JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIROMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

Suitability of Gypsum and Crushed Waste Brick Mix for Stabilization of Weak Subgrade Soil

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

By:

Assefa Takele Getaneh

MARCH 2020

JIMMA, ETHIOPIA

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Advisor: Dr. Ing. Fekadu Fufa

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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 **Assefa Takele Getaneh** 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 Highway Engineering.

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DECLARATION

Hereby declare that the work which is being presented in this Thesis entitles “Suitability of Gypsum and Crushed Waste Brick Mix for Stabilization of Weak Subgrade Soil” is original work of my own, has not been presented for a degree in any University and that all sources of materials used for this Thesis duly acknowledge.

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Name	Signature	Date

As a Thesis research advisor, we hereby certify that we have read and evaluated this thesis prepared, under our guidance, by Assefa Takele Getaneh entitled: Suitability of Gypsum and Crushed Waste Brick Mix for Stabilization of Weak Subgrade Soil. We recommend that it be submitted as fulfilling the thesis requirement.

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ABSTRACT

Expansive soil is one of the most abundant soils in Ethiopia, which mostly causes significant damage to structures such as buildings, roads and bridges due to their swell-shrink effect. In the area of expansive soil and scarcity of suitable construction materials, upgrading the locally available materials is one of best alternative ways. Soil stabilization by adding additives is one of the methods of upgrading substandard materials.

Therefore this study assessed the suitability of gypsum and crushed waste brick mix for stabilization of expansive soil to use as a road subgrade preparation. Expansive soil sample was collected from along Mettu-Burusa road and was investigated. Accordingly, expansive soil was stabilized with the mix of crushed waste brick and gypsum material proportion of 0%, 10%, 20%, 30%, 40 % and 0%, 2%, 4%, 6%, 8% respectively by weight of the total mix and laboratory tests such as Moisture Content, Grain size distribution, Atterberg Limit, Free Swell, Free Swell Index, Free Swell Ratio, Specific Gravity, Compaction, CBR and CBR-Swell are carried out to assess the alteration in its strength characteristics and index properties.

The subgrade material quality improved from A-7-5 to A-2-4 at combination 30% of crushed waste brick and 6% of gypsum with expansive soil. By the addition of stabilizer material to expansive soil the least plasticity index value obtained was 9.030 % and the CBR increased to 10.686% from initial CBR value at the percentage of 30% brick and 6% gypsum. The OMC and MDD was increased to 29.200% and 1.480g/cm^3 respectively and the free swell, free swell index, free swell ratio was decreased to 18%, 16.830%, 1.168 respectively and CBR-Swell decreased to 1.370%, from the initial untreated soil test at percentage of 40% crushed waste brick and 8% gypsum mix with expansive soil.

Based on the laboratory test results, it shown that the mixture of 30% of crushed waste brick and 6% of gypsum was the optimum combination material for stabilization of expansive soil to comply with the required technical specification specified in AASHTO. Treating expansive soil with the mix of crushed waste brick and gypsum respond and exhibited an improvement on its engineering properties including reduction in plasticity, increased strength and compaction characteristics.

Key word: Crushed Waste Brick; Expansive Soil; Gypsum; Stabilization.

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ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	ASTM International (American Society for Testing and Materials)
BKD	Brick Kiln Dust
BP	Brick Powder
CWB	Crushed Waste Brick
CBR	California Bearing Ratio
DBW	Demolished Bricks Waste
ERA	Ethiopia Road Authority
ESP	Exchangeable Sodium Percentage
G	Gypsum
JIT	Jimma Institute of Technology
LL	Liquid Limit
MDD	Maximum Dry Density
MS	Microsoft
N.L.	None Liquid
N.P.	None Plastic
OMC	Optimum Moisture Content
OPC	Ordinary Portland cement
PI	Plastic Index
PL	Plastic Limit
PP	Polypropylene
WSS	Weak Subgrade Soil
	<u>Units</u>
cc	Centimeter Cubic
Cm^3	Centimeter Cubic

^oC	Degree Centigrade
g/cm3	Gram Per Centimeter Cubic
Kg	Kilogram
KN	Kilo Newton
m	Meter
ml	Milliliter
mm	Millimeter
µm	Micrometer

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Worldwide the availability of natural construction materials within reasonable hauling distance is one of the major factors that have a direct impact on the investment cost of road projects. In areas where natural construction materials are readily available, roads can be constructed on Sound economic basis. However in some regions, natural construction materials are either not available or do not fulfill the quality requirements of road construction materials. Problems associated with these construction materials have been reported in Africa, Australia, Europe, India, and South America, the United States as well as some regions in Canada. In the United States alone, expansive clays have been estimated to produce at least two billion dollars of damage annually. In many areas of the tropics especially Africa and India, tropical expansive soils often known as black cotton soils are the major problematic soils. These soils show very strong swelling and shrinkage characteristics under changing moisture conditions [1].

Expansive soil is one of the most abundant soils in Ethiopia and unsuitable subgrade material covering about 40% of the area of Ethiopia [2]. Which mostly creates problems on built of structure. These problems need wider application of cost effective and environmental friendly technology of improving soil properties to be customized or adopted to the current road construction trend in Ethiopia. The swell-shrink effect of expansive soils causes significant damage to structures such as buildings, roads and bridges. This damage is due to moisture fluctuation caused by seasonal variation. One of the weak sub grade soils that not favorable for road construction is expansive soils. Properties of the weak sub grade soil vary from place to place due to topography, climate and content soils etc. Expansive soils are the soils which swell significantly when they come in contact with water and shrink when dry [3]. Expansive soil exhibit volume change when subjected to moisture variation. Swelling or expansive clays soil is those that contain swelling clay mineral and have high degree of shrink-swell reversibility with change in moisture content [4].

In general way treatment of unsuitable subgrade soils is accomplished by modification, stabilization, or removal and replacement. Modification refers to a short-term subgrade treatment that is intended to provide a stable working platform during construction. Stabilization refers to a subgrade treatment intended to provide structural stability for improved long-term performance. Removal and replacement, as the name indicates, involves removal of the unsuitable subgrade soil and replacement with a select material (usually granular backfill).

From several methods that available to mitigate the effects of swell-shrink nature of expansive soil is to stabilize it with admixtures that prevent it from volume changes or adequately modify the volume change characteristics of expansive soils [3]. Stabilization in a broad sense incorporates the various method employed for modifying the properties of a soil to improve its engineering performance.

Stabilizing agents are selected according to the type of soil and stability problem at hand and the economics of their use. The problem of waste disposal has become a major concern for planners and engineers in developed cities like Mettu.

According to the researchers [5] says demolished waste from the construction can also be used as an admixture to improve the stability of the soil and also DBW has many of its chemical properties similar to cement and as cement can be used for the stabilization of soil so can DBW. Demolished Bricks Waste is inexpensive and readily available so it is a better option for stabilization of soil.

According to, ERA [6] manual proposes: Alignment improvement (avoiding the area of expansive soil), Excavation/soil replacement (replacing expansive soil with good quality material along the road route), Stabilization with stabilizing agent and Minimizing of water content change (implementing measure to prevent water infiltration)

Out of these, Stabilization with stabilizing agent is the most effective method, and it is recommended that is applied as much as possible on which the study focus.

1.2. Statement of the Problem

The fact that expansive soils are major engineering problem makes their study an important aspect due to their tendency to swell in presence of moisture and shrink in moisture absence and the accruing cost involved in terms of economic loss when construction is undertaken without giving consider to the probability of their presence. A difficult problem in civil engineering works exists when the sub-grade is found to be clay soil. Soils having high clay content have the tendency to swell when their moisture content is allowed to increase [7].

Ethiopia is one of the country that have distributed weak subgrade soils. To reduce the impact of weak road subgrade soils, improvement of their engineering properties is required. Stabilizations is commonly used to improve the performance of soils with high plasticity, poor workability, and low strength and stiffness. To achieve effective soil stabilization, special attention needs to be given to proper type and concentration of the stabilizer. Besides, the effectiveness and efficiency of the stabilizer in terms of strength and durability improvement should be stated and specified. The strength and bearing capacity of the soil is impressively enhanced by soil stabilization through controlled compaction, proportioning and the expansion of reasonable admixtures [8].

Therefore, this research was used the mix of gypsum with crushed waste brick which available and cheap as stabilizer to evaluate the index properties, Atterberg limits, compaction and strength of the weak road subgrade soils and their behavior before and after stabilization.

1.3. Research Question

The major research questions are:

1. What are the engineering properties of the weak subgrade soil along Mettu-Burusa Road?
2. What are the effect of the mix of Gypsum with Crushed Waste Brick on soil strength?
3. What is the optimum percentage of Gypsum and Crushed Waste Brick Mix added to improve the soil strength?

1.4. Objectives of the Study

1.4.1. General Objective

The general objective of this study is to evaluate the Suitability of Gypsum and Crushed Waste Brick Mix as stabilizer of weak subgrade soil.

1.4.2. Specific Objectives

The specific objective of the study are:

1. To identify the engineering properties of weak subgrade soil along Mettu-Burusa Road.

2. To evaluate the effect of the mix of Gypsum with Crushed Waste Bricks on soil strength.
3. Determine the optimum mix of Gypsum with Crushed Waste Brick to be added to improve the soil strength.

1.5. Significance of the Study

The result can be utilized by the road contractors to construct a road that have a strong subgrade layer with good pavement condition with respect to the stabilizing agent in the future and on the other hand, this research can be reference for Jimma Institute of Technology students those who wants to carried out further study with respect to stabilizing material type.

1.6. Scope of the Study

The scope of study is to evaluate the Suitability of Gypsum and Crushed Waste Brick Mix for the use of Expansive Soil stabilizer depending on laboratory test. The laboratory test that was determine the effectiveness of Gypsum and Crushed Waste Brick Mix as stabilizing agents for Expansive Soils are Atterberg Limit, Sieve Analysis, Specific Gravity, Free Swell, Free Swell Index, Free Swell Ratio, Compaction, CBR, and CBR-Swell.

1.7. Limitations

The work was limited to the budget. During the subgrade soils sampling, the local people were not interested due to the lack of an awareness to those people through the respective agencies. The soil classification zone of the town wasn't prepared previously. Hence, the soil was identified by field investigation.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Subgrade Soil

The type of subgrade soil is largely determined by the location of the road. However, where the soils within the possible corridor for the road vary significantly in strength from place to place, it is clearly desirable to locate the pavement on the stronger soils if this does not conflict with other constraints. For this reason, the pavement engineer should be involved in the route corridor selection process when choices made in this regard influence the pavement structure and the construction costs [9].

The strength of the road subgrade for flexible pavements is commonly assessed in terms of the California Bearing Ratio (CBR) and this is dependent on the type of soil, its density, and its moisture content. Direct assessment of the likely strength or CBR of the subgrade soil under the completed road pavement is often difficult to make. Its value, however, can be inferred from an estimate of the density and equilibrium (or ultimate) moisture content of the subgrade together with knowledge of the relationship between strength, density and moisture content for the soil in question. This relationship must be determined in the laboratory. The density of the subgrade soil can be controlled within limits by compaction at suitable moisture content at the time of construction.

The moisture content of the subgrade soil is governed by the local climate and the depth of the water table on the road surface [9]. According to ERA, 2002 volume 1 (Flexible pavements and gravel roads) chapter three explains details concerning subgrade materials. According to the manual the strength of the Subgrade soil is assessed by the type of soil, its density and moisture content. According to ERA manual 2002 subgrades are classified from S1 to S6 based on the California bearing ratio (CBR), and are illustrated in table below.

Table 2. 1 CBR Range Subgrade Class [9].

Serial No.	Class	%CBR Range
1	S1	2
2	S2	3-4
3	S3	5-7
4	S4	8-14
5	S5	15-29
6	S6	30+

According to the soil and materials investigation report, sections of the route with CBR>3.5% and swell of about 2% can be used for Embankment construction which needs to be covered with blanketing material but if the CBR≥15% good subgrade material it not need covered with blanketing material[10]. From Bowls, 1992 CBR values and the quality of subgrades in pavement design are explained below.

Table 2. 2 CBR range Subgrade quality [10]

Serial No.	CBR (%) Range	Subgrade Quality
1	0-3	Very poor subgrade
2	3-7	Poor to fair subgrade
3	7-20	Fair subgrade
4	20-50	Good subgrade
5	50+	Excellent subgrade

The California Bearing Ratio test is conducted for evaluating the suitability of a soil for use as a sub grade, sub base or base course material in highway construction form laboratory conducted specimen. The test measures the shearing resistance of a soil under controlled moisture and density conditions, i.e., usually at optimum moisture content and corresponding degree of maximum dry density relevant to field compaction value [35].

The California bearing ratio (CBR) is to determine the relationship between force and penetration when a cylindrical plunger of a standard cross-sectional area is made to penetrate the soil at a given rate. At certain values of penetration that ratio of the applied force to a standard force expressed as a percentage.

The CBR values are used to determine the thickness of various layers. As it is evident, the required thickness of construction above a material decreases as the CBR value increases.

Addis Ababa City Roads Authority pavement design manual (2004) specifies subgrade materials with CBR values less than 3% and swelling potential greater than 2% need to be treated with stabilizing agents or replaced. The manual also recommends subgrade material which has been stabilized should not be assigned a CBR value of more than 15% for design purposes [36].

2.2. Practical Problem of Highway Construction

2.2.1. Sub-Grade Failure

One of the prime causes for the failure of pavement is excessive deformation in the sub-grade soil. This can be noticed is shown in Figure-2 in the form of excessive undulation or waves and corrugations in the pavement surface and also depression followed by heaving of pavement surface. The lateral shoving pavement near the edge along the wheel path of vehicles is due to insufficient bearing capacity or a shear failure in the sub-grade soil. Excessive unevenness of pavement surface is considered as pavement failure [11].

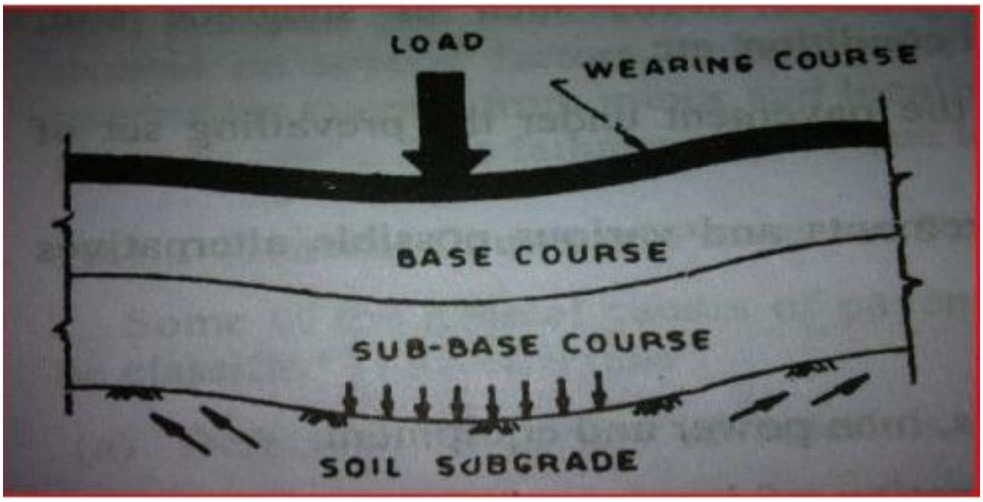


Figure 2. 1 Sub-grade failures [11]

2.3. Expansive Soils in Ethiopia

Distribution of expansive soil is generally a result of geological history, sedimentation and local climatic conditions. In Ethiopia, covering nearly 40% surface area of the country, expansive soils are observed in area such as central Ethiopia,… and the most Southern, South-west and south-east part of the capital Addis Ababa area in which the most major recent construction are being carried out [12].

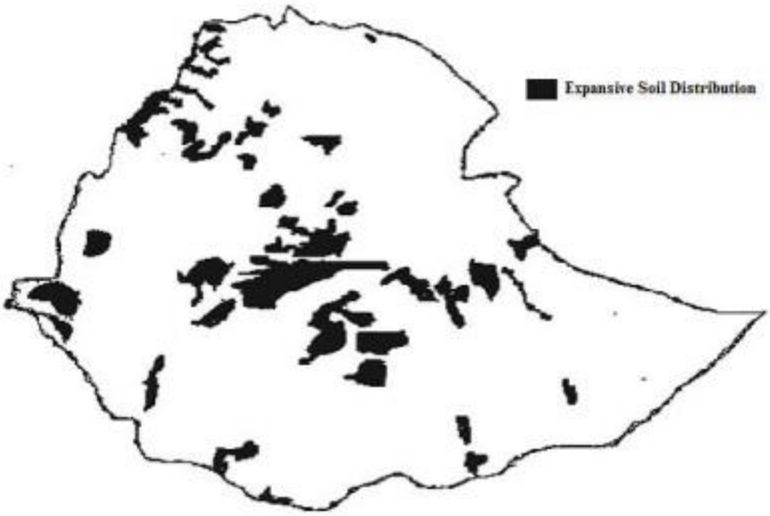


Figure 2. 2 Distribution of Expansive Soils in Ethiopia [12].

2.4. Swelling and Shrinkage of Expansive Soils

If environment of an expansive soil has not been changed, swelling does not take place. Environmental change can consist of pressure release due to excavation, desiccation caused by temperature increase, and volume increase due to moisture introduction.by far the most important element is the effect of water on expansive soils [13]. There must be a potential gradient, which can cause water migration, and a continuous passage through which water transfer can take place. With the introduction of water, volumetric expansion takes place. If pressure is applied to prevent expansion, the pressure required to maintain the initial volume is the swelling pressure. Thickness and location of the potentially expansive layers in a profile considerably influence potential movement. Greatest movement will occur in profile that has expansive clays extending from the surface to depths below the active zone. Less movement will occur if the expansive soil is overlain by non-expansive material or have got shallow depths. Water contents in the upper few meters of the expansive soil are affected by environmental factors [13]. In general, the movement of expansive soil occurs in uneven pattern and the resulting expansion is a magnitude that cannot be predicted by the classical elastic plastic theory [14]. However, the swelling behavior can be basically related to the combined effect of interacting factors that can be grouped into:

(a) Local geology:-include the rock type and ages as related to the type and amount of clay minerals, type and amount of cementing materials and the soil particles arrangement.

(b) Engineering properties factors: - included are moisture, Atterberg limits, and the dry density.

(c) Environmental factors:-include confining pressure, type and degree of weathering as related to amount of clay fraction, initial water content and water.

2.5. Classification of Soil

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. The most widely used general classification systems are: As shown on Table 2.4, soils rated A-6 or A-7 by AASHTO can be considered potentially expansive [15].

The soil with the lowest number, A-1, is the most suitable as a highway material or subgrade. In general, the lower is the number of soil, the more suitable is the soil.

Fine-grained soils are further rated for their suitability for highways by the group index (GI), determined as follows:

$$GI = (F - 35)[0.2 + 0.005(LL - 40)] + 0.01(F - 15)(PI - 10)$$

Where

F= Percentage by mass passing American Sieve no. 200(size 0.075mm), expressed as a whole number.

LL=Liquid limit (%), expressed as a whole number.

PI= Plastic index (%), expressed as a whole number.

The smaller the value of the group index, the better is the soil in that category. A group index of zero indicates a good subgrade, whereas a group index of 20 or greater shows a very poor subgrade [35].

I. AASHTO Classification

This is called American Association of State Highway Officials (AASHTO) classifications system is used for classifying soils for highways. The particle size analysis and the plasticity characteristics are required to classify a soil. The classification system is a complete system which classifies both coarse grained and fine grained soils. In this system, the soils are divided into 7 types, designated as A-1 to A-7.The soils A-1 and A-7 are Further subdivided in to two Categories and the soil A-2,in to four categories.

Table 2. 3 Particle Size Classification [34]

Classification system	Grain size (mm)
AASHTO	Gravel: 75 mm to 2.00 mm Sand: 2.00mm to 0.05 mm Silt : 0.05 mm to 0.002 mm Clay: <0.002 mm

Among the known classification Arora, (2004) describes the most widely used general classification systems American Association of State Highway Officials (AASHTO) Classification and Unified Soil Classification Systems (USCS) are the most common.

Table 2. 4 AASHTO soil classification system

General Classification	Granular Materials (35% or less of sample 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
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
a) Sieve analysis percent passing											
i. 2.00mm (No.10)	50 max	-	-	-	-	-	-	-	-	-	-
ii. 0.425mm (No.40)	30 max	50 max	51 min	-	-	-	-	-	-	-	-
iii. 0.075mm (No.200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
b) Characteristics of fraction passing No. 40											
i. Liquid limit	6 max		N.P.	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
ii. Plasticity Index				10 max	10 max	11 min	11 max	10 max	10 max	11 min	11 min
c) Usual types of significant constituent materials	Stone fragments-gravel and sand		Fine Sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
d) General rating as subgrade	Excellent to good					Fair to poor					

*If plasticity index is equal to or less than (liquid limit -30), the soil is A7-5 (i.e. PL>30%) If plasticity index is greater than (liquid limit -30), the soil is A7-6 (i.e. PL<30%)

II. Unified Soil Classification System

Table 2. 5 Unified Soil Classification system

Major Division			G/S	Type Names
Coarse grained soils. [more than 50% retained on No. 200 sieve /0.075mm]	Gravel [50% or more of coarse fraction retained on No.4 sieve(4.75mm)]	Clean gravels	GW	Well graded gravels
			GP	Poorly graded gravels
		Gravels with fines	GM	Silty gravels
			GC	Clayey gravels
	Sand [More than 50% coarse fraction passing on No.4 Sieve (4.75mm)]	Clean Sands	SW	Well graded Sands
			SP	Poorly graded Sands
		Sands with Fines	SM	Silty Sands
			SC	Clayey Sands
Fine grained soils. [50% or more passing No.200 (0.075mm)]	Silts and clays liquid limit 50% or less		ML	Inorganic silts of low plasticity
			CL	Inorganic clays of low to medium plasticity
			OL	organic silts of low plasticity
	Silts and clays liquid limit greater than 50%		MH	Inorganic silts of high plasticity
			CH	Inorganic clays of high plasticity
			OH	organic clays of medium of high plasticity
Highly Organic Soils			Pt	Peat ,Muck and other highly organic soils

Table 2. 6 Symbols used in USC system

	Symbol	Description
Primary	G	Gravel
	S	Sand
	M	Silt
	C	Clay
	O	Organic
	Pt.	Peat
Secondary	W	Well graded
	P	Poorly graded
	M	Non plastic fines
	C	Plastic fines
	L	Low plasticity
	H	High plasticity

2.6. 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 theme of this topic is to discuss different ways that are commonly used to identify expansive soils.

2.6.1. 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 usually have a color of black or grey, wide or deep shrinkage cracks, high dry strength and low wet strength, stickiness and low traffic ability when wet, cut surfaces have a shiny appearance, and appearance of cracks in nearby structures [16] [15]. Arid and semiarid areas are particular trouble spots because of large variations in rainfall and temperature.

2.6.2. Laboratory Identification

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

2.6.2.1. Indirect Methods

In this method simple soil property tests can be used for the evaluation of swelling potential of expansive soils. Such tests are easy to perform and should be included as routine tests in the investigation of expansive soils. Such tests may include [16] [15].

