JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
GEOTECHNICAL ENGINEERING SREAM

COMPARATIVE STUDY ON THE IMPROVEMENT IN ENGINEERING PROPERTIES OF EXPANSIVE SOIL MODIFIED WITH STONE DUST AND BRICK DUST FOR SUB GRADE CASE IN JIMMA

A Thesis submitted to School of Graduate Studies, Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree Master of Science in Civil Engineering (Geotechnical Engineering)

By

Adisalem Getachew Edea

March, 2022

Jimma, Ethiopia

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By: Adisalem Getachew Edea

Main Advisor: Damtew Tsige (PhD)

Co-Advisor: Mohammed Yasin (Msc)

March, 2022

Jimma, Ethiopia

DECLARATION

I, the undersigned, declare that the thesis entitled **"**Comparative Study on The Improvement in Engineering Properties of Expansive Soil Modified with Stone Dust and Brick Dust for Sub Grade Case in Jimma**"** is my own original work and that it has not been presented and will not be presented by me to any other University for similar or any other degree award.

Adisalem Getachew Edea	____________	_______________
[Researcher]	[Signature]	[Date]

This Research Paper has been submitted for examination with my approval as university supervisor.

Damtew Tsige (PhD)	____________	_______________
[Main Advisor]	[Signature]	[Date]
Mohammed Yasin (Msc)	____________	_______________
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APPROVAL SHEET

School of Graduate Studies

As a thesis research advisor, we hereby certify that we have read and evaluated this thesis prepared, under our guidance, by Adisalem Getachew Edea entitled: Comparative Study on The Improvement in Engineering Properties of Expansive Soil Modified with Stone Dust and Brick Dust for Sub Grade Case in Jimma. We recommend that it be submitted as fulfilling the thesis requirement.

Damtew Tsige (PhD)	______________________	______________________
Main Advisor:	Signature	Date
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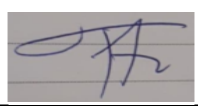
Main Advisor:	Signature	Date

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

Dr. Endalu Tadele		____________________
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Werku Firomsa (Msc)	__________________	____________________
Chairperson	Signature	Date

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ABSTRACT

Expansive soils are difficult to use as construction material for highways, airfields and lightweight structures. Expansive soils are susceptible to considerable volume changes due to seasonal variations and moisture content; light weight structures cannot exert the necessary counter load to overcome the swelling from expansive soil. The availability of expansive soil along the alignment of road projects has a significant influence on planning, design, construction, and maintenance of the road. Therefore, the aim of this study is to evaluate and compare the improvement in engineering properties of expansive soil modified with stone dust and brick dust as a sub-grade soil. Several methods have been developed for successful improvement of expansive Soils. For this study two sub grade soils were collected from Jimma Town around Shanen Gibe (jimma bus station) and around Merkato. A Soil samples were collected from depth of below 1.5m. Laboratory tests were conducted to determine moisture content, free swell test, grain size analysis, specific gravity, Hydrometer test, Atterberg limits, compaction test, California Bearing Ratio and CBR swell tests. Depending on the tests conducted in the laboratory the optimum percentage of stone dust and brick dust obtained were at 20% and 40% respectively. The laboratory test result confirmed that, modification of expansive soil with stone dust and brick dust improves its engineering properties of expansive soil. From the analysis results, the CBR value is increases from the 1.78% to 21.7% by using stone dust and from 1.78% to 8.75% by using brick dust at the optimum percentage. Addition of both stone dust and brick dust increases the plastic limit and decreases the liquid limit and plasticity index of the expansive soil sample. Generally, as the addition of both stone dust and brick dust ratio increased the FS, LL, PL, OMC, CBR swell decreased and inversely the PL, MDD are increased and recommended that modification of expansive soil with stone dust can be used to increase the strength capacity of foundation and subgrade. In addition both the stone dust and brick dust can be gained with low cost, locally available and finally makes the environment to become safe.

KEYWORDS*: Expansive soil, Stabilization, Brick dust, stone dust,*

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LIST OF ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
USCS	Unified Soil Classification System
BS	British standards
ERA	Ethiopian Road Authority
AACRA	Addis Ababa City Road Authority
JIT	Jimma Institute of Technology
CBR	California Bearing Ratio
FS	Free Swell
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
LL	Liquid Limit
PI	Plasticity Index
PL	Plastic Limit
Vf	Final Volume
Vi	Initial Volume
Ss1	Soil sample 1
Ss2	Soil sample 2
SD	Stone Dust
BD	Brick Dust
US	United State
K^+	potassium Ion
NP	Not Predicted

CHAPTER ONE

1. INTRODUCTION

1.1 Back Ground of the Study

Expansive soil refers to a soil 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. Ethiopia is amongst the list of countries where the occurrence and spatial distribution is recognized as significant (Nelson D. and Miller J., 1992).

Structures and roads constructed on expansive soils are exposed to different kinds of damages. Some of these damages are settlement on building, cracks both on buildings and roads, heaving and swelling. The damage of the structures on expansive soil is mostly due to the variation of water content; an increase in soil moisture causes swelling of the clay which results in vertical movements of the soil layers, where as a decrease in moisture cause shrinkage. These expansive soils are generally well defined clay layers containing mostly minerals called montmorillonites. Montmorillonites has an octahedral sheet sandwiched between two silica sheets. When this mineral is exposed to moisture, water is absorbed between interlayering lattice structures and exert an upward pressure. This upward pressure, known as swelling pressure, causes most of the damages associated with expansive soils. The variation of moisture content is mainly caused by changes in the field environment from natural conditions, changes related to construction, and usage effects on the moisture under the structure (Jemal J., 2014.).

The engineering properties of soil are depends upon the many points like minerals, water table, soil water behavior etc. Which vary as per area to area due to which we can't get desire properties suitable to our needs of construction to resolve this problem we have technique called stabilization, which means to stable or to modify or to improve the soil properties in positive matter.so we can have a construction works which fulfill our needs and objectives (Rajat, 2017).

Many researchers have shown that substantial damage has been occurring in Ethiopia on buildings and roads that are constructed on expansive soils. Sisay A., 2004 and Sime A., 2006 are among many researchers that have found out damage of structures founded on expansive soils. Therefore, the dominance of expansive soil in jimma town is a serious site problem to contractors, consultants, clients and the community as well by creating discomfort and huge financial loss.

The process of improving the strength and durability of soil is known as soil stabilization. The main aim of stabilization is cost reduction and to efficiently use the locally available material. Most common application of stabilization of soil is seen in construction of roads and airfields pavement. Thus, one has to look for appropriate and economical soil stabilization techniques to minimize/avoid the additional project cost and time required for the removal and replacement of the problematic soil. Soil stabilization is the alteration of one or more soil parameters property by mechanical or chemical treatments, to create an improved soil material possessing the desired engineering properties. The process includes the blending of soils to achieve a desired gradation or mixing of commercially available additives that may alter the gradation sizes, texture or plasticity, or act as a binder for cementation of the soil (Guyer, J. P., 2011.).

The expansive soils within Jimma Town contain a high Plasticity index and low CBR value; causing unstable subgrade soil which affects the upper pavement layers. Expansive soils found in this area are susceptible to considerable volume changes which causes severe damage at the intermittent of pavement sections (Robel T., 2019).

Due to availability of Brick materials in jimma zone; Peoples around jimma traditionally uses the waste product of brick for replacement of sand in concrete production and as floor hardcore material for the construction some residential houses. This research study evaluate and compare the performance of expansive soils modified with the stone dust ad brick dust for possible improvement of the engineering properties of Expansive soil and provides an opportunity to use the expansive soil for subgrade construction purpose.

1.2 Statement of the problem

Expansive soils have worldwide engineering problems. It is well known that it can be found in many parts of the world. Ethiopia is one of the countries that expansive soil is widely founded (S. Lakshman, 2018). They are found throughout and are commonly found in arid/ semi-arid regions, where there is high suctions and potentials for large water content charges on exposure/deficient which water can cause significant volume change (Salvant Raj, Feb. 2017). These expansive soils cause several problems for civil engineers. Different methods adopted to improve the engineering properties of expansive soils prior to use for construction purpose.

Expansive soils are difficult to use in the construction of highways, airfields and lightweight structures, because such light structures can't exert the necessary counter load to overcome the swelling. Substantial damage has been occurring in Ethiopia on buildings and roads that are constructed on expansive soil with severe economic consequences and loss of proper functioning of structures (Jemal J., 2014.). The Economic consequences resulting from Failures associated with expansive soils are substantial. Structural Cracks do not only affect the structural safety and aesthetics of the road but also bring about additional financial burden to owners for repair if the structure is to be salvaged at all (Sachim N., 2014).

Unsuitable soil materials along the alignment of road projects have a significant influence on planning, design, construction, and maintenance of the road. Expansive soils are susceptible to considerable volume changes due to seasonal variations and moisture content. The expansive soils within Jimma Town contain a high Plasticity index and low CBR value; causing unstable subgrade soil which affects the upper pavement layers (Robel T., 2019).

This research conduct laboratory investigation by using stone dust and brick dust to improve the engineering properties of expansive soil for subgrade construction and the study can be used as a guideline to select the most effective, suitable, economical stabilizing type and provide an opportunity to use the expansive soil for construction purpose by adjusting the engineering properties of expansive soil to the desired strength of the soil.

1.3 Research questions

- Can stone dust and brick dust improves the engineering properties of expansive soil?
- What is the optimum amount of stone dust and brick dust used to modify expansive soil and give the appropriate result?
- Comparatively which material improves the engineering properties of expansive soil more?

1.4 objectives

1.4.1 General Objective of the study

The general objective of the research is to evaluate and compare the improvement in engineering properties of expansive soil modified with stone dust and brick dust for sub-grade soil.

1.4.2 Specific Objective of the study

The specific objectives of this research work were the following;

- To assess the effect of stone dust and brick dust on the engineering properties of expansive soil.
- To determine the optimum proportion of stone dust and brick dust used for improving the engineering properties of expansive soil.
- To compare the changes in engineering properties of expansive soil modified with stone dust and with brick dust.

1.5 Significance of the study

This study compares the improvement in engineering properties of expansive soil modified with stone dust and brick dust to be used as road subgrade material. The City Administration of Jimma town will be benefited by using the study as a source of information and base for the construction industry that can help to minimize the time and cost of stabilizing subgrade soil by using locally available materials. The study also helps the community through creating job for producing and supplying of these materials. Most essentially, other researchers will use the findings as a reference for further research on the improvement of engineering properties of expansive soil for subgrade case in Jimma town.

1.6 Scope and limitation of the study

Two representative soil samples along the road section from different location of Jimma city were collected. The locations were previously confirmed by different investigators to be covered by expansive soils. The collected samples were disturbed and taken from below 1.5m depth. This study was done using the reuse of brick after molding and drying then crushing or waste material of brick. Laboratory tests conducted according to *ASTM and AASHTO* soil testing standard procedures.

In this research the proper stabilizer type and the ratio of stone dust and brick dust stabilizers to be used in future construction on Jimma Town expansive soil determined. The laboratory results from this study will be expected to be useful in designing better sub-grade of road pavements. This study was conducted by taking limited parameters of Atterberg limits, grain size, free swell, compaction, CBR and CBR swell potential on Expansive soils modified with stone dust and brick dust.

1.7 Thesis organization

This dissertation is organized into 5 chapters: Introduction; Literature Review; Materials and Research Methodology; Test Results and Discussion; Conclusion and Recommendations for future works and References.

Chapter 1: The requirement for the research study, the objectives, the scope of the study and then outline of the thesis are presented in this chapter.
Chapter 2: presents a literature study of the current knowledge in expansive soils. The literature review provides a fundamental basis for the concepts and work presented in the thesis. It reviews existing works related to this research and is concluded by outlining the uniqueness of this research to justify the significance of this research.
Chapter 3, this chapter briefly describes the study area, research methodology, material and laboratory testing procedures followed.
Chapter 4, this chapter outlines in Detail analysis of test results, discussion and evaluation of the findings.

Chapter 5, summarizes the findings from this research and provides recommendations regarding the direction for future.

Appendix at the back of the paper, presents detail laboratory readings, calculations with detail graphical interpretations and photos taken during the study.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Mineralogy of Expansive Soils

Expansiveness of soils is due to the presence of clay minerals. Clay particles have an effective diameter of 0.002mm or less. However, according to the particle size alone does not determine clay mineral. The three common types of clay minerals are Kaolinite, illite and montmorillonite which are crystalline hydrous aluminosilicates (Chen, 1988).

2.1.1 Kaolinite

Kaolinite has a structural unit made up of aluminum sheets joined to silica sheet and is symbolized as indicated in the fig 2.1 below. The bond that exists between layers is tight, and it is difficult to separate the layers. As a result, Kaolinite is relatively stable, and water is unable to enter into or between the layers (Nelson., 2010). Consequently, Kaolinite shows a low degree of expansiveness.

2.1.2 Illite

It has a basic structure similar to that of montmorillonite fig 2.1. But some of the silican atoms are replaced by aluminum, and, in addition, potassium ions are present between the tetrahedral sheet and adjacent crystals. The illite units are reasonably stable and so that minerals swell much less than montmorillonite (Chen, 1988).

2.1.3 Montmorillonite

It is the most common of all the clay mineral and is well known for its swelling properties. Its basic structure consists of an aluminum sheet sandwiched between two silica sheets and symbolically presents as fig 2.1. The bond between the individual units is relatively weak so that water is easily able to penetrate between the sheets and cause their separation and hence swelling. The most important aspect of the montimorillonite group is the ability for water molecules to be absorbed between the layers, initiating the volume of the minerals to increase when they come in contact with water (Nelson., 2010).

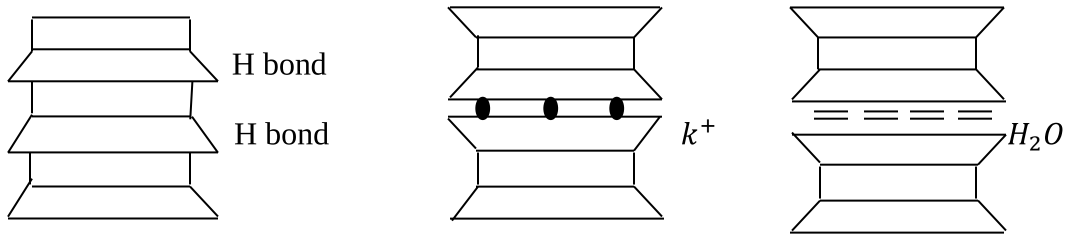

Figure 2. 1: Structural units of (a) Kaolinite, (b) Illite and (c)Montmorillonite clay (Craig, 1997)

2.2 Identification of Expansive Soils

Investigation of expansive soils generally consists of two important phases. The first is the visual identification and recognition of the soil as expansive and the second is sampling and measurement of material properties to be used as the basis for design. The purpose identification of expansive soil to ensure proper site selection, environmental compatibility, and economical designing, avoid construction delay as well as succeeding performance in infrastructure. The main aim of this topic is to discuss different ways that are commonly used to identify expansive soils.

2.2.1 Field Identification

Soils that can exhibit high swelling potential can be identified by field observations, mainly during reconnaissance and preliminary investigation stages. Important observations include (Nelson., 2010):

- ✓ They have a color of black or grey.
- ✓ Wide or deep shrinkage cracks.
- ✓ High dry strength and low wet strength.
- ✓ Stickiness and low trafficability when wet.
- ✓ Cut surfaces have a glazed or shiny appearance, like soap.
- ✓ Appearance of cracks in nearby structures.

2.2.2 Laboratory Identification

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

2.2.2.1 Mineralogical Identification

Clay mineralogy is a fundamental factor controlling expansive soil behavior. Clay minerals can be identified using a variety of techniques. The common type of these techniques that can be used are: X-ray diffraction, Differential thermal analysis, Dye adsorption, Chemical analysis and Electron microscope resolution. But these methods are not suitable for routine tests because: They are time consuming; they require expensive test equipment; and the results can only interpreted by specially trained technicians (Chen, 1988).

2.2.2.2 Direct Methods

These methods offer the most useful data by direct measurement; and tests are simple to perform and do not require any expansive laboratory equipment. Testing should be performed on a number of samples to avoid erroneous conclusions. Direct measurement of expansive soils can be achieved by the use of conventional one-dimensional consolidometer (Chen, 1988).

2.2.2.3 Indirect Methods

In this method simple soil property tests can be used for the evaluation of swelling potential of expansive soils using swelling test. Which indirectly give information about the soil property. Such tests are easy to perform and should be included as routine tests in the investigation of expansive soils (Chen, 1988). Such tests may include:

i) Atterberg Limits

In this method, measurements of the atterberg limits of the soil are conducted for identification of all soils and provide a wide acceptable means of rating. 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. 1: Relation between the swelling potential and the plasticity index (Chen, 1988).

Swelling Potential	Plasticity index
Low	0-15
Medium	10-35
High	20-35
Very high	>35

Ministry of Works and Unban Development of Ethiopia (2009) described that in Ethiopia all grayish or brownish clays with plasticity index greater than 25% can be identified as expansive. The classification or rating from low potential to high heaving potential usually depends on the clay content and plasticity.

ii) Free Swell Tests

The free swell test may be considered as a measurement of volume change in clay upon saturation and is one of the most commonly used simple tests to estimate the swelling potential of expansive clay.

Experiments indicated that a good grade of high swelling commercial bentonite will have a free swell of from 1200 to 2000%. Soils having a free swell value as low as 100 percent can cause considerable damage to lightly loaded structures, and soils having a free swell value below 50 percent seldom exhibit appreciable volume change even under very light loadings. The free swell of the soil is determined as the ratio of the change in volume to the initial volume, expressed as a percentage (Nelson D. and Miller J., 1992).

$$FS=\left(\frac{V_F-V_I}{V_I}\right)*100 \quad \text{……… 2.1}$$

Where: FS = free swell,

VI =initial volume &

VF =final volume

iii) Free Swell Index

Free swell index is also one of the most commonly used simple tests to estimate the swelling potential of expansive clay. The procedure involves in taking two oven dried soil samples passing through 425μm sieve, 10cc each were placed separately in two 100ml graduated soil sample. Distilled water was filled in one cylinder and kerosene in the other cylinder up to 100ml mark. The final volume of soil is computed after 24hours to calculate free swell index. The free swell index is then calculated using Equation below (Al-Rawas, 2006).

Free swell index= $\left(\frac{V_w - V_k}{V_k}\right)$*100 ……………………………………………..…… 2.2

Where: Vw = final volume in water,

Vk = final volume in kerosene

The relation between the degree of expansion and differential free swell index is shown in Table 2.2. It is normal to quantify 10cc as the volume occupied by 10g of soil. This does not account for variations of density (Al-Rawas, 2006).

Table 2. 2: Degree of expansion and differential free swell index (Craig, 1997)

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

iv) 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 Equation (2.3).

Free swell ratio = $\left(\frac{V_w}{V_k}\right)$*100 …………….…………………………… 2.3

Where: Vw = final volume in water,

Vk = final volume in kerosene

The relation between the degree of expansion and differential free swell ratio is given in Table 2.3.

Table 2. 3: Classification of Soils based on free swell ratio (Craig, 1997)

Free Swell Ratio	Soil Expansivity	Clay Type
<1	Negligible	Non-Swelling
1.0-1.5	Low	Mixture of non Swelling & Swelling
1.5-2.0	Moderate	Swelling
2.0-4.0	High	Swelling
>4	Very high	Swelling

2.3 Classification of Expansive Soils

Parameters determined from expansive soil identification tests have been combined in a number of different classification schemes. The classification system used for expansive soils are based on indirect and direct prediction of swell potential as well as combinations to arrive at a rating. There are a number of classification systems. The following are some of the common methods.

2.3.1 Classification Using General Methods

The most widely used general classification systems are:

2.3.1.1 AASHTO Classification

As shown on Table 2.4, soils rated A-6 or A-7 by AASHTO can be considered potentially expansive.

Table 2. 4: AASHTO soil classification chart (Nelson D. and Miller J., 1992).

General Classification	**Granular Materials (35% or less of total samples passing No.200)**							**Silt-clay Materials (More than 35% of total sample passing No.200)**			
Group classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
Sieve analysis percent passing	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				
2mm(No10)	50 max										
425μm(No40)	30 max	50 max	51 min								
75 μm (No200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of friction 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 type of significant constituent materials	Stone fragments - gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soil		Clay soils	
General rating as subgrade	Excellent to good					Fair to Poor					

2.3.1.2 Unified Soil Classification Systems

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

<u>Category Soil classification system</u>

Little or no expansion: GW, GP, GM, SW, SP, SM

Moderate expansion: GW, SC, ML, MH

High volume change: CL OL, CH, OH

No rating: PT

The above classification system can be summarized as follow:

a. All clay soil and organic soils exhibit high volume change.

b. All clayey gravels and sands and all silts exhibit moderate volume changes.

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

2.3.2 Classification Specific to Expansive Soil

The above classification system may give an initial alert that the soil may have expansive character but it does not provide useful information. A parameter determined from the expansive soil identification tests have been combined in a number of different classification schemes to give qualitative rating on the expansiveness of the soil. But the direct use of such classification systems as a basis for design may lead to an overly conservative construction in some places and inadequate construction in some areas (Nelson D. and Miller J., 1992). Hence, it is very important to emphasize that design decision has to be based on predicting testing and analysis, which provide reliable information. An indirect prediction of swell potential includes correlations based on index properties, swell and a combination of them. Some of such classification systems are:

i) **Method of Chen** (Chen, 1988) presented a single index method for identifying expansive soils using only plasticity index. Chen suggested four classes of clays according to their plasticity indices shown in Table 2.5.

Table 2. 5: Relation between the swelling potential of clays and the plasticity index (Chen, 1988).

Swelling Potential	Plasticity index
Low	0-15
Medium	10-35
High	20-35
Very high	>35

ii) **Method of Daksanamurthy and Raman (1973) Daksanamurthy and Raman (1973)** presented a single index method for identifying expansive soils using only liquid limit.

They suggested four classes of clays according to their liquid limits as shown in Table 2.6 (Al-Rawas, 2006).

Table 2. 6: Relation between the swelling potential of clays and the liquid limit (Al-Rawas, 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) USBR Method

This method is developed by Holtz and Gibbs; it is based on the simultaneous consideration of several soil properties. The typical relationships of these properties with swelling potential are shown in Table 2.7.

Table 2. 7: Classification based on united state bureau of reclamation method (Chen, 1988).

Colloid Content (%)	Plasticity index (%)	Shrinkage Limit (%)	Probable Expansion (%)	Degree of Expansion
<15	<18	>15	<10	Low
13-23	15-28	10-16	10-20	Medium
20-31	25-41	7-12	20-30	High
>28	>35	<11	>30	Very high

iv)Activity Method: This method proposed by seed, et.al. After an extensive study on swelling characteristics of remolded, artificially prepared and compacted clays (Chen, 1988) have developed a chart based on activity and percent clay sizes as shown in Figure 2.4. The activity here is defined as:

$$Ac = \frac{PI}{C-10} \quad \ldots\ldots 2.4$$

Where: Ac= activity,

C= percentage of clay size finer than 0.002mm,

PI= plasticity index

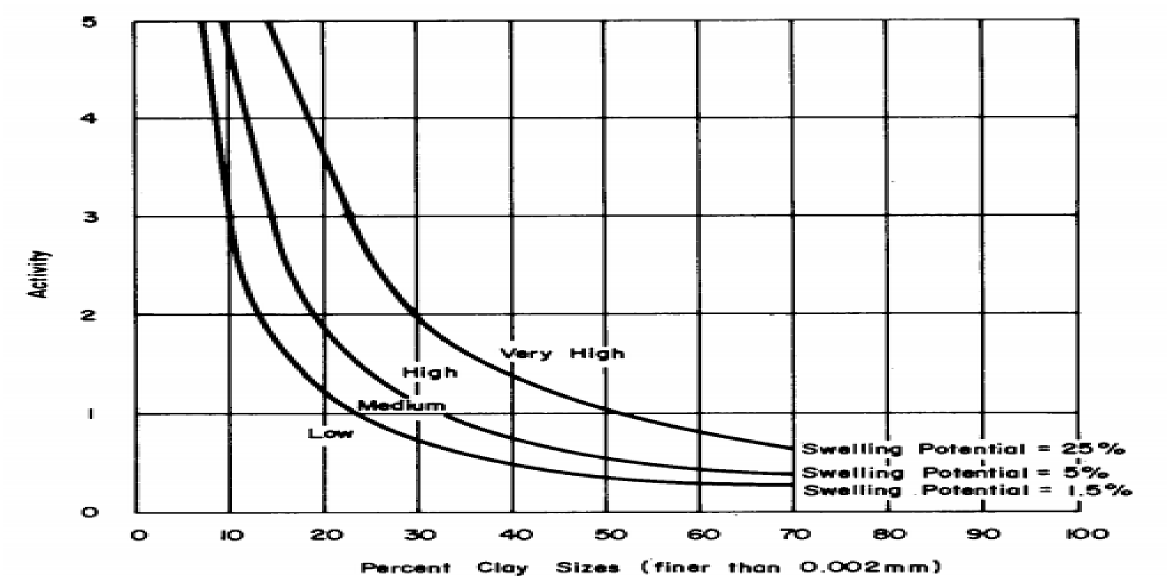

Figure 2. 2: Classification chart for swelling potential (Chen 1988).

v) Method of Skempton

This method is developed, by combining Atterberg limits and clay content into a single parameter called Activity. Activity is defined as:

$$\text{Activity (Ac)} = \frac{\text{Plasticity Index}}{\text{Percentage by weight finer than } 2\mu\text{m}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2.5$$

Skempton suggested three classes of clays according to their activity shown in Table 2.8.

Table 2. 8: Relation between clay activity and potential of expansion (Craig, 1997)

Activity	Potential of expansion
Ac < 0.75	Low (inactive)
0.75 < Ac < 1.25	Medium (normal)
Ac > 1.25	High (active)

2.4 Characteristics of Expansive Soils

Expansive soil is the term generally referred to any soil or rock that has potential for shrinking or swelling under changing moisture condition. The primary problem that arises with regard to expansive soil is that the deformations are significantly greater than elastic deformations and they cannot be predicted by classical elastic or plastic theories. Movement is usually in uneven pattern and of such a magnitude that it causes extensive damage to the structures and pavements resting on it (Fitsim Markos, 2018).

Soils usually encounter as sub-grade material during any road construction project and these sub-grade soils may vary from highly expansive to non-expansive in nature. Therefore, these sub-grade soils should be sufficiently investigated since the stability and performance of the pavements are greatly influenced by the nature of sub-grade soil as it serves as foundations for pavements. Essentially expansive soil is one that changes in volume in relation to changes in water content. These materials swell, and increase in volume, when they get wet and shrink when they dry (Chen, 1988).

Expansive soil is a term generally applied to any soil or rock material that has a potential for shrinking or swelling under changing moisture conditions. Subsequent swelling and shrinkage of this soil due to change in moisture cause damages to different structures, particularly light weight buildings and pavements such as this road project when available during investigation (Hemanta, 2015).

Expansive soils absorb water heavily, swell, become soft and lose strength. These soils are easily compressible when wet and possesses a tendency to heave during wet condition and shrink in volume and develop cracks during dry seasons of the year. These soils are characterized by extreme hardness and cracks when dry. Soils are called highly expansive when the free swell index that exceeds 50% and such soils undergo volumetric changes leading to pavement distortion, cracking and general unevenness due to seasonal wetting and drying (Rao, 2007).

Some partially saturated clayey soils are very sensitive to variations in water content and show excessive volume changes. Such soils, when they increase in volume because of an increase in their water contents, are classified as expansive soils (Das, 2010).

Expansive soils are found throughout many regions of the world, particularly in arid and semi-arid regions, as well as where wet conditions occur after prolonged periods of drought. Their distribution is dependent on geology (parent material), climate, hydrology, geomorphology and vegetation. Expansive soils occur and incur major construction costs around the world, with notable example found in Argentina, Australia, Canada, India, Ethiopia, Ghana and South Africa to name but a few. This indicates that the potentially expansive soils are confined to the semi-arid regions of the tropical and temperate climate zones. Expansive soils are in abundance where the annual evapotranspiration exceeds the precipitation (Chen 1988).

2.5 Problems caused Due to Expansive Soil

Roads are vital to link our communities and sustain the economy and quality of life in society. Roads constructed over the expansive soil observed with high maintenance expenditure in spite of high capital cost. This Problems Associated with Expansive Soils is very sensitive. Expansive soils occurring above water table undergo volumetric changes with changes in water content. Increase in moisture content causes the following effects:
1. Swell - Shrink Characteristics- This causes significant volume changes resulting severe damage to the foundations, buildings, roads retaining walls, canal linings, etc.

2. Horizontal Thrust- Increased water content in the soils adjacent to the foundation wall will cause the soils to expand and increase the lateral pressure applied to the foundation wall and it will cause minor cracking, bowing or movement of the wall and serious structural damage to or failure of the wall may occur.

3. Creep and Landslide - Expansive clay stone soils found as a layer under a more rigid top layer of soils, become unstable as the moisture content increases, allowing the clay stone and top layers of the soil to move. If the soil is located on a slope, the top layer of soil can creep

downhill or even cause a landslide. Consequently, a house with a weak foundation built on unstable slopes can be subjected to creeping of the structure downslope or to failure of the structures in a landslide.

4. Typical Structural Distress Patterns:-Buildings in arid areas tend to experience an edge lift, and conversely, in humid climates, the expansive soils may shrink when it dries, causing the edge to depress. The difference in water content between the interior and exterior of a building causes uplift force on the interior footings and walls, shrinkage settlement of the exterior walls and lateral thrust on the exterior walls.

5. Differential Settlement :- This can cause cracking, rutting and deformation in general distresses on road and runway pavements, failure of drainage structures (Bridges, Culverts) etc. the differential settlements creates series of bumps or corrugations, potholes on different road sections in various parts of the country which inturns reduces the riding quality of roads.

6. Bearing capacity:- When unsuitable expansive soil appears as the moisture content increases, expansion occurs and the bearing strength of this expansive soil decreases dramatically. The CBR may be reduced to less than 2 if the soil becomes completely saturated.

7. Susceptibility to erosion:- Similarly as mentioned above for this road when unsuitable expansive soil appears when they are or become dry, this expansive soil may present a sand like texture. In this state, they are prone to erosion to a much greater extent than that normally anticipated from their plasticity and clay content. (ERA, 2002)

2.6 How to overcome problems caused due to expansive soil

When dealing with expansive soils a number of approaches should be considered and include:

- ✓ Choose an alternative route and avoid expansive soil;
- ✓ Remove and replace expansive soil with a non-expansive alternative
- ✓ Design for a low strength and allow regular maintenance

- ✓ Physically alter expansive soils through disturbance and re-compaction
- ✓ Stabilization through chemical additives, such a lime treatment
- ✓ Control water content changes although very difficult over the life of a pavement.

Expansive soils are generally found in the Highlands and low lands of the Ethiopia. These soils undergo volumetric changes upon wetting and drying, thereby causing ground heave and settlement problems. This characteristic causes considerable construction defects if not adequately taken care of. Expansive soils are a worldwide problem that has several challenges for civil engineers. Such soils swell when given an access to water and shrink when they dry out. The most common and economical method for stabilizing these soils is using mechanical stabilization that prevent volume changes. The presence of montmorillonite clay mineral in expansive soils imparts them high swell–shrink potentials. Low rainfall has hindered the weathering of the active montmorillonite mineral into low active clay types such as illite and kaolinite. Further, the rainfall has not been sufficient to leach the clay particles far enough so that the overburden pressure can control the swell (Al-Rawas, 2006).

Different methods have been conducted to enhance and treat the geotechnical properties of the Expansive soils (such as strength and the stiffness) by treating it in situ. These methods include densifying treatments (such as compaction or preloading), pour water pressure reduction techniques (such as dewatering or electro-osmosis), the bonding of soil particles (by ground freezing, grouting, and chemical stabilization), and use of reinforcing elements such as geo textiles and stone columns (William P., 1997).

2.7 Soil Stabilization

Soil stabilization is the alteration of one or more soil properties, to create an improved soil material possessing the desired engineering properties. There are many methods of stabilizing soil to gain required engineering specifications. These methods range from mechanical to chemical stabilization. Most of these methods are relatively expensive to be implemented by slowly developing nations and the best way is to use locally available materials with relatively cheap costs affordable by their internal funds (Fikiri Fredrick Magafu, Wu Li, 2010).

The stabilization of soil is proved as the best alternative for the improvement of the expansive soil properties. By using the lime, cement, fly ash, Geo-textile materials, rice husk, ground nut shell, crushed seashell etc are used. But for the economical point of view locally available materials can be used as like sand, grit, stone dust etc. These materials as stabilizer also improve the properties of soil effectively. The mixture of this materials is increases the CBR value (soaked) of soil by 3-5%. It proves economical than the other (Vrunda Sule, Apr-2018).

When unsuitable materials are encountered measures like avoiding the route, redesigning the pavement with thicker sections or replacing the poor soil with good quality materials are practical but increasingly expensive options. With improved technological advances and concern for reduction of non-renewable resources, improving the properties of soil using chemical additives is gaining increased popularity (Caterpillar, 2006).

Identification and characterization of expansive soils and determining their expansion potential is one of the major fears. This is specially the case when dealing with light weight structures like road infrastructures, airfields, and small buildings etc. (Day, 2001).

2.8 Methods of Soil Stabilization

2.8.1 Mechanical Stabilization

Mechanical stabilization can be defined as a process of improving the stability and shear strength characteristics of the soil without altering the chemical properties of the soil (Guyer, J. P., 2011.) It is common to use both mechanical and chemical means to accomplish specified stabilization. The main methods of mechanical stabilization can be categorized into compaction, mixing or blending of two or more gradations, applying geo-reinforcement and mechanical remediation (Caterpillar, 2006).

2.8.2 Chemical stabilization

Chemical stabilization is the mixing of expansive soil with one or a combination of admixtures of powder, slurry or liquid. Chemical stabilization results in the modification of the soil through chemical reactions taking place between the stabilizer and the minerals present in the soil. Among the various chemical stabilization techniques adopted for expansive soils, additive stabilization is most widely adopted for controlling the swell-shrink properties of expansive soils (Meron, 2016).

The addition of inorganic and organic chemical compounds can increase the strength, bearing capacity and durability of soils these chemical compounds perform mainly as cementations and binding agents or as waterproof or as water repellant agent. The changes in the consistency of clay soils induced by many of these compounds are also important. The addition of chemicals to the soils improves the geotechnical properties of soils. These chemical whether it is organic or inorganic chemical compounds which are acts as cementations and bonding action.

Chemical stabilization, in which chemicals are added to expansive clays for reducing heave, also met with success. Lime has been found to be the most effective and economical of all additives. Addition of lime to expansive soils reduces swell potential and increases workability and strength. Lime is the most effective and widely used chemical additive for expansive soils (Nelson D. and Miller J., 1992).

Cement, lime slag, fly ash, sodium silicate etc. are used as inorganic stabilizer whereas Bituminous materials are used as an organic stabilizer The addition of chemical agents such as cement, cement kiln dust fly ash lime or a combination of these to soils, result in the formation of cementations bonds between soil particles and stabilizers and the physical and mechanical properties of the soil are altering significantly (Chen, 1988).

2.9 General Review about Stone Dust and Brick Dust

Crushed stone dust is material obtained from aggregate crushing industries. Use of such stone dust materials creates lots of problems in environment and public due to excess storage and dust accumulation. Considering this aspect an experimental study was conducted on expansive soil by mixing it with locally available crushed stone dust. The paper reflects the visionary light on the suitability of crusher dust as soil stabilizer for use in pavement construction. The role of crusher dust in improving the characteristics of expansive sub grade material is analyzed. The analysis of the result shows the addition of crushed stone dust improve the geotechnical properties of soil. The addition crushed stone dust reduces PI, Swelling and the optimum moisture content with an increase in MDD& CBR with an increase of crushed stone dust. A considerable amount of cost savings is also possible when the expansive clay soil is stabilized with crusher dust (Abubekir Jemal, 2019).

Quarries and aggregate crushers are basic requisites for construction industry and quarry dust is a byproduct of rubble crusher units. Disposal of such wastes poses lots of geo environmental problems such as landfill disposal problems and environmental hazards. Geotechnical and mineralogical characterization of quarry dust and its interaction behavior with soils can lead to viable solutions for its large-scale utilization and disposal Utilization of Quarry Dust. Improvement in engineering properties of soil such as an increase the CBR value reduces permeability, increase the compressive strength and increase the shear strength. Stabilization of the Sub grade Soil by Adding Quarry Dust increases the durability of pavement subgrade and avoids pot holes in highway which is one of major failure as it reduces the plasticity soil and it also benefits the design cost of construction (I.Rohini, 2018).

The effect of stone dust on geotechnical properties of poor soil and concluded that the CBR and MDD of poor soils can be improved by mixing stone dust. They also indicated that the liquid limit, plastic limit, plasticity index and optimum moisture content decrease by adding stone dust which in turn increases usefulness of soil as highway sub-grade material (Bshara & Bind, 2014).

The stabilization of Expansive is done to improve the engineering properties by using quarry dust. The conducted series of tests and concluded that addition of quarry dust decreases Liquid limit, Plastic limit, Plasticity index, Optimum moisture content, Cohesion and increases shrinkage limit, Maximum dry density, Angle of internal friction of expansive soil (Sabat, 2012).

Experimental study was conducted on locally available soil by mixing it with Stone Dust. The effect of randomly distributed Stone Dust on MDD, OMC, Specific gravity and CBR has been discussed. The percentage of stone dust by dry weight of soil was taken as 10%, 20%, 30%, 40% and 50%. Laboratory experiments favorably suggest that mixing stone dust with soil would be effective in improving soil properties (Naman A., 2015).

The experimental study carried out to assess the utilization of stone dust to improve the Engineering properties of expansive soil. The modification of soil is carried out by addition of stone dust to original expansive soils by increasing percentage of 0%, 10%, 20%, 30%, 40%, 50% and 60%.The effect of stone dust on liquid limit, plastic limit, plasticity index, dry density, optimum moisture content and CBR values is considered. addition of stone dust showed considerable increase in maximum dry density and considerable reduction in optimum moisture content. Stone dust has high specific gravity and the soaked CBR value (Manish Dixit and Kailas Patil, August 2016).

Expansive type of soil shows unpredictable behaviour with different kind of stabilizers. Soil stabilization is a process to treat a soil to maintain, alter or improve the performance of soil. In this study, the potential of burnt brick dust as stabilizing additive to expansive soil is evaluated for the improving engineering properties of expansive soil. The evaluation involves the determination of the swelling potential, linear shrinkage, atterberg's limits, & compaction test of expansive soil in its natural state as well as when mixed with varying proportion of burnt brick dust (from 30 to 50%) (S. Lakshman, 2018).

The black cotton soil is known as expansive type of soil which expands suddenly and start swelling when it comes in contact with moisture. Due to this property of soil the strength and other properties of soil are very poor. To improve its properties it is necessary to stabilize he soil by different stabilizers. In this study, the potential of burnt brick dust as stabilizing additive to expansive soil is evaluated for the improving engineering properties of expansive soil. The evaluation involves the determination of the swelling potential, linear shrinkage, atterberg's limits, & compaction test of expansive soil in its natural state as well as when mixed with varying proportion of burnt brick dust (30%, 40%, and 50%) with expansive soil (Sachin N. Bhavsar, December 2014).

Many times for various engineering purposes the Expansive soil does not have required soil properties and does not match the desired standards, in such cases the soil properties need to be upgraded. Brick Kiln Dust and Calcium Chloride are used in order to stabilize the weak soil and achieve desired strength. The results achieved showed that by adding brick kiln dust and calcium chloride the strength of soil can be enhanced to match the desired standards (Sayed Sohail Kazmi, Nov 2019).

Burnt brick powder is a waste powder generated from the burning of bricks with the soil covered by surroundings. Due to burning of soil bricks it hardened and at the time of removal the setup we get the powder form of brick. It has great ability to reduce the swelling potential of Expansive soil. Brick powder is a waste material available in abundance at brick kilns, is rich in silica and is available at very cheap cost. Chemical analysis of brick powder showed rich composition of silica of about 55% along with minor compositions of iron oxide (8%), aluminum oxide (15%), calcium oxide (7%), magnesium oxide (2%), and sulfur trioxide (1%) (Ali Aliabdo, 2014). Clay is responsible for the pozzolanic behavior of brick. Clay itself has no pozzolanic properties but when fired during brick making process it gains pozzolanic nature. (Rogers, 2011).

One of the main problems in the construction of bituminous paving mixture is the insufficiency amount of filler from crushing stone aggregate and cement supply is low. And also there is abundance of the brick material around jimma zone and used as filler in bituminous paving mix, it may save considerable investment; as well as reliable performance of the in-service highway can be achieved (Fisseha Wagaw, 2018).

A successful construction of highway requires the construction of a structure that is capable to carry the anticipated loads. In order to achieve this aim many studies have been conducted to select the suitable materials. Due to availability of brick dust and stone dust around Jimma zone this study investigate and compare the improvement of expansive soil with this local materials and it can be minimize the cost we offer for other stabilizing material like Cement and lime; also it is waste management.

CHAPTER THREE

3. MATERIALS AND RESEARCH METHODOLOGY

This chapter refers the approaches and techniques that the way to work the research in order to solve and overcome the problem that is happened due to expansive soil. It includes the Description of study area, sampling techniques, the procedure, data collection methods, the procedure of analysis of the data and the way of the study worked.

3.1 Study area Description

The study area is found in southwestern Ethiopia, Jimma town, Jimma is located 356km Southwest of Addis Ababa capital city of Ethiopia. It has latitude and longitude of 7°41'N and 36°50' E respectively. Also, its average elevation is 1780 m-2000m above sea level. The climatic condition of Jimma Town is considered as ideal for agriculture as well as human settlement. The town covers a total area of 18,412.54 square kilometers. The Town has a temperature that ranges from 20-30°C (https://en.wikipedia.org/wiki/Jimma).

Jimma is predominantly covered with red, black and gray soils. The red colored soils are found on rolling topography with higher elevation and well drainage condition. The black and gray soils, which cover the central and large part of the town, are found on flat topography of the town with lower elevation and unfavorable drainage condition (Jemal J., 2014.).

