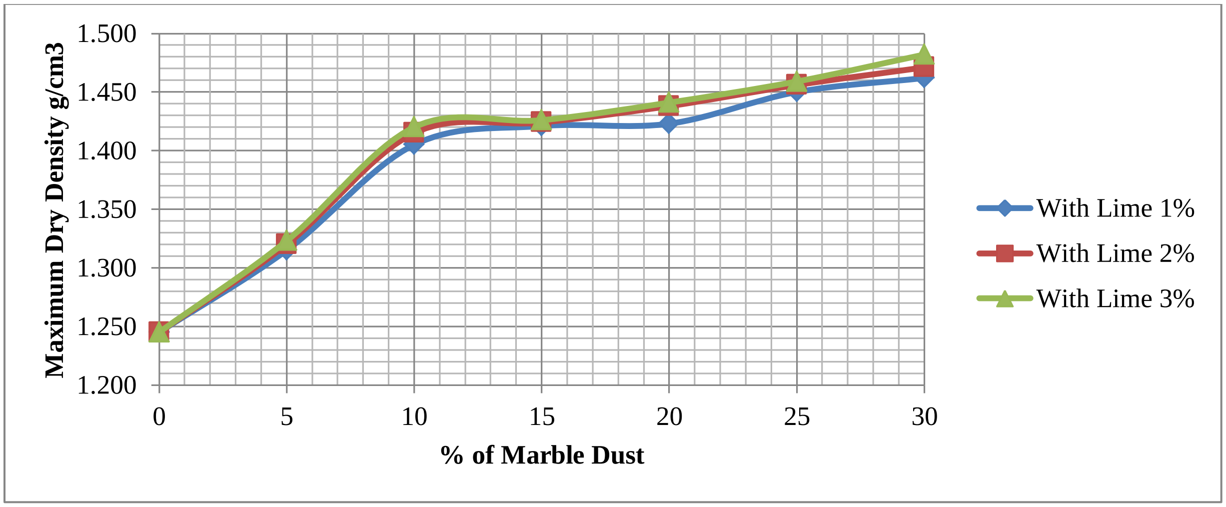

Figure 4. 15: Combined Effects of lime and marble dust on Maximum dry density of sample2

From the above table and figure it shows increasing maximum dry with growing marble dust and lime, mainly due to:

- Both marble dust and lime has small void in their particles
- Comparatively both marble dust and lime has more massive specific gravity than the soil sample

4.4.3.3.2 Optimum moisture content

The combined effect of marble dust and lime on the optimum moisture content of both sample1 and sample2 for differently fixed percentage lime and combined with the different percentage of marble dust as shown in the table 4.19 and 4.20.

Table 4.21: Combined Effects of lime and marble dust on optimum moisture content of sample 1

Sample 1(Bachobore) Optimum Moisture Content								
Lime 1%	Marble dust (%)	0	5	10	15	20	25	30
	Optimum Moisture content	37.1	36.4	35	33.65	28.575	27.8	27
Lime 2%	Marble dust (%)	0	5	10	15	20	25	30
	Optimum Moisture content	37.1	35.69	34.36	32.5	28.462	27	26.6
Lime 3%	Marble dust (%)	0	5	10	15	20	25	30
	Optimum Moisture content	37.1	35	34	28.5	27.4	26.77	23.5

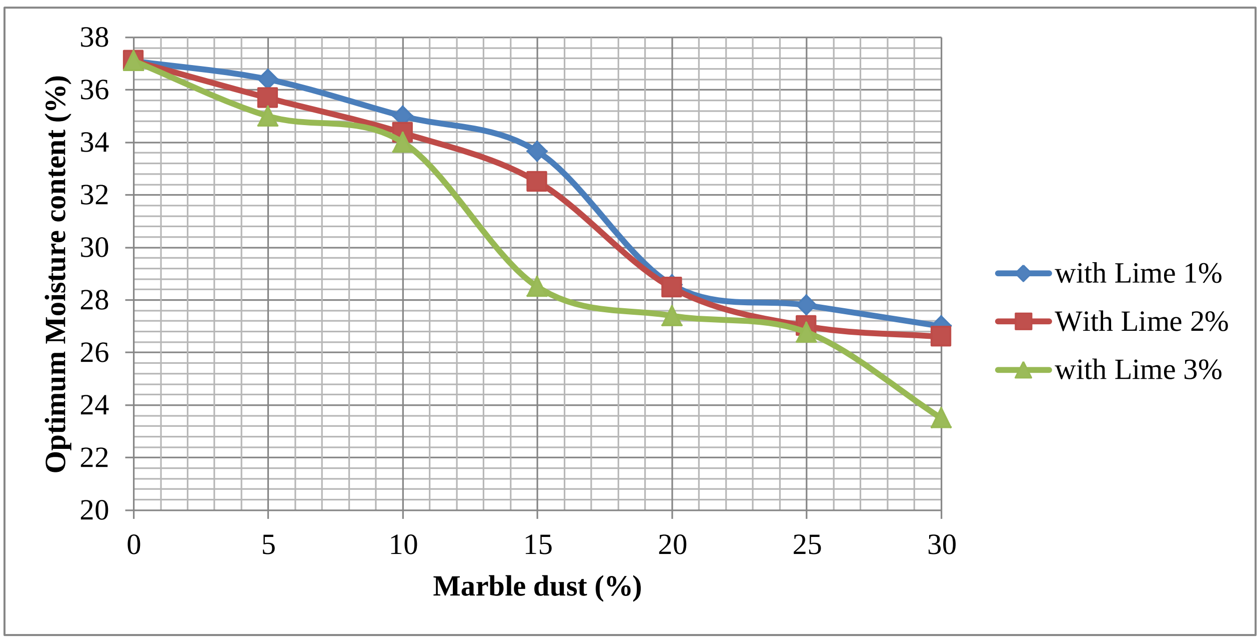

Figure 4. 16: Combined Effects of lime and marble dust on optimum moisture content of sample

Table 4.22: Effect of lime and marble dust alloy on optimum moisture content of sample 2

Sample 2(Kochi) Optimum Moisture Content								
Lime 1%	Marble dust (%)	0	5	10	15	20	25	30
	Optimum Moisture content	36.5	33	32.5	28.4	25.5	24.3	23.6
Lime 2%	Marble dust (%)	0	5	10	15	20	25	30
	Optimum Moisture content	36.5	31	30	25.74	25	22.5	22
Lime 3%	Marble dust (%)	0	5	10	15	20	25	30
	Optimum Moisture content	36.5	31	28.5	23.8	23	22.5	22

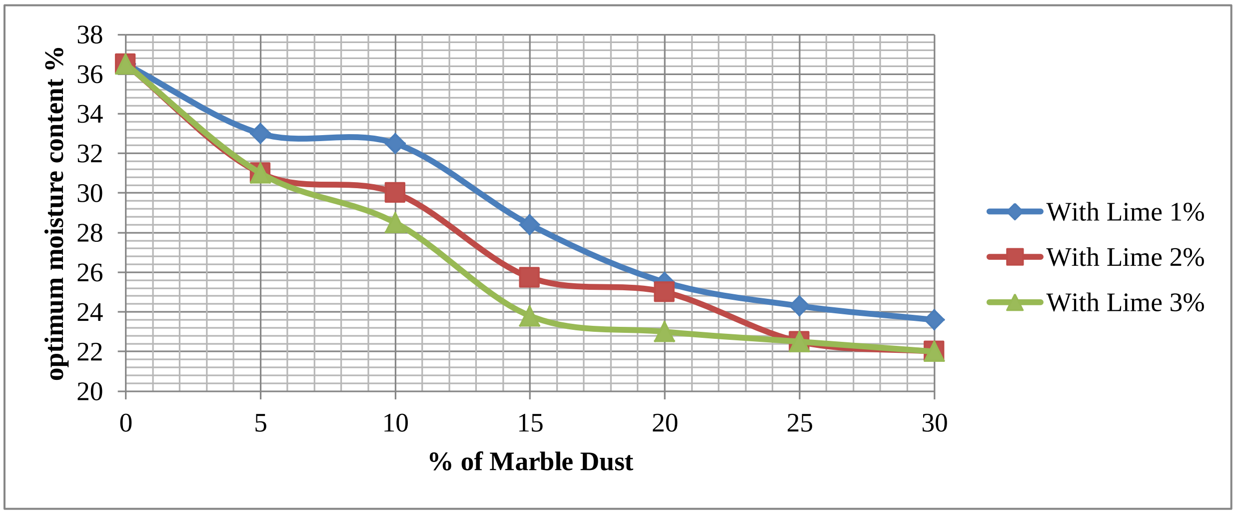

Figure 4. 17: Combined Effect of lime and marble dust on optimum moisture content of sample 2

From the above test result, it was observed that optimum moisture content of both sample soils is decreasing with increasing percentage lime and marble dust. For the maximum percentage of lime used in this study (3%) and combined with maximum percentage marble dust (30%), the optimum moisture content of natural soil(sample1 and sample2) was decreased from 37.1 and 36.5 to 23.5 and 22 respectively. Its almost 64% change when compared with its Natural condition, this is most probably due to:

- Both lime and marble are non-plastic material; perhaps when they blend with soil they facilitate compaction at low moisture content
- Decreasing moisture also due to pozzolanic reaction of both lime and marble dust with soil

4.4.3.4. Combined Effects of lime and marble on CBR Value

The CBR values are commonly used in the mechanical design and as an indicator of strength and bearing capacity of subgrade materials for use in road construction. Two samples are usually prepared for CBR tests; one is tested directly after sample preparation (unsoaked CBR), and the other one is after soaking in water for 96hr (soaked CBR). In this, research soaked CBR was conducted to the maximum dry density at optimum moisture content determined by standard proctor tests.

The combined effects of lime and marble dust on the CBR values of both sample1 and samples 2 are summarized in the table 5.23 and 4.24. The soaked condition of 1 point CBR tests are conducted on natural soil sample, with 30% marble dust, with 3% of lime and blending with different percentage dosage of lime and marble dust. From laboratory test results CBR values of Natural soil sample of both sample 1 and sample 2, are 1.2% and 0.92%, with addition of 30% marble dust the CBR values of Natural soil samples are changed to 2.06% and 1.84% respectively. Even though the CBR values are increased with respect to its natural condition, still the values are below the minimum recommended value for subgrade soils specified by Ethiopian Road Authority Manuals. According to ERA manuals 2002, the specification for materials suitable for use as subgrade material of not less than 3% CBR determined at MDD and OMC, hence the marble dust could be used in admixture stabilization with a more potent stabilizer such as cement and lime, to reduce the cost of stabilization.

From figures 4.23 and 4.24, as fixed percentage of lime that blended with different percentage marble dusts are increased, It can be seen that the CBR values of the soil samples are significantly increased, almost above the minimum recommended amounts that specified by ERA manual for subgrade soils, when different percentage of Marble dust with both natural soil samples are blended with 2% and 3% of lime. For instance, when 30% of marble dust with both soil sample combined with 2% and 3% of lime, the CBR values of Natural soil are changed from 1.2% to 5.33% and 6.16% respectively for sample 1 and for sample 2, It improved from 0.92% to 5.8% and 6.71% respectively.

When compared untreated soil sample with the sample treated with lime (1-3%) blended with marble dust (5-30%), 18%-420% increases in CBR values on sample 1, and 30%-650% increases on sample 2. On the other hand, 45%-200% and 9%-265% increases on CBR values on sample 1 and sample 2 respectively, when compared with the sample soil treated with maximum percentage of marble dust (30%).

Table 4.23: Combined Effect of lime and marble dust on CBR values of sample 1

CBR value of Sample: 1 (Bachobore)								
Lime 1%	Marble Dust (%)	Natural	5	10	15	20	25	30
	CBR at 2.54 Pen't	1.196	1.42	1.655	1.839	2.155	2.299	2.483
	CBR at 5.8 Pen't	1.153	1.093	1.153	1.578	1.639	2.064	2.125
Lime 2%	Marble Dust (%)	0	5	10	15	20	25	30
	CBR at 2.54 Pen't	1.20	1.75	2.30	2.85	3.86	4.48	5.33
	CBR at 5.8 Pen't	1.15	1.40	1.94	2.43	3.04	4.19	4.25
Lime 3%	Marble Dust (%)	0	5	10	15	20	25	30
	CBR at 2.54 Pen't	1.20	2.27	3.13	3.86	4.60	5.24	6.16
	CBR at 5.8 Pen't	1.15	2.25	2.55	2.97	3.46	4.37	5.40

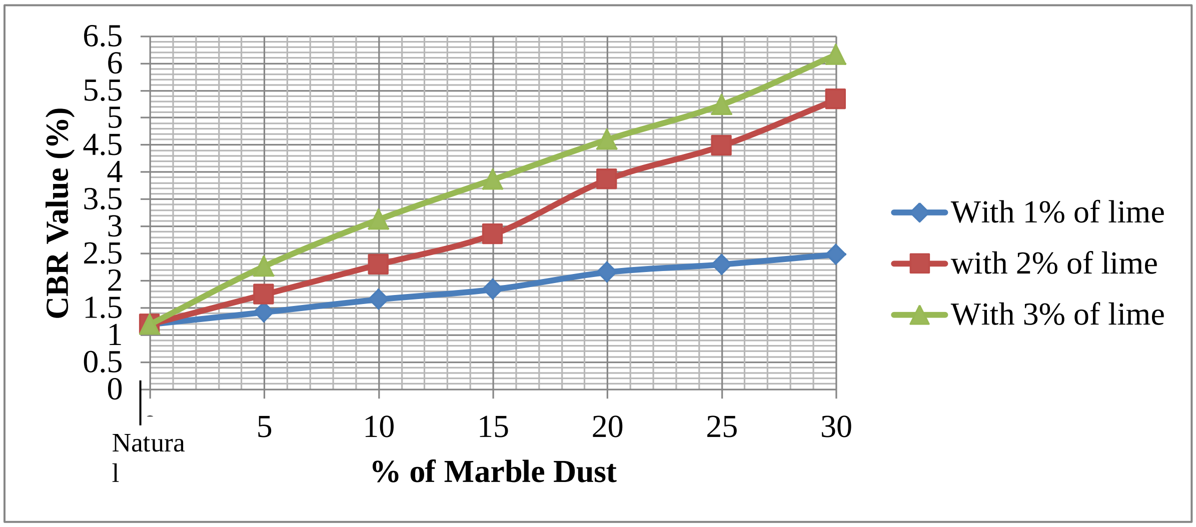

Figure 4. 18: Combined Effects of lime and marble dust on CBR values of sample 1

Table 4.24: Combined Effects of lime and marble dust on CBR values of sample 2

CBR value of Sample: 2 (Kochi)								
Lime 1%	Marble Dust (%)	Natural	**5**	**10**	**15**	**20**	**25**	**30**
	CBR at 2.54 Pen't	0.92	1.15	1.47	1.66	2.02	2.02	2.58
	CBR at 5.8 Pen't	0.79	0.92	1.21	1.27	1.64	1.58	1.94
Lime 2%	Marble Dust (%)	Natural	**5**	**10**	**15**	**20**	**25**	**30**
	CBR at 2.54 Pen't	0.92	3.04	3.13	3.31	4.23	5.24	5.79
	CBR at 5.8 Pen't	0.79	2.55	2.73	2.55	3.40	4.07	4.61
Lime 3%	Marble Dust (%)	Natural	**5**	**10**	**15**	**20**	**25**	**30**
	CBR at 2.54 Pen't	0.92	3.50	4.32	5.06	5.79	6.53	6.71
	CBR at 5.8 Pen't	0.79	2.73	3.76	4.49	4.80	4.64	5.22

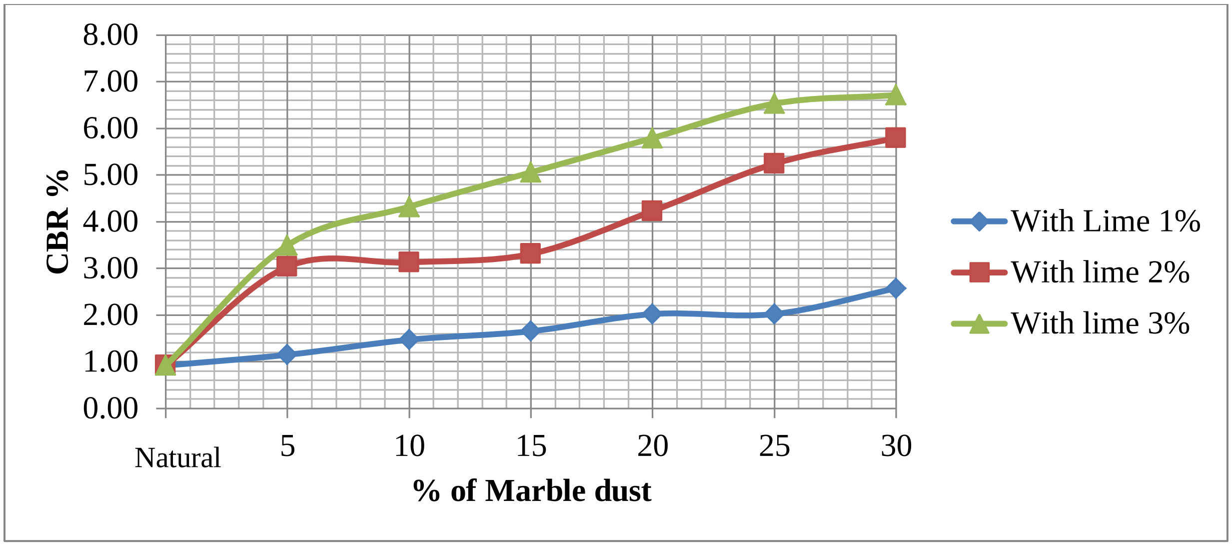

Figure 4. 19: Combined Effects of lime and marble dust on CBR values of sample 2

From the above tables and figures, it can be seen that the CBR values of both soil samples have been increasing as fixed percentage lime that added to the different percentage of marble dust increased. This increment may be attributed to the chemical and cementatious effects of lime on structural composition of soils is more significant than to that of marble dust, since both lime and marble dust have cementatious material which bonding between clay particles, lime and marble dust becomes strong, and the load bearing capacity has been increased.

Even though both lime and marble dust have cementatious materials, cementation alone doesn't improve strength properties of clay materials. From the reviewed literature, it can be seen that oxide amount in marble dust is less than oxide amount in lime. Hence flocculation and hydration are the primary mechanisms to improve the strength of clay soils; it may be the main reason that why marble dust alone has not shown significant improvement on CBR value.

4.5. Comparisons of the test results with standard and specification for subgrade materials

Table 4. 25: comparisons of stabilized soil sample one with standard and specifications

Sample One (Bachobore)										
Mix proportion		Test results (%)					Clasification System			
		LL	PL	PI	FS	CBR	USCS	AASHTO	ERA	U.S.B.R
Natural		105.6	40.12	65.48	105	1.20	CH	A-7-6	S1	Highly expansive
30% Marble		80	43.9	36.1	70	2.06	MH	A-7-5	S1	Mediam expansive
3% Lime		96.5	37.39	59.11	80	2.39	CH	A-7-5	S1	Mediam expansive
1% Lime +	5 % Marble	101.2	38.49	62.71	95	1.42	MH	A-7-5	S1	Mediam expansive
	10% Marble	97.6	40.91	56.69	70	1.66	MH	A-7-5	S1	Mediam expansive
	15% Marble	89.3	41.44	47.86	50	1.84	MH	A-7-5	S1	Mediam expansive
	20% Marble	84.8	41.03	43.77	50	2.16	MH	A-7-5	S1	Mediam expansive
	25% Marble	80.5	42.81	37.69	45	2.30	MH	A-7-5	S1	Low expansive
	30% Marble	77.5	42.87	34.63	50	2.48	MH	A-7-5	S1	Mediam expansive
2% Lime +	5% Marble	96.5	41.01	55.49	70	1.75	MH	A-7-5	S1	Mediam expansive
	10% Marble	93.3	42.1	51.2	65	2.30	MH	A-7-5	S1	Mediam expansive
	15% Marble	86	42.95	43.05	60	2.85	MH	A-7-5	S1	Mediam expansive
	20% Marble	80.6	42.3	38.3	50	3.86	MH	A-7-5	S2	Mediam expansive
	25% Marble	77	42.91	34.09	40	4.48	MH	A-7-5	S2	Low expansive
	30% Marble	73.6	43.35	30.25	40	5.33	MH	A-7-5	S3	Low expansive
3% Lime +	5% Marble	91.2	42.9	48.3	60	2.27	MH	A-7-5	S1	Mediam expansive
	10% Marble	85.8	43.18	42.62	45	3.13	MH	A-7-5	S2	Low expansive
	15% Marble	81	42.91	38.09	30	3.86	MH	A-7-5	S2	Low expansive
	20% Marble	74.2	43.03	31.17	30	4.60	MH	A-7-5	S2	Low expansive
	25% Marble	72.8	42.94	29.86	30	5.24	MH	A-7-5	S3	Low expansive
	30% Marble	68.2	42.09	26.11	20	6.16	MH	A-7-5	S3	Low expansive

Table 4. 26: Comparisons of stabilized soil sample two with standard and specifications

Sample Two (Kochi)										
Mix proportion		Test results (%)					Clasification System			
		LL	PL	PI	FS	CBR	USCS	AASHTO	ERA	U.S.B.R
Natural		98	38.5	59.5	110	0.92	CH	A-7-6	S1	Highly expansive
30% Marble		75.5	41.72	33.78	60	1.84	MH	A-7-5	S1	Mediam expansive
3% Lime		88	37.78	50.22	80	2.85	MH	A-7-5	S1	Mediam expansive
1% Lime +	5 % Marble	97	39.02	57.98	100	1.15	MH	A-7-5	S1	Mediam expansive
	10% Marble	92.5	39.5	53	85	1.47	MH	A-7-5	S1	Mediam expansive
	15% Marble	89	38.5	50.5	70	1.66	MH	A-7-5	S1	Mediam expansive
	20% Marble	85.2	40.56	44.64	60	2.02	MH	A-7-5	S1	Mediam expansive
	25% Marble	77.8	41.3	36.5	50	2.02	MH	A-7-5	S1	Mediam expansive
	30% Marble	71.6	41.85	29.75	50	2.58	MH	A-7-5	S1	Mediam expansive
2% Lime +	5% Marble	94.2	39.64	54.56	60	3.04	MH	A-7-5	S2	Mediam expansive
	10% Marble	91	41.9	49.1	60	3.13	MH	A-7-5	S2	Mediam expansive
	15% Marble	85	41.52	43.48	55	3.31	MH	A-7-5	S2	Mediam expansive
	20% Marble	82	43.37	38.63	50	4.23	MH	A-7-5	S2	Mediam expansive
	25% Marble	76	45.91	30.09	50	5.24	MH	A-7-5	S3	Mediam expansive
	30% Marble	73	44.6	28.4	40	5.79	MH	A-7-5	S3	Low expansive
3% Lime +	5% Marble	90	41.44	48.56	60	3.5	MH	A-7-5	S2	Mediam expansive
	10% Marble	86.5	42.61	43.89	50	4.32	MH	A-7-5	S2	Mediam expansive
	15% Marble	83	43.45	39.55	40	5.06	MH	A-7-5	S3	Low expansive
	20% Marble	79	45.07	33.93	30	5.79	MH	A-7-5	S3	Low expansive
	25% Marble	74.3	44.8	29.5	30	6.53	MH	A-7-5	S3	Low expansive
	30% Marble	69	45.42	23.58	30	6.71	MH	A-7-5	S3	Low expansive

As it shown in the above tables the result of laboratory test where compared with standard and specification of AASHTO, USCS, ERA and U.S.B.R

AASHTO soil classification system are classify soil based on; percentage of passing through sieve no 200, liquid limit and plasticity index, according to this classification system natural soil lies under A-7-6 was shifted to A-7-5 after stabilization.

USCS are classifying soil based on liquid limit and plasticity index, according to USCS, soil which is naturally lies under CH (high plasticity clay soil) was shifted to MH (elastic silt).

ERA manual are classify subgrade soil based on CBR values, according to ERA subgrade soil classification , soil which is initially fall under S1 which is not recommended to use as subgrade materials was shifted to S3 after stabilization , which can be used for the designing of flexible pavement for light and medium traffic.

U.S.B.R (United States Brue of reclamation) classify soil based their free swell values, according to this methods, soil which is highly expansive under natural condition was shifted to low expansive after stabilization Hence, as per this classification it will not create any problem with the structures to be founded on it.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

A series of laboratory test were carried out to study the improvement in geotechnical properties of a selected expansive soil stabilized with Lime and Marble dust alloy. The result from laboratory test are shown and discussed in previous chapter. Hereunder are the following conclusion and recommendation.

