JIMMA UNIVERSITY

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JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

Stabilization of Expansive Sub-Grade Soil Using Gypsum and Gypsum Blend with Brewery Spent Grain Ash

A research Proposal submitted to the School of Graduate Studies in Partial Fulfillment of the Degree of Master of Science in Civil Engineering (Highway Engineering)

By: Worku Yifru

March 2019

Jimma, Ethiopia

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DECLARATION

I hereby declare that this thesis entitled "Stabilization of Expansive Sub-Grade Soil Using Gypsum and Gypsum Blend with Brewery Spent Grain Ash." It is my original work and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for theses have been duly acknowledged.

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As Master research Advisors, we hereby certify that we have read and evaluated this MSc research prepared under our guidance, by **Worku Yifru** entitled: Stabilization of Expansive Sub-Grade Soil Using Gypsum and Gypsum Blend with Brewery Spent Grain Ash.

We recommend that it can be submitted as fulfilling the MSc Thesis requirements.

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ABSTRACT

Expansive soil problem is a serious problem due to a cause of damage for civil engineering structures and it influences the expansion of road construction in Ethiopia. Previously to reduce this problem, different stabilizer like cement, lime, flay ash, bitumen used to stabilize the expansive sub-grade soil but it requires high cost. Nowadays to be economical and due to the availability of material researcher use different innovative stabilizing agent from agricultural, industrial and agro-industrial waste like rice husk ash, molasses, groundnut ash, iron slag and Marble dust as a stabilizer.

Brewery spent grain is one of agro-industrial waste which produces from beer factory. This solid waste seed coat is made from melting of barley, maze or wheat after processed which covers around 85% of the total waste (Gupta, et al., 2010). *After converted to the ash characterize the pozzolanic property and elemental composition of BSG ash. However, it denies the pozzolanic according to ASTM D618 but it contains heavy cationic element which used for stabilization through cation exchange. Gypsum also used as a stabilizer but due to the availability, cost, applicability for other purpose requires high cost. The blending effect preferable than the individuals to modify the strength of expansive sub-grade soil. The aim of this study is to compare the effect and reduce the amount of gypsum required for stabilization of expansive sub-grade soil through partially replace of BSG ash.*

After conducted the required laboratory analysis for gypsum and BSG ash stabilized sub-grade by adding 5 – 20 percent with 5% interval. For gypsum stabilized the optimum effect happens at 20% which performed the high strength of sub-grade. PI, LS, OMC, MDD, CBR and CBR swell values for this percent were 24.93%, 11.43%, 30%, 1.475g/cm3, 5.51% & 3.87% respectively. The optimum effect of BSG ash stabilized for the strength of sub-grade happens at 5% with laboratory result of PI, LS, OMC, MDD, CBR and CBR swell were 36.3%, 15%, 29%, 1.472g/cm3, 4.97% & 4.08% respectively.

The Blending stabilization conducted with the optimum percent of gypsum taken as the cumulative amount of the two additives for different (G: BSG ash) ratio of 1:1, 1:2, 1:3 and 1:4. The optimum blending effect on the strength of stabilized sub-grade happens at 1:2 ratio which contains 6.7% of gypsum and 13.3% of BSG ash with laboratory result of PI, LS, OMC, MDD, CBR and CBR swell were 29.84%, 14.29%, 33%, 1.32, 5.53% & 3.65% correspondingly. Therefore, at 1:2 ratio 13.3% gypsum was replaced by BSG ash which have equivalent effect on the strength of sub-grade due to optimum percent of gypsum stabilized.

Key-word: Brewery Spent Grain ash, Gypsum, Expansive soil, Stabilization

TABLE of CONTENTS

LIST of TABLES

LIST of FIGURES

ACRONYM

AASHTO	American Association of Highway and Transportation Officials
ASTM	American Society for Testing and Materials British Standard
BSG	Brewers Spent Grain
CBR	California Bearing Ratio
CEC	Cation exchange capacity
CE	Cation exchange
ERA	Ethiopian Roads Authority
FSI	Free swell index
FSR	Free swell ratio
GSA	Groundnut shell ash
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PI	Plastic Index
PL	Plastic Limit
RHA	Rise husk ash
LS	Linear Shrinkage
USCS	Unified soil classfication systm
XRD	X-ray diffraction,
XRF	X-ray fluoresce

CHAPTER ONE

INTRODUCTION

1.1 Background

Engineering structures which construct on expansive soil will creates a problem due to swelling and shrinking behavior of sub-soil material. This type of soil becomes swells when it contacts with water and shrinks when it dry. In expansive soil areas, the soils are generally stiff and the chance of lightly loaded structures cracking due to settlement (Chen, 1988) and cause of damage for engineering structure like pavements, bridge and buildings. Expansive soil is a problem in Ethiopia (Alemayehu & Mesfin, 1999) as in other countries.

In order to treat this problem, stabilization should implement with different stabilizing additives to achieve the required specification of sub-soil materials. 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.

Commercial stabilizing agents like cement, lime and bitumen are used for soil stabilization. Although they are common additives, but due to the production industrially manufactured kept the cost financially high. On the other hand, large quantity of agricultural and domestic wastes like fly ash, bagasse ash (Barasa, et al., 2015), rice husk ash (Rama , et al., 2016), used as alternative and cost effective materials for soil stabilization.

Brewers Spent Grain (BSG) is one of solid agro-industrial waste from beer industry. It was reported that about 3.4 million tons of BSG from the brewing industry are produced in the Europe every year (Stojceska, et al., 2008). The Beer industry in Ethiopia has gone through tremendous growth around 15 Beer brands in the last two decades. Indirectly the production of BSG is a readily available with high volume.

Brewers Spent Grain (BSG) would have been developed and used successfully to partially replace some percent of gypsum for the reduction of construction cost. So, the use this wastes as an expansive soil stabilizer is a best solution.

1.2 Statement of problem

In the present days, Ethiopian economy is guide by agro-industrial practice. The waste material produced from these industries also increase through time. Hence beer production is one of the agro-industrial process that develop highly in Ethiopia and it release excessive production of solid waste of brewery spent grain (BSG). This solid waste seed coat is made from melting of barley, maze or wheat after processed which covers around 85% of the total waste (Stojceska, et al., 2008).

On the other hand, during the construction of road, the existing soil material should require special attention to be used as a sub-grade of pavement in order to reduce the problem due to expansiveness. This problem of material is the crucial cause for damage to engineering structures, buildings and transportation facilities for the case of highway pavement faller in many countries as well as Ethiopia and it contribute much amount of economic losses to the annual cost of damage for civil engineering structures (Bhavsar, et al., 2014). With regard to this problem treatment should require before construct the engineering structure by applying an appropriate, cost effective stabilization technique to improve the engineering properties of expansive sub-grade soil.

Previously there are many additives that used as stabilization for expansive clay soil such as Lime, cement, fly ash, bitumen, gypsum. From those common additives gypsum is one of higher cost, various application for construction sector and low accessibility of production in Ethiopia. Partially replace some percent brewery spent grain (BSG) ash in place of gypsum as stabilization material will reduce the problem in a great extent & the cost of construction may be minimized.

This study has been assessing the effect of BSG ash blend with Gypsum on engineering properties of expansive sub-grade materials for stabilization. Farther by applying the effective implement of this industrial waste as stabilization would have to reduce large financial losses, improve the stability of engineering structure like highway which are constructed on expansive sub-grade soil material and also use as agro-industrial waste treatment mechanism.

1.3 Research Question

- ✓ How to characterized the pozzolanic property of Brewery Spent Grain ash?
- ✓ What is the effect of Gypsum on the property expansive sub-grade soil?
- ✓ What is the effect of Brewery Spent Grain Ash on expansive sub-grade soil stabilization?
- ✓ What is the optimum percent of brewery spent grain ash required for partial replacement of gypsum as expansive sub-grade soil stabilization?

1.4 Research Objectives

1.4.1 General Objective

The general objective of this research was to stabilize the expansive sub-grade soil using gypsum and gypsum blend with brewery spent grain ash.