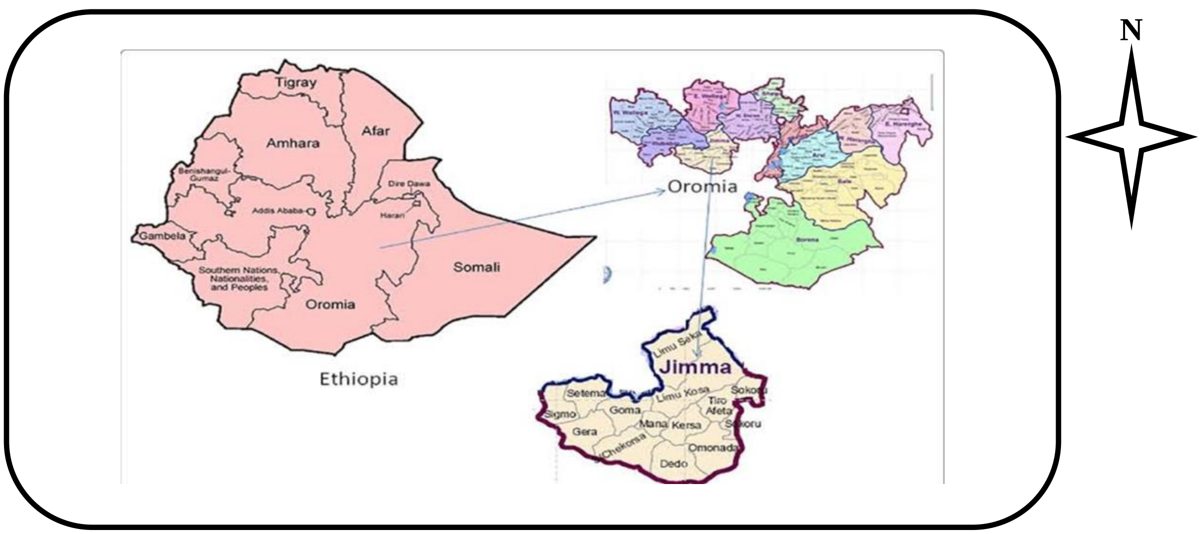

Figure 3. 1: Geographic location of jimma town

3.2 Study design

The research design was based on a purposive sampling. Selection processing of representative sampling focused on the area affected by expansive soil. The research methodologies that were used are quantitative and experimental approach so as to achieve the desired objective. The purpose of the research is to determine the effect of modifying expansive soil by using stone dust and brick dust to improve its engineering properties. To achieve the objective of the research the necessary step which took were mentioned as follows:

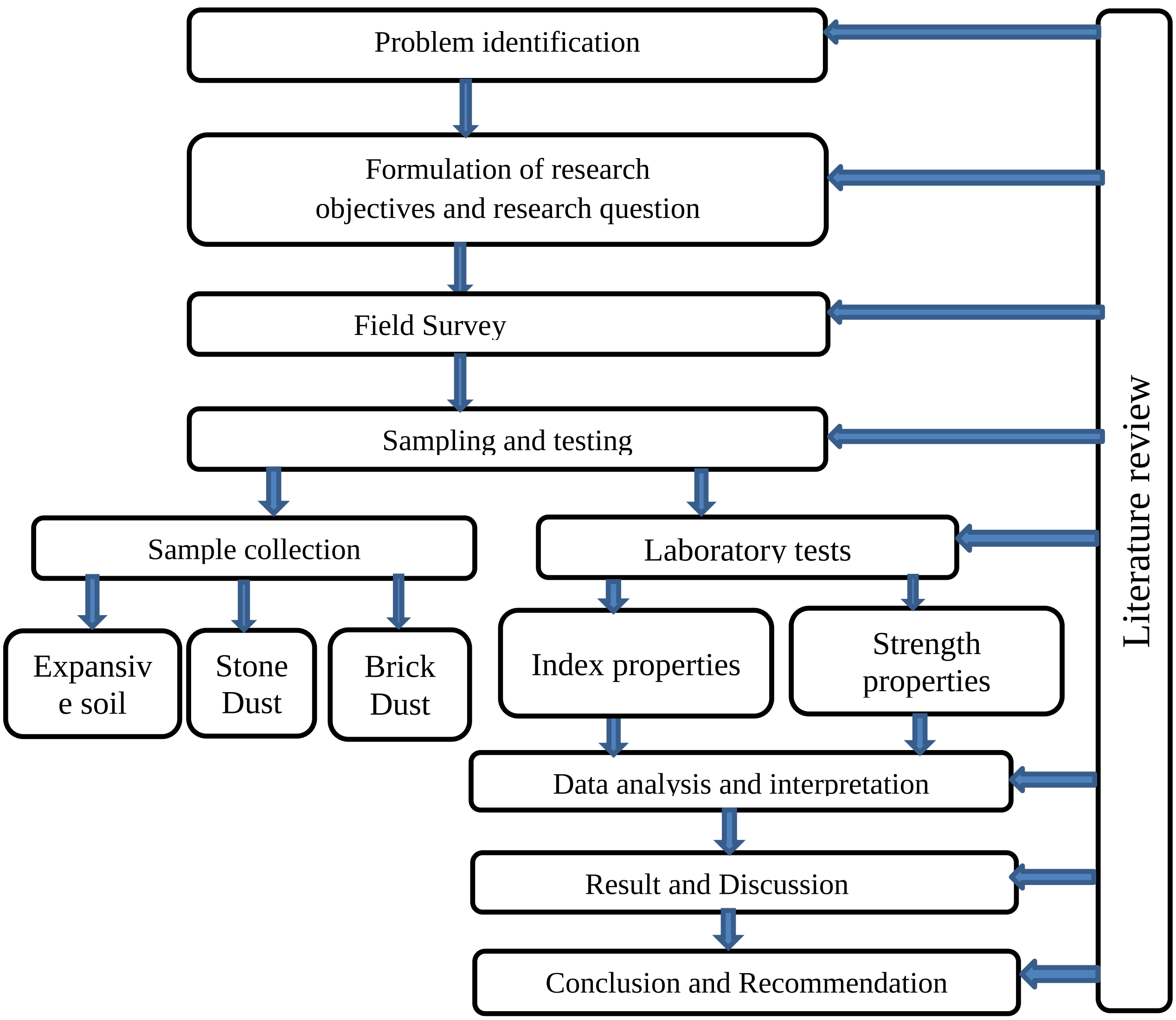

Figure 3. 2: Flow chart of Research design

3.3 Sample size and selection

The selection of sites for excavation is based on visual identification and by considering previous researches that are done on investigation of engineering properties of soil found in Jimma town. For this study expansive soil samples collected from Two test pits at depth below 1.5m for different geotechnical laboratory tests like; moisture content, Atterberg limits, compaction, specific gravity, grainsize analysis, free swell, and CBR tests performed on natural and modified expansive soil with stone dust and brick dust as per AASHTO and ASTM laboratory test standards. Based on the theories and laboratory tests performed, the results obtained were analyzed, compared and discussed thoroughly.

3.4 Sampling techniques and procedure

For this study, purposive sampling technique used to obtain representative soil sample. Disturbed soil samples for detail laboratory testing collected from two test pits at a depth below 1.5m in order to avoid the inclusion of organic materials. Excavation was made by hand, using shovel and samples collected manually and taken to Jimma university Soil testing laboratory.

For this study, the stone dust Samples were taken from the Ofole quarry site (crusher) in jimma and brick dust from jimma town merewa area brick production. The soil samples were collected from two different locations of jimma Town namely Shanan Gibe around jimma bus station (Ss1), and merkato (Ss2). The locations were selected by visual observation and by considering previous researches.

Then, laboratory experiments carried out according to ASTM and AASHTO soil testing standard procedures. In order to obtain the final results, first modifying materials preparation and testing was performed. Then based on the test results, expansive soil modifying materials proportioning was done by using different percentage of stone dust (5%, 10%, 15%, 20%, 25%, 30%) and Brick dust (5%, 10%, 20%, 30%, 40%, 50% and 60%). The optimum percentage required to achieve the research is at 20% of stone dust and 40% of Brick dust.

3.6 Study variable

3.6.1 Independent variables

In this study, The independent variables which is measured and manipulated to determine its relationship to observed phenomena are; moisture content, Gradation, Atterberg Limits (LL, PL, PI), Compaction (OMC , MDD), and CBR values.

3.6.2 Dependent variables

The dependent variables which are to be observed and measured to determine the effect of the independent variables are the optimum percentage of stone dust and brick dust used for stabilizing expansive soil.

3.7 Data collection process

Data obtained from laboratory tests to investigate and compare the performance of expansive soil modified with stone dust and brick dust for subgrade material. The soil samples and the stabilizers (stone dust and brick dust) samples were collected from jimma town. The laboratory Test conducted to investigate the effect of stone dust and brick dust on the CBR, Compaction (MDD and OMC), and index properties of expansive soil. The expansive soil was modified with stone dust and brick dust in varying percentages in order to get the required strength. The test result of the experiment meet with ERA standard and specifications used for the required structure.

3.7.1 Field survey

During this stage literature review and Preliminary visual survey were conducted on Jimma town expansive soil. Engineering geological map of Jimma town was used and visual identification of soils around the study area was conducted.

3.7.2 Laboratory tests

Various laboratory tests are used to identify and study the properties of soils. There are different tests to identify the Engineering properties of the soil. The standard laboratory specification used for this study was adapted from ASTM and AASHTO standards. The adapted standards for the study are presented in table 3.1.

Table 3. 1: Standard Testing Procedures

No.	Name of Test	ASTM	AASHTO
1	Specific Gravity	D 854-83	
2	Grain Size Analysis	D422-63	
3	Atterberg Limits	D4318-98	
4	Soil classification	D2487-98	
6	Modified compaction		T 180-95
7	CBR		T 193-93

In this study, different activities were carried out; from field soil identification up to the documentation of the paper. Generally, the study has three main stages in order to complete the research. The first was The-fieldwork stage. During this stage literature review and site selection for representative sample was selected. The second one is the field and laboratory work stage; in this stage the soil samples, stone dust and brick dust sample bringing to the laboratory and test was conducted. The last one is post fieldwork stage. The results from laboratory test, analysis of the test results was including interpretation and finally report preparation prepare.

The significance of the stabilizer for expansive soil strength improvement was studied by modifying stone dust and Brick dust with the collected samples in different percentages of stone dust at 0%, 5%, 10%, 15%, 20%, 25%, 30% and brick dust at 5%, 10%, 20%, 30%, 40%, 50%, 60% used to Perform the laboratory test. The laboratory tests conducted include determination of the Atterberg limits, compaction characteristics, and California Bearing Ratio (CBR) of treated expansive soil with stone dust and brick dust.

3.8 Sample Preparation

Sample Preparation Prior to treatment and testing, the sample prepared in accordance with the method described in AASHTO T87-86. This method involves air drying of samples and/or oven drying at 60ºC or less; breaking up the soil aggregates by rubber covered mallet.

Then, sieve analysis is performed to separate the dried soils into two groups. The first group involves preparing uniform samples for Atterberg limits, free swell, free swell index, and free swell ratio, the other for compaction and California bearing ratio tests. Then, soil - stone dust and brick dust mixed manually to get a uniform mix ratio for each test. Based on the theories and laboratory tests performed, the result obtained were analyzed, compared and discussed thoroughly.

3.9 Data Processing and Analysis

In this research data were obtained from laboratory tests to investigate and stabilize the soil sample with stone dust and brick dust. After sorting out the effective data, the numerical portion of the data were analyzed using Excel software, charts, tables, figures and other problem solving methodologies. A comparison of results attained of the stabilized expansive soil with road design manual requirements for a material being used as the sub-grade material were done using the ERA manual and reference with different design standards.

3.10 Laboratory testing procedures

3.10.1 Natural moisture content

Moisture content is the ratio of the mass of water to the mass of solids in the sample expressed as a percentage. The purpose of this study is to determine the water (natural moisture) content of the soils. The test conducted by drying the soil specimen in an oven at a temperature of $110° \pm 5°C$ to a constant mass. The loss of mass due to drying is considered to be water. The water content is calculated using the mass of water and the mass of the dry specimen.

3.10.2 Free Swelling

The free swelling test is used to determine the increase in the volume of soil without any external constraint when the sample of the soil subjected to submergence in the water. The free swell test is conducted by using 10gm of dry soil passing through sieve No 40 sieve. The swollen volume of samples are recorded as per IS 2720 part 40 (1977).

$FS=[\frac{Vf-Vo}{Vo}]*100$ Where: FSI = Free Swell,

Vf = Final volume in water,

Vo= volume of soil initial reading (volume of soil in kerosene)

3.10.3 Sieve Analysis

Sieve analysis test allows the determination of the distribution of particles sizes in materials. For present study (ASTM D422-63) method was used for analysis and the type of sieve used was wet sieve analysis. This test was aimed that the particle size distribution or gradation of the disturbed soil sample used for the sample particle distribution.

3.10.4 Hydrometer Analysis

Hydrometer analysis is primarily used to know the grain size distribution of a fine-grained soil having particles sizes smaller than 75μm using Hydrometer. Hydrometer analysis is based on Stokes law. According to this Law, the velocity at which grains settle down out of suspension, all other factors being equal, is dependent upon the shape, weight, and size of the grain size of the particles. Hydrometer analysis is a widely used method of obtaining an estimate of the distribution of soil particle sizes from the No. 200 (0.075 mm). A hydrometer test is conducted on 50gm of soil sample passing sieve No.200. The soil sample was soaked in chemical solution (Sodium hexa-meta phosphate) for 24 hours.

3.10.5 Specific Gravity

Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature. The importance of determining the specific gravity in this study is to determine particle sizes in hydrometer analysis. Specific gravity is defined as the ratio of the mass of a given volume of a material to the mass of an equal volume of water. In effect, it tells us how much the material is heavier than (or lighter) than water. The particular specific gravity of a soil actually denotes the specific gravity of the solid matter of the soil and refers, therefore, to the ratio of the mass of solid matter of a given soil sample to the mass of an equal volume (i.e equal to the volume of the solid matter) of water.

3.10.6 Atterberg Limits Tests

The Atterberg limits are a basic measure of the nature of a fine-grained soil. Depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic and liquid. It is based on a change in the soil's behavior. Determining the Atterberg's limits also used to compare the atterberg limit of engineering properties of soil with the other engineering behavior of soils, which helps to easily determine the other engineering properties soil; on the other hand, Atterberg limit can be used to differentiate between silt and clay, distinctions in a soil are used in assessing the soils that are to have structures built on them. Soils when wet retain water, and some expand in volume. The amount of expansion is related to the ability of the soil to take in water and its structural make-up. These tests are mainly used on expansive clay soils since these are the soils that expand and shrink due to moisture content. Clays and silts react with the water and thus change sizes and have varying shear strengths, these tests are used widely in the preliminary stages of designing any structure to ensure that the soil were used to get required amount of shear strength and not too much change in volume as it expands and shrinks with different moisture contents.

A wide variety of soil engineering properties have been correlated to the liquid and plastic limits, and these Atterberg limits are also used to classify a fine-grained soil according to the Unified Soil Classification system or AASHTO system.

The test procedure used for this study was *ASTM D 4318 -98* Standard Test Method. Representative soil samples were subjected to Atterberg limits testing to determine the plasticity of the soils. An Atterberg limits device was used to determine the liquid limit of each soil using the material passing through No. 40 sieve. The plastic limit of each soil was determined by using soil passing through a 425 µm sieve and rolling 3-mm diameter threads of soil until they began to crack. The plasticity index was then computed for each soil based on the liquid and plastic limit obtained. The liquid limit and plasticity index were then used to classify each soil.

3.10.7 Modified Compaction Test

The laboratory compaction test is being performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort. This test is a laboratory method of experimentally determining the optimum moisture content at which a given soil type will become compacted, dense and achieve its maximum dry density.

In general, the engineering properties expansive soil improves the geotechnical properties of the soil, by increasing the density of the soil. This test was done to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the sample material.

3.10.8 California Bearing Ratio (CBR)

The CBR test is one of the most commonly used methods to evaluate the strength of a sub grade soil, sub base, and base course material. The CBR value for a soil depends upon its density, moisture content, and moisture content after soaking.

The CBR values are determined by the force needed to penetrate the plunger 2.54 mm, and 5.08 mm into the compacted specimens. The method uses material passing 19 mm size and provides the CBR value of material at optimum water content. The specimen shall be soaked before penetration. A surcharge is placed on the surface to represent the mass of pavement material above the base course. Expansion of the sample is measured during soaking to check for potential swelling. To determine the strength and swelling potential of the samples, a test has been carried out by 4-days soaking three point CBR and loaded Swell testing procedure. The material strength has been used for design purpose by interpolating the CBR values at different compaction levels, with 10, 30 and 65 blows and compacting in 5 layers by heavy compaction. Water to be added was calculated from compaction test results which are the OMC obtained at MDD and by considering the natural moisture content of the material on the test.

The investigation of the possibility to use the modifying expansive soil with stone dust and Brick dust for construction purpose depends on the bearing capacity of the soil in order to carry the load applied on it, therefore it is very important to analyze the bearing capacity of the soil whether it satisfies the required design standard for all-cause, and it is also important to state which ratio of the blended soil percentage satisfy which type of grade requirement for construction of sub grade of a highway. The laboratory CBR test is generally carried out on remolded samples. The sample should be compacted to the expected field dry density of the appropriate water content.

They are two types of CBR - one point CBR and three point CBR. Three points is recommended to get good and accurate result. Between the two types there is difference is in the number of molds and layers. If the process is within one point CBR The value is expected 100% and required one mold and 56 blows 5 layers, within three points CBR Value is expected greater than 95% and required three molds, 10 blows 30 blows and 65 blows The CBR values were determined at 2.54mm penetration of 95% of MDD for the sub-grade. The CBR values that present study was get in 2.54mm is greater than that of the CBR Value of 5.08mm. To consider the worst case, the sample was soaked for 4 days. So in this study the sample was soaked for 96 hours. The 95% of maximum dry density of the sample was founded by multiplying the Maximum dry density at each sample. It means a compaction attained in filled is 95% of the relative density.

Swell ratio= (Reading after soaking – Reading before soaking)/Height of specimen * 100

The Height of the specimen is calculated from the Height of mold minus the height of base plate and height of disk plate. The height of mold that the present study was used are 172.5mm and the height of disk plate and base plate is 10mm and 50mm respectively. This result becomes=172.5-(10+50) =112.5mm and the swelling calculated as; Swell%= (h final-h initial)/hs * 100.

According to AACRA design manual suitability of sub-grade soils based on CBR values were presented in table 3.2.

Table 3. 2: Suitability of sub grade materials based on CBR values adapted from (AACRA, 2004).

Soil class based on USCS	Typical Design CBR value (%)	Suitability
GW	40-80	Good to Excellent
GP	30-60	Good to Excellent
GM	40-60	Good
GC	20-30	Good
SW	20-40	Good
SP	10-40	Fair to Good
SM	15-40	Fair to Good
SC	4-20	Poor to Fair
ML	15 or less	Poor to Fair
CL	15 or less	Poor to Fair
OL	5 or less	Poor
MH	10 or less	Poor
CH	15 or less	Poor to Fair
CH	5 or less	Poor

3.10.9 Classification of the Soil

The purpose of soil classification is to make the possible estimation of soil properties by a relation with soils of the same class whose properties are known and to provide the geotechnical engineers, classify soils according to their engineering properties as they relate to use for foundation support or building material. The classification system for soils is unified soil classification system (USCS) and AASHTO soil classification system.

AASHTO classify the soil into seven major groups: A-l up to A-7. Soils classified under groups A-1, A-2, and A-3 are granular materials of which more than 35% or less of the particles pass through the No. 200 sieve. Soils of which more than 35% pass through the No.

200 sieve are classified under groups A-4, A-5, 4-6, and A-7. And the USCS classifying the minerals and organo-mineral soils for engineering purposes based on laboratory determination of particle-size.

3.11 Experimental Design

For this study the collected soil samples were highly expansive clay soils. Since the soil samples do not full fills the standards, they need modification. The modifiers used for this study were stone dust and brick dust. Based on the literature review and physical properties of the materials, the ratio of stone dust used for this study was from 5% - 30% and Brick dust from 5% - 60% by weight and using these locally available materials for improving engineering properties of expansive soils is an economical solution for jimma town as it is available in large quantity.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

This chapter presented the laboratory test results of expansive soil and the effect of expansive soil modified with stone dust and brick dust for subgrade construction purpose. The expansive soil samples were mixed with the stone dust and brick dust of varying proportion by weight. The laboratory test such as: Atterberg's limit, gradation test, compaction and CBR are carried out on expansive soil modified with stone dust and brick dust for the improvement of engineering properties of subgrade soil.

4.1 Laboratory Test Result of Expansive Soil Sample

In this study for the determination engineering properties of natural soil; laboratory tests such as: Natural moisture content, specific gravity, Free Swell, Atterberg limit, compaction characteristics and CBR tests conducted on expansive soil. The detailed result of these test are presented here under.

4.1.1 Natural moisture content

The purpose of this test is to determine the water (natural moisture) content of the soils. The summary of moisture content for expansive soil samples were tabulated in table 4.1.

Table 4. 1: Summary of Natural soil moisture content of soil samples

Sample No.	Natural moisture content
Ss1	37.36%
Ss2	47.07%

4.1.2 Specific Gravity

The importance of determining the specific gravity in this study is to determine particle sizes in hydrometer analysis. This test was conducted on fined grained particles of materials used for the study and summary of the test results are tabulated as followed in Table 4.1.

Table 4. 2: summary of Specific Gravity analysis for the soil samples

Soil Sample No.	Specific gravity of soil (ASTM D-854-83)
Ss1	2.49
Ss2	2.52

As Table 4.2 showed that soil sample 1 has an average specific gravity of 2.49 and soil sample 2 has an average specific gravity of 2.52. This value was used in determination of particle sizes of soil in hydrometer analysis.

4.1.3 Particle size distribution

The determination of grain size analysis can be performed by two ways one is by mechanical analysis and the other is by hydrometer analysis. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles. For this study both wet sieve analysis and hydrometer analysis was done. The tabular experimental results are presented in appendix and the combined particle size distribution curves are shown in Figure 4.1.

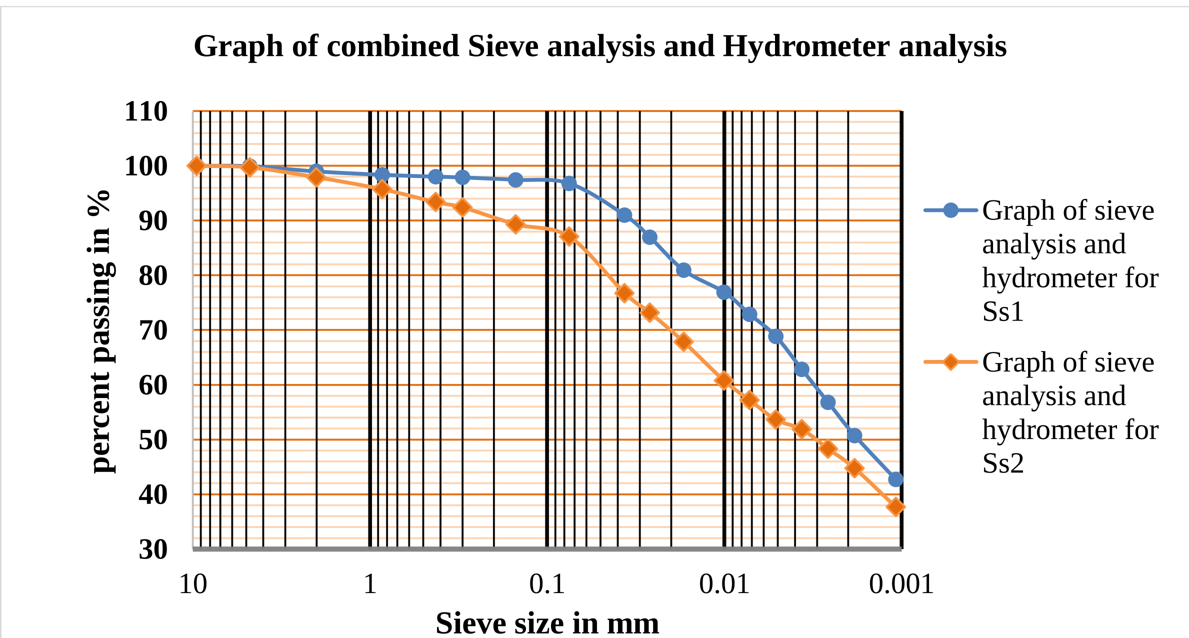

Figure 4. 1: particle size distribution curve

From the laboratory test result, almost 96.79% of the soil sample 1 pass through sieve No.200 which shows almost the soil sample 1 was fine grained soil and 87.05 % of the soil sample 2 pass through sieve No.200 as shown in figure 4.1 which shows almost the soil sample 2 was fine grained soil.

4.1.4 Free Swell Test Result

The free swell tests are used to know the expansiveness of the soil. The soil sample for this study was classified under highly expansive soil. The table 4.3 shows the free swell test result of natural soil.

The free swelling test is used to determine the increase in the volume of soil without any external constraint when the sample of the soil subjected to submergence in the water.

Table 4. 3: Free swell result of natural soil samples

Soil Sample No.	Depth (m)	Free Swell Final Reading(ml)	Free Swell (%)
Ss1	1.5	20.80	108.00
Ss2	2	18.90	89.00

As shown in table 4.3 the free swell of natural soil is above 50% this indicate that the soil is highly expansive soil.

4.1.5 Atterberg Limits

The Atterberg limit tests were performed for natural soil of all the collected samples. The main objective of these tests is to identify the plasticity of the soil.

Table 4. 4: Atterberg limit test result of expansive soil

Sample No.	Atterberg Limits			ERA (2002) Requirement for PI (< 30%)
	LL	PL	PI	
Ss1	103.7	36.7	67.0	Poor
Ss2	87.0	37.4	49.6	Poor

From table 4.4 the laboratory test result shows the plastic limit of both soil samples is greater than 30%. According to ERA Standard Technical Specifications manual (2002); the test result shows the soil is unsuitable (below the requirement) for road subgrade construction.

4.1.6 Classification of the Soil

The classification system according to unified soil classification system (USCS) and AASHTO for expansive soil samples taken for this study was presented on table 4.5, figure 4.2 and figure 4.3.

Table 4. 5: AASHTO and USCS soil classification

Soil Sample	Atterberg Limits			Soil classification	
	LL	PL	PI	USCS	AASHTO
Ss1	103.7	36.7	67.0	CH	A-7-5
Ss2	87.0	37.4	49.6	CH	A-7-5

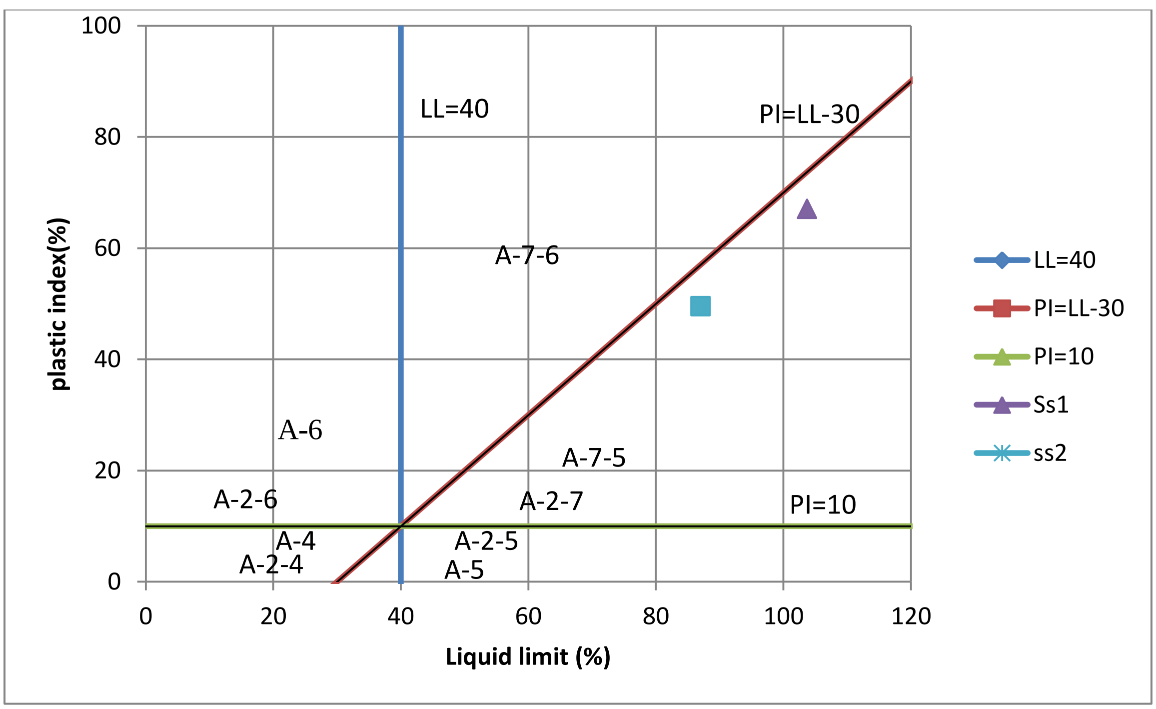

Figure 4. 2: AASHTO soil classification

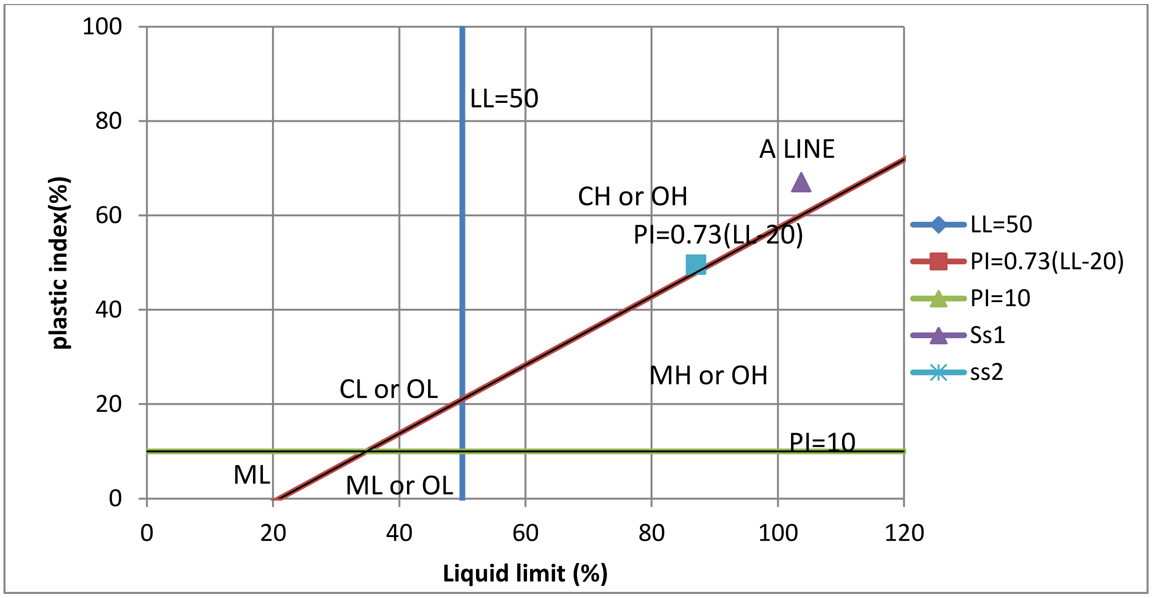

Figure 4. 3: USCS soil classification

As figure 4.2 and 4.3 shows the soil samples taken for this study classified under CH and A-7-5 these indicate that the soil is highly expansive and classified as highly clay. This result is due to high value of liquid limit and plasticity index. Soils under this class were poor for sub grade construction.

4.1.7 California Bearing Capacity (CBR)

In this study the CBR test conducted to measure the bearing capacity of soil used for subgrade material. Table 4.6 shows the compaction and CBR test result of natural soil samples.

Table 4. 6: The Compaction and CBR test result for the Natural soil sample

Sample Name	compaction test			CBR @ 95% of MDD	CBR Swell	Class of sub-grade
	OMC (%)	MDD (g/cm3)	95% of MDD			
Expansive soil sample1 (Ss1)	30.47	1.34	1.27	1.78	7.45	Not suitable
Expansive soil sample2 (Ss2)	29.30	1.36	1.29	1.95	6.86	Not suitable

Based on the suitability of sub-grade soils the studied natural soils were classified under Poor and not allowed to use for sub-grade materials and the soils needs modification.

4.2 Effect of Adding stone dust and Brick dust on engineering properties of Expansive soil

4.2.1 Effect of Adding Stone dust and Brick dust on Free swell index

Table 4.7 and table 4.8 shows the effect of adding stone dust and brick dust on free swell index of expansive soil.

Table 4. 7: The effect of stone dust on Free swell index

Sample Name	SS1			SS2		
Percentage of Stone Dust	Final volume (ml)	Free swelling (%)	Percentage of improvement (%)	Final volume (ml)	Free swelling (%)	Percentage of improvement (%)
0%	20.8	108.0	0.0	18.9	89.0	0.0
5%	18.0	80.0	25.9	17.5	75.0	15.7
10%	16.8	68.0	37.0	16.3	63.0	29.2
15%	15.0	50.0	53.7	14.8	48.0	46.1
20%	13.5	35.0	67.6	13.5	35.0	60.7
25%	12.3	23.0	78.7	12.4	24.0	73.0
30%	11.6	16.0	85.2	11.3	13.0	85.4

Table 4. 8: The effect of brick dust on Free swell index

Sample Name	SS1			SS2		
Percentage of Brick Dust	Final volume (ml)	Free swelling (%)	Percentage of improvement (%)	Final volume (ml)	Free swelling (%)	Percentage of improvement (%)
0%	20.8	108.0	0.0	18.9	89.0	0.0
5%	19.3	93.0	13.9	18.1	81.0	9.0
10%	18.0	80.0	25.9	17.5	75.0	15.7
20%	16.7	67.0	38.0	15.5	55.0	38.2
30%	14.5	45.0	58.3	13.9	39.0	56.2
40%	13.3	33.0	69.4	12.8	28.0	68.5
50%	12.3	23.0	78.7	12.0	20.0	77.5
60%	12.0	20.0	81.5	11.4	14.0	84.3

From table 4.7 and 4.8 the effect of free swell from the laboratory test result indicates that the free swell index values of the expansive soil have decreased with the increase in the percentage of stone dust and brick dust this resulted to the reduction of swelling of the expansive soil. From the test results, it is observed that addition of stone dust and brick dust with expansive soil is effective to reduce the free swelling index of expansive soils.

4.2.2 Effect of Adding Stone dust and Brick dust on Atterberg Limits

For this study the Atterberg limit tests conducted at different ratios of stone dust and brick dust. The main objective of this modification is to reduce the plasticity index. The effect of adding stone dust and brick dust on the expansive soil sample show the changes on the Atterberg limit of the expansive soil. The variation of Atterberg limit values for the present study the laboratory test results presented on table 4.9.

Table 4. 9: The effect of stone dust on the atterberg limit of the soil

Sample Name	Ss1				Ss2			
Percentage of Stone dust	LL	PL	PI	Percentage of improvement (%)	LL	PL	PI	Percentage of improvement (%)
0%	103.7	36.7	67.0	0.0	87.0	37.4	49.6	0.0
5%	93.7	39.3	54.4	18.9	78.4	38.2	40.2	18.9
10%	88.8	41.9	46.8	30.1	70.0	40.1	30.0	39.5
15%	83.8	45.1	38.7	42.3	64.5	41.0	23.5	52.5
20%	76.0	49.5	26.4	60.6	61.4	42.3	19.0	61.6
25%	67.0	50.7	16.3	75.7	56.4	43.2	13.2	73.3
30%	63.0	51.4	11.7	82.6	53.3	44.0	9.4	81.1

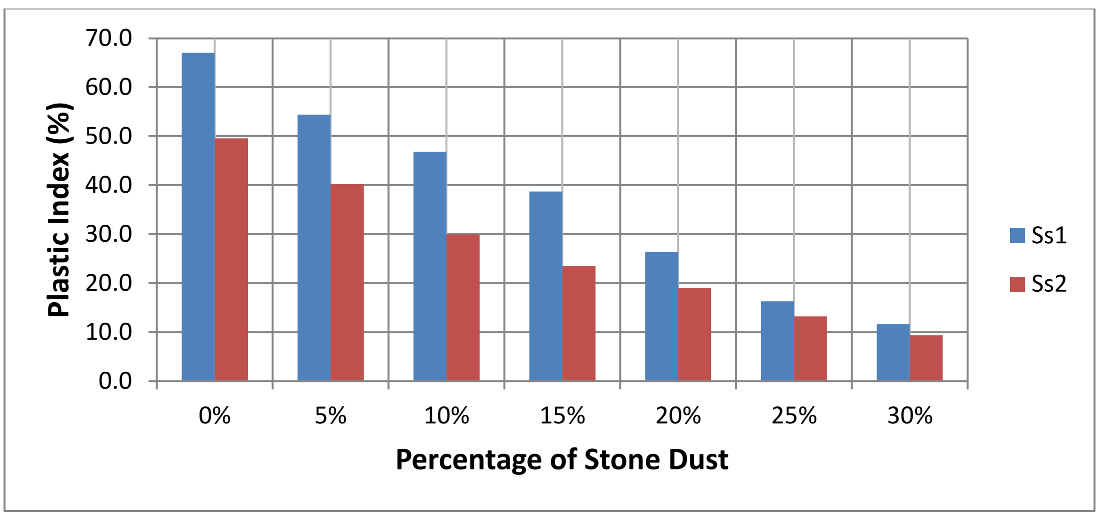

Figure 4. 4: effect of stone dust on the atterberg limit of the soil

Table 4.9 and figure 4.4 shows, after the addition of the stone dust the liquid limit decreases from 103.7 to 76.0 and plasticity index also decrease from 67.0 to 26.40. Thus, modifying expansive soil sample 1 with 20% stone dust shows improvement in geotechnical properties of expansive soil by 60.6%; which satisfies ERA requirement. Also modifying expansive soil sample 2 with 20% stone dust the liquid limit decreases from 87.0 to 61.4 and plasticity index also decrease from 49.6 to 19.0. This shows improvement in geotechnical properties of expansive soil by 61.6%. It satisfies the ERA requirement for subgrade construction.

Table 4. 10: The effect of brick dust on the atterberg limit of the soil

Sample Name	Ss1				Ss2			
Percentage of Brick Dust	LL (%)	PL (%)	PI (%)	Percentage of improvement (%)	LL (%)	PL (%)	PI (%)	Percentage of improvement (%)
0%	103.7	36.7	67.0	0.0	87.0	37.4	49.6	0.0
5%	94.7	39.2	55.4	17.3	81.3	40.1	41.1	17.0
10%	88.7	42.4	46.3	30.9	72.6	41.9	30.7	38.0
20%	84.3	43.8	40.5	39.6	67.7	42.7	25.0	49.5
30%	78.8	47.5	31.3	53.3	63.7	43.2	20.5	58.6
40%	70.7	49.9	20.8	69.0	61.0	43.7	17.4	65.0
50%	67.0	51.4	15.6	76.7	57.7	43.9	13.9	72.0
60%	63.2	52.7	10.5	84.3	55.2	44.2	11.0	77.9

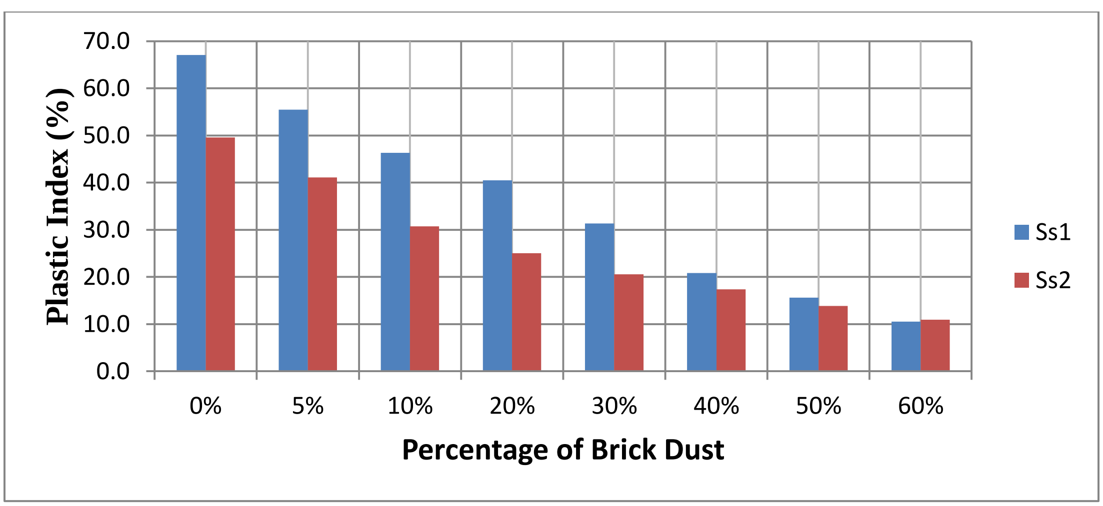

Figure 4. 5: effect of brick dust on the atterberg limit of the soil

This shows after the addition of the brick dust the liquid limit decreases from 103.7 to 70.7 and plasticity index is also decrease from 67.0 to 20.80 for soil sample one, this shows that the addition of brick dust in the expansive soil can improve the geotechnical properties of expansive soil.

The result showed that there is a reduction in plastic index as increasing the ratio of both stone dust and brick dust. The highest reduction in plastic index occurs when it was stabilized with maximum ratios and the minimum reduction occurs at minimum ratios. Comparatively the amount of the stone dust used to stabilize the expansive soil is much less than that of the brick dusts for the same improvement. In general from table 4.9 and table 4.10 for stone dust and brick dust stabilization the following observation have been made.

- ✓ Liquid limit decreases with increasing ratio of stone dust and brick dust.
- ✓ Plastic limit increases with increasing ratio of stone dust and brick dust.
- ✓ Plastic index decreases with increasing ratio of stone dust and brick dust.

As observed from the above table changing stabilization ratio changes liquid limit, plastic limit and plastic index values of the soil.

4.2.3 Effect of Adding stone dust and Brick dust on Compaction Test

The compaction test result shows that the addition of different percentages of stone dust and Brick dust on the expansive soil change the compaction characteristics OMC decrease and reversibly the MDD of the expansive soil increase. The optimum moisture content and maximum dry density of stabilized soils are presented in table 4.11.