5.1 Conclusion

Based on the findings of the study, conclusions are drawn:

- From field investigation expansive soils of five different place in Jimma town where identified, of them **Technic sefer**, **Bachobore** and **Kochi** soils were classified under highly expansive soil and merkato and Kitto furdisa were classified under medium expansive soil.
- Laboratory test result indicates that the natural subgrade soil of the subject area was classified as a material of deficient engineering property to be used as a sub-grade material. It requires first modification and stabilization to improve its workability and engineering property.
- With the addition of lime and marble dust, the liquid limit and plasticity index decreased, maximum decrement on liquid limit and plastic index value is achieved when both soil samples were mixed with 3% of lime and 30% marble dust combined.
- The addition of marble dust and lime on both natural soil sample resulted in a remarkable increased in the maximum dry density and a decreased in optimum moisture content.
- Free swell values of both soil sample goes decreasing as combined percentage of lime, and marble dust increased, maximum decrement on free swell value is achieved at combinations of 3% lime and 30% marble dust, it decreased from105% and 110% to 30% and 20% respectively for sample1 and sample2. With this combination, both soil samples are shifted from highly expansive to low expansive soil. Hence, it will not create any problem with the structures to be founded on it.
- Soaked CBR values of both soil sample increases with increase in combined percentage of lime, and marble dust, maximum increment in CBR value is achieved a combination of 3% lime and 30% marble dust, the CBR value increased from 1.1% and 0.98% to 6.2% and

6.7%% respectively for sample1 and sample two, which can be used for the designing of flexible pavement for light and medium traffic. Hence, combination of marble dust and lime can actively improve the strength of the expansive soil.

- The strength gained by the soil samples depend upon the percentage proportion of the admixtures added. Combinations of 3% of lime and 30% of marble dust were found to be a percentage proportion of admixtures which yielded maximum strength as well as minimum swelling potential and plasticity in the soil sample.
- Unlike lime in combination with marble dust the improvement achieved by marble dust alone on the poor geotechnical properties of expansive soil was limited. Hence, the development up to 30% marble dust content was not satisfactory. Therefore, marble dust is not a sufficient standalone stabilizer for highly plastic expansive soils of Jimma town. However, marble dust plus/in combination with a small percentage of lime can efficiently stabilize this soil.
- Comparison of the results obtained with some specifications showed that the improvements obtained from this stabilization, and it was satisfied ERA Standard Specification for subgrade materials
- Combining two local materials (lime and marble dust) can efficiently improve the poor geotechnical properties of this soil and help in increase land resources available for construction projects. In addition to this, it will reduce the pollution and degradation of marble dust on environments.

Finally, it is concluded that the results from this study agree well with some recent reviews from literature related to the potential utilization of marble dust or with other addictive materials in road construction.

5.2 Recommendations

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

- The soil used in this study has specific properties and the CBR tests were conducted on soaked samples without consideration of the time effect after mixing additives with the soil. From previous study as time allowed for curing increased the rate of strength gained also increased, hence more studies are needed, by considering the different effect of curing time after mixing marble dust and lime with soil.
- From previous studies the stabilizing effect is primarily a function of the chemical composition in it, fineness, and addition level of the stabilizer as well as the type of parent soil. Hence this paper concluded that marble dust from Ethiopian marble industry was not shown significant improvement on expansive soils of the study area thus more investigation is needed on physical and chemical composition of marble dust in order to know the reason.
- Combination of lime and marble dust is an effective soil stabilization agent based on the results observed and described in this thesis. It is recommended that it can be considered for use in the stabilization of soil for sub-grade materials, which capable to reduce thickness of sub-grade
- As per the literature review, it may use two or more wastes simultaneously for the study and find out the optimum values of them by replace constant amount of one waste and vary others or vary all the wastes and with many more other combinations. Hence, it is recommended that more research shall be conducted on combining effect of marble dust with other waste material such as bagasse, stone dust and cement kiln dust to be more economical.

Further research is proposed on

- Economic analysis of combined different percentage of lime and marble dusts to know the best economical mix ratio.
- The combined effect of lime marble dust on lateritic soils.
- Secondary reaction of marble dust using more advanced methods like X-ray Diffraction analysis.

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APPENDIX

APPENDIX ONE

SUMMARY OF TEST RESULTS OF NATURAL SOILS

1. Natural Soil

1.1. Atterberg Limits

Sample 1 (Bachobore)

	Liqued limit			Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	33	26	17		
CAN CODE	H33	LB	CD	L33	M
MASS OF CAN	18.622	17.501	17.479	6.37	6.177
MASS OF CAN +WET SOIL	40.656	40.717	42.215	12.234	12.92
MASS OF CAN+DRY SOIL	29.612	28.69	29.166	10.58	10.961
MASS OF WATER	11.044	12.027	13.049	1.654	1.959
MASS OF DRY SOIL	10.99	11.189	11.687	4.21	4.784
MOISTURE CONTENT(%)	100.4914	107.4895	111.654	39.28741	40.949
				PL=40.12	

plastic index	
PI	65.48
PL	40.12
LL	105.6

Sample 2 (Kochi)

	LL			PL	
TRIAL	1.00	2.00	3.00	1	2
NO:- OF BLOWS	30.00	23.00	19.00		
CAN CODE	p1	A	B	G2	B2
MASS OF CAN	16.93	17.89	18.07	6.18	6.28
MASS OF CAN +WET SOIL	40.41	42.89	39.77	11.57	13.04
MASS OF CAN+DRY SOIL	28.89	30.46	28.91	10.04	11.20
MASS OF WATER	11.52	12.43	10.86	1.53	1.84
MASS OF DRY SOIL	11.96	12.58	10.84	3.86	4.92
MOISTURE CONTENT(%)	96.31	98.84	100.17	39.67	37.32
				PL= 38.5	

PI	59.50
PL	38.50
LL	98

1.2. Grain size analysis

Sieve analysis			sample two: (kochi)		
Sieve No	Sieve Opening (mm)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
No 4	4.75	0.6	0.12	0.12	99.88
No 10	2	9.89	1.978	2.098	97.902
No 20	0.85	5.64	1.128	3.226	96.774
No 40	0.425	2.15	0.43	3.656	96.344
No 60	0.25	1.16	0.232	3.888	96.112
No 100	0.15	0.87	0.174	4.062	95.938
No 200	0.075	1.1	0.22	4.282	95.718
pan	-------	478.59	95.718	100	0

Sieve analysis			sample one: (Bachobore)		
Sieve No	Sieve Opening (mm)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
No 4	4.75	0	0	0	100
No 10	2	2.62	0.524	0.524	99.476
No 20	0.85	4.43	0.886	1.41	98.59
No 40	0.425	3.7	0.74	2.15	97.85
No 60	0.25	2.65	0.53	2.68	97.32
No 100	0.15	1.72	0.344	3.024	96.976
No 200	0.075	1.73	0.346	3.37	96.63
pan	-------	483.15	96.63	100	0

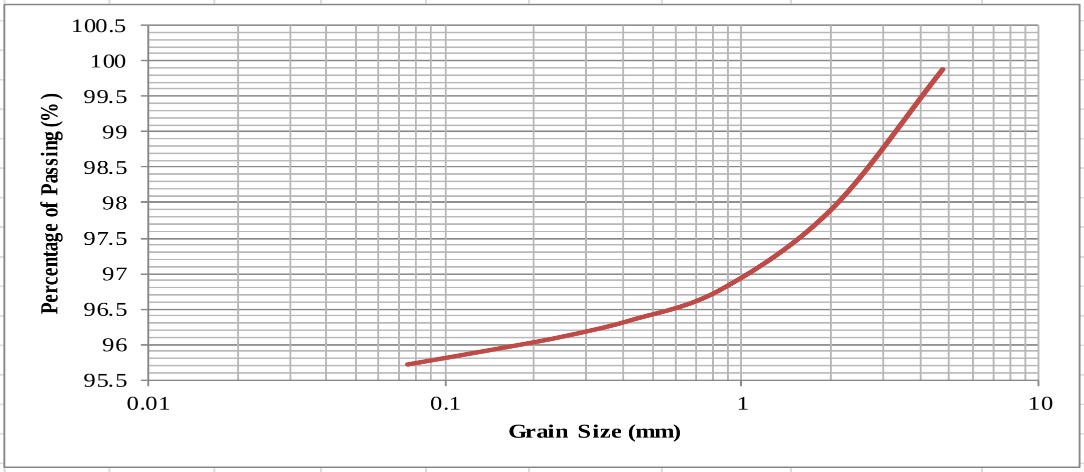
Hydrometer reading its adjustment					Sample: two(Kochi)							
time (min)	hydrometer reading, R	T	TC	Dc	Rcp	a	percent of fine	RCl	L(cm)	K	D	combined
1	52	20	0.15	7	45.15	0.367	33.127	53	7.6	0.013	0.037	31.709
2	51	20	0.15	7	44.15	0.367	32.394	52	7.8	0.013	0.026	31.007
5	47	20	0.15	7	40.15	0.367	29.459	48	8.4	0.013	0.017	28.197
10	43	20	0.15	7	36.15	0.367	26.524	44	9.1	0.013	0.013	25.388
15	41	20	0.15	7	34.15	0.367	25.056	42	9.4	0.013	0.011	23.984
30	40	20	0.15	7	33.15	0.367	24.323	41	9.6	0.013	0.008	23.281
60	37	20	0.15	7	30.15	0.367	22.122	38	10.1	0.013	0.005	21.174
120	34	21	0.4	7	27.4	0.367	20.104	35	10.5	0.013	0.004	19.243
240	31	22	0.65	7	24.65	0.367	18.086	32	11.1	0.013	0.003	17.312
480	28	22	0.65	7	21.65	0.367	15.885	29	11.5	0.013	0.002	15.205
960	25	20	0.15	7	18.15	0.367	13.317	26	12	0.013	0.001	12.747
1440	23	20	0.15	7	16.15	0.367	11.850	24	12.4	0.013	0.001	11.342

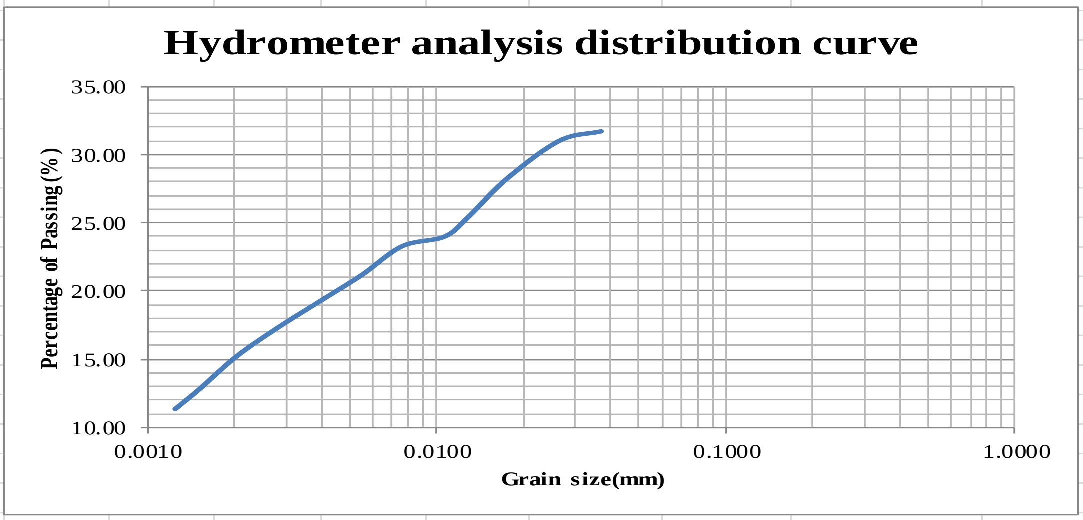
Hydrometer reading its adjustment					Sample: one(Bachobore)							
time (min)	hydrometer reading, R	T	TC	Dc	Rcp	a	percent of fine	RCl	L(cm)	K	D	combined
1	52	20	0.15	7	45.15	0.380	34.283	53	7.6	0.014	0.038	33.128
2	51	20	0.15	7	44.15	0.380	33.524	52	7.8	0.014	0.027	32.394
5	48	20	0.15	7	41.15	0.380	31.246	49	8.3	0.014	0.018	30.193
10	46	20	0.15	7	39.15	0.380	29.727	47	8.6	0.014	0.013	28.726
15	45	20	0.15	7	38.15	0.380	28.968	46	8.8	0.014	0.011	27.992
30	43	20	0.15	7	36.15	0.380	27.449	44	9.1	0.014	0.008	26.524
60	41	20	0.15	7	34.15	0.380	25.931	42	9.4	0.014	0.005	25.057
120	39	20	0.15	7	32.15	0.380	24.412	40	9.7	0.014	0.004	23.589
240	36	22	0.65	7	29.65	0.380	22.514	37	10.2	0.013	0.003	21.755
480	33	22	0.65	7	26.65	0.380	20.236	34	10.7	0.013	0.002	19.554
960	32	20	0.15	7	25.15	0.380	19.097	33	10.9	0.014	0.001	18.453
1440	31	20	0.15	7	24.15	0.380	18.338	32	11.1	0.014	0.001	17.720

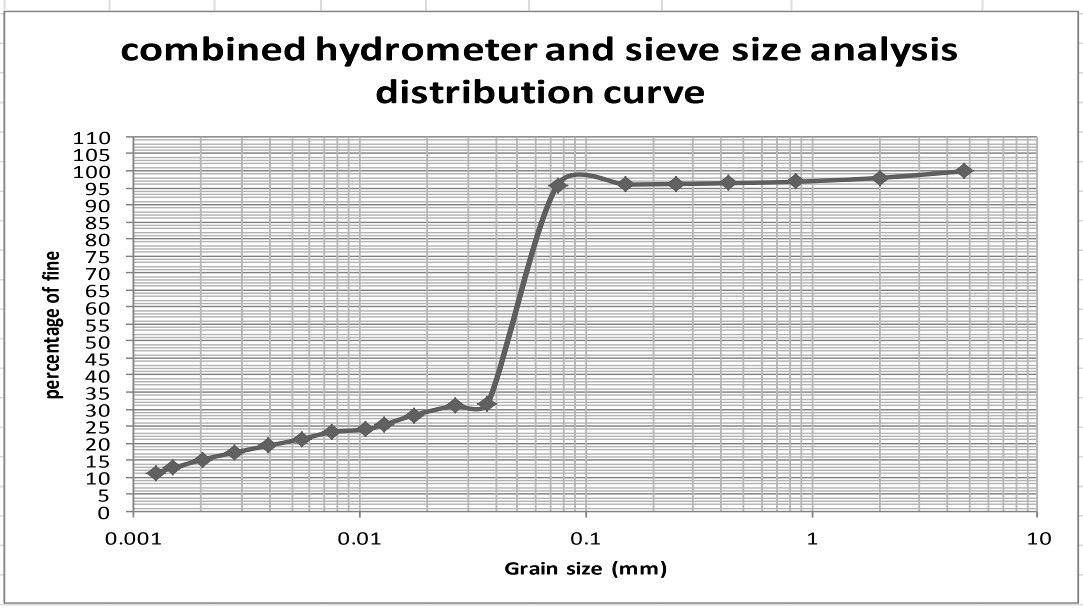
hydrometric and sieve analysis combined	sample2(kochi
Sieve size(mm)	Percentage of passing (%)
4.75	99.9
2	97.9
0.85	96.8
0.425	96.3
0.25	96.1
0.15	95.9
0.075	95.7
0.037	31.7
0.026	31.0
0.017	28.2
0.013	25.4
0.011	24.0
0.008	23.3
0.005	21.2
0.004	19.2
0.003	17.3
0.002	15.2
0.001	12.7
0.001	11.3

hydrometric and sieve analysis combined	sample1(bachobore
Sieve size(mm)	Percentage of passing (%)
4.75	100.0
2	99.5
0.85	98.6
0.425	97.9
0.25	97.3
0.15	97.0
0.075	96.6
0.038	33.1
0.027	32.4
0.018	30.2
0.013	28.7
0.011	28.0
0.008	26.5
0.005	25.1
0.004	23.6
0.003	21.8
0.002	19.6
0.001	18.5
0.001	17.7

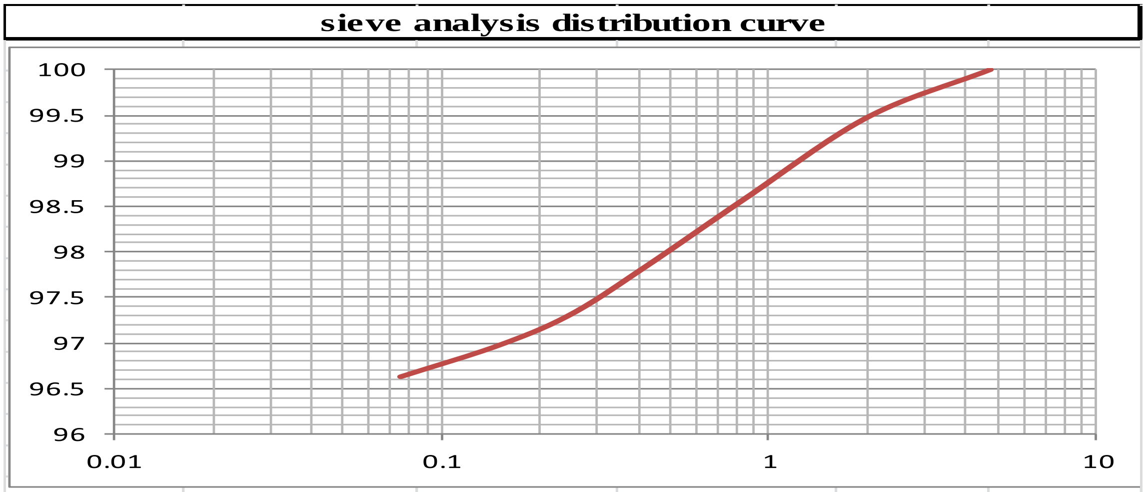
Sample two: kochi

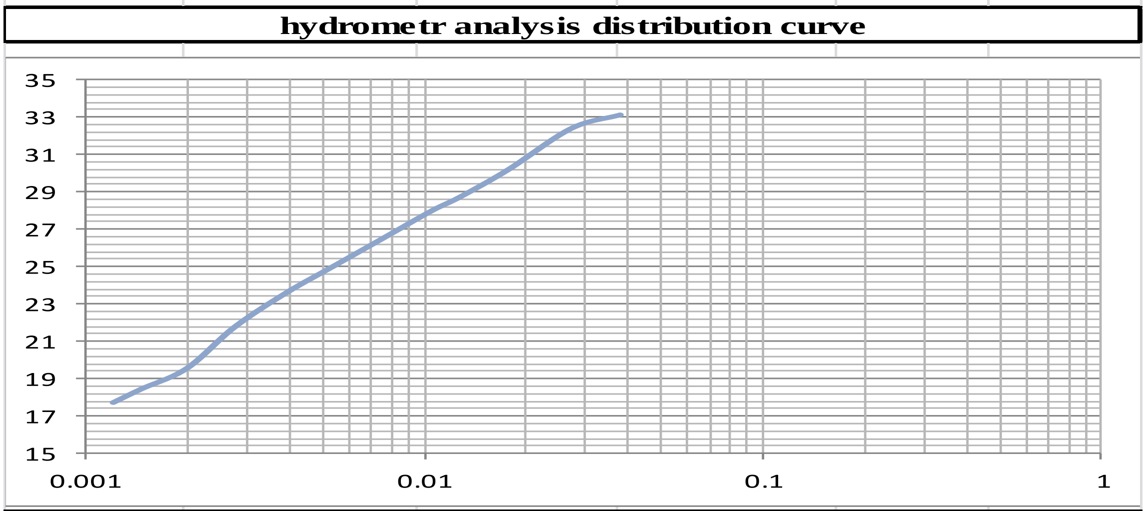


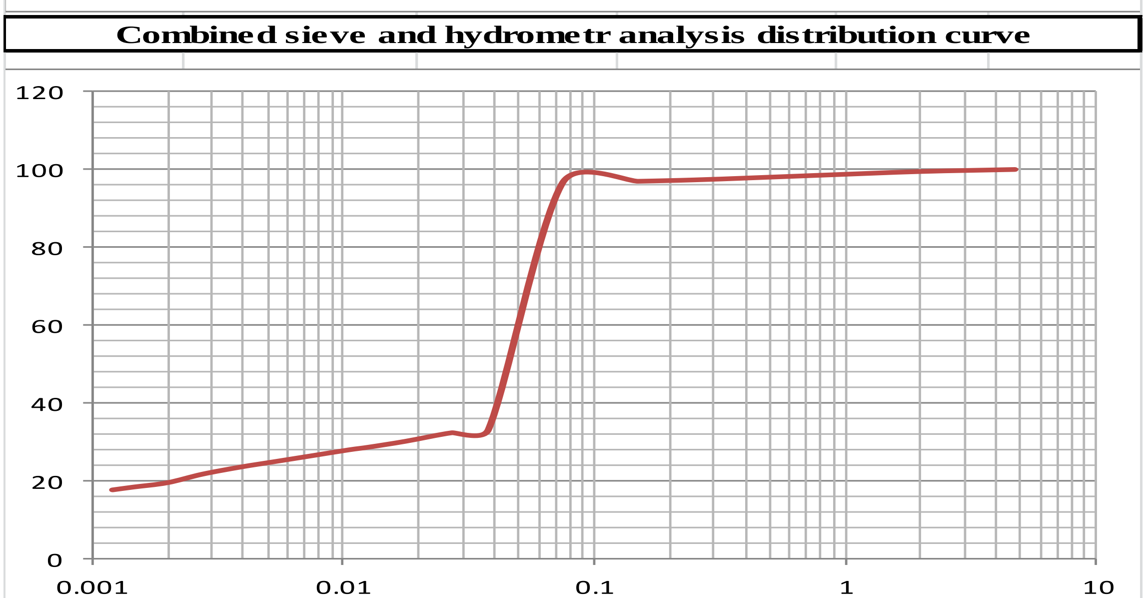




Sample one Bachobore



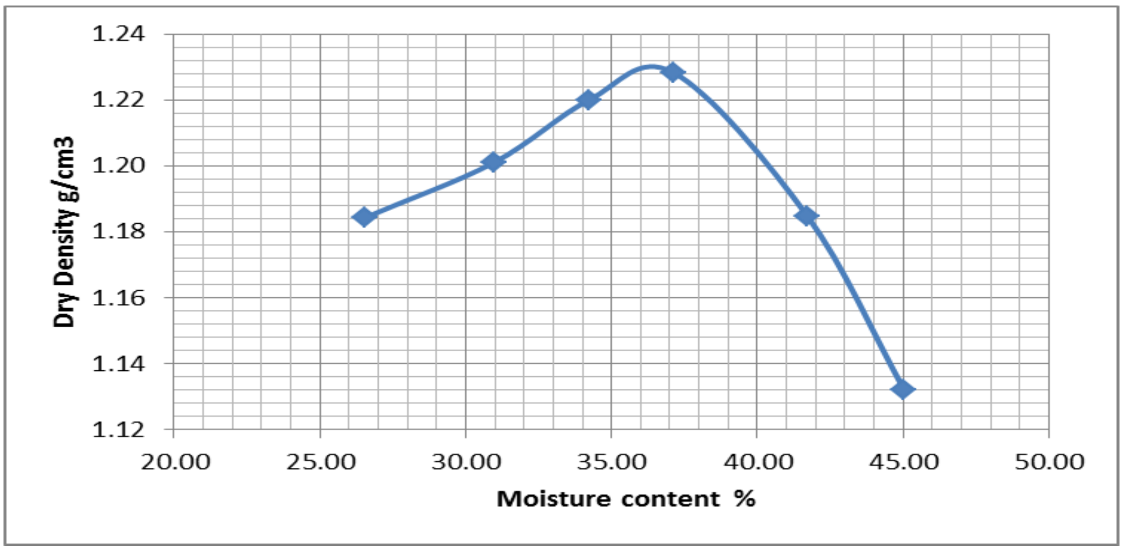




1.3 Moisture Density Relationship (Procter Test)

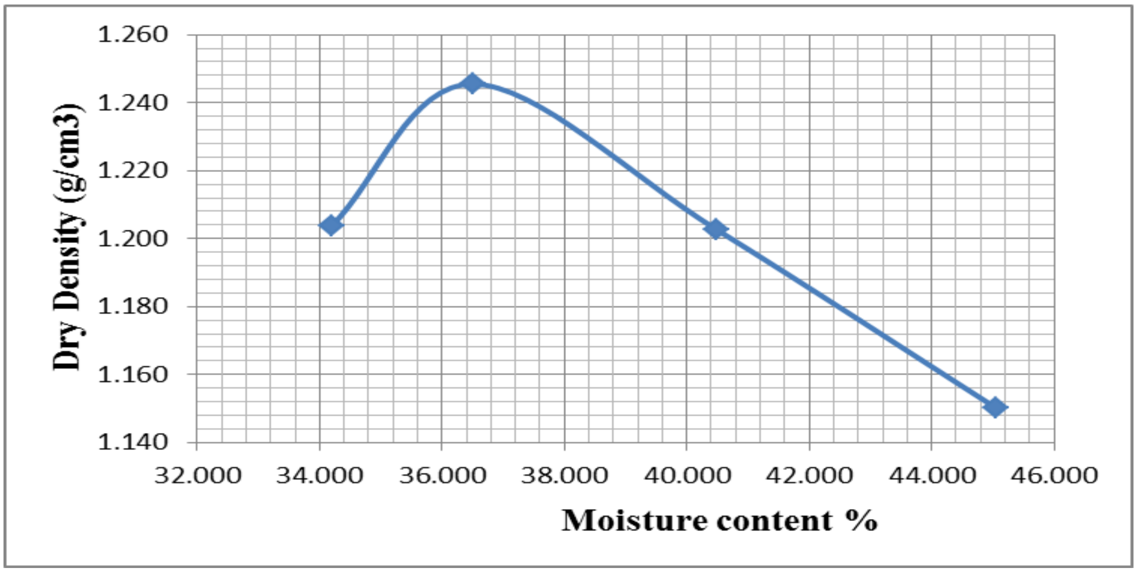
Sample 1

Additive Content				0% or Natural soil Bacho bore								
Volume of Mold (cm3)					944							
Trial No.	Trial -1		Trial - 2		Trial - 3		Trial - 4		Trial - 5		Trial -6	
Wt. Soil + Mold (g)	4415		4485		4545		4590		4585		4550	
Wt. Mold (g)	3000		3000		3000		3000		3000		3000	
Wt. Soil (g)	1415		1485		1545		1590		1585		1550	
Wet Density (g/cm3)	1.499		1.573		1.637		1.684		1.679		1.642	
Dry Density (g/cm3)	1.184		1.201		1.219		1.228		1.185		1.132	
Water Content Sample												
Can No.	A2	B3	H23	T4C2	LB	HC33	A	P1	1B	I	CD	B
Can + Wet Soil (g)	93.981	93.92	94.655	94.23	92.683	97.425	96.545	91.838	92.49	95.13	101.76	98.477
Can + Dry Soil (g)	77.704	78.173	76.978	75.708	72.89	77.994	75.536	71.284	72.611	70.415	75.539	73.567
Mass of Can (g)	17.99	17.288	19.12	16.68	17.497	18.616	17.882	16.931	17.152	18.471	17.48	18.071
Mass of Dry Soil (g)	59.714	60.885	57.858	59.028	55.393	59.378	57.654	54.353	55.459	51.944	58.059	55.496
Mass of Water (g)	16.277	15.747	17.677	18.522	19.793	19.431	21.009	20.554	19.879	24.715	26.221	24.91
Water Content (%)	27.26	25.86	30.55	31.38	35.73	32.72	36.44	37.82	35.84	47.58	45.16	44.89
Average Water Content (%)	26.56		30.97		34.23		37.13		41.71		45.02	
Dry Density (kg/m3)	1184.363		1201.152		1219.307		1228.287		1184.813		1132.188	