I. Atterberg Limits

In this method, measurement of the Atterberg limits of the soil are conducted for identification of all soils and provide a wide acceptable means of rating. Liquid limit less than 35% indicates low plasticity, between 35% and 50% intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity [17]. 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 2.7 below.

Table 2. 7 Relation between the swelling potential of clays and the plasticity index [17].

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

While it may be true that high swelling soil will manifest high index property, the converse is not true [16].

II. Free Swell Test

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 percent. 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 percentage can be computed using Equation (2.1) from the relationship between initial and swelled volume [16] [15].

$$\text{Free swell (\%)} = \frac{V_f - V_i}{V_i} \tag{2.1}$$

Where; V_i=Initial Volume, V_f= 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 (2.2) [18].

$$\text{Free Swell Index (\%)} = \frac{V_w - V_k}{V_k} * 100 \qquad (2.2)$$

Where; V_w = Final Volume in Water, V_k = Final Volume in Kerosene

The relation between the degree of expansion and differential free swell index is as shown table 2.6. It is normal to quantify 10cc as the volume occupied by 10g of soil. This does not account for variations of density [18]

Table 2. 8 Degree of expansion and differential free swell index [18].

Free Swell Index (%)	Degree of Expansion
Less than 20	Low
20 to 35	Moderate
35 to 50	High
Greater than 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 10cm^3 oven dried soil passing through 425µm sieve in distilled water to that of Kerosene Equation (2.3).

$$\text{Free Swell Index (\%)} = \frac{V_w}{V_k} \qquad (2.3)$$

Where; V_w = Final Volume in Water, V_k = Final Volume in Kerosene

The relation between the degree of expansion and differential free swell index is as shown Table 2.6.

2.6.2.2. Direct Methods

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

Table 2. 9 Classification of Soils based on free swell ratio [18].

Free Swell Ratio	Soil Expansivity	Clay
<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

2.7. Physical Properties of Expansive Soils

The most important physical properties of expansive soils are [16]: Index properties, moisture content, dry density and Fatigue of Swelling.

2.7.1. Index Properties

The simplified classification of expansive properties can be conventionally used by Engineers as a guide for the choice of structures on expansive soils. Some of the index properties to be identified and used are Soil Classification, Liquid Limit, Standard penetrations and the likes [16].

2.7.2. Moisture Content

If the moisture content of the clay remains unchanged, there will be no volume change irrespective of the high swelling potential. When the moisture content of the clay is changed volume expansion both in the vertical and horizontal direction will take place. Complete saturation is not necessary to accomplish swelling. Slight changes of moisture content in the magnitude of only 1 to 2 percent is sufficient to cause detrimental swelling. The initial moisture content of the expansive soils controls the amount of swelling. The relationship between the initial moisture content and the capability of swelling [16].

Very dry clays with natural moisture content below 15 percent usually indicate danger. Such expansive soils easily absorb moisture as high as 35 percent with a resultant damaging expansion to structures. Conversely clays with moisture contents above 30 percent indicate that most of the expansion has already taken place and further expansion will be small.

However moist clays may desiccate due to lowering of water table or other changes in physical condition and up on subsequent wetting will again exhibit swelling potential [16].

2.7.3. Dry Density

The dry density of the clay is another index property of the expansive soils. Generally exhibit high swelling potential. The dry density of the clays is also reflected by standard penetration resistance test results. Clays with penetration resistance in excess of 15 usually possess some swelling potential [16].

2.8. Soil Properties to Stabilize

Most of stabilization has to be undertaken in soft soils (silty, clayey peat or organic soils) in order to achieve desirable engineering properties. Fine grained granular materials are the easiest to stabilize due to their large surface area in relation to their particle diameter [19]. A clay soil compared to others has a large surface area due to flat and elongated particle shapes. On the other hand, silty materials can be sensitive to small change in moisture and, therefore, may prove difficult during stabilization [20].

2.9. Soil Stabilization

Soil stabilization is the alteration of one or more soil properties, by mechanical or chemical means to create an improved soil material possessing the desired engineering properties. The process may include blending of soil to achieve a desired gradation or mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil [21] [22]. Soils may be stabilized to increase strength and durability or to prevent erosion and dust generation. The various types of stabilization for the soil are Mechanical soil stabilization, Soil cement stabilization, Soil-lime stabilization, using inorganic admixture [11].

The researchers explores the Advantages of soil stabilization as follow**:** [23] Stabilized soil functions as a working platform for the project, Stabilization waterproofs the soil, Stabilization improves soil strength, Stabilization helps reduce soil volume change due to temperature or moisture, Stabilization improves soil workability, Stabilization reduces dust in work environment, Stabilization upgrades marginal materials, Stabilization improves durability, Stabilization dries wet soils, Stabilization conserves aggregate materials and Stabilization reduces cost.

2.10. Methods of Stabilization

2.10.1. 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. The main method of mechanical stabilization can be categorized in to compaction, mixing or blending of two or more gradation, applying geo-reinforcement and mechanical [24] [21].

2.10.2. Chemical Stabilization

Chemical stabilization involves mixing or injecting the soil with chemically active compounds such as Portland cement, lime, fly ash, calcium or sodium chloride or with viscoelastic materials such as bitumen. Chemical stabilizers can be broadly divided into three groups, Traditional stabilizers such as hydrated lime, Portland cement and Fly ash; Non-traditional stabilizers comprised of sulphated oils, ammonium chloride, enzymes, polymers, and potassium compounds; and by- product stabilizers which include cement kiln dust, lime kiln dust etc. Among these, the most widely used chemical additives are lime, Portland cement and fly ash. Although stabilization with fly ash may be more economical when compared to the other two, the composition of fly ash can be highly variable [7].

2.11. Waste Bricks as Stabilizer for Weak Subgrade Soil

2.11.1. Bricks

Bricks are a widely used construction and building material around the world. Conventional bricks are produced from clay with high temperature kiln firing or from ordinary Portland cement (OPC) concrete, and thus contain high embodied energy and have large carbon footprint. In many areas of the world, there is already a shortage of natural source material for production of the conventional bricks [25].

Brick is one of the most common building materials, and it is also one of the largest components of waste generated from both construction and demolition. Reuse of this waste would reduce the environmental and social impacts of construction. One potential bulk use of such waste is as a cementing agent for soil stabilization [26].

2.11.2. Effects of Waste Bricks on Strength

By supplanting soil by almost 35% of brick dust and 5% of lime of its dry weight it gives most extreme change in the building properties of expansive soil. So utilization of brick dust and lime is best for stabilization since it gives positive outcomes as stabilizer and furthermore it is a waste usage. The ideal estimation of most extreme dry thickness and the unconfined compressive strength increases excessively with increasing amount of brick dust and lime up to 6% lime and 25 % brick. The CBR value increases up to 1000%with the use of brick dust and lime. It was discovered that there is a most extreme change in quality properties for the blend of lime and brick dust when contrasted with lime/brick dust exclusively. This to discover an application for mechanical waste to enhance the properties of expansive soil both in dikes and pavement constructions. So the ideal rates of lime and block tidy were seen at 6% lime and 25% brick dust for enhancing the properties of expansive soil. Brick dust and lime has great potential for use in geotechnical use of soils is a demonstrated strategy to spare time and cash on development ventures. Lime modification synthetically changes mud soils into friable, workable, compactable material. Brick dust and lime adjustment makes expansive soil more stable and increases its engineering properties, their impact on it is positive and they should be used as stabilizers as brick dust is a waste and it can be used preferably to increase properties of black cotton soil [8].

According to the researcher justified when 40% of demolished bricks waste is added to in expansive soils it is increases the dry density of the stabilized soils and the optimum moisture content value showed a decreasing trend for the soil stabilized with DBW as the DBW content is increased [5].

2.11.2.1. Effects of Brick on Specific Gravity and CBR Value

As the researcher states depending on laboratory results; the addition of 0.2%, 0.3%, 0.4%, 0.5% of Polypropylene fiber and 20%, 25%, 30%, 35% Brick powder increases the Specific Gravity and also he identified the CBR value is 8%, by stabilizing with polypropylene fibers and brick powder (demolition brick masonry waste) [27].

2.11.3. Effects of Brick on Liquid and Plastic Limit

As the researcher says [28] Liquid limit tests have been conducted for various trial proportions of clay and BKD and optimum quantity of BKD to be mixed with clay is found out such that liquid limit of the mix is not more than 30%.

Liquid limit and plastic limit tests have been conducted for various trial proportions of red soil and BKD and optimum quantity of BKD to be mixed with red soil is found out such that plasticity index of the mix is not more than 6%.

The results of the experimental research show that brick kiln dust can effectively be used as a soil stabilizer for both subgrade and sub base layers as the CBR value of both is increased. A considerable amount of cost savings is also possible when the expansive clay soil is stabilized with BKD [28].

The main findings of the researchers [29] the suitability of the Brick Kiln Waste (BKW) as a stabilizer for clayey soils is examined as follow: With addition of the BKW, the clayey soil became more coarse and appropriate as a partial fill material for highways and foundations of buildings, The dry density of the blended soil slightly reduced by 3% and 7% respectively when the BKW added was 20% and 40%, Values of cohesion and friction angle of the clayey soil were reduced and increased respectively by 40% and 39% when the BKW added was 40%, In comparison to clayey soil, ultimate bearing capacity of the blended soils increased by 21% when the BKW mixed was 40% and The results presented in this study suggest that the BKW could be utilized as a stabilizer in clayey soils to be used in highway embankments and foundations of buildings.

2.12. Gypsum as Stabilizer for Weak Sub-Grade Soils

2.12.1. Gypsum

Gypsum is source of calcium which is major mechanism that binds soil organic matter to clay in soil which stability to the soil aggregates. Gypsum complements or even magnifies the beneficial effects of water soluble polymers used as amendments to improve soil structure. Gypsum is a soft white mineral consisting of hydrated calcium sulfate. The chemical formula is calcium sulfate dehydrate ($CaSO4.\ 2(H2O)$). Gypsum has better properties than organic additives because it does not cause air pollution, relatively cheap, fire resistant, and resistant to deterioration by biological factors and chemicals [30].

According to the researchers explore [31] it is the mineral calcium sulphate with two water molecules attached. By weight it is 79% calcium sulphate and 21% water. Gypsum has 23% calcium and 18% sulphur and its solubility is 150 times that of limestone, hence it is a natural source of plant nutrients. Gypsum naturally occurs in sedimentary deposits from ancient sea beds. Gypsum is mined and made into many products like drywall used in construction, agriculture and industry. It is also a by-product of many industrial processes. In a soil to which gypsum, calcium carbonate or cement was added, the content of dispersible clay was related to both exchangeable sodium percentage (ESP) and electrical conductivity (EC). The electrolyte concentration in the soil which could be maintained by addition of calcium carbonate was such that an ESP of >3 was required to maintain clay coagulation. Small amounts of gypsum (0.2%) coagulated most of the clay by lowering the ESP and raising the electrolyte concentration. However, the clay gradually dispersed as the soil was subjected to wetting and drying cycles and the electrolyte concentration was decreased. The most efficient use of gypsum would appear to be as small annual additions. The addition of cement resulted in the stabilization of particles 250-2000μm diameter, i.e. cementation as opposed to coagulation. Both processes resulted in changes to various physical properties and mechanical properties of the soil. It is suggested that both coagulation and cementation in a soil may be achieved by the addition of gypsum and cement or lime, with significant improvements of soil structure.

2.12.2. Effects of Gypsum on Strength

As the researchers says that at low gypsum contents (i.e., gypsum content ranging from zero to about 30% by weight) there was a slight increase in the maximum dry density associated with a slight decrease in the optimum water content when gypsum content increased up to 15% [32].

Researchers conclude that depending on experimental result [33] by mixing the expansive soil with different percentages of gypsum (2%, 4%, 6%, and 8%) and curing for seven days the results obtained, the optimum moisture content (OMC) and maximum dry density (MDD) at 4% gypsum is 11.76% and 19.16KN/m^3 and The swelling of soil reduced from 47% to 4.16% and CBR Value increases from 2.73% to 7.57%.

According to the researchers [7] they conclude based on laboratory test result the effect of gypsum and NaCl on weak sub grade soils: The liquid limit, plastic limit and plasticity index decreased as the chemicals (NaCl &gypsum) Content increased, The additions of chemicals (NaCl & Gypsum) to the soil increase the maximum dry density and reduce the optimum moisture content, The addition of sodium chloride and gypsum as stabilizing agents produces a marked increase in CBR value.

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1. General Description of the Sampling Area

The place of sample was Mettu town, located in the Illubabor Zone of Oromia Region and 600Km far from Addis Ababa, the capital city of Ethiopia. This location was found between latitude and longitude of 8°17'04''N 35°36'17''E and 8°19'39''N 35°32'09''E and the altitude of the center of the town was 1605m. Mettu is the capital town of Illubabor Zone.

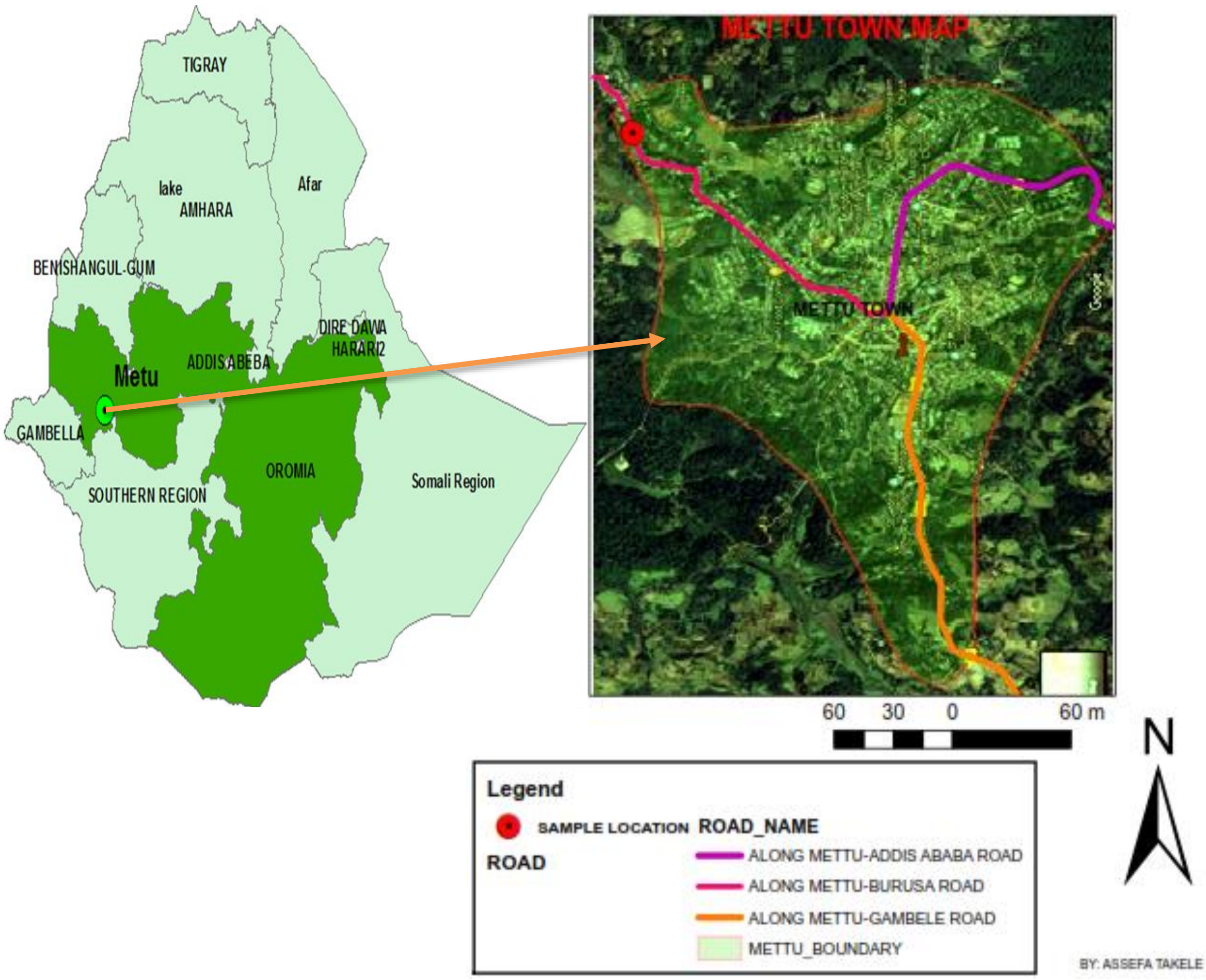


Figure 3. 1 Location of sample (Source (GIS and https://www.google.com/maps/search/Mettu/))

3.1.1. Identification of Soil in the Sample Area

Site visiting is the first and foremost for investigation of soil natures. Site visit was made to the places to get information about the texture of soils around the vicinity area.

Furthermore, consulting with the town municipality administrative body and other concerned people were also arranged to collect information about the geology, soil texture and other historical futures of the town. After observation of the soil type in the whole around Mettu town, weak (expansive) soil was located along Mettu-Burusa road.

3.1.2. Climate

Mettu is generally characterized by warm climate with a mean annual maximum temperature of 30^{o}c and a mean annual minimum temperature of 10^{o}c. The annual rainfall ranges from 1138 to 1690 mm and the soil type is well drained clay loam to silty clay. Maximum precipitationoccurs during the three months period, June to August, with minimum rainfall in December and January. (Central Statistical Office, Statistical Abstract (1963 and 1965).

3.2. Study Design

The research study was conducted by using both experimental and analytical methods. Qualitative and quantitative studies were employed in this study area. Qualitative study gives impression on the findings where a quantitative study was used to describe the numerical aspects of the research findings, based from laboratory results. The overall research design have shown in Figure 3.2.

3.3. Study Procedure

The procedure utilized throughout the conduct of this research study was as follows: Continuous Reviewed related literatures on methods of stabilization, types of stabilizers and properties of Gypsum and Brick includes articles, reference books, research papers, laboratory test and standards specifications like ERA, AASHTO and ASTM. Necessary data collection, organization, comparison and analysis were obtained, and then subsequently compared the laboratory test results with preexisting literature and standard specifications. A conclusion and recommendation are drawn based on the results.

3.4. Study Variables

There are two type of variables that have been taken into consideration. The dependent variables for this research is the strength of gypsum and crushed waste brick mix stabilized subgrade soil whereas the independent is the physical & Engineering properties of untreated and treated weak subgrade Soil and Dosage of Gypsum-Brick waste.

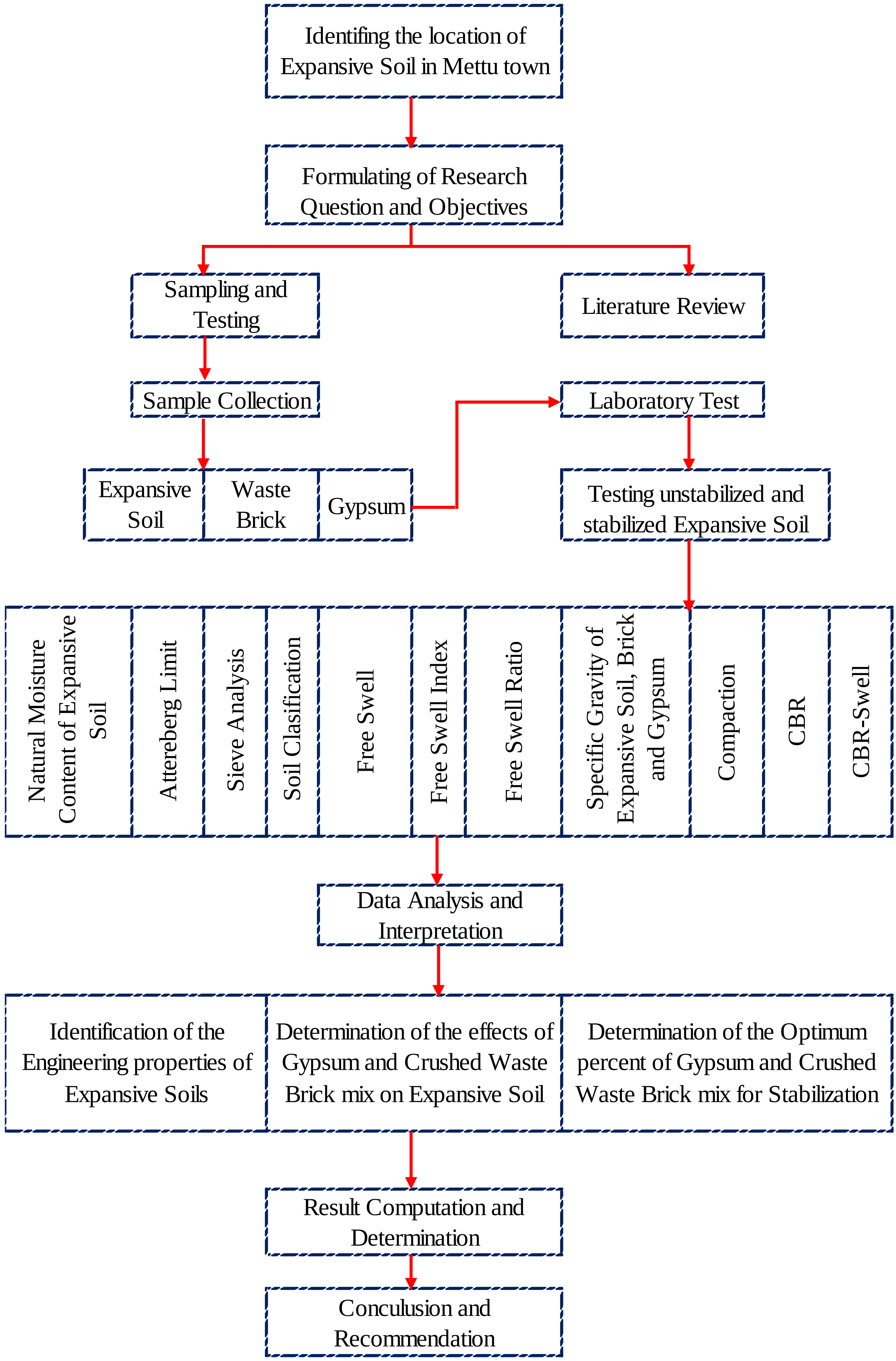


Figure 3. 2 Research Design

3.5. Data and Sample Collection Process

Before starting any data collection formal letter was obtained from JIT. Data collection process included:

- ✓ Field visual inspection, field investigation,
- ✓ After finished the initial visual inspection and categorized the soil conditions of the area and then selected the representative locations for sampling based on the availability of expansive soil.
- ✓ Disturbed soil sample was excavated from test pit up to a maximum depth of 1.5m in order to avoid the inclusion of organic matter. The test pit is shown in Figure 3.3. The soil sample collected along Mettu-Burusa was black cotton soil and selected for laboratory test due to its expansiveness.
- ✓ Finally the results from laboratory test were analyzed with standard specifications.

Figure 3. 3 Photo of Expansive Soil Observed and Sampled along Mettu-Burusa road **(5:10AM, July22/2019**)

3.6. Sample Preparation

About 150 Kg weak sub grade soil/expansive soil sample was brought from sample area to Jimma Institute of Technology University highway engineering soil lab. The gypsum used in this study was purchased from the open market from authorized dealers in Jimma. Waste Brick was collocated from Jimma town.