1.4.2 Specific Objectives

To achieve the main objective, the research will have the following specific objectives

- ✓ To determine the pozzolanic property of Brewery Spent Grain ash.
- ✓ To investigate the effect on the properties of expansive sub-grade soil stabilized with gypsum.
- ✓ To determine the effect on the properties of expansive sub-grade soil stabilized with Brewery Spent Grain ash.
- ✓ To determine the optimum amount of Brewery Spent Grain ash required for partial replacement of gypsum for expansive soil stabilization.

1.5 Significance of Study

The significance of the research was to use BSG ash as partial replacement of scares and expensive stabilizer for the stabilization of expansive sub grade soil. It also uses the alternative stabilizer which is environmentally friendly.

The positive results from this study indicated that locally available marginal materials used for the stabilizer of expansive sub grade soil. So that the government of Ethiopia will beneficial from using abundantly available resources of Agro-industrial waste instead of scares and expensive stabilizer to treat the problem due to expansiveness.

Additionally, the beer factory had gone further income and it serves as a waste treatment mechanism. Moreover, this research also serves as a reference guide for users, students and researchers who study about the related area for the application of industrial and agro-industrial waste use as an innovative stabilizer.

1.6 Scope of the Study

To address the general objectives of this research, the study was supported by different literatures, books, laboratory manuals and lab experiments. Characterize the physical and chemical properties of material also be done. However, the finding of this study was limited for one representative sample of expansive clay sub grade soil, after conducting the required laboratory test result indicated that the material is not suitable for road subgrade duo to highly expansiveness behavior. The study also investigates the effect of gypsum, brewer spent grain ash and the blending of the two through partially replacement of gypsum with BSG ash on the engineering properties of expansive or weak sub grade soil through stabilization. To develop the conclusion and recommendation based on laboratory result after conducting different laboratory tests such as gran size analysis, specific gravity, Atterberg limit, free swell for natural soil, liner shrinkage, maximum dry density, optimum moisture content, CBR and CBR swell for each respective stabilizer. The results were analyzed according to ERA, AASHTO and ASTM specification.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Soil is the weathered material which consists mainly sand and clay in the upper layers of the earth's crust. Much fine material has also been deposited by flooding of the land by the sea and the rivers. This process of sedimentation occurs many areas in the world. The problems due to the behavior of soil as a result of human activities like settlement of a road or a railway under the influence of its own weight and the traffic load (Verruijt, 2010).

Soil includes all earth materials, organic and inorganic, occurring in the zone overlying the rock crust. The behavior of a structure depends upon the properties of the soil materials on which the structure rests as well as properties of the soil materials depend upon the properties of the rocks from which they are derived. Soils are formed by the process of weathering of the parent rock might be by mechanical disintegration, and/or chemical decomposition prossece (Murthy, 1996).

Expansive soil always creates a problem for civil engineers for the construction structures like roads, bridge, buildings and others because of its peculiar cyclic swell shrink behavior. This type of soil swells when it comes in contact with water during the wet season and shrinks when it dry. Because of this movement lightly loaded structures such as foundations, highway pavements and canal beds on them were severely damaged (Chen, 1988). Expansive soil was a problem in Ethiopia as in other countries. To minimize this problem, implement different techniques of altering the nature of soil to make it a suitable material through stabilization by using industrial and agricultural wastes.

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

There are different additives to stabilized the expansive soil materials. Although industrial manufactured additives like cement, Lime, flay ash, bitumen etc are used as common traditional stabilizer, the cost of this material for stabilization financially high. Additionally, due to shortage of availability and high applicability through time those additives are difficult to use as a stabilizer.

The large quantity of agricultural and industrial wastes were produced like fly ash, bagasse ash, rice husk ash, brewery spent grain etc. creates a potential negative impact on the environment causing air and water pollution which affecting the local ecosystem. Hence safe disposal mechanism for those waste materials was required.

The use of those material as alternative for an innovative stabilizer of expansive sub grade soil whether fully or partially replace the common additives for stabilization was best solution as project cost minimization and waste disposal mechanism.

Brewery spent gain is one of the major industrial by-products which produce from barley through Beer process. It was the high waste industrial by-product and increase production through time in Ethiopia due to the development of beer factory. This paper tries to investigate the effect of brewery spent grain ash for partial replacement of Gypsum used as the stabilizer of expansive sub grade soil.

2.2 Soil Classification System

Soil classification is the arrangement of soil in to groups which have similar behavior (Dr. Arora, 2004). The main objective of any soil classification system is predicting the engineering properties and behavior of a soil based on a few simple laboratory or field tests. Based on the laboratory or field test results, identify the soil and categorized into groups with similar engineering characteristics. Although there are many classification systems like particle size, textural, AASHTO and USCS classification, the last two classification systems are more common.

2.2.1 AASHTO Classification System

According to AASHTO, Particle size analysis and plasticity characteristics are required to classify soil for both coarse-grained and fine-grained from A-1 to A-7 of soil classification.

This classification system required particle size analysis, plasticity index and liquid limit should be determined to grouped the soil with similar engineering characteristics (Dr. Arora, 2004).

Table 2. 1 AASHTO Soil Classification System (Nelson and Miller, 1992)

Soil group		Grain size %passing			Liquid limit	Plasticity index	Mineral type	Sub-grade range
		#10 sieve	#40 sieve	#200 sieve				
A-1	A-1-a	≤50	≤30	≤15		≤6	Stone, gravel sand	Excellent to good
	A-1-b		≤50	≤25		≤6		
A-3			≥51	≤10		Nonplastic	Fine sand	
A-2	A-2-4			≤35	≤40	≤10	Silty sand Clayey gravel and sand	
	A-2-5			≤35	≥41	≤10		
	A-2-6			≤35	≤40	≥11		
	A-2-7			≤35	≥41	≥11		
A-4				≥36	≤40	≤10	Silty soil	
A-5				≥36	≥41	≤10	Silty soil	Fair to poor
A-6				≥36	≤40	≥11	Clayey soil	Fair to poor
A-7	A-7-5			≥36	≥41	≥11 PI≤LL-30	Clayey soil	Fair to poor
	A-7-6			≥36	≥41	≥11 PI>LL-30	Clayey soil	Fair to poor

2.2.2 USCS Classification System

Unified soil classfication system (USCS) was first developed by casagrande in 1948 and modefied by Bureau of reclimetion and crop engineers of USA (Kalinski, 2011). It has also accepted by American Society of Testing Mterials (ASTM) and mostpopular classification system for all types engineering problems involving soli. This method is used to categorized the soil with similar engineering properties, including strength, permeability and compressibility which specifying soil types to achieve a desired performance (Kalinski, 2011).

According to USCS, soils are classified as coarse-grained or fine-grained as follows:

- Coarse-grained when soil sample retained on sieve #200 (0.075 mm) more than 50 percent. Coarse-grained soils are further classified as:

- ✓ Gravels if 50 percent or more of the coarse fraction is retained on #4 (4.75mm) sieve
- ✓ Sands if 50 percent or more of the coarse fraction passes through #4 (4.75 mm) sieve.

❖ Fine-grained if 50 percent or more of the sample passes #200 (0.075 mm) sieve. Fine-grained soils are further classified according to whether their liquid limit is less than or greater than 50 percent.