Table 4. 11: The effect of stone dust on Compaction test of the soil

Sample Name	**SS1**		**SS2**	
Percentage of Stone Dust	OMC	MDD	OMC	MDD
0%	30.47	1.34	29.30	1.36
5%	28.85	1.40	27.70	1.44
10%	26.60	1.46	25.30	1.48
15%	25.22	1.51	24.00	1.54

20%	24.20	1.56	22.90	1.59
25%	22.10	1.60	21.18	1.62
30%	21.60	1.65	20.86	1.66

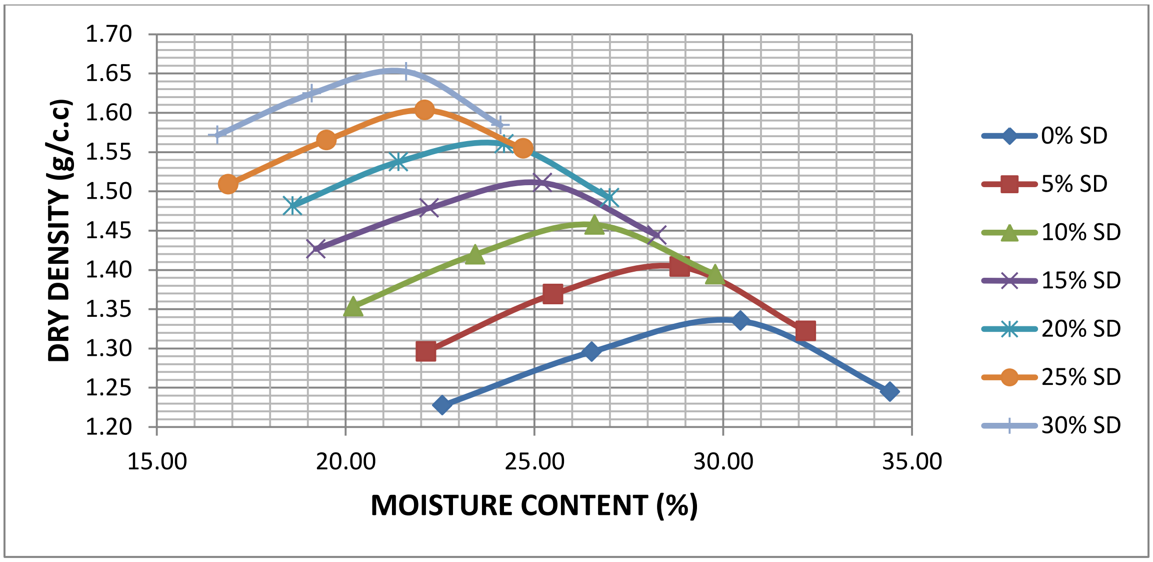

Figure 4. 6: The effect of stone dust on Compaction test of the Ss1

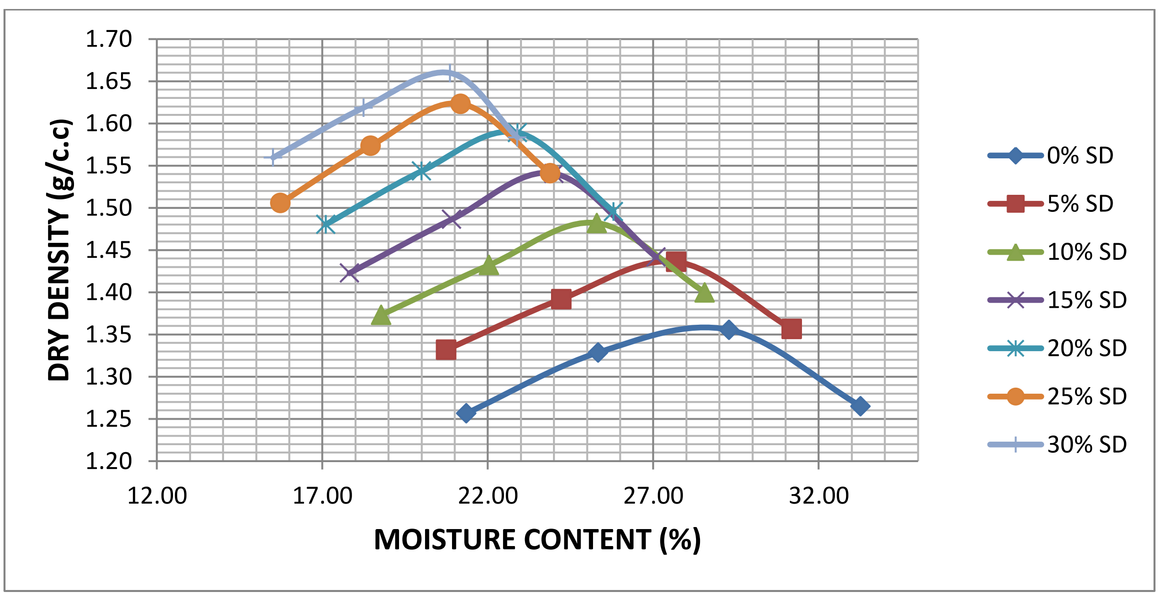

Figure 4. 7: The effect of stone dust on Compaction test of the Ss2

Table 4. 12: The effect of brick dust on Compaction test of the soil

Sample Name	Ss1		Ss2	
Percentage of Brick Dust	OMC	MDD	OMC	MDD
0%	30.47	1.34	29.30	1.36
5%	29.07	1.35	28.50	1.38
10%	28.10	1.37	27.60	1.40
20%	27.71	1.40	26.70	1.44
30%	26.80	1.43	24.72	1.47
40%	25.92	1.45	23.10	1.50
50%	25.04	1.49	21.65	1.54
60%	24.31	1.51	20.66	1.58

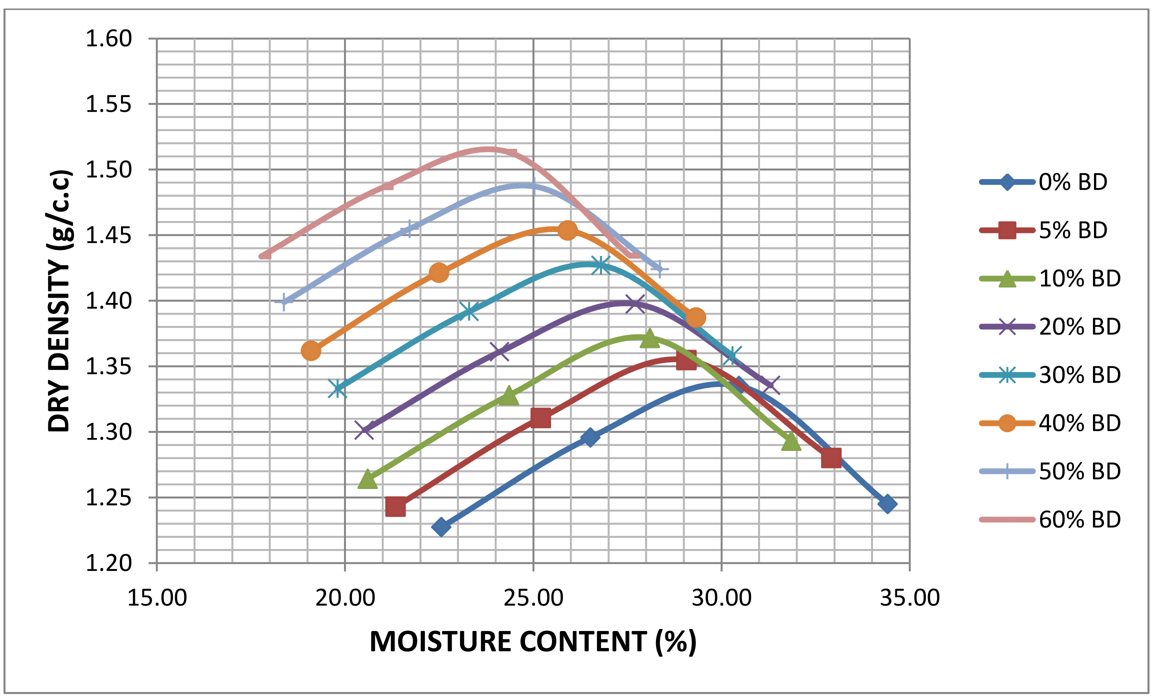

Figure 4. 8: The effect of brick dust on Compaction test of the Ss1

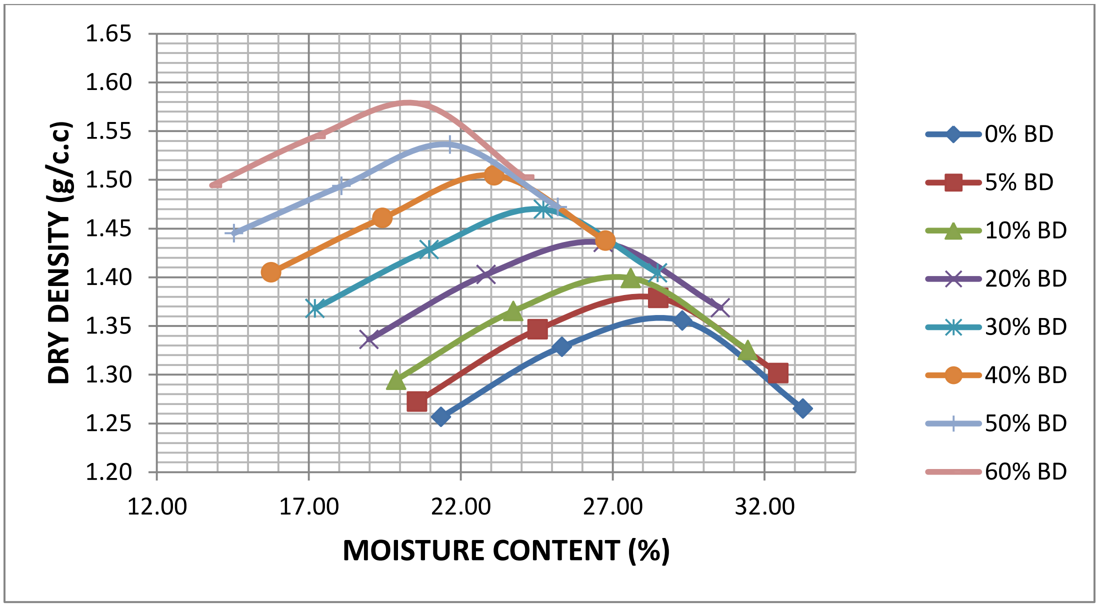

Figure 4. 9: The effect of brick dust on Compaction test of the Ss2

From the above table 4.11 and 4.12 the optimum moisture content of the samples decrease and the maximum dry density increases when both stone dust and brick dust added to the expansive soil. The MDD shows a slight increase and OMC shows a decrease in the modification of weak subgrade soil with stone dust and brick dust.

The compaction test showed that the addition of stone dust and Brick dust on the expansive soil change the compaction characteristics OMC and MDD of the expansive soil, from the laboratory test result it can be seen that there is a decrease in the OMC and increase in MDD value with increasing in the percentage of both stone dust and brick dust. And also addition of the stone dust to expansive soil improves the geotechnical properties of expansive soil more than that of brick dust.

4.2.4 Effect of Adding Stone dust and Brick dust on CBR Test

The laboratory test result that shows the effect of adding stone dust on CBR value of subgrade soil presented on Table 4.13. The addition of stone dust on expansive soil increases the strength of the expansive soil and improves the geotechnical properties of expansive soil.

Table 4. 13: Effect of Adding Stone dust on CBR Test

Sample Name	SS1			SS2		
Percentage of Stone Dust	Dry Density at 95% of MDD	CBR	Percentage of improvement (%)	Dry Density at 95% of MDD	CBR	Percentage of improvement (%)
0%	1.27	1.78	0.0	1.29	1.95	0.0
5%	1.33	4.97	179.2	1.37	5.25	169.2
10%	1.39	8.98	404.5	1.41	9.46	385.1
15%	1.43	14.30	703.4	1.46	15.82	711.3
20%	1.48	21.70	1119.1	1.51	22.92	1075.4
25%	1.52	16.28	814.6	1.54	16.91	767.2
30%	1.57	10.80	506.7	1.58	11.50	489.7

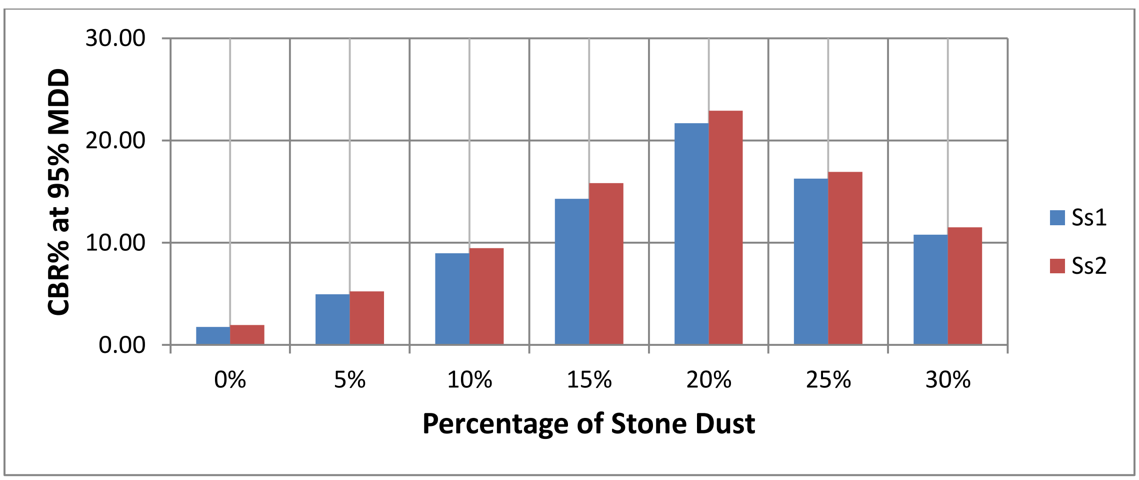

Figure 4. 10: Effect of adding Stone dust on CBR Test

The laboratory test result that shows the effect of adding brick dust on CBR value of subgrade soil presented on Table 4.1. The addition of brick dust on expansive soil increases the strength of the expansive soil and improves the geotechnical properties of expansive soil.

Table 4. 14: Effect of Adding Brick dust on CBR Test

Sample Name	SS1			SS2		
Percentage of Brick Dust	Dry Density at 95% of MDD	CBR	Percentage of improvement (%)	Dry Density at 95% of MDD	CBR	Percentage of improvement (%)
0%	1.27	1.78	0.0	1.29	1.95	0.0
5%	1.28	2.12	19.1	1.31	2.49	27.7
10%	1.30	3.52	97.8	1.33	4.15	112.8
20%	1.33	5.30	197.8	1.37	5.96	205.6
30%	1.36	6.96	291.0	1.40	7.52	285.6
40%	1.38	8.75	391.6	1.43	9.91	408.2
50%	1.42	5.28	196.6	1.46	6.05	210.3
60%	1.43	4.73	165.7	1.50	4.30	120.5

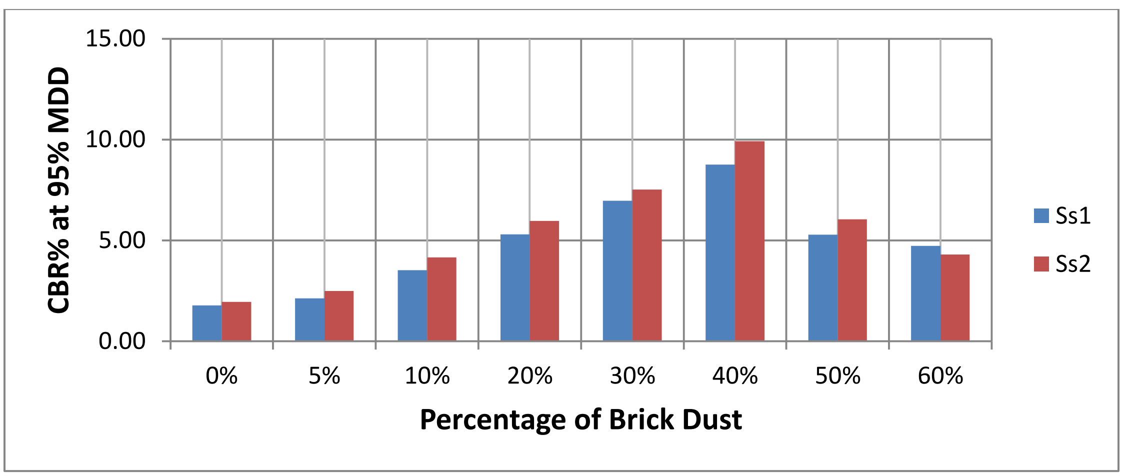

Figure 4. 11: Effect of Adding Brick dust on CBR Test

Addition of stone dust and Brick dust on expansive soil shows the CBR value of the soil increases as the percentage of stone dust and Brick dust increase. The MDD value in CBR is increases until it reaches the optimum. It increased up to 20% of adding stone dust and 40% of adding brick dust. And initially the result of expansive soil shows there this too low CBR value which is 1.78 and 1.95 for the two soil samples respectively and when 20% stone dust is added to this expansive soil the value of CBR increased to 21.70 and 22.92 for the two soil samples. Also the result shows there is improvement in engineering property of expansive soil by 1119.1% and 1075.4% respectively. When 40% brick dust is added to this expansive soil the value of CBR changed to 8.75 and 9.91 for the two soil samples. And the property of expansive soil improved by 391.6% and 408.2% respectively.

From table 4.15 and table 4.16 in both *Stone dust* and *Brick dust* stabilized Expansive soils the following observations have been made

- ✓ CBR values of natural sub grade soils of the two soil samples were not fulfills the requirement of sub-grade soils as per ERA standard (CBR> 5%).
- ✓ As the percentage of stone dust and brick dust increase the CBR value increase until it reaches the maximum or the required strength.
- ✓ The optimum percentage of the present study indicates at 20% of stone dust and 40% of brick dust used for improvement of expansive soil.
- ✓ By the same ratio the improvement of sample 2 is much greater than sample 1 using both *Stone dust* and *Brick dust.*
- ✓ For the same improvement the amount of stone dust used is much less than the brick dust.
- ✓ The improvement done at optimum ratio fulfills ERA standard (CBR > 5%) to use for sub-grade.

According to ERA low volume pavement manual specification it is not allowed to use CBR values less than 3%, because from both a technical and economic perspective it would normally be inappropriate to lay a pavement on soils of such bearing capacity. The improved soil using both Stone dust and Brick dust was very suitable for subgrade soils. According to AACRA design manual suitability of sub-grade soils based on CBR values are presented as table 3.9. Based on the suitability of sub-grade soils the studied natural soils were classified under Poor and not allowed to use for sub-grade materials. But, the stabilized soils at optimum ratio were classified under fair to good for sub-grade materials.

4.2.5 Effect of adding stone dust and brick dust on CBR Swell Test

The *Stone dust* and *Brick dust* mixtures with soil compacted in CBR molds at optimum moisture content with maximum dry density gauged for swelling characteristics before and after soaking for four days to evaluate the percent of swell. The test result at different ratios were presented in table 4.15 and table 4.16

Table 4. 15: Effect of Adding stone dust on CBR swell Test

Sample Name	Ss1			Ss2		
Percentage of Stone Dust	CBR % at 95 % MDD	Swell %	Percentage of improvement (%)	CBR % at 95 % MDD	Swell %	Percentage of improvement (%)
0%	1.78	7.45	0.0	1.95	6.86	0.0
5%	4.97	5.98	19.7	5.25	4.95	27.8
10%	8.98	4.11	44.8	9.46	3.05	55.5
15%	14.30	2.65	64.4	15.82	1.95	71.6
20%	21.70	1.76	76.4	22.92	1.34	80.5
25%	16.28	1.03	86.2	16.91	0.98	85.7
30%	10.80	0.64	91.4	11.50	0.56	91.8

Table 4. 16: Effect of Adding Brick dust on CBR swell Test

Sample Name	Ss1			Ss2		
Percentage of Brick Dust	CBR % at 95 % MDD	Swell %	Percentage of improvement (%)	CBR % at 95 % MDD	Swell %	Percentage of improvement (%)
0%	1.78	7.45	0.0	1.95	6.86	0.0
5%	2.12	6.03	19.1	2.49	5.09	25.8
10%	3.52	5.16	30.7	4.15	4.18	39.1
20%	5.30	3.67	50.7	5.96	2.92	57.4
30%	6.96	2.53	66.0	7.52	1.95	71.6

40%	8.75	1.65	77.9	9.91	1.22	82.2
50%	5.28	1.28	82.8	6.05	1.05	84.7
60%	4.73	0.91	87.8	4.30	0.79	88.5

Table 4.15 and table 4.16 shows, modifying expansive soil with optimum percentage of 20% stone dust improves the CBR swelling result of expansive soil from 7.45% and 6.86% to 1.76% and 11.34%. It shows improvement by 76.4% and 80.5% for soil sample one and two respectively. By using the optimum percentage of brick dust 40% the expansive soil improves the CBR swelling result of expansive soil from 7.45% and 6.86% to 1.65% and 1.22%. It shows improvement by 77.9% and 82.2% for soil sample one and two respectively. It satisfies the ERA requirement for subgrade construction.

4.2.6 Effect of adding stone dust on the classification of the soil.

From figures 4.2 and figure 4.3 the expansive soil for this study classified under A-7-6 according to AASHTO and classified under CH according to USCS. But after the addition of the stone dust and brick dust the soil classified under A-2-7 according to AASHTO and classified under MH according to USCS as shown in figure 4.12 and figure 4.13.

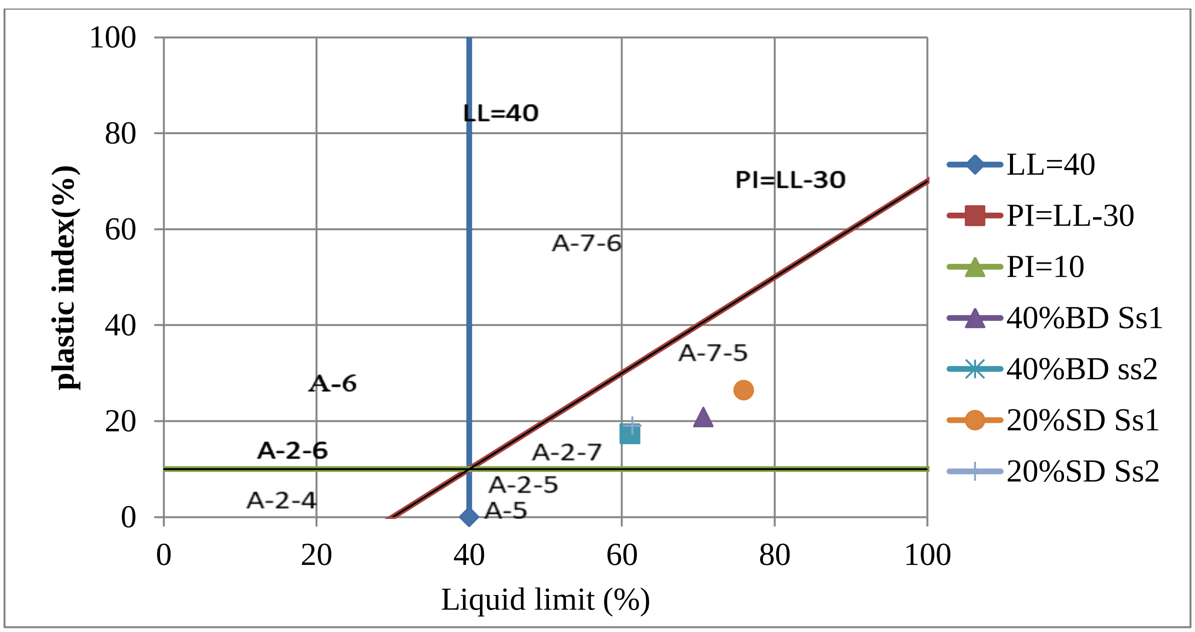

Figure 4. 12: The AASHTO soil classification for Ss1 & Ss2

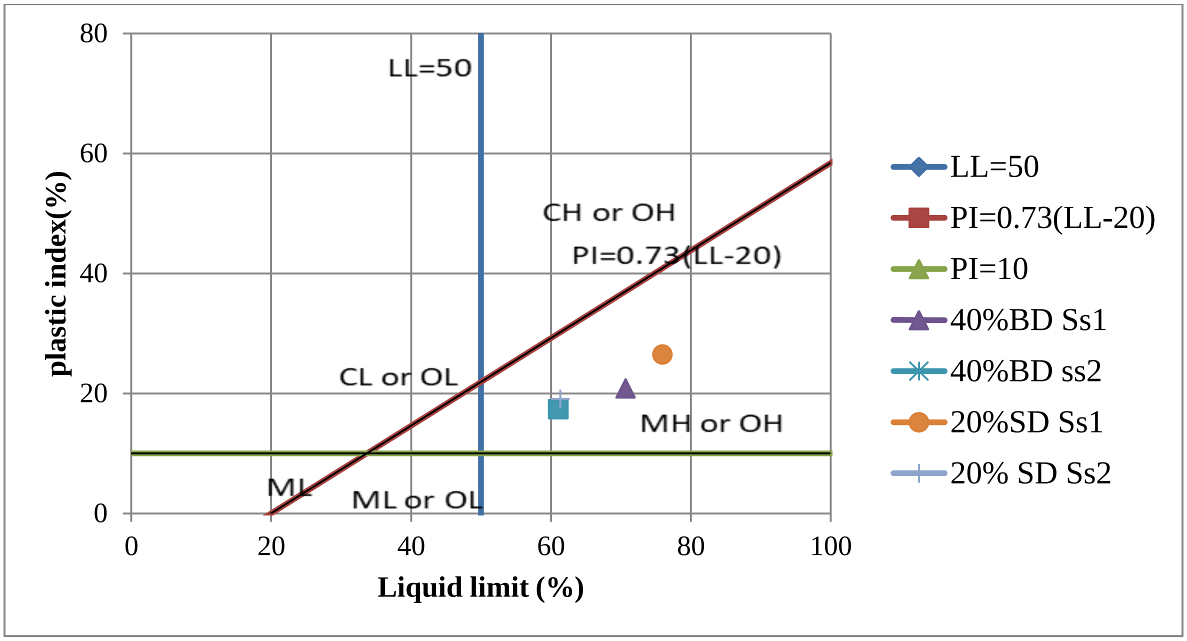

Figure 4. 13: The USCS soil classification for Ss1 & Ss2 modified with 40% Brick dust and 20% Stone dust

4.3 Discussion on effect of stone dust and brick dust and optimum percentage determination

The effect of adding stone dust and brick dust to the expansive soil makes to change the properties of expansive soil. Adding both stone dust and brick dust to expansive soil leads to make radical change in laboratory test of free swell index, atterberg limit, compaction characteristic CBR and CBR swell. In compaction characteristic, when the stone dust and brick dust added to expansive soil makes to decrease the optimum moisture content and inversely increase the maximum dry density. These shows that adding stone dust and brick dust can improve the compaction characteristic of MDD and OMC. And also the addition of stone dust and brick dust on the CBR Can increase the result of CBR value and inversely it decreases the swelling potential of Expansive soil. The value of CBR are increased from 1.78% to 21.70% and from 1.95% to 22.92 by using stone dust for both soil samples and the value of CBR also increased from 1.78% to 8.75% and from 1.95% to 9.91 by using brick dust for both soil samples. this indicate that adding stone dust and brick dust to expansive soil can change the engineering properties of expansive soil which is used for subgrade. So the addition of stone dust and brick dust on expansive soil resulted to decrease on free swell, OMC, LL, PI and in the CBR swell. inversely the addition of stone dust and brick dust on expansive soil makes to increase in the value of PL, MDD and CBR this indicate that the effect of adding stone dust and brick dust on the expansive soil changes the properties of expansive soil and increase the strength of the expansive soil. Therefore, the addition of both stone dust and brick on expansive soil improve the geotechnical properties of expansive soil.

The value of CBR after adding of 20% stone dust and 40% Brick dust decreased this indicate that the optimum percentage required to achieve the study. This indicates that the required strength to achieve the study was at addition of 20% of stone dust and 40% of brick dust. Generally adding stone dust and Brick dust to expansive soil can make to create effects on Laboratory test of soil so that as the result indicate adding stone dust and Brick dust to expansive soil is important in terms of obtaining strength and cost. The optimum percentage of this study is at addition of 20% of stone dust and 40% of Brick dust to expansive soil. This indicates the required strength to achieve the study was at 20% of stone dust and 40% of Brick dust.

4.4 Cost analysis for natural and modified Expansive soil

From conducted laboratory test the untreated soil has CBR value of 1.78% and 1.95%, for the minimum CBR value of 2%, the subgrade strength class to be assigned is S1 subgrade strength class As per ERA Pavement Design, Manual Volume 1, 2013. The following preliminary information has been derived from material investigations

- ✓ The materials which may be considered for cement- or lime-stabilization have relatively low percentages of fines and low plasticity, thus making cement-stabilization more promising.
- ✓ Granular sub base materials are available in sufficient quantities and cement stabilization of the sub base is uneconomical when compared to bank-run materials. Stabilization of sub base materials will not be further considered.

- ✓ All other materials entering the composition of the possible pavement structures are available in various quantities and associated transport/ construction costs.

Based on the above, and with the S1/T7 and S2/T7 combination of traffic and subgrade strength classes, Table 17 and Table 18 indicate the possible alternate pavement structures before and after stabilization.

Table 4. 17 Possible Pavement Structure before stabilization

Pavement Components	Possible Alternate Pavement Structures			
	Alternate Structure 1	Alternate Structure 2	Alternate Structure 3	Alternate Structure No. 4
Surfacing (asphalt concrete)	5cm AC	15cm AC	15cm AC	5cm AC
Roadbase:-				
- Crushed Stone	15cm	25cm		-
- Cement or lime stabilized CB-1	12.5cm	-	25cm	-
- Cement or lime stabilized CB-2	-	-	-	-
- Bituminous stabilized	-	-	-	20cm
Granular sub-base	17.5cm	17.5 cm	22.5cm	32.5cm
Selected fill	20cm	30cm	30cm	30cm
Buffer layer	60cm	60cm	60cm	60cm

Table 4. 18 Possible Pavement Structure after stabili

Pavement Components	Possible Alternate Pavement Structures			
	Alternate Structure No. 1	Alternate Structure No. 2	Alternate Structure No. 3	Alternate Structure No. 4
Surfacing (asphalt concrete)	5cm AC	15cm AC	15cm AC	5cm AC

Roadbase: ·				
- Crushed Stone	15cm	25cm	-	-
- Cement or lime stabilized CB-1	12.5cm	-	25cm	-
- Cement or lime stabilized CB-2	-	-	-	-
- Bituminous stabilized	-	-	-	20cm
Granular sub-base	17.5cm	22.5 cm	22.5 cm	12.5 cm
Selected fill	-	-	-	-

The alternate structures including cement stabilized layers appeared and the alternate including only crushed stone road base and sub base also appear at a disadvantage. Since Granular sub base materials are available in sufficient quantities and cement stabilization of the sub base is uneconomical when compared to bank-run materials. Stabilization of sub base materials will not be further considered. Therefore the alternative 2 is best Alternate Pavement Structure. With these Alternatives the total pavement thickness is 875mm for natural and 625mm for stabilized sub grade soil. The recommended pavement structure is given in Figure 4.14 and Figure 4.15.

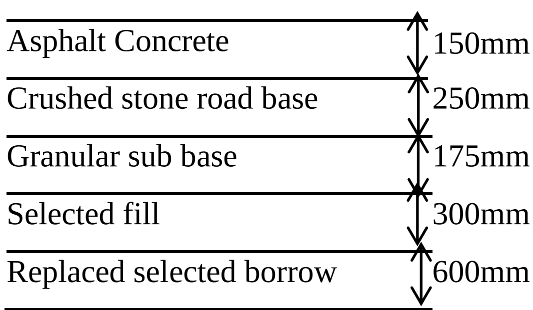

Figure 4. 14 Pavement structure before stabilization

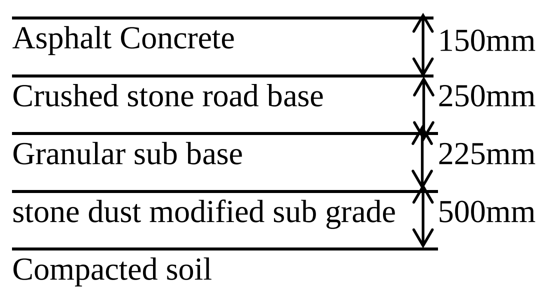

Figure 4. 15 Pavement structure after stabilization

The quantitative costs of pavement for natural and stabilized sub grade are given in Tables 4.19 and 4.20 trough Table 4.21 respectively.

Table 4. 19 Quantitative cost for natural subgrade soil

Item no.	item description	unit	Rate	Length (m)	Width (m)	Depth (m)	Amount
1	Sub Grade						
	1.1 Site Clearing	m2	22.91	1000	3.7	1	84,765.79
	1.2 Balk excavation in expansive soil not exceeding 1.5m	m3	134.76	1000	3.7	0.6	299,173.39
	1.3 Disposal of excavated material (5KM hauling distance)	m3	139.55	1000	3.7	0.6	309,807.43
	1.4 Road bed preparation compaction to 93% MDD	m2	65.13	1000	3.7	1	240,995.84
	1.5 Selected material production and hauling (5km)	m3	162.51	1000	3.7	0.6	360,773.00
	1.6 Placing and compacting selected material to 95% MDD	m2	77.81	1000	3.7	1	287,879.19
	Sub Total						**1,583,394.63**
2	Capping layer/selected material	m3	203.39	1000	3.7	0.3	225,763.96
3	SUB BASE						
	Gravel sub base 97%, MDD (Mat. From 5KM)	m3	235.59	1000	3.7	0.175	152,543.00
4	Base course						
5	Crushed stone road base	m3	614.16	1000	3.7	0.25	568,095.71
6	15cm Asphalt Concrete	m2	1500	1000	3.7	1	5,550,000.00
	Sub Total						**6,496,402.68**
	Total Cost of Construction						**8,079,797.31**

Table 4. 20 Quantitative cost for Stone dust stabilized Expansive soil

Road Section	unit	price
Clearing and Grubbing within Road Prism	m2	22.91
Purchase Cost of Stabilizer including transport		
Purchase Cost of Stabilizer from local crusher	m3	781.25
For 1m3 of Expansive soil, 0.25m3 of stone dust required(by using 20% SD which is optimum)	m3	195.31
Purchase Cost of Stabilizer of stone dust	m2	114.89
Placing of Stabilizer		
Hauling of Stabilizer	m2	77.76
Mixing of Stabilizer	m2	105.46
Placing of Stabilizer	m2	77.81
Total Quantitative Cost	m2	**398.84**

Table 4. 21 Quantitative cost of pavement after stabilizing with stone dust

item no	item description	unit	rate	Length (m)	Width (m)	Depth (m)	Amount
1	Stabilized sub grade	m2	398.84	1000	3.7	1	1,475,694.53
2	Gravel Sub base 97% Mdd (From 5KM)	m3	235.59	1000	3.7	0.225	196,126.72
3	Crushed Stone Road Base	m3	614.16	1000	3.7	0.25	568,095.71
4	15cm Asphalt Surfacing	m2	1500.00	1000	3.7	1	5,550,000.00
	Total Cost						**7,789,916.96**

The comparisons of the cost benefits were made from Table 4.19 to Table 4.21. As shown in the tables, the total quantitative cost of stone dust stabilized subgrade was estimated as **7,789,916.96** Birr/km against the cost of **8,079,797.31** Birr/km for replacing selective borrow material from a 5km distance. The saving in cost for stone dust stabilization is estimated to be 6.80% of construction cost of sub grade which is 3.60% of total construction cost.

Table 4. 22 Quantitative cost for Brick dust stabilized Expansive soil

Road Section	Unit	Price
Clearing and Grubbing within Road Prism	m2	22.91
Purchase Cost of Stabilizer including transport		
Purchase Cost of Stabilizer from local brick kilns	m3	187.5
For 1m3 of Expansive soil, 0.67m3 of Brick dust required(by using 40% BD which is optimum)	m3	125.63
Purchase Cost of Stabilizer of brick dust	m2	83.75
Placing of Stabilizer		
Hauling of Stabilizer	m2	77.76
Mixing of Stabilizer	m2	105.46
Placing of Stabilizer	m2	77.81
Total Quantitative Cost	m2	**367.7**

Table 4. 23 Quantitative cost of pavement after stabilizing with brick dust

item no	item description	unit	rate	Length (m)	Width (m)	Depth (m)	Amount
1	Stabilized sub grade	m2	367.70	1000	3.7	1	1,360,477.62
2	Gravel Sub base 97% Mdd (From 5KM)	m3	235.59	1000	3.7	0.225	239,710.43
3	Crushed Stone Road Base	m3	614.16	1000	3.7	0.25	568,095.71
4	15cm Asphalt Surfacing	m2	1,500.00	1000	3.7	1	5,550,000.00
	Total Cost						**7,674,700.05**

The comparisons of the cost benefits were made from Table 4.19, table 4.22 and Table 4.23. As shown in the tables, the total quantitative cost of brick dust stabilized subgrade was estimated as **7,674,700.05** Birr/km against the cost of **8,079,797.31** Birr/km for replacing selective borrow material from a 5km distance. The saving in cost for brick dust stabilization is estimated to be 14.08% of construction cost of sub grade which is 5.01% of total construction cost.

CHAPTER FIVE

4 CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

The present studies indicate that, the soil samples collected for the study were highly expansive soil. This expansive soil is not good for construction of road pavements. So the modification of expansive soil with stone dust and Brick dust is very crucial in improving in engineering properties of expansive soil.

Based on the laboratory results, the effect of adding stone dust and brick dust to expansive soil decreases the value of FSI, LL, PI, OMC, CBR swell and increase the value of PL, MDD & CBR. The optimum percentages of stone dust and Brick dust observed at 20% & 40% respectively.

From the addition of stone dust and Brick dust to expansive soil the following conclusions were drawn from the test results obtained from the investigations carried out:

- The Free Swell Index (FSI) of Expansive soil decrease with the addition of both stone dust and Brick dust in different percentages.
- It has been observed that the liquid limit decreased from 103.7% to 76% with the addition of 20% stone dust and from 103.7% to 70.7% with the addition of 40% brick dust to soil sample one.
- The Maximum Dry Density (MDD) increase and the Optimum Moisture Content (OMC) decrease as the percentage of stone Dust and brick dust increases. It is observed that MDD of stone dust stabilizes soils increases from 1.34 to 1.56 and 1.36 to 1.59 also for brick dust case MDD increases from 1.34 to 1.45 and 1.36 to 1.50 for Ss1 and Ss2 respectively. Thus, the compaction result show that; as the percentage of the stone dust and brick dust content of the sample increases; the optimum moisture content of the soil decrease and the dry density of the soil increase, the minimum optimum moisture content, and maximum dry density are obtained at 20 % of stone dust and 40% of brick dust mixing percentage.
- From the laboratory test results it is concluded that the effect of adding stone dust and brick dust on Expansive soil gives positive result. By replacing the expansive soil by 20% stone

dust and 40% brick dust of its dry weight the maximum improvement in the engineering properties of Expansive soil were achieved. So using both stone dust and brick dust is an alternative for modification of expansive soil because it gives positive results and also it is a waste utilization.

- Waste management can be done economically; therefore, using stone dust and brick dust for improving engineering properties of the soils is an economical solution for jimma town as it is available in large quantity.
- Generally, the effect of adding of stone dust to expansive soil highly increases the PL, MDD, CBR and decreases the FS, LL, PI, OMC, CBR swell of the expansive soil sample compared to the brick dust.

4.2 Recommendation

Depend on the modification of expansive soil with stone dust and brick dust study results, the following points were recommended:

- Improving engineering properties of expansive soil with brick dust was not studied in jimma town. It is recommended to do the detail geological investigation so that nature and mineralogical content of the material can further be proved.
- This study was conducted by taking limited samples. It is recommended to conduct the research by a large number of samples. Therefore, the findings should be considered as indicative rather than definitive for the whole study area.
- The present study was conducted by taking limited samples, parameters in order to have the full understanding the effect of the stone dust and brick dust on the expansive soil more samples and parameters, the mineralogical tests should also be performed to have more understood the effect of mineralogical content effect on the modified expansive soil.
- For the practical applicability of the modified expansive soil is crucial in terms of cost and availability. So in order to get safe environmental, durable and stable structure modifying expansive soil with stone dust and brick dust plays a great role.

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ANNEX

Annex A: Laboratory Test Result Analysis of Soil Sample 1

Annex A-1: Natural Moisture Content

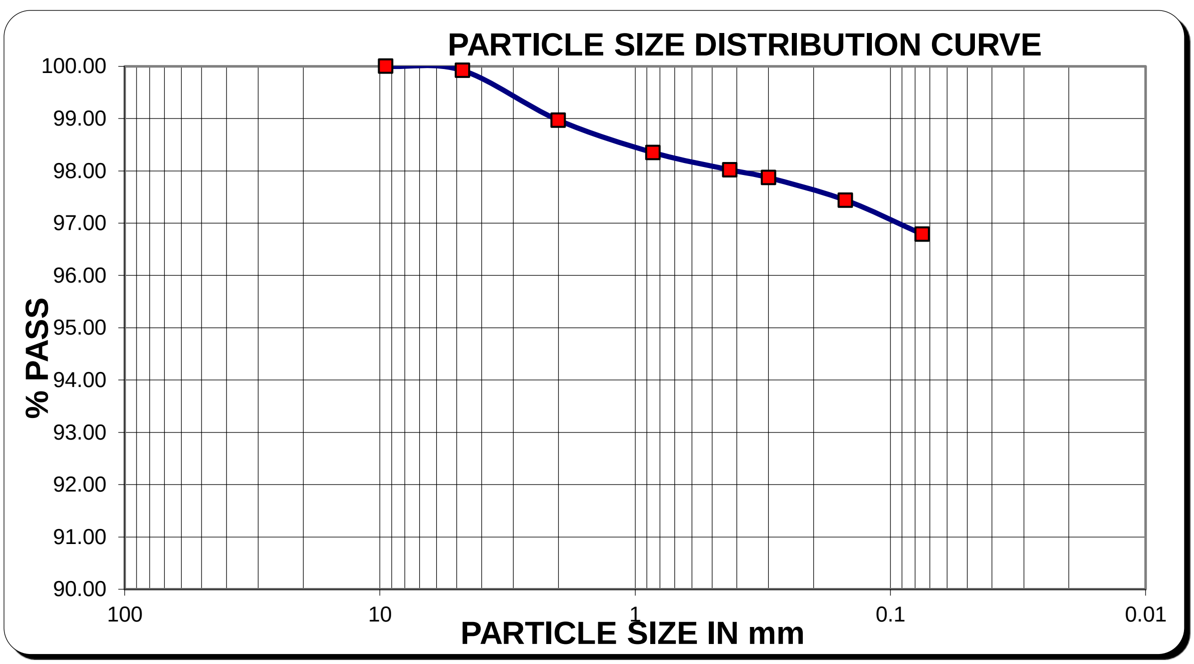
	Ss1		
Specimen number	1	2	3
Mass of can (g) M_C	17.8	41.3	17.6
Mass of can and moist soil (g) M_{CMS}	142.60	132.80	102.80
Mass of can and dry soil (g) M_{CDS}	108.7	107.7	79.8
Mass of water(g) M_w	33.90	25.10	23.00
Mass of dry soil(g) M_{DS}	90.90	66.40	62.20
Water content(%) w	37.29%	37.80%	36.98%
Average water content(%) w =	**37.36%**		

Annex A-2: Specific Gravity Analysis

Specific gravity of soil at test Temprature,G at Tx ℃ (ASTM D-854-83)			
SG for natural Ss1			
Trial No.	1	2	3
Mass of dry, clean Calibrated pycnometer, Mp	31.52	31.56	30.19
Mass of dry soil + pycnometer, Mps, in g	56.52	56.56	55.19
Mass of pycnometer+dry soil+water at temperature Tx, in ℃, g	140.62	140.12	140.05
Test temperature(Tx),℃	22	22	22
Density of water at Tx, g/cm3	0.9978	0.9978	0.9978
Mass of density bottle + water at temperature Ti^℃(21℃),g	125.61	125.22	125.09
Density of water at Ti g/ml at 21℃	0.9980	0.9980	0.9980
Correction factor, k	0.9998	0.9998	0.9998
Specific gravity G at Tx℃	2.502	2.475	2.490
Average specific gravity at Tx℃	2.49		

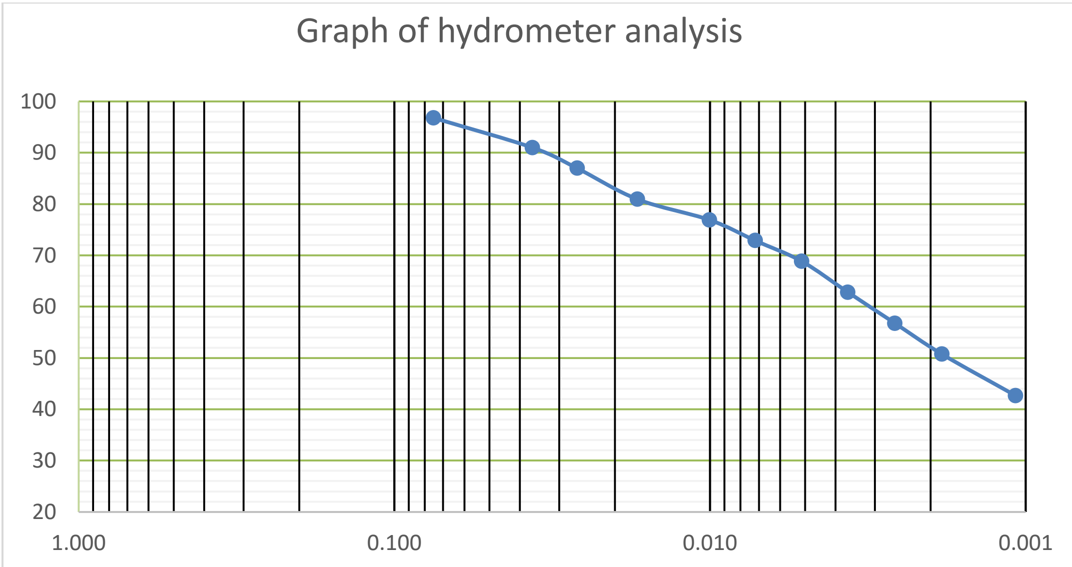
Annex A-3: Wet Sieve Analysis

Sieve Size(mm)	Mass retained (gm)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Cumulative Percentage Passing (%)
9.5	0	0.00	0.00	100.00
4.75	0.8	0.08	0.08	99.92
2	9.5	0.95	1.03	98.97
0.85	6.2	0.62	1.65	98.35
0.425	3.3	0.33	1.98	98.02
0.3	1.5	0.15	2.13	97.87
0.15	4.3	0.43	2.56	97.44
0.075	6.5	0.65	3.21	96.79
Total 1	32.1			
Pass	967.9			
Total	1000			