The weak subgrade soil were mixed with the crushed brick and gypsum by percentage of the weight of soil taken for each samples tests starting from 0 to 40% within 10% difference and 0 to 8% within 2% difference respectively. That means a total of five samples of weak subgrade soil with and without stabilizer were subjected to Atterberg limit, Sieve analysis, Free swell, Free Swell Index, Free Swell Ratio, Specific gravity, Compaction, CBR and CBR-Swell tests.

Table 3. 1 Mix Proportion of Materials

No.	Materials		
	Weak Subgrade Soil (WSS, %)	Crushed Waste Brick (CWB, %)	Gypsum (G, %)
1	100	0	0
2	88	10	2
3	76	20	4
4	64	30	6
5	52	40	8

3.7. Laboratory Tests

For the selected samples the laboratory tests were conducted:

- ❖ Natural moisture content (AAHSTO T93-86),
- ❖ Sieve analysis (AASHTO T-146),
- ❖ Specific gravity (ASTM D 854, 92 or AASHTO T100-93),
- ❖ Atterberg limit (AASHTO T-89 and T-80),
- ❖ Compaction test (AASHTO T-180) and
- ❖ California Bearing Ratio test (AASHTO T-193).

3.7.1. Natural Moisture Content

This test is one of the most significant index properties used in establishing a correlation between soil behavior and its index properties. The water content of a material is used in expressing the phase relation of air, water, and solids in a given volume of material. From the sampling site, moist soil samples were collected using plastic bags. The plastic bags were tied to reduce loss of natural moisture content.

According to AASHTO T93-86 Oven-drying method was used to determine the moisture contents of the samples. The oven-drying method, small, representative specimens obtained from large bulk samples were weighed as received, then oven-dried at 105°C for 24 hours. The sample was then reweighted, and the difference in weight was assumed to be the weight of the water driven off during drying. The difference in weight was dividing by the weight of the dry soil, giving the water content on a dry weight basis. For more laboratory test result information see Appendix-I.

3.7.2. Particle Size Distribution

Grain size analysis is an attempt to determine the relative properties of different grain sizes which make up a soil mass.

The test includes the determination of the particle size distribution for the natural soil. The tests are conducted in accordance with AASHTO T88-93 testing procedures. Approximately, 50gm of dry soil passing No. 200 sieve is performed a hydrometer analysis to measure the amount of silt and clay size particles.

The sample is then washed through a series of sieves with progressively smaller screen sizes to determine the percentage of sand-sized particles in the specimens. To do this analysis, a wet preparation method is performed which is given in AASHTO T-146. First 1kg of dried soil was washed on 0.075mm opening sieve size, then the washed soil oven-dried retained on 0.075mm sieve size. The dried sample is shaken manually and the weight of material retained on each sieve is determined and expressed as a percentage of the original sample. Detailed procedures for performing a grain size analysis of coarse and fine materials are given in AASHTO Method T-27 [34].

Figure 3. 4 The process of shaking the soil manually **(9:25PM, August 21/2019)**

3.7.3. Atterberg Limit Test

The test includes the determination of the liquid limits, plastic limits and the plasticity index for the Expansive soil and the mixture of soil with Gypsum and Crushed Waste Brick. The tests are conducted in accordance with AASHTO T89-90 or ASTM D 4318 testing procedures.

3.7.3.1. Liquid Limit

The soil sample for liquid limit is air dried and 200g of the material passing through No. 40 sieve (425μm aperture) was obtained and thoroughly mixed with water to form a homogeneous paste on a flat glass plate. A portion of the soil water mixture is then placed in the cup of the Casagrande apparatus, leveled off parallel to the base and divided by drawing the grooving tool along the diameter through the centre of the hinge. The cup is then lifted up and dropped by turning the crank until the two parts of the soil come into contact at the bottom of the groove. The number of blows at which that occurred was recorded and a little quantity of the soil was taken and its moisture content determined. The test is performed for well–spaced out moisture content from the drier to the wetter states. The values of the moisture content (determined) and the corresponding number of blows is then plotted on graph and the liquid limit is determined as the moisture content corresponding to 25 blows. The same procedure is also carried out for the treated soil with increment of Gypsum and Crushed Waste Brick mix content.

3.7.3.2. Plastic Limit

A portion of the Expansive soil and the mixture of soil with Gypsum and Crushed Waste Brick used for the liquid limit test is retained for the determination of plastic limit.

The ball of the Expansive soil is moulded between the fingers and rolled between the palms of the hand until it dried sufficiently, even though the soil is already relatively drier than the ones used for liquid limit. The sample is then divided into approximately two equal parts. Each of the parts is rolled into a thread between the first finger and the thumb. The thread is then rolled between the tip of the fingers of one hand and the glass. This continued until the diameter of the thread is reduced to about 3mm. The movement continued until the thread shears both longitudinally and transversely. The crumbled Expansive soil is then put in the moisture container and the moisture content determined. The same procedure is also carried out for the treated soil with increment of Gypsum and Crushed Waste Brick content.

3.7.3.3. Plasticity Index

The plasticity index of the Expansive soil and the mixture of soil with Gypsum and Crushed Waste Brick is the difference between the liquid limits and their corresponding plastic limits. The plasticity indexes of the samples are calculated using Equation (3.1).

$$PI = LL - PL \tag{3.1}$$

Figure 3. 5 The process of determining Atterberg limit **(10:30PM, August 29/2019)**

3.7.4. Soil Classification

The soil is classified using the AASHTO soil classification system. Using the particle size distribution and the Atterberg limits, AASHTO designates a group name for each soil. A visual-manual procedure can also be used to identify soils easily in the field; however, all classifications provided in this research are based on the laboratory testing procedure.

3.7.5. Free Swell Test

The test includes the determination of the free swell for the Expansive soil and the mixture of soil with Gypsum and Crushed Waste Brick. This test has not yet been standardized by AASHTO and ASTM. The method was suggested by Nelson and Miller, (1992) to measure the expansive potential of cohesive soils. The free swell test gives a fair approximation of the degree of expansiveness of the soil sample. The procedure consists of pouring very slowly of 10 cubic centimeters of that part of the dry soil passing No. 40 sieve in to a 100 cubic centimeters graduated measuring cylinder and letting the content stand for approximately 24 hours until all the soil completely settles on the bottom of the graduating cylinder. Then the final volume of the soil is noted. Finally, free swell value is calculated using Equation (2.1).

3.7.6. Free Swell Index Test

The test includes the determination of the free swell index of the Expansive soil and the mixture of soil with Gypsum and Crushed Waste Brick. The tests are conducted in accordance with IS: 2720 (Part 40) 1977testing procedure.

Two samples of oven dried soil 10cc each, passing through 425 micron sieve are taken. One is put in a 100cubic centimeters graduated glass cylinder containing kerosene. The other sample is put in a similar cylinder containing distilled water. Both the samples are left undisturbed for 24 hours and then their volumes are noted. Then free swell index is determined using Equation (2.2). The same procedure is also carried out for the treated soil with increment of Gypsum and Crushed Waste Brick mix content.

Figure 3. 6 The process of testing free swell **(2:00AM, August 29/2019)**

3.7.7. Free Swell Ratio Test

In this study, recommended procedure of Sridharan and Prakash is adopted.10gm oven dried soil passing through 425 micron is added to 100ml of distilled water in a jar and another 10gm of same sample is added to 100ml of Kerosene. After 24hours, sediment volumes of samples are measured to determine free swell ratio. Free swell ratio is the ratio of change in volume in water to change in volume in kerosene after 24 hours. Then free swell ratio is determined using Equation (2.3). The same procedure is also carried out for the treated soil with increment of Gypsum and Crushed Waste Brick mix content.

3.7.8. Specific Gravity

The specific gravity of solid matter in a material particle may be defined as the ratio of the unit weight of solid matter to the unit weight of water and which is the measure of the heaviness of the soil particles are determined by the method of pychnometer method using a soil sample passing No. 10 sieve and oven dried at105 degree centigrade. The test includes the determination of the specific gravity for the Expansive soil and the mixture of soil with Gypsum and Crushed waste Brick. The test is conducted in accordance with AASHTO T100-93 testing procedure. The value of specific gravity calculated using Equation (3.2).

$$G_S = \frac{\Sigma[^{A*K}/_{(A+B)-C}]}{n} \qquad (3.2)$$

Where:

Gs = Specific gravity at 20°C

A = Mas of oven dry sample

B = Mas of pynometer + water

C = Mas of pynometer + water + sample

K = Temperature change factor to 20^{o}C

n = Number of trial

Figure 3. 7 The process of determining specific gravity **(11:30PM, August 29/2019)**

3.7.9. Moisture - Density Relationship

The purpose of a laboratory compaction test is to determine the proper amount of mixing water to use when compacting the soil in the field and the resulting degree of denseness can be expected from compaction at this optimum water content.

This laboratory test was performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort. The overall objective of this test was to obtain the moisture content –dry density relationship for a different soils type by adding different Gypsum and Crushed waste Bricks contents and hence to determine the optimum moisture content and maximum dry density.

According to AASHTO T-180 laboratory modified proctor compaction test was used to determine the maximum dry density and optimum moisture content of soil under investigation. 4000g of air dried expansive soils with stabilizer material samples were prepared by measuring their proportion and made to pass through 19mm sieve size. The soil samples with crushed waste brick and gypsum material mixed with water. The samples are compacted in five layers in a 101.6mm diameter steel mold with a Rammer of 5 kg weight falling freely from a height of 450mm manually. Each layer was compacted 25 blows.

Figure 3. 8 The process of compaction **(4:00AM, August 21/2019)**

The bulk density is then calculated for each compacted specimen using the following Equation (3.3).

$$\text{Bulk Density } {}^{gm}/_{cm^3} = \frac{\text{Mass of Wet Soil(gm)}}{\text{Volume of Mold (cm}^3)} \qquad (3.3)$$

The moisture content is calculated for each compacted specimen using the following Equation (3.4).

$$\text{Moisture content (\%)} = \frac{\text{Mass of moisture(gm)}}{\text{Mass of Dry soil(gm)}} * 100 \qquad (3.4)$$

The dry density is calculated for each compacted specimen using the following Equation (3.5).

$$\text{Dry Density } {}^{gm}/_{cm^3} = \frac{\text{Bulk Density } {}^{gm}/_{cm^3}}{\text{(100+Moisture content (\%))}} * 100 \qquad (3.5)$$

Finally the values of the moisture content (determined) and the corresponding dry density is then plotted on graph and the optimum moisture content with corresponding to maximum dry density is determined as deduced the maximum point on the resulting curves.

3.7.10. California Bearing Ratio (CBR)

According to AASHTO T-193, the method uses soil particles that pass 19 mm size and provides after the determination of the optimum moisture content (OMC) and natural moisture content, calculate the amount of water for each CBR test. 4000 grams of air dried samples were prepared to pass through 19mm sieve for different proportion of the mix of Gypsum and Crushed waste Bricks 2, 4, 6, 8 and 10, 20, 30, 40 percentage respectively with expansive soil. The soil samples mixed with gypsum-crushed waste brick stabilizing agent material and optimum water. Five different samples were compacted in five layers of three point CBR tests at 10 blows, 30 blows, and 65 blows. The specimen shall be soaked prior to penetration. A surcharge is placed on the surface to represent the mass of pavement material above sub-grade. The sample is soaked for 4 days to simulate its weakest condition in the field Expansion of the sample is measured during soaking to check for potential swelling. The principle to find CBR is to determine the relation between force and penetration when a computerized cylindrical plunger with a standard cross-section area is made to penetrate the soil at a given rate. At certain values of penetration the ratio of the applied force to a standard force, expressed as a percentage, is defined as the California Bearing Ratio (CBR). The Californian Bearing Ratio (CBR) shall be determined at 95% of compaction or maximum dry density.

Figure 3. 9 determination of CBR value and CBR-Swell **(2:30AM, August 28/2019)**

The CBR value is calculated for each compacted specimen using the following Equation (3.6).

$$\text{CBR Value } (\%) = \frac{\text{Penetration Load(KN)}}{\text{Standared Load(KN)}} * 100 \qquad (3.6)$$

The % of compaction is calculated for each compacted specimen using the following Equation (3.7).

$$\% \text{ of Compaction} = \frac{\text{Modified Max.Dry Density,gm/cm}^3}{\text{Dry density before soak,gm/cm}^3} * 100 \qquad (3.7)$$

The dry density at 95% of MDD is calculated for each compacted specimen using the following Equation (3.8).

$$\text{Dry Density at 95\% of MDD}, \frac{\text{gm}}{\text{cm}^3} = \text{Modified Max. Dry Density}, \frac{\text{gm}}{\text{cm}^3} * 0.95 \qquad (3.8)$$

3.7.11. CBR-Swell Test

The mixtures of expansive soil with gypsum and waste brick 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. At the end of 4 days make a final dial reading on the soaked specimens and calculate the swell as a percentage of the initial sample length using the following Equation (3.9).

$$Percent\ swell(\%) = \frac{Change\ in\ length\ in\ mm\ during\ soaking}{Original\ sample\ length(mm)} * 100 \tag{3.9}$$

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Introduction

This chapter presents the results of laboratory tests and a discussion pertinent to the results. The relevant engineering property of the soil is evaluated both for natural and stabilized soil samples separately. The tests include Natural Moisture Content, Sieve Analysis, Specific Gravity, Atterberg Limits, Free Swell, Free Swell Index, Free Swell Ratio, Compaction and California Bearing Ratio (CBR) and CBR-Swell.

4.2. Engineering Properties of Natural Soil

The results of the tests conducted for identification and/or determination of properties of the natural soil before applying gypsum and crushed waste brick are discussed as follow.

4.2.1. Grain Size Analysis

This test was performed to determine the percentage of different grain sizes enclosed within a soil. 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 according to *ASTM 152-H*. Finally the analysis was combined and the particle size distribution curve was plotted as Figure 4.1.

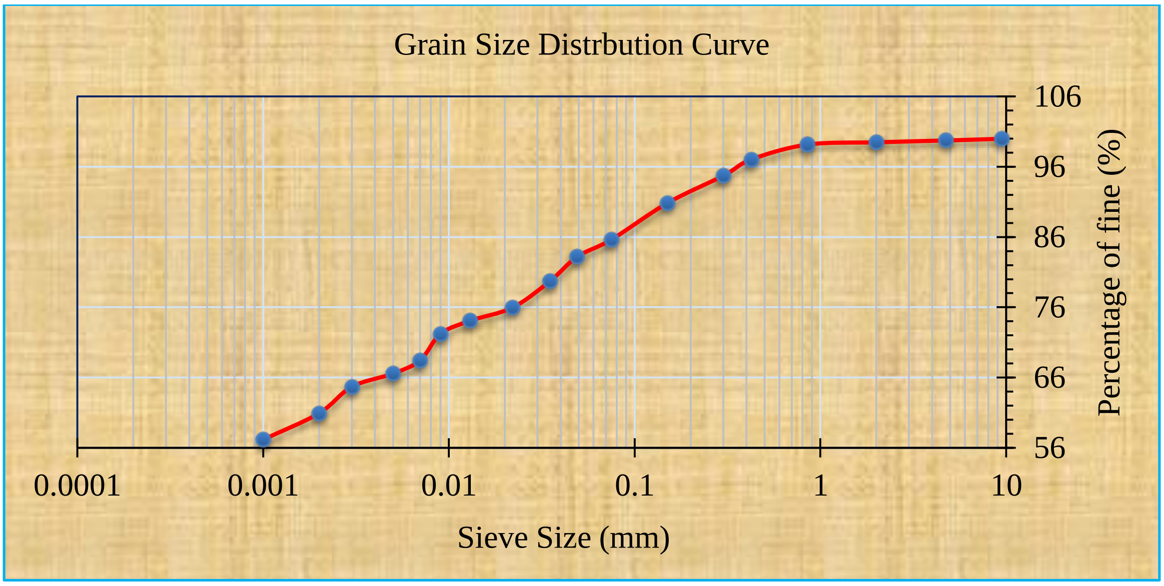


Figure 4. 1 Particle size distribution curve of the expansive soil

The result from the test is used to determine the particle size distribution with applicable specification requirement and it also helps to determine the soil class together with the Atterberg limits. As shown in Figure 4.1 on the particle size distribution curve almost 85.650% of the soil is passing through No. 200 sieve size and 60.920% was silty soil and 57.160% was clay soil. The laboratory data analysis is attached in Appendix-I.

4.2.2. Atterberg Limit Test

The Liquid Limit and Plastic Limits of soil indicate the water contents a certain changes in the physical behavior of soil that was being observed. Figure 4.2 show relationship between number of blow and water content for determinations of liquid limit. The laboratory data analysis is attached in Appendix-II.

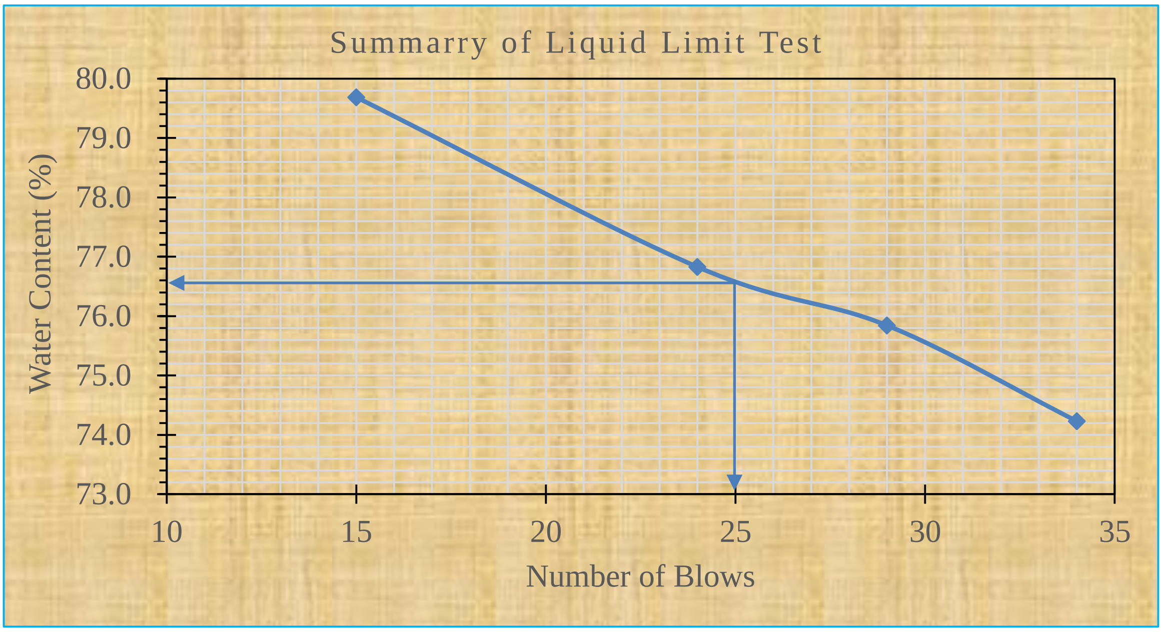


Figure 4. 2 Determination of Liquid Limit of expansive soils

Table 4. 1 Atterberg Limit test result for natural soil

Atterberg Limit's	Percentage, (%)
Liquid Limit, LL	76.500
Plastic Limit, PL	40.000
Plastic Index, PI	36.500

According to Table 2.6 depending on the result of Plastic index the natural soil is highly plastic clay [17].

4.2.3. Soil Classification

After the completion of the Atterberg Limit Test and the sieve analysis, the soil samples were classified according to AASHTO and USCS. Depending on percentage passing 75µm obtained from sieve analysis and liquid limit, plastic limit and plasticity index obtained from Atterberg Limit test the natural soil sample was classified according to AASHTO and USCS soil classification. According to Table 2.4 AASHTO soil classification system, the soil grouped under the A-7-5 soil class and also according to Table 2.5 USCS natural soil classification the soil is classified under MH, CH and OH.

Soils under this class are generally classified as a material of poor engineering property to be used as a sub-grade material and also the group index of natural soil was 38 greater than 20, therefore the soil was very poor subgrade material [35].

4.2.4. Specific Gravity Test

This is the measure of the density of a soil relative to that of water. Based on test result specific gravity at 20^{o}C of natural soil was 2.650. The summary of the test result is tabulated while the laboratory test analysis and plots are given in Appendix-I.

4.2.5. Free Swell, Free Swell Index and Free Swell Ratio

Free swell test result indicate the potential expansiveness of soil sample without being loaded. Free swell index is also one of the most commonly used simple tests to estimate the swelling potential of expansive clay and free swell ratio is determine the swell property.

Table 4. 2 Swell Properties of Natural soil

Swell Properties of Natural soil	Percentage	Description
Free Swell, %	82.000	
Free Swell Index, %	60.920	Greater than 50%, Degree of Expansion is very high
Free Swell Ratio	1.609	Between 1.5-2, Soil Expansivity is moderate

Depending on Table 4.2 results that are related to swelling characteristics of the soil are also indicate that the soil is highly expansive clay with a free swell of about 82%, free swell index of 60.920% and free swell ratio of 1.609. According to Table 2.7 free swell index greater than 50%, so the degree expansion of the soil is very high [18].

4.2.6. Compaction Test

Compaction test has been conducted for the natural soil under consideration to determine the maximum dry density and optimum moisture content of the soil. The value of laboratory data analysis is attached in Appendix-II.

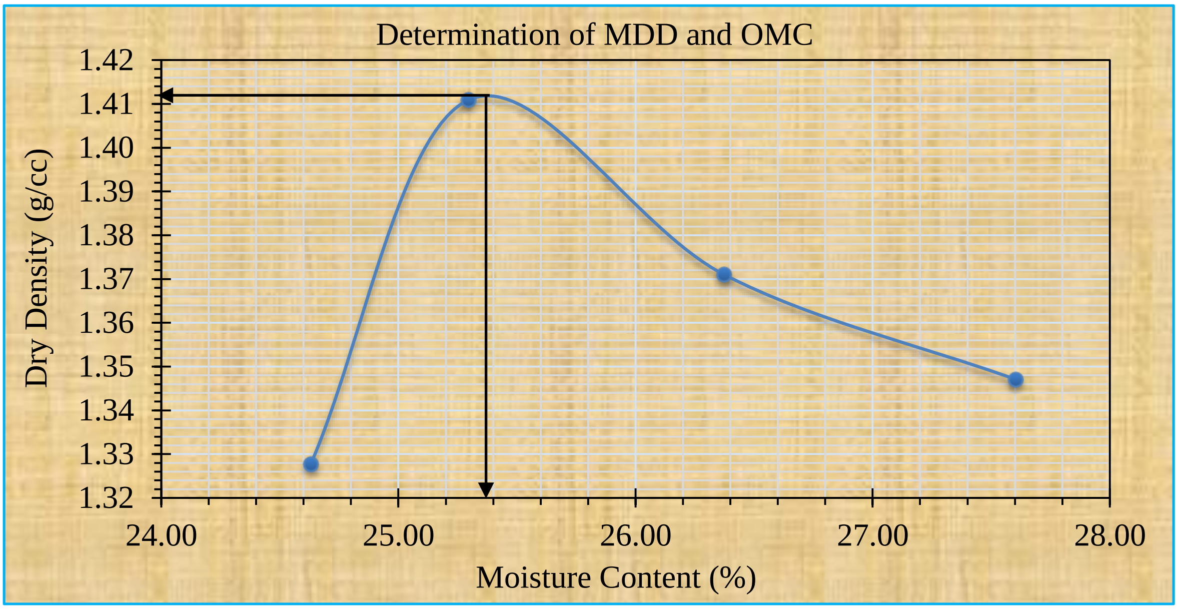


Figure 4. 3 Density-Moisture Content Relationship for natural Soil

From Figure 4.3, the maximum value represents the optimum moisture content and maximum dry density. The purpose of drawing the compaction curves shown in figure is to show the peak Moisture-Density relationship and to extract MDD and OMC values from the curve. From Moisture-Density Content Relationship graph or compaction curve the optimum moisture content is 25.400% and the maximum dry density becomes 1.412g/cm^3.