Table 2. 2 Unified Soil Classification System (ASTM D2487)

Major Group	Sub-Group	Symbol	Description
Coarse-Grained soil (>50% retained #200 sieve)	**Gravels** (>50% coarse fraction retained on #4 sieve)	GW	Well-graded gravels and gravel-sand mixtures (little or no fines)
		GP	Poorly-graded gravels and gravel-sand mixtures (little or no fines)
		GM	Silty gravels (gravel-sand-silt mixtures)
		GC	clayey gravels (gravel-sand-clay mixtures)
	Sands (>=50% coarse fraction pass through #4 sieve)	SW	Well-graded sands and gravelly-sands mixtures (little or no fines)
		SP	Poorly-graded sands and gravelly-sands mixtures (little or no fines)
		SM	Silty sands (sand-silt mixtures)
		SC	clayey sands (sand-clay mixtures)
Fine-Grained soil (>=50% pass through #200 sieve	**Silts and Clays** (with Liquid Limit <50%)	ML	Inorganic silt (very fine sands, silty or clayey sands)
		CL	Inorganic clays of low-to medium plasticity
		OL	organic silts and silty-clay of low plasticity
	Silts and Clays (with Liquid Limit >=50%)	MH	Inorganic silts, elastic silts
		CH	Inorganic clay of high plasticity
		OH	Organic clay of medium-to high plasticity
		PT	Peat muck and other organic soil

2.3 Expansive Clay Soil

According to (Matalucci, 1962) Clay material is a natural, earthy, fine-grained material which when mixed with a limited amount of water develops plastic properties and composition of crystalline minerals consisting of essentially hydrous aluminum silicates. Based on the Atterberg limits value and gradation test to describe the clay soil qualitatively as having low, medium, high, or very high expansion potential. In general, these soils classified as CL or CH as per USCS as well as A-6, or A-7 as per AASHTO classification systems may be considered as expansive soil (Murphy, 2010). Expansive clay soils are problematic soils because of their inherent potential to undergo volume changes corresponding to changes in the moisture variation. It starts swell or shrink excessively due to change in moisture content (Bhavsar, et al., 2014).

2.3.1 Origin of Expansive Clay Soil

The parent materials that can be associated with expansive soil into two groups. first group comprises the basic igneous rocks such as basalts, dolerite sills, dykes and gabbro. In these soils, the feldspar and pyroxene minerals of the parent rocks have decomposed to form montmorillonite and other secondary minerals. The second group comprises the sedimentary rocks that contain montmorillonite as a constituent which breaks down physically to form expansive soils (Chen, 1988).

2.3.2 Composition of Clay Minerals

Clay have the great rolls for expansive behavior of the soil. Clays are composed of extremely small crystalline particles of one or more members of a small group of minerals. These minerals are essentially hydrous aluminum silicates, with magnesium or iron replacing wholly or partially for the aluminum. Many clay materials may contain organic material and water-soluble salts.

Table 2. 3 Clay minerals

Name of mineral			Structural formula
I	Kaolin group	Kaolinite	$Al_4Si_4O_{10}(OH)_8$
		Halloysite	$Al_4Si_4O_6(OH)_{16}$
II	Montmorillonite group	Montmorillonite	$Al_4Si_8O_{20}(OH)_4$ n H_2O
III	Illite group	Illite	$K_y(AlFe_2.Mg_4.Mg_6)Si_{8-y}Al_y(OH)O_{20}$

The three most important groups of clay minerals are montmorillonite, Illite, and kaolinite, which are crystalline hydrous alumina-silicates with the help of X-ray technology minerals are identified (Alemayehu & Mesfin, 1999) (Chen , 1975).

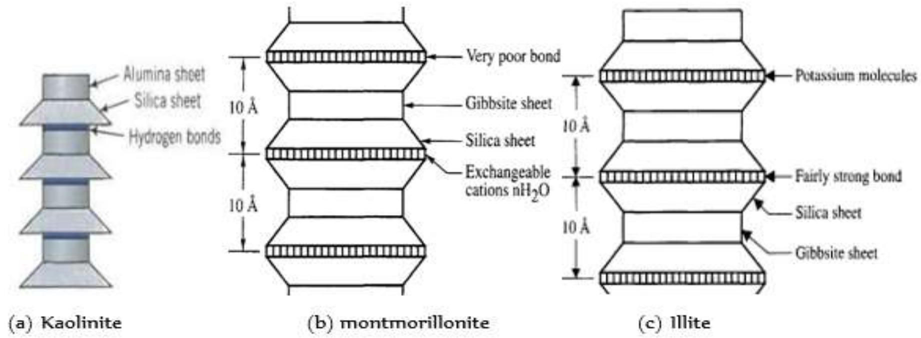


Figure 2. 1 Structure of clay minerals

Kaolinite

Kaolinite is the common clay in humid tropical region and the least active of the three clay minerals figure 2.1(a). The general chemical formula is $Al_2 (Si_2O_5) (OH)_4$.

Illite

Illite is medium active mica like clay minerals and a predominant constituent of many shells. The potassium ions (K^+) occur between unit layers. It does not swell as much in the presence of water as does montmorillonite figure 2.1(c). The composition of this mineral is K_y $Al_2[Fe_2$ $Mg_2Mg_3]$ $(Si_{4-y}$ $Al_y)$ O_1.

Montmorillonite

Montmorillonite is more colloidal than kaolinite and more active mineral. The structural arrangement of this mineral is composed of two silica tetrahedral sheets with a central alumina octahedral sheet. Water can enter between the sheets, causing them to expand significantly and thus the structure can break into 10Å thick structural units. Soils containing a considerable amount of montmorillonite minerals will exhibit high swelling and shrinkage characteristics. Bentonite clay belongs to the montmorillonite group figure 2.1(b). The general chemical formula is Al_2 [Mg] (Si_4O_{10}) $(OH)_2$ + XH_{20}.

The three common types of clay mineral have different expansiveness property.

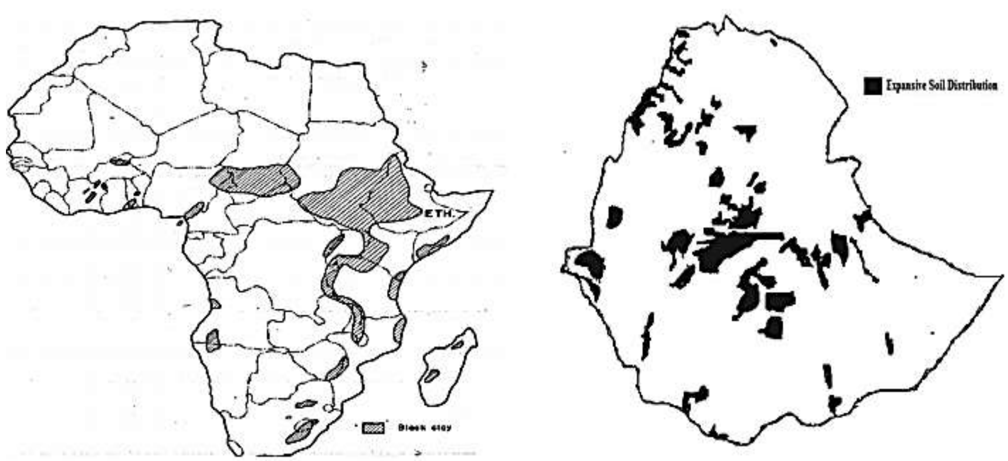
- Kaolinite => low degree of expansiveness
- Illite => moderate degree of expansiveness
- Montmorillonite => very high degree of expansiveness

2.3.3 Impact of Expansive Soil

The six major world natural hazards are earthquakes, landslides, expansive soils, hurricane and flood. Among America's most destructive natural hazards, expansive soils problem has the second place next to hurricane wind problem in terms of dollar losses to buildings. According to the study, it was projected that by the year 2000, losses due to expansive soil would exceed 4.5 billion dollars annually (Chen, 1988).

2.3.4 Distribution of Expansive Soil

Expansive soils problem is widespread throughout world. The countries which affect by this problems are Australia, United States, Canada, China, Israel, India, and Spain, Israel, Turkey, Argentina, Venezuela (Chen, 1988; Murthy, 1996) (Chen , 1975). It also widespread in the African continent Figure 2.4 (a), occurring in South Africa, Ethiopia, Kenya, Mozambicans, Morocco, Ghana, Nigeria (Alemayehu & Mesfin, 1999).



a) Expansive soil in Africa (Alemayehu & Mesfin, 1999) b) Expansive soil in Ethiopia (Nardos , 2015)

Figure 2. 2 Distribution of Expansive Soils in Africa and Ethiopia

Expansive soil problem also observed in central part Ethiopia Figure 2.4 (b) following the major trunk road like Addis Ababa - Ambo, Addis Ababa - Weliso, Addis Ababa to Debere-Berehan, Addis Ababa - Gohatsion, Addis Ababa -Mojo. Also the cover the area like Mekelle, Bahirdar, Gambela, Arba-Minch 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 (Bantayehu , 2017) (Nardos , 2015). The soil type in and around Bahir-Dar (Dagmawe, 2007) up to Wereta is highly expansive.