Sample 2

Soil Moisture-Density Relationship Data Sheet For Sample-2 KOCHI								
Additive Content				1%Lime + 5%Marble				
Volume of Mold (cm3)	944							
Trial No.	Trial - 1		Trial - 2		Trial - 3		Trial - 4	
Wt. Soil + Mold (g)	4525		4605		4595		4575	
Wt. Mold (g)	3000		3000		3000		3000	
Wt. Soil (g)	1525		1605		1595		1575	
Wet Density (g/cm3)	1.615		1.700		1.690		1.668	
Dry Density (g/cm3)	1.204		1.245		1.203		1.150	
Water Content Sample								
Can No.	G53	A	T1C1	L3	G73	J	N4	T4C4
Can + Wet Soil (g)	93.52	91.281	80.964	88.24	105.543	91.505	105.278	104.879
Can + Dry Soil (g)	74.123	72.759	64.011	69.402	80.469	69.945	78.52	77.373
Mass of Can (g)	17.406	18.598	17.632	17.744	17.73	17.356	17.28	18.089
Mass of Dry Soil (g)	56.717	54.161	46.379	51.658	62.739	52.589	61.24	59.284
Mass of Water (g)	19.397	18.522	16.953	18.838	25.074	21.56	26.758	27.506
Water Content (%)	34.20	34.20	36.55	36.47	39.97	41.00	43.69	46.40
Average Water Content (%)	34.20		36.51		40.48		45.05	
Dry Density (kg/m3)	1203.786		1245.485		1202.735		1150.283	



1.4 Californian Bearing Ratio (CBR) Tests

Sample1

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193				
Ring factor N/div		12.14		
sample type	1 (Bachobore)	Amount of Additive in %		Natural
Blow/Layer		56/5		
PENT.(mm)		DIAL	LOAD (KN)	CBR %
0		0	0.000	
0.64		10	0.121	
1.27		12	0.146	
1.96		13	0.158	
2.54		13	0.158	1.196
3.18		14	0.170	
3.81		14	0.170	
4.45		15	0.182	
5.08		19	0.231	1.1533
7.62			0	
10.6			0	
12.7				

Sample2

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193 1 point				
Ring factor N/div		12.14		
sample	1 (kochi)	Amount of Additive in %		0% or Natural
Blow/Layer		56/5		
PENT.(mm)		DIAL	LOAD (KN)	CBR %
0		0	0.000	
0.64		8	0.097	
1.27		9	0.109	
1.96		10	0.121	
2.54		10	0.121	0.920
3.18		11	0.134	
3.81		12	0.146	
4.45		12	0.146	
5.08		13	0.158	0.7891
7.62		14	0.170	
10.6		15	0.182	
12.7		15	0.182	

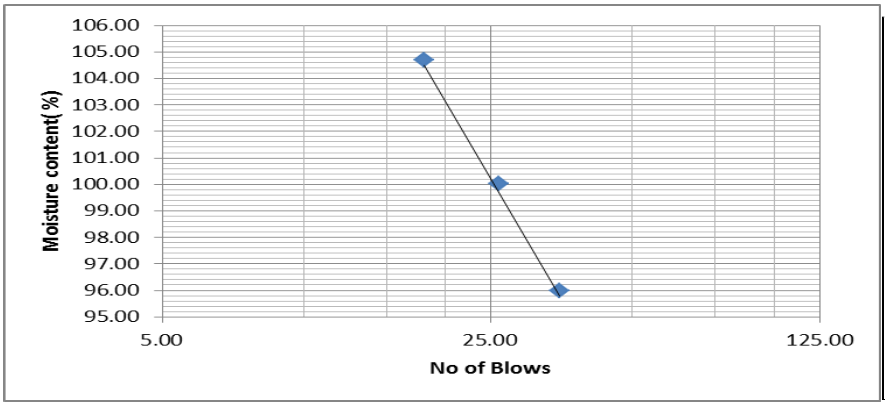
APPENDIX 2

SUMMARY OF TEST RESULTS OF STABILIZED SOILS

2.1 Atterberg Limits

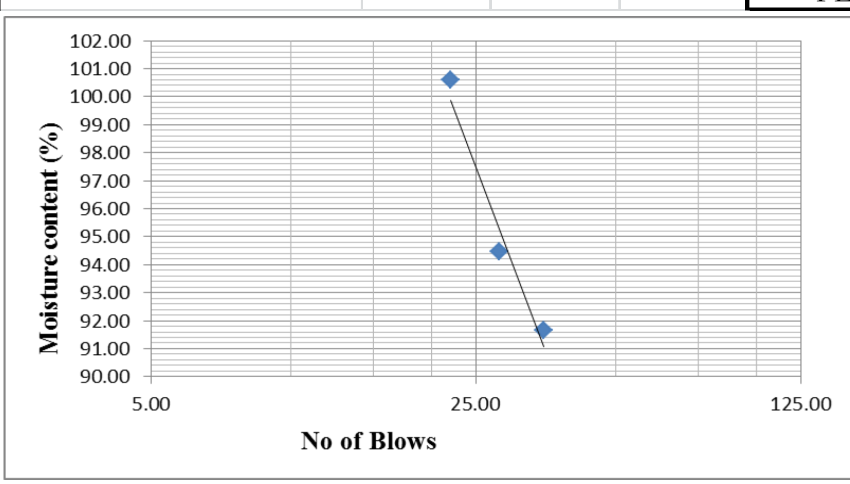
Sample 1

Bacho Bore 1% lime+ Marble 5%					
Liqued limit				Plastic limits	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	35.00	26.00	18.00		
CAN CODE	HC42	HC13	B3	B	C2
MASS OF CAN	17.42	18.18	17.28	5.48	5.26
MASS OF CAN +WET SOIL	40.69	46.30	40.04	10.65	13.03
MASS OF CAN+DRY SOIL	29.29	32.24	28.40	9.27	10.79
MASS OF WATER	11.40	14.07	11.64	1.38	2.25
MASS OF DRY SOIL	11.87	14.06	11.12	3.80	5.53
MOISTURE CONTENT(%)	95.97	100.01	104.69	36.37	40.61
				PL=38.49	



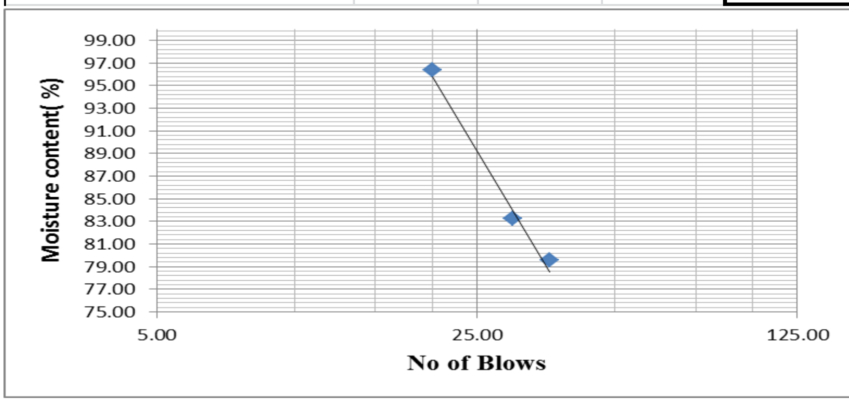
plastic index		
LL	PL	PI
101.20	38.49	62.71

Bacho Bore 1% lime+ Marble 10%					
Liqued limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	35.00	28.00	22.00		
CAN CODE	1A	X	A	i	3.00
MASS OF CAN	17.64	16.95	18.60	6.05	6.28
MASS OF CAN +WET SOIL	37.55	41.77	44.96	15.51	15.49
MASS OF CAN+DRY SOIL	28.03	29.71	31.74	12.81	12.77
MASS OF WATER	9.52	12.05	13.22	2.70	2.72
MASS OF DRY SOIL	10.39	12.76	13.14	6.76	6.49
MOISTURE CONTENT(%)	91.67	94.48	100.60	39.88	41.94
				PL= 40.91	



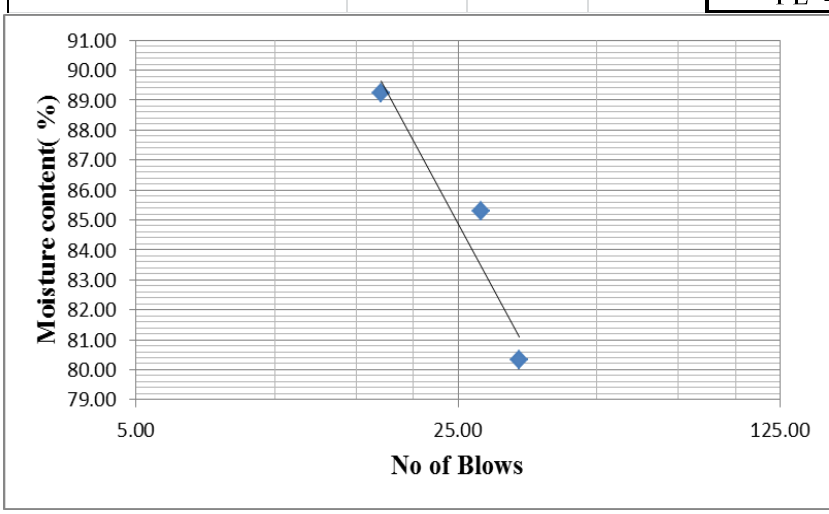
plastic index		
LL	PL	PI
97.60	40.91	56.69

Bacho Bore 1% lime+ Marble 15%					
Liqued limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	36.00	30.00	20.00		
CAN CODE	3.00	t5C1	B	II	1.00
MASS OF CAN	17.05	17.86	18.12	5.78	6.72
MASS OF CAN +WET SOIL	36.27	39.02	38.79	10.54	11.02
MASS OF CAN+DRY SOIL	27.75	29.40	28.64	9.13	9.78
MASS OF WATER	8.52	9.61	10.15	1.41	1.25
MASS OF DRY SOIL	10.70	11.54	10.52	3.35	3.06
MOISTURE CONTENT(%)	79.61	83.28	96.41	42.17	40.71
				PL= 41.44	



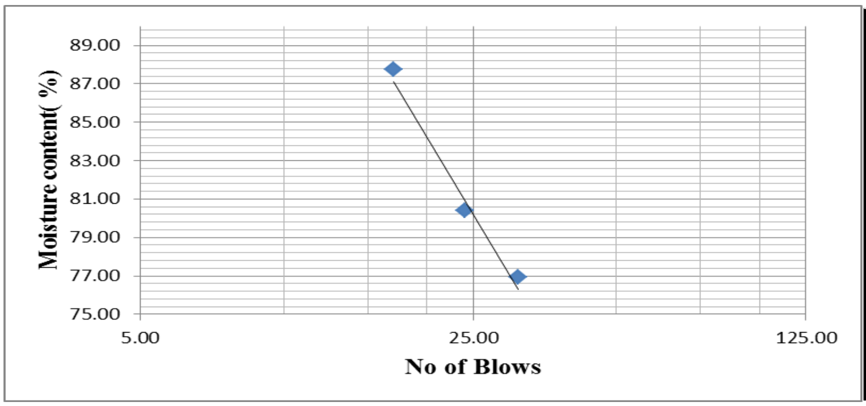
plastic index		
PI	47.86
PL	41.44
LL	89.30

Bacho Bore 1% lime+ Marble 20%					
Liqued limit				Platic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	34	28	17		
CAN CODE	ATR-1-2	H-2-3	G-53	II	PL1
MASS OF CAN	17.45	17.57	17.55	5.83	6.54
MASS OF CAN +WET SOIL	40.21	44.96	46.24	12.44	15.39
MASS OF CAN+DRY SOIL	30.07	32.35	32.71	10.55	12.77
MASS OF WATER	10.14	12.61	13.53	1.89	2.62
MASS OF DRY SOIL	12.62	14.78	15.16	4.72	6.23
MOISTURE CONTENT(%)	80.34	85.29	89.22	40.02	42.04
				PL=41.03	



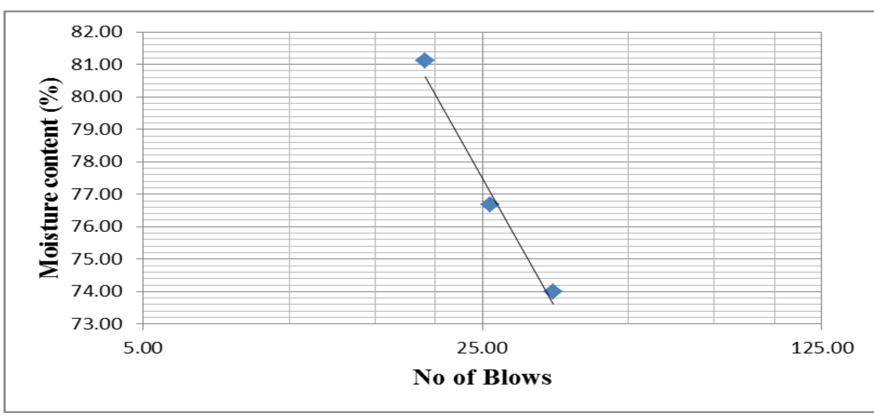
PI	43.77
PL	41.03
LL	84.80

Bacho Bore 1% lime+ Marble 25%					
Liqued limit				**Plastic limit**	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	31	24	17		
CAN CODE	Hc23	Hc51	SS	M	N
MASS OF CAN	19.12	17.59	17.64	6.18	6.29
MASS OF CAN +WET SOIL	42.19	41.42	40.12	12.54	11.69
MASS OF CAN+DRY SOIL	32.16	30.80	29.62	10.69	10.02
MASS OF WATER	10.03	10.62	10.51	1.85	1.67
MASS OF DRY SOIL	13.04	13.21	11.97	4.51	3.74
MOISTURE CONTENT(%)	76.94	80.40	87.75	41.01	44.61
				PL=42.81	



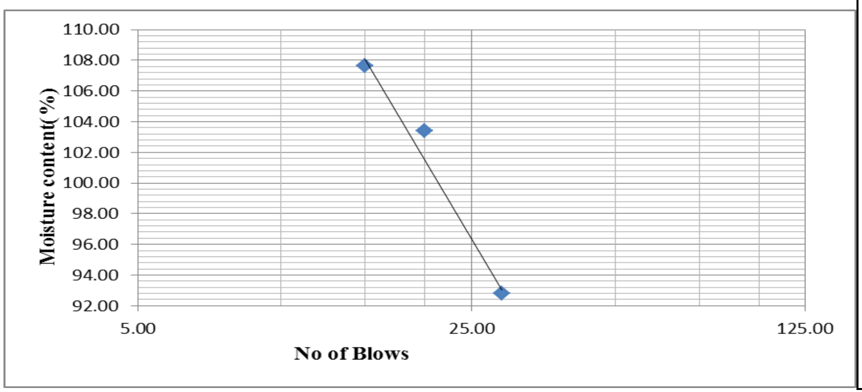
PI	37.69
PL	42.81
LL	80.50

Bacho Bore 1% lime+ Marble 30%					
Liqued limit				**Plastic limit**	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	35	26	19		
CAN CODE	T4C2	T2C2	T5C2	K	2.00
MASS OF CAN	18.09	17.38	19.99	5.79	5.60
MASS OF CAN +WET SOIL	42.79	41.72	42.32	14.90	16.51
MASS OF CAN+DRY SOIL	32.29	31.16	32.32	12.19	13.20
MASS OF WATER	10.50	10.56	10.00	2.70	3.31
MASS OF DRY SOIL	14.20	13.77	12.33	6.41	7.60
MOISTURE CONTENT(%)	73.99	76.69	81.12	42.18	43.57
				PL=42.87	



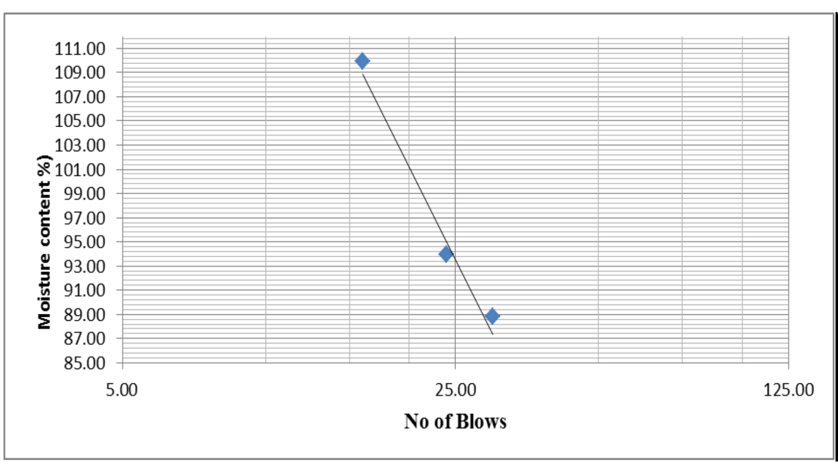
PI	34.63
PL	42.87
LL	77.50

Bacho Bore 2% lime+ Marble 5%					
Liqued limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	29	20	15		
CAN CODE	C2	T5C1	B	2.00	K
MASS OF CAN	17.53	17.84	18.11	5.60	5.79
MASS OF CAN +WET SOIL	38.51	41.40	49.00	10.01	10.58
MASS OF CAN+DRY SOIL	28.41	29.42	32.99	8.72	9.20
MASS OF WATER	10.10	11.98	16.02	1.30	1.38
MASS OF DRY SOIL	10.88	11.58	14.88	3.12	3.40
MOISTURE CONTENT(%)	92.80	103.38	107.64	41.51	40.52
				PL=41.01	



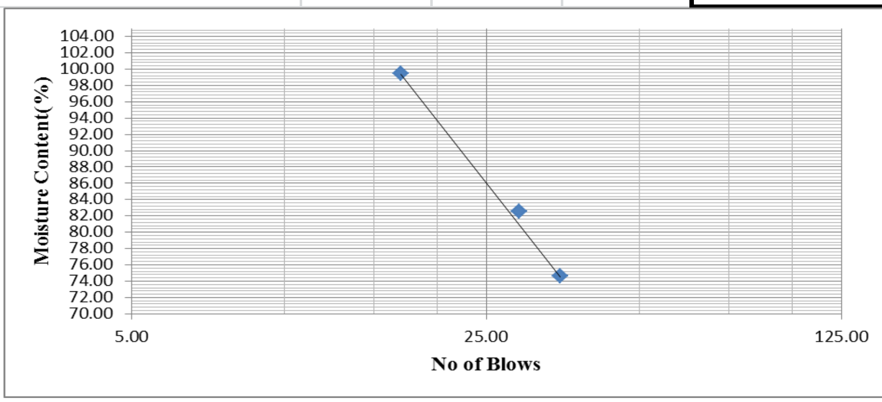
plastic index		
PI	PL	LL
55.49	41.01	96.50

Bacho Bore 2% lime+ Marble 10%					
Liqued limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	30	24	16		
CAN CODE	T11	3.00	H-2-3	C-2	III
MASS OF CAN	17.34	17.04	17.57	6.19	6.66
MASS OF CAN +WET SOIL	47.51	38.87	39.88	10.26	14.86
MASS OF CAN+DRY SOIL	33.32	28.30	28.20	9.06	12.42
MASS OF WATER	14.19	10.58	11.68	1.20	2.44
MASS OF DRY SOIL	15.98	11.26	10.63	2.87	5.76
MOISTURE CONTENT(%)	88.78	93.96	109.94	41.76	42.44
				PL=42.10	

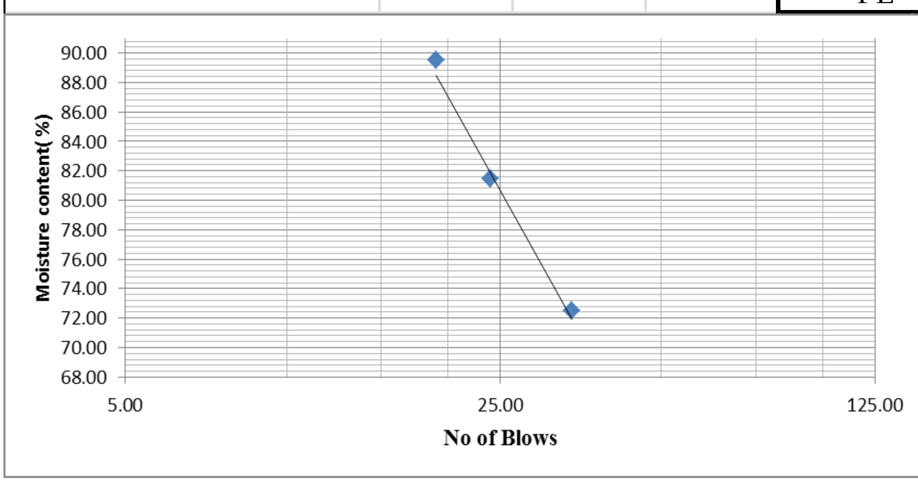


plastic index		
PI	PL	LL
51.20	42.10	93.30

Bacho Bore 2% lime+ Marble 15%					
Liqued limit				Plastic limits	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	35	29	17		
CAN CODE	X	I	Nc11	13	N3
MASS OF CAN	16.96	18.48	18.82	6.38	5.56
MASS OF CAN +WET SOIL	36.03	38.70	41.30	13.10	12.72
MASS OF CAN+DRY SOIL	27.88	29.55	30.09	11.05	10.60
MASS OF WATER	8.15	9.14	11.21	2.05	2.12
MASS OF DRY SOIL	10.92	11.08	11.27	4.67	5.04
MOISTURE CONTENT(%)	74.65	82.54	99.46	43.85	42.05
				PL=42.95	