4.2.7. California Bearing Ratio (CBR) Test

CBR test was done to determine the strength of a given material and how it was behave when subjected to loading. This had been determined by measuring the relationship between force and penetration when a cylindrical plunger is made to penetrate the soil at given rate. The OMC and MDD of the sample were used to prepare a specimen for CBR test after 4 days soaking to consider the unpredictable increase in moisture. The summary of the laboratory test analysis and plots are given in Appendix-II.

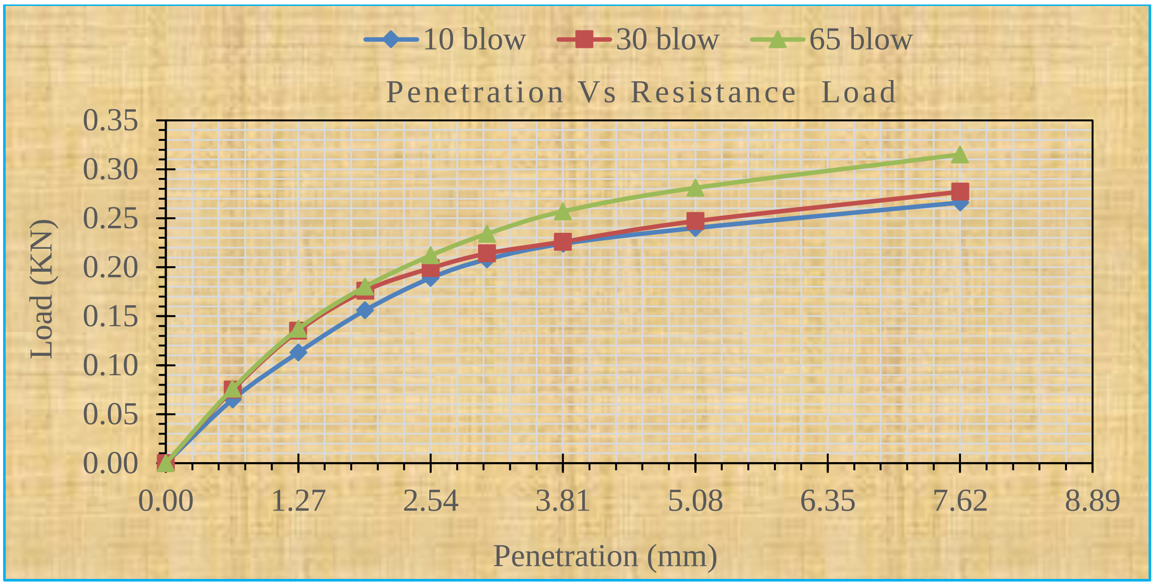


Figure 4. 4 Resistance Load Vs Penetration of Natural Soil

After the CBR specimen was weighed placed under the CBR machine the load required to cause the penetration is applied and plotted against measured penetration. The loads at 2.54mm and 5.08mm penetration are recorded.

Table 4. 3 CBR test results for natural Soil

Sample	CBR Value (%) at 2.54mm penetration depth			CBR Value (%) at 5.08mm penetration depth		
	Blow					
	10	30	65	10	30	65
Weak subgrade/Expansive soil	1.420	1.490	1.590	1.200	1.240	1.410

According to Table 4.3 the CBR value at 2.54mm penetration depth is greater than the CBR at 5.08mm penetration depth for 10, 30 and 65 blow. As the number of blow increases the CBR value increases. CBR value test result is less than 3%, this show that the material is not used for construction of Subgrade layer or it need treatment [36].

4.2.8. CBR Value of Natural Soil at 95% of Compaction

The CBR value of natural soil at 95% of compaction determined from the relation of corrected CBR and percent of compaction graph.

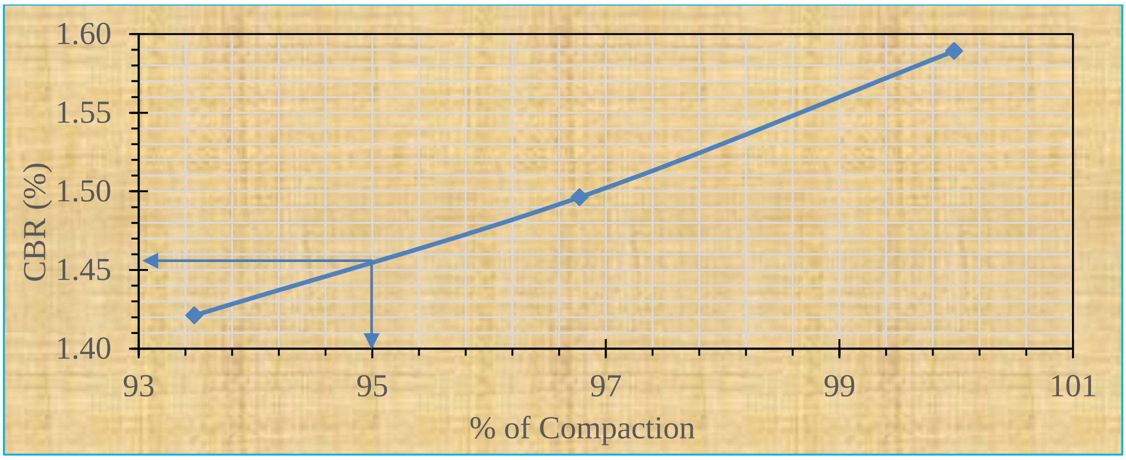


Figure 4. 5 The relation between CBR and percent of compaction of natural soil

According to Figure 4.5 the CBR value natural soil was 1.456%. Depending on Table 2.2 the quality of the soil was very poor subgrade material [10]. 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. Subgrade materials with CBR values less than 3% and swelling potential greater than 2% need to be treated with stabilizing agents or replaced [36]. Therefore, the soil requires initial modification and/or stabilization to improve its workability and engineering property.

Table 4. 4 Geotechnical properties of the natural soil

Property of Soil	Observed Value
Natural Moisture Content (NMC), %	30.560
Percentage Passing No. 200 Sieve, %	85.650
Silty,% (0.05mm-0.002mm)	60.920
Clay, % (<0.002mm)	57.160
Liquid Limit (LL), %	76.500
Plastic Limit (PL), %	40.000
Plastic Index (PI), %	36.500
Group Index (GI)	38.000
AASHTO soil classification	A-7-5
USCS group symbol	MH, CH and OH
Specific Gravity (Gs)	2.650
Free Swell (FS), %	82.000

Free Swell Index (FSI), %	60.920
Free Swell Ratio (FSR)	1.609
Maximum Dry Density (MDD), g/cm3	1.412
Optimum Moisture Content (OMC), %	25.400
Soaked CBR value, %	1.456
CBR-Swell, %	6.560
Color	Black

Hence, the soil was found to be highly plastic expansive clay with low bearing capacity when it is soaked and high swelling potential and fell below the standard recommendations for most geotechnical construction works especially highway construction.

4.3. Properties of Crushed Brick and Gypsum

Bricks are produced from clay with high temperature kiln firing or from ordinary Portland cement (OPC) concrete [25].

Gypsum is a soft white mineral consisting of hydrated calcium sulfate. The chemical formula is calcium sulfate dehydrate ($CaSO_4 . 2(H_2O)$). By weight it is 79% calcium sulphate and 21% water. Gypsum has 23% calcium and 18% sulphur [31].

Table 4. 5 Properties of Crushed Brick and Gypsum

Properties	Brick	Gypsum
Specific gravity at 20oc, Gs	2.010	2.380
Liquid Limit, LL (%)	40.250	N.L.
Plastic Limit, PL (%)	N.P.	N.P.
Plastic Index, PI (%)	-	-
Free swell, %	10.000	1.000

Depending on laboratory test Table 4.5 Specific gravity test result of gypsum was high relative to brick, but less relative to soil.

Figure 4. 6 Determination of Atterberg limit of Brick **(2:40AM, August 30/2019)**

4.4. Effect of the Mix of Gypsum and Crushed Waste Brick on Expansive Soil Engineering properties

4.4.1. The Effect of Gypsum and Crushed Waste Brick Mix on Atterberg Limit

Table 4. 6 Laboratory test results of Atterberg Limit

Natural Soils and Percent's of Stabilizer	LL (%)	PL (%)	PI (%)	The reduction of PI (%)
WSS+ 0% CWB + 0% G	76.500	40.000	36.500	-
WSS + 10% CWB + 2% G	74.400	38.800	35.620	2.410
WSS + 20% CWB + 4% G	60.220	34.480	25.740	27.740
WSS + 30% CWB + 6% G	40.000	30.970	9.030	64.920
WSS + 40% CWB + 8% G	39.800	N.P.	-	-

The highest reduction in plastic index occur when it was stabilized by the combination of 30% brick with 6% gypsum ratio and the minimum reduction occur when it was stabilized by the combination of 10% brick with 2% gypsum ratio.

In general from Table 4.6 for gypsum and crushed waste brick mix stabilization for expansive soil the following observation have been made.

- ❖ Liquid limit decreases with increasing the mix of gypsum and crushed waste brick ratio to the expansive soil. This is on the grounds that when gypsum synthetically consolidates with water, it can be utilized viably to dry wet soil.
- ❖ Plastic limit decreases with increasing the mix of gypsum and crushed waste brick ratio and plastic limit became undetermined as the stabilizer increased to 40% of crushed waste brick and 8% of gypsum to expansive soil. These effects are due to the partial replacement of plastic particles (expansive soil) with Crushed Waste

Brick and Gypsum which is non plastic materials and flocculation and agglomeration of clay particles caused by cation exchange may be the other cause.

- ❖ Plastic index decreases up to the mixture of expansive soils with mix of 30% brick and 6% gypsum.
- ❖ Changing stabilization ratio changes liquid limit, plastic limit and plastic index values of the expansive soil. Details of the Atterberg limit test results are shown in Appendix-II.

4.4.2. The Effect of Gypsum and Crushed Waste Brick Mix on Soil Classification

The most widely used soil classification systems are AASHTO systems. The AASHTO classification system classify soils into seven major groups from A-1 to A-7 with 12 subgroups. The system is based on particle size, liquid limit and plasticity index of the soil.

Table 4. 7 Soil Classification

Sample	Atterberg Limit			Soil Classification
	LL	PL	PI	AASHTO
Expansive soil	76.500	40.000	36.500	A-7-5
WSS+10%CWB+2%G	74.400	38.800	35.620	A-7-5
WSS+20%CWB+4%G	60.220	34.480	25.740	A-7-5
WSS+30%CWB+6%G	40.000	30.970	9.030	A-2-4
WSS+40%CWB+8%G	39.800	-	-	-

The soils classification according to AASHTO system plasticity chart is as follows.

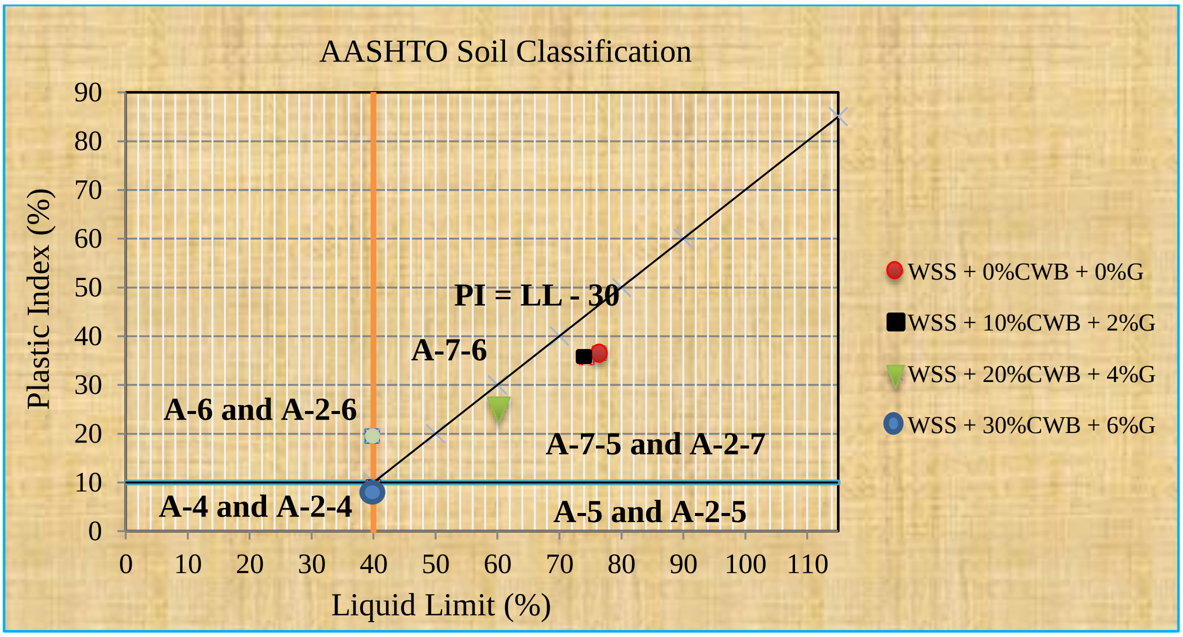


Figure 4. 7 Soil Classification based on Liquid Limit and Plastic Index

Depending on Table 2.4 AASHTO soil classification system the soil is improved from A-7-5 to A-2-4 the mixture of soil with stabilizer at the percentage of stabilization 30% crushed waste brick and 6% gypsum.

4.4.3. Effect of Gypsum and Crushed Waste Brick Mix on Swelling Characteristics

4.4.3.1. Free Swell

The effect of gypsum and crushed waste brick mix on the free swell of the expansive soil is shown in Figure 4.8. Details of the free swell test results are shown in Appendix-II.

According to results shown in figure, increasing the mix proportion of Gypsum and Crushed Waste Brick reduces the free swell of expansive soil to 18% from 82% when 40% crushed waste brick and 8% gypsum was added. This is due to crushed waste Brick a strong inter particle bond develops with gypsum and soil, this cementing bond offers great resistance to swelling and also does not allow the water to escape from soil to induce shrinkage. The highest reduction in free swell is attained when the expansive soil is treated with 30% of crushed waste brick and 6% of gypsum mix which is 58.850% reduction compared to untreated expansive soil.

Generally the result showed the combination of crushed waste brick and gypsum were effective to reduce the swelling potential of expansive soils.

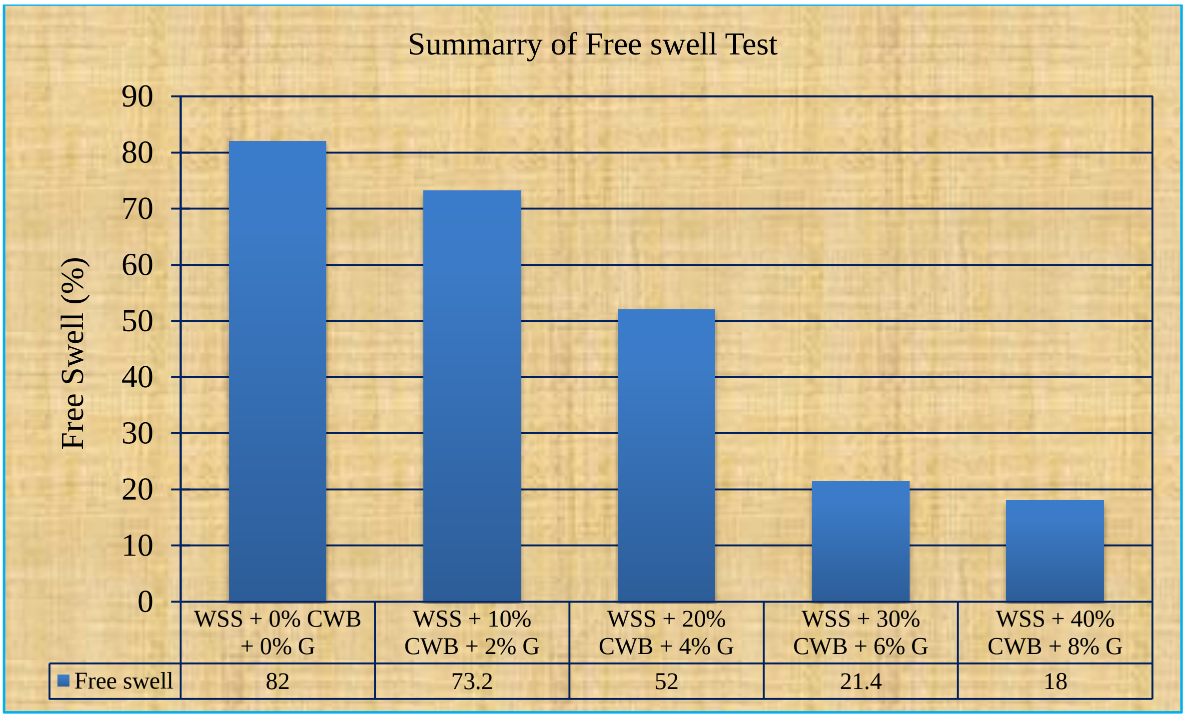


Figure 4. 8 Changes in free swell with varying percentage of gypsum and crushed waste brick

4.4.3.2. Free Swell Index

The effect of gypsum and crushed waste brick mix on the free swell index of the expansive soil is shown in Figure 4.9. Details of the free swell index test results are shown in Appendix-II.

According to results shown in figure, as increasing the percentage of Gypsum and Crushed Waste Brick mix, reduces the free swell index of expansive soil from 60.920% to 16.832% when 40% crushed waste brick and 8% gypsum was added. The highest reduction in free swell index is 56.150 %attained when the expansive soil is stabilized with 30% of crushed waste brick and 6% of gypsum mix when compared to unstabilized expansive soil. According to Table 2.7 [17] the swelling potential reduced form very high to medium as the content of Gypsum and Crushed Waste Brick became increased. From Table 2.8 the Degree of Expansion of treated sample became low due to increasing of Gypsum and Crushed Waste Brick [18].

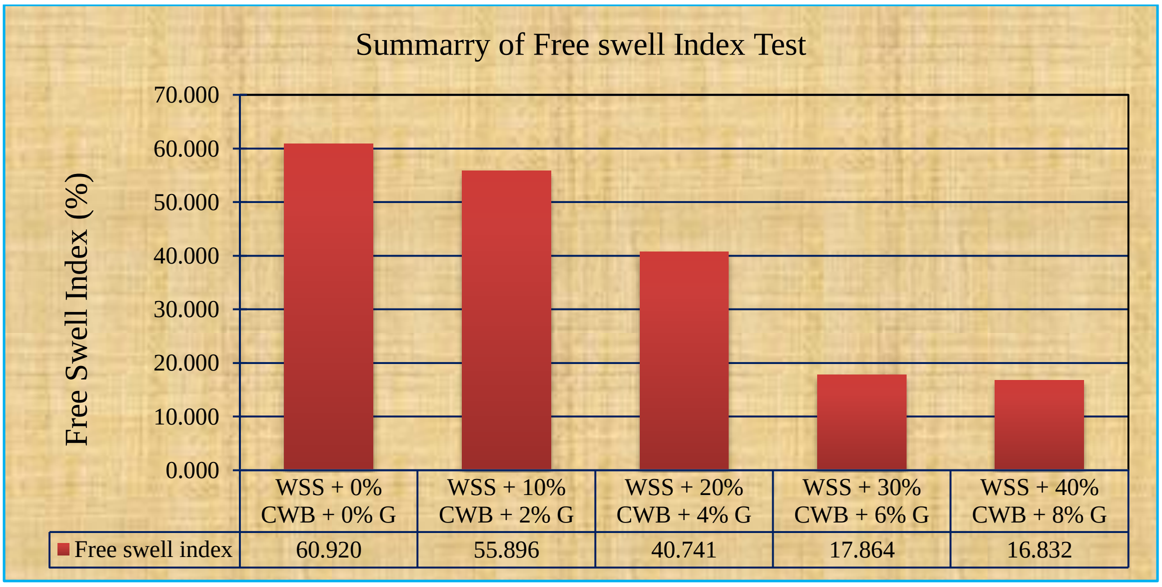


Figure 4. 9 Changes in free swell index with varying percentage of gypsum and crushed waste brick

4.4.3.3. Free Swell Ratio

As it is shown in Figure 4.10 when the mix of gypsum and crushed waste brick added to the expansive soil the free swell ratio decreased. As the content of gypsum and crushed waste brick mix increased from 0% to 8% gypsum + 40% brick, the free swell ratio decreased from 1.609 to 1.168. The highest reduction in free swell ratio is 16.250% attained when the expansive soil is stabilized with 30% of crushed waste brick and 6% of gypsum mix when compared to unstabilized expansive soil. From Table 2.9 the Soil Expansivity of treated sample became low due to increasing the percentage of Gypsum and Crushed Waste Brick to expansive soil [18].

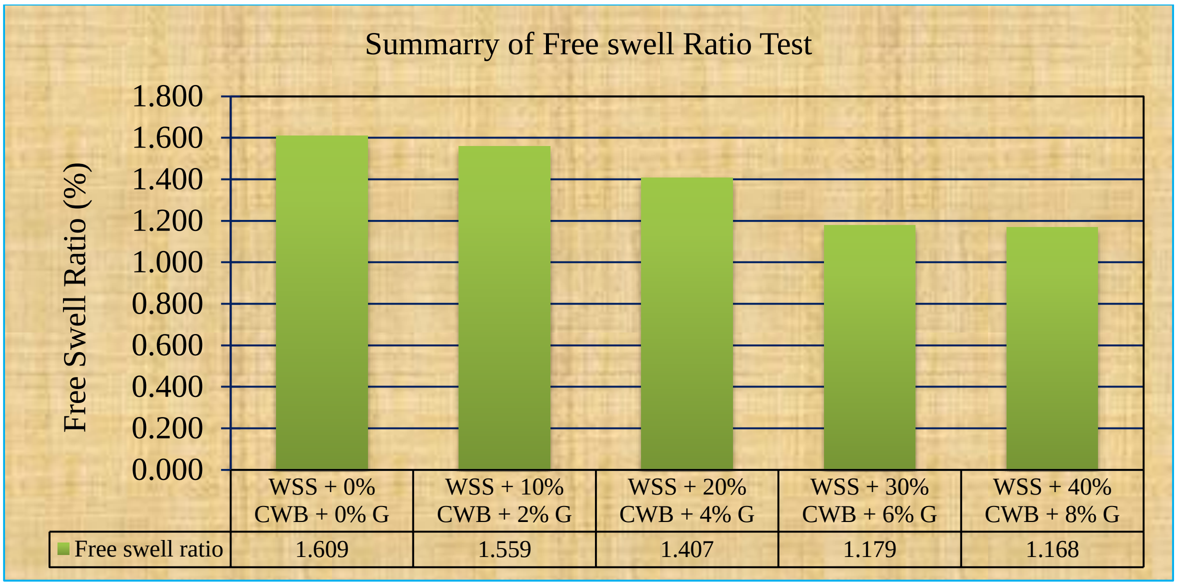


Figure 4. 10 Changes in free swell ratio with varying percentage of gypsum and crushed waste brick

4.4.4. The Effect of Gypsum and Crushed Waste Brick Mix on Compaction

Figure 4.11 show the relationship between moisture content and dry density and Summarized results are tabulated in Table 4.8 below. The details of the test results are attached in Appendix II.