2.3.5 Nature of Expansive Clay Soils

Soils materials which have high clay content are mostly responsible for expansiveness behavior. This material becomes to swell when the moisture through it increase and It becomes shrinks greatly on drying and develop cracks on the surface. These soils possess a high plasticity index (Alemayehu & Mesfin, 1999; Murthy, 1996) and their color varies from dark grey to black. The general characteristics of Black cotton soils are:

- Easy to recognize these soils in the field during either dry or wet seasons.
- Shrinkage cracks are visible on the ground surface during dry seasons.
- The maximum width of these cracks may be up to 20 mm or more and they travel deep into the ground.
- Dry black cotton soil requires a hammer to break.
- During rainy seasons, these soils become very sticky and very difficult to traverse.

Water clay interaction

In nature every soil particle is surrounded by water. Since the centers of positive and negative charges of water molecules do not coincide, the molecules behave like dipoles. The negative charge on the surface of the soil particle attracts the positive (hydrogen) end of the water molecules (Budhu, 2000) (Braja & Das, 2008).

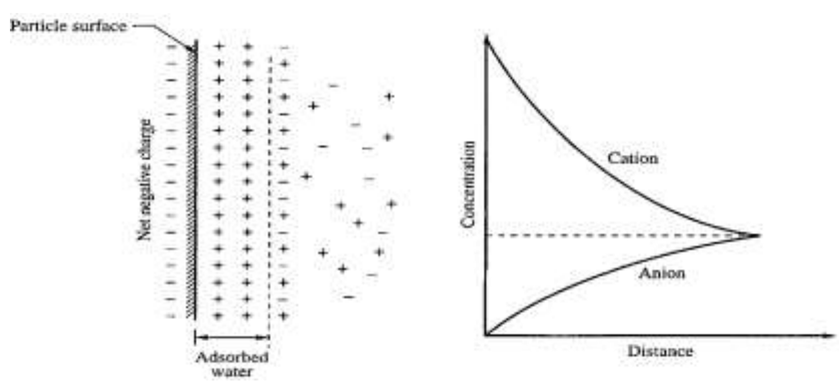


Figure 2. 3 Adsorbed water layer surrounding a soil particle

Cation Exchange

Clay particle are normally negatively charged. Similarly charged particles repel each other and cause a dispersion in soil. These negatively charged clay particles can be held together with positively charged cations. The process is termed as flocculation. Different cations have different flocculation power. Cation exchange is the process in which weak flocculator cations are replaced with cations of high flocculating power.

Cation exchange capacity (CEC)

Cation exchange capacity of soil represents the number of exchangeable cations in the clay mineral which can be replaced by the cations of higher replacing power than the absorbed cations. The CEC of a soil is a function of the amount and type of soil colloids present.

Swell potential

Swell potential is the measure of volumetric change in various soils on their interaction with water. Different experimental and empirical methods have been developed to determine swell potential of clayey soils.

Table 2. 4 Soil Classification Based on Swell Potential, CEC and PI

Soil type	Swell Potential (Seed et al., 1962)	cation exchange capacity (Yilmaz I., 2004)	Plasticity Index PI
Very High swelling	> 25	> 55	>35
High swelling	5 – 25	37 – 55	20-35
Medium swelling	1.5 – 5	27 – 37	10-25
Low swelling	< 1.5	< 27	0-15

2.3.6 Identification Method of Expansive clay soil

Generally, it has two way of identification mechanism for expansive soil.

2.3.6.1 Field Identification

The soil which have high swelling potential can be identified through field observations without any laboratory test by simply observe the physical behavior of the soil. Those behavior includes (Nelson & Miller, 1992):

- The color was black or gray.
- Wide or deep shrinkage cracks.
- The strength was High when it dry and low during wet.
- Stickiness and low traffic ability when wet.
- Appearance of cracks in nearby structures.

2.3.6.2 Laboratory Recognition of Expansive Soils

There are three different methods of classifying potentially expansive soils. Such as:

1. **Mineralogical Identification**

According to (Chen , 1975), Various methods of mineralogical identification are important in a research laboratory in exploring the basic properties of clays. These properties are a fundamental factor controlling expansive soil behavior (Nelson & Miller, 1992) by conducting such test:

- X-ray diffraction,
- Differential thermal analysis,
- Dye adsorption,
- Chemical analysis, and
- Electron microscope resolution.

But these methods are not suitable for routine tests because of time consuming, require expensive test equipment and results can only interpret by specially trained technicians.

2. **Single Index Method**

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 Atterberg limit, free swell, cation exchange capacity (Nelson & Miller, 1992)

3. **Direct Methods**

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

2.4 Soil Stabilization

In the past when the soil on the site was poor engineering characteristics and Bearing capacity, the site should be change other alternative which pass through a suitable location. Otherwise remove poor subsoil and replace the selected material and compact it to achive the required design spesification. The current practice due to the lack of alternativ land for high expansion construction of highway and other civil engineering structurs, several methods of soil improvement should apply to modify the engineering properties of the natural problematic soils such as, expansive soft clays and organic soils to meet the design specifications. This state the art review focuses on soil stabilization.

Soil stabilization is a geotechnical technique of increasing and maintaining the stability of soil mass and chemical or mechanical alteration of soil to enhance their engineering properties. Stabilization increases soil strength, decreases plasticity, lowering or sometimes increases permeability, hence resulting in higher soil strength, lower volume changes due to temperature or moisture variations and increases workability of soil (Sikarwa & Trivedi K.M , 2017).

The soil available for construction of any civil engineering structure often do not meet the requirements for construction. The process by which the properties of soil are improved so as to meet the construction requirement is called stabilization (Alemayehu & Mesfin, 1999).

2.4.1 Definition of Stabilization

According to the Universal Dictionary, stability means, "The quality or state of being stable, strength to stand and to resist being moved, fixedness as contrasting to fluidity, not subject to change or destruction, not easily moved from a state of equilibrium."

Additionally, It defined as a modification of an existing soil so as to improve its bearing or load absorbing characteristics (Matalucci, 1962), Also it is the process of blending and mixing materials with a soil to improve certain engineering properties of the soil in order to achieve a desired gradation or the mixing of commercially available additives that may alter the gradation, texture or plasticity act as a binder for cementation of the soil.

2.4.2 Advantages of Soil Stabilization

Individual project conditions dictate different reasons for treatment. These will have great impact on the type and percentage of additive required. Common reasons for the need for stabilizations (Bhavsar , et al., 2014) are:

- Provide a working platform for construction of subsequent layers by drying out wet areas and/or temporarily increasing strength properties
- Reduce shrink/swell of expansive soils or existing materials.
- Increase strength to provide long-term support for the pavement structure.
- Reduce pavement thickness and improve durability.
- Reduce moisture susceptibility and improves soil workability.
- Utilize local materials and upgrades materials.
- For the reduction of cost.

2.5 Stabilization Mechanism

Soil stabilization mechanism is the method which used to change one or more engineering properties of soil so as to improve the desired performance. The mechanism of stabilization may be broadly classified in to two categories. Those are mechanical (physical) stabilization and chemical stabilization. Mechanical method includes replacement with non-expansive fill and compaction. Whereas chemical stabilization enhances the geotechnical properties of clayey soil by addition of different materials, in different amount such as fly ash, quick lime, Portland cement, bitumen, calcium chloride, magnesium chloride, potassium chloride, etc. The overall stabilization mechanism as shown in figure below.