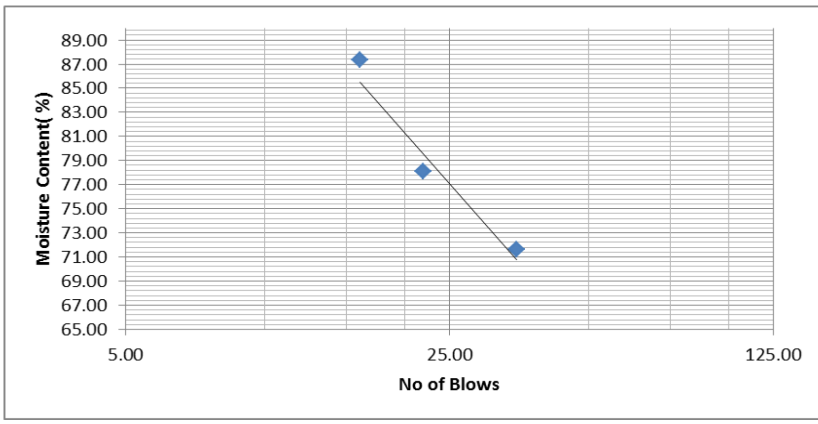


Bacho Bore 2% lime+ Marble 20%					
Liqued limit				Plastic limits	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	34	24	19		
CAN CODE	II	B-3	J	3	T6
MASS OF CAN	17.99	17.28	17.40	6.27	6.11
MASS OF CAN +WET SOIL	34.37	40.32	36.39	11.60	12.18
MASS OF CAN+DRY SOIL	27.49	29.98	27.42	10.01	10.33
MASS OF WATER	6.88	10.34	8.97	1.59	1.85
MASS OF DRY SOIL	9.50	12.70	10.02	3.74	4.22
MOISTURE CONTENT(%)	72.48	81.43	89.50	42.50	43.91
				PL=43.20	



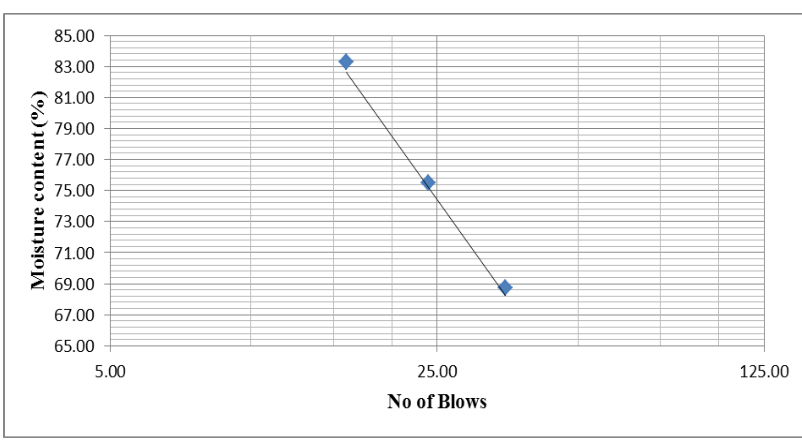
plastic index		
LL	PL	PI
80.60	42.30	38.30

Bacho Bore 2% lime+ Marble 25%					
Liqued limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	35	22	16		
CAN CODE	T1C1	NC-22	W-1	A	6.00
MASS OF CAN	17.54	17.62	17.99	6.29	5.26
MASS OF CAN +WET SOIL	44.05	40.49	37.31	12.44	11.50
MASS OF CAN+DRY SOIL	32.98	30.46	28.30	10.65	9.64
MASS OF WATER	11.06	10.03	9.01	1.79	1.87
MASS OF DRY SOIL	15.45	12.84	10.32	4.36	4.38
MOISTURE CONTENT(%)	71.63	78.12	87.32	41.16	42.65
				PL= 41.91	



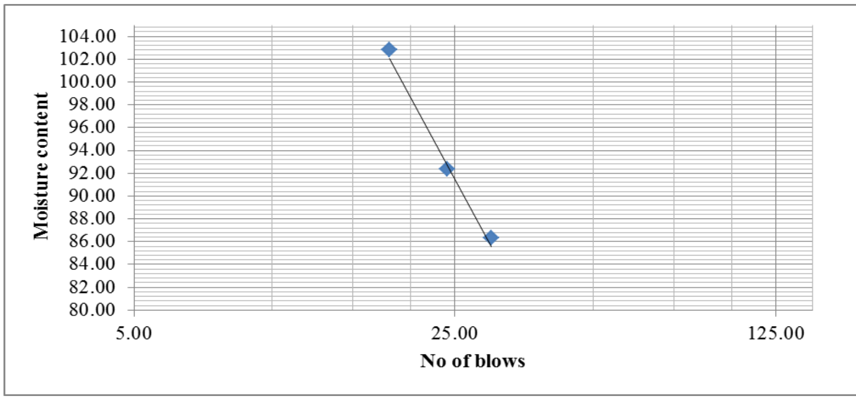
plastic index		
LL	PL	PI
77.00	42.91	34.09

Bacho Bore 2% lime+ Marble 30%					
Liqued limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	35	24	16		
CAN CODE	G53	NC63	T2C2	N2	4.00
MASS OF CAN	17.48	17.35	18.92	6.17	6.44
MASS OF CAN +WET SOIL	41.09	37.97	39.01	12.25	15.39
MASS OF CAN+DRY SOIL	31.47	29.10	29.88	10.40	12.70
MASS OF WATER	9.62	8.87	9.13	1.85	2.69
MASS OF DRY SOIL	13.99	11.75	10.97	4.23	6.26
MOISTURE CONTENT(%)	68.72	75.49	83.26	43.72	42.98
				PL= 43.35	



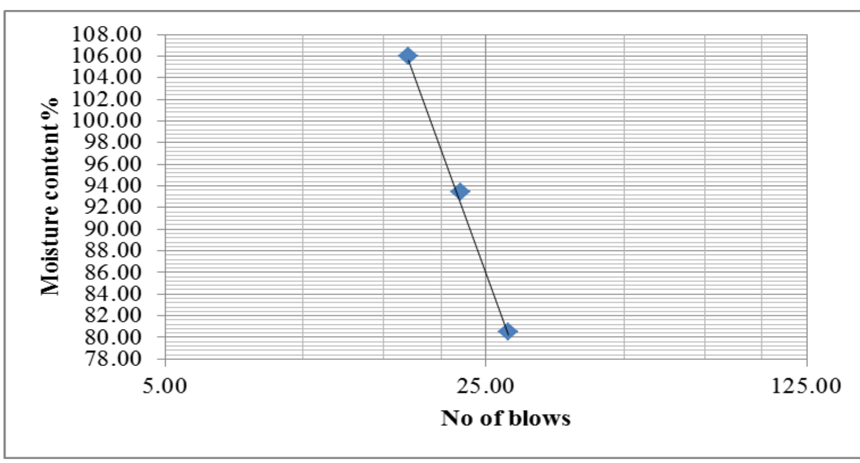
plastic index		
LL	PL	PI
73.60	43.35	30.25

Bacho Bore 3% lime+ Marble 5%					
Liquid limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	30	24	18		
CAN CODE	Nc22	G53	Nc63	L3	D2
MASS OF CAN	17.61	17.54	17.35	6.42	5.48
MASS OF CAN +WET SOIL	47.45	41.66	40.35	14.12	11.67
MASS OF CAN+DRY SOIL	33.63	30.08	28.69	11.82	9.83
MASS OF WATER	13.82	11.58	11.66	2.31	1.84
MASS OF DRY SOIL	16.02	12.54	11.35	5.40	4.35
MOISTURE CONTENT(%)	86.30	92.33	102.81	42.71	42.27
				PL = 42.49	



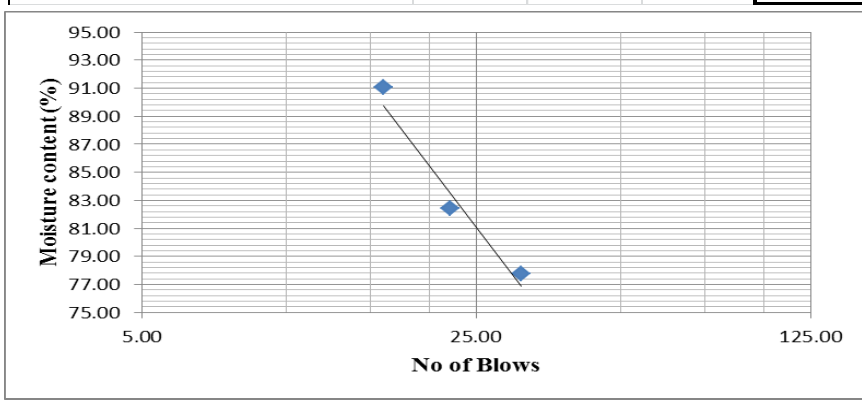
plastic index		
	LL	91.20
	PL	42.90
	PI	48.30

Bacho Bore 3% lime+ Marble 10%					
Liquid limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	28	22	17		
CAN CODE	A	T5c1	NC4	B2	III
MASS OF CAN	18.60	17.86	18.12	6.29	5.78
MASS OF CAN +WET SOIL	40.64	37.66	35.55	15.29	13.50
MASS OF CAN+DRY SOIL	30.81	28.09	26.58	12.57	11.18
MASS OF WATER	9.83	9.56	8.96	2.73	2.32
MASS OF DRY SOIL	12.21	10.23	8.46	6.28	5.40
MOISTURE CONTENT(%)	80.53	93.45	105.96	43.43	42.94
				PL=43.18	



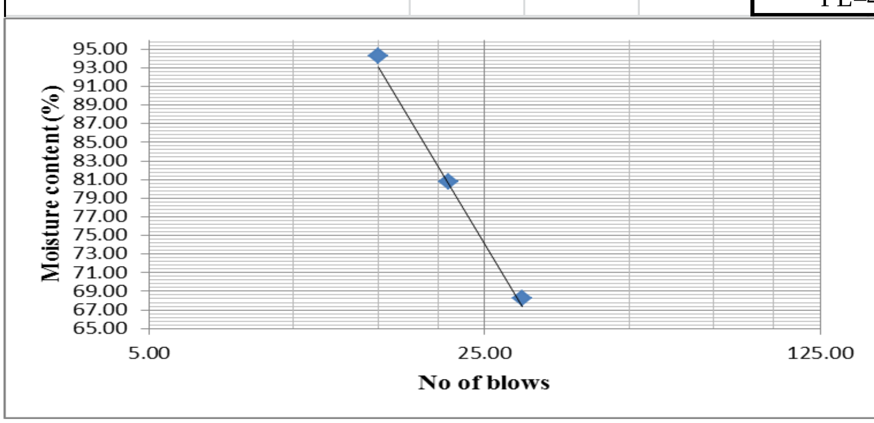
plastic index		
	LL	85.80
	PL	43.18
	PI	42.62

Bacho Bore 3% lime+ Marble 15%					
Liquid limit				**Plastic limit**	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	31	22	16		
CAN CODE	N4	St.25	Lc42	T6	J
MASS OF CAN	17.48	18.81	17.67	6.21	6.05
MASS OF CAN +WET SOIL	34.21	35.82	40.98	12.18	12.81
MASS OF CAN+DRY SOIL	26.89	28.14	29.87	10.38	10.79
MASS OF WATER	7.32	7.69	11.11	1.80	2.02
MASS OF DRY SOIL	9.41	9.32	12.20	4.17	4.75
MOISTURE CONTENT(%)	77.75	82.45	91.05	43.29	42.52
				PL =42.91	



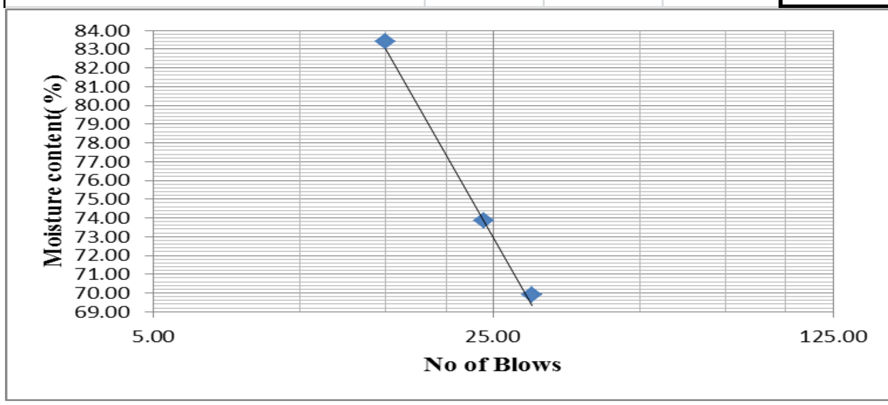
plastic index		
PI	38.09	
PL	42.91	
LL	81.00	

Bacho Bore 3% lime+ Marble 20%					
Liquid limit				**Plastic limit**	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	30	21	15		
CAN CODE	N4	St.25	Lc42	N2	C2
MASS OF CAN	17.06	18.50	17.17	6.17	6.18
MASS OF CAN +WET SOIL	36.39	35.29	38.60	14.95	13.14
MASS OF CAN+DRY SOIL	28.55	27.79	28.20	12.35	11.02
MASS OF WATER	7.84	7.51	10.40	2.61	2.12
MASS OF DRY SOIL	11.49	9.29	11.03	6.17	4.84
MOISTURE CONTENT(%)	68.20	80.78	94.31	42.22	43.83
				PL=43.03	



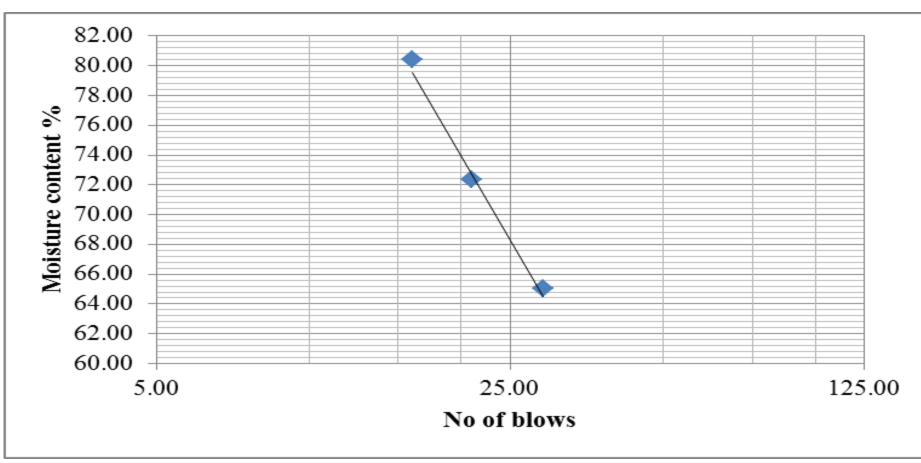
plastic index		
PI	31.17	
PL	43.03	
LL	74.20	

Bacho Bore 3% lime+ Marble 25%					
Liquid limit				**Plastic limit**	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	30	24	15		
CAN CODE	H23	T4c2	H53	2.00	K
MASS OF CAN	19.13	18.09	17.58	5.63	5.79
MASS OF CAN +WET SOIL	44.79	36.87	40.56	12.82	14.20
MASS OF CAN+DRY SOIL	34.23	28.89	30.11	10.66	11.67
MASS OF WATER	10.56	7.97	10.45	2.16	2.53
MASS OF DRY SOIL	15.10	10.80	12.53	5.04	5.88
MOISTURE CONTENT(%)	69.90	73.84	83.41	42.91	42.98
				42.94	



plastic index		
	PI	29.86
	PL	42.94
	LL	72.80

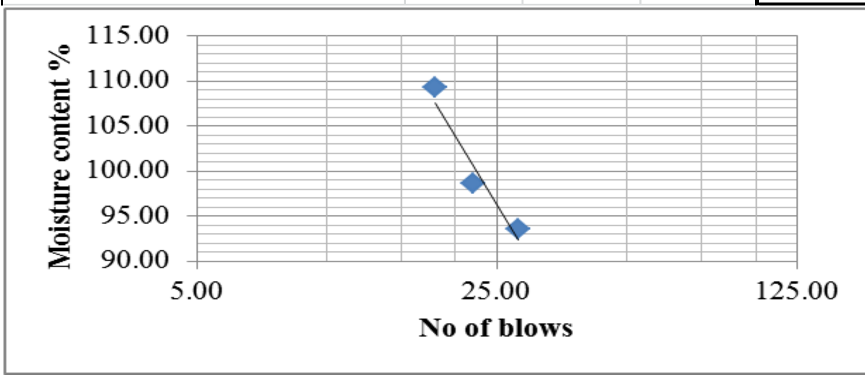
Bacho Bore 3% lime+ Marble 30%					
Liquid limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	29	21	16		
CAN CODE	X	Nc11	I	II	M
MASS OF CAN	16.96	18.82	18.48	5.84	6.18
MASS OF CAN +WET SOIL	38.35	38.92	38.48	13.18	13.77
MASS OF CAN+DRY SOIL	29.92	30.48	29.56	11.00	11.52
MASS OF WATER	8.43	8.44	8.92	2.17	2.25
MASS OF DRY SOIL	12.96	11.66	11.08	5.16	5.34
MOISTURE CONTENT(%)	65.03	72.35	80.44	42.11	42.07
				PL= 42.09	



plastic index		
	PI	26.11
	PL	42.09
	LL	68.20

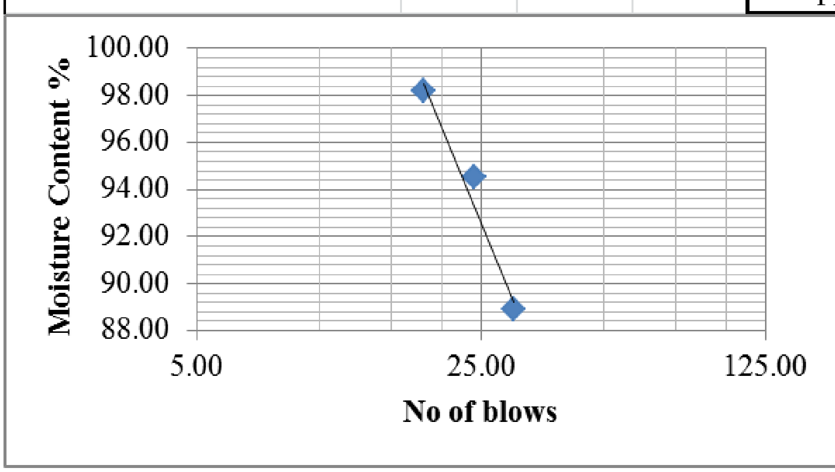
Sample 2

kochi 1% lime and 5% marble					
Liquid limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	28	22	18		
CAN CODE	Nc42	D	H23	D2	M
MASS OF CAN	17.15	18.48	17.57	5.48	6.18
MASS OF CAN +WET SOIL	35.31	40.45	38.16	13.68	13.72
MASS OF CAN+DRY SOIL	26.53	29.54	27.40	11.42	11.56
MASS OF WATER	8.77	10.91	10.76	2.26	2.16
MASS OF DRY SOIL	9.38	11.06	9.83	5.94	5.38
MOISTURE CONTENT(%)	93.57	98.60	109.38	37.96	40.09
				PL=39.02	



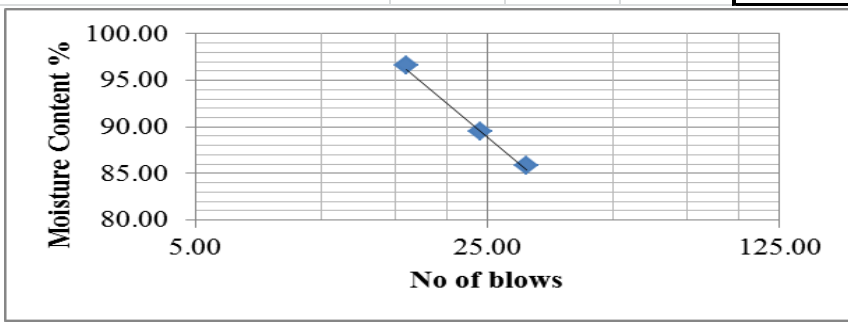
Plastic index		
PI	57.98	
PL	39.02	
LL	97.00	

kochi 1% lime and 10% marble					
Liquid limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	30	24	18		
CAN CODE	Hc12	Nc11	T5c1	II	L3
MASS OF CAN	18.09	18.81	17.84	5.83	6.41
MASS OF CAN +WET SOIL	36.13	41.07	41.18	15.57	15.61
MASS OF CAN+DRY SOIL	27.64	30.26	29.61	12.79	13.02
MASS OF WATER	8.49	10.82	11.56	2.77	2.59
MASS OF DRY SOIL	9.55	11.45	11.77	6.96	6.61
MOISTURE CONTENT(%)	88.90	94.50	98.19	39.84	39.16
				PL=39.50	



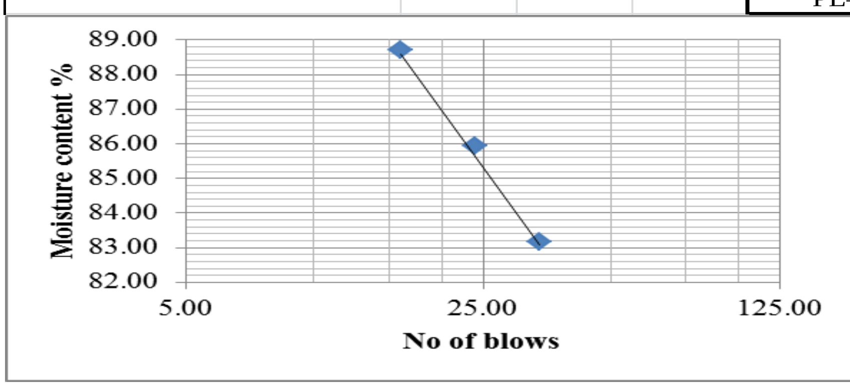
Plastic index	
PI	53.00
PL	39.50
LL	92.50

kochi 1% lime and 15% marble					
Liquid limit				**Plastic limit**	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	31	24	16		
CAN CODE	N1	Hc23	N3	N2	T6
MASS OF CAN	17.63	19.12	17.04	6.17	6.21
MASS OF CAN +WET SOIL	41.88	40.18	39.82	12.77	11.71
MASS OF CAN+DRY SOIL	30.68	30.23	28.63	10.89	10.11
MASS OF WATER	11.20	9.95	11.19	1.89	1.60
MASS OF DRY SOIL	13.05	11.11	11.59	4.72	3.90
MOISTURE CONTENT(%)	85.82	89.54	96.59	40.02	41.13
				PL= 40.58	



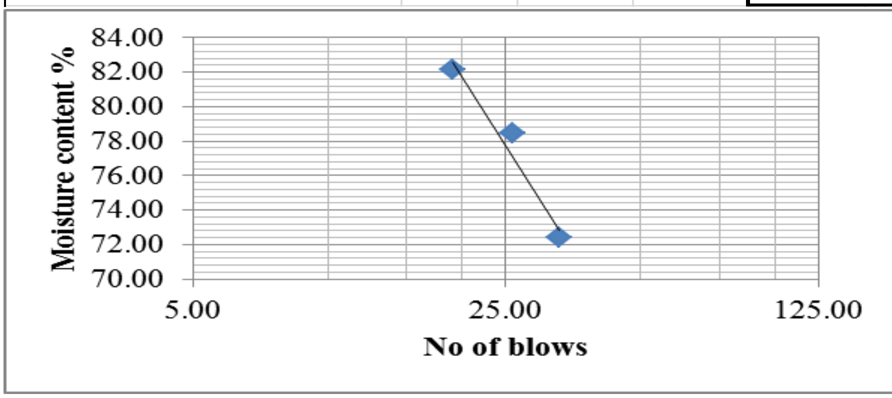
PI	50.50
PL	38.50
LL	89.00

kochi 1% lime and 20% marble					
Liquid limit				**Plastic limit**	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	34	24	16		
CAN CODE	St.25	I	3.00	4.00	EE
MASS OF CAN	18.93	18.46	17.05	6.44	5.90
MASS OF CAN +WET SOIL	40.99	39.14	40.03	15.54	14.46
MASS OF CAN+DRY SOIL	30.97	29.58	29.23	13.00	11.91
MASS OF WATER	10.02	9.56	10.80	2.54	2.55
MASS OF DRY SOIL	12.05	11.12	12.18	6.57	6.01
MOISTURE CONTENT(%)	83.17	85.95	88.71	38.64	42.48
				PL= 40.56	