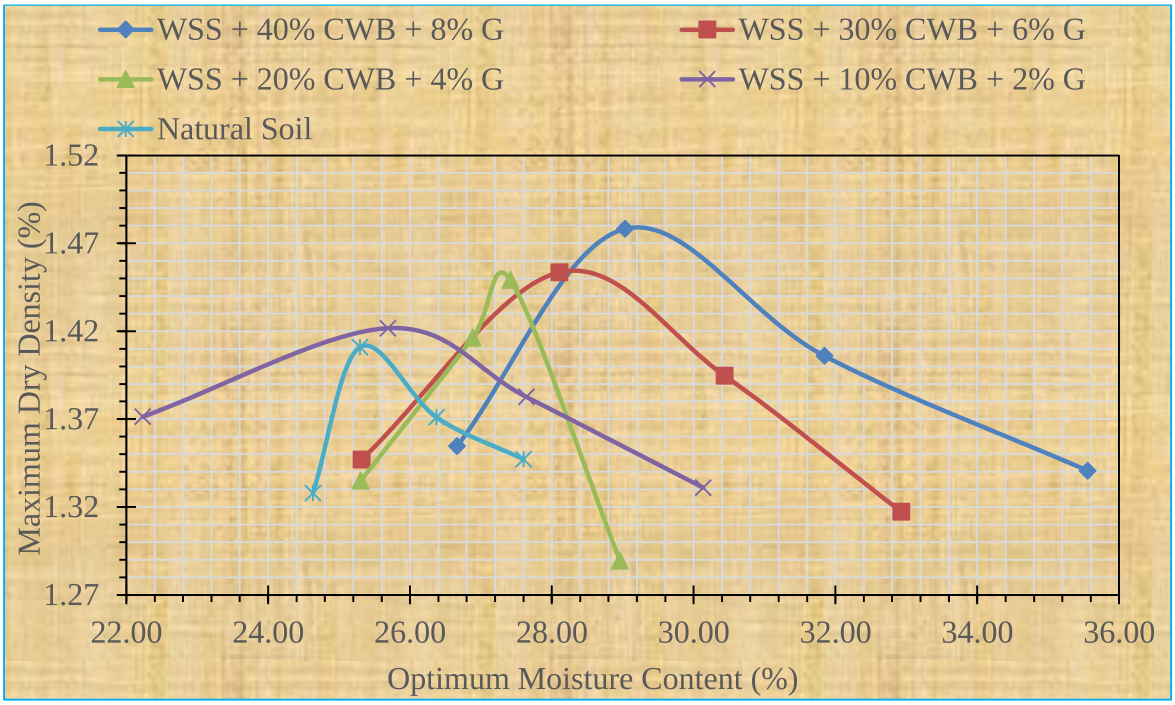


Figure 4. 11 Density-Moisture Content Relationship

The increase in the dry density was as a result of the increasing percentage of brick and gypsum particles that were ready to perform the soil particles, thus filling up the voids spaces and densely packing the soil particles together. However, the drop in density resulted from the excess water, waste brick and gypsum remaining after the increasing quantity has been used up for the stabilization process. It was Nothing gained by adding more waste crushed brick and gypsum than that corresponding to the content of reactive clay minerals in the soil.

Table 4. 8 Summary of MDD and OMC laboratory test results for Gypsum and Crushed Waste Brick

Natural Soil and percent of Stabilizer	MDD (g/cm^3)	OMC (%)
WSS + 0% CWB + 0% G	1.412	25.400
WSS + 10% CWB + 2% G	1.423	25.500
WSS + 20% CWB + 4% G	1.450	27.300
WSS + 30% CWB + 6% G	1.456	28.250
WSS + 40% CWB + 8% G	1.480	29.200

From Table 4.8 the results showed that as stabilization proportion has increased, the optimum moisture content and maximum dry density increased. The Expansive soil laboratory test OMC increased from 25.400% at 0% brick and gypsum to 29.200% at 40% brick and 8% gypsum. It is observed that maximum dry density of Expansive soil was increased from 1.412 to 1.480 g/cm^3 up to addition of 40% crushed brick and 8% gypsum expansive soil. This is because of the frictional resistance from crushed waste brick dust in addition to the cohesion from expansive soil and gypsum gives the binding property to the soil.

4.4.5. Effect of the Mix of Gypsum and Crushed Waste Brick on CBR and CBR-Swell

4.4.5.1. CBR Value at 10, 30 and 65 Blow

The soaked CBR values for all the samples increased with percentage of the mix of Gypsum and crushed waste Bricks increased. Results are illustrated in Table 4.9 below. The details of the laboratory results was attached in Appendix-II.

Table 4. 9 CBR test result of the treated expansive soils at different penetration depth and blows

Natural Soil and percent of Stabilizer	CBR Value (%) at 2.54mm penetration depth			CBR Value (%) at 5.08mm penetration depth		
	10 Blow	30 Blow	65 Blow	10 Blow	30 Blow	65 Blow
WSS+ 0% CWB + 0% G	1.420	1.490	1.590	1.200	1.240	1.410
WSS + 10% CWB + 2% G	1.560	1.720	1.950	1.490	1.660	1.840
WSS + 20% CWB + 4% G	3.490	4.020	4.920	3.000	3.560	4.810
WSS + 30% CWB + 6% G	9.190	10.900	13.900	9.910	11.360	12.860
WSS + 40% CWB + 8% G	7.130	7.950	8.700	6.760	7.910	8.910

According to Table 4.9, the CBR value at 2.54mm and 5.08mm penetration depth for 10 blow, 30 blow and 65 blow are increases as content of stabilizer increases to expansive soil and also as number of blow increases, at constant mix of expansive soil with gypsum and crushed waste brick stabilizer agent, the value of CBR increases. The increase in CBR value in increasing of number blow from 10 to 30 to 65 can be explained as a result of better compaction and packing of the mix. A better compaction improves intermolecular attractions which in turn enhance the strength of the subgrade material.

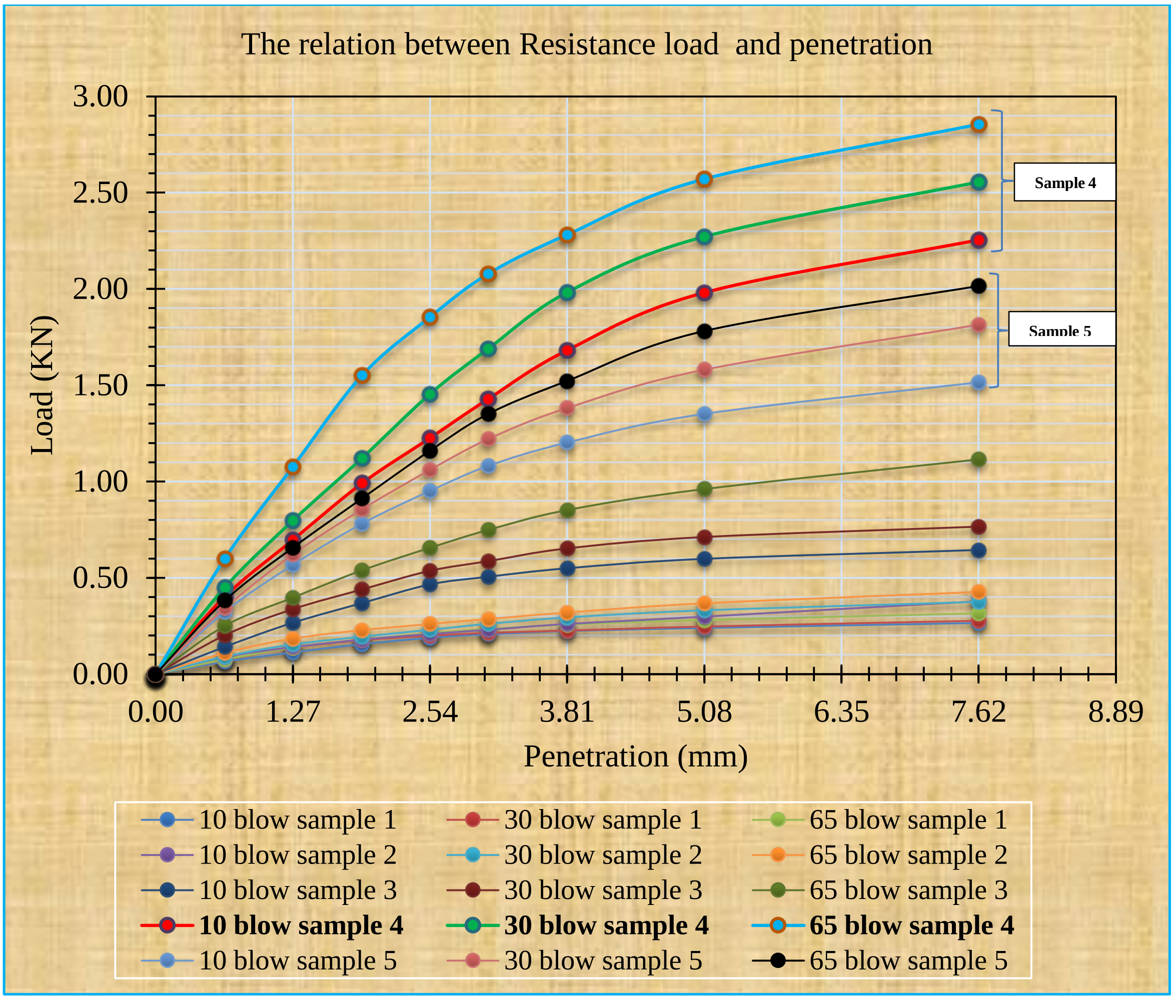


Figure 4. 12 Resistance Load Vs Penetration of expansive soil with stabilizer

As indicated in Figure 4.12 Variation of Penetration and Resistance load with addition of gypsum and crushed waste brick mix content to expansive soil and number of blow. As the mixture of expansive soil with gypsum and crushed waste brick content increases to 30% of crushed waste brick and 6% of gypsum the load carrying capacity of the soil increases, then starts to decrease as the increment of gypsum and crushed waste brick mix to 40% of CWB and 8% of gypsum.

4.4.5.2. CBR at 95% of Compaction

The CBR value at 95% of compaction determined from the relation of corrected CBR and percent of compaction graph. The effect of gypsum and crushed waste brick mix on the CBR of Expansive soil was presented in the Figure 4.13 and the laboratory test analysis data was found in appendix-II.

The soaked CBR value at 95% of compaction of the unstabilized and stabilized Expansive soil sample improved from 1.456% to10.686% at combination of 30% of crushed waste brick and 6% of gypsum. According to Table 2.1 the treated expansive soil is improved to S4 subgrade class. This shows that the mix of gypsum and crushed waste bricks stabilizer agent can effectively stabilize an expansive soil for a road construction.

According to the researcher justified that CBR>3.5% and swell of about 2% can be used for Embankment construction which needs to be covered with blanketing material but if the CBR≥15% good subgrade material it not need covered with blanketing material [10]. Therefore, the improved expansive soil using the mix of Gypsum and crushed waste Bricks was need to be covered with blanketing material when preparing subgrade layer.

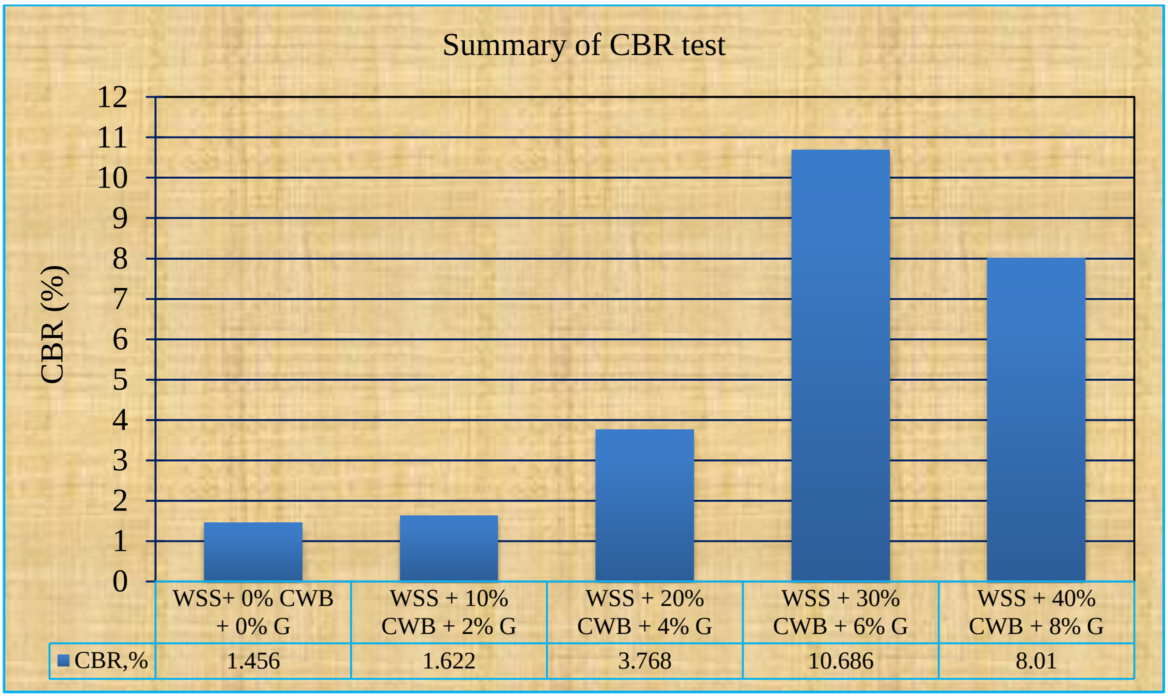


Figure 4. 13 The CBR value at 95% of compaction

Generally, the CBR value started to decrease when it reached to the combination expansive soil with the percentage of 40% of crushed waste brick and 8% of gypsum mix. The percentages above the mix of 20% of crushed waste brick and 4% of gypsum were satisfied the quality and the strength the expansive soils. Thus we can take gypsum and crushed waste brick as a weak subgrade soils stabilizer for road subgrades, but need covered with blanketing material.

4.4.5.3. CBR-Swell %

The effect of gypsum-brick on the CBR-Swell of Expansive soil is presented in the Figure 4.14 and the laboratory test analysis data was found in appendix-II.

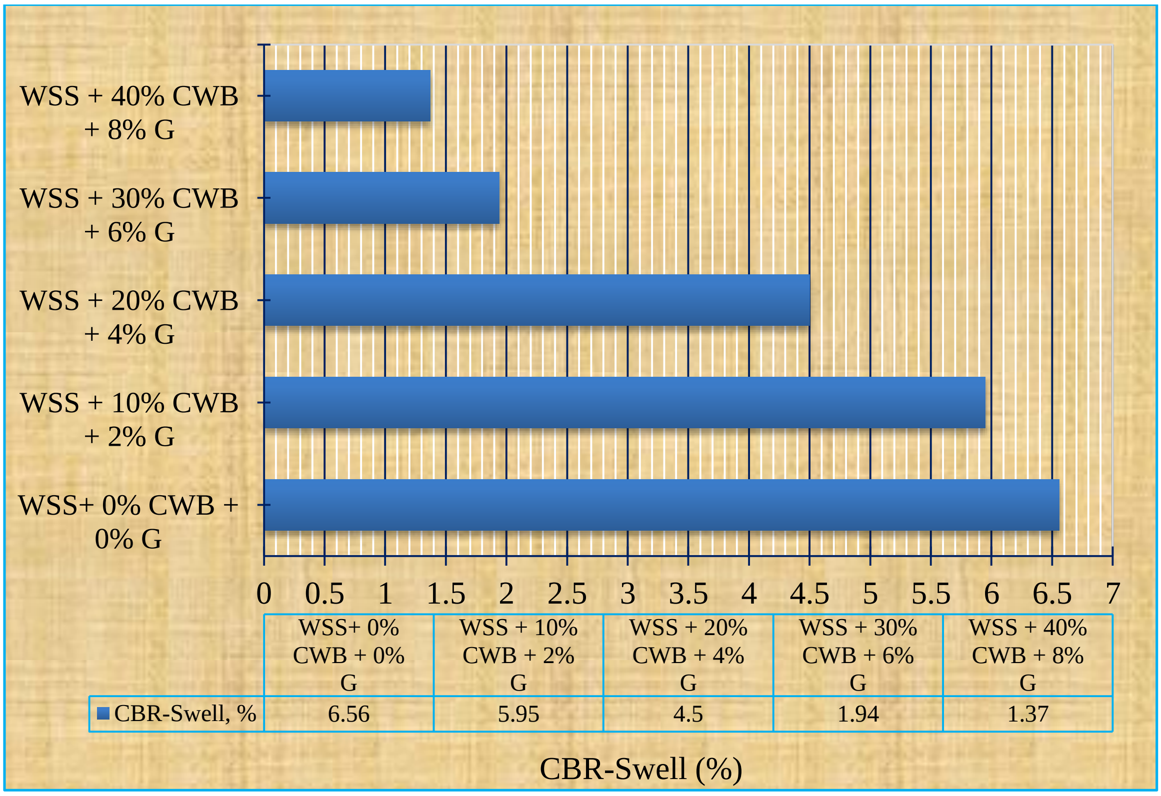


Figure 4. 14 Graphical representation of gypsum-crushed waste brick % Vs CBR-Swell

From the Figure 4.14, the percent swell of the stabilized weak expansive soils samples are decreased linearly as the percentage of stabilizer getting increased and vice versa. The CBR-Swells are decreased from 6.560% to 1.370% as the percent of stabilizer agent increased. This means the swell and the amount of stabilizer have inversely proportional relation. When the value of the percent CBR-Swell decreased the properties of the soil is getting improved.

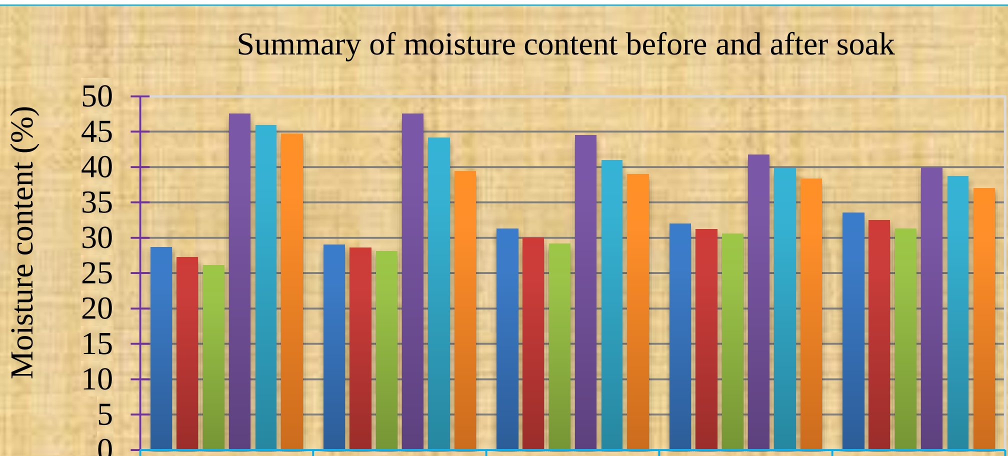
4.4.6. Effect of the Mix of Gypsum and Crushed Waste Brick on Dry Density and Moisture Content Before and After Soak of Expansive Soil

From Table 4.10 at 10, 30, and 65 blow dry density before soak greater than after soak as the percentage of gypsum and crushed waste brick was increased, this was due to decreased the intermolecular attractions and create a void for water accumulation after soak. On other hand the dry density was increased as the amount of gypsum and crushed waste brick percentage was increased.

Table 4. 10 Dry Density test results before and after soak

Sample	Dry Density					
	Before Soak			After Soak		
	10 Blow	30 Blow	65 Blow	10 Blow	30 Blow	65 Blow
WSS+ 0% CWB + 0% G	1.320	1.366	1.412	1.241	1.289	1.322
WSS + 10% CWB + 2% G	1.332	1.389	1.422	1.247	1.350	1.407
WSS + 20% CWB + 4% G	1.335	1.420	1.487	1.278	1.364	1.415
WSS + 30% CWB + 6% G	1.348	1.422	1.518	1.289	1.375	1.454
WSS + 40% CWB + 8% G	1.378	1.432	1.547	1.291	1.384	1.468

Based on Figure 4.15 the moisture content directly affected by number of blow and gypsum-crushed waste brick stabilizer. As number of blow was increased the moisture content decreased for both before and after soak. As the percentage of gypsum and crushed waste brick mix was increased, the moisture content also increased for all blow before soak, but after soak the moisture content was decreased. The moisture content after soak was higher than before soak. The moisture content before and after soak have inversely relationship.



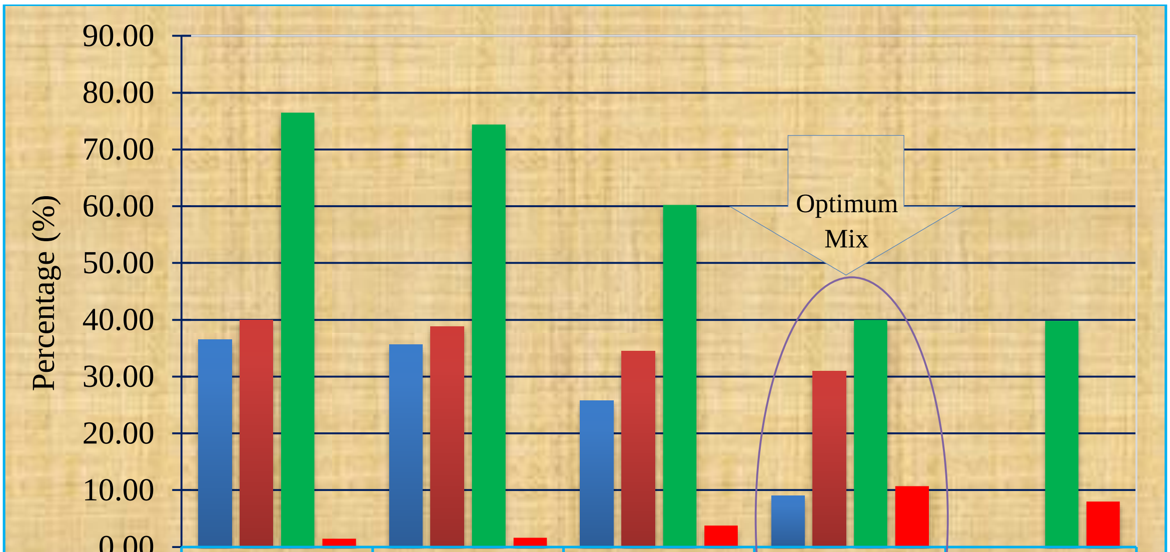
	WSS+ 0% CWB + 0% G	WSS + 10% CWB + 2% G	WSS + 20% CWB + 4% G	WSS + 30% CWB + 6% G	WSS + 40% CWB + 8% G
10 blow before soak	28.7	29	31.3	32	33.5
30 blow before soak	27.3	28.6	30	31.2	32.5
65 blow before soak	26.1	28.1	29.2	30.6	31.3
10 blow after soak	47.5	47.5	44.5	41.7	39.9
30 blow after soak	45.9	44.1	41	39.8	38.7
65 blow after soak	44.7	39.4	39	38.3	37

Figure 4. 15 Moisture Content before and after soak

4.5. The optimum Mix of Gypsum with Crushed Waste Brick to be added to improve the Expansive Soils

Depending on Figure 4.16 the CBR value increased form 1.456% to 10.686% as the percentage of gypsum and crushed waste brick increased from zero to 30% of crushed waste brick and 6% of gypsum to expansive soil, then decreased to 8.010% at the mix of 40% crushed waste brick and 8% gypsum with expansive soil and According to Atterberg limit test results shows in Figure 4.16 the plastic index results decreased from 36.500% to 9.030% as the amount of gypsum and crushed waste brick increased to expansive soil, then became to non-plastic. This is due to none plastic material of gypsum and crushed waste brick in high amount in expansive soil. On the other hand based on Table 2.4. AASHTO soil classification system and Atterberg limit test result value the expansive soil was improved from poor to good as the amount of stabilizer increased to the combination of 30% of brick and 6% of gypsum with expansive soil.