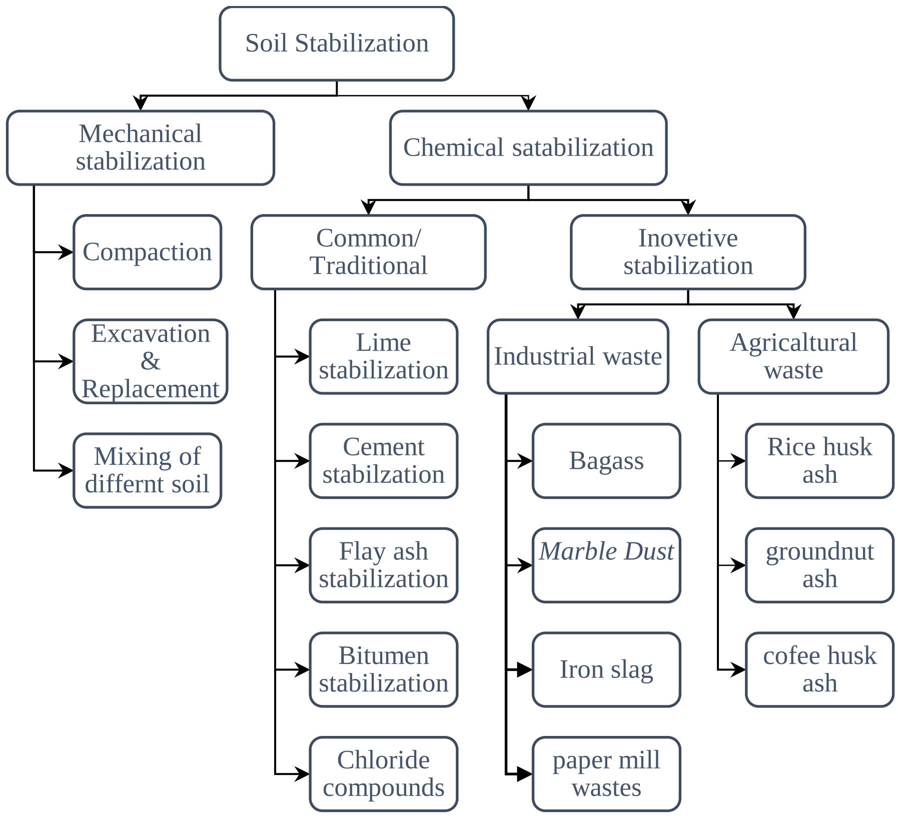


Figure 2. 4 Stabilization Mechanism

2.5.1 Mechanical Stabilization

Mechanical stabilization is a stabilization technic that improve the engineering properties of subgrade soil without altering any chemical admixtures or stabilizer. This method is used to improve stability weak sub grade and shear strength characteristics of the soil through compaction, replacement unsuitable material with non-expansive fill, addition of aggregates, soil reinforcement and mixing or blending soils with different gradations to obtain a material that meet the required specification.

2.5.2 Chemical stabilization

Chemical stabilization includes the mixing or injecting of chemical substances into the soil. Expansive clayey soil by addition of different materials with different amount such as Portland cement, lime, asphalt, calcium chloride, sodium chloride, and paper mill wastes are common chemical stabilizing agents (Habtamu , 2015). The effectiveness of these additives depends on the soil conditions, stabilizer properties and type of construction.

Those stabilizer materials are categorized in to Organic and inorganic chemicals. Organic like Cement, Lime, fly ash, gypsum and Bituminous stabilizer have both been used in the laboratory with successful results. Other inorganic chemicals such as sodium silicate, calcium hydroxide, sodium chloride, calcium chloride, and phosphoric acid have been used to stabilize expansive soil (Chen , 1975).

2.5.3 Chemical stabilization Process

Chemical additives used as a stabilizer of expansive soils through different process. Those process which used for stabilize soils and modify their properties through cation exchange, flocculation, agglomeration and pozzolanic reactions.

2.5.3.1 Cation Exchange

Negatively charged clay particles adsorb cations of specific type and amount. The replacement or exchange of cations depends on several factors, primarily the valence of the cation. Higher valance cations such as the calcium ion Ca^{2+} easily replace cations of lower valance such as sodium ions Na^{+} (Mitchell & Soga, 2005) which reduce the space between the clay surface as shown in figure 2.5.

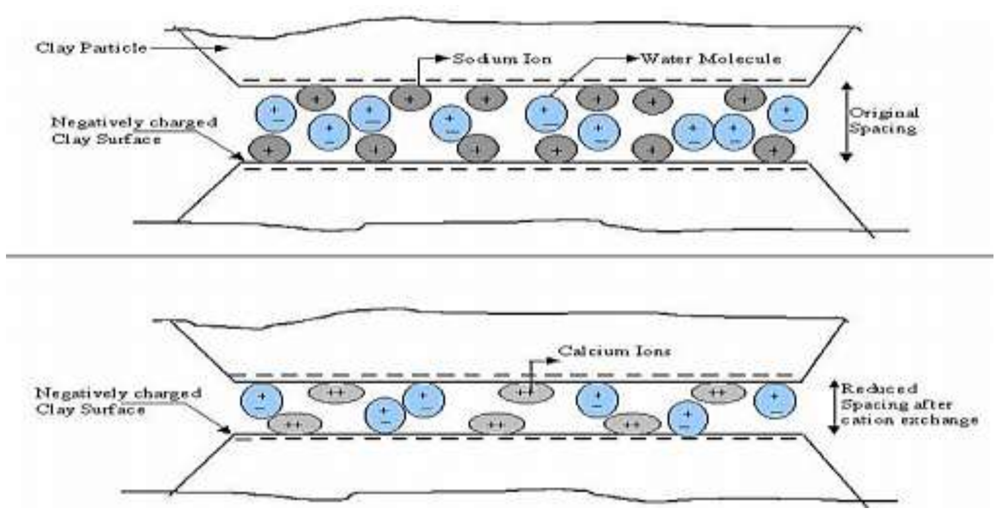


Figure 2. 5 Reduction of space in clay layer through cation exchange

Other conditions are equal cation with different metallic series replace each other, trivalent cations are held more tightly than divalent and the divalent cations are held more tightly than monovalent cations (Mitchell & Soga, 2005).

A typical replace ability series are:

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

- ☞ Decrease Swelling Potential and diffuse double layer (DDL)
- ☞ Decrease the Expansiveness of the clay as flow from Na^{+} to Th^{4+}

2.5.3.2 Flocculation and Agglomeration

Cation exchange reaction result in the flocculation and agglomeration of the soil particles with consequent reduction in the amount of clay-size materials and hence the soil surface area, which inevitably accounts for the reduction in plasticity. Flocculation and agglomeration change the clay texture from that of a plastic, fine grained material to that of a granular soil (Yazici, 2004). Flocculation is the process of clay particles altering their structure from a flat, parallel structure to a more random orientation. Agglomeration is thought to occur as the flocculated clay particles begin to form weak bonds at the edge surface interfaces of the clay particles, because of the deposition of cementitious material at the clay particle interfaces.

2.5.3.3 Pozzolanic Reactions

Pozzolanic reaction is a secondary process of soil stabilization. One prerequisite for the formation of additional cementing materials is the solution of silica and alumina from clay components. The high pH environment of a soil cement system increases the solubility and reactivity of the silica and alumina present in clay particles. The degree of the crystallinity of the minerals and particle size distribution are some factors influencing solubility. It is postulated that calcium ions combine with silica and alumina dissolved from the clay lattice to form additional cementitious material (C-S-H and C-A-H), (Tasong, 1999).

Calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) are the two outputs in pozzolanic reactions.

$$Ca^{2+} + 2(OH)^{-} + SiO2 \text{ (Clay Silica)} \rightarrow CSH$$

$$Ca^{2+} + 2(OH)^{-} + Al2O3 \text{ (Clay Alumina)} \rightarrow CAH$$

2.6 Stabilizing Agent for Expansive Clay Soil

Stabilizing agents are manufactured commercial products, industrial or agricultural by-product that, when added to the soil in the proper quantities improve some engineering characteristics of the soil such as strength, texture, workability and plasticity.