Annex A-4: Hydrometer Analysi

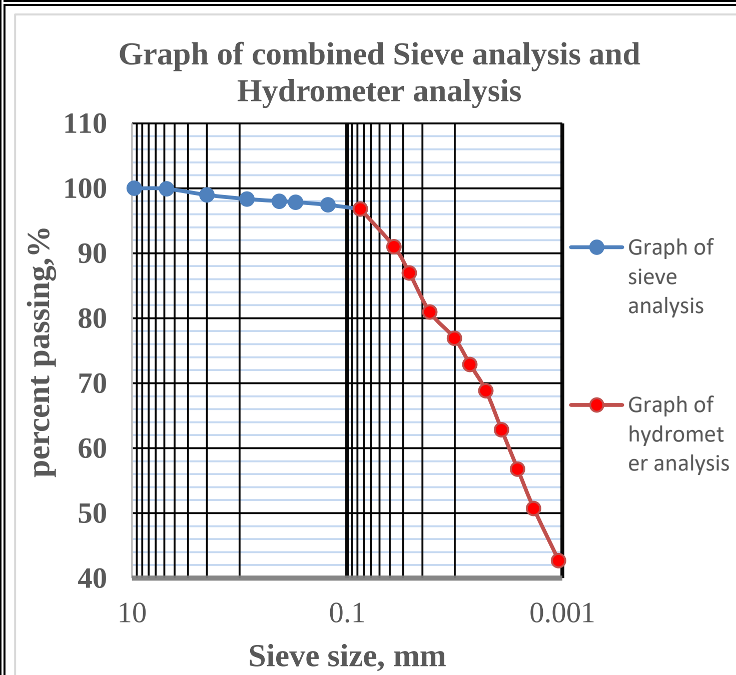
Soil Sample 1			correction for hydrometer reading					Correction factor (a)	Eff. Depth of Hydrometer (L)	Values of K	Diameter of soil Particle (mm)	% finer, P	Adjusted % of finer
Time (min.)	Actual Hydrometer Reading	Temp.	T° corr.	meniscus correction	zero correction	Composite Correction	Corrected H.Reading						
1	49	21	0.2	1	-5	-3.8	45.2	1.040	8.3	0.01419	0.041	94.02	91.00
2	47	21	0.2	1	-5	-3.8	43.2	1.040	8.6	0.01419	0.029	89.86	86.97
5	44	21	0.2	1	-5	-3.8	40.2	1.040	9.1	0.01419	0.019	83.62	80.93
15	42	21	0.2	1	-5	-3.8	38.2	1.040	9.5	0.01419	0.011	79.46	76.91
30	40	21	0.2	1	-5	-3.8	36.2	1.040	9.8	0.01419	0.008	75.30	72.88
60	38	21	0.2	1	-5	-3.8	34.2	1.040	10.1	0.01419	0.006	71.14	68.85
120	35	21	0.2	1	-5	-3.8	31.2	1.040	10.6	0.01419	0.004	64.90	62.81
240	32	21	0.2	1	-5	-3.8	28.2	1.040	11.1	0.01419	0.003	58.66	56.77
480	29	21	0.2	1	-5	-3.8	25.2	1.040	11.6	0.01419	0.002	52.42	50.73
1440	25	21	0.2	1	-5	-3.8	21.2	1.040	12.2	0.01419	0.001	44.10	42.68



AnnexA-5: Combined Sieve Analysis

particle size	percent pass
9.5	100
4.75	99.92
2	98.97
0.85	98.35
0.4250	98.02
0.300	97.87
0.150	97.44
0.075	96.79
0.036	91.00
0.026	86.97
0.017	80.93
0.010	76.91
0.007	72.88
0.005	68.85
0.004	62.81
0.003	56.77
0.002	50.73
0.001	42.68

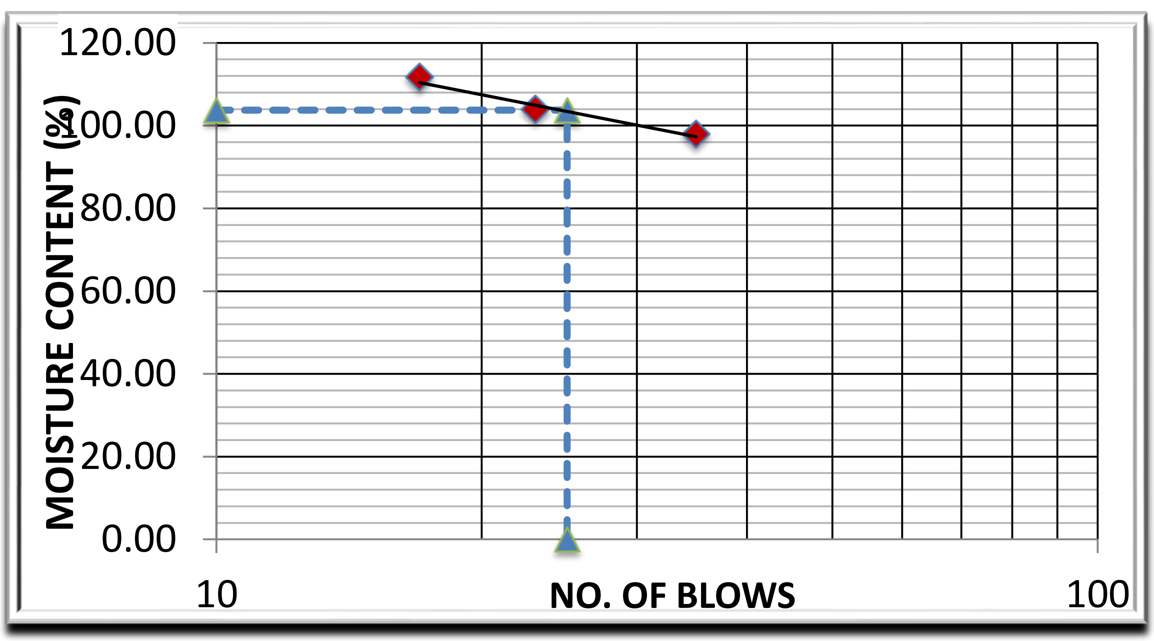
% of soil particle size	AASHTO	USCS
% of gravel	1.03	0.08
% of Sand	2.18	3.13
% of Silt	46.06	27.94
% of Clay	50.73	68.85



Annex A-6: Atterberg Limit Test Result

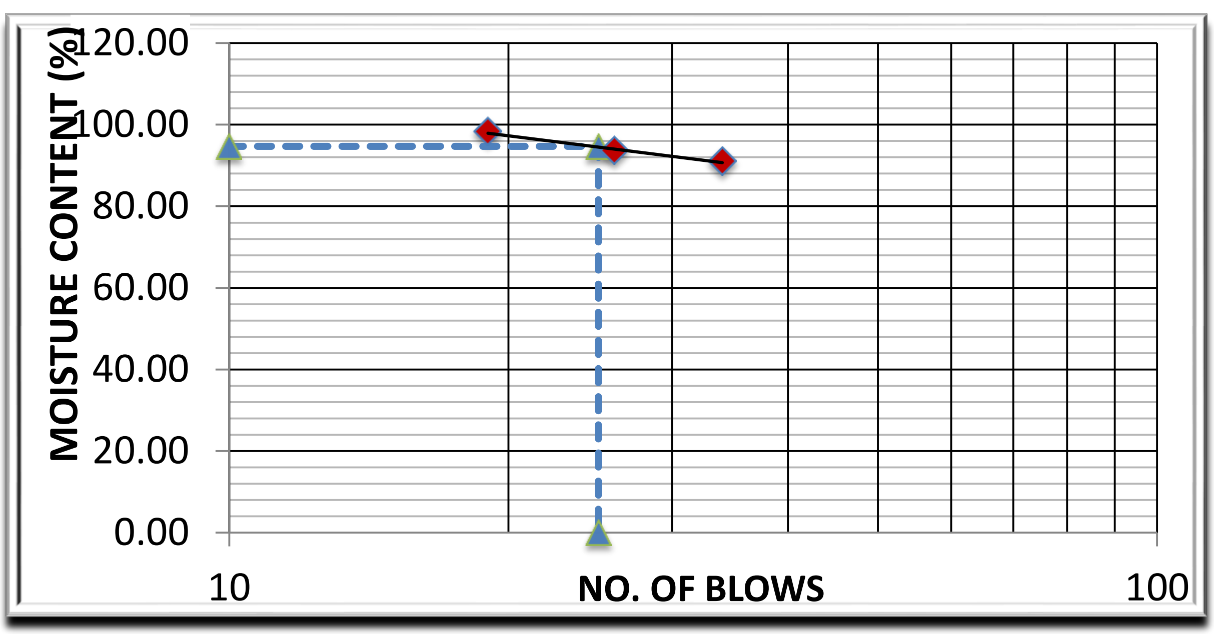
Natural soil

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	35	23	17		
Wt.of cont. + wet soil (g.)	28.00	27.80	16.30	24.90	21.70
Wt.of cont. + dry soil (g.)	23.10	22.50	10.60	23.50	20.20
Wt. of water (g.)	4.90	5.30	5.70	1.40	1.50
Wt. container (g.)	18.10	17.40	5.50	19.60	16.20
Wt. dry soil (g.)	5.00	5.10	5.10	3.90	4.00
Water Content (%)	98.00	103.92	111.76	35.90	37.50
Liquid Limit, LL(%)	**103.7**			**AV. PL (%)**	36.7
Plastic Limit, PL(%)	**36.7**				
Plasticity Index, PI(%)	**67.0**				



5%Brick Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	34	26	19		
Wt.of cont. + wet soil (g.)	16.70	18.70	31.50	21.80	23.30
Wt.of cont. + dry soil (g.)	11.60	12.70	25.70	20.30	21.50
Wt. of water (g.)	5.10	6.00	5.80	1.50	1.80
Wt. container (g.)	6.00	6.30	19.80	16.40	17.00
Wt. dry soil (g.)	5.60	6.40	5.90	3.90	4.50
Water Content (%)	91.07	93.75	98.31	38.46	40.00
Liquid Limit, LL(%)	**94.7**			**AV. PL (%)**	39.2
Plastic Limit, PL(%)	**39.2**				
Plasticity Index, PI(%)	**55.4**				

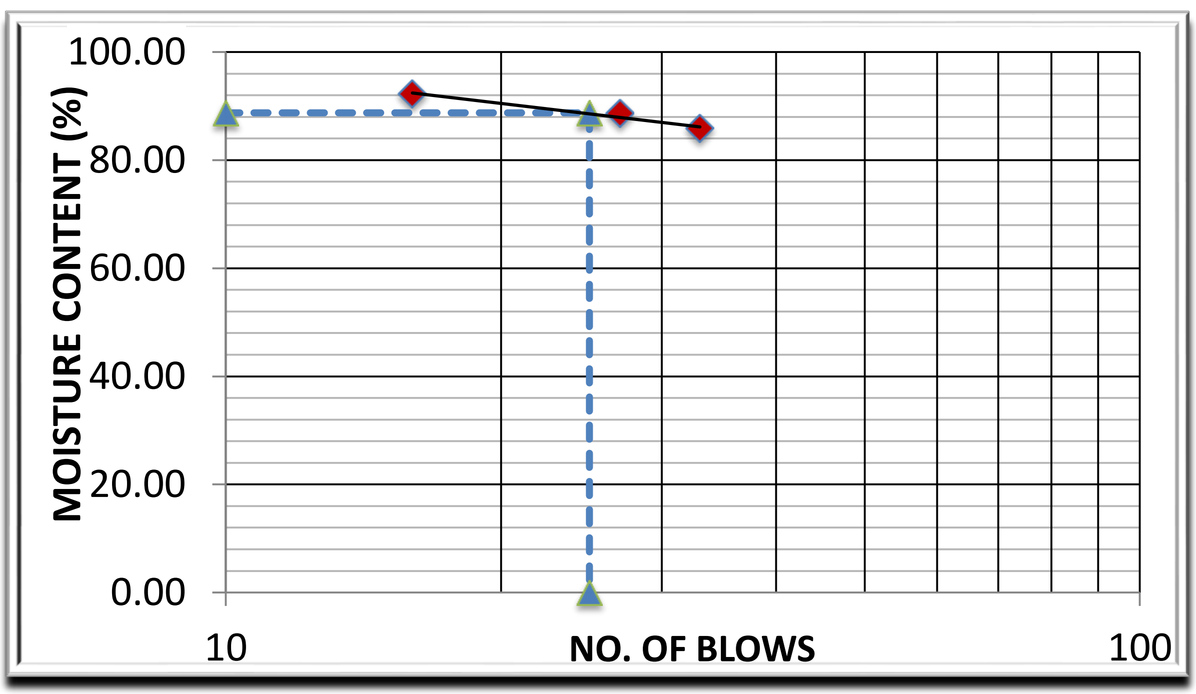


10% Brick Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	33	27	16		
Wt.of cont. + wet soil (g.)	18.40	31.30	26.30	16.80	17.90
Wt.of cont. + dry soil (g.)	12.90	25.80	21.50	13.70	14.60
Wt. of water (g.)	5.50	5.50	4.80	3.10	3.30
Wt. container (g.)	6.50	19.60	16.30	6.50	6.70
Wt. dry soil (g.)	6.40	6.20	5.20	7.20	7.90
Water Content (%)	85.94	88.71	92.31	43.06	41.77

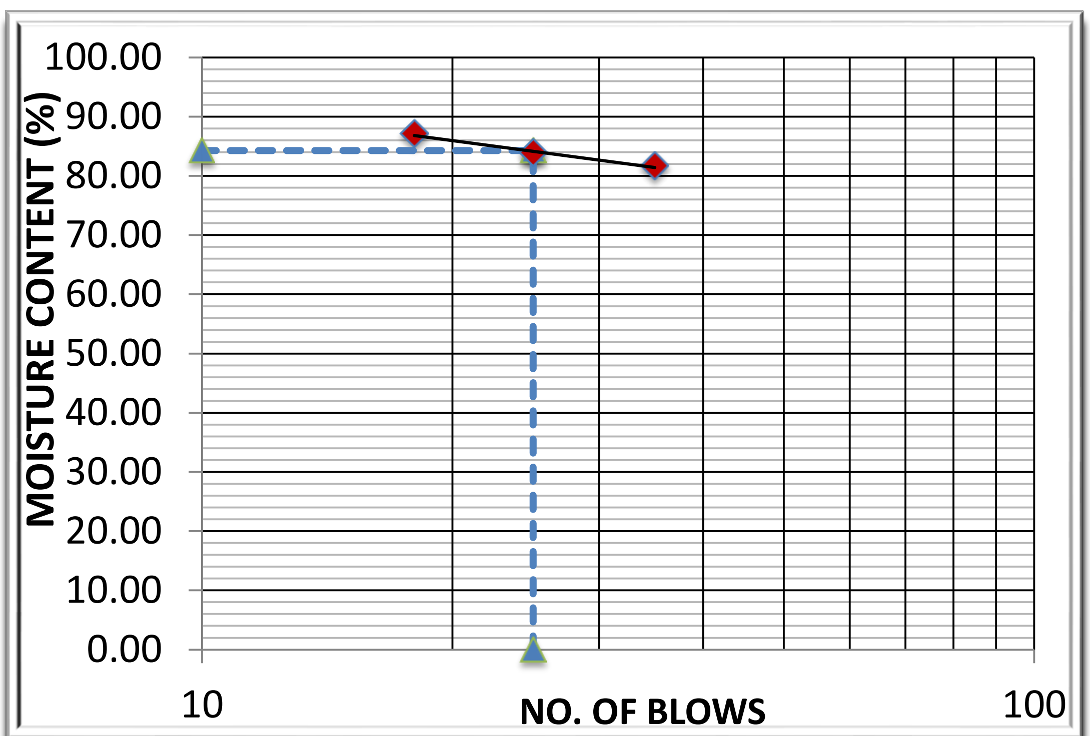
AV. PL (%)	42.4

Liquid Limit, LL(%)	**88.7**
Plastic Limit, PL(%)	**42.4**
Plasticity Index, PI(%)	**46.3**



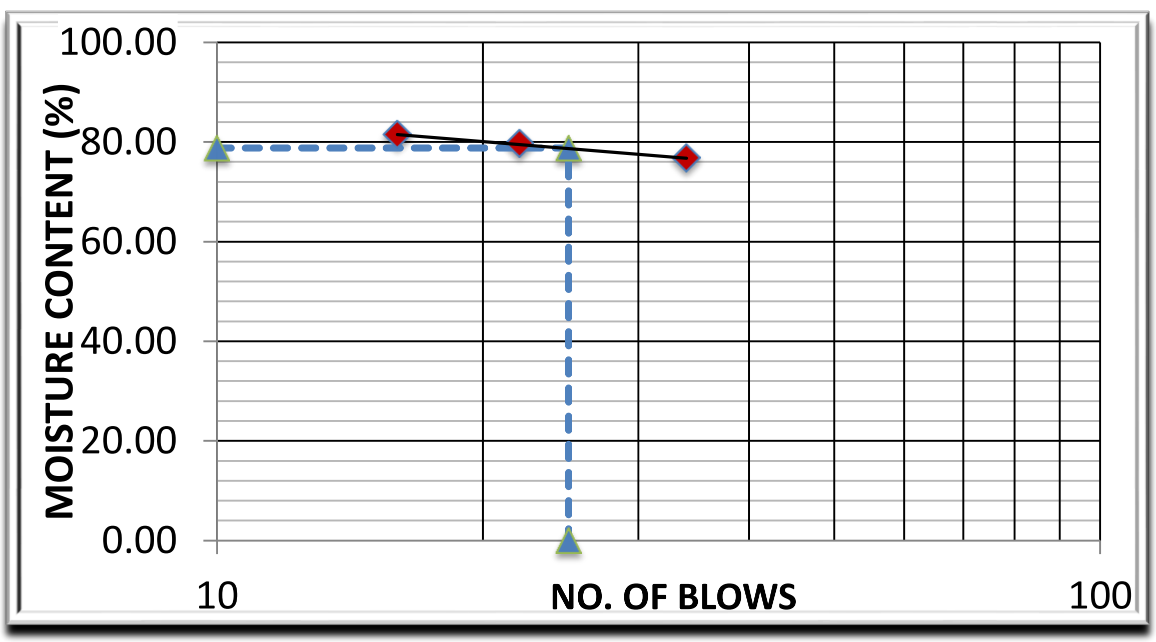
20% Brick Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	35	25	18		
Wt.of cont. + wet soil (g.)	32.20	16.30	34.60	23.00	14.50
Wt.of cont. + dry soil (g.)	26.40	11.60	27.80	21.00	12.10
Wt. of water (g.)	5.80	4.70	6.80	2.00	2.40
Wt. container (g.)	19.30	6.00	20.00	16.60	6.40
Wt. dry soil (g.)	7.10	5.60	7.80	4.40	5.70
Water Content (%)	81.69	83.93	87.18	45.45	42.11
Liquid Limit, LL(%)	**84.3**			**AV. PL (%)**	43.8
Plastic Limit, PL(%)	**43.8**				
Plasticity Index, PI(%)	**40.5**				



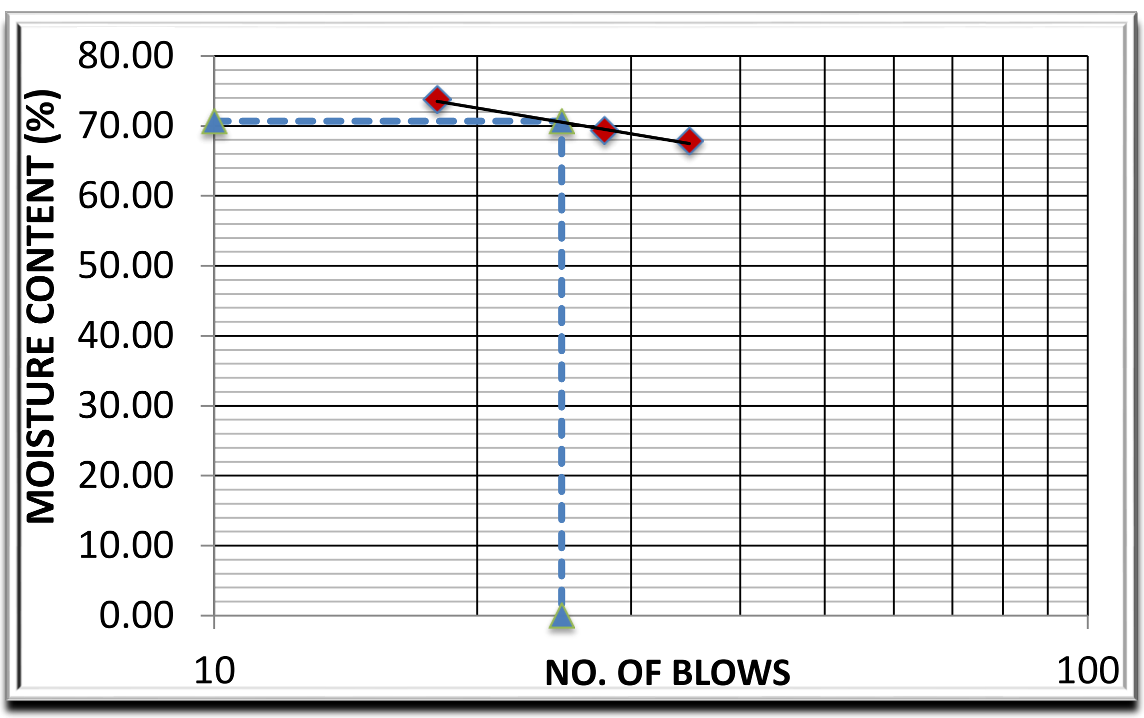
30% Brick Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	34	22	16		
Wt.of cont. + wet soil (g.)	31.20	29.70	37.70	25.10	24.80
Wt.of cont. + dry soil (g.)	25.90	23.80	30.60	23.30	22.90
Wt. of water (g.)	5.30	5.90	7.10	1.80	1.90
Wt. container (g.)	19.00	16.40	21.90	19.60	18.80
Wt. dry soil (g.)	6.90	7.40	8.70	3.70	4.10
Water Content (%)	76.81	79.73	81.61	48.65	46.34
Liquid Limit, LL(%)	**78.8**			**AV. PL (%)**	47.5
Plastic Limit, PL(%)	**47.5**				
Plasticity Index, PI(%)	**31.3**				



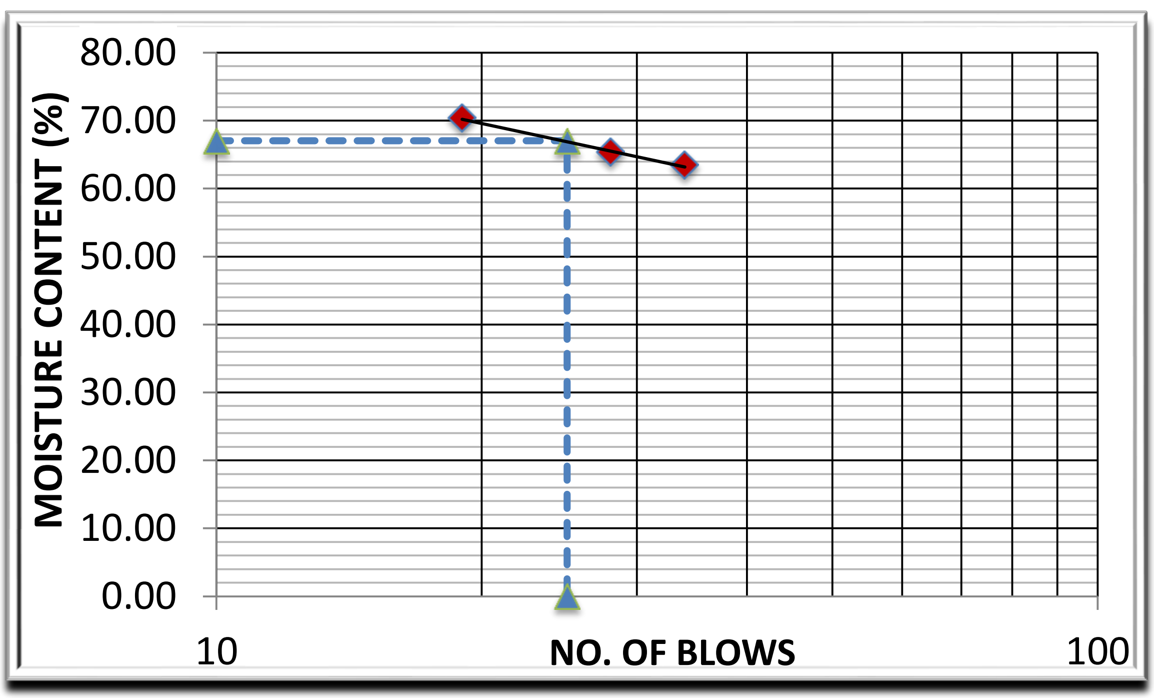
40% Brick Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	35	28	18		
Wt.of cont. + wet soil (g.)	42.10	18.40	38.10	18.10	30.98
Wt.of cont. + dry soil (g.)	34.50	13.20	29.10	14.20	26.90
Wt. of water (g.)	7.60	5.20	9.00	3.90	4.08
Wt. container (g.)	23.30	5.70	16.90	6.20	18.90
Wt. dry soil (g.)	11.20	7.50	12.20	8.00	8.00
Water Content (%)	67.86	69.33	73.77	48.75	51.00
Liquid Limit, LL(%)	**70.7**			**AV. PL (%)**	49.9
Plastic Limit, PL(%)	**49.9**				
Plasticity Index, PI(%)	**20.8**				



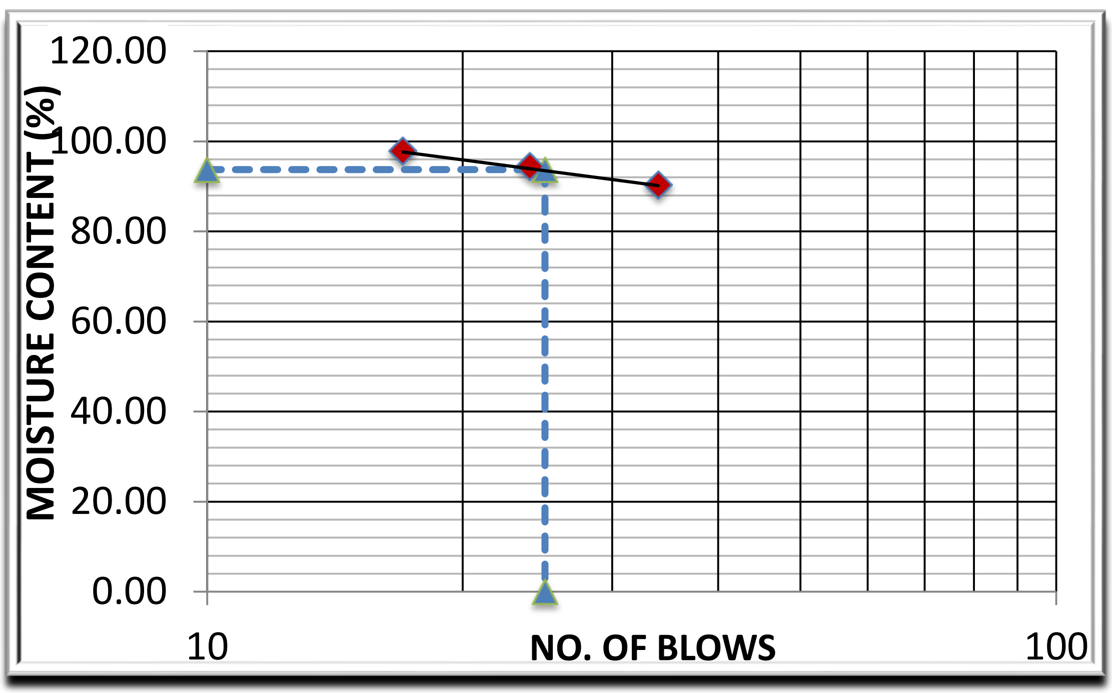
50% Brick Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	34	28	19		
Wt.of cont. + wet soil (g.)	39.20	38.80	39.00	27.50	30.20
Wt.of cont. + dry soil (g.)	31.20	30.10	30.90	25.60	27.90
Wt. of water (g.)	8.00	8.70	8.10	1.90	2.30
Wt. container (g.)	18.60	16.80	19.40	22.00	23.30
Wt. dry soil (g.)	12.60	13.30	11.50	3.60	4.60
Water Content (%)	63.49	65.41	70.43	52.78	50.00
Liquid Limit, LL(%)	**67.0**			**AV. PL (%)**	51.4
Plastic Limit, PL(%)	**51.4**				
Plasticity Index, PI(%)	**15.6**				



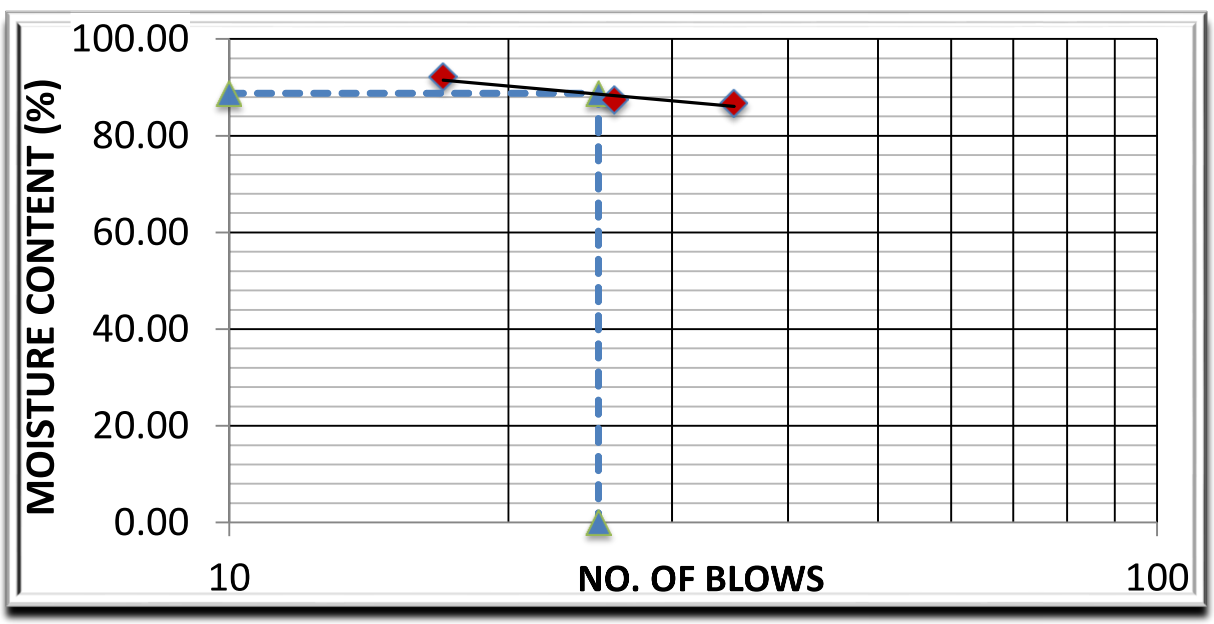
5% Stone Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	34	24	17		
Wt.of cont. + wet soil (g.)	20.20	21.10	39.30	23.20	22.00
Wt.of cont. + dry soil (g.)	13.70	14.40	26.10	21.50	20.40
Wt. of water (g.)	6.50	6.70	13.20	1.70	1.60
Wt. container (g.)	6.50	7.30	12.60	17.10	16.40
Wt. dry soil (g.)	7.20	7.10	13.50	4.40	4.00
Water Content (%)	90.28	94.37	97.78	38.64	40.00
Liquid Limit, LL(%)	**93.7**			**AV. PL (%)**	39.3
Plastic Limit, PL(%)	**39.3**				
Plasticity Index, PI(%)	**54.4**				



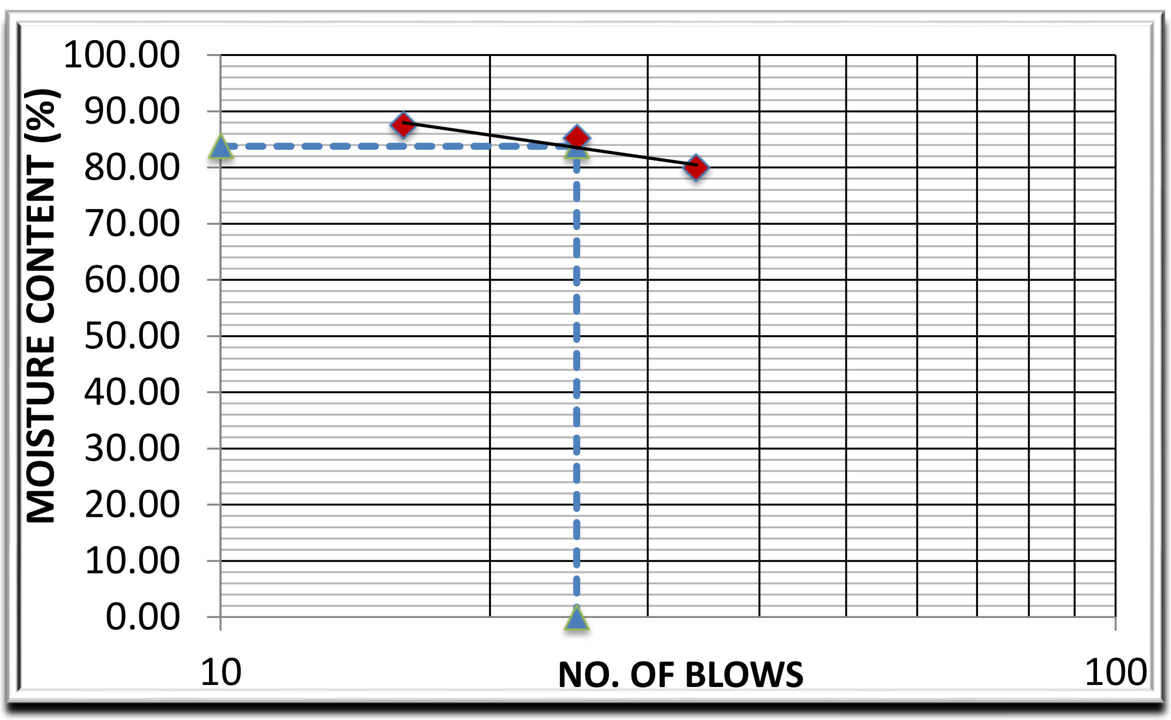
10% Stone Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	35	26	17		
Wt.of cont. + wet soil (g.)	19.40	41.70	39.10	17.10	15.11
Wt.of cont. + dry soil (g.)	13.50	29.90	29.70	13.90	12.60
Wt. of water (g.)	5.90	11.80	9.40	3.20	2.51
Wt. container (g.)	6.70	16.40	19.50	6.40	6.50
Wt. dry soil (g.)	6.80	13.50	10.20	7.50	6.10
Water Content (%)	86.76	87.41	92.16	42.67	41.15
Liquid Limit, LL(%)	**88.8**			**AV. PL (%)**	41.9
Plastic Limit, PL(%)	**41.9**				
Plasticity Index, PI(%)	**46.8**				



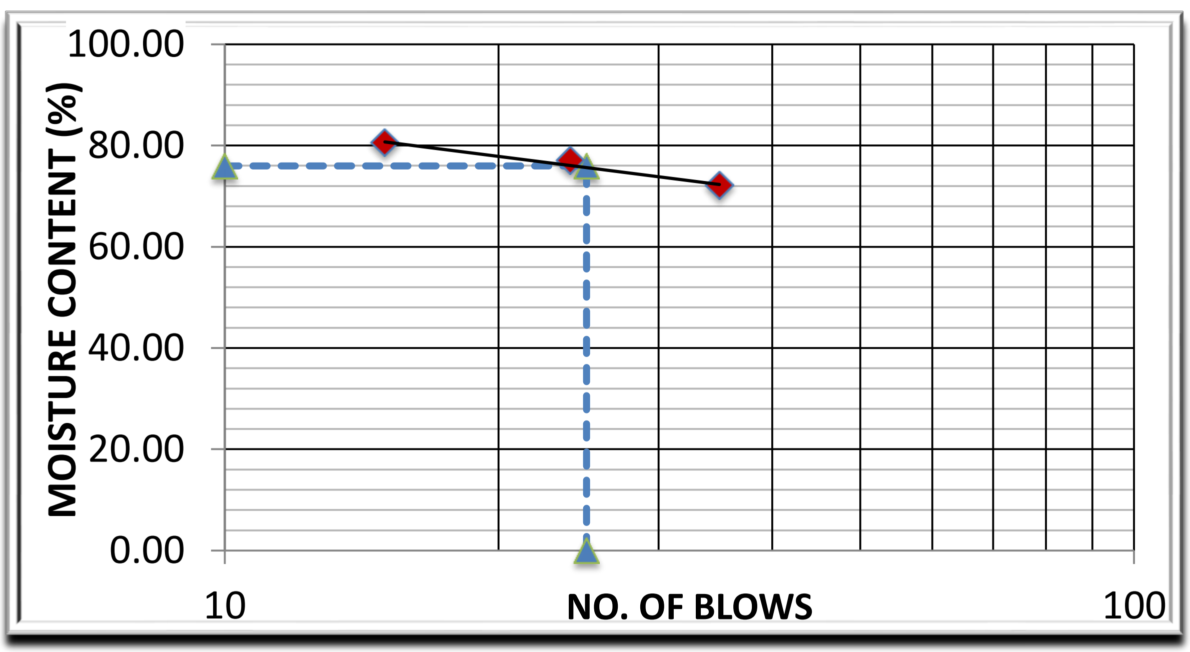
15% stone dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	34	25	16		
Wt.of cont. + wet soil (g.)	31.50	37.40	33.50	25.10	23.50
Wt.of cont. + dry soil (g.)	24.30	27.60	22.30	19.30	19.10
Wt. of water (g.)	7.20	9.80	11.20	5.80	4.40
Wt. container (g.)	15.30	16.10	9.50	6.50	9.30
Wt. dry soil (g.)	9.00	11.50	12.80	12.80	9.80
Water Content (%)	80.00	85.22	87.50	45.31	44.90
Liquid Limit, LL(%)	**83.8**			**AV. PL (%)**	45.1
Plastic Limit, PL(%)	**45.1**				
Plasticity Index, PI(%)	**38.7**				



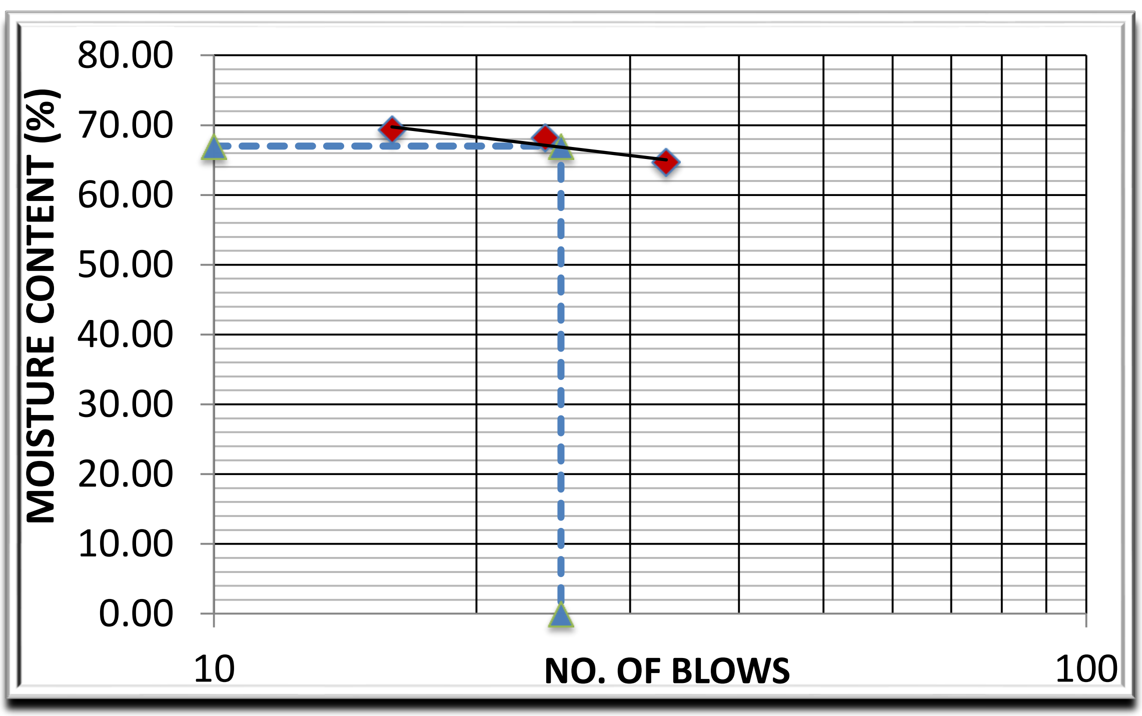
20% stone dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	35	24	15		
Wt.of cont. + wet soil (g.)	33.00	30.70	29.60	29.40	33.50
Wt.of cont. + dry soil (g.)	26.50	25.30	24.20	24.30	28.50
Wt. of water (g.)	6.50	5.40	5.40	5.10	5.00
Wt. container (g.)	17.50	18.30	17.50	14.00	18.40
Wt. dry soil (g.)	9.00	7.00	6.70	10.30	10.10
Water Content (%)	72.22	77.14	80.60	49.51	49.50
Liquid Limit, LL(%)	**76.0**			**AV. PL (%)**	49.5
Plastic Limit, PL(%)	**49.5**				
Plasticity Index, PI(%)	**26.4**				



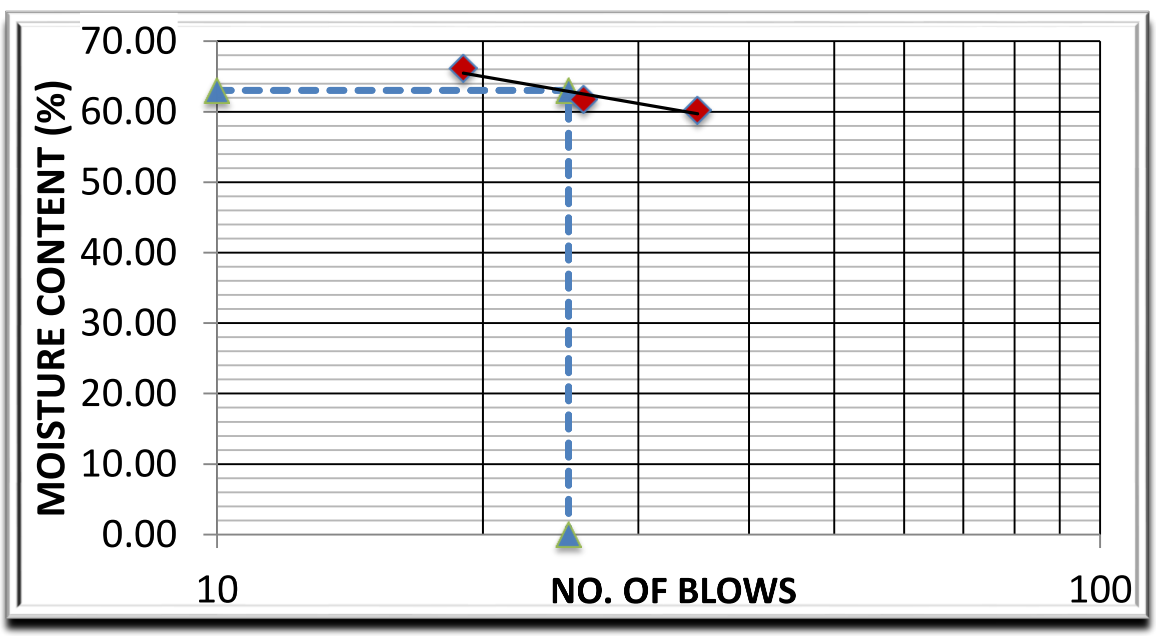
25% Stone Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	33	24	16		
Wt.of cont. + wet soil (g.)	28.70	31.00	32.50	23.80	21.30
Wt.of cont. + dry soil (g.)	24.30	25.20	23.90	18.30	16.40
Wt. of water (g.)	4.40	5.80	8.60	5.50	4.90
Wt. container (g.)	17.50	16.70	11.50	7.50	6.70
Wt. dry soil (g.)	6.80	8.50	12.40	10.80	9.70
Water Content (%)	64.71	68.24	69.35	50.93	50.52
Liquid Limit, LL(%)	**67.0**			**AV. PL (%)**	50.7
Plastic Limit, PL(%)	**50.7**				
Plasticity Index, PI(%)	**16.3**				



30% Stone Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	35	26	19		
Wt.of cont. + wet soil (g.)	36.20	35.40	38.60	31.90	38.20
Wt.of cont. + dry soil (g.)	30.60	29.10	29.80	28.20	32.60
Wt. of water (g.)	5.60	6.30	8.80	3.70	5.60
Wt. container (g.)	21.30	18.90	16.50	21.00	21.70
Wt. dry soil (g.)	9.30	10.20	13.30	7.20	10.90
Water Content (%)	60.22	61.76	66.17	51.39	51.38
Liquid Limit, LL(%)	**63.0**			**AV. PL (%)**	51.4
Plastic Limit, PL(%)	**51.4**				
Plasticity Index, PI(%)	**11.7**				