Therefore depending on the value of CBR and AASHTO soil classification system the optimum mix of Gypsum with crushed waste brick to be added to improve the expansive soils was the combination of crushed waste brick and gypsum which was achieved maximum CBR value and minimum Plastic Index of the material.



	WSS + 0% CWB + 0% G	WSS + 10% CWB + 2% G	WSS + 20% CWB + 4% G	WSS + 30% CWB + 6% G	WSS + 40% CWB + 8% G
PI, %	36.50	35.62	25.74	9.03	
PL, %	40.00	38.78	34.48	30.97	
LL, %	76.50	74.40	60.22	40.00	39.80
CBR, %	1.456	1.622	3.768	10.686	8.01

Figure 4. 16 Results of liquid limit, plastic limit, plastic index and CBR value

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

Expansive soils are characterized by volume change due to variation in moisture content. These soils swell when they get moisture and shrink when they are dry. Since moisture changes in soils bring the change in volume of the soils it brings severe movement of structures built on such soils experiences cracking and progressive damages. Therefore, these problematic soils when encountered as sub grade should be avoided or treated properly.

The objective of this study is to quantify the improvements achieved on the engineering properties of expansive soils due to the mix of gypsum and crushed waste brick stabilization. The laboratory tests conducted for this study were moisture content, specific gravity, grain size analysis, Atterberg limits, free swell test, free swell index, compaction, CBR and CBR swell tests. The test procedures were based on AASHTO and ASTM laboratory test standards. The stabilization was done using 10, 20, 30 and 40% of crushed waste brick and 2, 4, 6 and 8% of gypsum by weight. From the study the following findings are deduced:

- ✓ The properties of natural sub grade soils was expansive clay soil.
- ✓ Based on the AASHTO (American Association of State Highway Transportation Official) soil classification system, the original soil samples was A-7-5 and the group index was 38.
- ✓ Based on the AASHTO soil classification was grouped under poor subgrade soil.
- ✓ The sub grade soils considered for this study have a very low load bearing capacity and high swelling potential which makes the soils unsuitable for sub grade without improvement.
- ✓ The specific gravity of original expansive soil was 2.650. The specific gravity of the gypsum was 2.380 and the specific gravity of crushed brick was 2.010.
- ✓ The liquid limit and the plastic limit decreased from 76.500% to 39.800% and 40.000% to non-plastic respectively as the amount of gypsum and crushed waste brick mix was increased.
- ✓ The plastic index is decreased from 36.500% to 9.030% at stabilization of soil with 30% crushed waste brick and 6% gypsum.

- ✓ The soil classification improved to A-2-4 stabilized the expansive soil with the combination of 30% of Crushed Waste Brick + 6% of Gypsum based on AASHTO soil classification system.
- ✓ The optimum moisture content increased with increment of gypsum and crushed waste brick content. The optimum moisture content of weak subgrade soil changed from 25.400% to 29.200%.
- ✓ The engineering properties of the expansive soils is improved due to stabilized by gypsum and crushed waste brick stabilizer. The free swell, free swell index, free swell ratio, CBR-Swell were decreased from 82.000% to 18.000%, 60.920% to 16.830%, 1.609 to 1.168, 6.560% to 1.370% respectively and MDD increased from 1.412g/cm^3 to 1.480g/cm^3 as the increment of gypsum and crushed waste brick to 40% of crushed waste brick and 8% of gypsum mix.
- ✓ The CBR value increases from 1.456% to 10.686% as the content of gypsum and crushed waste brick increases from 0% to 6% G + 30% CWB then decreased to 8.010% as increased the stabilizer to 8% G + 40% CWB.

From the above discussion it can be concluded that the optimum combination of gypsum and crushed waste brick to improve the expansive soil is the mixture of expansive soil with the combination of 30% of crushed waste brick and 6% of gypsum.

Generally the mix of crushed waste brick with gypsum can effectively utilized with weak subgrade soil in improving the soil CBR values and MDD. The use of Crushed Brick resulted in utilization of demolition wastes and found to be economical for local area. This will results in the utilization of rejected weak soil in construction. From the results, it is concluded that impact of Crushed Brick and Gypsum is positive.

5.2. RECOMMENDATIONS

It is highly recommended to use the mix of crushed waste brick and gypsum stabilizer for the effective construction and cost minimization of the project at the indicated percentage gypsum- and crushed waste brick.

Designers and contractors shall be aware of gypsum and crushed waste brick can be taken as a weak subgrade stabilizer and considering it in any difficulties related to subgrade strength and use gypsum-waste brick as a stabilizer. ERA and other respective agencies has also included gypsum and crushed waste brick as a stabilizer for weak subgrade soils in the manuals, specification and contract agreements.

This research recommends the following areas for further research on gypsum and crushed waste brick stabilizer and weak subgrade soil strength.

- As this study was done for specific area and specific stabilizers, it is recommended as more investigation shall be performed on different parts of the country by mixing with other stabilizers.
- Effects of gypsum and crushed waste brick for weak subgrade soil stabilization is also one perspective to study further for additional choice of stabilizers.
- Effects gypsum and crushed waste brick stabilized subgrades in pavement thickness reduction in flexible and rigid pavement design shall be investigate.

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APPENDIX-I

NATURAL MOISTURE CONTENT OF SOIL, SIEVE ANALYSIS AND SPECIFIC GRAVITY

NATURAL MOISTURE CONTENT DETERMINATION

ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil

Project:- Thesis

Sample:- Weak Subgrade Soils/Expansive Soils

Location of Sample:- Mettu Town

Place of Test:- Jimma Institute of Technology University

Stabilizer:- Crushed Waste Brick and Gypsum

Researcher Name:- Assefa Takele

Date:- August-05/2011

Pit Location	Along Mettu-Burusa road		
Test No	1.00	2.00	3.00
Wt. of Container, (g)	17.11	17.43	17.52
Wt. of container + wet soil, (g)	113.29	140.74	139.59
Wt. of container + dry soil, (g)	90.40	112.80	110.59
Wt. of water, (g)	22.89	27.94	29.00
Wt. of dry soil, (g)	73.29	95.37	93.07
Moisture container, (%)	31.23	29.30	31.16
Average	30.56		

Sieve Analysis AASHTO Designation:T27				
project:- Thesis				
Sample:- Weak Subgrade Soils/Expansive Soils				
Location of Sample:- Mettu Town				
Place of Test:- Jimma Instituite of Technology University				
stabilizer:- Crushed Waste Brick and Gypsum				
Researcher Name:- Assefa Takele				
Date:- August-13/2011				
Wet Gradiation				
Wt. of Oven Dry Sample Before Washing (gm):- 1000				
Wt. of Oven Dry Sample After Washing (gm):- 392.9				
Between Mettu and Burusa				
Sieve size (mm)	mass of retain on each seive(g)	Persentage of retained soil	cumulative % of retain soil	persentage of passing particle
9.5	0.00	0.00	0.00	100.00
4.75	0.94	0.24	0.24	99.76
2	1.02	0.26	0.50	99.50
0.85	1.30	0.33	0.83	99.17
0.425	8.30	2.11	2.94	97.06
0.3	9.10	2.32	5.26	94.74
0.15	15.30	3.89	9.15	90.85
0.075	20.40	5.19	14.35	85.65
pan	336.50	85.65	100.00	0.00
sum	392.9			

Hydrometer Analysis ASTM 152-H											
project:- Thesis											
Sample:- Weak Subgrade Soils/Expansive Soils											
Location of Sample:- Mettu Town											
Place of Test:- Jimma Instituite of Technology University											
stabilizer:- Crushed Waste Brick and Gypsum											
Researcher Name:- Assefa Takele											
Date:- August-30/2011											
Gs= 2.65											
Dry weight of soil, Ws= 50g					Temperature of test=21			Temp. corr.= -4.85+0.25T		0.65	
Meniscus correction, Fm =1					Zero Correction, Fz =6						
Times(min)	TEMP.	R=H. reading	corr. For temp.	corr. H. reading	a= values	% finerin susp.p=(Ra/w)*100	corr.Hcl (H+Fm)	corr.length(cm)	K	Diametre (D)	% finer
1	21	51	0.4	45.4	1	90.8	52	13.2	0.01348	0.049	85.37
2	21	48	0.4	42.4	1	84.8	49	13.75	0.01348	0.035	79.73
5	21	46	0.4	40.4	1	80.8	47	13.8	0.01348	0.022	75.97
15	21	45	0.4	39.4	1	78.8	46	14.2	0.01348	0.013	74.09
30	21	44	0.4	38.4	1	76.8	45	14.3	0.01348	0.009	72.21
60	21	42	0.4	36.4	1	72.8	43	14.7	0.01348	0.007	68.45
120	21	41	0.4	35.4	1	70.8	42	14.8	0.01348	0.005	66.57
240	21	40	0.4	34.4	1	68.8	41	15	0.01348	0.003	64.69
480	21	38	0.4	32.4	1	64.8	39	15.3	0.01348	0.002	60.92
1440	21	36	0.4	30.4	1	60.8	37	15.6	0.01348	0.001	57.16

DETERMINATION OF SPECIFIC GRAVITY

project:- Thesis
Sample:- Weak Subgrade Soils/Expansive Soils
Location of Sample:- Mettu Town
Place of Test:- Jimma Institiute of Technology University
stabilizer:- Crushed Waste Brick and Gypsum
Researcher Name:- Assefa Takele
Date:- August-21/2011

Specific gravity test data for natural soil

Determination Code	1	2
Mass of dry, clean Calibrated pycnometer,	31.28	36.31
Mass of oven dry sample(gm) A	25	25
Mass of Pycnometer + water(gm) B	122.5	134.2
Mass of Pycnometer + water + sample(gm) C	138.38	149.43
Mass of Pycnometer + sample(gm) D	56.28	61.31
Observed temperature of water,Ti	23	23

Water Temperature(^{O}C)

°C	18	19	20	21	22	23	24	25	26	27	28	29	30
k	1.0016	1.0014	1.001	1.0009	1.007	1.0005	1.0003	1.000	0.9997	0.9983	0.998	0.9977	0.9974

Temperature of contents of pycnometer when	21	21
K for Tx	1.0009	1.0009
Specific gravity at 20oc, Gs=A*k/(A+B-	2.74	2.56
Average Specific gravity at 20oc, Gs	2.65	

Specific gravity test data for Brick Dust

Determination Code	1	2
Mass of dry, clean Calibrated pycnometer,	31.9	31.05
Mass of oven dry sample(gm) A	25	25
Mass of Pycnometer + water(gm) B	130.36	127.65
Mass of Pycnometer + water + sample(gm) C	142.82	140.23
Mass of Pycnometer + sample(gm) D	56.9	56.05
Observed temperature of water,Ti	23	23

Water Temperature(^{O}C)

°C	18	19	20	21	22	23	24	25	26	27	28	29	30
k	1.0016	1.0014	1.0012	1.0009	1.007	1.0005	1.0003	1.000	0.9997	0.9983	0.998	0.9977	0.9974

Temperature of contents of pycnometer when	22	21
K for Tx	1.0070	1.0009
Specific gravity at 20oc, Gs=A*k/(A+B-C)	2.01	2.01
Average Specific gravity at 20oc, Gs	2.01	

Specific gravity test data for Gypsum

Determination Code	1	2
Mass of dry, clean Calibrated pycnometer,	33.38	31.59
Mass of oven dry sample(gm) A	25	25
Mass of Pycnometer + water(gm) B	137.73	125.17
Mass of Pycnometer + water + sample(gm) C	150.39	141.03
Mass of Pycnometer + sample(gm) D	58.38	56.59
Observed temperature of water,Ti	23	24

Water Temperature(^{O}C)

°C	18	19	20	21	22	23	24	25	26	27	28	29	30
k	1.0016	1.0014	1.0012	1.0009	1.007	1.0005	1.0003	1.000	0.9997	0.9983	0.998	0.9977	0.9974

Temperature of contents of pycnometer when	21	21
K for Tx	1.0009	1.0009
Specific gravity at 20oc, Gs=A*k/(A+B-C)	2.03	2.74
Average Specific gravity at 20oc, Gs	2.38	

APPENDIX-II

FREE SWELL, ATTERBERG LIMIT, COMPACTION AND CBR DETERMINATION

FREE SWELL TEST

project:- Thesis

Sample:- Weak Subgrade Soils/Expansive Soils

Location of Sample:- Mettu Town

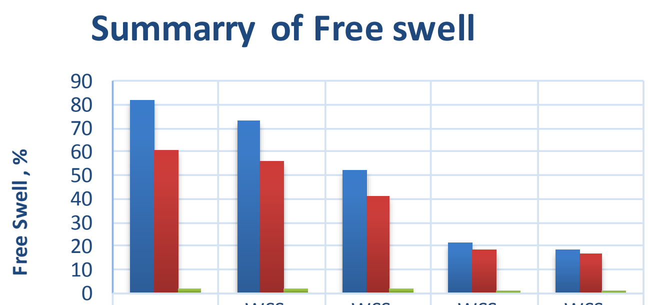
Place of Test:- Jimma Instituite of Technology University

stabilizer:- Crushed Waste Brick and Gypsum

Researcher Name:- Assefa Takele

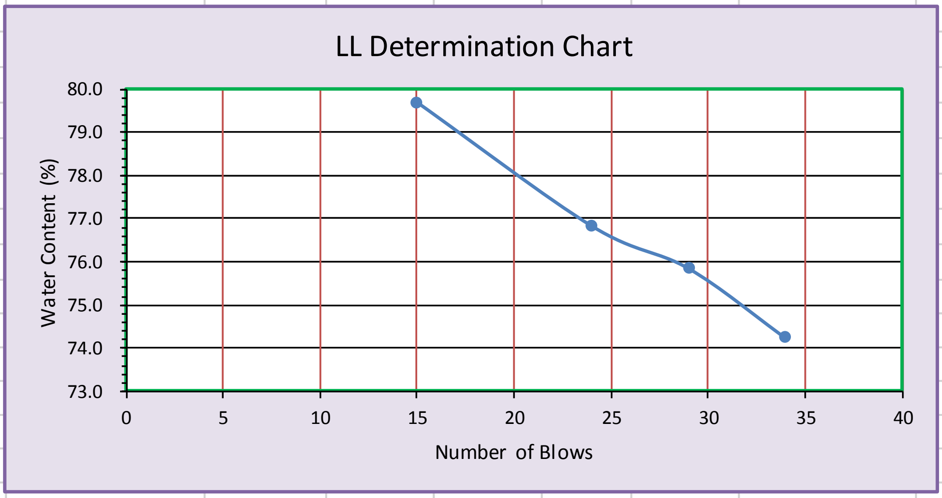
Date:- August-30/2011

Soils with different percent ratio of stabilizer	Initial volume	Finila volume in water	Final vlume in kersene	free swell	free swell index	free swell ratio	Reduction of FS	Reduction of FSI	Reduction of FSR
	Vo (ml)	Vw (ml)	Vk (ml)	FS,%	FSI (%)	FSR			
WSS + 0% CWB + 0% G	10	18.2	11.31	82	60.920	1.609	0	0	0
WSS + 10% CWB + 2% G	10	17.32	11.11	73.2	55.896	1.559	-10.732	-8.25	-3.122
WSS + 20% CWB + 4% G	10	15.2	10.8	52	40.741	1.407	-28.962	-27.1	-9.721
WSS + 30% CWB + 6% G	10	12.14	10.3	21.4	17.864	1.179	-58.846	-56.2	-16.25
WSS + 40% CWB + 8% G	10	11.8	10.1	18	16.832	1.168	-15.888	-5.78	-0.876



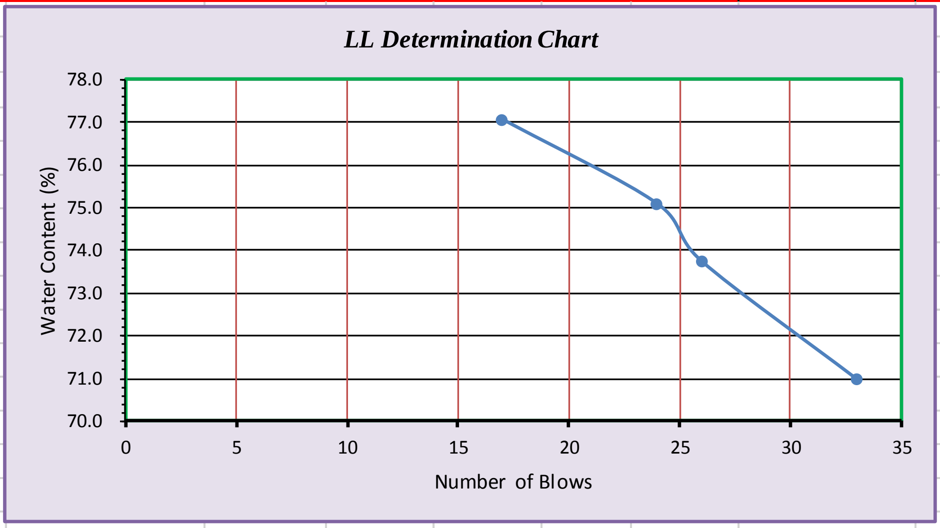
	WSS + 0% CWB + 0% G	WSS + 10% CWB + 2% G	WSS + 20% CWB + 4% G	WSS + 30% CWB + 6% G	WSS + 40% CWB + 8% G
Free swell	82	73.2	52	21.4	18
Free swell index	60.920	55.896	40.741	17.864	16.832
Free swell ratio	1.609	1.559	1.407	1.179	1.168

DETERMINATION OF LIQUID LIMIT & PLASTIC LIMIT OF SOIL TEST METHOD : AASHTO T89						
project:- Thesis						
Sample:- Weak Subgrade Soils/Expansive Soils						
Location of Sample:- Mettu Town						
Place of Test:- Jimma Instituite of Technology University						
stabilizer:- Crushed Waste Brick and Gypsum						
Researcher Name:- Assefa Takele						
Date:- August-13/2011						
Sample 1:-WSS + 0%BW + 0%G						
Determination	*Liquid Limit*				*Plastic Limit*	
Number of blows	*34*	*29*	*24*	15		
Test No	1	2	3	4	1	2
Container Code	P1	T3	A13	H23	H23	C8
Wt. of container + wet soil, g	31.43	37.86	32.97	37.52	24.90	10.70
Wt. of container + dry soil, g	25.64	29.98	26.77	29.36	22.50	10.10
Wt. of container, g	17.84	19.59	18.7	19.12	18.70	6.56
Wt. of water, g	5.79	7.88	6.20	8.16	2.40	0.60
Wt. of dry soil, g	7.80	10.39	8.07	10.24	3.80	3.54
Moisture content, %	*74.2*	*75.8*	*76.8*	79.69	63.16	*16.9*
					Average	40.1



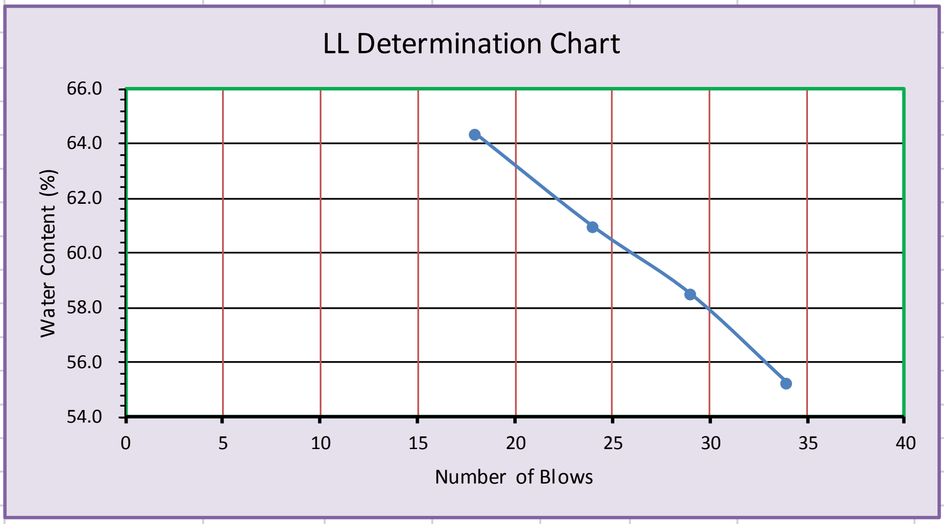
Liquid Limit (LL)	**76.5**
Plastic Limit (PL)	**40.1**
Plastic Index (PI)=LL-PL	**36.4**

Sample 2:- WSS + 10%BW + 2%G						
Determination	***Liquid Limit***				***Plastic Limit***	
Number of blows	*33*	*26*	*24*	17		
Test No	1	2	3	4	1	2
Container Code	C1	T3	A13	B01	A16	T4
Wt. of container + wet soil, g	39.5	37.90	37.60	45.50	21.30	8.78
Wt. of container + dry soil, g	31.84	30.09	29.58	33.50	20.14	8.01
Wt. of container, g	21.05	19.50	18.90	17.93	17.24	5.96
Wt. of water, g	7.66	7.81	8.02	12	1.16	0.77
Wt. of dry soil, g	10.79	10.59	10.68	15.57	2.90	2.05
Moisture content, %	*71.0*	*73.7*	*75.1*	77.07	40.00	*37.6*
					Average(PL)	38.8



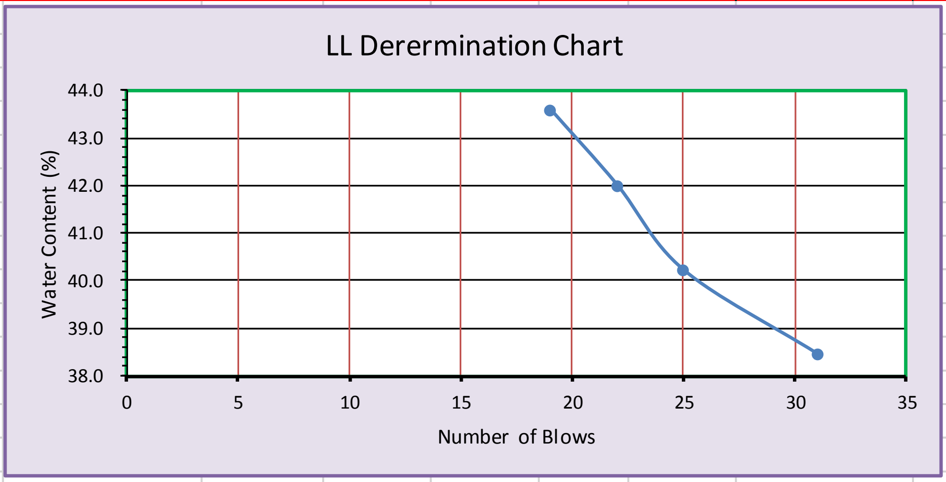
Liquid Limit (LL)	**74.4**
Plastic Limit (PL)	**38.8**
Plastic Index (PI)=LL-PL	35.62