2.6.1 Common or Traditional Stabilizing Agent

Common stabilizing agents are well known manufactured commercial products that used for stabilizing of problematic soil such as Portland cement, lime, fly ash, gypsum, water soluble salts, various types of bituminous compounds and various combinations of the above have been used with very successful results (Matalucci, 1962). Each stabilizer has its own particular influence on the properties of different sub grade soil.

2.6.2 Innovative Stabilizing Agent

Growing cost of traditional stabilizing agents and the need for the economical utilization of industrial and agricultural wastes for beneficial engineering purposes has encouraged an investigation into the stabilizing potential of expansive clay soil. Thus, the possible use of agricultural waste, such as bagasse ash, rice husk ash (Rama , et al., 2016), groundnut ash (Sampan, 2007) and industrial wastes, such as molasses (Barasa, et al., 2015), iron slag are considerably reduce the cost of construction and as well as reduce or eliminate the environmental hazards caused by such waste. These stabilizing agents is preferable due to the following reason: -

- Due accessibility and production of innovative stabilizers such as industrial or agricultural wastes are far cheaper than common/traditional stabilizers.
- Innovative stabilizers are environmentally friendly compared with common stabilizers
- Waste management from the huge factories also can be done economically by using as a stabilizer

Therefore, use of these innovative stabilizers for improving engineering properties of the Soil are an economical solution for Ethiopia as it is available in large.

2.7 Gypsum

Gypsum is a soft sulfate mineral composed of calcium sulfate dihydrate, with the chemical formula $CaSO_4 \cdot 2H_2O$. It is the mineral calcium sulphate with two water molecules attached. It contains 23% calcium, 18% Sulphur and its solubility is 150 times that of limestone. Gypsum naturally occurs in sedimentary deposits from ancient sea beds and it is also a by-product of many industrial processes. Specific gravity value was obtained as a range between 2.32 to 2.36.

2.7.1 Physical properties of Gypsum

Physical properties of Gypsum (Goyal, et al., 2016)

Table 2. 5 Physical properties of Gypsum

Chemical classification	Sulphate
Color	Colorless, white
Specific gravity	2.3
Chemical composition	Hydrous calcium Sulphate, $CaSO_4.2H_2O$
Crystal system	Monoclinic
Use	Use to manufacture dry wall, plaster, joint compound, agricultural soil treatment

2.7.2 Application of Gypsum

Gypsum has different application such as used as a plaster material, in wallboard, pottery, casting, sculptures, fertilizers, a retarder in cement and principle use as setting time regulator for Portland cement industry. Generally, Gypsum board and Gypsum powders are widely used as construction materials mainly for interior finishing like partition, walls, ceiling and also used for cement and stucco production. The demand for gypsum is directly related with the growth in the construction sector.

Different research shows that the effect of gypsum, phosphogypsum and combination of gypsum products with other stabilizing agents and admixtures used as a stabilizer for weak soil. According to (Yilmaz & Civelekoglu, 2009) gypsum can also be effectively used as a stabilizing agent (Usama , et al., 2011) effect of the soaking condition for gypsum stabilization and (Nurhayat, 2008) the effect of natural gypsum and waste phosphogypsum were used as admixtures to improve the engineering properties soft soil.

2.7.3 Dejen gypsum factory production

Dejen gypsum factory plc, the first manufacturer of gypsum powder for plastering & chalk, gypsum board and gypsum ceiling board in Ethiopia, is manufacturing best qualities of gypsum powder which able to produce around 50 thousand tons per year.

The row material for Dejen gypsum factory, the rock is extracted from Abay wild region that white gypsum rock for molding purpose of housing construction, black gypsum rock for chuck production and brown gypsum rock for board production. The other row materials for Gypsum Powder Production is citric acid (CH_3COOH) to increase setting time chuck & fuel coal, wood for thermal processing as a source of heat for calcinations purpose.

2.8 Beer Industry waste

The Beer industry generates large amounts of wastes such as spent grain 14 to 20 kg/hl, spent hops 0.2 to 0.4 kg/hl, residual yeast 1.5 to 3kg/hl and Diatomaceous earth 0.1 to 0.2kg/hl being the most common (Mathias, et al., 2014).

2.8.1 History of Beer Industry in Ethiopian

The Beer industry in Ethiopia has gone through fantastic growth in the last two decades. It transformed into one of the most competitive industries in Ethiopia with millions of birr spent on advertisements alone. The growth of beer factory increases from time to time in Ethiopia. Nowadays, it reaches around top 15 Beer brands. Indirectly, the waste from these factories are increase through time in Ethiopia.

2.8.2 Brewers Spent Grain (BSG)

Brewing industry generates relatively large amounts of wastes like spent grain, spent hops and yeast being the most common. The residual solid fraction known as brewers spent grain. BSG is the most abundant brewing by-product that covers around 85% of total waste generated from beer factory (Gupta, et al., 2010). It is a readily available, high-volume low-cost by-product of brewing (Waldron , et al., 2010) (Robertson , et al., 2010). It was reported that about 3.4 million tons of BSG from the brewing industry are produced in Europe every year (Stojceska, et al., 2008) and over 4.5 million tons in US alone.

Figure 2. 6 Brewers Spent Grain

Brewery spent grain and Brewer's spent yeast are commonly produced byproduct feeds across all beer factories in Ethiopia. According to (Getu, et al., 2018) study out of 12 beer factories which operating in the year 2016/17 G.C were generate 26,722.8 tons of dry brewery spent grain as shown in Table 2.6. Major BSG producing companies taken as percentage share of the total produce were: BGI company St. George beer factories at (Adis Abeba, Kombolcha, Hawassa and Zebidar) 38%), Henken Prv. Lmt share company (Harar, Walia and Bedele) breweries 24%, Dashen Brewery share company in (Gonder and Debre-Birhan) 17%, Meta Abo brewery 8%, Habesha brewery 7% and Raya brewery 6% at the year of 2016/17 G.C (Getu, et al., 2018). Similarly, the total spent yeast production from all beer factories available in the country for same fiscal year was 360,758.1 hl.

Table 2. 6 Annual BSG and spent yeast production of Ethiopian beer factory at 2016/17 G.C

Name of beer Factor	BSG production (tons, dry mass)	Spent yeast Production (hectoliter)	BSG to Malt ratio	Factory gate price (Birr/kg dry mass)	
				BSG	Spent yeast
Meta Abo brewery	2,073.6	27,993.6	0.18	1.20	Disposed
Walia brewery	2,684.7	36,243.5	0.16	1.00	0.20
Bedele brewery	1,841	24,853.5	0.36	0.20	Free charge
Harar brewery	1,926.7	26,010.5	-	-	-
St. George, Adis Abeba	2,820	38,070	-	-	-
St. George, Kombelcha	2,740.1	36,991.4	-	0.28	Disposed
St. George, Hawassa	2,768.7	37,377.5	-	-	-
Dashen, Debre Birhan	1,832.6	24,740.1	0.20	0.60	Disposed
Dashen, Gonder	2,602.5	35,133.8	0.18	0.31	Disposed
Habesha brewery	1,828.4	24,683.4	0.20	0.25	Disposed
Zebidar brewery	1,883.5	25,427.3	0.32	0.40	Disposed
Raya brewery	1,721	23,233.5	0.25	0.15	Disposed
Total	26,722.8	360,758.1			