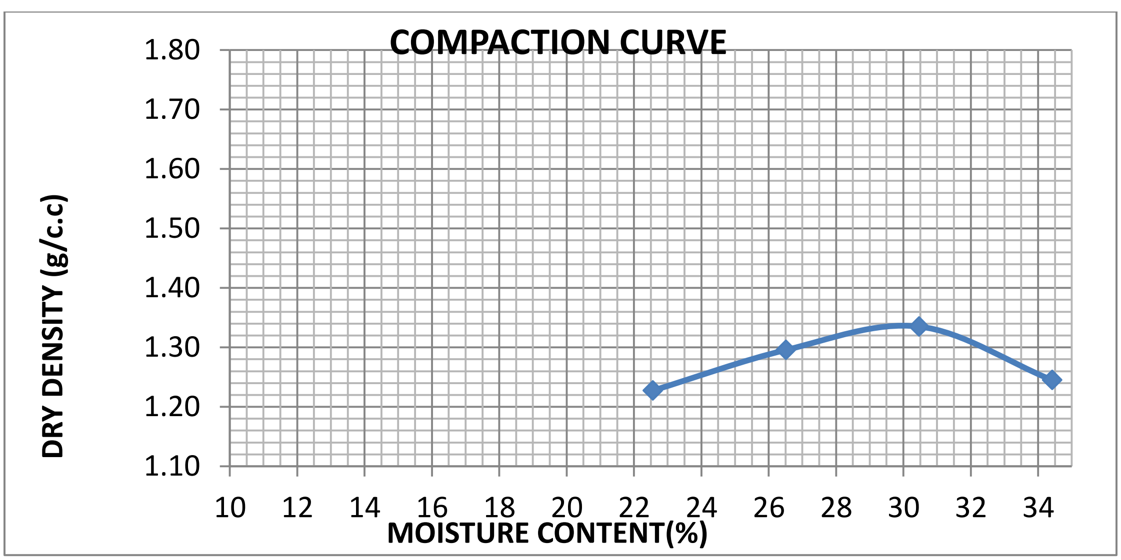


Annex A-8: Compaction Test Result

Natural soil

trial No.	1		2		3		4	
wt of wet soil+mold	9758.4		10045.1		10262.5		10117.3	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.50		1.64		1.74		1.67	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	88.9	115.9	83.1	84.7	232.7	150.6	186.5	151.2
wt of dry soil+can	75.7	98.3	69.5	70.0	185.9	119.6	145.4	116.8
wt of can	17.5	19.6	17.5	15.5	33.1	17.3	25.1	17.6
moisture content,%	22.68	22.44	26.15	26.88	30.63	30.30	34.16	34.68
Average moisture content,%	22.56		26.52		30.47		34.42	
dry density, g/cc	1.23		1.30		1.34		1.24	

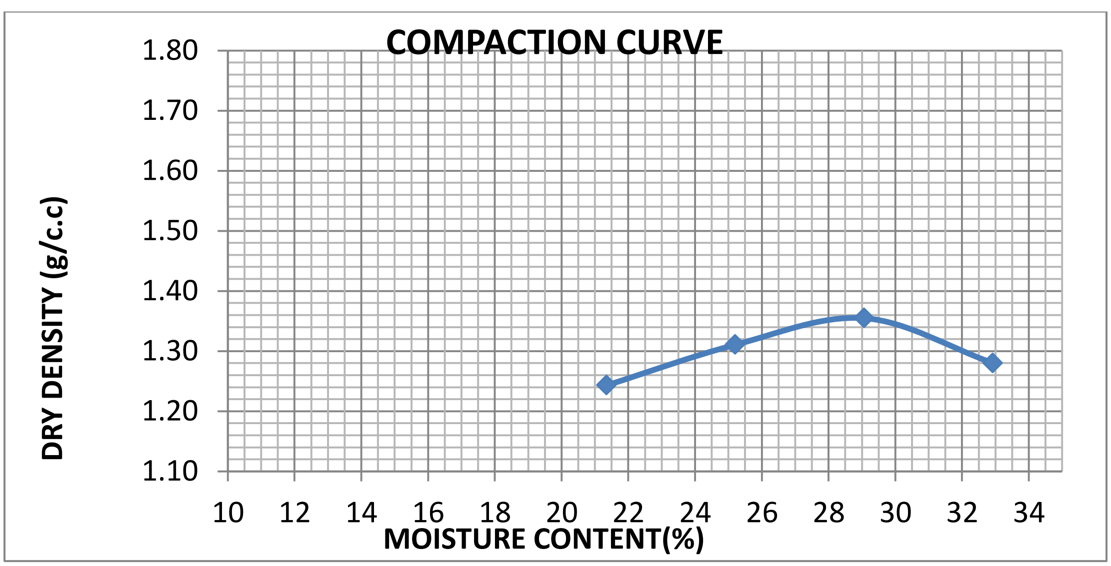
MDD (gm/cm3)	**OMC (%)**
1.34	**30.47**



5% Brick Dust

trial No.	1		2		3		4	
wt of wet soil+mold	9766.8		10048.4		10277.1		10177.3	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.51		1.64		1.75		1.70	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	108.6	88.7	121.3	136.4	151.5	180.5	148.3	186.9
wt of dry soil+can	93.4	76.6	101.2	113.5	121.5	143.9	115.8	145.6
wt of can	22.2	19.9	21.5	22.6	18.7	17.5	16.9	20.4
moisture content,%	21.35	21.34	25.22	25.19	29.18	28.96	32.86	32.99
Average moisture content,%	21.34		25.21		29.07		32.92	
dry density, g/cc	1.24		1.31		1.35		1.28	

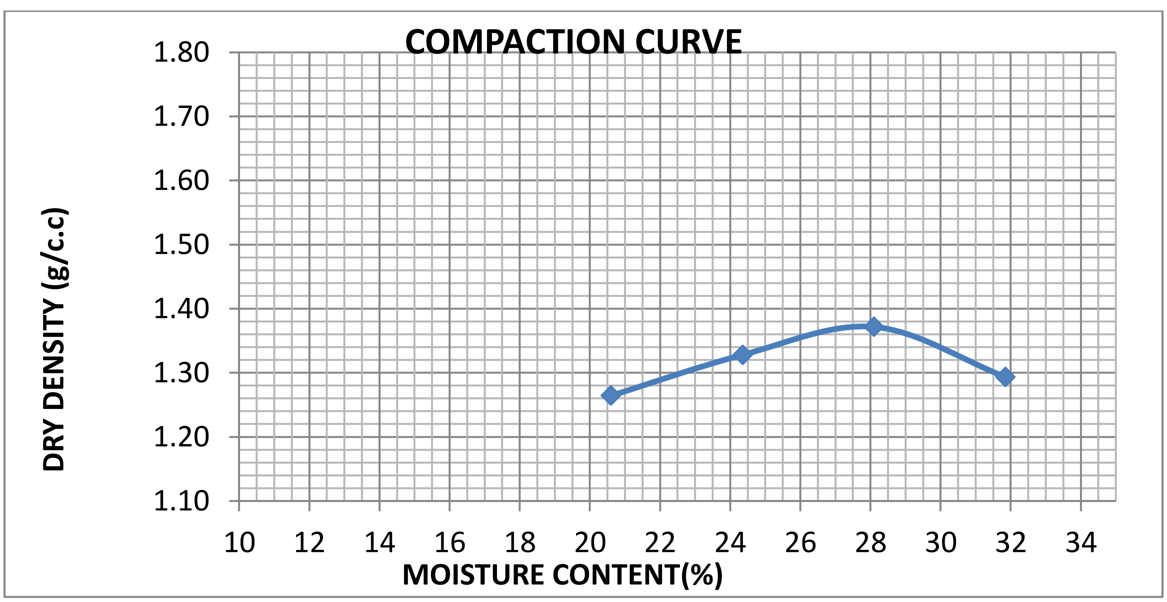
MDD (gm/cm3)	OMC (%)
1.35	**29.1**



10% Brick Dust

trial No.	1		2		3		4	
wt of wet soil+mold	9802.0		10070.8		10295.0		10185.3	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.52		1.65		1.76		1.71	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	189.9	195.0	157.2	98.8	206.2	177.4	179.5	168.1
wt of dry soil+can	163.6	166.5	133.1	82.9	168.6	142.3	144.0	136.2
wt of can	35.5	28.7	34.2	17.6	34.6	17.6	32.3	36.3
moisture content,%	20.53	20.68	24.37	24.35	28.06	28.15	31.78	31.93
Average moisture content,%	20.61		24.36		28.10		31.86	
dry density, g/cc	1.26		1.33		1.37		1.29	

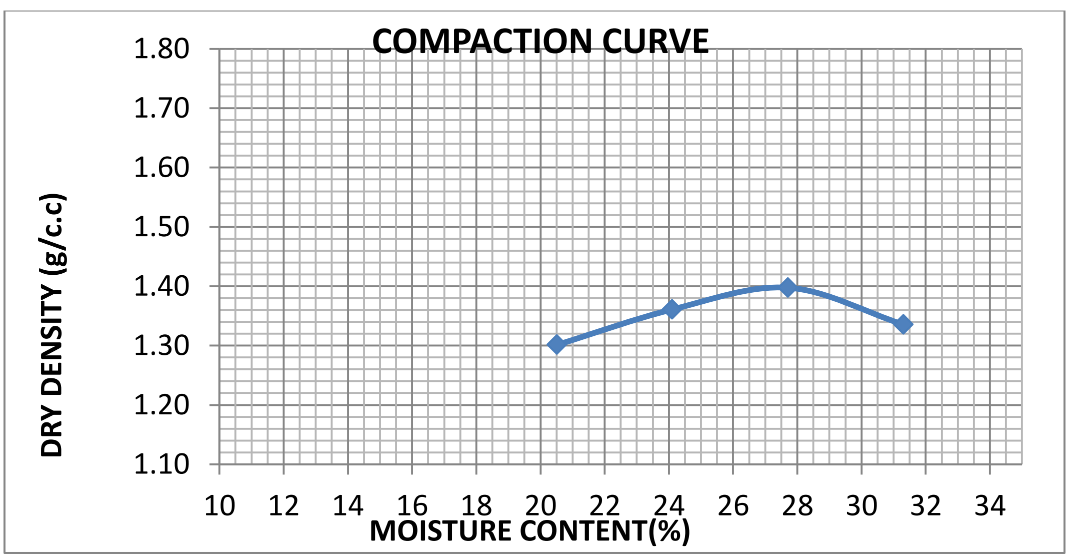
MDD (gm/cm3)	OMC (%)
1.37	28.1



20% Brick Dust

trial No.	1		2		3		4	
wt of wet soil+mold	9894.1		10150.8		10354.0		10287.4	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.57		1.69		1.78		1.75	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	140.6	171.4	137.2	118.4	149.8	152.8	164.1	169.4
wt of dry soil+can	120.3	145.2	115.4	98.8	121.1	123.5	130.0	134.4
wt of can	21.1	17.8	25.1	17.4	17.7	17.6	21.2	22.5
moisture content,%	20.46	20.57	24.14	24.08	27.76	27.67	31.34	31.28
Average moisture content,%	20.51		24.11		27.71		31.31	
dry density, g/cc	1.30		1.36		1.40		1.34	

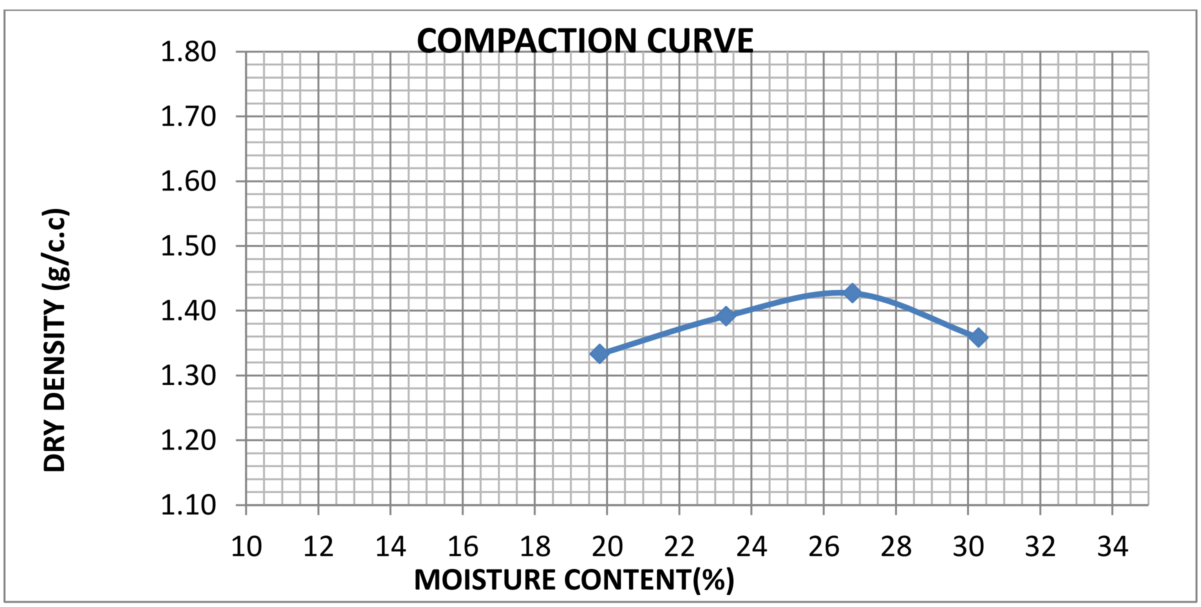
MDD (gm/cm3)	OMC (%)
1.4	**27.7**



30% Brick Dust

trial No.	1		2		3		4	
wt of wet soil+mold	9955.3		10208.0		10406.0		10322.0	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.60		1.72		1.81		1.77	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	139.7	151.5	100.7	134.4	164.7	126.2	188.5	218.8
wt of dry soil+can	120.3	131.0	85.1	112.1	137.1	103.2	150.3	177.7
wt of can	22.5	27.3	17.5	17.3	34.2	17.3	25.0	41.2
moisture content,%	19.84	19.77	23.08	23.52	26.82	26.78	30.49	30.11
Average moisture content,%	19.80		23.30		26.80		30.30	
dry density, g/cc	1.33		1.39		1.43		1.36	

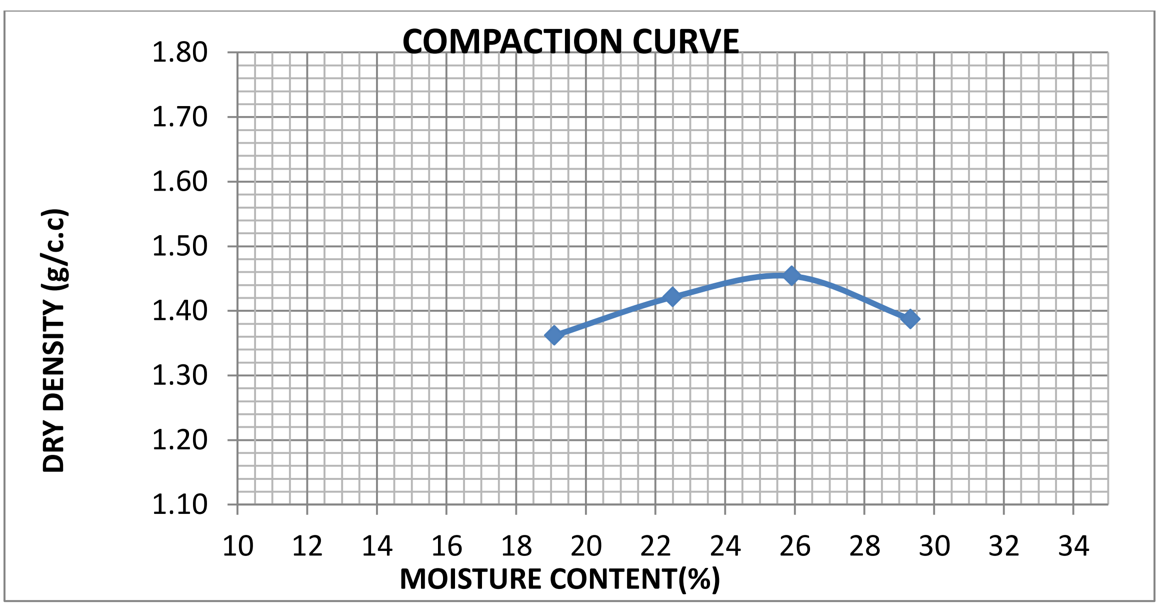
MDD (gm/cm3)	OMC (%)
1.43	26.8



40% Brick Dust

trial No.	1		2		3		4	
wt of wet soil+mold	10008.0		10261.2		10450.9		10373.3	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.62		1.74		1.83		1.79	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	154.4	113.2	120.6	137.2	165.4	137.9	148.6	145.0
wt of dry soil+can	132.5	98.1	102.1	116.1	135.0	113.4	120.0	117.8
wt of can	17.9	19.0	21.1	20.9	17.8	18.8	22.4	25.1
moisture content,%	19.11	19.09	22.84	22.16	25.94	25.90	29.30	29.34
Average moisture content,%	19.10		22.50		25.92		29.32	
dry density, g/cc	1.36		1.42		1.45		1.39	

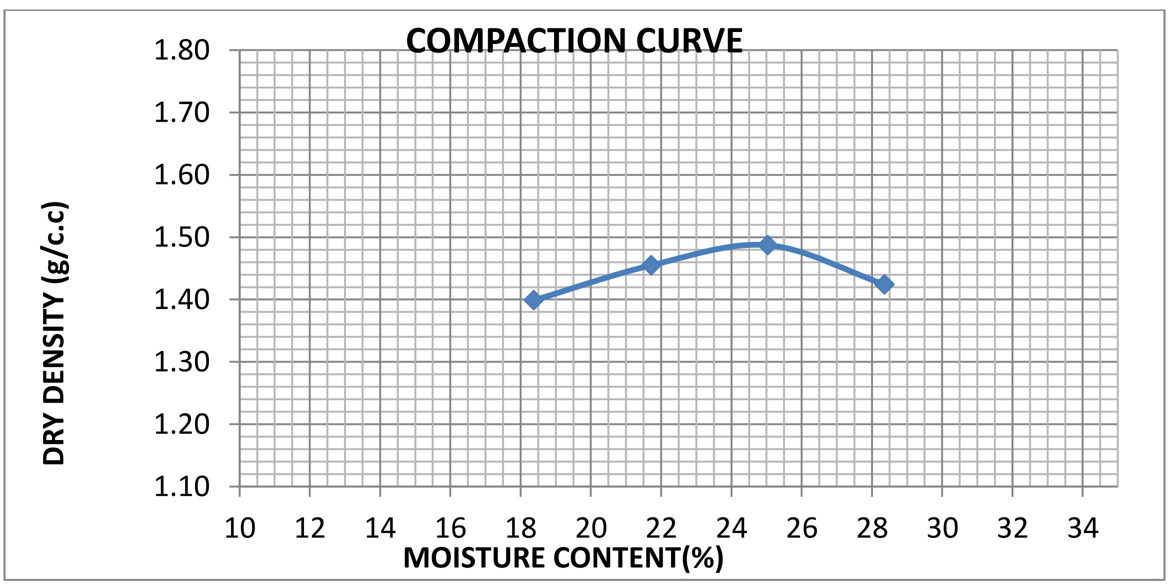
MDD (gm/cm3)	**OMC (%)**
1.45	**25.9**



50% Brick Dust

trial No.	1		2		3		4	
wt of wet soil+mold	10080.5		10324.5		10512.4		10445.9	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.66		1.77		1.86		1.83	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	157.1	154.2	171.3	204.2	167.7	144.8	214.6	130.5
wt of dry soil+can	137.1	135.5	147.0	174.1	141.5	119.3	175.7	105.4
wt of can	29.8	32.3	34.9	35.8	36.6	17.7	37.8	17.4
moisture content,%	18.64	18.12	21.68	21.76	24.98	25.10	28.21	28.52
Average moisture content,%	18.38		21.72		25.04		28.37	
dry density, g/cc	1.40		1.45		1.49		1.42	

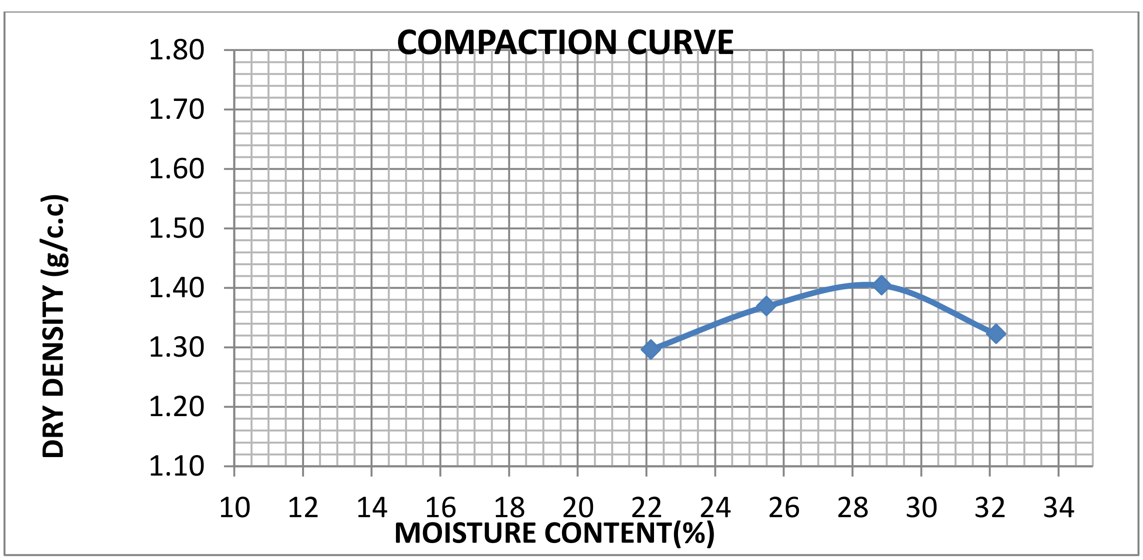
MDD (gm/cm3)	OMC (%)
1.49	**25.0**



5% Stone Dust

trial No.	1		2		3		4	
wt of wet soil+mold	9925.6		10212.1		10405.5		10275.6	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.58		1.72		1.81		1.75	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	140.6	174.9	132.6	139.0	138.6	157.6	160.4	154.8
wt of dry soil+can	118.2	146.5	109.1	114.4	112.8	126.6	125.1	122.8
wt of can	17.6	17.4	17.8	17.0	23.1	19.5	16.8	22.1
moisture content,%	22.27	22.00	25.74	25.26	28.76	28.94	32.60	31.78
Average moisture content,%	22.13		25.50		28.85		32.19	
dry density, g/cc	1.30		1.37		1.40		1.32	

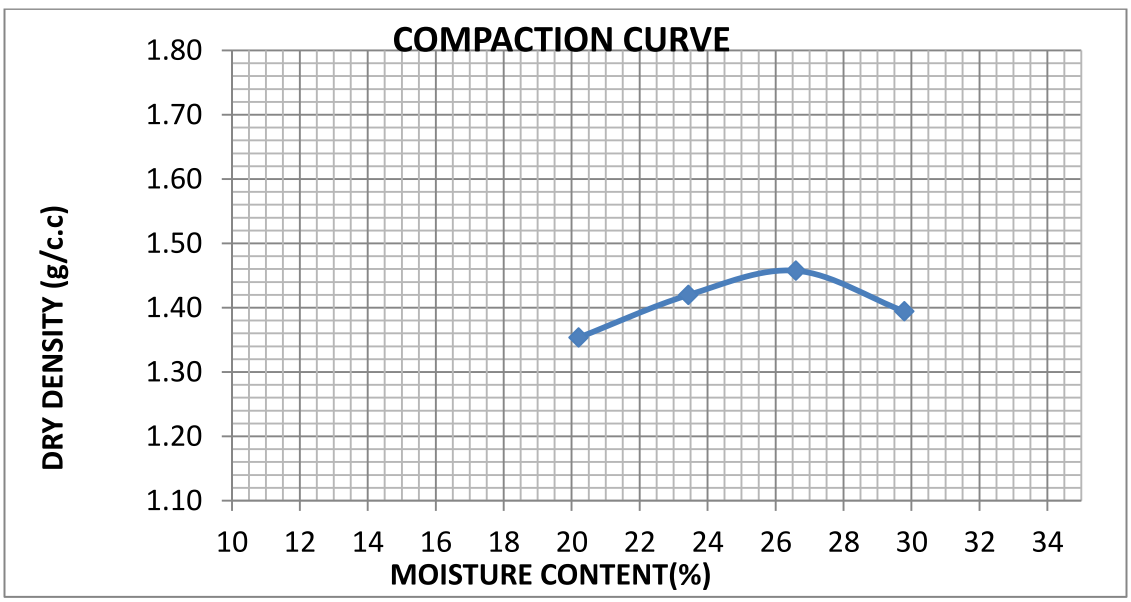
MDD (gm/cm3)	**OMC (%)**
1.4	**28.9**



10% Stone Dust

trial No.	1		2		3		4	
wt of wet soil+mold	10018.9		10285.3		10482.1		10406.6	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.63		1.75		1.85		1.81	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	134.0	144.7	131.5	156.6	119.5	123.7	110.7	151.0
wt of dry soil+can	114.5	123.3	109.8	130.2	98.3	101.5	89.7	121.1
wt of can	17.5	17.9	17.0	17.8	19.1	17.5	18.8	21.3
moisture content,%	20.10	20.30	23.38	23.49	26.77	26.43	29.62	29.96
Average moisture content,%	20.20		23.44		26.60		29.79	
dry density, g/cc	1.35		1.42		1.46		1.39	

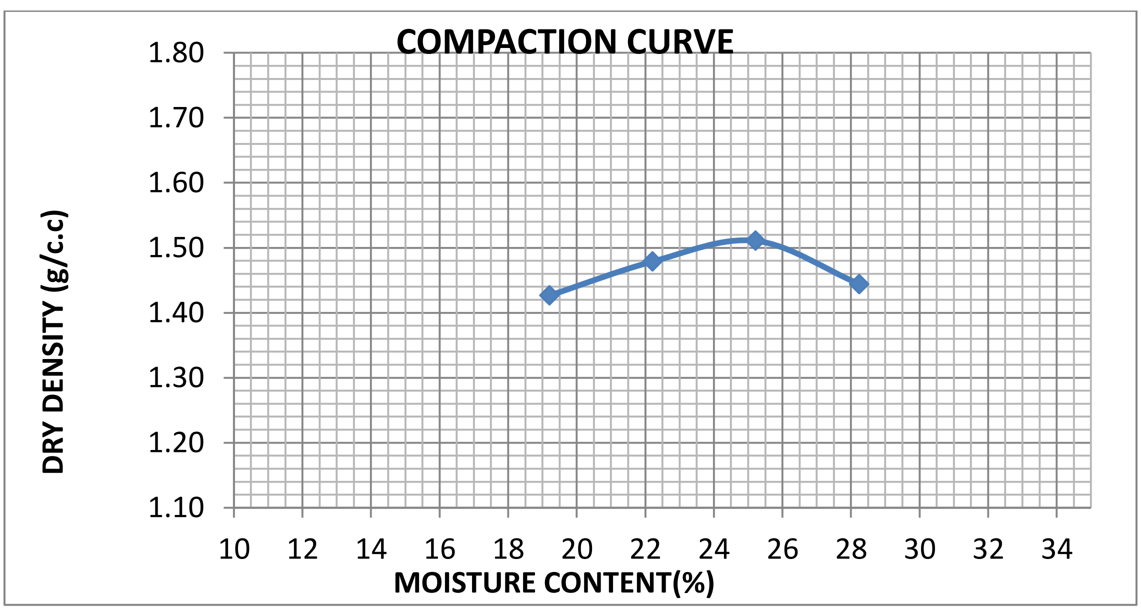
MDD (gm/cm3)	OMC (%)
1.46	**26.6**



15% Stone Dust

trial No.	1		2		3		4	
wt of wet soil+mold	10175.3		10401.5		10580.8		10496.6	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.70		1.81		1.89		1.85	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	116.5	126.5	151.6	137.3	125.0	158.8	123.5	141.5
wt of dry soil+can	101.2	109.1	127.5	115.5	103.3	131.2	100.5	114.6
wt of can	21.2	18.9	18.5	17.8	17.6	21.3	18.7	19.8
moisture content,%	19.13	19.29	22.11	22.31	25.32	25.11	28.12	28.38
Average moisture content,%	19.21		22.21		25.22		28.25	
dry density, g/cc	1.43		1.48		1.51		1.44	

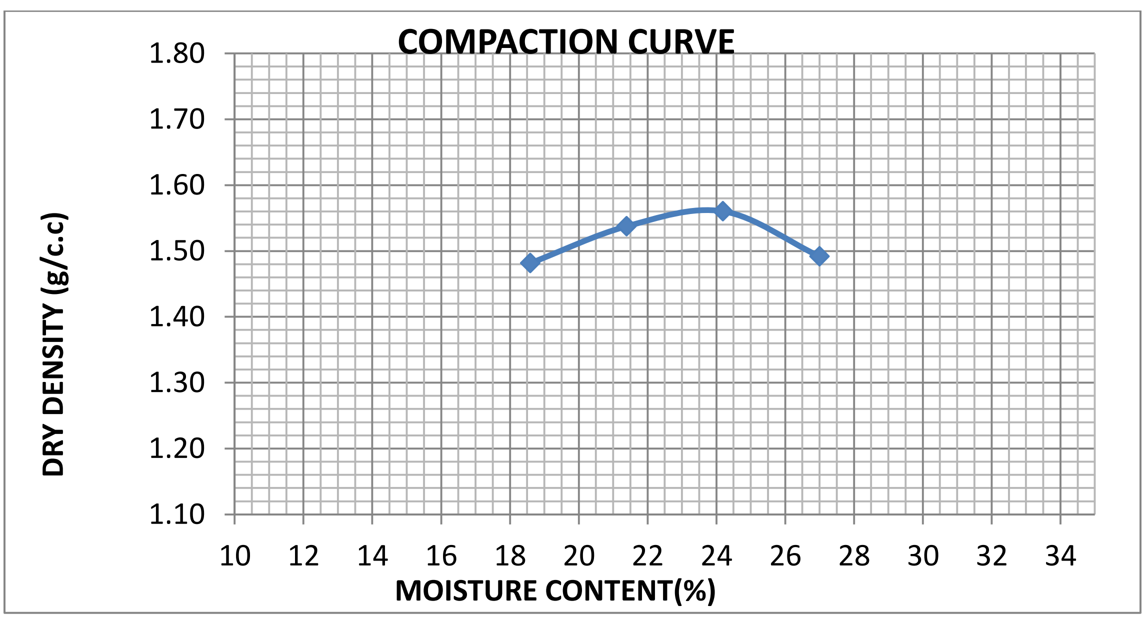
MDD (gm/cm3)	**OMC (%)**
1.51	**25.2**



20% Stone Dust

trial No.	1		2		3		4	
wt of wet soil+mold	10295.3		10527.5		10678.6		10586.6	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.76		1.87		1.94		1.89	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	128.6	153.9	141.8	133.0	126.2	114.4	132.0	163.4
wt of dry soil+can	111.5	132.6	120.0	112.5	106.0	96.3	107.8	132.3
wt of can	19.7	17.9	17.8	17.0	22.3	21.7	18.1	17.2
moisture content,%	18.63	18.57	21.33	21.47	24.13	24.26	26.98	27.02
Average moisture content,%	18.60		21.40		24.20		27.00	
dry density, g/cc	1.48		1.54		1.56		1.49	

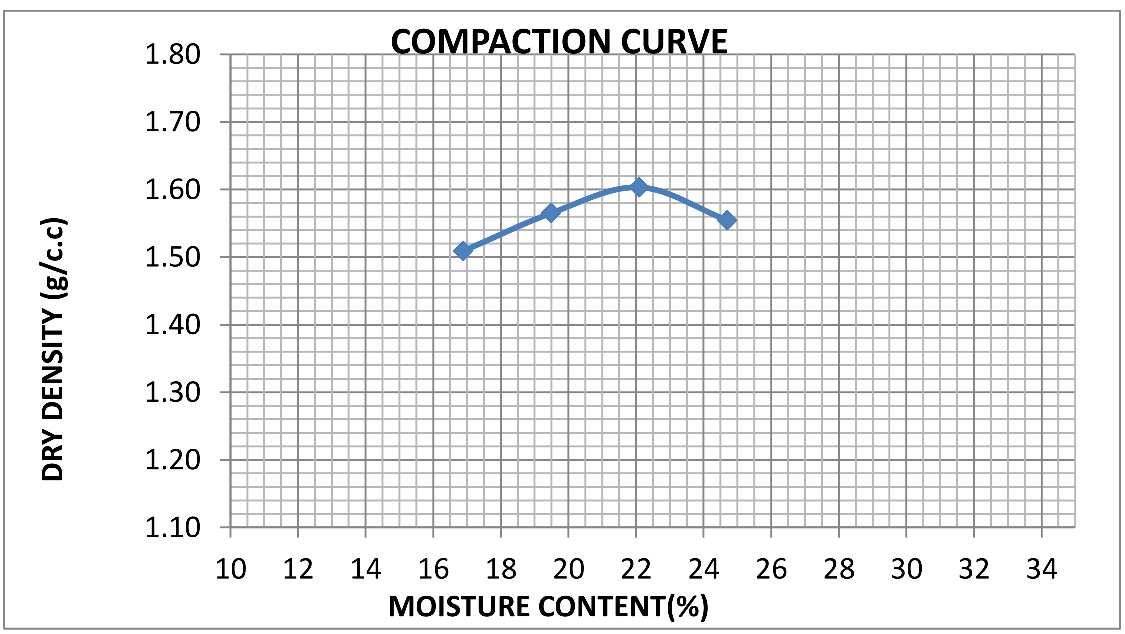
MDD (gm/cm3)	OMC (%)
1.56	**24.2**



25% Stone Dust

trial No.	1		2		3		4	
wt of wet soil+mold	10309.7		10535.4		10720.8		10680.0	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.76		1.87		1.96		1.94	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	140.1	155.9	151.4	134.2	131.6	155.7	143.4	146.9
wt of dry soil+can	124.5	136.6	130.0	115.4	111.2	130.8	118.7	121.1
wt of can	32.2	22.3	21.0	18.3	19.0	18.0	18.1	17.3
moisture content,%	16.90	16.89	19.63	19.36	22.13	22.07	24.55	24.86
Average moisture content,%	16.89		19.50		22.10		24.70	
dry density, g/cc	1.51		1.57		1.60		1.55	

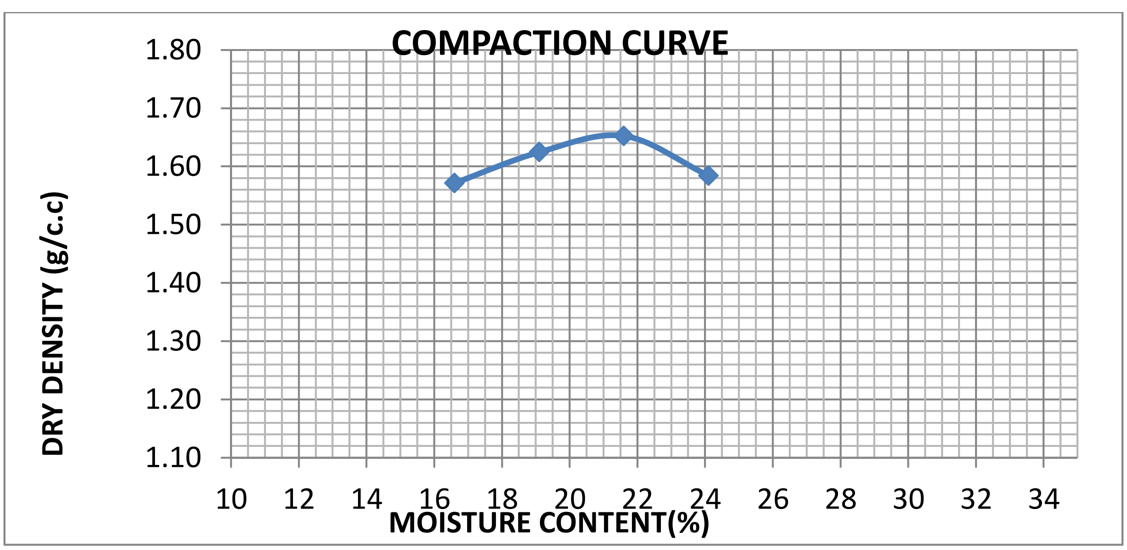
MDD (gm/cm3)	OMC (%)
1.6	**22.1**



30% Stone Dust

trial No.	1		2		3		4	
wt of wet soil+mold	10455.0		10672.4		10830.5		10738.4	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.83		1.93		2.01		1.97	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	137.4	178.5	217.1	122.0	151.7	149.6	159.4	199.1
wt of dry soil+can	122.5	155.6	187.6	105.3	130.7	128.3	131.9	166.6
wt of can	32.3	18.7	32.8	18.1	33.3	29.9	17.6	32.0
moisture content,%	16.48	16.73	19.06	19.15	21.56	21.65	24.06	24.15
Average moisture content,%	16.60		19.10		21.60		24.10	
dry density, g/cc	1.57		1.62		1.65		1.58	

MDD (gm/cm3)	OMC (%)	
1.65	**21.6**	



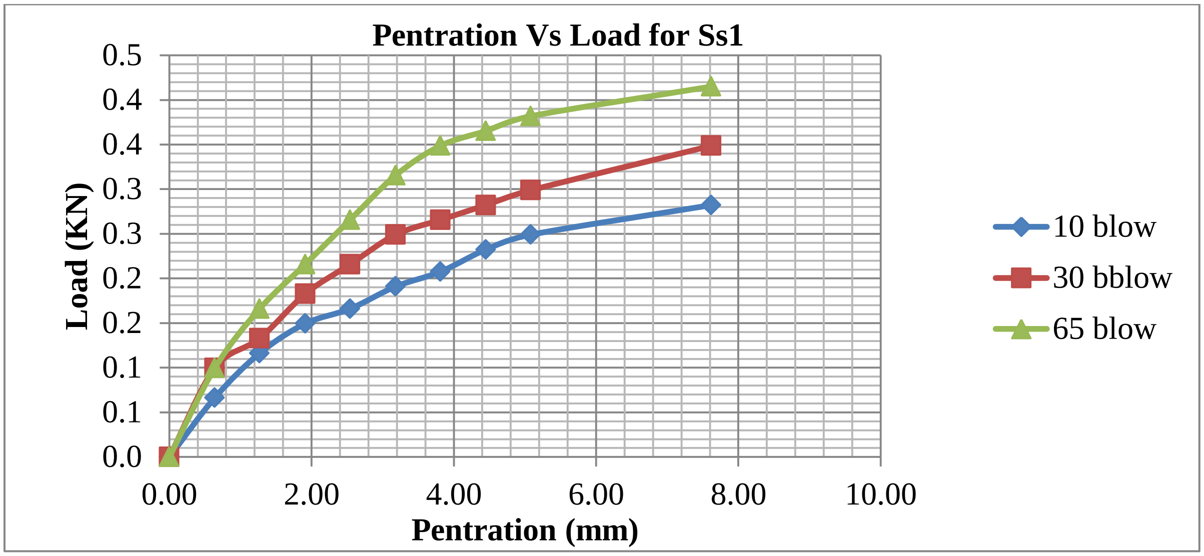
Annex A-9: CBR Test Result

Natural soil

Compaction Determination of natural Ss1							
COMPACTION DATA		**10 Blows**		**30 Blows**		**65 Blows**	
		Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mould No.		C1	C1	C2	C2	C3	C3
Mass of soil + Mould	g	12758.7	13201.6	12888.2	13333.2	13245.6	13594
Mass Mould	g	9405.7	9405.7	9399.1	9399.1	9530.5	9530.5
Mass of Soil	g	3353	3795.9	3489.1	3934.1	3715.1	4063.5
Volume of Mould	g	2123	2123	2123	2123	2123	2123
Wet density of soil	g/cc	1.579	1.788	1.643	1.853	1.750	1.914
Dry density of soil	g/cc	1.213	1.202	1.265	1.264	1.343	1.340

Moisture Determination										
MOISTURE CONTENT DATA		**10 Blows**			**30 Blows**			**65 Blows**		
		Before soak		**After soak**	**Before soak**		**After soak**	**Before soak**		**After soak**
Container no.		A13	C	P10	MK	E11	T1C1	P10	T5C2	C1
Mass of wet soil + Container	g	167.3	150.8	225.5	127.5	141.5	162.0	126.9	140.9	204.1
Mass of dry soil + Container	g	137.2	123.1	165.1	102.3	117.2	116.1	101.4	112.3	155.9
Mass of container	g	36.4	32.5	41.2	17.6	36.6	17.5	17.4	17.8	43.5
Mass of water	g	30.1	27.7	60.4	25.2	24.3	45.9	25.5	28.6	48.2
Mass of drysoil	g	100.8	90.6	123.9	84.7	80.6	98.6	84.0	94.5	112.4
Moisture content	%	29.9	30.6	48.7	29.8	30.1	46.6	30.4	30.3	42.9
Average moisture content	%	30.2		48.7	30.0		46.6	30.3		42.9

Swell Determination						
	10 Blows		**30 Blows**		**65 Blows**	
	Gauge rdg mm	**Swell in %**	**Gauge rdg mm**	**Swell in %**	**Gauge rdg mm**	**Swell in %**
Initial	0.00	6.74	0	7.45	0.00	6.31
Final	7.84		8.67		7.34	

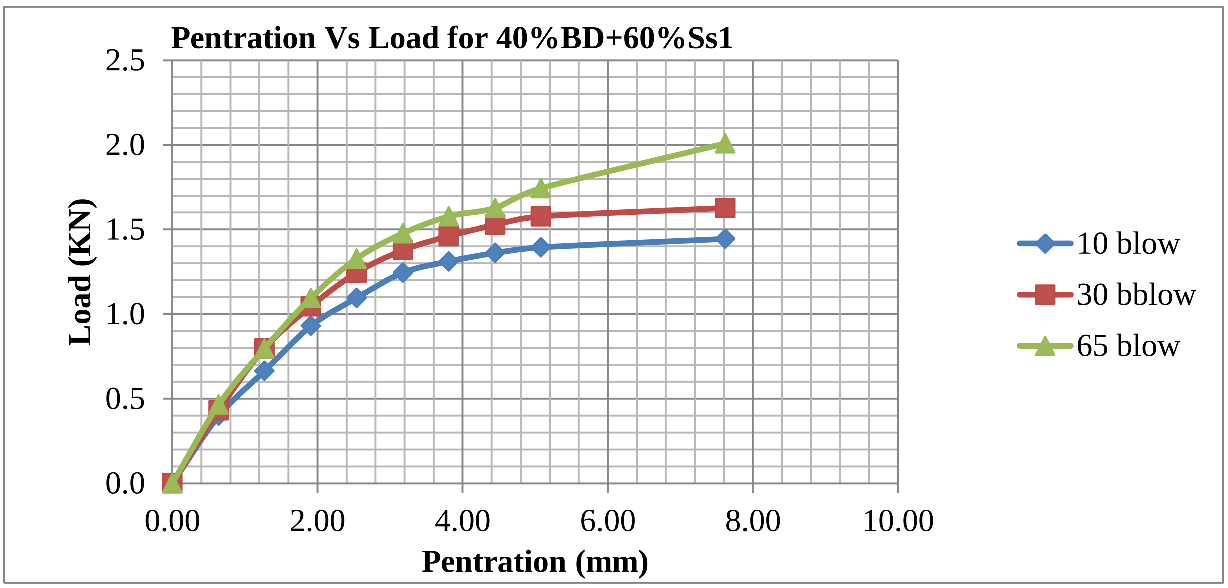


40% Brick dust

40% Brick Dust Compaction Determination							
COMPACTION DATA		10 Blows		30 Blows		65 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		C1	C1	C2	C2	C3	C3
Mass of soil + Mould	g	12949.1	13132.4	13137.2	13285.6	13342.1	13472
Mass Mould	g	9348.1	9348.1	9365.9	9365.9	9409.2	9409.2
Mass of Soil	g	3601	3784.3	3771.3	3919.7	3932.9	4062.8
Volume of Mould	g	2123	2123	2123	2123	2123	2123
Wet density of soil	g/cc	1.696	1.783	1.776	1.846	1.853	1.914
Dry density of soil	g/cc	1.355	1.349	1.410	1.409	1.472	1.469