Sample 3:- WSS + 20%BW + 4%G						
Determination	***Liquid Limit***				***Plastic Limit***	
Number of blows	*34*	*29*	*24*	18		
Test No	1	2	3	4	1	2
Container Code	T3	B01	C1	A13	A6	A4
Wt. of container + wet soil, g	42.73	41.50	39.69	40.31	9.45	22.89
Wt. of container + dry soil, g	34.50	32.80	32.6	32.01	8.20	22.23
Wt. of container, g	19.60	17.93	20.97	19.11	5.27	19.72
Wt. of water, g	8.23	8.70	7.09	8.3	1.25	0.66
Wt. of dry soil, g	14.90	14.87	11.63	12.9	2.93	2.51
Moisture content, %	*55.2*	*58.5*	*61.0*	64.34	42.66	*26.3*
					Average(PL)	34.48



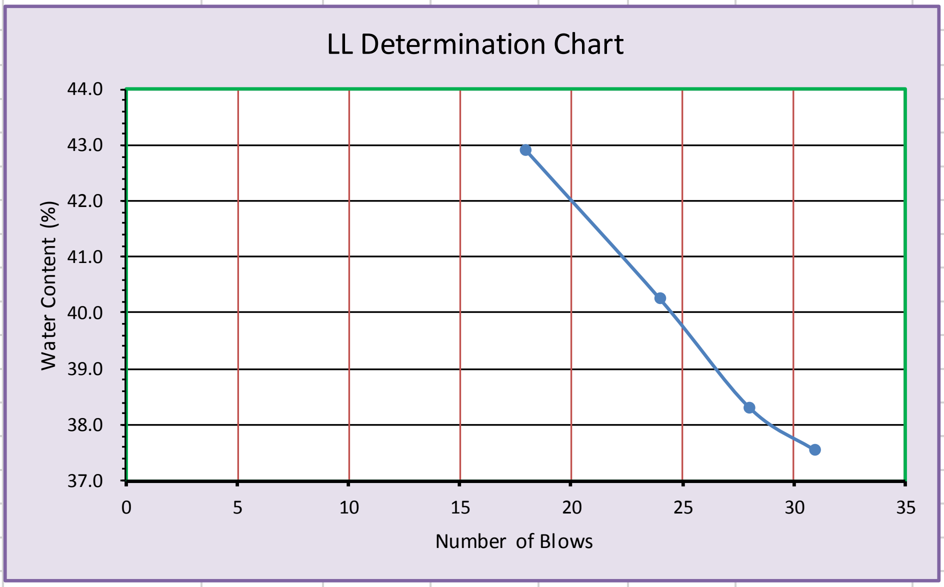
Liquid Limit (LL)	**60.22**
Plastic Limit (PL)	**34.48**
Plastic Index (PI)=LL-PL	**25.74**

Sample 4:- WSS + 30%BW + 6%G						
Determination	***Liquid Limit***				***Plastic Limit***	
Number of blows	*31*	*25*	*22*	19		
Test No	1	2	3	4	1	2
Container Code	T4	C8	H23	A16	B01	C8
Wt. of container + wet soil, g	32.40	24.73	49.65	35.85	22.98	9.47
Wt. of container + dry soil, g	25.06	19.30	40.5	30.20	22.13	8.39
Wt. of container, g	5.98	5.80	18.72	17.24	17.93	5.80
Wt. of water, g	7.34	5.43	9.15	5.65	0.85	1.08
Wt. of dry soil, g	19.08	13.50	21.78	12.96	4.20	2.59
Moisture content, %	*38.5*	*40.2*	*42.0*	43.60	20.24	*41.7*
					Average(PL)	30.97



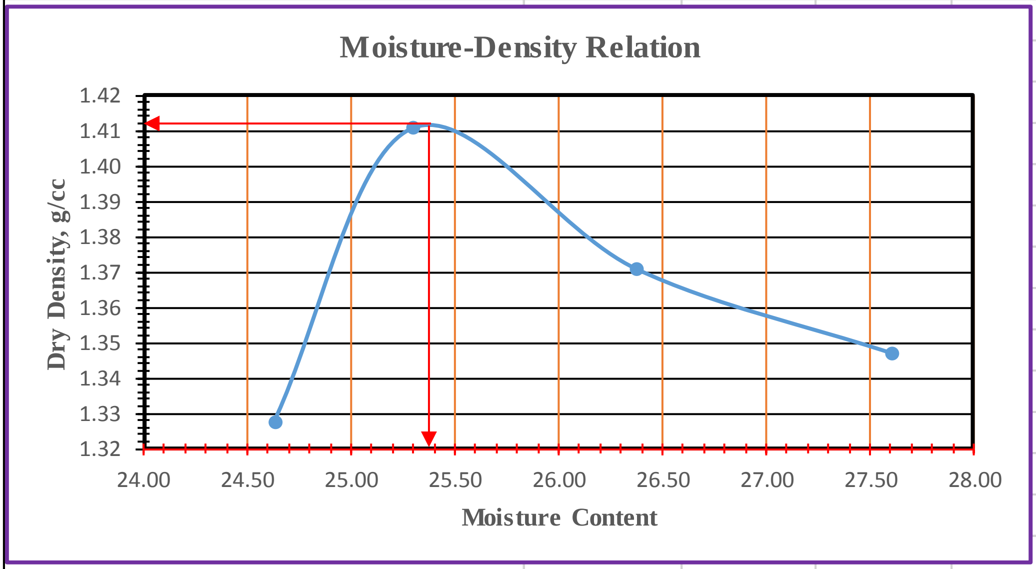
Liquid Limit (LL)	**40.2**
Plastic Limit (PL)	**30.97**
Plastic Index (PI)=LL-PL	**9.23**

Sample 5:- WSS + 40%BW + 8%G						
Determination	***Liquid Limit***				***Plastic Limit***	
Number of blows	*31*	*28*	*24*	18		
Test No	1	2	3	4	1	2
Container Code	LL	T6	A16	G3	G3	T3
Wt. of container + wet soil, g	28.59	27.57	33.2	35.85	20.30	23.92
Wt. of container + dry soil, g	22.90	21.90	25.4	30.02	19.36	23.58
Wt. of container, g	7.74	7.10	6.02	16.43	16.43	19.60
Wt. of water, g	5.69	5.67	7.80	5.83	0.94	0.34
Wt. of dry soil, g	15.16	14.80	19.38	13.59	2.93	3.98
Moisture content, %	*37.5*	*38.3*	*40.2*	42.90	32.08	*8.5*
					Average(PL)	20.31



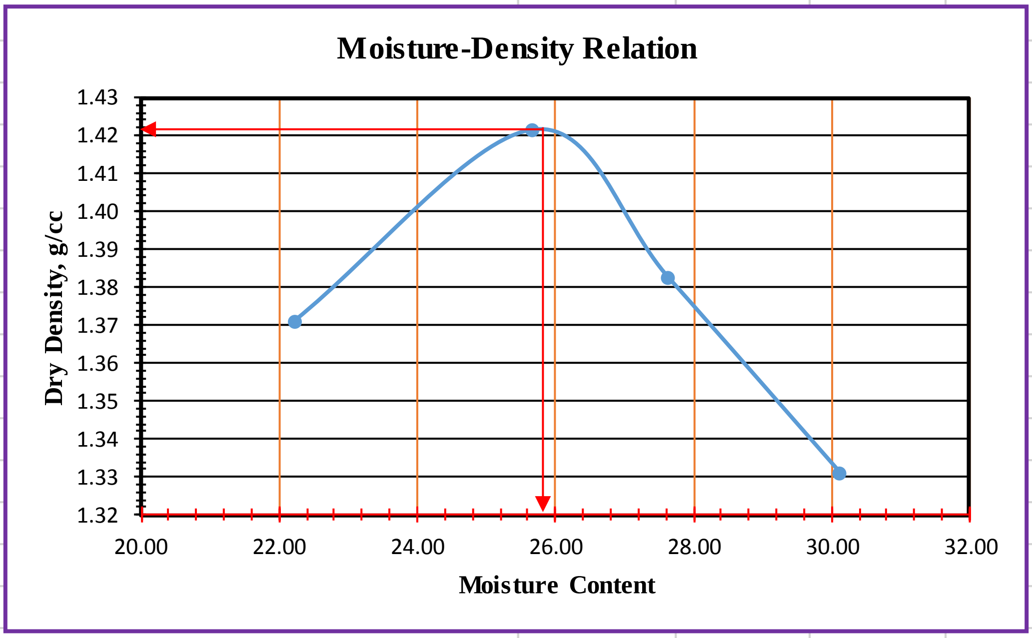
Liquid Limit (LL)	**39.8**
Plastic Limit (PL)	**20.31**
Plastic Index (PI)=LL-PL	**19.49**

MOISTURE-DENSITY (COMPACTION) TEST RESULTS				
TEST METHOD:-ASTM D 1557				
project:- Thesis				
Sample:- Weak Subgrade Soils/Expansive Soils				
Location of Sample:- Mettu Town				
Place of Test:- Jimma Instituite of Technology University				
stabilizer:- Crushed Waste Brick and Gypsum				
Researcher Name:- Assefa Takele				
Date:- August-13/2011				
Sample 1:-WSS+0%BW+0%G				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	570	890	1210	1530
Mass of Mold+Wet soil(gm)(A)	6216.1	6456.2	6381.3	6352.3
Mass of Mold(gm)(B)	2701.3	2701.3	2701.3	2701.3
Mass of Wet Soil(gm)A-B=C	3514.8	3754.9	3680	3651
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.65	1.77	1.73	1.72
Moisture Determination				
Container Code .	A1	B1	C1	D1
Mass of Wet soil+Container(gm)(F)	63.96	96.73	86.49	70.3
Mass of dry soil+container(gm)(G)	56.3	84.1	72.1	58.9
Mass of container(gm)(H)	25.2	34.17	17.54	17.6
Mass of moisture(gm)F-G=(I)	7.66	12.63	14.39	11.4
Mass of Dry soil(gm)G-H=(J)	31.1	49.93	54.56	41.3
Moisture content % (I/J)*100=K	**24.63**	**25.30**	**26.37**	**27.60**
Dry Density gm/cm^3 E/(100+K)*100	**1.33**	**1.41**	**1.37**	**1.35**



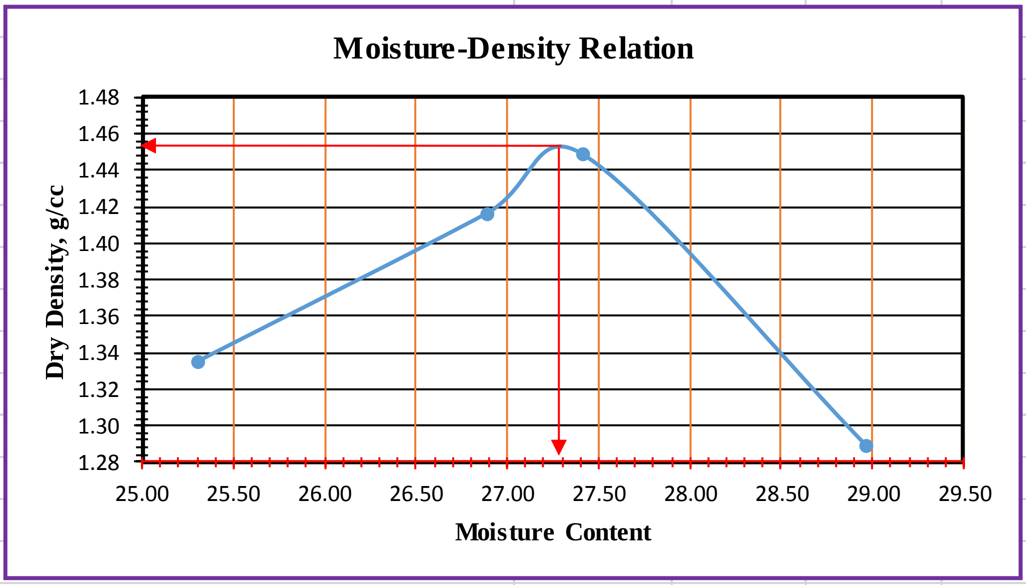
Optimum moisture content (%)	25.400
Maximum Dry Density (g/cm3)	1.412

Sample 2:-WSS+10%BW+2%G				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	530	1050	1370	1690
Mass of Mold+Wet soil(gm)(A)	6261.43	6496.6	6449.59	6380.23
Mass of Mold(gm)(B)	2701.3	2701.3	2701.3	2701.3
Mass of Wet Soil(gm)A-B=C	3560.13	3795.3	3748.29	3678.93
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.68	1.79	1.76	1.73
Moisture Determination				
Container Code .	A1	A2	A3	A4
Mass of Wet soil+Container(gm)(F)	130.44	150.5	119.23	145.23
Mass of dry soil+container(gm)(G)	111.3	125.3	100.1	116.3
Mass of container(gm)(H)	25.2	27.2	30.9	20.3
Mass of moisture(gm)F-G=(I)	19.14	25.2	19.13	28.93
Mass of Dry soil(gm)G-H=(J)	86.1	98.1	69.2	96
Moisture content % (I/J)*100=K	**22.23**	**25.69**	**27.64**	**30.14**
Dry Density gm/cm^3 E/(100+K)*100	**1.37**	**1.42**	**1.38**	**1.33**



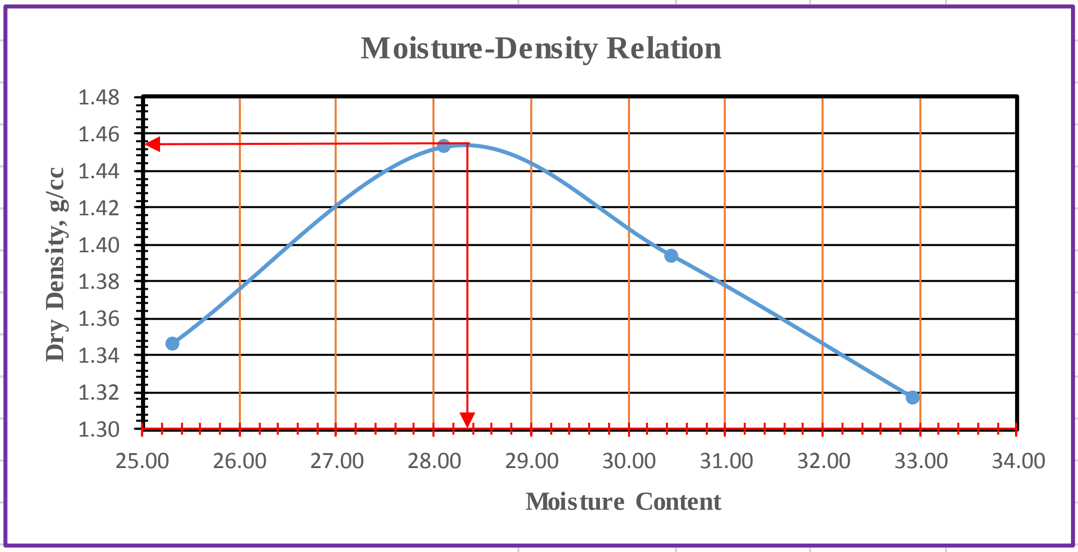
Optimum moisture content (%)	25.5
Maximum Dry Density (g/cm3)	1.423

Sample 3:-WSS+20%BW+4%G				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	525	845	1165	1485
Mass of Mold+Wet soil(gm)(A)	6254.2	6518.2	6623.1	6233.2
Mass of Mold(gm)(B)	2701.3	2701.3	2701.3	2701.3
Mass of Wet Soil(gm)A-B=C	3552.9	3816.9	3921.8	3531.9
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.67	1.80	1.85	1.66
Moisture Determination				
Container Code .	A1	B1	C1	D1
Mass of Wet soil+Container(gm)(F)	73.6	63.2	63.6	91.3
Mass of dry soil+container(gm)(G)	65.3	55	53.1	79.6
Mass of container(gm)(H)	32.5	24.5	14.8	39.2
Mass of moisture(gm)F-G=(I)	8.3	8.2	10.5	11.7
Mass of Dry soil(gm)G-H=(J)	32.8	30.5	38.3	40.4
Moisture content % (I/J)*100=K	**25.30**	**26.89**	**27.42**	**28.96**
Dry Density gm/cm^3 E/(100+K)*100	**1.33**	**1.42**	**1.449**	**1.29**



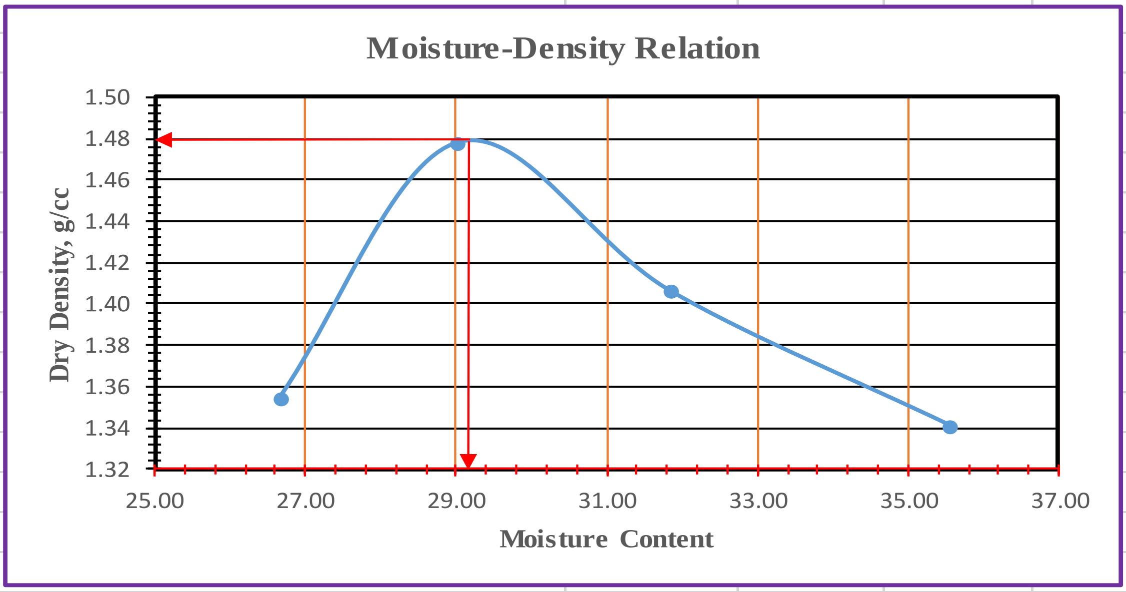
Optimum moisture content (%)	27.30
Maximum Dry Density (g/cm3)	1.45

Sample 4:-WSS+30%BW+6%G				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	530	850	1170	1490
Mass of Mold+Wet soil(gm)(A)	6286.3	6656.3	6565.3	6420.3
Mass of Mold(gm)(B)	2701.3	2701.3	2701.3	2701.3
Mass of Wet Soil(gm)A-B=C	3585	3955	3864	3719
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.69	1.86	1.82	1.75
Moisture Determination				
Container Code .	A1	B1	C1	D1
Mass of Wet soil+Container(gm)(F)	60.9	91	98.2	85.3
Mass of dry soil+container(gm)(G)	52.9	72.46	76.5	66.3
Mass of container(gm)(H)	21.3	6.5	5.2	8.6
Mass of moisture(gm)F-G=(I)	8	18.54	21.7	19
Mass of Dry soil(gm)G-H=(J)	31.6	65.96	71.3	57.7
Moisture content % (I/J)*100=K	**25.32**	**28.11**	**30.43**	**32.93**
Dry Density gm/cm^3 E/(100+K)*100	**1.35**	**1.45**	**1.39**	**1.32**



Optimum moisture content (%)	28.250
Maximum Dry Density (g/cm3)	1.456

Sample 5:-WSS+40%BW+8%G				
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4000	4000	4000	4000
Water Added(cc)	580	900	1220	1540
Mass of Mold+Wet soil(gm)(A)	6345.5	6752.5	6638.3	6561.3
Mass of Mold(gm)(B)	2701.3	2701.3	2701.3	2701.3
Mass of Wet Soil(gm)A-B=C	3644.2	4051.2	3937	3860
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.72	1.91	1.85	1.82
Moisture Determination				
Container Code .	A1	B1	C1	D1
Mass of Wet soil+Container(gm)(F)	64.2	88.3	123.6	132.3
Mass of dry soil+container(gm)(G)	51.74	70.3	98.6	100.3
Mass of container(gm)(H)	5.01	8.3	20.1	10.3
Mass of moisture(gm)F-G=(I)	12.46	18	25	32
Mass of Dry soil(gm)G-H=(J)	46.73	62	78.5	90
Moisture content % (I/J)*100=K	**26.66**	**29.03**	**31.85**	**35.56**
Dry Density gm/cm^3 E/(100+K)*100	**1.35**	**1.48**	**1.41**	**1.34**



Optimum moisture content (%)	29.20
Maximum Dry Density (g/cm3)	1.48

CBR –CALIFORNIA BEARING RATIO TEST- THREE POINT METHOD

ALONG METTU-BURUSA

project:- Thesis

Sample:- Weak Subgrade Soils/Expansive Soils

Location of Sample:- Mettu Town

Place of Test:- Jimma Instituite of Technology University

stabilizer:- Crushed Waste Brick and Gypsum

Researcher Name:- Assefa Takele

Date:- August-22/2011 to 26/2011

Sample 1:-Weak Subgrade Soils

Compaction Determination

COMPACTION DATA		10 Blows		30 Blows		65 Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Mould No.		N10	N10	N30	N30	N65	N65
Mass of soil + Mould	g	10573.6	10852.7	10672.1	10971.1	10741.5	11023.4
Mass Mould	g	6966.4	6966.4	6977.9	6977.9	6960.9	6960.9
Mass of Soil	g	3607.2	3886.3	3694.2	3993.2	3780.6	4062.5
Volume of Mould	g	2124	2124	2124	2124	2124	2124
Wet density of soil	g/cc	1.698	1.830	1.739	1.880	1.780	1.913
Dry density of soil	g/cc	1.320	1.241	1.366	1.289	1.412	1.322

Moisture Determination

MOISTURE CONTENT DATA		10 Blows		30 Blows		65Blows	
		Before soak	After soak	Before soak	After soak	Before soak	After soak
Container no.		D5	M	P64	P65	A01	P2
Mass of wet soil + Container	g	82.88	113.00	119.50	84.10	90.20	101.3
Mass of dry soil + Container	g	70.03	89.50	105.45	69.54	75.25	75.36
Mass of container	g	25.21	40.00	53.95	37.80	17.92	17.30
Mass of water	g	12.9	23.5	14.1	14.6	15.0	25.9
Mass of drysoil	g	44.8	49.5	51.5	31.7	57.3	58.1
Moisture content	%	28.7	47.5	27.3	45.9	26.1	44.7