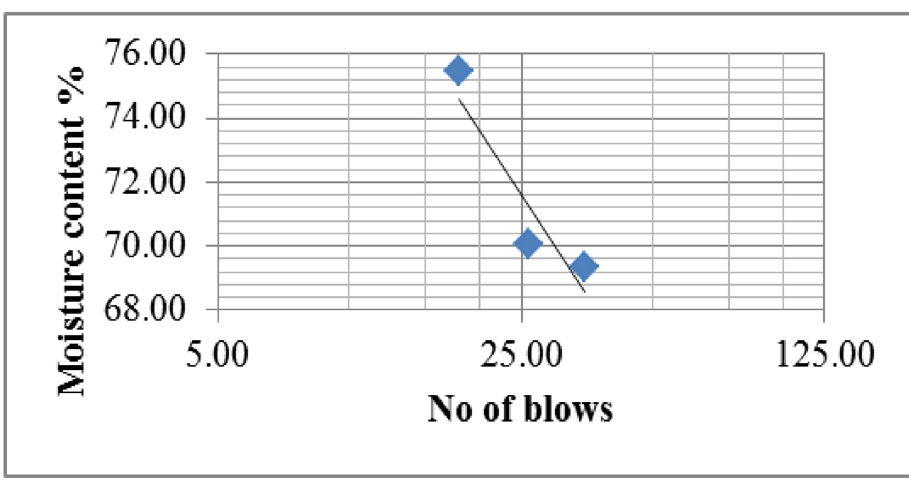
PI	44.64
PL	40.56
LL	85.20

kochi 1% lime and 25% marble					
Liquid limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	33	26	18		
CAN CODE	A	D33	X	3.00	N3
MASS OF CAN	18.59	17.46	16.94	4.27	5.55
MASS OF CAN +WET SOIL	41.93	46.20	41.66	14.84	14.33
MASS OF CAN+DRY SOIL	32.13	33.57	30.51	11.80	11.72
MASS OF WATER	9.81	12.63	11.15	3.03	2.61
MASS OF DRY SOIL	13.54	16.10	13.57	7.53	6.16
MOISTURE CONTENT(%)	72.43	78.46	82.16	40.24	42.37
				PL= 41.3	



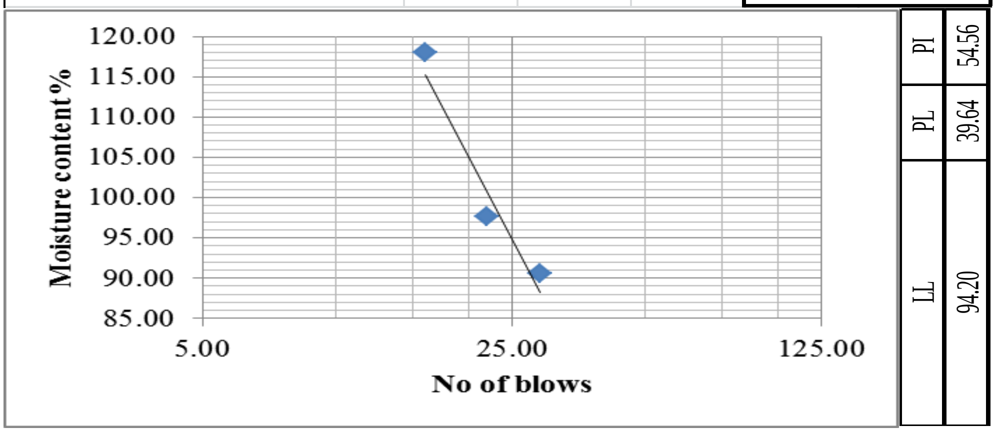
PI	36.50
PL	41.30
LL	77.80

kochi 1% lime and 30% marble					
Liquid limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	35	26	18		
CAN CODE	G53	Nc63	C2	6.00	PL1
MASS OF CAN	17.41	17.34	17.53	5.26	6.53
MASS OF CAN +WET SOIL	46.24	46.13	40.41	13.22	14.13
MASS OF CAN+DRY SOIL	34.43	34.27	30.57	10.82	11.94
MASS OF WATER	11.80	11.86	9.84	2.40	2.19
MASS OF DRY SOIL	17.02	16.93	13.04	5.57	5.40
MOISTURE CONTENT(%)	69.33	70.07	75.44	43.09	40.61
				PL= 41.85	

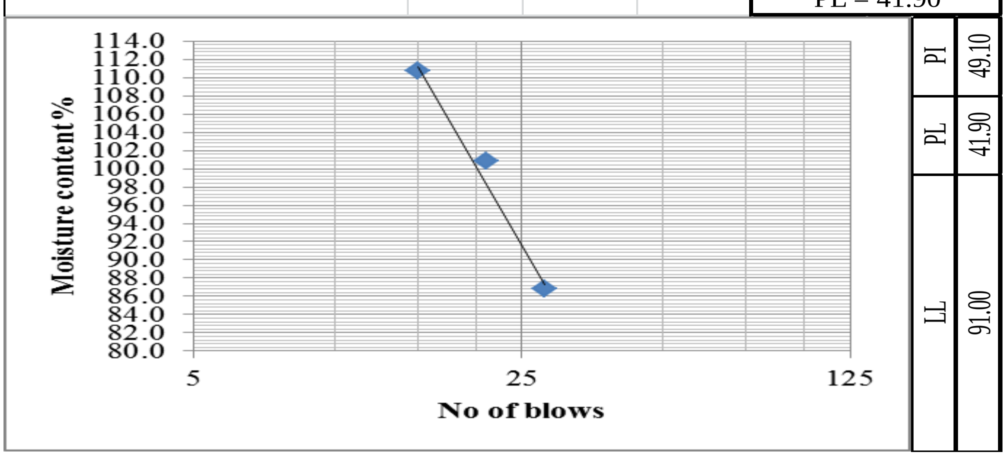


PI	29.75
PL	41.85
LL	71.60

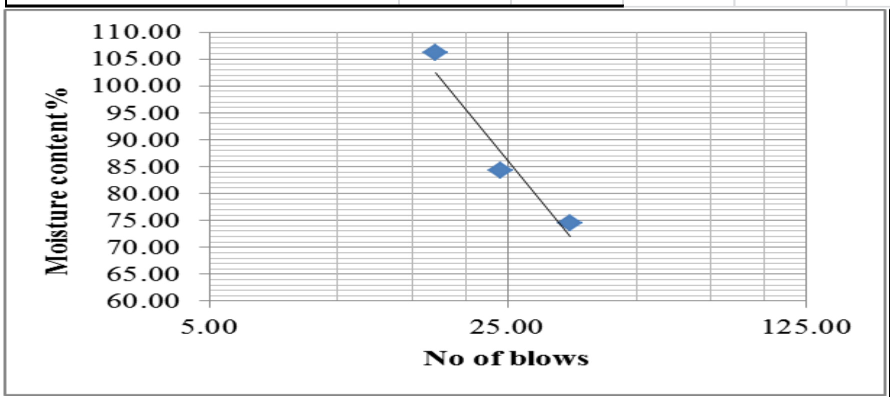
kochi 2% lime and 5% marble					
	Liquid limit			Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	29	22	16		
CAN CODE	St.47	B	St.25	III	2.00
MASS OF CAN	17.07	18.09	17.56	6.67	5.63
MASS OF CAN +WET SOIL	35.67	38.44	54.34	15.53	14.11
MASS OF CAN+DRY SOIL	26.83	28.39	34.44	13.01	11.71
MASS OF WATER	8.84	10.05	19.91	2.52	2.41
MASS OF DRY SOIL	9.76	10.30	16.88	6.34	6.08
MOISTURE CONTENT(%)	90.65	97.63	117.96	39.70	39.58
				PL=39.64	



kochi 2% lime and 10% marble					
	Liquid limit			Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	30	26	19		
CAN CODE	T1c2	1B	HcS2	G2	III
MASS OF CAN	17.62	17.22	17.24	6.19	5.78
MASS OF CAN +WET SOIL	33.76	36.18	41.21	11.33	12.28
MASS OF CAN+DRY SOIL	26.26	26.66	28.61	9.80	10.37
MASS OF WATER	7.50	9.52	12.60	1.53	1.91
MASS OF DRY SOIL	8.63	9.44	11.37	3.61	4.59
MOISTURE CONTENT(%)	86.88	100.88	110.76	42.29	41.51
				PL = 41.90	

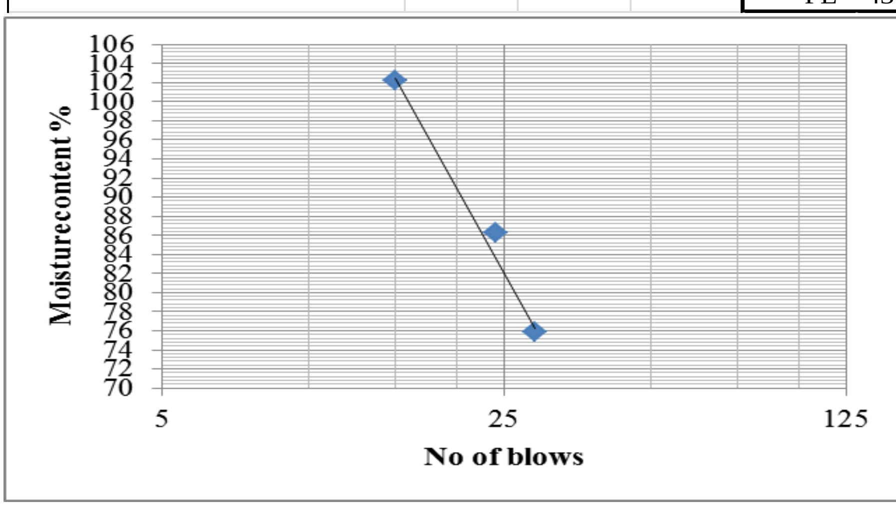


kochi 2% lime and 15% marble					
Liquid limit				**Plastic limit**	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	35	24	17		
CAN CODE	I	1A	D2	L3	K
MASS OF CAN	18.46	17.62	18.83	6.41	5.79
MASS OF CAN +WET SOIL	43.12	39.07	40.83	12.05	12.43
MASS OF CAN+DRY SOIL	32.59	29.26	29.49	10.38	10.50
MASS OF WATER	10.53	9.82	11.33	1.67	1.93
MASS OF DRY SOIL	14.13	11.64	10.67	3.97	4.71
MOISTURE CONTENT(%)	74.47	84.36	106.22	42.05	40.98
				Pl = 41.52	



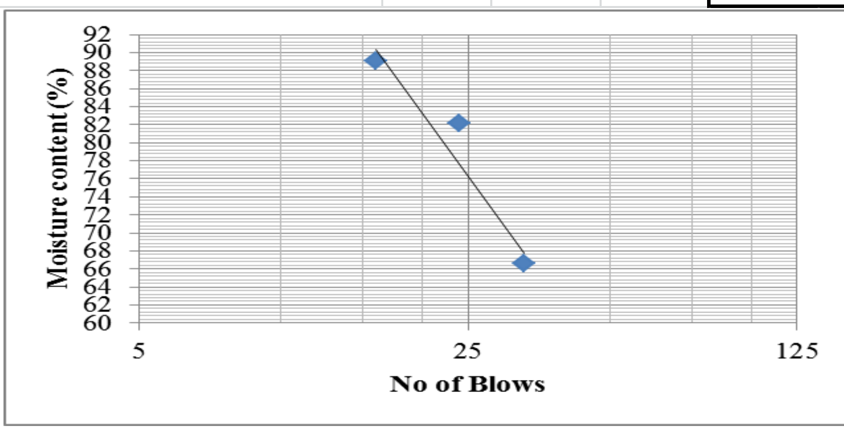
PI	43.48
PL	41.52
LL	85.00

kochi 2% lime and 20% marble					
Liquid limit				**Plastic limit**	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	30	24	15		
CAN CODE	T4C2	T1C1	HC23	EE	N3
MASS OF CAN	18.11	17.68	19.13	5.90	5.55
MASS OF CAN +WET SOIL	38.06	33.15	37.78	12.57	11.45
MASS OF CAN+DRY SOIL	29.46	25.98	28.36	10.52	9.70
MASS OF WATER	8.60	7.17	9.43	2.06	1.75
MASS OF DRY SOIL	11.34	8.31	9.23	4.61	4.15
MOISTURE CONTENT(%)	75.82	86.30	102.17	44.57	42.18
				PL = 43.37	



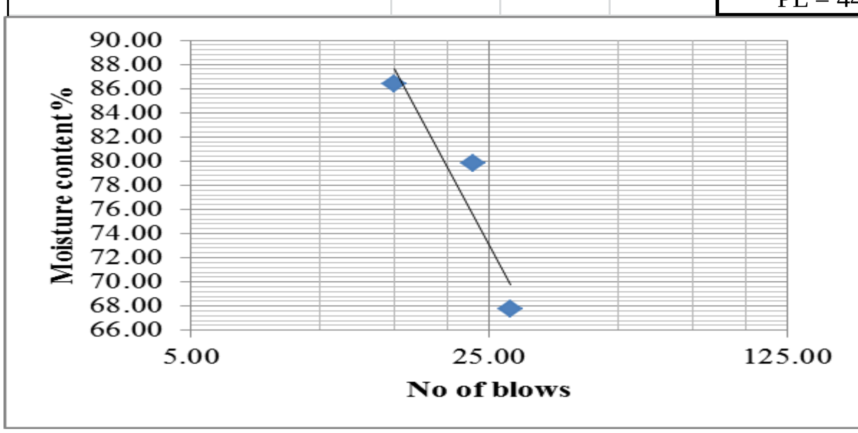
PI	38.63
PL	43.37
LL	82.00

kochi 2% lime and 25% marble					
Liquid limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	33	26	16		
CAN CODE	X	2_2	C8	4	A
MASS OF CAN	16.94	17.38	17.68	6.44	6.29
MASS OF CAN +WET SOIL	38.46	34.58	43.90	14.41	14.88
MASS OF CAN+DRY SOIL	29.86	26.82	31.55	11.94	12.14
MASS OF WATER	8.60	7.76	12.35	2.47	2.75
MASS OF DRY SOIL	12.92	9.44	13.87	5.50	5.85
MOISTURE CONTENT(%)	66.56	82.17	89.08	44.90	46.92
				PL =45.91	



PI	30.09
PL	45.91
LL	76.00

kochi 2% lime and 30% marble					
Liquid limit				Plastic limit	
TRIAL	1	2	3	1	2
NO:- OF BLOWS	28	23	15		
CAN CODE	T1	HC31	LC31	J	PL1
MASS OF CAN	17.50	17.97	17.41	6.61	6.54
MASS OF CAN +WET SOIL	34.75	43.87	36.49	14.06	14.41
MASS OF CAN+DRY SOIL	27.78	32.38	27.65	11.74	12.00
MASS OF WATER	6.97	11.50	8.85	2.32	2.41
MASS OF DRY SOIL	10.28	14.40	10.24	5.13	5.47
MOISTURE CONTENT(%)	67.77	79.80	86.43	45.15	44.04
				PL = 44.60	

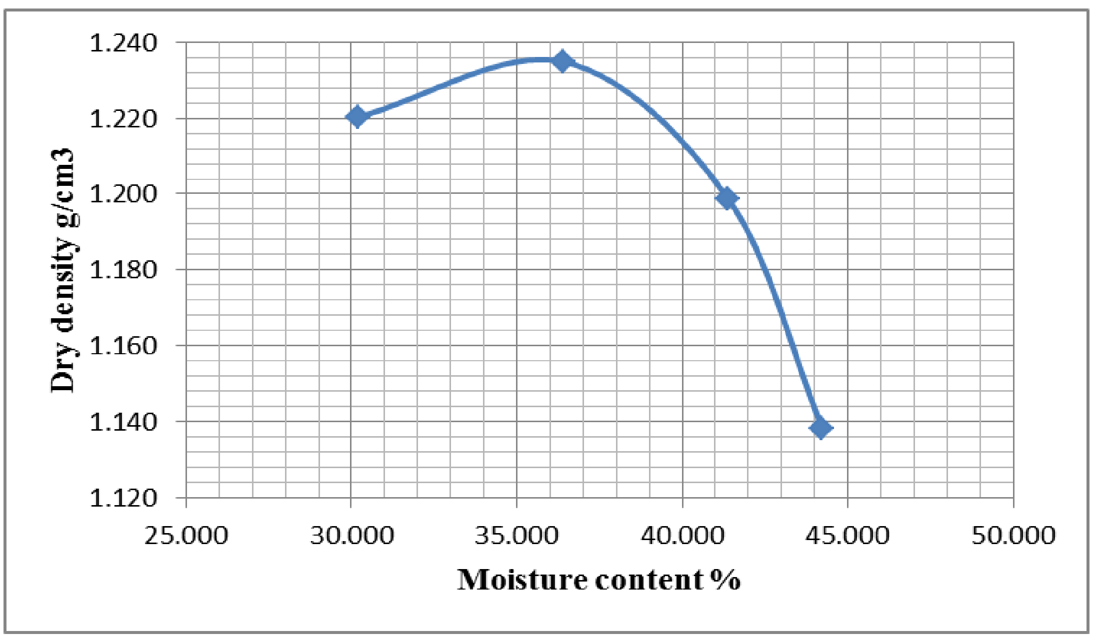


PI	28.40
PL	44.60
LL	73.00

2.2 Moisture Density Relationship (Procter Test)

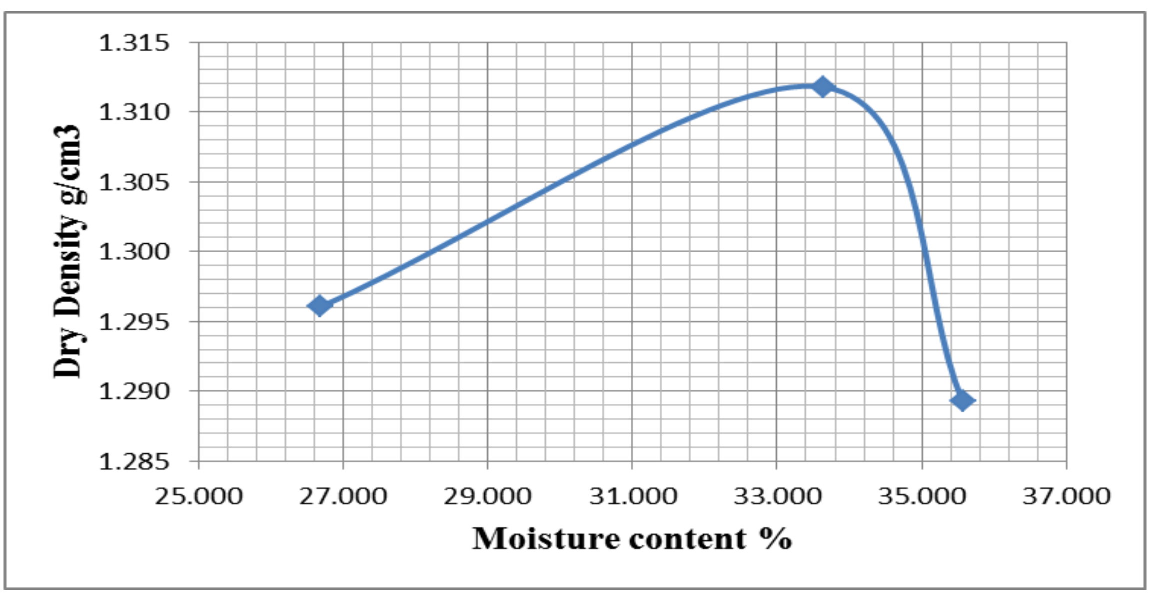
Soil Moisture-Density Relationship Data Sheet For Sample-1

Additive Content					1%Lime + 5%Marble			
Volume of Mold (cm3)			944					
Trial No.	Trial - 1		Trial - 2		Trial - 3		Trial - 4	
Wt. Soil + Mold (g)	4500		4590		4600		4550	
Wt. Mold (g)	3000		3000		3000		3000	
Wt. Soil (g)	1500		1590		1600		1550	
Wet Density (g/cm3)	1.589		1.684		1.695		1.642	
Dry Density (g/cm3)	1.220		1.235		1.199		1.138	
Water Content Sample								
Can No.	1	2	1	2	1	2	1	2
Can + Wet Soil (g)	107.2	85.05	119.45	107.79	97.53	111.84	114.97	102.98
Can + Dry Soil (g)	86.32	69.63	92.8	83.58	74.32	84.03	85.06	76.92
Mass of Can (g)	17.981	18.007	18.99	17.605	17.62	17.519	17.384	18.043
Mass of Dry Soil (g)	68.339	51.623	73.81	65.975	56.7	66.511	67.676	58.877
Mass of Water (g)	20.88	15.42	26.65	24.21	23.21	27.81	29.91	26.06
Water Content (%)	30.55	29.87	36.11	36.70	40.93	41.81	44.20	44.26
Average Water Content (%)	30.21		36.40		41.37		44.23	
Dry Density (kg/m3)	1220.305		1234.831		1198.890		1138.433	

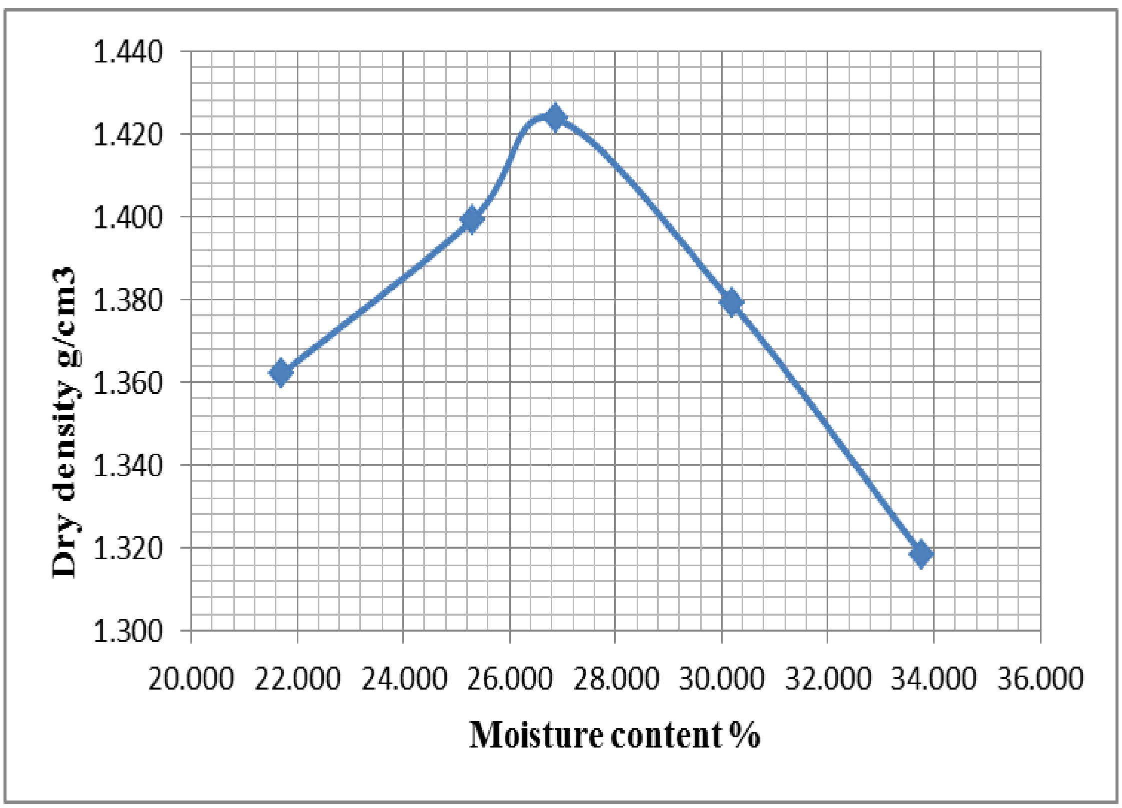


Soil Moisture-Density Relationship Data Sheet For Sample-1

Additive Content								
	1%Lime + 15%Marble							
Volume of Mold (cm3)	944							
Trial No.	Trial -1		Trial - 2		Trial - 3		Trial - 4	
Wt. Soil + Mold (g)	4550		4655		4650		4560	
Wt. Mold (g)	3000		3000		3000		3000	
Wt. Soil (g)	1550		1655		1650		1560	
Wet Density (g/cm3)	1.642		1.753		1.748		1.653	
Dry Density (g/cm3)	1.296		1.312		1.289		1.172	
Water Content Sample								
Can No.	1	2	1	2	1	2	1	2
Can + Wet Soil (g)	100.17	96.06	82.28	92.23	86.21	96.89	114.29	106.26
Can + Dry Soil (g)	83.06	79.16	65.95	73.55	68.51	75.73	86.19	80.62
Mass of Can (g)	18.04	16.7	17.66	17.76	17.7	17.45	17.67	18.043
Mass of Dry Soil (g)	65.02	62.46	48.29	55.79	50.81	58.28	68.52	62.577
Mass of Water (g)	17.11	16.9	16.33	18.68	17.7	21.16	28.1	25.64
Water Content (%)	26.31	27.06	33.82	33.48	34.84	36.31	41.01	40.97
Average Water Content (%)	26.69		33.65		35.57		40.99	
Dry Density (kg/m3)	1296.076		1311.772		1289.268		1172.085	