Moisture Determination										
MOISTURE CONTENT DATA		10 Blows			30 Blows			65 Blows		
		Before soak		After soak	Before soak		After soak	Before soak		After soak
Container no.		A13	C	T1	T1C1	A12	G19	G4	P10	T5C2
Mass of wet soil + Container	g	123.3	140.2	168.3	128.9	125.7	228.1	138.4	133.9	168.3
Mass of dry soil + Container	g	105.8	115.5	136.5	108.3	103.5	182.2	116.7	114.0	133.3
Mass of container	g	36.4	17.4	37.6	29.4	17.4	34.2	32.8	36.8	17.6
Mass of water	g	17.5	24.7	31.8	20.6	22.2	45.9	21.7	19.9	35.0
Mass of drysoil	g	69.4	98.1	98.9	78.9	86.1	148.0	83.9	77.2	115.7
Moisture content	%	25.2	25.2	32.2	26.1	25.8	31.0	25.9	25.8	30.3
Average moisture content	%	25.2		32.2	25.9		31.0	25.8		30.3

Swell Determination						
	10 Blows		30 Blows		65 Blows	
	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
Initial	0.00	2.03	0	1.65	0.00	1.53
Final	2.36		1.92		1.78	

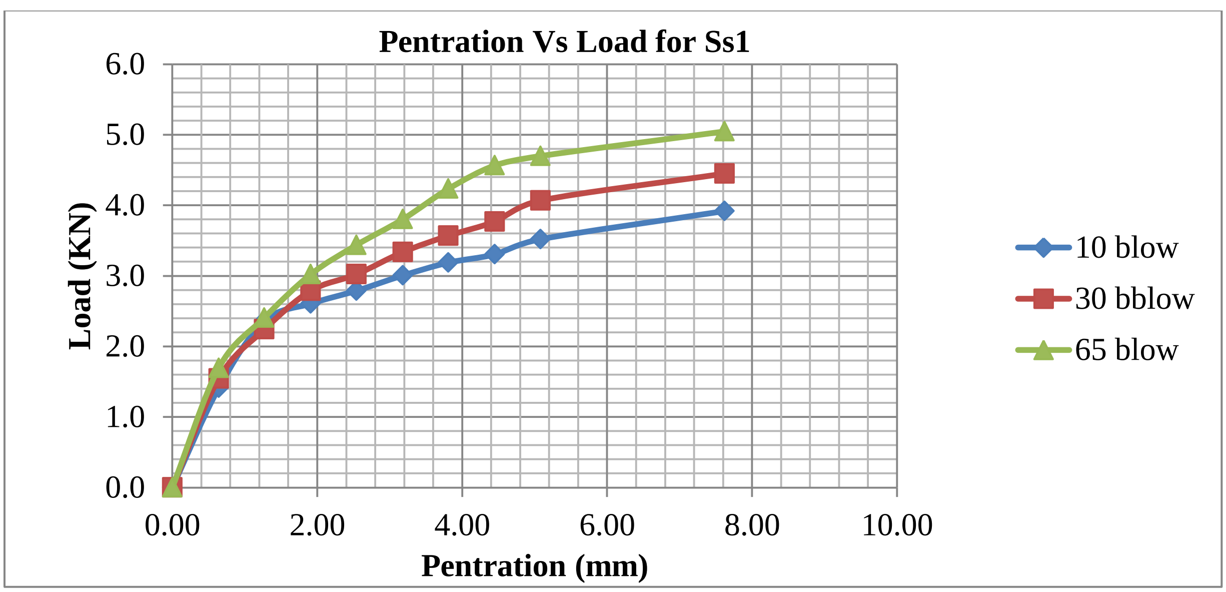


20% Stone dust

20% Stone dust Compaction Determination							
COMPACTION DATA		10 Blows		30 Blows		65 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		C1	C1	C2	C2	C3	C3
Mass of soil + Mould	g	13244.2	13384.1	13398.6	13519.1	13538.2	13625.5
Mass Mould	g	9406.4	9406.4	9389.5	9389.5	9410.3	9410.3
Mass of Soil	g	3837.8	3977.7	4009.1	4129.6	4127.9	4215.2
Volume of Mould	g	2123	2123	2123	2123	2123	2123
Wet density of soil	g/cc	1.808	1.874	1.888	1.945	1.944	1.985
Dry density of soil	g/cc	1.459	1.447	1.522	1.507	1.567	1.555

Moisture Determination										
MOISTURE CONTENT DATA		10 Blows			30 Blows			65 Blows		
		Before soak		After soak	Before soak		After soak	Before soak		After soak
Container no.		CK	M	C5	W2	12	A3	W2	P3	ZZ
Mass of wet soil + Container		145.7	141.2	172.8	162.5	154.3	143.9	135.6	157.7	155.2
Mass of dry soil + Container	g	121.5	118.3	141.1	136.0	128.0	119.2	115.6	134.3	125.4
Mass of container	g	20.6	22.1	33.5	25.6	19.3	34.2	32.8	36.8	17.6
Mass of water	g	24.2	22.9	31.7	26.5	26.3	24.7	20.0	23.4	29.8
Mass of drysoil	g	100.9	96.2	107.6	110.4	108.7	85.0	82.8	97.5	107.8
Moisture content	%	24.0	23.8	29.5	24.0	24.2	29.1	24.2	24.0	27.6
Average moisture content	%	23.9		29.5	24.1		29.1	24.1		27.6

Swell Determination						
	10 Blows		30 Blows		65 Blows	
	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
Initial	0.00	2.16	0	1.76	0.00	1.68
Final	2.52		2.05		1.95	



Annex B: Laboratory Test Result Analysis of Sample 2

Annex B-1: Natural Moisture Content

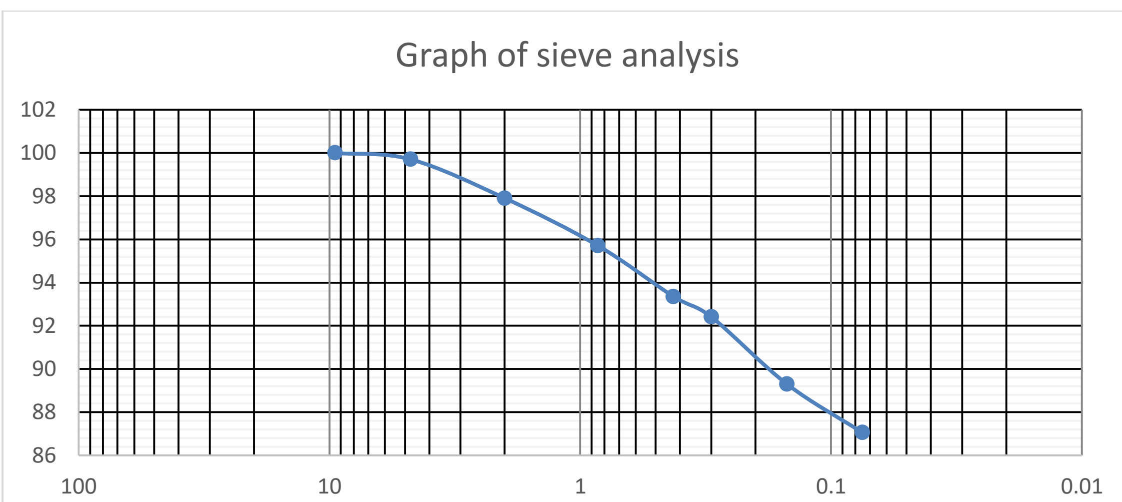
	Ss2		
Specimen number	1	2	3
Mass of can (g) M_C	17.5	17.6	17.3
Mass of can and moist soil (g) M_{CMS}	87.20	88.20	83.20
Mass of can and dry soil (g) M_{CDS}	65.2	65.6	62.1
Mass of water(g) M_w	22.00	22.60	21.10
Mass of dry soil(g) M_{DS}	47.70	48.01	44.80
Water content(%) w	46.12%	47.07%	47.10%
Average water content(%) w =	**46.76%**		

Annex B-2: Specific Gravity Test Result

Specific gravity of soil at test Temprature,G at Tx °C (ASTM D-854-83)			
SG for natural Ss2			
Trial No.	1	2	3
Mass of dry, clean Calibrated pycnometer, Mp	25.37	26.51	25.82
Mass of dry soil + pycnometer, Mps, in g	50.37	51.51	50.82
Mass of pycnometer+dry soil+water at temperature Tx, in °C, g	136.93	137.58	136.03
Test temperature(Tx),°C	24	24	24
Density of water at Tx, g/cm3	0.997	0.997	0.997
Mass of density bottle+water at temperature Ti^°C(21°C),g	122.22	122.31	120.82
Density of water at Ti,g/ml at 21°C	0.998	0.998	0.998
Correction factor,k	0.999	0.999	0.999
Specific gravity G at Tx°C	2.428	2.569	2.554
Average specific gracity at Tx°C	2.52		

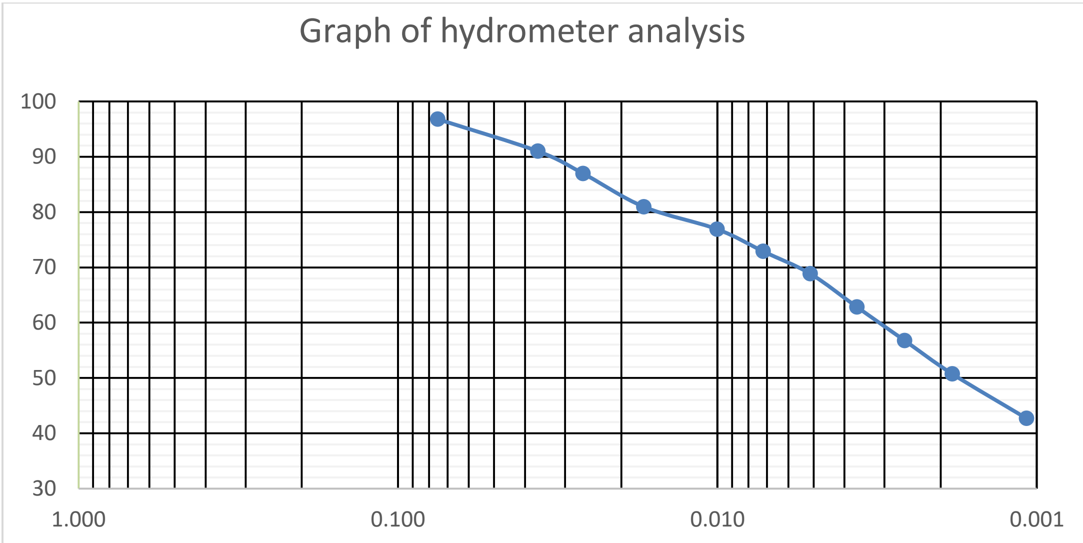
Annex B-3: Wet Sieve Analysis

Sieve Size(mm)	Mass retained (gm)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Cumulative Percentage Passing (%)
9.5	0	0	0	100
4.75	4.4	0.29	0.29	99.71
2	27	1.80	2.09	97.91
0.85	33	2.20	4.29	95.71
0.425	35.3	2.35	6.65	93.35
0.3	14.2	0.95	7.59	92.41
0.15	46.59	3.11	10.70	89.30
0.075	33.7	2.25	12.95	87.05
Total 1	194.19			
Pass	1305.81			
Total	1500			



Annex B-4: Hydrometer Analysis

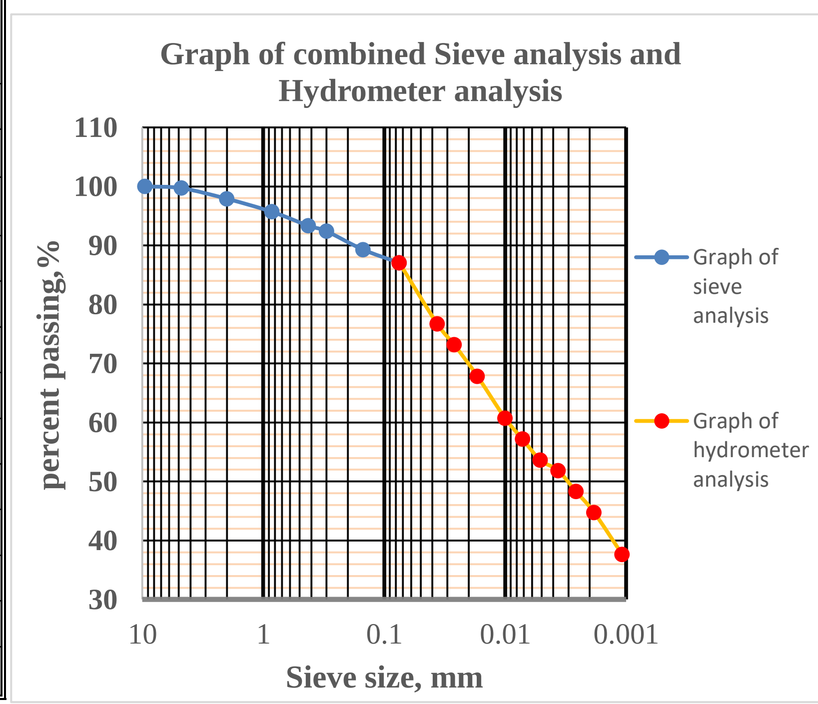
			correction for hydrometer reading										
Time (min.)	**Actual Hydrometer Reading**	**Temp.**	**T° corr.**	**meniscus correction**	**zero correction**	**Composite Correction**	**Corrected H. Reading**	**Correction factor (a)**	**Eff. Depth of Hydrometer (L)**	**Values of K**	**Diameter of soil Particle (mm)**	**% finer, P**	**Adjusted % of finer**
1	47	21	0.2	1	-5	-3.8	43.2	1.020	8.6	0.01405	0.041	88.13	76.72
2	45	21	0.2	1	-5	-3.8	41.2	1.020	9.0	0.01405	0.030	84.05	73.17
5	42	21	0.2	1	-5	-3.8	38.2	1.020	9.5	0.01405	0.019	77.93	67.84
15	38	21	0.2	1	-5	-3.8	34.2	1.020	10.1	0.01405	0.012	69.77	60.74
30	36	21	0.2	1	-5	-3.8	32.2	1.020	10.4	0.01405	0.008	65.69	57.18
60	34	21	0.2	1	-5	-3.8	30.2	1.020	10.8	0.01405	0.006	61.61	53.63
120	33	21	0.2	1	-5	-3.8	29.2	1.020	10.9	0.01405	0.004	59.57	51.86
240	31	21	0.2	1	-5	-3.8	27.2	1.020	11.2	0.01405	0.003	55.49	48.30
480	29	21	0.2	1	-5	-3.8	25.2	1.020	11.6	0.01405	0.002	51.41	44.75
1440	25	21	0.2	1	-5	-3.8	21.2	1.020	12.2	0.01422	0.001	43.25	37.65



Annex B-5: Combined Sieve Analysis

particle size	percent pass
9.5	100
4.75	99.71
2	97.91
0.85	95.71
0.4250	93.35
0.300	92.41
0.150	89.30
0.075	87.054
0.036	76.72
0.026	73.17
0.017	67.84
0.010	60.74
0.007	57.18
0.005	53.63
0.004	51.86
0.003	48.30
0.002	44.75
0.001	37.65

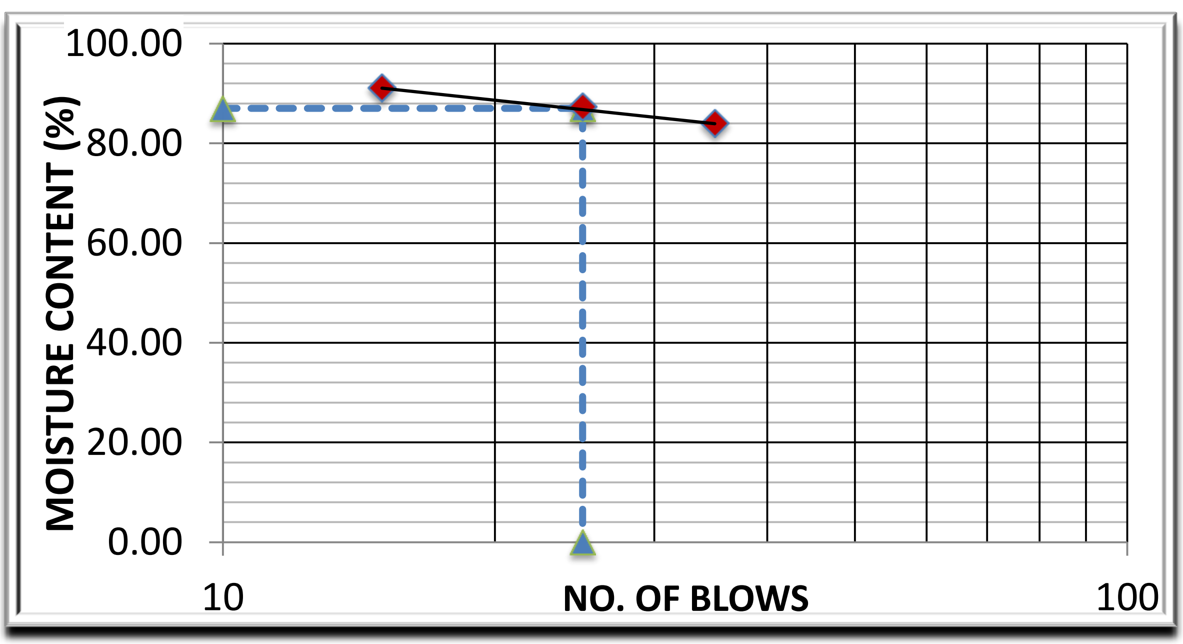
% of soil particle size	AASHTO	USCS
% of gravel	2.09	0.29
% of Sand	10.85	12.65
% of Silt	42.30	33.42
% of Clay	44.75	53.63



Annex B-6: Atterberg Limit Test Result

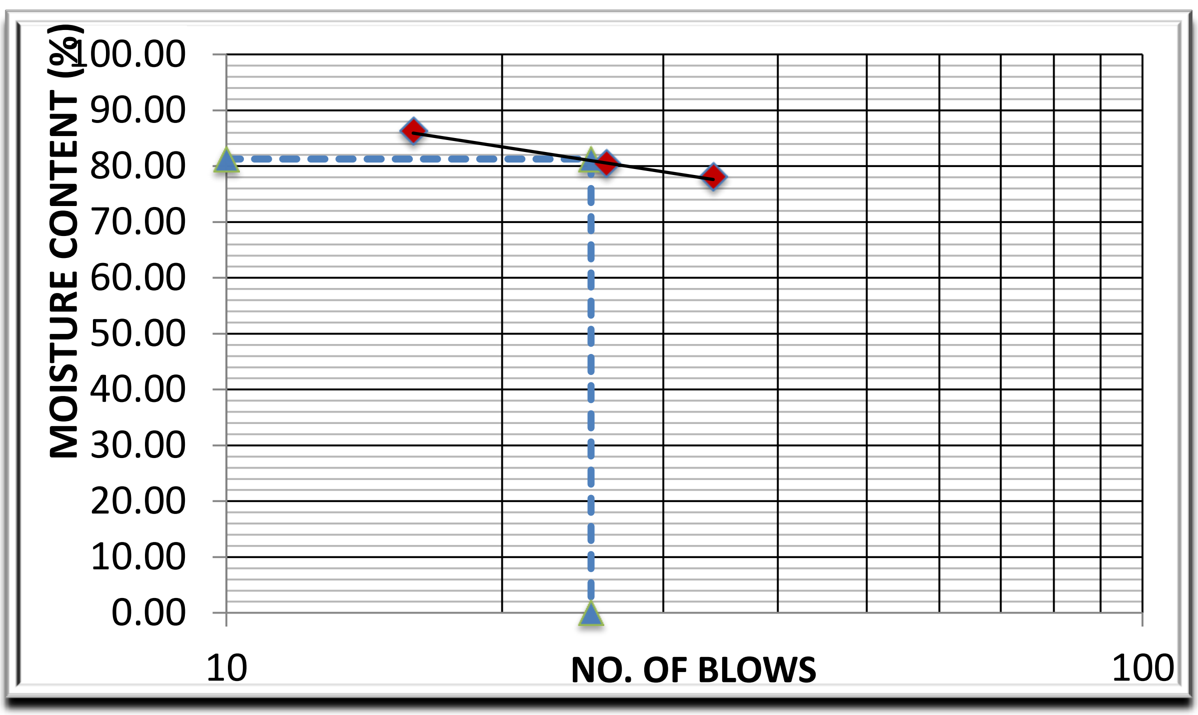
Natural soil

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	15	25	35		
Wt.of cont. + wet soil (g.)	36.90	38.70	34.80	14.00	17.40
Wt.of cont. + dry soil (g.)	27.60	28.68	26.90	11.89	14.80
Wt. of water (g.)	9.30	10.02	7.90	2.11	2.60
Wt. container (g.)	17.40	17.20	17.50	6.30	7.80
Wt. dry soil (g.)	10.20	11.48	9.40	5.59	7.00
Water Content (%)	91.18	87.28	84.04	37.75	37.14
Liquid Limit, LL(%)	**87.0**			**AV. PL (%)**	37.4
Plastic Limit, PL(%)	**37.4**				
Plasticity Index, PI(%)	**49.6**				



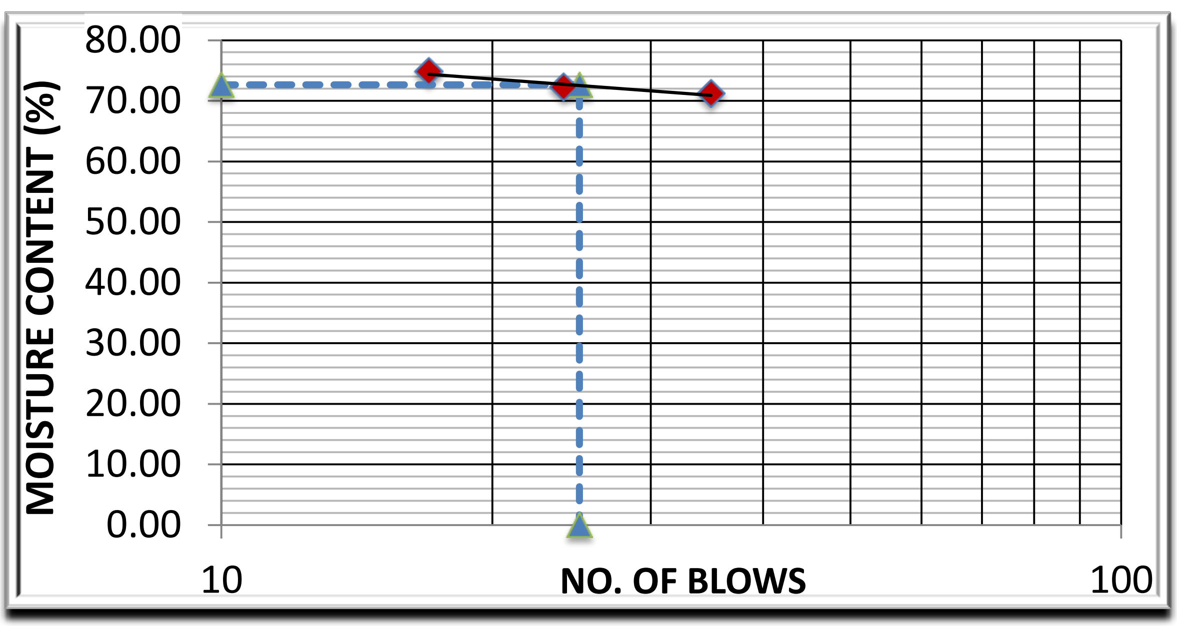
5% Brick Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	16	26	34		
Wt.of cont. + wet soil (g.)	31.90	35.70	40.50	18.40	19.40
Wt.of cont. + dry soil (g.)	25.60	28.30	28.00	15.30	16.00
Wt. of water (g.)	6.30	7.40	12.50	3.10	3.40
Wt. container (g.)	18.30	19.10	12.00	7.60	7.50
Wt. dry soil (g.)	7.30	9.20	16.00	7.70	8.50
Water Content (%)	86.30	80.43	78.13	40.26	40.00
Liquid Limit, LL(%)	**81.3**			**AV. PL (%)**	40.1
Plastic Limit, PL(%)	**40.1**				
Plasticity Index, PI(%)	**41.1**				



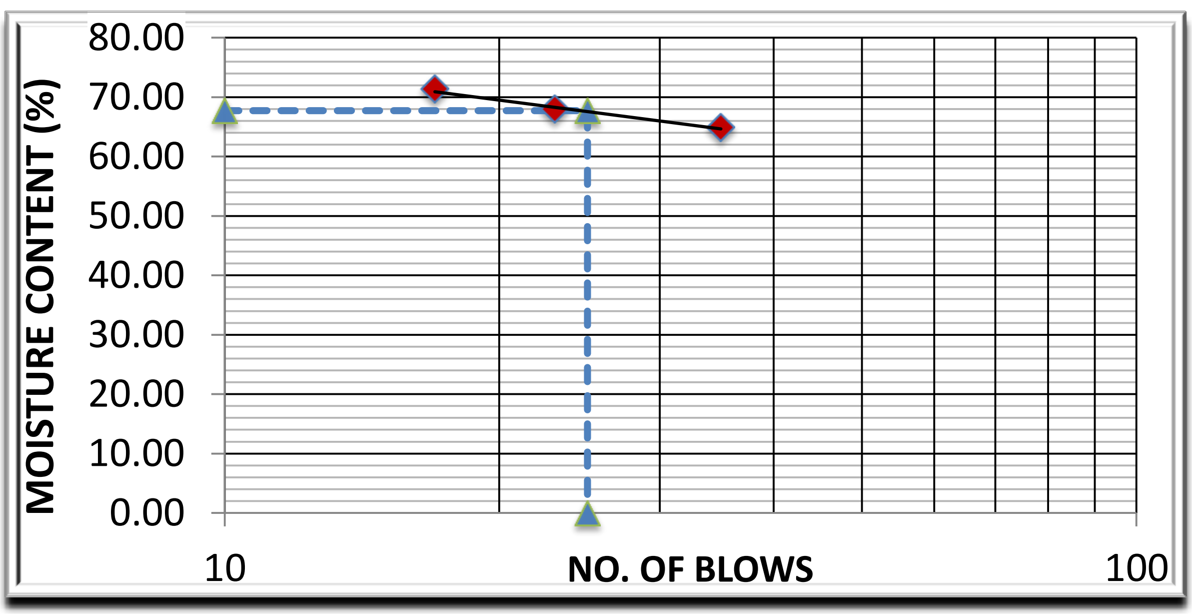
10% Brick Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	17	24	35		
Wt.of cont. + wet soil (g.)	50.60	50.60	37.40	15.96	26.80
Wt.of cont. + dry soil (g.)	39.60	41.20	29.00	13.50	24.40
Wt. of water (g.)	11.00	9.40	8.40	2.46	2.40
Wt. container (g.)	24.90	28.20	17.20	7.60	18.70
Wt. dry soil (g.)	14.70	13.00	11.80	5.90	5.70
Water Content (%)	74.83	72.31	71.19	41.69	42.11
Liquid Limit, LL(%)	**72.6**			**AV. PL (%)**	41.9
Plastic Limit, PL(%)	**41.9**				
Plasticity Index, PI(%)	**30.7**				



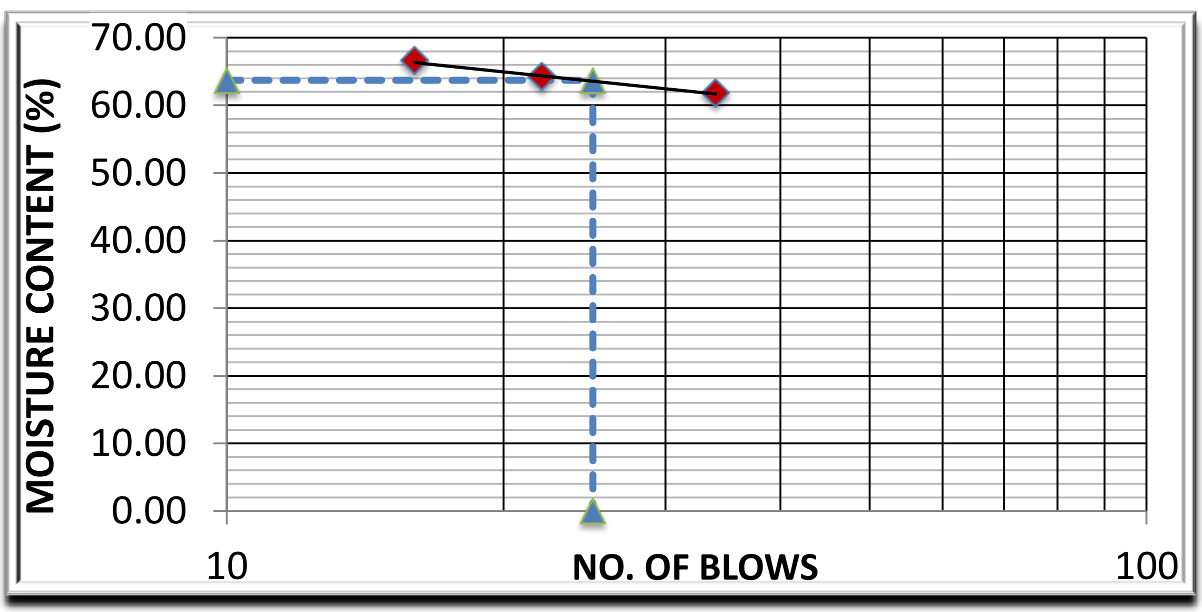
20% Brick Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	17	23	35		
Wt.of cont. + wet soil (g.)	35.50	36.00	28.00	14.00	12.90
Wt.of cont. + dry soil (g.)	28.50	29.40	19.30	11.70	10.80
Wt. of water (g.)	7.00	6.60	8.70	2.30	2.10
Wt. container (g.)	18.70	19.70	5.90	6.30	5.90
Wt. dry soil (g.)	9.80	9.70	13.40	5.40	4.90
Water Content (%)	71.43	68.04	64.93	42.59	42.86
Liquid Limit, LL(%)	**67.7**			**AV. PL (%)**	42.7
Plastic Limit, PL(%)	**42.7**				
Plasticity Index, PI(%)	**25.0**				



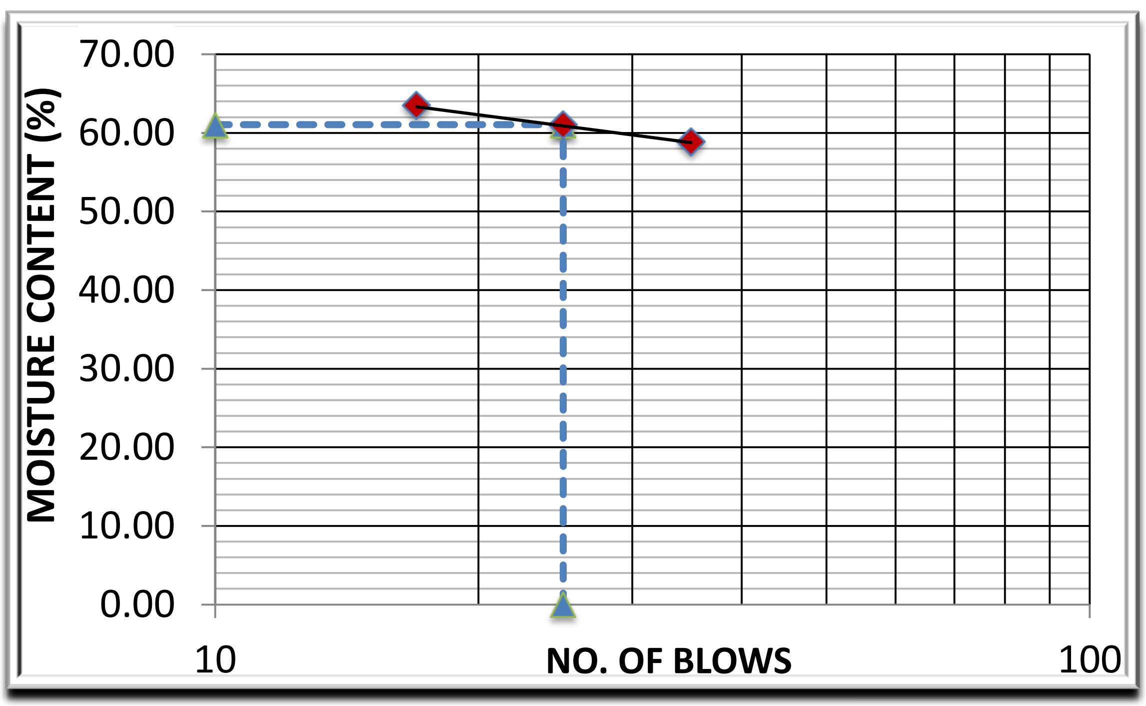
30% Brick Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	16	22	34		
Wt.of cont. + wet soil (g.)	22.10	30.60	28.80	12.60	26.20
Wt.of cont. + dry soil (g.)	15.70	21.60	20.20	10.80	24.20
Wt. of water (g.)	6.40	9.00	8.60	1.80	2.00
Wt. container (g.)	6.10	7.60	6.30	6.60	19.60
Wt. dry soil (g.)	9.60	14.00	13.90	4.20	4.60
Water Content (%)	66.67	64.29	61.87	42.86	43.48
Liquid Limit, LL(%)	**63.7**			**AV. PL (%)**	43.2
Plastic Limit, PL(%)	**43.2**				
Plasticity Index, PI(%)	**20.5**				



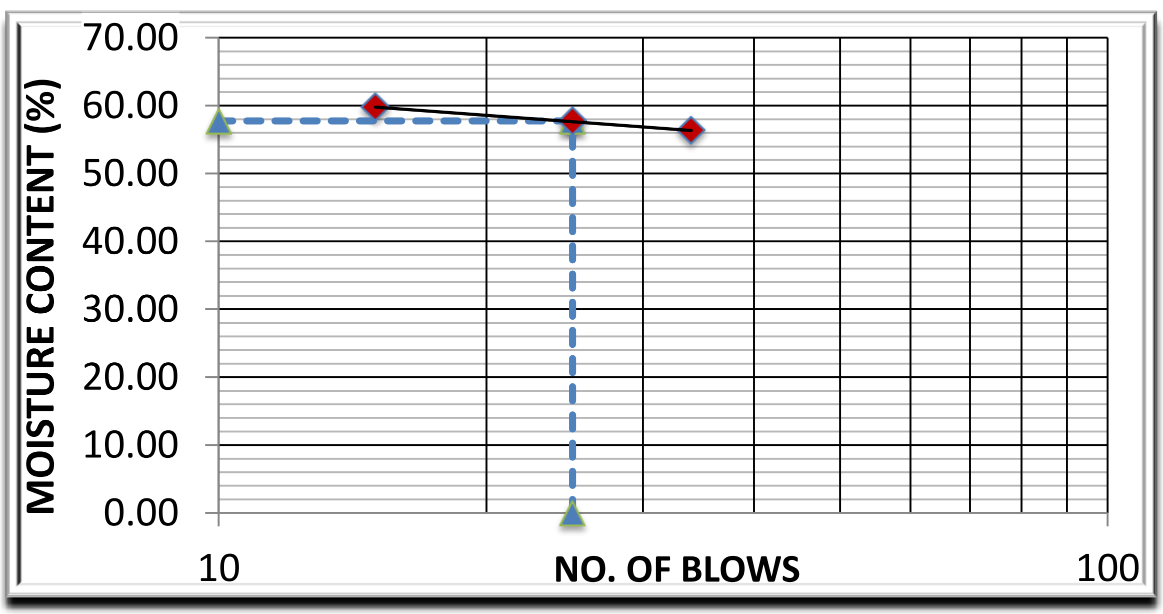
40% Brick Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	17	25	35		
Wt.of cont. + wet soil (g.)	26.40	37.20	31.00	31.40	19.60
Wt.of cont. + dry soil (g.)	18.40	31.40	22.40	27.30	15.40
Wt. of water (g.)	8.00	5.80	8.60	4.10	4.20
Wt. container (g.)	5.80	21.90	7.80	17.90	5.80
Wt. dry soil (g.)	12.60	9.50	14.60	9.40	9.60
Water Content (%)	63.49	61.05	58.90	43.62	43.75
Liquid Limit, LL(%)	**61.0**			**AV. PL (%)**	43.7
Plastic Limit, PL(%)	**43.7**				
Plasticity Index, PI(%)	**17.4**				



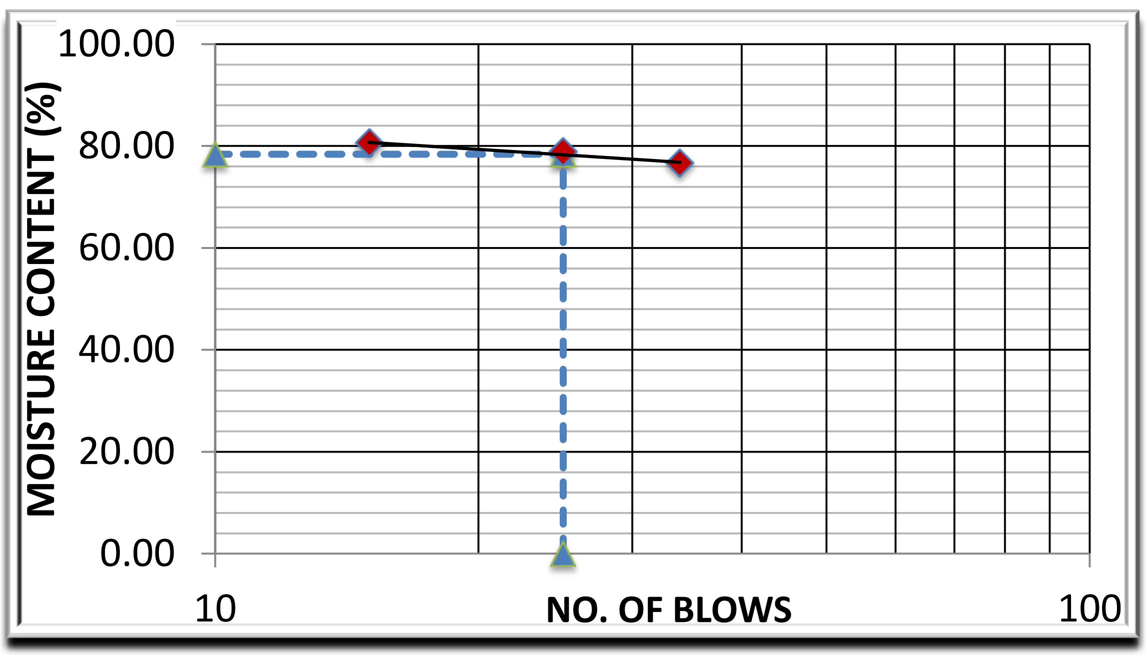
50% Brick Dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	15	25	34		
Wt.of cont. + wet soil (g.)	30.60	33.60	38.20	26.50	29.20
Wt.of cont. + dry soil (g.)	21.50	27.30	31.60	22.40	23.60
Wt. of water (g.)	9.10	6.30	6.60	4.10	5.60
Wt. container (g.)	6.30	16.40	19.90	13.00	10.90
Wt. dry soil (g.)	15.20	10.90	11.70	9.40	12.70
Water Content (%)	59.87	57.80	56.41	43.62	44.09
Liquid Limit, LL(%)	**57.7**			**AV. PL (%)**	43.9
Plastic Limit, PL(%)	**43.9**				
Plasticity Index, PI(%)	**13.9**				



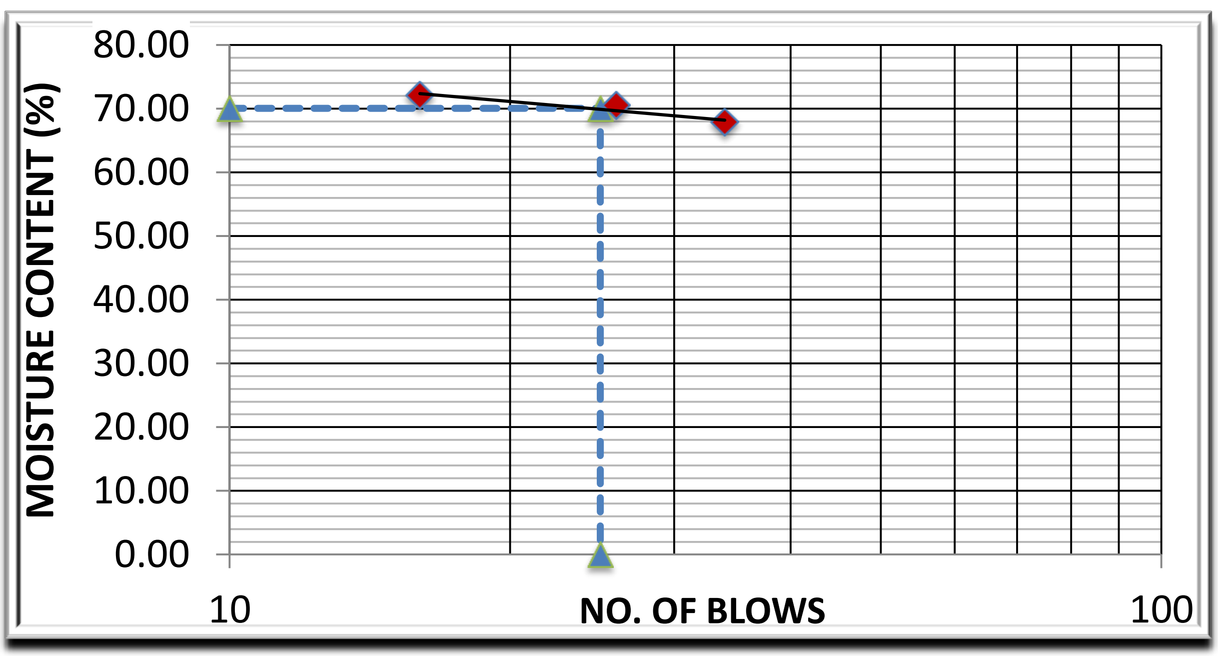
5% Stone dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	15	25	34		
Wt.of cont. + wet soil (g.)	30.10	28.50	34.50	17.70	20.00
Wt.of cont. + dry soil (g.)	22.20	19.90	26.60	14.50	16.20
Wt. of water (g.)	7.90	8.60	7.90	3.20	3.80
Wt. container (g.)	12.40	9.00	16.30	6.10	6.30
Wt. dry soil (g.)	9.80	10.90	10.30	8.40	9.90
Water Content (%)	80.61	78.90	76.70	38.10	38.38
Liquid Limit, LL(%)	**78.4**			**AV. PL (%)**	38.2
Plastic Limit, PL(%)	**38.2**				
Plasticity Index, PI(%)	**40.2**				



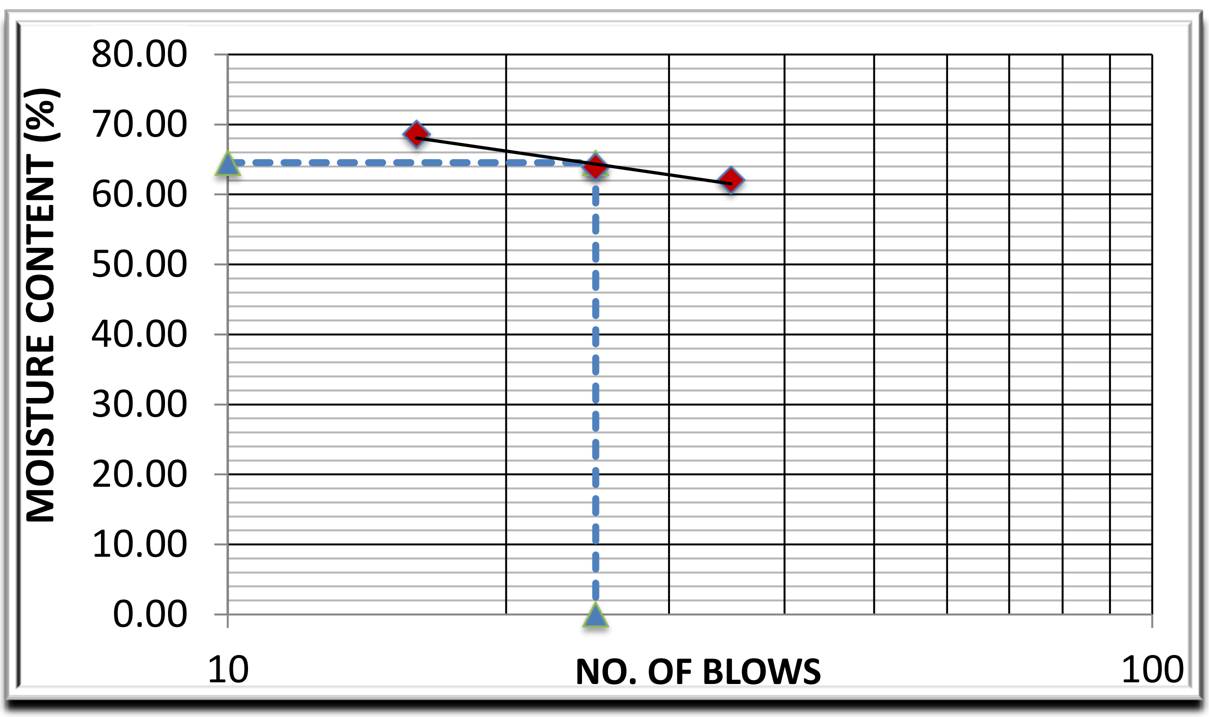
10% Stone dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	16	26	34		
Wt.of cont. + wet soil (g.)	38.60	37.90	42.10	18.30	24.30
Wt.of cont. + dry soil (g.)	28.50	30.00	33.20	15.20	19.90
Wt. of water (g.)	10.10	7.90	8.90	3.10	4.40
Wt. container (g.)	14.50	18.80	20.10	7.40	9.00
Wt. dry soil (g.)	14.00	11.20	13.10	7.80	10.90
Water Content (%)	72.14	70.54	67.94	39.74	40.37
Liquid Limit, LL(%)	**70.0**			**AV. PL (%)**	40.1
Plastic Limit, PL(%)	**40.1**				
Plasticity Index, PI(%)	**30.0**				