CBR Penetration Determination

Penetration after 96 hrs Soaking Period — **Surcharge Weight:-4.55 KG**

10 Blows			30 Blows			65Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.00		0.00	0.00		0.00	0.00	
0.641	0.065		0.642	0.075		0.64	0.076	
1.271	0.113		1.269	0.135		1.27	0.137	
1.911	0.156		1.913	0.176		1.91	0.18	
2.54	0.189	1.42	2.541	0.199	1.49	2.541	0.212	1.59
3.08	0.208		3.08	0.214		3.08	0.234	
3.811	0.224		3.81	0.226		3.81	0.257	
5.08	0.24	1.20	5.081	0.247	1.24	5.08	0.281	1.41
7.621	0.266		7.621	0.277		7.619	0.315	

Modified Max.Dry Density g/cc	1.412	OMC %	25.4

Swell Determination

Date		10 Blows Gauge rdg mm	Swell in %	30 Blows Gauge rdg mm	Swell in %	65 Blows Gauge rdg mm	Swell in %
22/12/2011	Initial	15.43	7.04	19.14	6.56	16.94	6.43
25/12/2011	Final	23.62		26.78		24.42	

Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %	Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %
2.54mm		0.2	1.4	7.04	2.54mm		0.2	1.5	6.56
5.08mm		0.2	1.2		5.08mm		0.2	1.2	

Dry Density at 95% of MDD: 1.341

Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %	No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction
					10	28.7	1.320	1.42	93
2.54mm		0.2	1.6	6.43	30	27.3	1.366	1.50	97
5.08mm		0.3	1.4		65	26.1	1.412	1.59	100

CBR % at 95 % MDD	1.456	Swell %	6.56

Sample 2:-WSS + 10% BW + 2% G

Compaction Determination

COMPACTION DATA		10 Blows Before soak	10 Blows After soak	30 Blows Before soak	30 Blows After soak	65 Blows Before soak	65 Blows After soak
Mould No.		N10	N10	N30	N30	N65	N65
Mass of soil + Mould	g	10665	10922.1	10798.7	11136.5	10880.5	11176.3
Mass Mould	g	7016.3	7016.3	7004.7	7004.7	7010.9	7010.9
Mass of Soil	g	3648.7	3905.8	3794	4131.8	3869.6	4165.4
Volume of Mould	g	2124	2124	2124	2124	2124	2124
Wet density of soil	g/cc	1.718	1.839	1.786	1.945	1.822	1.961
Dry density of soil	g/cc	1.332	1.247	1.389	1.350	1.422	1.407

Moisture Determination

MOISTURE CONTENT DATA		10 Blows Before soak	10 Blows After soak	30 Blows Before soak	30 Blows After soak	65Blows Before soak	65Blows After soak
Container no.		P1	MK	A13	DH	A	G
Mass of wet soil + Container	g	101.30	90.20	56.30	55.78	69.50	108.3
Mass of dry soil + Container	g	82.50	66.81	48.00	43.89	58.10	82.67
Mass of container	g	17.60	17.59	19.00	16.94	17.50	17.66
Mass of water	g	18.8	23.4	8.3	11.9	11.4	25.6
Mass of drysoil	g	64.9	49.2	29.0	27.0	40.6	65.0
Moisture content	%	29.0	47.5	28.6	44.1	28.1	39.4

CBR Penetration Determination

Penetration after 96 hrs Soaking Period — Surcharge Weight:-4.55 KG

10 Blows Pen.mm	10 Blows Load, KN	10 Blows CBR %	30 Blows Pen.mm	30 Blows Load, KN	30 Blows CBR %	65Blows Pen.mm	65Blows Load, KN	65Blows CBR %
0.00	0.00		0.00	0.00		0.00	0.00	
0.64	0.089		0.64	0.091		0.64	0.11	
1.27	0.14		1.271	0.154		1.275	0.184	
1.91	0.179		1.91	0.194		1.91	0.228	
2.54	0.208	1.56	2.542	0.23	1.72	2.541	0.26	1.95
3.08	0.23		3.08	0.261		3.081	0.286	
3.81	0.26		3.81	0.294		3.816	0.319	
5.08	0.298	1.49	5.08	0.331	1.66	5.08	0.367	1.84
7.62	0.378		7.621	0.375		7.621	0.426	

Modified Max.Dry Density g/cc	1.423	OMC %	25.5

Swell Determination

Date		10 Blows Gauge rdg mm	Swell in %	30 Blows Gauge rdg mm	Swell in %	65 Blows Gauge rdg mm	Swell in %
22/12/2011	Initial	15.62	6.51	18.43	5.95	17.89	5.55
25/12/2011	Final	23.20		25.36		24.35	

Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %	Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %
2.54mm		0.2	1.6	6.51	2.54mm		0.2	1.7	5.95
5.08mm		0.3	1.5		5.08mm		0.3	1.7	

Dry Density at 95% of MDD: 1.352

Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %
2.54mm		0.3	1.9	5.55
5.08mm		0.4	1.8	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction
10	28.1	1.332	1.56	94
30	28.6	1.389	1.73	98
65	29.0	1.422	1.95	100

CBR % at 95 % MDD	1.622	Swell %	5.95

Sample 3:-WSS + 20% BW + 4% G

Compaction Determination

COMPACTION DATA		10 Blows Before soak	10 Blows After soak	30 Blows Before soak	30 Blows After soak	65 Blows Before soak	65 Blows After soak
Mould No.		N10	N10	N30	N30	N65	N65
Mass of soil + Mould	g	10699.9	10902.6	10919.3	11086.3	11002.9	11153.9
Mass Mould	g	6977.7	6977.7	7000.6	7000.6	6920.2	6920.2
Mass of Soil	g	3722.2	3924.9	3918.7	4085.7	4082.7	4233.7
Volume of Mould	g	2124	2124	2124	2124	2124	2124
Wet density of soil	g/cc	1.752	1.848	1.845	1.924	1.922	1.993
Dry density of soil	g/cc	1.335	1.278	1.420	1.364	1.487	1.434

Moisture Determination

MOISTURE CONTENT DATA		10 Blows Before soak	10 Blows After soak	30 Blows Before soak	30 Blows After soak	65Blows Before soak	65Blows After soak
Container no.		C1	A16	T3	D5	H23	HC12
Mass of wet soil + Container	g	63.80	55.49	74.99	58.54	65.00	53.2
Mass of dry soil + Container	g	53.60	43.70	62.20	48.84	54.50	43.35
Mass of container	g	21.00	17.23	19.50	25.20	18.60	18.09
Mass of water	g	10.2	11.8	12.8	9.7	10.5	9.9
Mass of drysoil	g	32.6	26.5	42.7	23.6	35.9	25.3
Moisture content	%	31.3	44.5	30.0	41.0	29.2	39.0

CBR Penetration Determination

Penetration after 96 hrs Soaking Period — Surcharge Weight:-4.55 KG

10 Blows Pen.mm	Load, KN	CBR %	30 Blows Pen.mm	Load, KN	CBR %	65Blows Pen.mm	Load, KN	CBR %
0.00	0.00		0.00	0.00		0.00	0.00	
0.641	0.142		0.64	0.202		0.64	0.251	
1.27	0.267		1.27	0.337		1.27	0.397	
1.91	0.369		1.91	0.439		1.91	0.539	
2.541	0.466	3.49	2.542	0.536	4.02	2.54	0.656	4.92
3.081	0.506		3.081	0.586		3.08	0.749	
3.811	0.55		3.81	0.652		3.81	0.852	
5.08	0.599	3.00	5.082	0.711	3.56	5.081	0.961	4.81
7.62	0.645		7.62	0.765		7.62	1.115	

Modified Max.Dry Density g/cc	1.450	OMC %	27.3

Swell Determination

Date		10 Blows Gauge rdg mm	10 Blows Swell in %	30 Blows Gauge rdg mm	30 Blows Swell in %	65 Blows Gauge rdg mm	65 Blows Swell in %
22/12/2011	Initial	17.88	5.27	18.32	4.50	15.22	4.28
25/12/2011	Final	24.01		23.56		20.20	

Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %	Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %
2.54mm		0.5	3.5	5.27	2.54mm		0.5	4.0	4.50
5.08mm		0.6	3.0		5.08mm		0.7	3.6	

Dry Density at 95% of MDD: 1.378

Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %
2.54mm		0.7	4.9	4.28
5.08mm		1.0	4.8	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction
10	29.2	1.335	3.50	92
30	30.0	1.420	4.03	98
65	31.3	1.487	4.92	103

CBR % at 95 % MDD	3.768	Swell %	4.50

Sample 4:-WSS + 30% BW + 6% G

Compaction Determination

COMPACTION DATA		10 Blows Before soak	10 Blows After soak	30 Blows Before soak	30 Blows After soak	65 Blows Before soak	65 Blows After soak
Mould No.		N10	N10	N30	N30	N65	N65
Mass of soil + Mould	g	10723.3	10982.4	10909.8	11180.8	11109.2	11273.1
Mass Mould	g	6945.3	6945.3	6971.2	6971.2	6952.3	6952.3
Mass of Soil	g	3778	4037.1	3938.6	4209.6	4156.9	4320.8
Volume of Mould	g	2124	2124	2124	2124	2124	2124
Wet density of soil	g/cc	1.779	1.901	1.854	1.982	1.957	2.034
Dry density of soil	g/cc	1.348	1.341	1.414	1.418	1.499	1.471

Moisture Determination

MOISTURE CONTENT DATA		10 Blows Before soak	10 Blows After soak	30 Blows Before soak	30 Blows After soak	65Blows Before soak	65Blows After soak
Container no.		D5	M	P64	P65	A01	P2
Mass of wet soil + Container	g	82.88	113.00	123.40	83.50	88.40	52.7
Mass of dry soil + Container	g	68.90	91.50	106.90	70.50	71.90	42.90
Mass of container	g	25.21	40.00	53.95	37.80	17.92	17.30
Mass of water	g	14.0	21.5	16.5	13.0	16.5	9.8
Mass of drysoil	g	43.7	51.5	53.0	32.7	54.0	25.6
Moisture content	%	32.0	41.7	31.2	39.8	30.6	38.3

CBR Penetration Determination

Penetration after 96 hrs Soaking Period — Surcharge Weight:-4.55 KG

10 Blows Pen.mm	10 Blows Load, KN	10 Blows CBR %	30 Blows Pen.mm	30 Blows Load, KN	30 Blows CBR %	65Blows Pen.mm	65Blows Load, KN	65Blows CBR %
0.00	0.00		0.00	0.00		0.00	0.00	
0.641	0.402		0.642	0.45		0.64	0.6	
1.271	0.697		1.269	0.797		1.27	1.077	
1.911	0.991		1.913	1.121		1.91	1.551	
2.54	1.226	9.19	2.541	1.454	10.90	2.541	1.854	13.90
3.08	1.429		3.08	1.689		3.08	2.079	
3.811	1.682		3.81	1.982		3.81	2.282	
5.08	1.981	9.91	5.081	2.271	11.36	5.08	2.571	12.86
7.621	2.255		7.621	2.555		7.619	2.855	

Modified Max.Dry Density g/cc	1.456	OMC %	28.250

Swell Determination

Date		10 Blows Gauge rdg mm	Swell in %	30 Blows Gauge rdg mm	Swell in %	65 Blows Gauge rdg mm	Swell in %
23/12/2011	Initial	15.43	2.47	19.14	1.94	16.94	1.68
26/12/2011	Final	18.30		21.40		18.90	

Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %	Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %
2.54mm		1.2	9.2	2.47	2.54mm		1.5	10.9	1.94
5.08mm		2.0	9.9		5.08mm		2.3	11.4	

Dry Density at 95% of MDD: 1.383

Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %
2.54mm		1.9	13.9	1.68
5.08mm		2.6	12.9	

No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction
10	30.6	1.348	9.91	93
30	31.2	1.414	11.36	97
65	32.0	1.499	13.90	103

CBR % at 95 % MDD	10.686	Swell %	1.94

Sample 5:- WSS + 40% BW + 8% G

Compaction Determination

COMPACTION DATA		10 Blows Before soak	10 Blows After soak	30 Blows Before soak	30 Blows After soak	65 Blows Before soak	65 Blows After soak
Mould No.		N10	N10	N30	N30	N65	N65
Mass of soil + Mould	g	10899.7	11009.7	10956.6	11184.1	11253.6	11384.5
Mass Mould	g	6992.5	6992.5	6953.5	6953.5	6973.5	6973.5
Mass of Soil	g	3907.2	4017.2	4003.1	4230.6	4280.1	4411
Volume of Mould	g	2124	2124	2124	2124	2124	2124
Wet density of soil	g/cc	1.840	1.891	1.885	1.992	2.015	2.077
Dry density of soil	g/cc	1.378	1.352	1.423	1.436	1.535	1.516

Moisture Determination

MOISTURE CONTENT DATA		10 Blows Before soak	10 Blows After soak	30 Blows Before soak	30 Blows After soak	65Blows Before soak	65Blows After soak
Container no.		A01	A13	D5	A4	C8	A16
Mass of wet soil + Container	g	51.81	47.23	46.69	46.74	57.16	55.1
Mass of dry soil + Container	g	43.20	39.20	41.40	39.20	44.90	42.30
Mass of container	g	17.50	19.09	25.10	19.72	5.70	7.72
Mass of water	g	8.6	8.0	5.3	7.5	12.3	12.8
Mass of drysoil	g	25.7	20.1	16.3	19.5	39.2	34.6
Moisture content	%	33.5	39.9	32.5	38.7	31.3	37.0

CBR Penetration Determination

Penetration after 96 hrs Soaking Period — Surcharge Weight:-4.55 KG

10 Blows Pen.mm	Load, KN	CBR %	30 Blows Pen.mm	Load, KN	CBR %	65Blows Pen.mm	Load, KN	CBR %
0.00	0.00		0.00	0.00		0.00	0.00	
0.643	0.324		0.642	0.344		0.641	0.383	
1.27	0.567		1.271	0.621		1.272	0.656	
1.911	0.781		1.91	0.856		1.91	0.912	
2.541	0.951	7.13	2.541	1.061	7.95	2.54	1.16	8.70
3.08	1.081		3.081	1.221		3.08	1.351	
3.81	1.202		3.81	1.382		3.81	1.522	
5.08	1.351	6.76	5.08	1.581	7.91	5.08	1.781	8.91
7.622	1.515		7.62	1.815		7.622	2.015	

Modified Max.Dry Density g/cc	1.480	OMC %	29.2

Swell Determination

Date		10 Blows Gauge rdg mm	10 Blows Swell in %	30 Blows Gauge rdg mm	30 Blows Swell in %	65 Blows Gauge rdg mm	65 Blows Swell in %
23/12/2011	Initial	18.69	2.03	17.80	1.37	16.61	1.11
26/12/2011	Final	21.05		19.40		17.90	

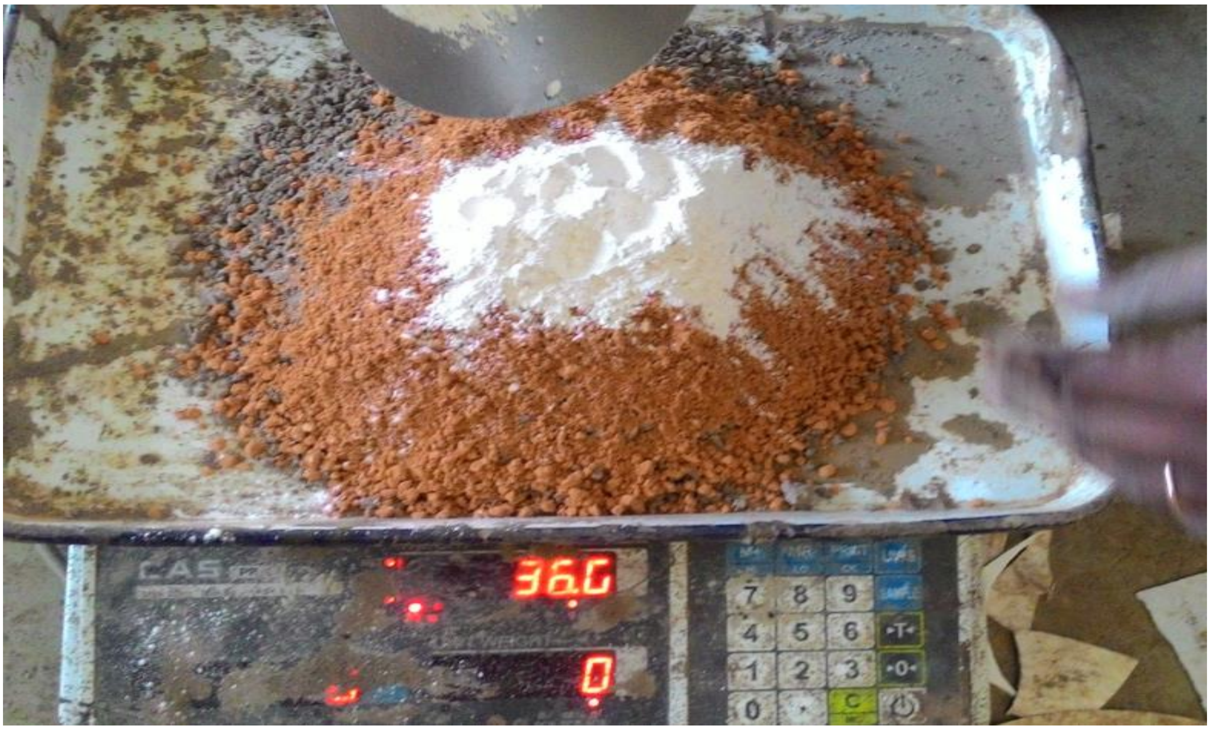
Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %	Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %
2.54mm		1.0	7.2	2.03	2.54mm		1.1	8.0	1.37
5.08mm		1.4	6.8		5.08mm		1.6	7.9	
					Dry Density at 95% of MDD:				1.406

Penetration (mm)	Load KN Top	Load KN Bottom	Corr. CBR %	Swell %	No.of blows	MCBS %	DDBS g/cm3	Correcrt CBR %	% OF Compaction
					10	33.5	1.378	7.15	93
2.54mm		1.2	8.7	1.11	30	32.5	1.423	7.98	96
5.08mm		1.8	8.9		65	31.3	1.535	8.91	104

CBR % at 95 % MDD	8.010	Swell %	1.37

APPENDIX III

LABORATORY ACTIVITY PHOTO

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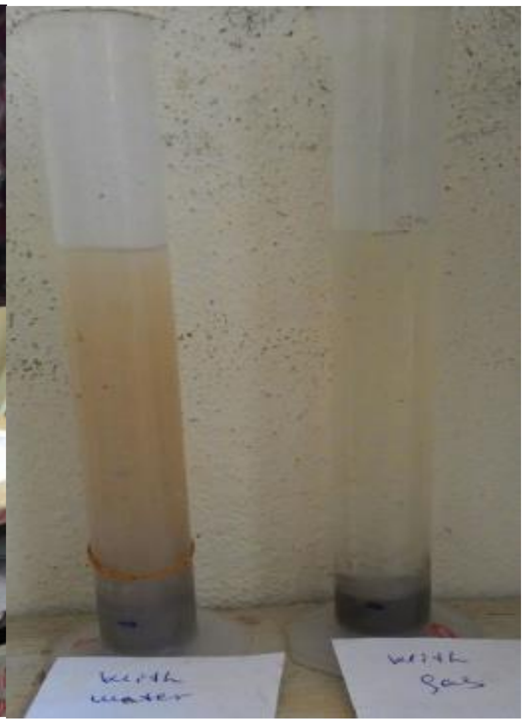
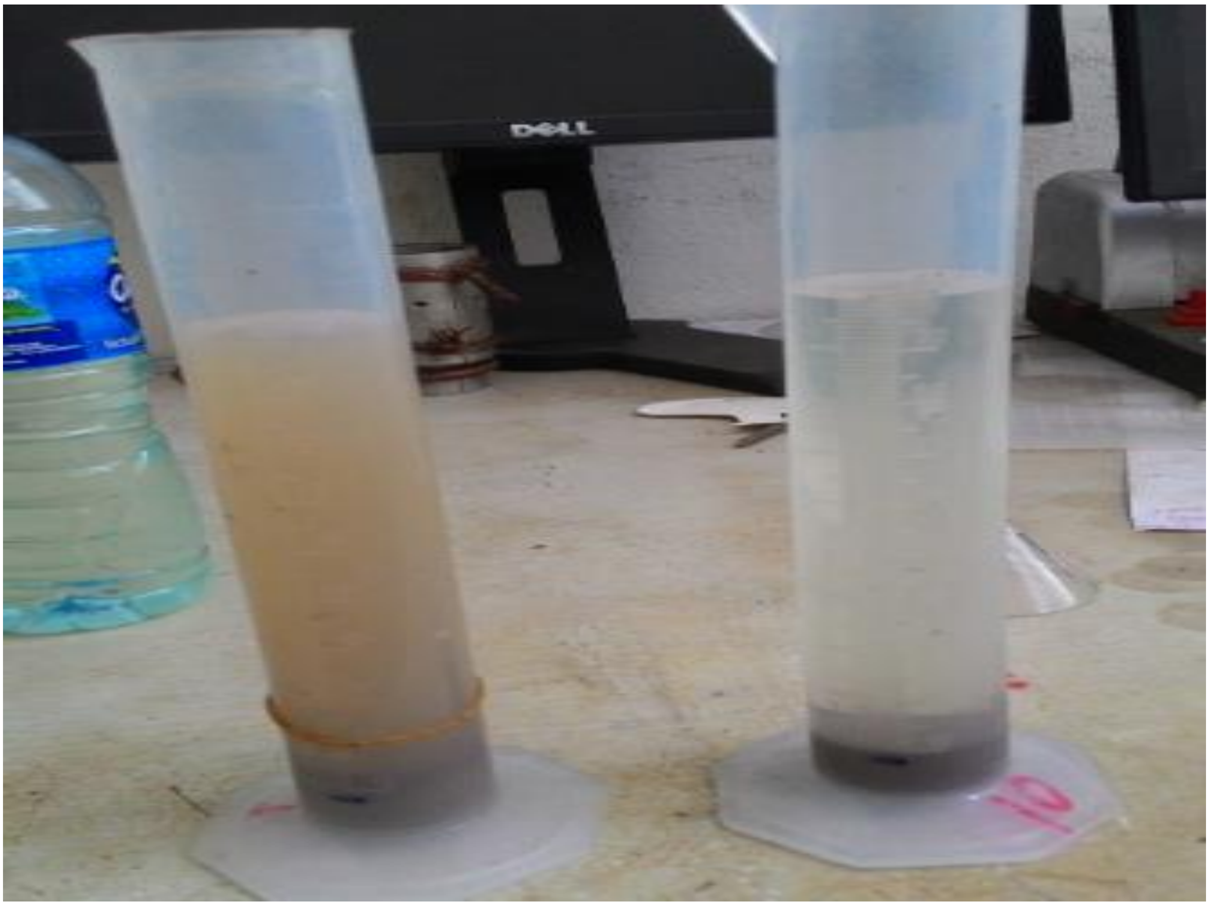

with water
with gas


DELL