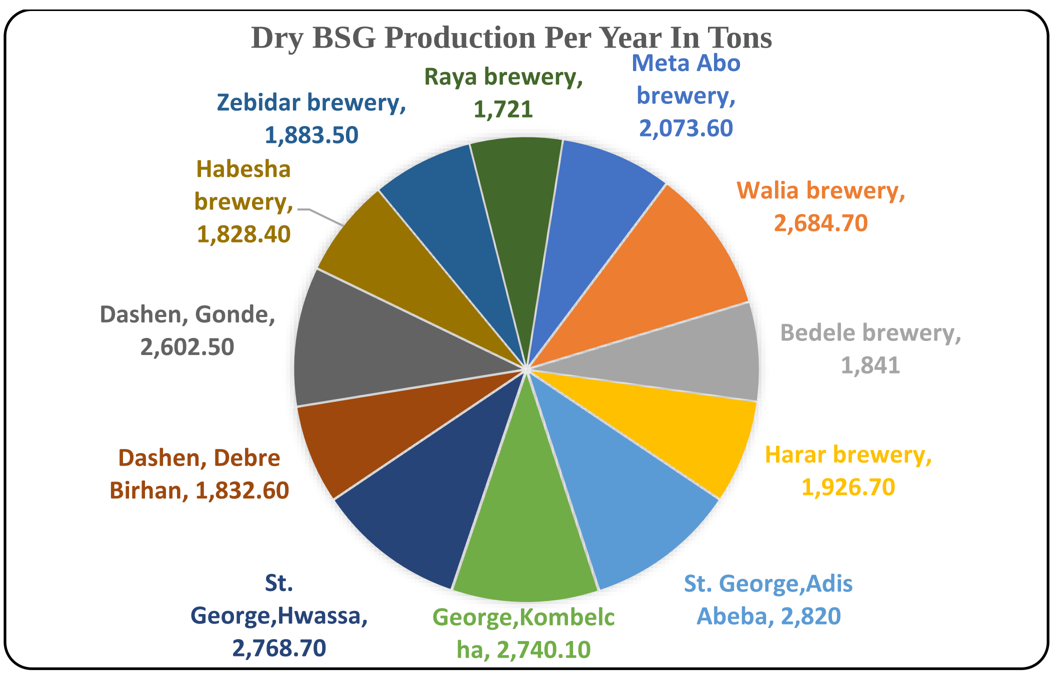


Figure 2. 7 Dry BSG production from Ethiopian beer factory at 2016/17 G.C

2.8.3 Mineralogical Composition of BSG

In addition to cellulose, hemicellulose, lignin and proteins, BSG composition also contains several minerals, which include calcium, sodium, potassium, magnesium, aluminum, iron, barium, strontium, manganese, copper, zinc, phosphorus, sulfur, chromium and silicon, at levels varying from 5.9 to 10 740.0 mg kg^{-1} dry weight (Roberto & Mussatto , 2006) (Khidzir , et al., 2010).

2.8.4 Potential Applications for Brewers' Spent Grain

Although BSG is the main by-product of the brewing process, it has received little attention as a marketable commodity and its disposal is often an environmental problem. Some possible applications for this agro-industrial by-product used as food ingredient for animals, fuel for energy production, charcoal production, brick production (Ferraz , et al., 2013), paper manufacture, adsorbent of heavy metals, substrate cultivation, enzyme production and biotechnological processes (Mussatto, et al., 2006) and (Jay, 2008). But in Ethiopia it is not much applicable rather than animal Food.

CHAPTER THREE

MATERIALS AND METHODOLOGY

The research work was intended to check the suitability of Gypsum and Brewery Spent Grain ash to improve and stabilize expansive sub-grade soil.

3.1 Study Area

The study area was located in Amhara region around Bahir Dar city approximately 578 km north-northwest far from Addis Ababa, having a latitude and longitude of 11°36′ - 11°52′N & 37°23′- 37°38′ E respectively at an elevation of about 1,800m above sea level.

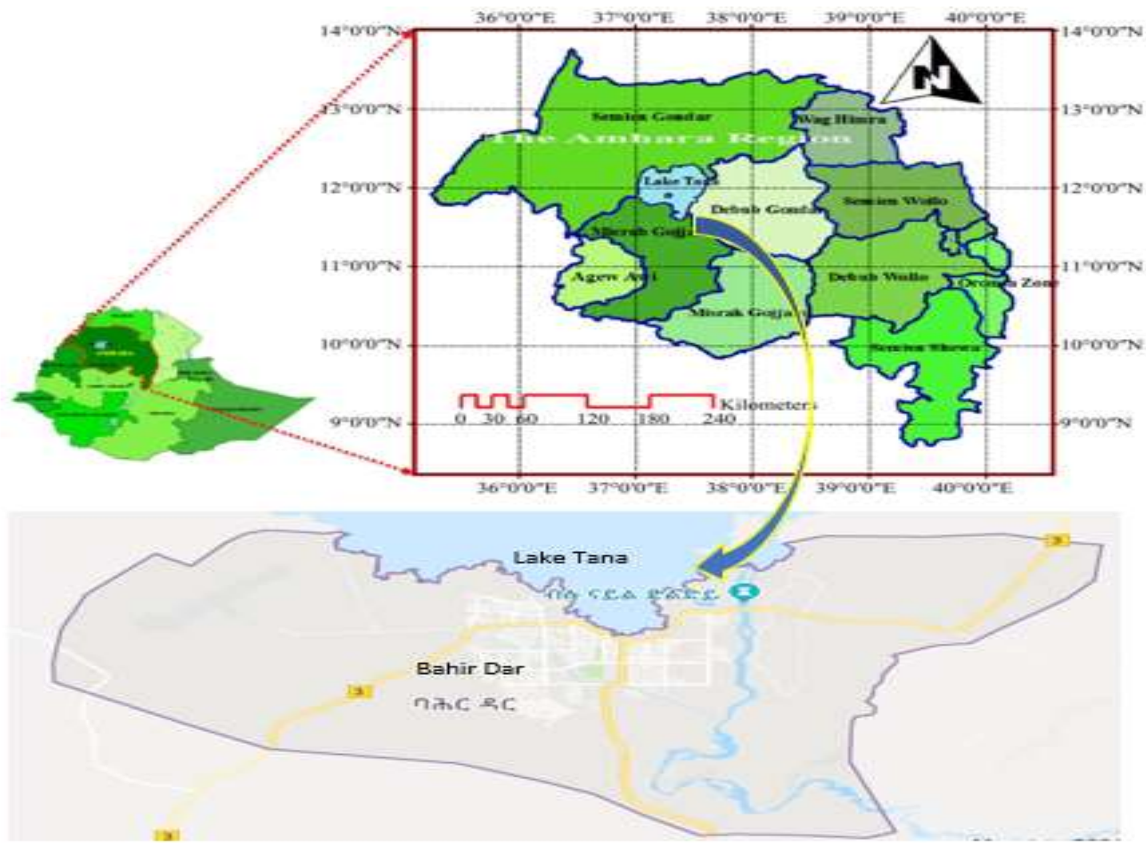


Figure 3. 1 Location of Study Area

Source: - https://www.google.com/maps and https://en.wikipedia.org

3.2 Materials

Details about Soil, Gypsum and Brewery Spent grain ash used in this research are given in this section.

3.2.1 Expansive Clay Soil

The soil for this study was collected around Bahir-Dar between Woreta and Hamusit road segment at location of 11°50’11.45” N 37°37’57.94” E and at Elevation of 1799.8m as indicated in Fig 3.2. The disturbed sample was picked along the soil profile at the depth of 2m to avoid the inclusion of organic matter. Preliminary checks indicated that the soil was grayish black in color, highly crack and plastic in nature as shown in Figure 3.2 below.