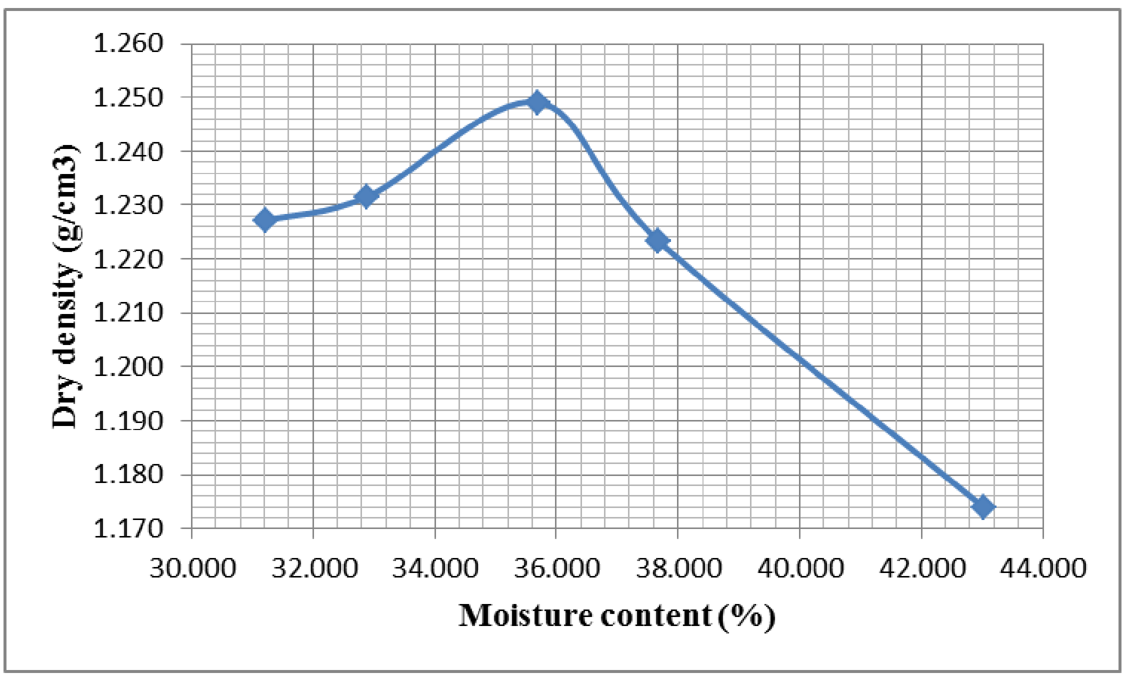


Soil Moisture-Density Relationship Data Sheet For Sample-1										
Additive Content			lime1% and marble 30%							
Volume of Mold (cm3)			944							
Trial No.	Trial -1		Trial - 2		Trial - 3		Trial - 4		Trial - 5	
Wt. Soil + Mold (g)	4560		4650		4700		4690		4660	
Wt. Mold (g)	2995		2995		2995		2995		2995	
Wt. Soil (g)	1565		1655		1705		1695		1665	
Wet Density (g/cm3)	1.658		1.753		1.806		1.796		1.764	
Dry Density (g/cm3)	1.362		1.399		1.424		1.379		1.319	
Water Content Sample										
Can No.	1	2	1	2	1	2	1	2	1	2
Can + Wet Soil (g)	98.23	92.87	99.23	101.16	103.51	89.24	110.87	114.64	97.74	104.6
Can + Dry Soil (g)	83.984	79.424	82.533	84.494	85.594	74.082	89.761	91.801	77.762	82.432
Mass of Can (g)	17.67	18.14	17.62	17.5	18.99	17.605	18.07	17.98	18.043	17.38
Mass of Dry Soil (g)	66.314	61.284	64.913	66.994	66.604	56.477	71.691	73.821	59.719	65.052
Mass of Water (g)	14.246	13.446	16.697	16.666	17.916	15.158	21.109	22.839	19.978	22.168
Water Content (%)	21.48	21.94	25.72	24.88	26.90	26.84	29.44	30.94	33.45	34.08
Average Water Content (%)	21.71		25.30		26.87		30.19		33.77	
Dry Density (kg/m3)	1362.105		1399.190		1423.626		1379.163		1318.556	



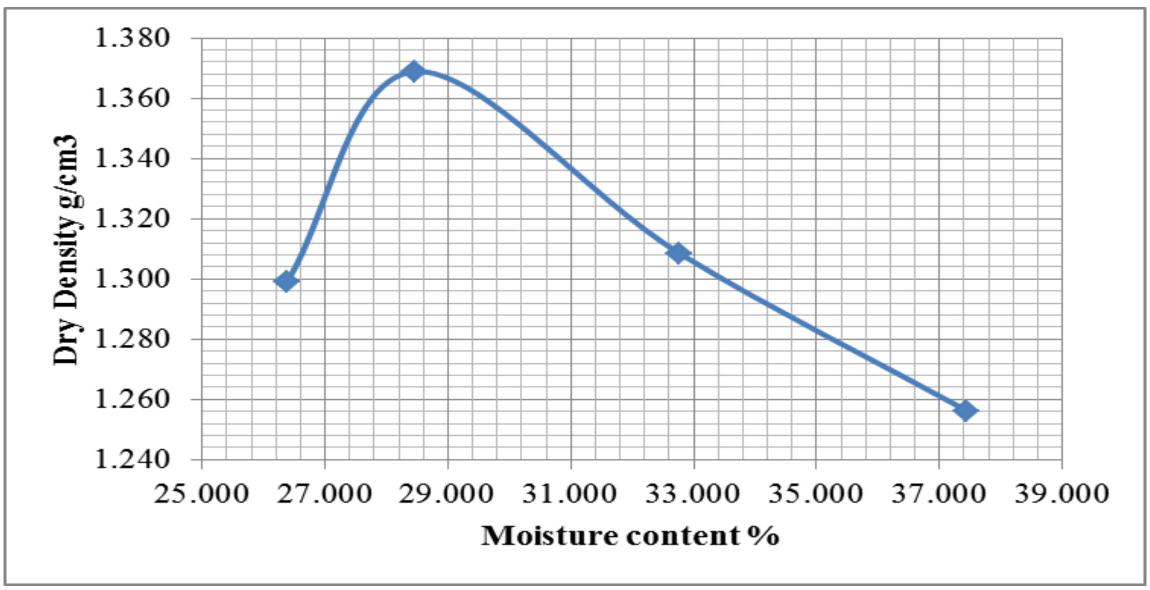
Soil Moisture-Density Relationship Data Sheet For Sample-1

Additive Content	lime 2% and marble 5%									
Volume of Mold (cm3)	944									
Trial No.	Trial -1		Trial - 2		Trial - 3		Trial - 4		Trial - 5	
Wt. Soil + Mold (g)	4515		4540		4595		4585		4580	
Wt. Mold (g)	2995		2995		2995		2995		2995	
Wt. Soil (g)	1520		1545		1600		1590		1585	
Wet Density (g/cm3)	1.610		1.637		1.695		1.684		1.679	
Dry Density (g/cm3)	1.227		1.232		1.249		1.223		1.174	
Water Content Sample										
Can No.	1	2	1	2	1	2	1	2	1	2
Can + Wet Soil (g)	96.06	105.28	92.79	106.89	94.8	108.23	95.21	104.02	98	101.57
Can + Dry Soil (g)	77.384	84.566	73.974	85.098	74.82	84.362	73.913	80.614	73.527	76.411
Mass of Can (g)	17.64	18.1	17.17	18.36	18.9	17.42	17.42	18.48	16.94	17.63
Mass of Dry Soil (g)	59.744	66.466	56.804	66.738	55.92	66.942	56.493	62.134	56.587	58.781
Mass of Water (g)	18.676	20.714	18.816	21.792	19.98	23.868	21.297	23.406	24.473	25.159
Water Content (%)	31.26	31.16	33.12	32.65	35.73	35.65	37.70	37.67	43.25	42.80
Average Water Content (%)	31.21		32.89		35.69		37.68		43.02	
Dry Density (kg/m3)	1227.147		1231.596		1249.088		1223.321		1173.940	



Soil Moisture-Density Relationship Data Sheet For Sample-1

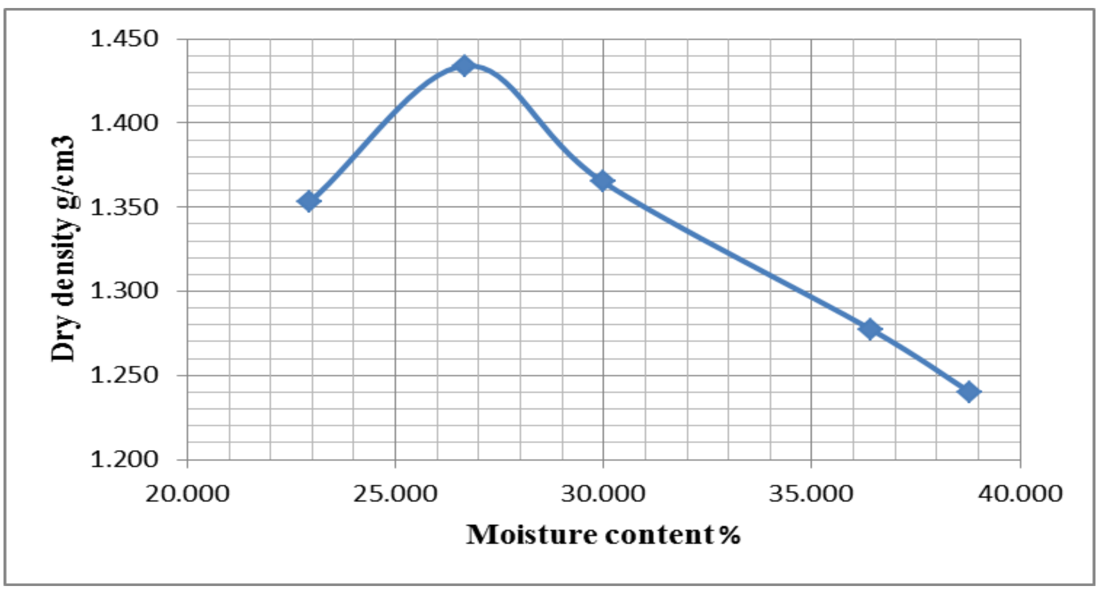
Additive Content								
2%Lime + 20%Marble								
Volume of Mold (cm3)	944							
Trial No.	Trial -1		Trial - 2		Trial - 3		Trial - 4	
Wt. Soil + Mold (g)	4540		4650		4630		4620	
Wt. Mold (g)	2990		2990		2990		2990	
Wt. Soil (g)	1550		1660		1640		1630	
Wet Density (g/cm3)	1.642		1.758		1.737		1.727	
Dry Density (g/cm3)	1.299		1.369		1.309		1.256	
Water Content Sample								
Can No.	1	2	1	2	1	2	1	2
Can + Wet Soil (g)	104.75	104.31	87.91	94.07	80.6	87.77	86.38	88.36
Can + Dry Soil (g)	85.999	86.66	72.66	76.995	65.095	70.416	67.8	69.115
Mass of Can (g)	17.06	17.64	18.91	17.19	17.79	17.43	17.97	17.95
Mass of Dry Soil (g)	68.939	69.02	53.75	59.805	47.305	52.986	49.83	51.165
Mass of Water (g)	18.751	17.65	15.25	17.075	15.505	17.354	18.58	19.245
Water Content (%)	27.20	25.57	28.37	28.55	32.78	32.75	37.29	37.61
Average Water Content (%)	26.39		28.46		32.76		37.45	
Dry Density (kg/m3)	1299.156		1368.872		1308.550		1256.233	



Soil Moisture-Density Relationship Data Sheet For Sample-1

Additive Content	lime 2% and marble 30%

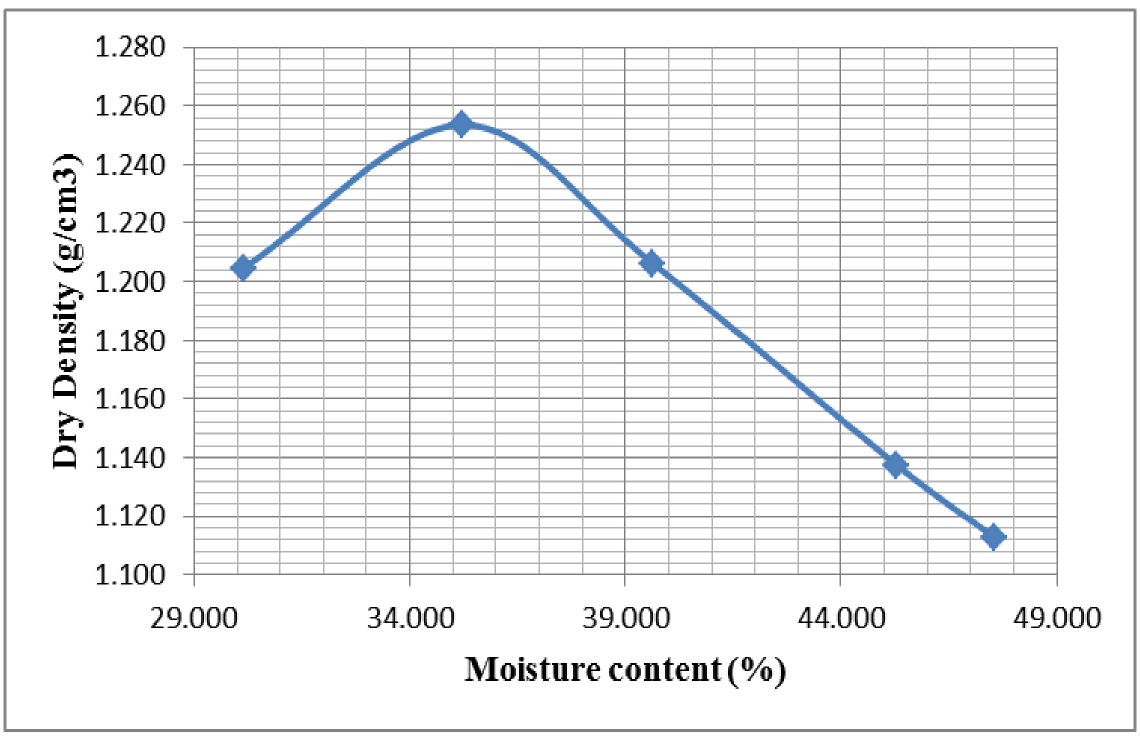
Volume of Mold (cm3)			944							
Trial No.	Trial -1		Trial - 2		Trial - 3		Trial - 4		Trial - 5	
Wt. Soil + Mold (g)	4570		4715		4675		4645		4625	
Wt. Mold (g)	3000		3000		3000		3000		3000	
Wt. Soil (g)	1570		1715		1675		1645		1625	
Wet Density (g/cm3)	1.663		1.817		1.774		1.743		1.721	
Dry Density (g/cm3)	1.353		1.434		1.365		1.277		1.240	
Water Content Sample										
Can No.	1	2	1	2	1	2	1	2	1	2
Can + Wet Soil (g)	114.56	107.85	92.094	87.333	90.013	110.019	97.23	92.2	97.52	98.66
Can + Dry Soil (g)	98.188	92.215	76.012	73.047	73.371	88.655	76.097	72.22	75.388	76.24
Mass of Can (g)	25.36	25.32	16.965	18.37	17.879	17.372	17.451	17.929	18.122	18.639
Mass of Dry Soil (g)	72.828	66.895	59.047	54.677	55.492	71.283	58.646	54.291	57.266	57.601
Mass of Water (g)	16.372	15.635	16.082	14.286	16.642	21.364	21.133	19.98	22.132	22.42
Water Content (%)	22.48	23.37	27.24	26.13	29.99	29.97	36.03	36.80	38.65	38.92
Average Water Content (%)	22.93		26.68		29.98		36.42		38.79	
Dry Density (kg/m3)	1352.952		1434.093		1365.103		1277.384		1240.332	



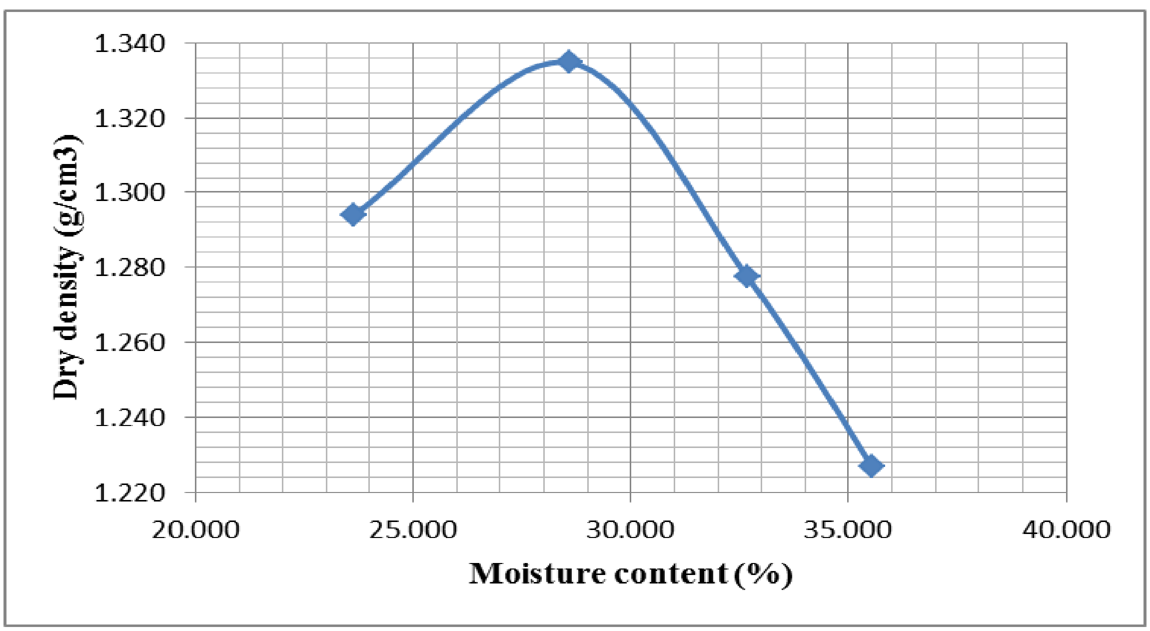
Soil Moisture-Density Relationship Data Sheet For Sample-1

Additive Content	lime 3% and marble 5%

Volume of Mold (cm3)	944									
Trial No.	Trial -1		Trial - 2		Trial - 3		Trial - 4		Trial - 5	
Wt. Soil + Mold (g)	4480		4600		4590		4560		4550	
Wt. Mold (g)	3000		3000		3000		3000		3000	
Wt. Soil (g)	1480		1600		1590		1560		1550	
Wet Density (g/cm3)	1.568		1.695		1.684		1.653		1.642	
Dry Density (g/cm3)	1.205		1.254		1.206		1.137		1.113	
Water Content Sample										
Can No.	1	2	1	2	1	2	1	2	1	2
Can + Wet Soil (g)	87.86	86.4	77.94	78.92	78.375	77.335	64.861	72.972	105.273	104.156
Can + Dry Soil (g)	71.44	70.54	62.436	62.857	61.595	60.05	49.98	55.799	77.198	76.078
Mass of Can (g)	17.724	17.177	18.18	17.47	18	17.64	17.36	17.61	17.801	17.401
Mass of Dry Soil (g)	53.716	53.363	44.256	45.387	43.595	42.41	32.62	38.189	59.397	58.677
Mass of Water (g)	16.42	15.86	15.504	16.063	16.78	17.285	14.881	17.173	28.075	28.078
Water Content (%)	30.57	29.72	35.03	35.39	38.49	40.76	45.62	44.97	47.27	47.85
Average Water Content (%)	30.14		35.21		39.62		45.29		47.56	
Dry Density (kg/m3)	1204.658		1253.526		1206.329		1137.379		1112.739	

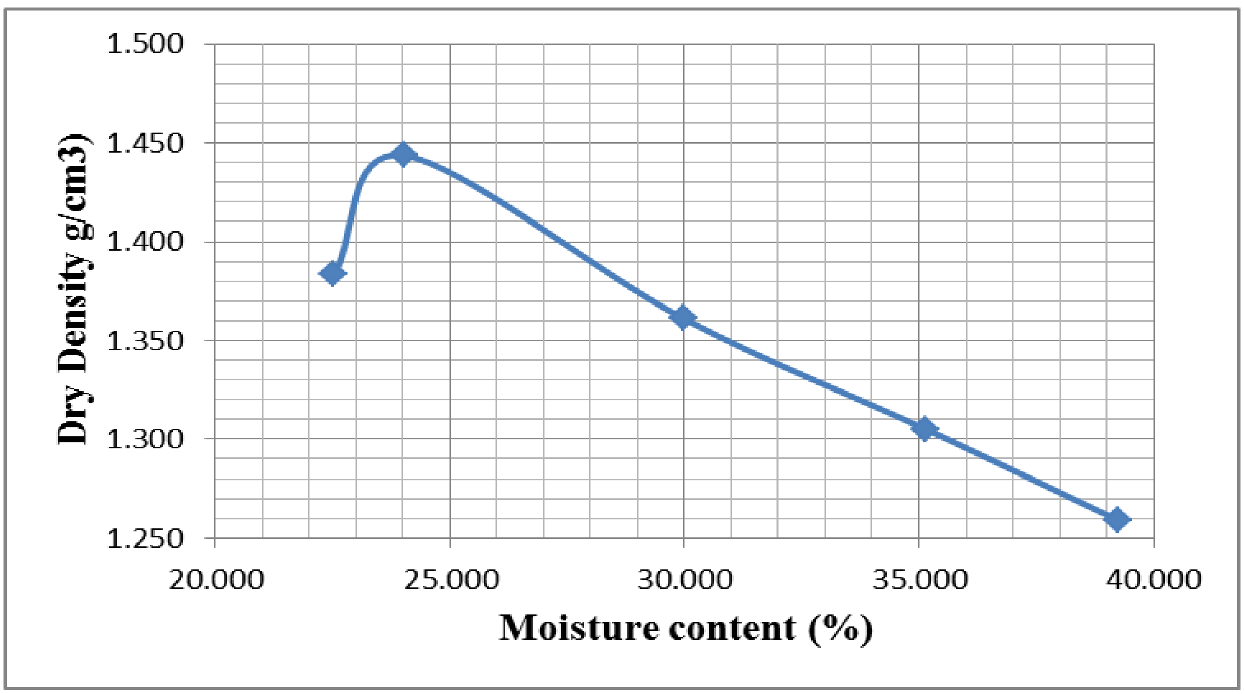


Soil Moisture-Density Relationship Data Sheet For Sample-1								
Additive Content	**lime 3% and marble 15%**							
Volume of Mold (cm3)	944							
Trial No.	Trial-1		Trial -2		Trial - 3		Trial - 4	
Wt. Soil + Mold (g)	4500		4610		4590		4560	
Wt. Mold (g)	2990		2990		2990		2990	
Wt. Soil (g)	1510		1620		1600		1570	
Wet Density (g/cm3)	1.600		1.716		1.695		1.663	
Dry Density (g/cm3)	1.294		1.335		1.277		1.227	
Water Content Sample								
Can No.	1	2	1	2	1	2	1	2
Can + Wet Soil (g)	81.517	100.102	108.81	93.7	96.47	86.51	96.93	88.51
Can + Dry Soil (g)	69.62	83.911	90.618	76.85	76.634	69.87	76.393	69.994
Mass of Can (g)	17.54	17.54	27.71	17.21	16.68	18.32	18.91	17.626
Mass of Dry Soil (g)	52.08	66.371	62.908	59.64	59.954	51.55	57.483	52.368
Mass of Water (g)	11.897	16.191	18.192	16.85	19.836	16.64	20.537	18.516
Water Content (%)	22.84	24.39	28.92	28.25	33.09	32.28	35.73	35.36
Average Water Content (%)	23.62		28.59		32.68		35.54	
Dry Density (kg/m3)	1293.955		1334.598		1277.423		1227.023	