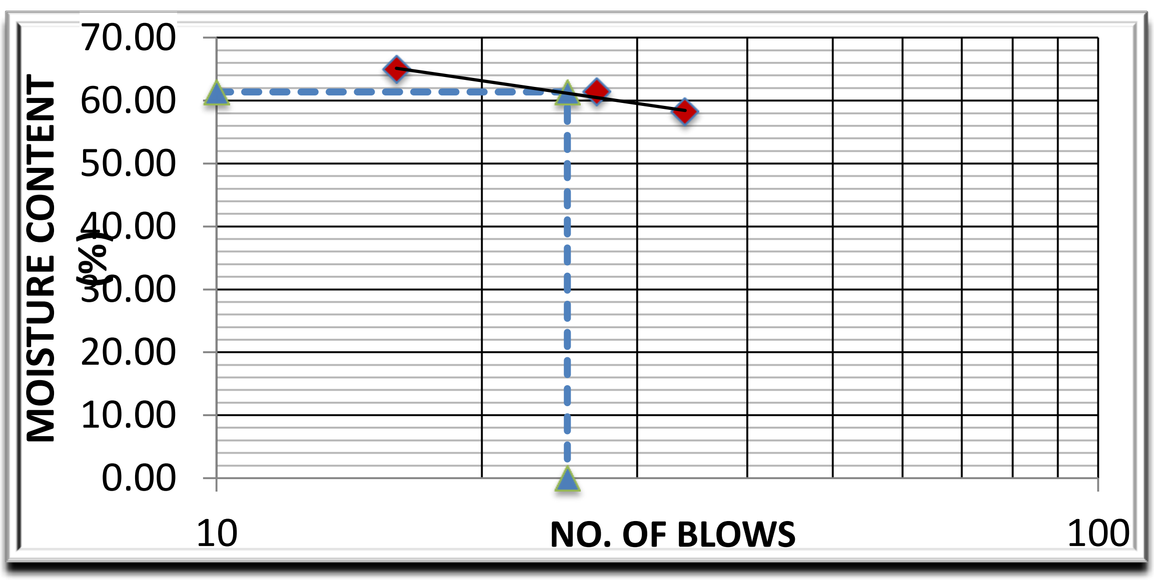
15% Stone dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	16	25	35		
Wt.of cont. + wet soil (g.)	42.70	35.50	33.00	18.40	19.80
Wt.of cont. + dry soil (g.)	34.40	29.30	26.30	14.80	16.10
Wt. of water (g.)	8.30	6.20	6.70	3.60	3.70
Wt. container (g.)	22.30	19.60	15.50	6.00	7.10
Wt. dry soil (g.)	12.10	9.70	10.80	8.80	9.00
Water Content (%)	68.60	63.92	62.04	40.91	41.11
Liquid Limit, LL(%)	**64.5**			**AV. PL (%)**	41.0
Plastic Limit, PL(%)	**41.0**				
Plasticity Index, PI(%)	**23.5**				



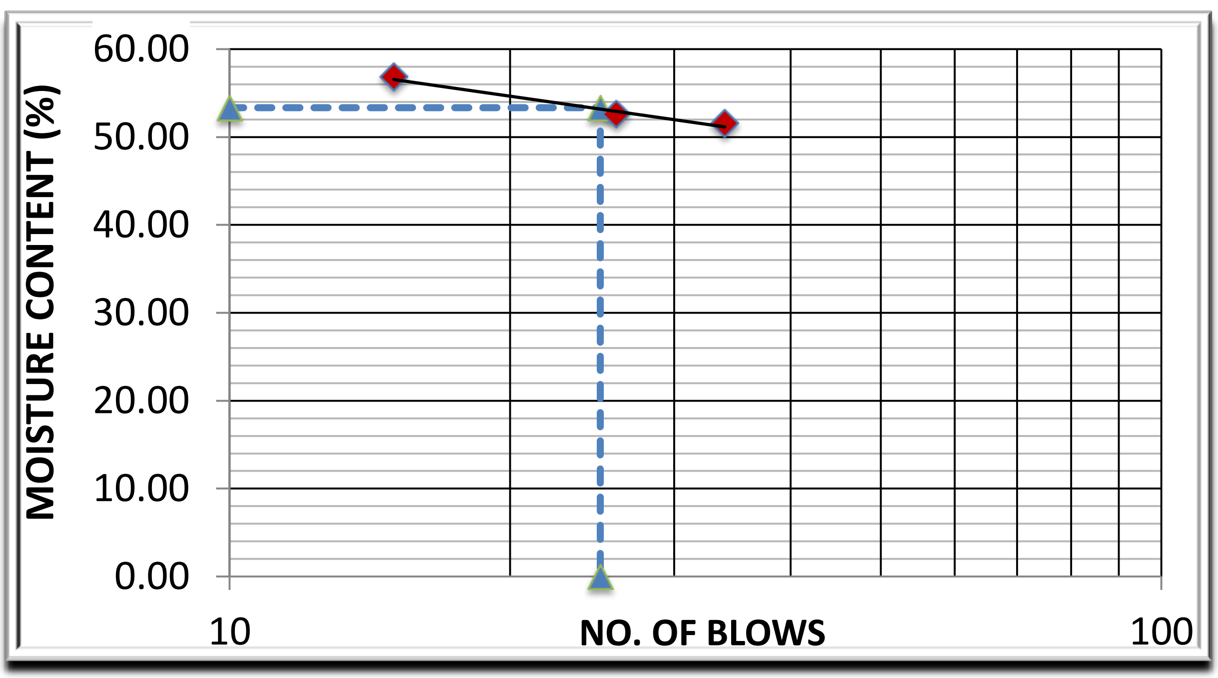
20% Stone dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	16	27	34		
Wt.of cont. + wet soil (g.)	35.90	36.20	37.30	14.60	27.70
Wt.of cont. + dry soil (g.)	26.60	30.00	31.30	12.30	25.30
Wt. of water (g.)	9.30	6.20	6.00	2.30	2.40
Wt. container (g.)	12.30	19.90	21.00	6.90	19.60
Wt. dry soil (g.)	14.30	10.10	10.30	5.40	5.70
Water Content (%)	65.03	61.39	58.25	42.59	42.11
Liquid Limit, LL(%)	**61.4**			**AV. PL (%)**	42.3
Plastic Limit, PL(%)	**42.3**				
Plasticity Index, PI(%)	**19.0**				



30% Stone dust

	Liquid limit			PLASTIC LIMIT	
Trial No.	1	2	3	1	2
No. Blows	15	26	34		
Wt.of cont. + wet soil (g.)	27.40	33.30	35.70	28.10	30.30
Wt.of cont. + dry soil (g.)	22.00	28.30	30.80	22.40	23.60
Wt. of water (g.)	5.40	5.00	4.90	5.70	6.70
Wt. container (g.)	12.50	18.80	21.30	9.40	8.40
Wt. dry soil (g.)	9.50	9.50	9.50	13.00	15.20
Water Content (%)	56.84	52.63	51.58	43.85	44.08
Liquid Limit, LL(%)	**53.3**			**AV. PL (%)**	44.0
Plastic Limit, PL(%)	**44.0**				
Plasticity Index, PI(%)	**9.4**				

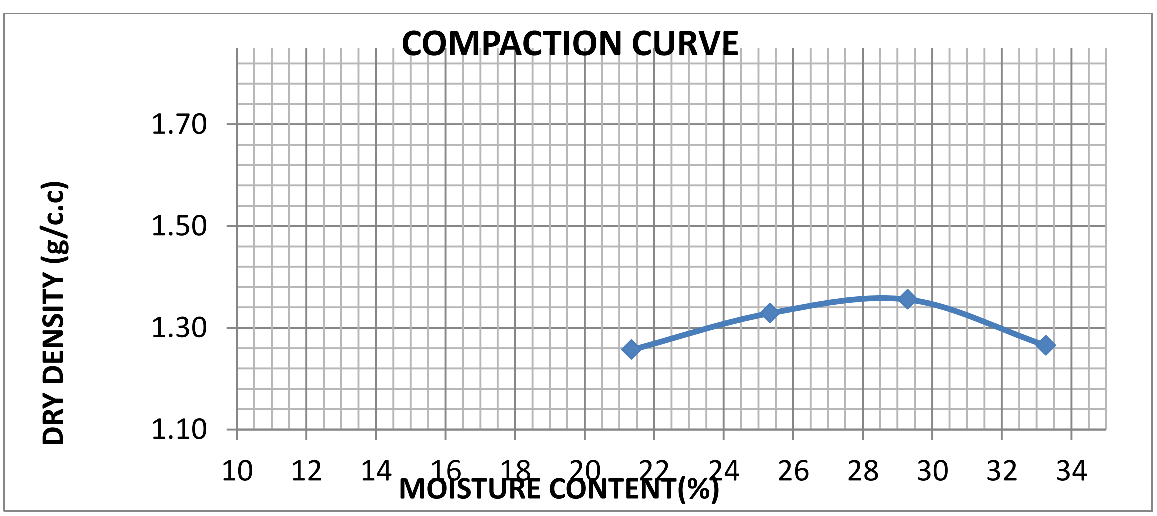


Annex B-8: Compaction Test Result

Natural soil

trial No.	1		2		3		4	
wt of wet soil+mold	9802.3		10100.2		10285.6		10144.1	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.52		1.67		1.75		1.69	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	140.8	116.1	140.0	139.0	154.5	143.1	161.9	176.5
wt of dry soil+can	120.0	99.3	115.3	114.5	123.6	114.7	126.0	136.8
wt of can	22.5	20.7	17.3	18.3	18.2	17.7	17.7	17.9
moisture content,%	21.33	21.37	25.20	25.47	29.32	29.28	33.15	33.39
Average moisture content,%	21.35		25.34		29.30		33.27	
dry density, g/cc	1.26		1.33		1.36		1.27	

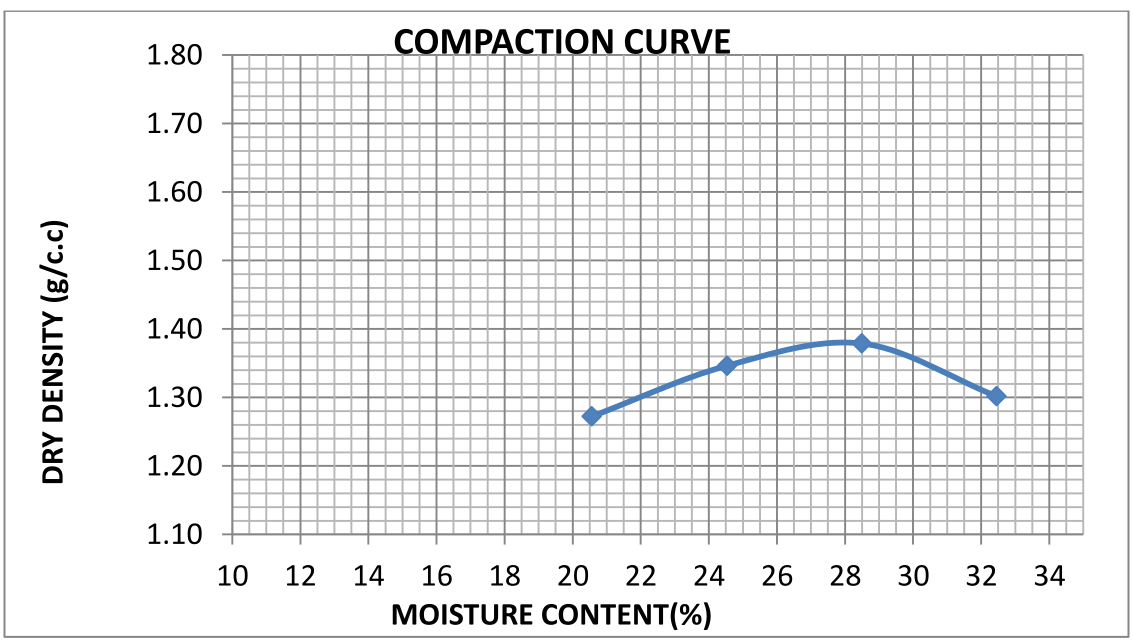
MDD (gm/cm3)	OMC (%)
1.36	**29.3**



5% Brick Dust

trial No.	1		2		3		4	
wt of wet soil+mold	9822.0		10124.8		10326.3		10225.3	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.53		1.68		1.77		1.72	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	180.2	181.5	156.2	120.9	174.3	134.6	173.5	146.3
wt of dry soil+can	155.2	154.2	129.6	100.5	142.5	108.7	136.6	115.0
wt of can	32.4	22.8	20.9	17.6	31.2	17.6	22.4	19.0
moisture content,%	20.36	20.78	24.47	24.61	28.57	28.43	32.31	32.60
Average moisture content,%	20.57		24.54		28.50		32.46	
dry density, g/cc	1.27		1.35		1.38		1.30	

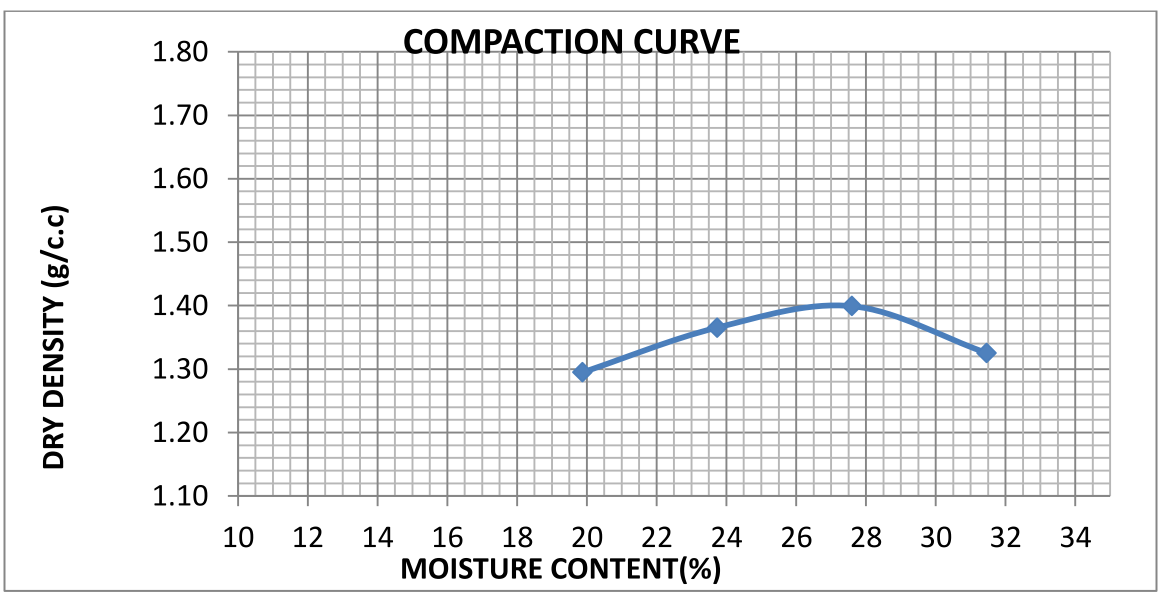
MDD (gm/cm3)	OMC (%)
1.38	**28.5**



10% Brick Dust

trial No.	1		2		3		4	
wt of wet soil+mold	9860.2		10151.5		10355.0		10263.8	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.55		1.69		1.79		1.74	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	118.6	133.9	125.0	162.4	149.1	148.0	153.0	149.7
wt of dry soil+can	102.3	114.4	105.1	135.4	120.7	119.8	120.1	118.6
wt of can	19.0	17.8	21.0	22.0	17.9	17.5	17.0	18.3
moisture content,%	19.57	20.19	23.66	23.81	27.63	27.57	31.91	31.01
Average moisture content,%	19.88		23.74		27.60		31.46	
dry density, g/cc	1.29		1.37		1.40		1.33	

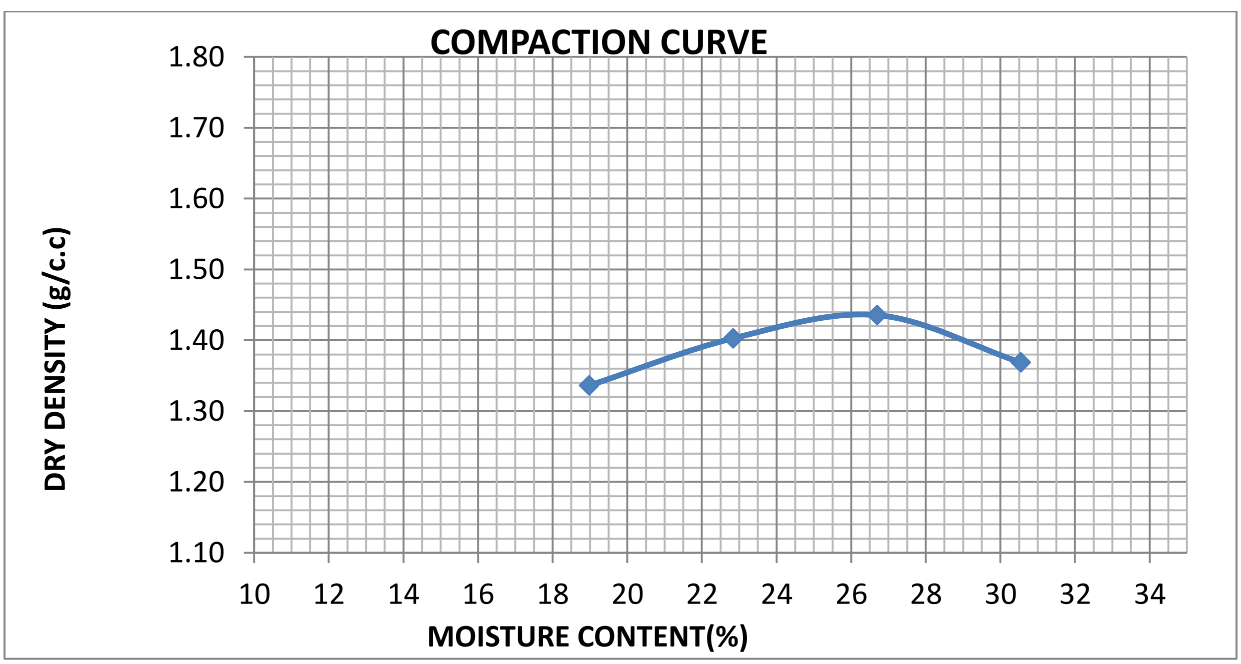
MDD (gm/cm3)	OMC (%)
1.4	**27.6**



20% Brick Dust

wt of wet soil+mold	9940.0		10223.2		10426.0		10358.0	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.59		1.72		1.82		1.79	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	156.5	146.6	141.9	128.0	163.5	133.3	153.3	143.5
wt of dry soil+can	135.0	126.3	118.8	107.5	135.5	111.2	121.5	114.3
wt of can	21.8	19.3	17.5	17.9	31.4	27.8	18.3	17.9
moisture content,%	18.99	18.97	22.80	22.88	26.90	26.50	30.81	30.29
Average moisture content,%	18.98		22.84		26.70		30.55	
dry density, g/cc	1.34		1.40		1.44		1.37	

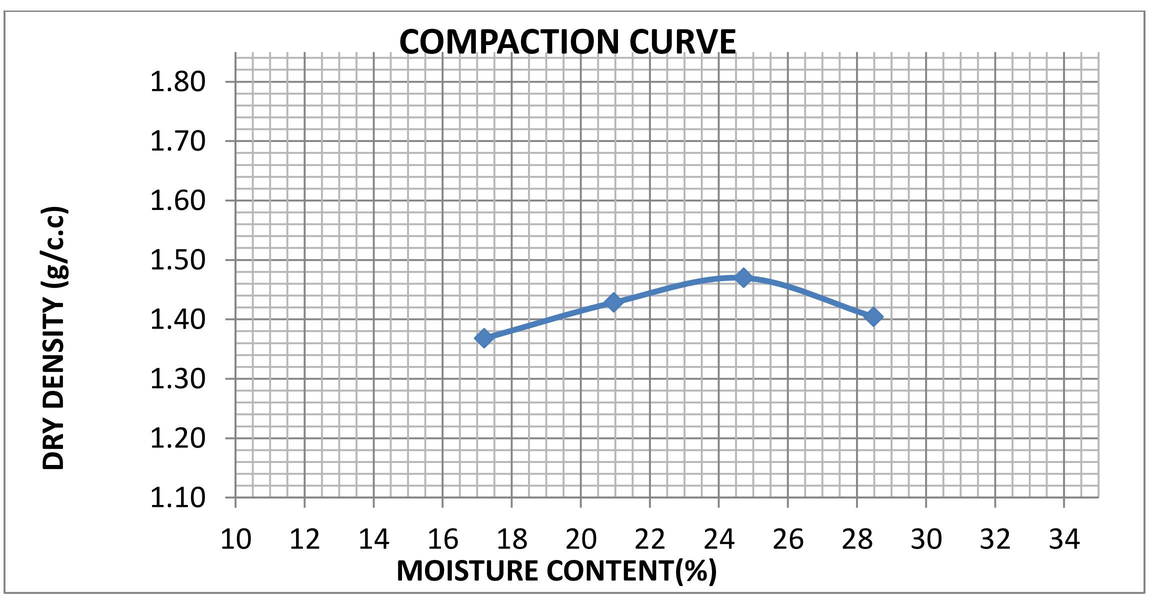
MDD (gm/cm3)	OMC (%)
1.44	**26.7**



30% Brick Dust

trial No.	1		2		3		4	
wt of wet soil+mold	9968.8		10233.0		10456.4		10395.6	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.60		1.73		1.83		1.80	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	137.0	147.5	141.9	148.0	144.1	164.0	138.8	175.7
wt of dry soil+can	119.6	128.6	120.3	125.5	119.3	135.9	112.8	143.6
wt of can	18.9	18.3	17.8	17.6	18.4	22.9	21.3	31.2
moisture content,%	17.28	17.14	21.07	20.85	24.58	24.87	28.42	28.56
Average moisture content,%	17.21		20.96		24.72		28.49	
dry density, g/cc	1.37		1.43		1.47		1.40	

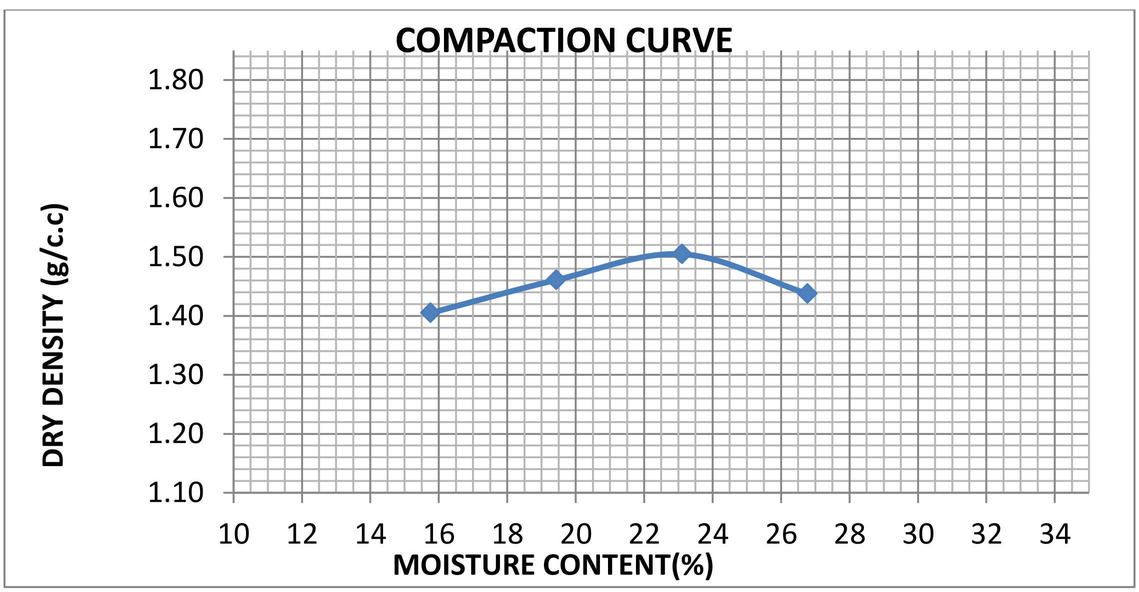
MDD (gm/cm3)	**OMC (%)**
1.47	**24.7**



40% Brick Dust

trial No.	1		2		3		4	
wt of wet soil+mold	10017.4		10268.7		10497.2		10434.1	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.63		1.74		1.85		1.82	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	159.2	152.1	158.0	141.7	143.3	152.5	161.7	164.4
wt of dry soil+can	142.1	135.1	135.6	121.5	119.8	127.8	133.0	135.2
wt of can	33.0	27.8	19.8	18.0	17.7	21.3	26.5	25.4
moisture content,%	15.67	15.84	19.34	19.52	23.02	23.19	26.95	26.59
Average moisture content,%	15.76		19.43		23.10		26.77	
dry density, g/cc	1.40		1.46		1.50		1.44	

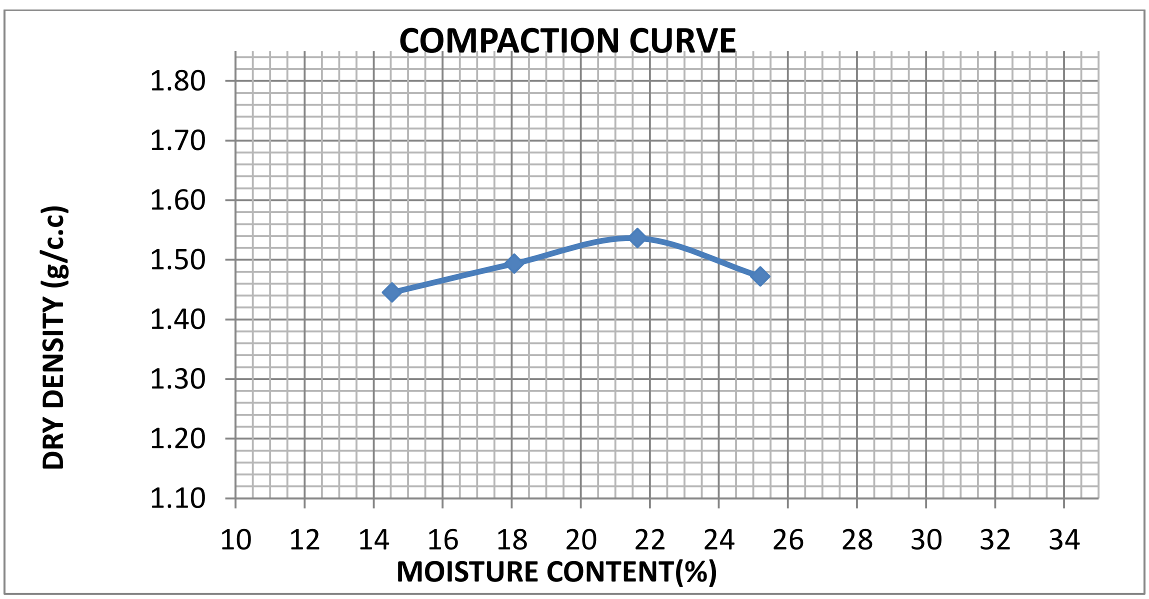
MDD (gm/cm3)	**OMC (%)**
1.5	**23.1**



50% Brick Dust

trial No.	1		2		3		4	
wt of wet soil+mold	10078.8		10308.9		10532.0		10477.9	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.66		1.76		1.87		1.84	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	129.1	143.0	166.3	162.7	154.0	148.8	148.9	161.1
wt of dry soil+can	115.0	128.9	144.5	141.1	131.1	126.3	123.0	132.2
wt of can	17.5	32.4	23.4	22.1	24.5	23.3	19.8	18.0
moisture content,%	14.46	14.61	18.00	18.15	21.48	21.81	25.10	25.31
Average moisture content,%	14.54		18.08		21.65		25.20	
dry density, g/cc	1.45		1.49		1.54		1.47	

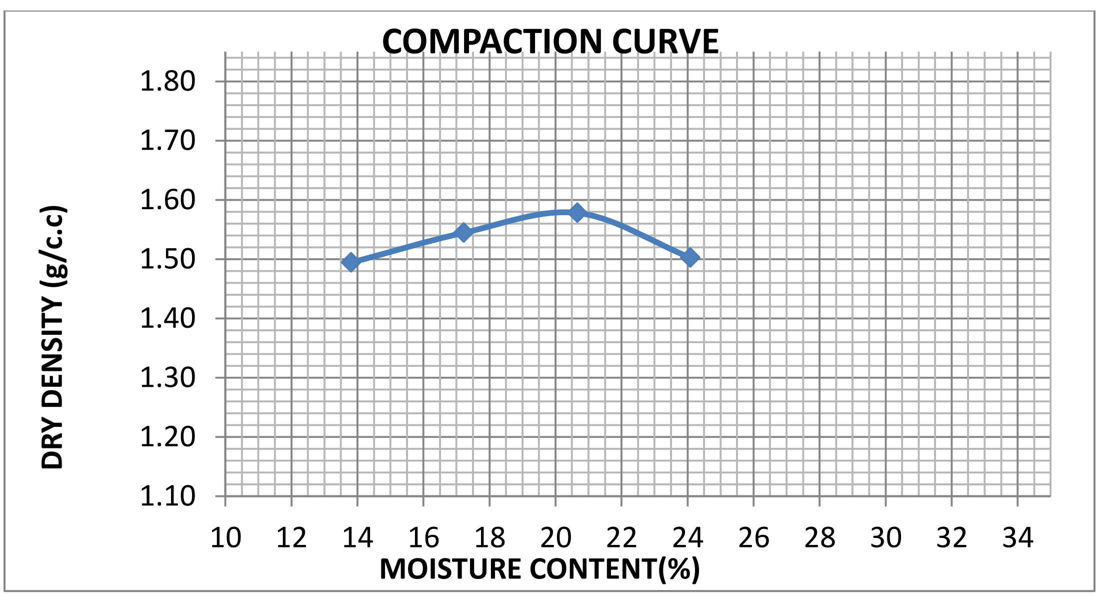
MDD (gm/cm3)	**OMC (%)**
1.54	**21.7**



60% Brick Dust

trial No.	1		2		3		4	
wt of wet soil+mold	10175.4		10408.7		10607.2		10523.2	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.70		1.81		1.90		1.86	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	154.2	140.0	150.9	138.7	127.0	144.9	142.9	173.3
wt of dry soil+can	138.2	126.6	132.0	121.4	108.7	123.2	118.6	144.1
wt of can	22.1	29.8	22.0	21.1	19.6	18.8	17.7	22.9
moisture content,%	13.78	13.84	17.18	17.27	20.54	20.79	24.08	24.09
Average moisture content,%	13.81		17.23		20.66		24.09	
dry density, g/cc	1.49		1.54		1.58		1.50	

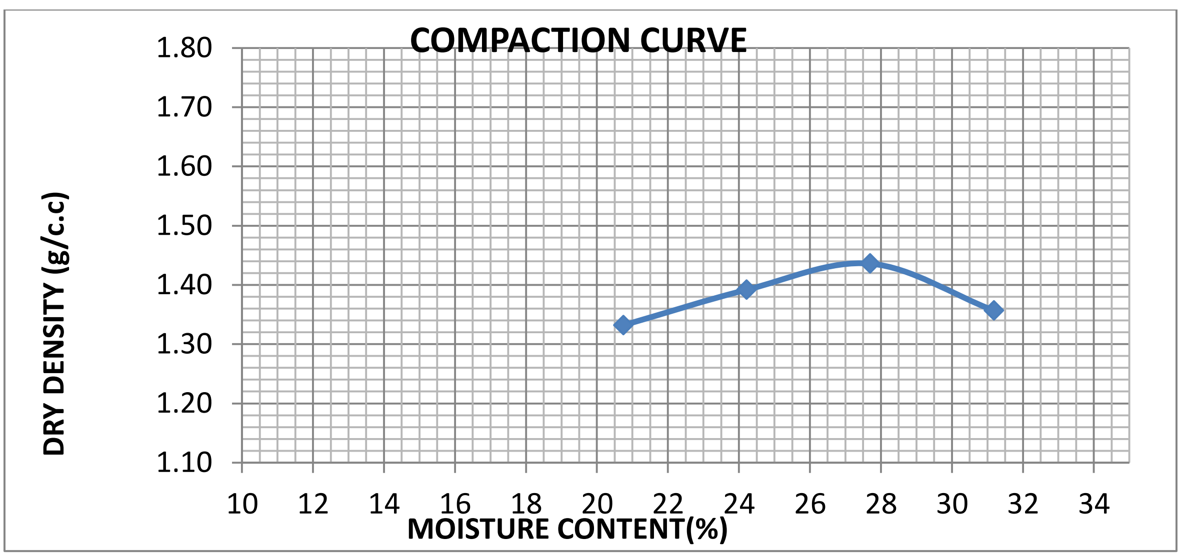
MDD (gm/cm3)	OMC (%)
1.58	**20.7**



5% Stone dust

trial No.	1		2		3		4	
wt of wet soil+mold	9979.3		10235.6		10457.7		10343.1	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.61		1.73		1.83		1.78	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	147.2	153.3	133.1	149.0	154.9	164.6	162.4	167.4
wt of dry soil+can	125.5	131.2	111.2	124.3	125.4	133.0	128.0	132.5
wt of can	20.3	25.3	21.0	22.1	19.1	18.7	17.3	21.0
moisture content,%	20.63	20.87	24.28	24.17	27.75	27.65	31.07	31.30
Average moisture content,%	20.75		24.22		27.70		31.19	
dry density, g/cc	1.33		1.39		1.44		1.36	

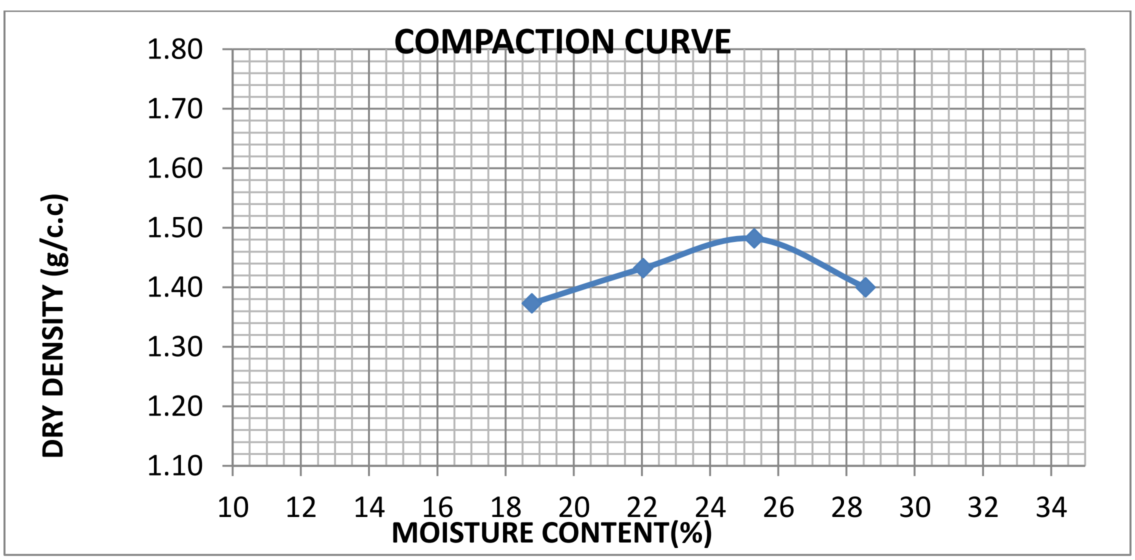
MDD (gm/cm3)	**OMC (%)**
1.44	**27.7**



10% Stone dust

trial No.	1		2		3		4	
wt of wet soil+mold	10027.3		10275.5		10506.9		10385.2	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.63		1.75		1.86		1.80	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	156.5	144.7	163.8	167.8	147.2	152.9	173.7	164.6
wt of dry soil+can	135.6	125.0	139.1	142.2	121.4	125.8	140.1	136.0
wt of can	23.3	21.0	25.3	27.8	19.8	18.3	22.3	36.0
moisture content,%	18.61	18.94	21.70	22.38	25.39	25.21	28.52	28.60
Average moisture content,%	18.78		22.04		25.30		28.56	
dry density, g/cc	1.37		1.43		1.48		1.40	

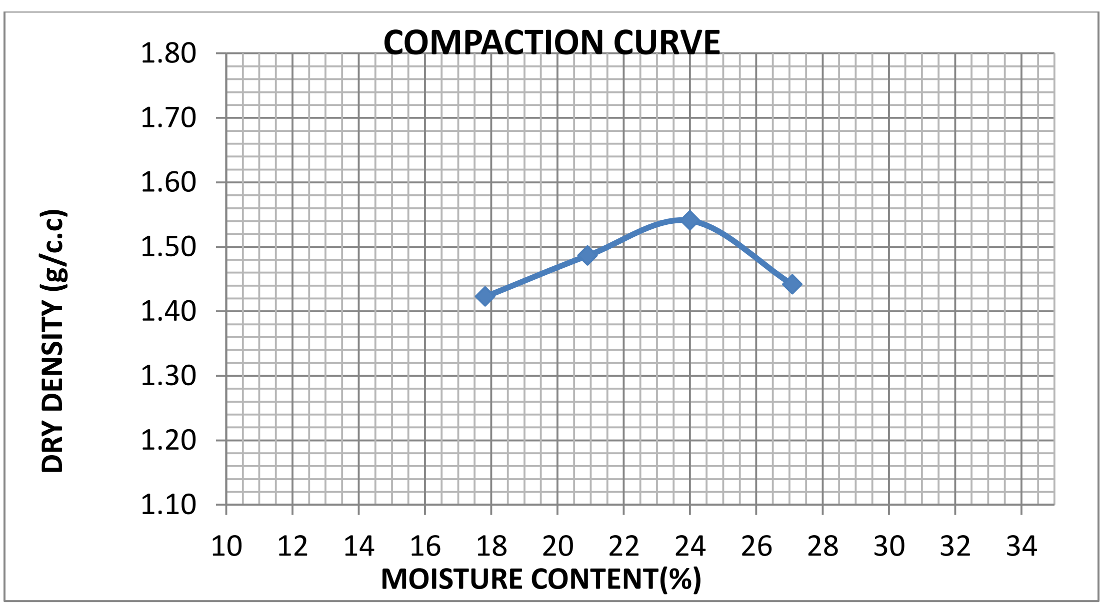
MDD (gm/cm3)	**OMC (%)**
1.48	**25.3**



15% Stone dust

trial No.	1		2		3		4	
wt of wet soil+mold	10123.3		10380.2		10620.4		10454.5	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.68		1.80		1.91		1.83	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	149.2	145.9	138.1	155.5	143.8	148.5	146.1	149.6
wt of dry soil+can	130.2	126.8	117.4	132.5	120.1	123.5	118.7	121.5
wt of can	24.2	19.0	18.6	22.3	21.0	19.7	17.8	17.5
moisture content,%	17.92	17.72	20.95	20.87	23.92	24.08	27.16	27.02
Average moisture content,%	17.82		20.91		24.00		27.09	
dry density, g/cc	1.42		1.49		1.54		1.44	

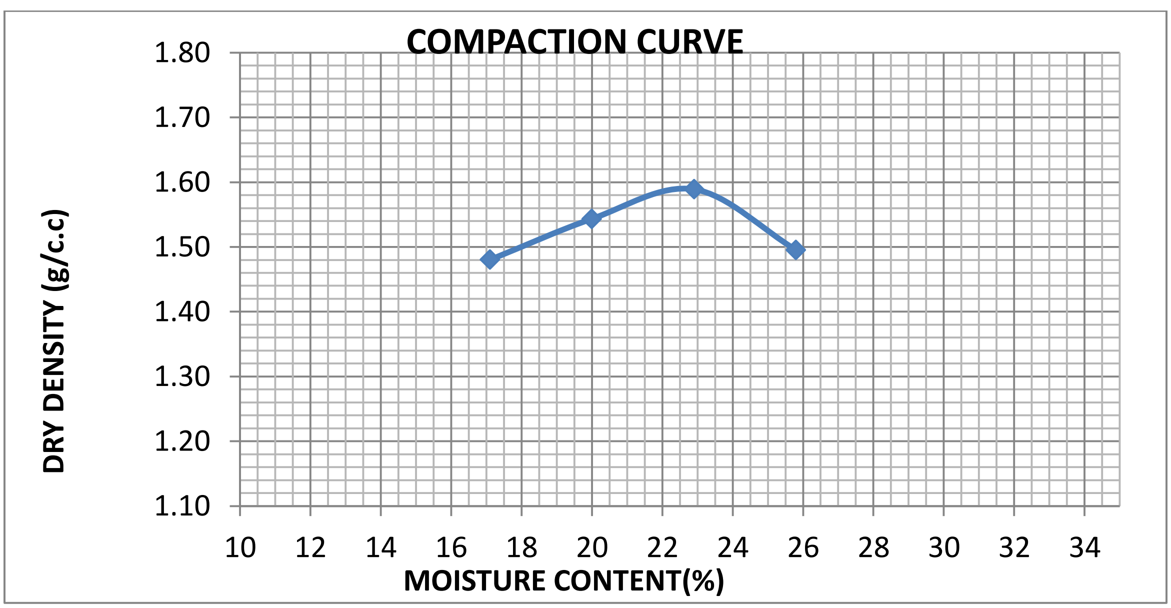
MDD (gm/cm3)	OMC (%)
1.54	**24.0**



20% Stone dust

trial No.	1		2		3		4	
wt of wet soil+mold	10245.0		10497.1		10711.0		10558.8	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.73		1.85		1.95		1.88	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	145.8	149.2	147.0	149.8	164.5	160.2	179.1	182.3
wt of dry soil+can	127.1	130.1	125.6	128.5	137.7	134.5	148.8	152.1
wt of can	18.7	17.5	17.4	23.2	21.0	22.0	32.1	34.3
moisture content,%	17.25	16.96	19.78	20.23	22.96	22.84	25.96	25.64
Average moisture content,%	17.11		20.00		22.90		25.80	
dry density, g/cc	1.48		1.54		1.59		1.50	

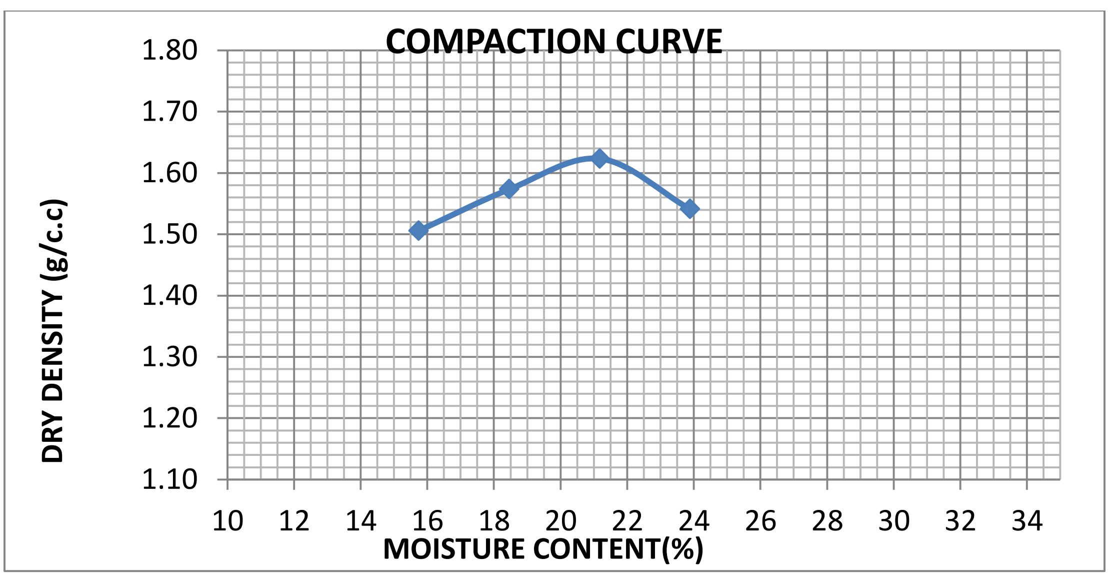
MDD (gm/cm3)	OMC (%)
1.59	**22.9**



25% Stone dust

trial No.	1		2		3		4	
wt of wet soil+mold	10264.4		10522.0		10740.9		10618.1	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.74		1.86		1.97		1.91	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	158.4	142.2	153.8	168.3	159.6	161.4	161.3	146.7
wt of dry soil+can	140.1	125.6	133.3	145.3	135.1	138.9	135.6	123.3
wt of can	22.5	21.3	22.5	20.5	19.3	32.8	27.8	25.5
moisture content,%	15.56	15.92	18.50	18.43	21.16	21.21	23.84	23.93
Average moisture content,%	15.74		18.47		21.18		23.88	
dry density, g/cc	1.51		1.57		1.62		1.54	

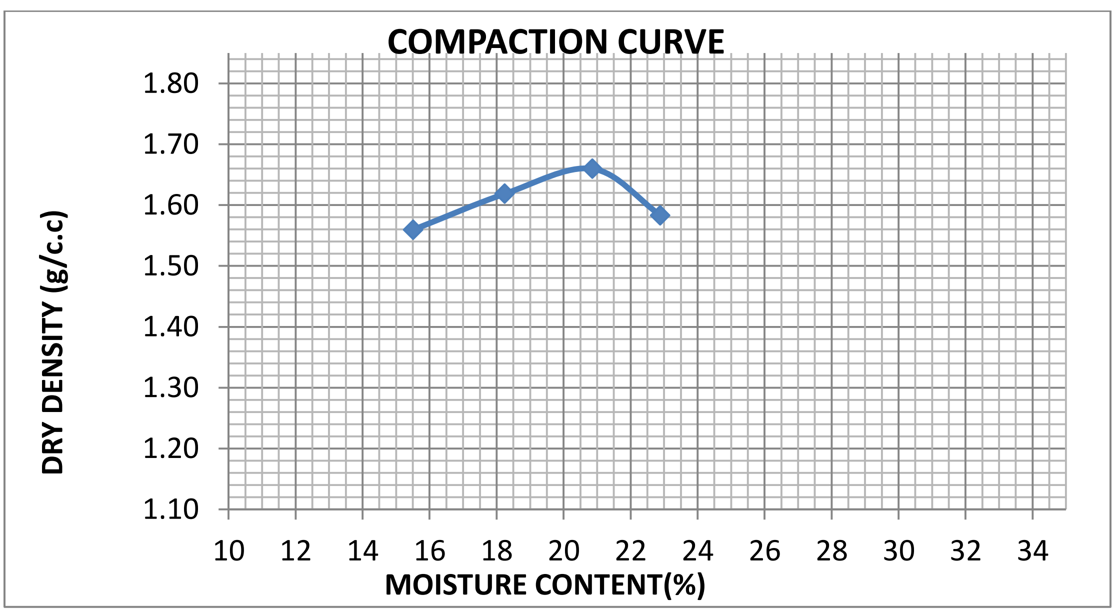
MDD (gm/cm3)	OMC (%)
1.62	**21.2**



30% Stone dust

trial No.	1		2		3		4	
wt of wet soil+mold	10389.3		10628.2		10823.3		10695.6	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.80		1.91		2.01		1.95	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	144.7	141.8	151.0	147.8	148.1	140.6	157.0	141.2
wt of dry soil+can	127.5	125.3	130.1	128.0	125.6	119.5	131.1	118.2
wt of can	17.8	17.8	17.6	17.5	17.8	18.3	18.0	17.7
moisture content,%	15.68	15.35	18.58	17.92	20.87	20.85	22.90	22.89
Average moisture content,%	15.51		18.25		20.86		22.89	
dry density, g/cc	1.56		1.62		1.66		1.58	

MDD (gm/cm3)	**OMC (%)**
1.66	**20.9**



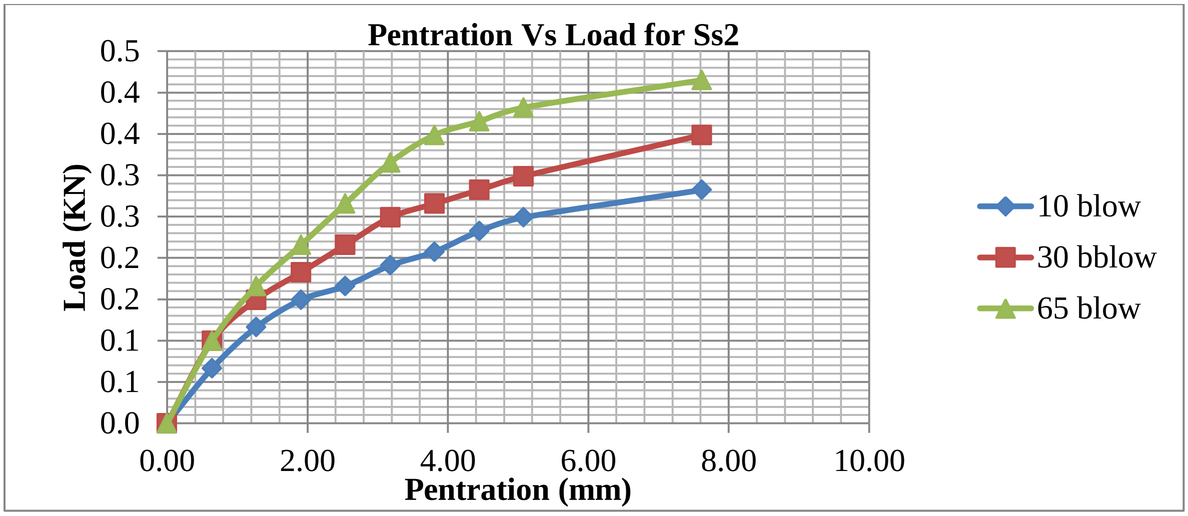
Annex B-9: CBR Test Result

Natural soil

Compaction Determination for Ss2							
COMPACTION DATA		10 Blows		30 Blows		65 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		C1	C1	C2	C2	C3	C3
Mass of soil + Mould	g	12758.7	13201.6	12888.2	13333.2	13245.6	13594
Mass Mould	g	9405.7	9405.7	9399.1	9399.1	9530.5	9530.5
Mass of Soil	g	3353	3795.9	3489.1	3934.1	3715.1	4063.5
Volume of Mould	g	2123	2123	2123	2123	2123	2123
Wet density of soil	g/cc	1.579	1.788	1.643	1.853	1.750	1.914
Dry density of soil	g/cc	1.213	1.202	1.265	1.264	1.343	1.340

Moisture Determination										
MOISTURE CONTENT DATA		10 Blows			30 Blows			65 Blows		
		Before soak		After soak	Before soak		After soak	Before soak		After soak
Container no.		A13	C	P10	MK	E11	T1C1	P10	T5C2	C1
Mass of wet soil + Container	g	167.3	150.8	225.5	127.5	141.5	162.0	126.9	140.9	204.1
Mass of dry soil + Container	g	137.2	123.1	165.1	102.3	117.2	116.1	101.4	112.3	155.9
Mass of container	g	36.4	32.5	41.2	17.6	36.6	17.5	17.4	17.8	43.5
Mass of water	g	30.1	27.7	60.4	25.2	24.3	45.9	25.5	28.6	48.2
Mass of drysoil	g	100.8	90.6	123.9	84.7	80.6	98.6	84.0	94.5	112.4
Moisture content	%	29.9	30.6	48.7	29.8	30.1	46.6	30.4	30.3	42.9
Average moisture content	%	30.2		48.7	30.0		46.6	30.3		42.9

Swell Determination						
	10 Blows		30 Blows		65 Blows	
	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %
Initial	0.00	6.74	0	7.45	0.00	6.31
Final	7.84		8.67		7.34	



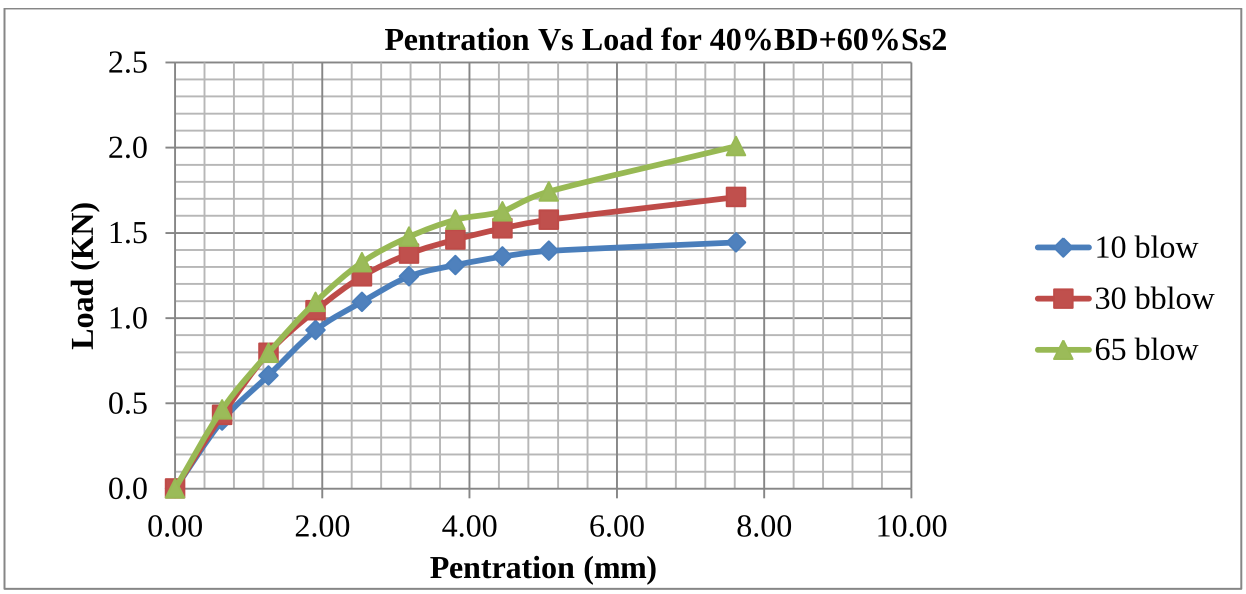
40% Brick Dust

40% Brick Compaction Determination							
COMPACTION DATA		10 Blows		30 Blows		65 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		C1	C1	C2	C2	C3	C3
Mass of soil + Mould	g	12949.1	13132.4	13137.2	13285.6	13342.1	13472
Mass Mould	g	9348.1	9348.1	9365.9	9365.9	9409.2	9409.2
Mass of Soil	g	3601	3784.3	3771.3	3919.7	3932.9	4062.8
Volume of Mould	g	2123	2123	2123	2123	2123	2123
Wet density of soil	g/cc	1.696	1.783	1.776	1.846	1.853	1.914
Dry density of soil	g/cc	1.355	1.349	1.410	1.409	1.472	1.469

Moisture Determination									
MOISTURE CONTENT DATA		10 Blows			30 Blows			65 Blows	
		Before soak		After soak	Before soak		After soak	Before soak		After soak
Container no.		A13	C	T1	T1C1	A12	G19	G4	P10	T5C2
Mass of wet soil + Container	g	123.3	140.2	168.3	128.9	125.7	228.1	138.4	133.9	168.3
Mass of dry soil + Container	g	105.8	115.5	136.5	108.3	103.5	182.2	116.7	114.0	133.3
Mass of container	g	36.4	17.4	37.6	29.4	17.4	34.2	32.8	36.8	17.6
Mass of water	g	17.5	24.7	31.8	20.6	22.2	45.9	21.7	19.9	35.0

Mass of drysoil	g	69.4	98.1	98.9	78.9	86.1	148.0	83.9	77.2	115.7
Moisture content	%	25.2	25.2	32.2	26.1	25.8	31.0	25.9	25.8	30.3
Average moisture content	%	25.2		32.2	25.9		31.0	25.8		30.3

Swell Determination						
	10 Blows		**30 Blows**		**65 Blows**	
	Gauge rdg mm	**Swell in %**	**Gauge rdg mm**	**Swell in %**	**Gauge rdg mm**	**Swell in %**
Initial	0.00	2.03	0	1.65	0.00	1.53
Final	2.36		1.92		1.78	



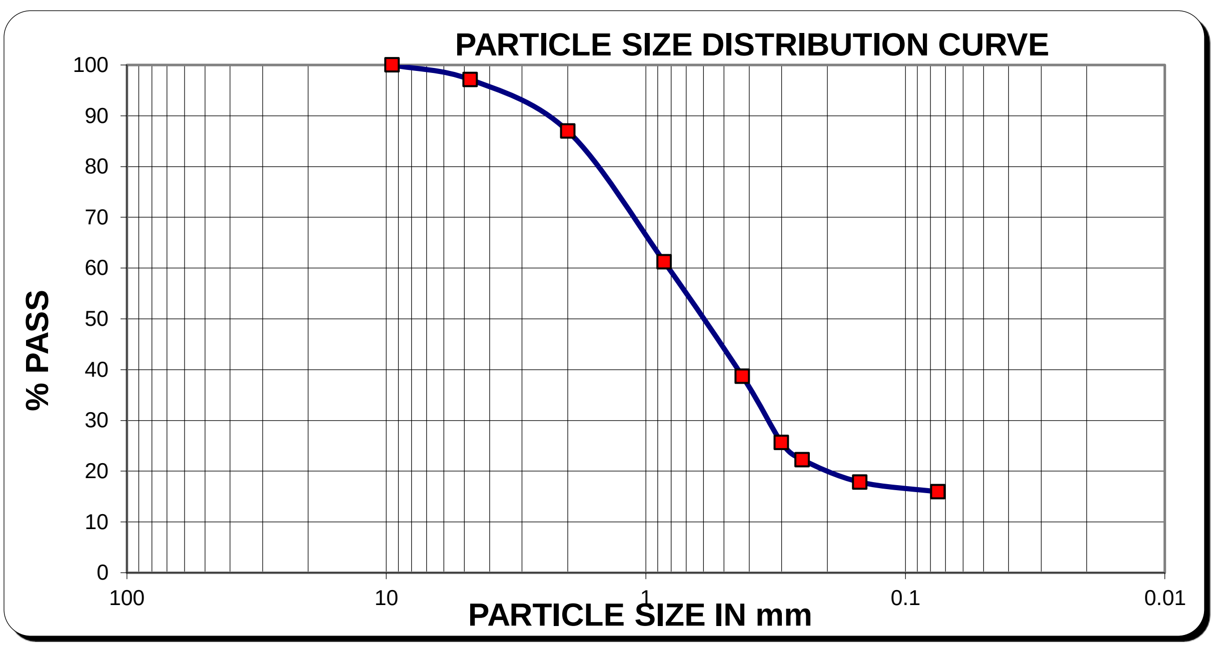
Annex C: Physical Properties of Brick Dust

Annex C-1: Specific Gravity

Specific gravity of soil at test Temprature,G at Tx °C (ASTM D-854-83)			
SG for Brick Dust			
Trial No.	1	2	3
Mass of dry, clean Calibrated pycnometer, Mp	25.12	26.48	25.22
Mass of dry soil + pycnometer, Mps, in g	50.12	51.48	50.22
Mass of pycnometer+dry soil+water at temperature Tx, in °C, g	135.84	137.33	134.7
Test temperature(Tx),°C	22	22	22
Density of water at Tx, g/cm3	0.9978	0.9978	0.9978
Mass of density bottle+water at temperature Ti^°C(21°C),g	120.93	121.99	119.48
Density of water at Ti,g/ml at 21°C	0.9980	0.9980	0.9980
Correction factor,k	1.000	1.000	1.000
Specific gravity G at Tx°C	2.477	2.587	2.556
Average specific gracity at Tx°C	2.54		

Annex C-2: Wet Sieve Analysis

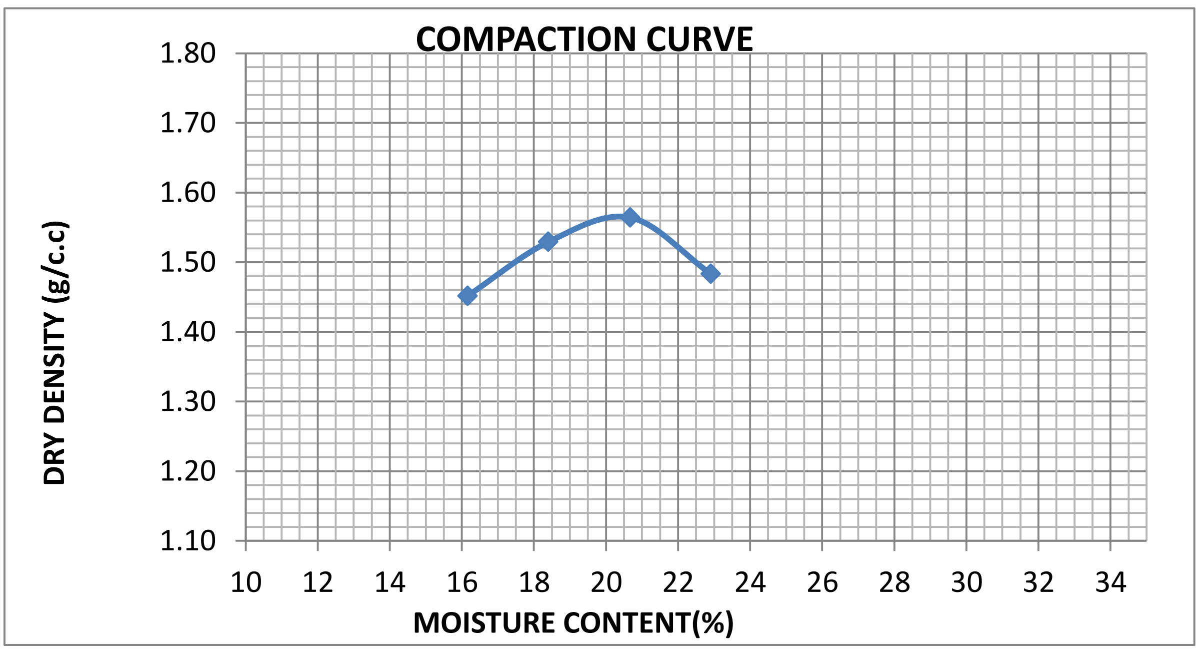
Sieve Size(mm)	Mass retained (gm)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Cumulative Percentage Passing (%)
9.5	0	0	0	100
4.75	28.80	2.88	2.88	97.12
2	101.40	10.14	13.02	86.98
0.85	257.60	25.76	38.78	61.22
0.425	225.00	22.50	61.28	38.72
0.3	130.80	13.08	74.36	25.64
0.25	33.60	3.36	77.72	22.28
0.15	44.20	4.42	82.14	17.86
0.075	19.20	1.92	84.06	15.94
Total 1	840.6			
pan	159.4			
Total	1000			



Annex C-3: Compaction test result:

trial No.	1		2		3		4	
wt of wet soil+mold	10145.2		10408.6		10572.0		10435.0	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	1.69		1.81		1.89		1.82	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	127.5	137.1	150.9	139.5	140.7	135.3	160.7	147.9
wt of dry soil+can	112.3	120.4	130.2	121.1	119.6	115.3	134.0	123.6
wt of can	17.8	17.6	17.5	21.3	18.2	17.9	17.5	17.5
moisture content,%	16.08	16.25	18.37	18.44	20.81	20.53	22.92	22.90
Average moisture content,%	16.16		18.40		20.67		22.91	
dry density, g/cc	1.45		1.53		1.56		1.48	

MDD (gm/cm3)	**OMC (%)**
1.56	**20.67**



Summary of physical properties of brick dust

No.	Test Description		Test Result
1	Specific gravity (kg/m3)		2.54
2	Particle size	Gravel	13.02
		Sand	71.04
		Fine	15.94
3	LL,PL,PI		NP
4	OMC		20.67
5	MDD		1.56
6	CBR		7.30

Annex D: Physical Properties of Stone Dust

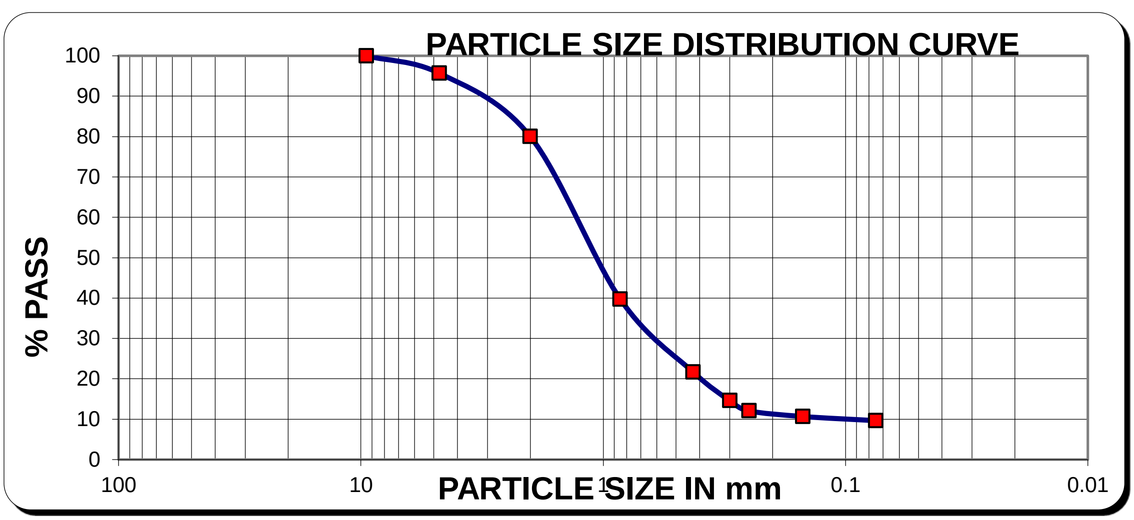
Annex D-1 Specific Gravity

Specific gravity of soil at test Temprature,G at Tx °C (ASTM D-854-83)			
SG for Stone Dust			
Trial No.	1	2	3
Mass of dry, clean Calibrated pycnometer, Mp	26.31	22.57	25.68
Mass of dry soil + pycnometer, Mps, in g	51.61	47.57	50.78
Mass of pycnometer+dry soil+water at temperature Tx, in °C, g	137.14	134.28	138.67
Test temperature(Tx),°C	24	24	24
Density of water at Tx, g/cm3	0.997	0.997	0.997
Mass of density bottle+water at temperature Ti^°C(21°C),g	121.15	118.18	122.43
Density of water at Ti,g/ml at 21°C	0.998	0.998	0.998

Correction factor,k	0.999	0.999	0.999
Specific gravity G at Tx°C	2.716	2.809	2.833
Average specific gracity at Tx°C	2.79		

Annex D-2: Wet Sieve Analysis

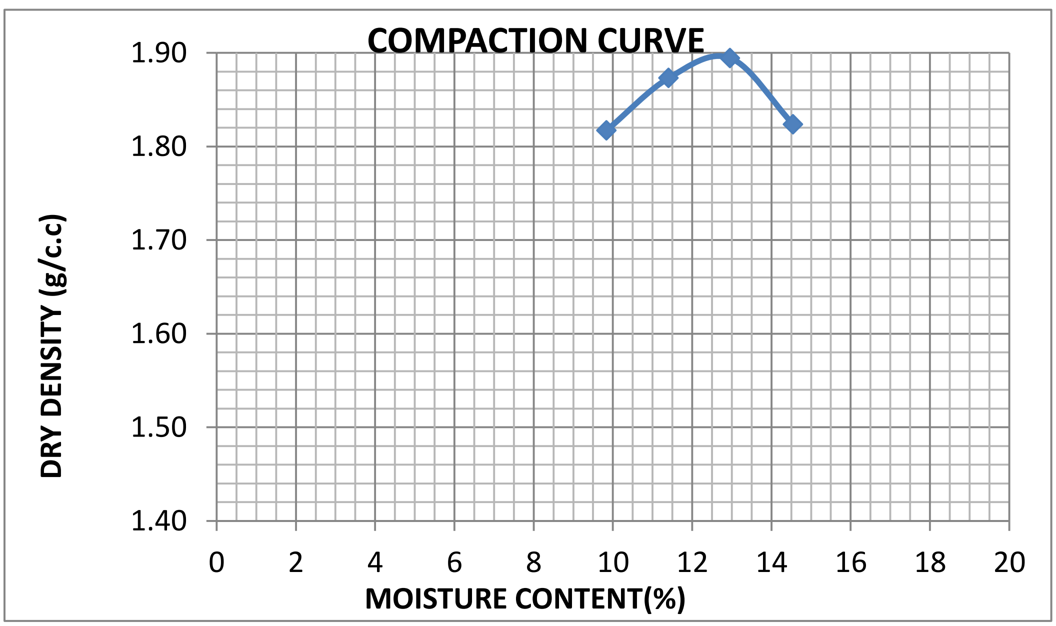
Sieve Size(mm)	Mass retained (gm)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Cumulative Percentage Passing (%)
9.5	0	0	0	100
4.75	64.7	4.31	4.31	95.69
2	234.9	15.66	19.97	80.03
0.85	604.6	40.31	60.28	39.72
0.425	270.9	18.06	78.34	21.66
0.3	106.2	7.08	85.42	14.58
0.25	37.7	2.51	87.93	12.07
0.15	21	1.40	89.33	10.67
0.075	15.3	1.02	90.35	9.65
Total 1	1355.3			
pan	144.7			
Total	1500			



Annex D-3: Compaction test result:

trial No.	1		2		3		4	
wt of wet soil+mold	10802.6		10995.0		11108.0		10999.6	
wt of mold	6564.8		6564.8		6564.8		6564.8	
volume of mold	2123.0		2123.0		2123.0		2123.0	
Bulk density, g/cc	2.00		2.09		2.14		2.09	
Can No.	1	2	1	2	1	2	1	2
wt of wet soil+can	154.2	129.0	145.4	132.5	139.0	132.2	135.0	121.4
wt of dry soil+can	142.3	119.6	132.5	120.6	125.5	119.3	120.6	108.4
wt of can	23.6	22.3	17.6	17.9	21.3	19.8	22.1	18.6
moisture content,%	10.03	9.66	11.23	11.59	12.96	12.96	14.62	14.48
Average moisture content,%	9.84		11.41		12.96		14.55	
dry density, g/cc	1.82		1.87		1.89		1.82	

MDD (gm/cm3)	OMC (%)
1.89	**12.96**



Summary of physical properties of Stone dust

No.	Test Description		Test Result
1	Specific gravity (kg/m3)		2.79
2	Particle size	Gravel	19.97
		Sand	70.38
		Fine	9.65
3	LL,PL,PI		NP
4	OMC		12.96
5	MDD		1.89
6	CBR		21.60

Annex E: Cost break down for materials

Work Item: Clearing and Grubbing

Performance: 1000.00 m2/day

: 125.00m2/hr

Material Cost					Labor cost					Equipment cost				
Mat. Type	Unit	Qty	Rate	Cost/ unit	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equip. type	Qty	UF	Rental rate hrly	Rental rate Total
					Construction Foreman	1	0.50	51.37	25.69	Dozer	1	1	2,131.84	2,131.84
					Laborers	2	1.00	17.29	34.57					
					Dozer Operator	1	1.00	77.09	77.09					
					Helper	1	1.00	21.77	21.77					
Total				-	**Total**				159.13	**Total**				2,131.84

A = Material Unit Cost = 0.00 birr/m2

B = Manpower Unit Cost = 1.27 birr/m2

C = Equipment Unit Cost :17.05 Birr/m2

Direct cost of work item =A+B+C= 18.33 Birr/m2

Total cost = 22.91 Birr/m2

Work Item : Bulk excavation In expansive soil not exceeding 150cm .

Performance rate : 170.00 m3/day

21.25 m3/hr

Material Cost					Labor cost					Equipment cost				
Mat. Type	Unit	Qty	Rate	Cost/ unit	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equip. type	Qty	UF	Rental rate hrly	Rental rate Total
					Const. Foreman	1	0.50	51.37	25.69	Dozer	1	1	2,131.84	2,131.84
					Laborers	2	1.00	17.29	34.57					
					Dozer Operator	1	1.00	77.09	77.09					
					Helper	1	1.00	21.77	21.77					
Total				-	**Total**				159.13	**Total**				2,131.84

A = Material Unit Cost = 0.00 Birr/m3

B = Manpower Unit Cost= 7.49 Birr/m3

C = Equipment Unit Cost = 100.32 birr/m3

Direct cost of work item =A+B+C= 107.81 Birr/m3

Total cost = 134.76 Birr/m3

Work Item: Disposal of excavated material 5km. from the site.

Performance rate: 320.00 m3/day

: 40.00m3/hr

Material Cost					Labor cost					Equipment cost				
Mat. Type	Unit	Qty	Rate	Cost/ unit	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equipment type	Qty	UF	Rental rate hrly	Rental rate Total
					data collector	1.00	0.50	21.77	10.89	Dump Truck	6.00	1	612.88	3,677.31
					Loader Operator	1.00	0.75	51.37	38.53	Loader	1.00	1	574.33	430.75
					D/Truck Operator	6.00	1.00	51.37	308.22					
Total				-	**Total**				357.64	**Total**				4,108.06

A = Material Unit Cost =0.00 Birr/m3

B = Manpower Unit Cost =8.94 Birr/m3

C = Equipment Unit Cost =102.70 Birr/m3

Direct cost of work item =A+B+C= 111.64 Birr/m3

Total cost = 139.55 Birr/m3

Work Item: Road bed Preparation and the compaction of material, Compaction to 93% of MDD

Performance rate: 1000.00 m3/day

: 125.00m3/hr

Material Cost					Labor cost					Equipment cost				
Mat. Type	Unit	Qty	Rate	Cost/ unit	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equip. type	Qty	UF	Rental rate hrly	Rental rate Total
					Water tuck Operator	2	1.00	51.37	102.74	Grader	2	1	1,223.41	2,446.81
					Grader Operator	2	1.00	77.09	154.19	Water Truck	2.00	1.00	286.95	573.91
					Labourer Forman	1.00	1.00	27.43	27.43	Roller	2.00	0.75	601.77	902.66
					Construction Forman	1.00	0.25	51.37	12.84	Dozer	1.00	1.00	2,131.84	2,131.84
					Dozer Operator	1.00	1.00	77.09	77.09					
					Roller Operator	2.00	1.00	41.94	83.88					
Total				-	**Total**				458.18	**Total**				6,055.23

A = Material Unit Cost=0.00 Birr/m3

B = Manpower Unit Cost =3.67 Birr/m3

C = Equipment Unit Cost =48.44 Birr/m3

Direct cost of work item = A+B+C = 52.11 Birr/m3

Total cost = 65.13 Birr/m3

Work Item: Placing and Compacting selected material to 95% MDD

Performance rate: 600.00 m3/day

: 75.00m3/hr

Material Cost					Labor cost					Equipment cost				
Mat. Type	Unit	Qty	Rate	Cost/ unit	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equip. type	Qty	UF	Rental rate hrly	Rental rate Total
					Grader Operator	2	1	77.09	154.19	Grader	2	1	1,223.41	2446.81
					Roller Operator	2	1	41.94	83.88	Roller	2	1	601.77	1203.54
					Construction Forman	1	1	51.37	51.37	Water Truck	2	1	286.95	573.91
					Water TruckOperator	2	1	51.37	102.74					
					Labourer	3	1.00	17.29	51.86					
Total				-	**Total**				444.04	**Total**				4,224.27

A = Material Unit Cost=0.00 Birr/m3

B = Manpower Unit Cost =5.92 Birr/m3

C = Equipment Unit Cost = 56.32 Birr/m3

Direct cost of work item = A+B+C = 62.24 Birr/m3

Total cost = 77.81 Birr/m3

Work Item: Select Material Production

Performance rate: 600.00 m3/day

: 75.00m3/hr

Material Cost					Labor cost					Equipment cost				
Mat. Type	Unit	Qty	Rate	Cost/ unit	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equip. type	Qty	UF	Rental rate hrly	Total
					Dozer Operator	2	1	77.09	154.19	Dozer	2	1	2,131.84	4,263.68
					Helper	3	1.00	21.77	65.31					
Total				-	**Total**				219.50	**Total**				4,263.68

A = Material Unit Cost=0.00 Birr/m3

B = Manpower Unit Cost =2.93 Birr/m3

C = Equipment Unit Cost =56.85 Birr/m3

Direct cost of work item = A+B+C = 59.78 Birr/m3

Total cost = 74.72 Birr/m3

Work Item: Select Material Hauling

Cap.	**12.00**	**t for L/Unl (min)**	**8.00**	Performance rate (m3/day)	**606.32**
Av.Dis (km)	**9.00**	**Total t(hr)**	**0.95**	(m3/hr)	**76.00**
Av.Sp.(km/hr)	**25.00**				

Material Cost					**Labor cost**					**Equipment cost**				
Mat. Type	**Unit**	**Qty**	**Rate**	**Cost/ unit**	**Title**	**Qty**	**UF**	**Indexed hrly cost**	**Total hrly cost**	**Equip. type**	**Qty**	**UF**	**Rental rate hrly**	**Rental rate Total**
					Construction Forman	1	1	51.37	51.37	Loader	2	1	574.33	1,148.67
					Dump Truck driver	6	1	51.37	308.22	Dump Truck	6	1	612.88	3,677.31
					Loader	2	1	51.37	102.74					
					Laborer	2	1	17.29	34.57					
Total				-	**Total**				496.91	**Total**				4,825.97

A = Material Unit Cost =0.00 Birr/m3

B = Manpower Unit Cost =6.56 Birr/m3 C = Equipment Unit Cost =63.68 Birr/m3

Direct cost of work item = A+B+C = 70.23 Birr/m3

Total cost = 87.79 Birr/m3

Work Item: Select Material Production

Performance rate: 600.00 m3/day

: 75.00m3/hr

Material Cost					Labor cost					Equipment cost				
Mat. Type	**Unit**	**Qty**	**Rate**	**Cost/ unit**	**Title**	**Qty**	**UF**	**Indexed hrly cost**	**Total hrly cost**	**Equip. type**	**Qty**	**UF**	**Rental rate hrly**	**Total**
					Dozer Operator	1	1	77.09	154.19	Dozer	1	1	2,131.84	2,131.84
					Construction Forman	1	1	51.37	51.37					
					Laborers	3	1	17.29	51.86					
Total				-	**Total**				219.50	**Total**				2,131.84

A = Material Unit Cost=0.00 Birr/m3

B = Manpower Unit Cost =2.40 Birr/m3

C = Equipment Unit Cost =28.42 Birr/m3

Direct cost of work item = A+B+C = 30.83 Birr/m3

Total cost = 38.54 Birr/m3

Work Item: Borrow Material Hauling

Cap.	**12.00**	**t for L/Unl (min)**	**8.00**	Performance rate (m3/day)	**605.35**
Av.Dis (km)	**9.00**	**Total t(hr)**	**0.95**	(m3/hr)	**76.00**
Av.Sp.(km/hr)	**22.00**				

Material Cost					**Labor cost**					**Equipment cost**				
Mat. Type	**Unit**	**Qty**	**Rate**	**Cost/ unit**	**Title**	**Qty**	**UF**	**Indexed hrly cost**	**Total hrly cost**	**Equip. type**	**Qty**	**UF**	**Rental rate hrly**	**Rental rate Total**
										Loader	1	1	574.33	574.33
					Dump Truck driver	6	1	51.37	308.22	Dump Truck	6	1	612.88	3,677.31
					Loader	1	1	51.37	51.37					
					Labourer	2	1	17.29	34.57					
Total				-	**Total**				394.17	**Total**				4,251.64

A = Material Unit Cost =0.00 Birr/m3

B = Manpower Unit Cost =5.21 Birr/m3 C = Equipment Unit Cost =56.19 Birr/m3

Direct cost of work item = A+B+C = 61.4 Birr/m3

Total cost = 76.75 Birr/m3

Work Item: Selected subgrade material (capping layer) compacted to 95% of MDD

Performance rate: 600.00 m3/day

: 75.00m3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	**Unit**	**Qty**	Rate	Cost/ unit	**Title**	**Qty**	**UF**	Indexed hrly cost	Total hrly cost	**Equipment type**	**Qty**	**UF**	Rental rate hrly	Total
Select Mat. Prod.	m3	1.15	30.83	35.45										
Select Mat. Hauling	m3	1.15	61.40	70.61	Grader Operator	2	1	77.09	154.19	Grader	2	1	1,223.41	2446.81
					Roller Operator	2	1	41.94	83.88	Roller	2	1	601.77	1203.55
					Construction Forman	1	0.5	51.37	25.69	Water Truck	1	0.5	286.95	143.48
					Labourer Forman	1	1	27.43	27.43					
					Water Truck	1	0.5	51.37	25.69					
					Labourer	8	1	17.29	138.29					
Total				106.059	**Total**				455.17	**Total**				3793.84

A = Material Unit Cost =106.1Birr/m3

B = Manpower Unit Cost = 6.07 Birr/m3

C = Equipment Unit Cost =50.58 Birr/m3

Direct cost of work item = A+B+C =**162.71** Birr/m3

Total cost =**203.39** Birr/m3

Work Item: Gravel sub base compacted to 97% of MDD (125mm - 275mm compacted layer thickness)

Performance rate: 500.00 m3/day

: 62.5.00m3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/ unit	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equip. type	Qty	UF	Rental rate hrly	Total
Subbase Mat. Production	m3	1.25	25.89	32.36	Const. Forman	1	0.7	51.371	35.96	Grader	2	1	1223.41	2446.81
Subbase Mat. Hauling	m3	1.25	76.99	96.23	Laborers Forman	1	1	27.430	27.43	Roller	1	1	601.77	601.77
					laborers	10	1	17.287	172.87	W/Truck	1	1	286.95	286.95
					Grader Op.	1	1	77.095	77.10					
					Roller Op.	1	1	41.939	41.94					
					W/Truck Op.	1	1	51.371	51.37					
Total				128.6	Total				406.67	Total				3335.54

A = Material Unit Cost =128.59Birr/m3

B = Manpower Unit Cost = 6.51 Birr/m3

C = Equipment Unit Cost =53.36 Birr/m3

Direct cost of work item = A+B+C =**188.47** Birr/m3
Total cost =**235.59** Birr/m3

Work Item: compacted Crushed stone road base

Performance rate: 700.00 m3/day

: 87.5.00m3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	**Unit**	**Qty**	**Rate**	**Cost/ unit**	**Title**	**Qty**	**UF**	**Indexed hrly cost**	**Total hrly cost**	**Equip. type**	**Qty**	**UF**	**Rental rate hrly**	**Total**
Quary Rock Prod	m3	1.25	143.01	178.76	Roller Opr.	2	1	41.94	83.88	Hand tools	5	1	10	50
Quary Rock Haul.	m3	1.25	47.75	59.69	W/Truck dr.	2	1	51.37	102.74	Roller	2	1	601.77	1203.55
Base Course Crushing	m3	1.25	138.94	173.68	Grader Opr.	2	1	77.09	154.19	W/Truck	2	1	286.95	573.91
Base Course Hauling	m3	1.25	49.43	61.79	Con. Foreman	1	1	51.37	51.37	Grader	2	1	1,223.41	2446.81
					Laborers	8	1	17.29	138.30					
Total				436.42	Total				530.48	Total				4274.27

A = Material Unit Cost =436.41Birr/m3   B = Manpower Unit Cost = 6.06 Birr/m3   C = Equipment Unit Cost =48.85 Birr/m3

Direct cost of work item = A+B+C =**491.33 Birr/m3**
Total cost =**614.16 Birr/m3**

Work Item: Hauling of Stabilizer

Cap.	**12.00**	**t for L/Unl (min)**	**8.00**	Performance rate (m3/day)	**320.00**
Av.Dis (km)	**24**	**Total t(hr)**	**1.50**	(m3/hr)	**40.00**
Av.Sp.(km/hr)	**35.00**				

Material Cost					**Labor cost**					**Equipment cost**				
Mat. Type	**Unit**	**Qty**	**Rate**	**Cost/ unit**	**Title**	**Qty**	**UF**	**Indexed hrly cost**	**Total hrly cost**	**Equip. type**	**Qty**	**UF**	**Rental rate hrly**	**Rental rate Total**
					Dump Truck driver	5	1	51.37	51.37	Loader	1	1	574.33	574.33
					Loader opp.	1	1	51.37	256.85	Dump Truck	5	1	612.88	1532.21
					Labourer	3	1	17.29	51.86					
					Helper	1	1	21.77	21.77					
Total				-	**Total**				381.86	**Total**				2106.54

A = Material Unit Cost =0.00 Birr/m3

B = Manpower Unit Cost =9.55 Birr/m3

C = Equipment Unit Cost =52.66 Birr/m3

Direct cost of work item = A+B+C = 62.21 Birr/m3

Total cost = 77.76 Birr/m3

Work Item: mixing of Stabilizer

Performance rate: 420.00 m3/day

: 52.50m3/hr

Material Cost					Labor cost					Equipment cost				
Mat. Type	**Unit**	**Qty**	**Rate**	**Cost/ unit**	**Title**	**Qty**	**UF**	**Indexed hrly cost**	**Total hrly cost**	**Equip. type**	**Qty**	**UF**	**Rental rate hrly**	**Total**
					Loader Opr.	2	1	51.37	102.74	Loader	2	1	574.33	1148.67
					W/Truck dr.	2	1	51.37	102.74	W/Truck	2	1	286.95	573.91
					Dozer Opr.	1	1	77.09	77.09	Dozer	1	1	2,131.84	2131.84
					Con. Foreman	1	1	51.37	51.37					
					Helper	2		51.37	102.74					
					Laborers	8	1	17.29	138.30					
Total					Total				574.99	Total				3854.42

A = Material Unit Cost =0.00Birr/m3

B = Manpower Unit Cost = 10.95 Birr/m3

C = Equipment Unit Cost =73.42 Birr/m3

Direct cost of work item = A+B+C =**84.38 Birr/m3**
Total cost =**105.46 Birr/m3**

Work Item: placing of Stabilizer

Performance rate: 600.00 m3/day

: 75.00m3/hr

Material Cost					Labor cost					Equipment cost				
Mat. Type	**Unit**	**Qty**	**Rate**	**Cost/ unit**	**Title**	**Qty**	**UF**	**Indexed hrly cost**	**Total hrly cost**	**Equip. type**	**Qty**	**UF**	**Rental rate hrly**	**Total**
					Roller Opr.	2	1	41.94	83.88	Hand tools	3	1	10	30
					W/Truck dr.	2	1	51.37	102.74	Roller	2	1	601.77	1203.55
					Grader Opr.	2	1	77.09	154.19	W/Truck	2	1	286.95	573.91
					Helper	1	1	21.77	21.77	Grader	2	1	1,223.41	2446.81
					Labourer	3	1	17.29	51.86					
Total				0	Total				414.4409	Total				4254.27

A = Material Unit Cost =0.00Birr/m3

B = Manpower Unit Cost = 5.53 Birr/m3

C = Equip. Unit Cost =56.72 Birr/m3

Direct cost of work item = A+B+C =**62.25 Birr/m3**
Total cost =**77.81 Birr/m3**

Annex F: Photo Taken During Study