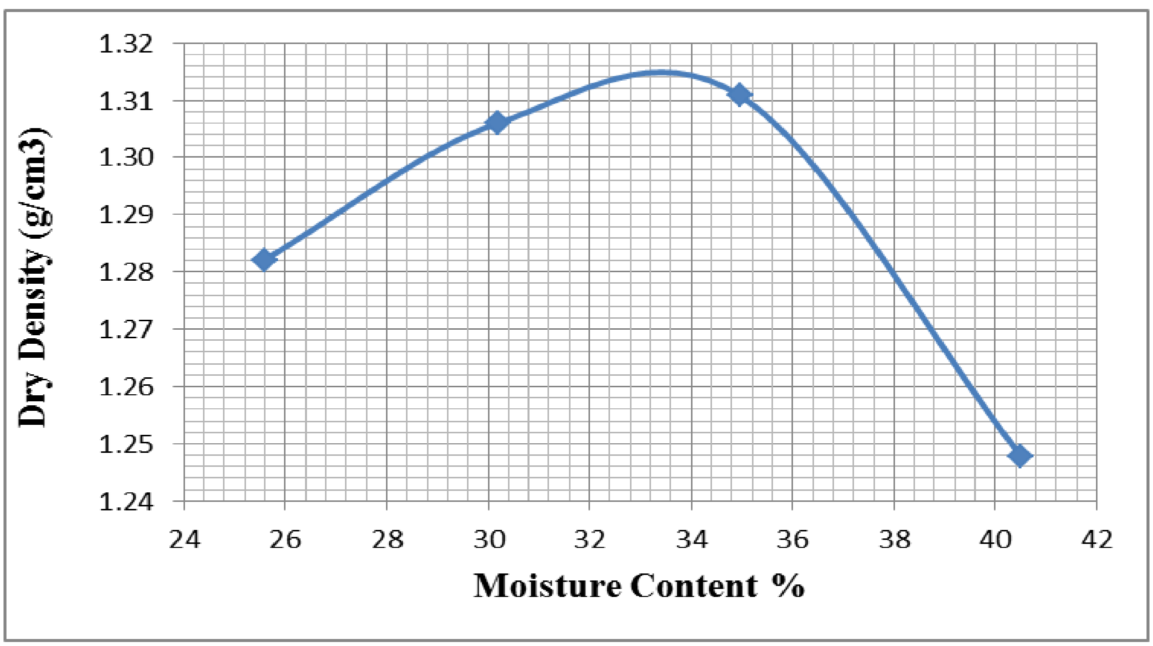
Soil Moisture-Density Relationship Data Sheet For Sample-1

Additive Content										3%Lime + 30%Marble
Volume of Mold (cm3)					944					
Trial No.	Trial-1		Trial -1		Trial - 2		Trial - 3		Trial - 5	
Wt. Soil + Mold (g)	4600		4690		4670		4665		4655	
Wt. Mold (g)	3000		3000		3000		3000		3000	
Wt. Soil (g)	1600		1690		1670		1665		1655	
Wet Density (g/cm3)	1.695		1.790		1.769		1.764		1.753	
Dry Density (g/cm3)	1.383		1.444		1.361		1.305		1.259	
Water Content Sample										
Can No.			1	2	1	2	1	2	1	2
Can + Wet Soil (g)	96.85	99.41	111.68	109.64	85.62	75.095	110.01	100.02	90.85	95.86
Can + Dry Soil (g)	82.44	84.1	93.867	91.45	69.79	61.88	85.95	78.55	70.3	73.83
Mass of Can (g)	17.46	17.178	17.68	17.63	17.33	17.51	17.44	17.478	17.893	17.69
Mass of Dry Soil (g)	64.98	66.922	76.187	73.82	52.46	44.37	68.51	61.072	52.407	56.14
Mass of Water (g)	14.41	15.31	17.813	18.19	15.83	13.215	24.06	21.47	20.55	22.03
Water Content (%)	22.18	22.88	23.38	24.64	30.18	29.78	35.12	35.16	39.21	39.24
Average Water Content (%)	22.53		24.01		29.98		35.14		39.23	
Dry Density (kg/m3)	1383.303		1443.627		1361.036		1305.172		1259.225	



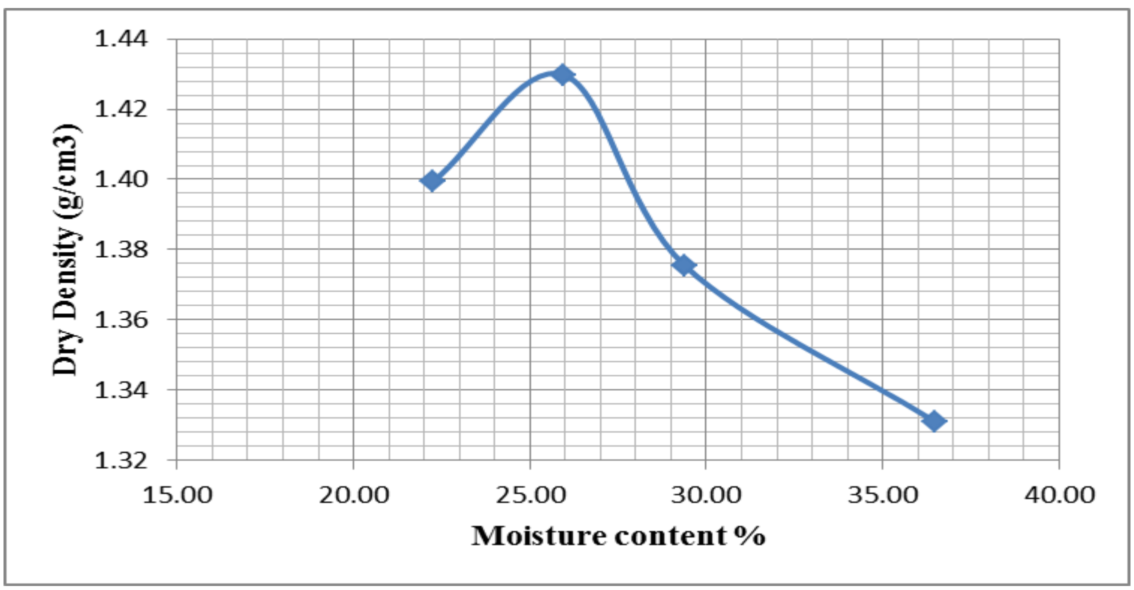
Soil Moisture-Density Relationship Data Sheet For Sample-2

Additive Content								
Additive Content	**1%Lime + 5%Marble**							
Volume of Mold (cm3)	944							
Trial No.	Trial -1		Trial - 2		Trial - 3		Trial - 4	
Wt. Soil + Mold (g)	4520		4605		4670		4655	
Wt. Mold (g)	3000		3000		3000		3000	
Wt. Soil (g)	1520		1605		1670		1655	
Wet Density (g/cm3)	1.610		1.700		1.769		1.753	
Dry Density (g/cm3)	1.282		1.306		1.311		1.248	
Water Content Sample								
Can No.	1	2	1	2	1	2	1	2
Can + Wet Soil (g)	100.66	101.35	81.18	102.89	97.8	92.83	104.52	89.62
Can + Dry Soil (g)	83.53	84.47	66.26	83.5	77.142	73.379	79.65	68.86
Mass of Can (g)	17.87	17.178	16.959	19.11	17.68	18.106	17.99	17.81
Mass of Dry Soil (g)	65.66	67.292	49.301	64.39	59.462	55.273	61.66	51.05
Mass of Water (g)	17.13	16.88	14.92	19.39	20.658	19.451	24.87	20.76
Water Content (%)	26.09	25.08	30.26	30.11	34.74	35.19	40.33	40.67
Average Water Content (%)	25.59		30.19		34.97		40.50	
Dry Density (kg/m3)	1282.117		1305.964		1310.749		1247.813	

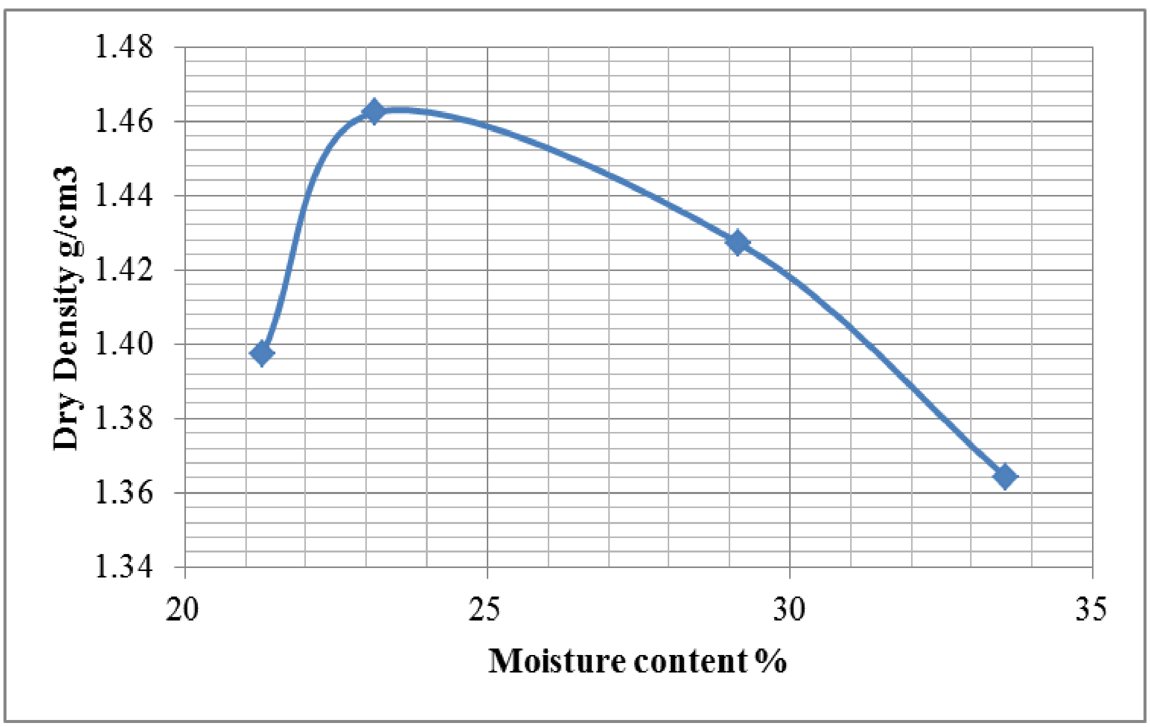


Soil Moisture-Density Relationship Data Sheet For Sample-2

Additive Content		**1%Lime +20%Marble**						
Volume of Mold (cm3)	944							
Trial No.	Trial-1		Trial -2		Trial -3		Trial -4	
Wt. Soil + Mold (g)	4615		4700		4680		4715	
Wt. Mold (g)	3000		3000		3000		3000	
Wt. Soil (g)	1615		1700		1680		1715	
Wet Density (g/cm3)	1.711		1.801		1.780		1.817	
Dry Density (g/cm3)	1.399		1.430		1.375		1.331	
Water Content Sample								
Can No.			1	2	1	2	1	2
Can + Wet Soil (g)	104.52	89.62	99.75	97.64	102.04	94.015	109.357	117.71
Can + Dry Soil (g)	88.4	76.86	83.089	80.79	83.31	76.69	86.69	88.94
Mass of Can (g)	17.99	17.81	17.649	17.07	18.92	18.32	17.192	17.688
Mass of Dry Soil (g)	70.41	59.05	65.44	63.72	64.39	58.37	69.498	71.252
Mass of Water (g)	16.12	12.76	16.661	16.85	18.73	17.325	22.667	28.77
Water Content (%)	22.89	21.61	25.46	26.44	29.09	29.68	32.62	40.38
Average Water Content (%)	22.25		25.95		29.38		36.50	
Dry Density (kg/m3)	1399.413		1429.790		1375.479		1330.977	

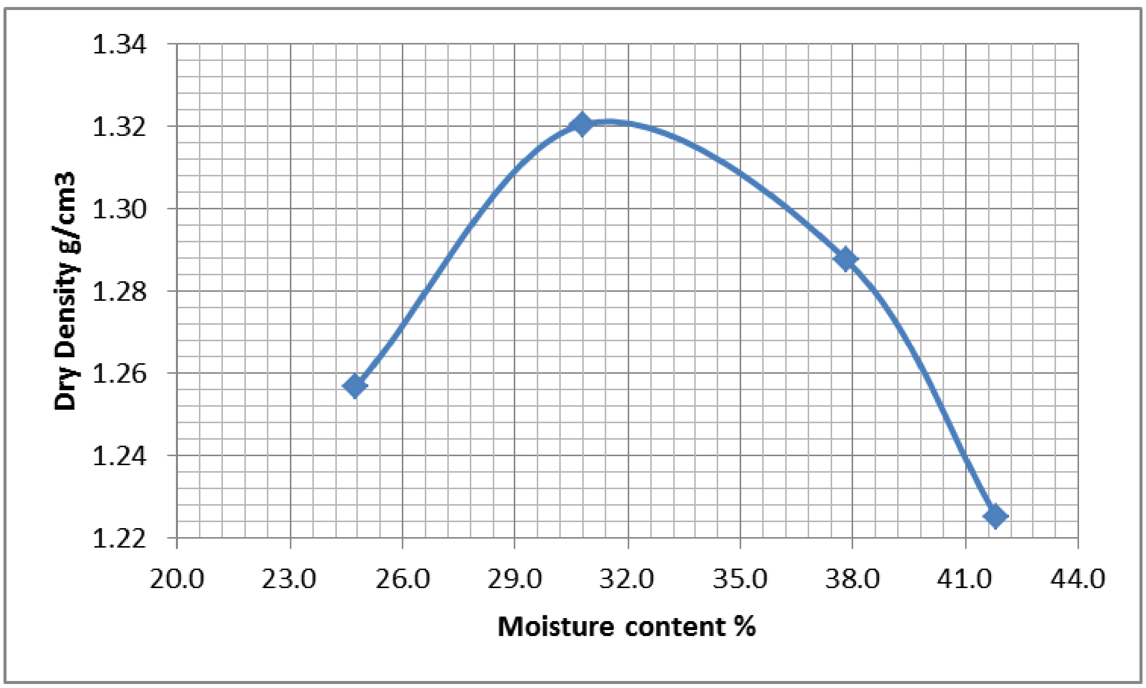


Soil Moisture-Density Relationship Data Sheet For Sample-2								
Additive Content			**1%Lime +30%Marble**					
Volume of Mold (cm3)	944							
Trial No.	Trial-1		Trial -2		Trial - 3		Trial - 4	
Wt. Soil + Mold (g)	4600		4700		4740		4720	
Wt. Mold (g)	3000		3000		3000		3000	
Wt. Soil (g)	1600		1700		1740		1720	
Wet Density (g/cm3)	1.695		1.801		1.843		1.822	
Dry Density (g/cm3)	1.397		1.462		1.427		1.364	
Water Content Sample								
Can No.			1	2	1	2	1	2
Can + Wet Soil (g)	104.687	101.5	92.23	91.516	111.1	95.589	103.08	100.92
Can + Dry Soil (g)	88.959	87.15	78.367	77.484	89.739	78.03	80.27	81.83
Mass of Can (g)	17.254	17.641	18.369	16.967	16.696	17.58	18.618	18.49
Mass of Dry Soil (g)	71.705	69.509	59.998	60.517	73.043	60.45	61.652	63.34
Mass of Water (g)	15.728	14.35	13.863	14.032	21.361	17.559	22.81	19.09
Water Content (%)	21.93	20.64	23.11	23.19	29.24	29.05	37.00	30.14
Average Water Content (%)	21.29		23.15		29.15		33.57	
Dry Density (kg/m3)	1397.412		1462.364		1427.240		1364.120	

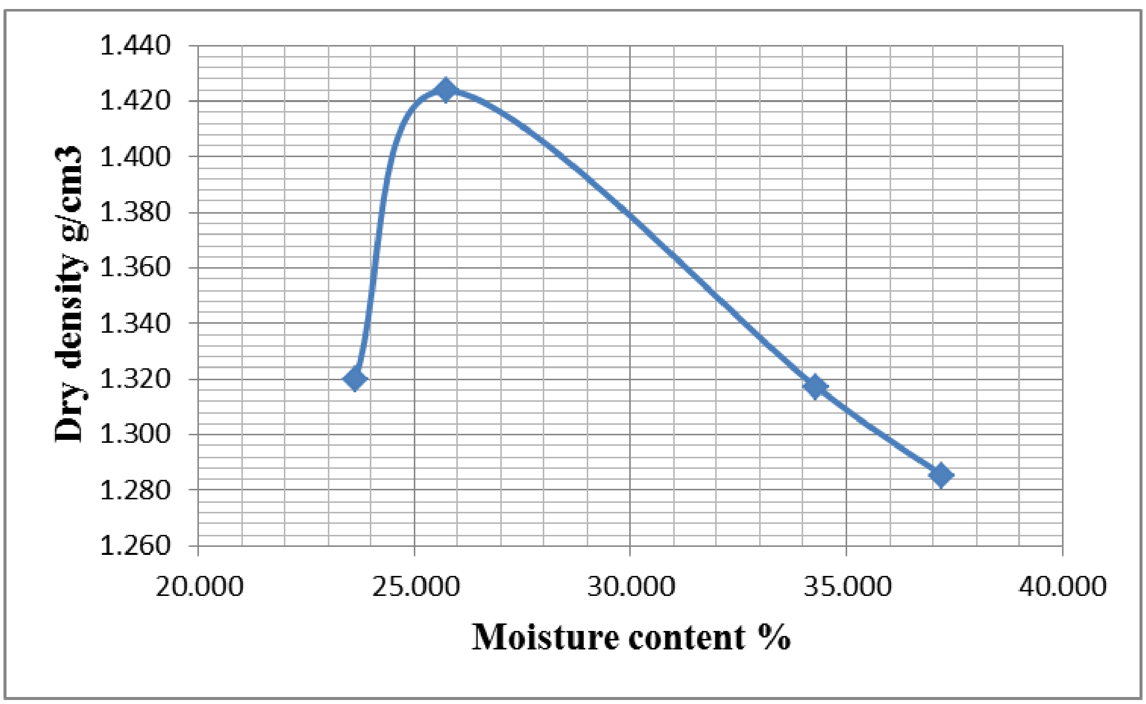


Soil Moisture-Density Relationship Data Sheet For Sample-2

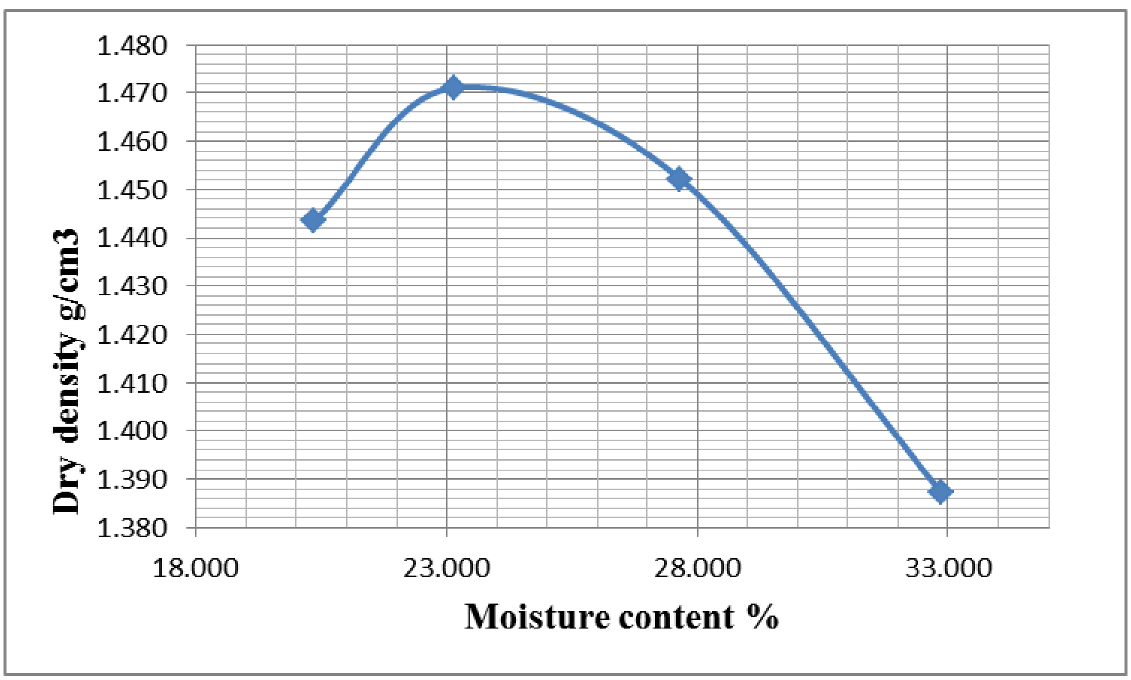
Additive Content					**2%Lime + 5%Marble**			
Volume of Mold (cm3)			944					
Trial No.	Trial -1		Trial - 2		Trial - 3		Trial - 4	
Wt. Soil + Mold (g)	4480		4630		4675		4640	
Wt. Mold (g)	3000		3000		3000		3000	
Wt. Soil (g)	1480		1630		1675		1640	
Wet Density (g/cm3)	1.568		1.727		1.774		1.737	
Dry Density (g/cm3)	1.257		1.320		1.288		1.225	
Water Content Sample								
Can No.	1	2	1	2	1	2	1	2
Can + Wet Soil (g)	95.08	97.75	84.45	102.74	103.869	93.305	108.743	91.425
Can + Dry Soil (g)	79.929	81.953	68.55	82.712	80.162	72.65	81.98	69.19
Mass of Can (g)	18.371	18.486	16.956	17.583	17.64	17.874	15.91	17.637
Mass of Dry Soil (g)	61.558	63.467	51.594	65.129	62.522	54.776	66.07	51.553
Mass of Water (g)	15.151	15.797	15.9	20.028	23.707	20.655	26.763	22.235
Water Content (%)	24.61	24.89	30.82	30.75	37.92	37.71	40.51	43.13
Average Water Content (%)	24.75		30.78		37.81		41.82	
Dry Density (kg/m3)	1256.737		1320.261		1287.516		1225.006	



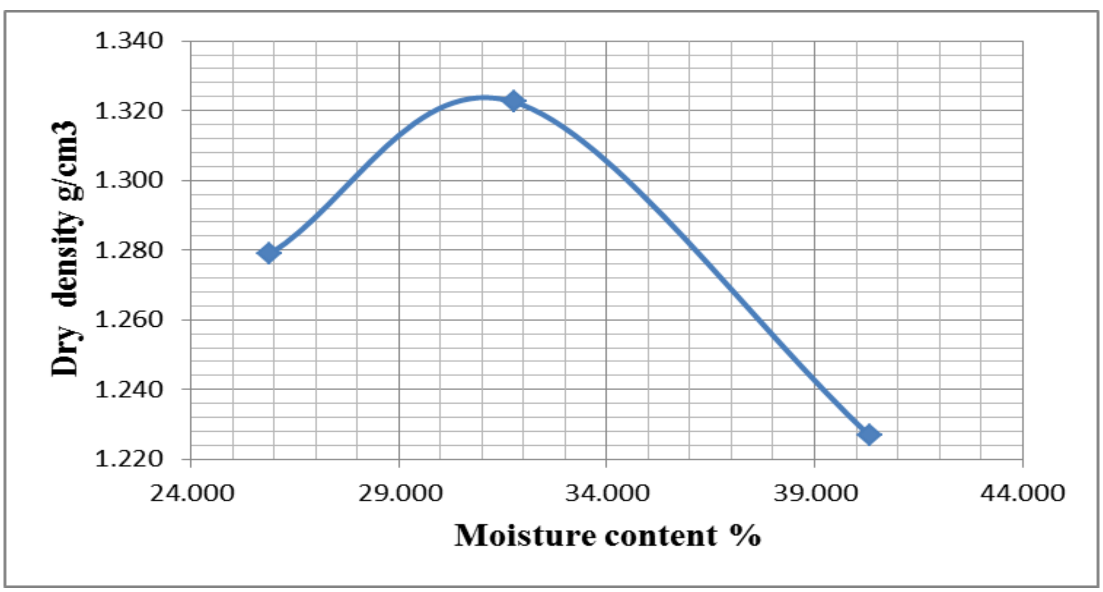
Soil Moisture-Density Relationship Data Sheet For Sample-2								
Additive Content	**2%Lime +15%Marble S2**							
Volume of Mold (cm3)	944							
Trial No.	Trial-1		Trial -2		Trial - 3		Trial - 4	
Wt. Soil + Mold (g)	4540		4690		4670		4665	
Wt. Mold (g)	3000		3000		3000		3000	
Wt. Soil (g)	1540		1690		1670		1665	
Wet Density (g/cm3)	1.631		1.790		1.769		1.764	
Dry Density (g/cm3)	1.320		1.424		1.317		1.285	
Water Content Sample								
Can No.			1	2	1	2	1	2
Can + Wet Soil (g)	92.8	102.87	99.117	90.897	98.88	95.94	95.54	83.765
Can + Dry Soil (g)	78.77	86.381	82.4	75.933	78.195	76.355	74.758	65.595
Mass of Can (g)	18.489	17.582	18.369	16.957	18.598	18.598	17.87	17.641
Mass of Dry Soil (g)	60.281	68.799	64.031	58.976	59.597	57.757	56.888	47.954
Mass of Water (g)	14.03	16.493	16.717	14.964	20.685	19.585	20.782	18.17
Water Content (%)	23.27	23.97	26.11	25.37	34.71	33.91	36.53	37.89
Average Water Content (%)	23.62		25.74		34.31		37.21	
Dry Density (kg/m3)	1319.616		1423.771		1317.165		1285.445	



Soil Moisture-Density Relationship Data Sheet For Sample-2								
Additive Content	**2%Lime +30%Marble**							
Volume of Mold (cm3)	944							
Trial No.	Trial-		Trial -1		Trial - 2		Trial - 3	
Wt. Soil + Mold (g)	4640		4710		4750		4740	
Wt. Mold (g)	3000		3000		3000		3000	
Wt. Soil (g)	1640		1710		1750		1740	
Wet Density (g/cm3)	1.737		1.811		1.854		1.843	
Dry Density (g/cm3)	1.443		1.471		1.452		1.387	
Water Content Sample								
Can No.	1	2	1	2	1	2	1	2
Can + Wet Soil (g)	105.28	101.42	92.256	104.14	107.398	102.922	115.403	106.32
Can + Dry Soil (g)	90.272	87.371	78.01	88.102	86.879	85.568	91.632	84.078
Mass of Can (g)	17.45	17.476	17.65	17.374	17.666	17.955	17.898	17.7
Mass of Dry Soil (g)	72.822	69.895	60.36	70.728	69.213	67.613	73.734	66.378
Mass of Water (g)	15.008	14.049	14.246	16.038	20.519	17.354	23.771	22.242
Water Content (%)	20.61	20.10	23.60	22.68	29.65	25.67	32.24	33.51
Average Water Content (%)	20.35		23.14		27.66		32.87	
Dry Density (kg/m3)	1443.474		1471.058		1452.190		1387.200	



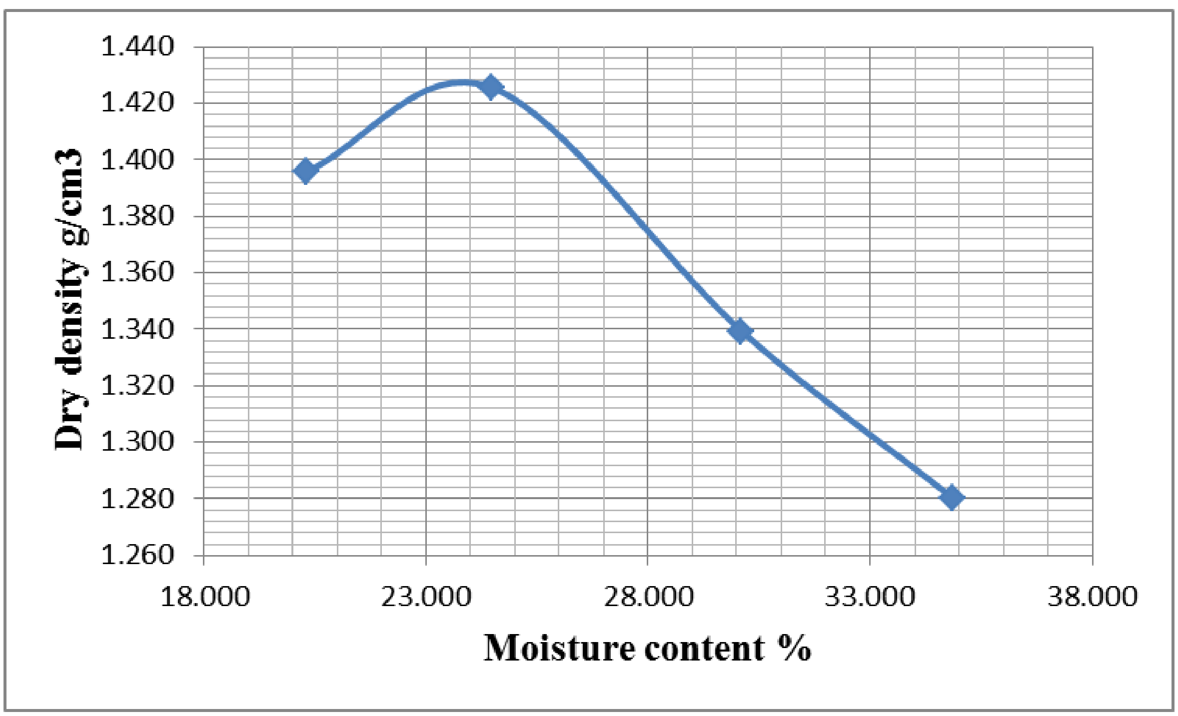
Soil Moisture-Density Relationship Data Sheet For Sample-2						
Additive Content	**3%Lime +5%Marble S2**					
Volume of Mold (cm3)	944					
Trial No.	Trial -1		Trial - 2		Trial - 3	
Wt. Soil + Mold (g)	4520		4645		4625	
Wt. Mold (g)	3000		3000		3000	
Wt. Soil (g)	1520		1645		1625	
Wet Density (g/cm3)	1.610		1.743		1.721	
Dry Density (g/cm3)	1.279		1.323		1.227	
Water Content Sample						
Can No.	1	2	1	2	1	2
Can + Wet Soil (g)	86.616	87.742	109.076	88.989	95.18	103.491
Can + Dry Soil (g)	72.5	73.295	86.88	71.979	73.134	78.523
Mass of Can (g)	18.167	17.317	18.029	17.617	17.475	17.683
Mass of Dry Soil (g)	54.333	55.978	68.851	54.362	55.659	60.84
Mass of Water (g)	14.116	14.447	22.196	17.01	22.046	24.968
Water Content (%)	25.98	25.81	32.24	31.29	39.61	41.04
Average Water Content (%)	25.89		31.76		40.32	
Dry Density (kg/m3)	1278.984		1322.505		1226.732	



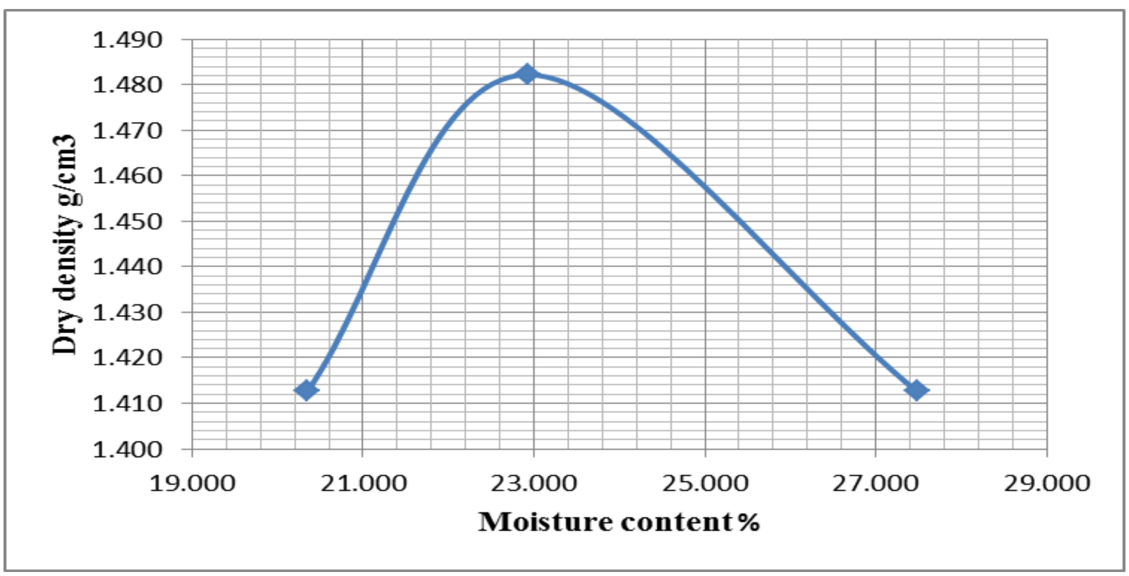
Soil Moisture-Density Relationship Data Sheet For Sample-2

Additive Content	**3%Lime +15%Marble S2**

Volume of Mold (cm3)	944							
Trial No.	Trial -1		Trial - 2		Trial - 3		Trial - 4	
Wt. Soil + Mold (g)	4585		4675		4645		4630	
Wt. Mold (g)	3000		3000		3000		3000	
Wt. Soil (g)	1585		1675		1645		1630	
Wet Density (g/cm3)	1.679		1.774		1.743		1.727	
Dry Density (g/cm3)	1.396		1.426		1.339		1.280	
Water Content Sample								
Can No.	1	2	1	2	1	2	1	2
Can + Wet Soil (g)	69.734	74.965	75.363	65.702	80.061	83.153	87.409	91.149
Can + Dry Soil (g)	61.615	64.72	64.136	56.256	65.77	67.895	69.655	71.668
Mass of Can (g)	17.546	18.518	18.76	17.185	17.168	18.365	17.723	16.808
Mass of Dry Soil (g)	44.069	46.202	45.376	39.071	48.602	49.53	51.932	54.86
Mass of Water (g)	8.119	10.245	11.227	9.446	14.291	15.258	17.754	19.481
Water Content (%)	18.42	22.17	24.74	24.18	29.40	30.81	34.19	35.51
Average Water Content (%)	20.30		24.46		30.10		34.85	
Dry Density (kg/m3)	1395.712		1425.658		1339.369		1280.468	



Soil Moisture-Density Relationship Data Sheet For Sample-2						
Additive Content	**1%Lime +30%Marble**					
Volume of Mold (cm3)	944					
Trial No.	Trial-1		Trial -2		Trial - 3	
Wt. Soil + Mold (g)	4605		4720		4700	
Wt. Mold (g)	3000		3000		3000	
Wt. Soil (g)	1605		1720		1700	
Wet Density (g/cm3)	1.700		1.822		1.801	
Dry Density (g/cm3)	1.413		1.482		1.413	
Water Content Sample						
Can No.	1	2	1	2	1	2
Can + Wet Soil (g)	106.38	104.52	92.856	103.14	107.158	102.922
Can + Dry Soil (g)	91.272	89.871	78.01	88.102	86.879	85.568
Mass of Can (g)	17.45	17.476	17.65	17.374	17.666	17.955
Mass of Dry Soil (g)	73.822	72.395	60.36	70.728	69.213	67.613
Mass of Water (g)	15.108	14.649	14.846	15.038	20.279	17.354
Water Content (%)	20.47	20.23	24.60	21.26	29.30	25.67
Average Water Content (%)	20.35		22.93		27.48	
Dry Density (kg/m3)	1412.721		1482.187		1412.617	



2.3 Californian Bearing Ratio (CBR) Tests

Sample one 1

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div		12.14	
sample / 1 (Bachobore)		Amount of Additive in %	1% lime and 5% marble
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	8	0.097	
1.27	13	0.158	
1.96	15	0.182	
2.54	16	0.194	1.472
3.18	16	0.194	
3.81	16	0.194	
4.45	17	0.206	
5.08	18	0.219	1.0926
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div		12.14	
sample / 1(Bachobore)		Amount of Additive in %	1% lime and 10% marble
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	8	0.097	
1.27	13	0.158	
1.96	15	0.182	
2.54	18	0.219	1.655
3.18	19	0.231	
3.81	19	0.231	
4.45	19	0.231	
5.08	19	0.231	1.1533
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193				
Ring factor N/div		12.14		
sample	1(Bachobore)	Amount of Additive in %		1% lime and 15% marble
Blow/Layer	56/5			
PENT.(mm)	DIAL	LOAD (KN)	CBR %	
0	0	0.000		
0.64	10	0.121		
1.27	14	0.170		
1.96	16	0.194		
2.54	20	0.243	1.839	
3.18	22	0.267		
3.81	24	0.291		
4.45	25	0.304		
5.08	26	0.316	1.5782	
7.62		0		
10.6		0		
12.7				

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193				
Ring factor N/div		12.14		
sample	1(Bachobore)	Amount of Additive in %		1% lime and 20% marble
Blow/Layer	56/5			
PENT.(mm)	DIAL	LOAD (KN)	CBR %	
0	0	0.000		
0.64	14	0.170		
1.27	16	0.194		
1.96	20	0.243		
2.54	23	0.279	2.115	
3.18	24	0.291		
3.81	25	0.304		
4.45	26	0.316		
5.08	27	0.328	1.6389	
7.62		0		
10.6		0		
12.7				

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div	12.14		
sample 1(Bachobore)	Amount of Additive in %	1% lime and 25% marble	
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	11	0.134	
1.27	16	0.194	
1.96	20	0.243	
2.54	25	0.304	2.299
3.18	28	0.340	
3.81	31	0.376	
4.45	33	0.401	
5.08	34	0.413	2.0638
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div	12.14		
sample 1(Bachobore	Amount of Additive in %	1% lime and 30% marble	
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	11	0.134	
1.27	16	0.194	
1.96	22	0.267	
2.54	27	0.328	2.483
3.18	31	0.376	
3.81	33	0.401	
4.45	34	0.413	
5.08	35	0.425	2.1245
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193				
Ring factor N/div		**12.14**		
sample	**2 (bacho bore)**	Amount of Additive in %		**2% lime and 5% marble**
Blow/Layer	**56/5**			
PENT.(mm)	**DIAL**		**LOAD (KN)**	**CBR %**
0	0		0.000	
0.64	13		0.158	
1.27	15		0.182	
1.96	17		0.206	
2.54	19		0.231	1.747
3.18	20		0.243	
3.81	21		0.255	
4.45	22		0.267	
5.08	23		0.279	1.3961
7.62			0	
10.6			0	
12.7				

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193				
Ring factor N/div		**12.14**		
sample	**1(Bachobore)**	Amount of Additive in %		**2% lime and 10% marble**
Blow/Layer	**56/5**			
PENT.(mm)	DIAL		LOAD (KN)	CBR %
0	0		0.000	
0.64	11		0.134	
1.27	19		0.231	
1.96	22		0.267	
2.54	25		0.304	2.299
3.18	28		0.340	
3.81	30		0.364	
4.45	31		0.376	
5.08	32		0.388	1.9424
7.62			0	
10.6			0	
12.7				

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193				
Ring factor N/div		12.14		
sample	2 (bacho bore)	Amount of Additive in %		2% lime and 15% marble
Blow/Layer		56/5		
PENT.(mm)		**DIAL**	**LOAD (KN)**	**CBR %**
0		0	0.000	
0.64		9	0.109	
1.27		22	0.267	
1.96		26	0.316	
2.54		31	0.376	2.851
3.18		34	0.413	
3.81		37	0.449	
4.45		39	0.473	
5.08		40	0.486	2.428
7.62			0	
10.6			0	
12.7				

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193				
Ring factor N/div		12.14		
sample	1(Bachobore)	Amount of Additive in %		1% lime and 20% marble
Blow/Layer		56/5		
PENT.(mm)		DIAL	LOAD (KN)	CBR %
0		0	0.000	
0.64		16	0.194	
1.27		27	0.328	
1.96		34	0.413	
2.54		42	0.510	3.863
3.18		44	0.534	
3.81		46	0.558	
4.45		48	0.583	
5.08		50	0.607	3.035
7.62			0	
10.6			0	
12.7				

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div		12.14	
sample 2 (bacho bore)		Amount of Additive in %	2% lime and 25% marble
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	24	0.291	
1.27	36	0.437	
1.96	43	0.522	
2.54	52	0.631	4.782
3.18	56	0.680	
3.81	61	0.741	
4.45	65	0.789	
5.08	69	0.838	4.1883
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div		12.14	
sample 2 (bacho bore)		Amount of Additive in %	2% lime and 30% marble
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	25	0.304	
1.27	36	0.437	
1.96	49	0.595	
2.54	58	0.704	5.334
3.18	63	0.765	
3.81	65	0.789	
4.45	68	0.826	
5.08	70	0.850	4.249
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div	12.14		
sample 1(Bachobore)		Amount of Additive in %	3% lime and 5% marble
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	13	0.158	
1.27	20	0.243	
1.96	22	0.267	
2.54	29	0.352	2.667
3.18	32	0.388	
3.81	35	0.425	
4.45	36	0.437	
5.08	37	0.449	2.2459
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div	12.14		
Sample type (1)Bachobore		Amount of Additive in %	3% lime and 10% marble
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	16	0.194	
1.27	25	0.304	
1.96	30	0.364	
2.54	34	0.413	3.127
3.18	37	0.449	
3.81	40	0.486	
4.45	41	0.498	
5.08	42	0.510	2.5494
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div	12.14		
Sample	**(1)Bachobore**	Amount of Additive in %	**3% lime and 15% marble**
Blow/Layer	56/5		
PENT.(mm)	**DIAL**	**LOAD (KN)**	**CBR %**
0	0	0.000	
0.64	19	0.231	
1.27	30	0.364	
1.96	36	0.437	
2.54	42	0.510	3.863
3.18	45	0.546	
3.81	47	0.571	
4.45	48	0.583	
5.08	49	0.595	2.9743
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div	12.14		
sample	**(1) Bachobore**	Amount of Additive in %	**3% lime and 20% marble**
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	18	0.219	
1.27	30	0.364	
1.96	42	0.510	
2.54	50	0.607	4.598
3.18	54	0.656	
3.81	56	0.680	
4.45	57	0.692	
5.08	57	0.692	3.4599
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div	12.14		
Sample (1) Bacho bore		Amount of Additive in %	3% lime and 25% marble
Blow/Layer	56/5		
PENT.(mm)	**DIAL**	**LOAD (KN)**	**CBR %**
0	0	0.000	
0.64	24	0.291	
1.27	31	0.376	
1.96	43	0.522	
2.54	**57**	**0.692**	**5.242**
3.18	61	0.741	
3.81	66	0.801	
4.45	69	0.838	
5.08	**72**	**0.874**	**4.3704**
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div	12.14		
Sample 1 (bacho bore)		Amount of Additive in %	3% lime and 30% marble
Blow/Layer	56/5		
PENT.(mm)	**DIAL**	**LOAD (KN)**	**CBR %**
0	0	0.000	
0.64	29	0.352	
1.27	52	0.631	
1.96	59	0.716	
2.54	67	0.813	6.162
3.18	74	0.898	
3.81	80	0.971	
4.45	85	1.032	
5.08	89	1.080	5.4023
7.62		0	
10.6		0	
12.7			

Sample two 2

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div		12.14	
sample type	2 (kochi)	Amount of Additive in %	1% lime and 5% marble
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	5	0.061	
1.27	8	0.097	
1.96	10	0.121	
2.54	12.5	0.152	1.150
3.18	13	0.158	
3.81	13	0.158	
4.45	14	0.170	
5.08	15	0.182	0.9105
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div		12.14	
sample type	2 (kochi)	Amount of Additive in %	1% lime and 10% marble
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	5	0.061	
1.27	8	0.097	
1.96	13	0.158	
2.54	16	0.194	1.472
3.18	18	0.219	
3.81	19	0.231	
4.45	20	0.243	
5.08	20	0.243	1.214
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div	12.14		
sample type 2 (kochi)	Amount of Additive in %	1% lime and 15% marble	
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	9	0.109	
1.27	13	0.158	
1.96	15	0.182	
2.54	18	0.219	1.655
3.18	19	0.231	
3.81	20	0.243	
4.45	20	0.243	
5.08	21	0.255	1.2747
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div	12.14		
sample type 2(kochi)	Amount of Additive in %	1% lime and 20% marble	
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	11	0.134	
1.27	14	0.170	
1.96	16	0.194	
2.54	22	0.267	2.023
3.18	24	0.291	
3.81	25	0.304	
4.45	26	0.316	
5.08	27	0.328	1.6389
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div	12.14		
sample type: 2(kochi)	Amount of Additive in %		1% lime and 25% marble
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	11	0.134	
1.27	14	0.170	
1.96	17	0.206	
2.54	22	0.267	2.023
3.18	24	0.291	
3.81	25	0.304	
4.45	25	0.304	
5.08	26	0.316	1.5782
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div	12.14		
sample type: 2 (kochi)	Amount of Additive in %		1% lime and 30% marble
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	15	0.182	
1.27	20	0.243	
1.96	24	0.291	
2.54	28	0.340	2.575
3.18	30	0.364	
3.81	31	0.376	
4.45	31.5	0.382	
5.08	32	0.388	1.9424
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193				
Ring factor N/div		12.14		
sample type	**2 (kochi)**	Amount of Additive in %	**2% lime and 5% marble**	
Blow/Layer	**56/5**			
PENT.(mm)	DIAL	LOAD (KN)	CBR %	
0	0	0.000		
0.64	16	0.194		
1.27	22	0.267		
1.96	28	0.340		
2.54	33	0.401	3.035	
3.18	37	0.449		
3.81	40	0.486		
4.45	41	0.498		
5.08	42	0.510	2.5494	
7.62		0		
10.6		0		
12.7				

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193				
Ring factor N/div		12.14		
sample type	**2 (kochi)**	Amount of Additive in %	**2% lime and 10% marble**	
Blow/Layer	**56/5**			
PENT.(mm)	DIAL	LOAD (KN)	CBR %	
0	0	0.000		
0.64	15	0.182		
1.27	23	0.279		
1.96	30	0.364		
2.54	35	0.425	3.219	
3.18	37	0.449		
3.81	41	0.498		
4.45	43	0.522		
5.08	45	0.546	2.7315	
7.62		0		
10.6		0		
12.7				

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div		12.14	
sample type 2 (kochi)		Amount of Additive in %	2% lime and 15% marble
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	11	0.134	
1.27	19	0.231	
1.96	28	0.340	
2.54	36	0.437	3.311
3.18	39	0.473	
3.81	40	0.486	
4.45	41	0.498	
5.08	42	0.510	2.5494
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193			
Ring factor N/div		12.14	
sample type 2 (kochi)		Amount of Additive in %	2% lime and 20% marble
Blow/Layer	56/5		
PENT.(mm)	DIAL	LOAD (KN)	CBR %
0	0	0.000	
0.64	15	0.182	
1.27	26	0.316	
1.96	37	0.449	
2.54	46	0.558	4.231
3.18	50	0.607	
3.81	53	0.643	
4.45	55	0.668	
5.08	56	0.680	3.3992
7.62		0	
10.6		0	
12.7			

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193				
Ring factor N/div		12.14		
sample type	2 (kochi)	Amount of Additive in %	2% lime and 30% marble	
Blow/Layer	56/5			
PENT.(mm)	DIAL	LOAD (KN)	CBR %	
0	0	0.000		
0.64	33	0.401		
1.27	52	0.631		
1.96	59	0.716		
2.54	63	0.765	5.794	
3.18	69	0.838		
3.81	73	0.886		
4.45	75	0.911		
5.08	76	0.923	4.6132	
7.62		0		
10.6	5	0		
12.7				

CALIFORNIA BEARING RATIO (CBR) AASHTO T-193				
Ring factor N/div		12.14		
sample type	2 (kochi)	Amount of Additive in %	2% lime and 25% marble	
Blow/Layer	56/5			
PENT.(mm)	DIAL	LOAD (KN)	CBR %	
0	0	0.000		
0.64	31	0.376		
1.27	45	0.546		
1.96	54	0.656		
2.54	57	0.692	5.242	
3.18	59	0.716		
3.81	61	0.741		
4.45	65	0.789		
5.08	67	0.813	4.0669	
7.62		0		
10.6	5	0		
12.7				