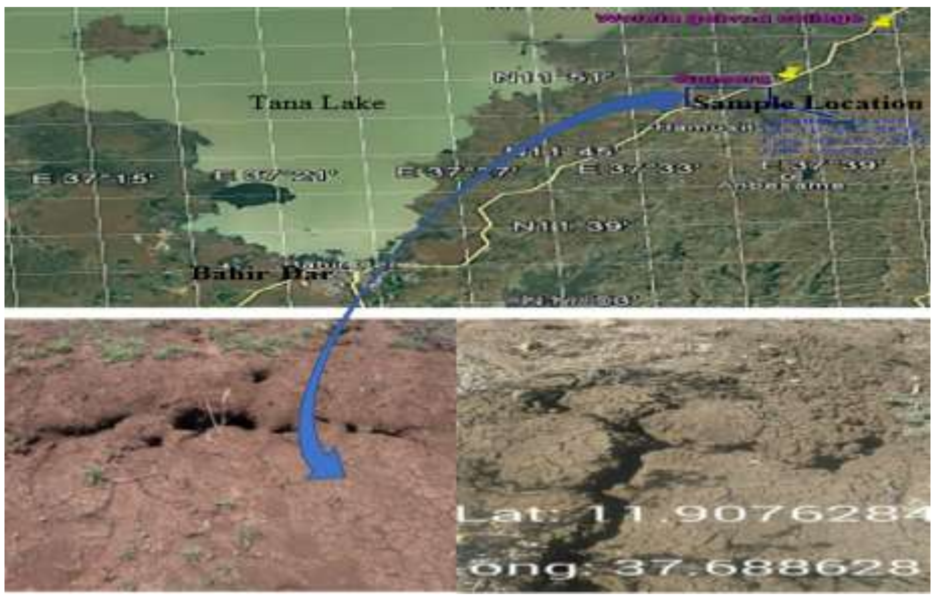


Figure 3. 2 Photo for Sample Soil

Source google earth

3.2.2 Gypsum

Gypsum used in this study was obtained from the local market which is the production of Dejen gypsum factory. It was denoted as later G.

3.2.3 Brewery Spent Grain ash

Brewery Spent Grain was obtained from North Gondar Dashen Brewery Share Company. The collected brewery spent grain was dry and burnt under uncontrolled condition (open burning) to obtain the ash form. After convert to ash then sieved through No.40 (0.425mm).

This fraction passing sieved material used throughout the tests. Brewery Spent Grain ash was donated as BSG ash.

Figure 3. 3 Brewery spent grain ash

3.3 Study Design

This research methodology followed the experimental type which designed to answer the research questions and achieve its objectives based on experimental findings through quantitative, qualitative and comparative analysis approach. The overall activity and research process in the study include:

- ❖ Problem identification of the study area
- ❖ Material collection and Preparation of the sample for laboratory test
- ❖ Burning of brewery spent grain to convert the ash form and prepare for test
- ❖ Conduct laboratory test for subgrade with gypsum to select the optimum percent require.
- ❖ Blending of stabilizer by taking the optimum percent of gypsum as a cumulative value of BSG ash and gypsum with different ratio.
- ❖ Specify the optimum percent of BSG ash required for partial replacement of gypsum

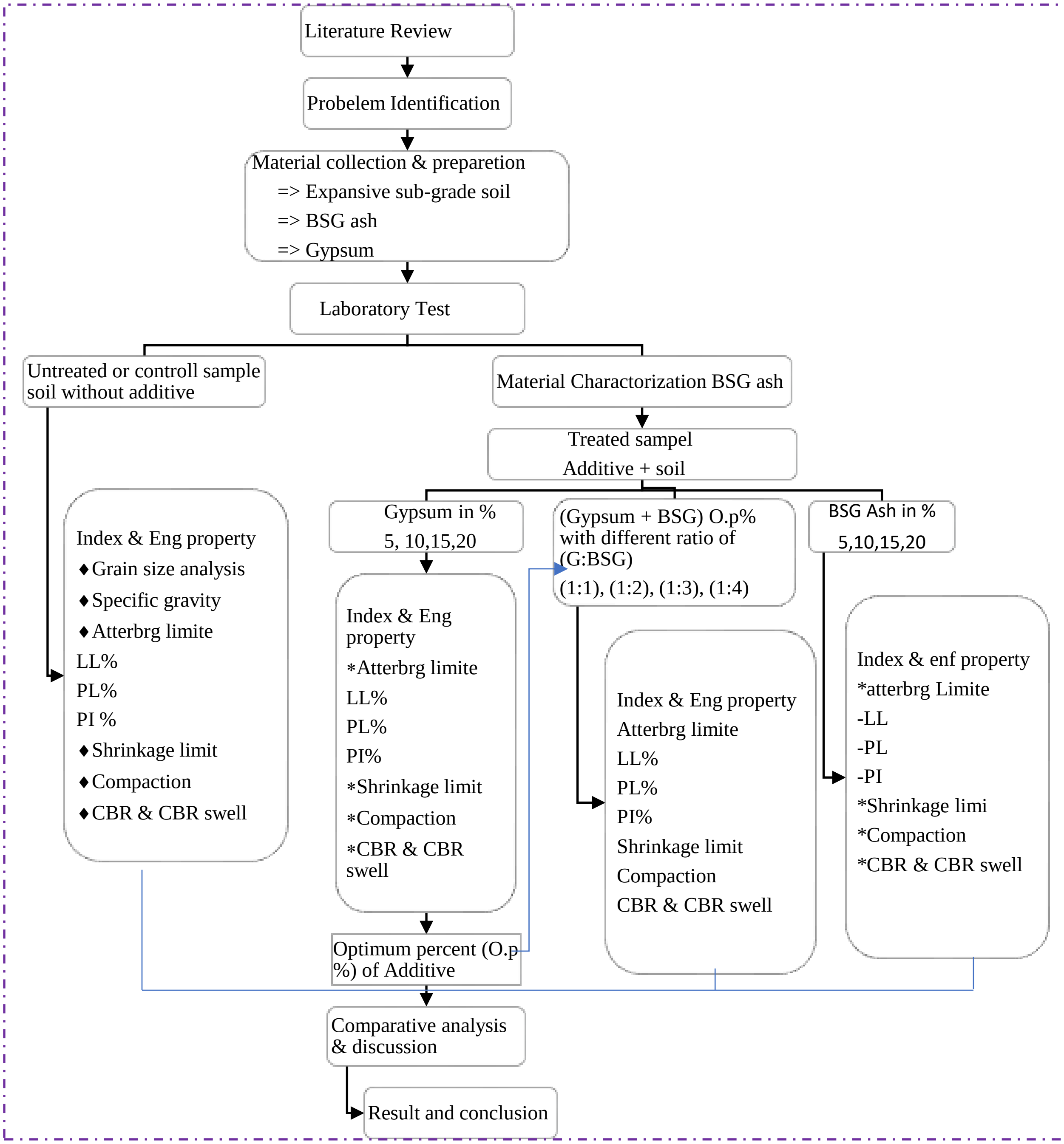


Figure 3. 4 Study Design Flow Chart

3.4 Study Variable

The study variables which consist in the research contained both independent and dependent variables.

3.4.1 Independent Variable

Independent variables are the presumed cause of dependent variable. Those variables in this research includes specific gravity, Atterberg limit, linear shrinkage, MDD, OMC, CBR, CBR swell and Dosages of (gypsum and BSG ash).

3.4.2 Dependent Variable

The dependent variable of this research was Stabilized of Expansive sub-grade soil.

3.5 Sampling techniques

The sampling technique used for this research were a purposive sampling. The experimental investigation of the study was executed particularly on the expansive sub-grade soil sample.

3.6 Sample preparation

Collect the sample from study area then air dried and mixed with stabilizer in their corresponding percentage as shown in table 3.1 below to prepared the sample by Appling dry mixed with expansive sub-grade soil. These percentage values are used for the preparation of sample to conduct all the required laboratory test.

To determine the percentage for blending stabilization for each stabilizer:

G + BSG ash = Optimum % of gypsum ………… (a)

G / BSG ash = ratio ………………………………. (b)

From the above two expression determine the percentage of Gypsum and BSG ash for blending stabilization.

Table 3. 1 . Percentage of proposed stabilizer

Percentage of stabilizer				
Gypsum stabilization	Blending stabilization			BSG ash Stabilization
	G: BSG ash ratio	Commutative value 20%		
% of G		% of G	% of BSG ash	% of BSG ash
5	1:1	10	10	5
10	1:2	6.7	13.3	10
15	1:3	5	15	15
20	1:4	4	16	20

3.7 Laboratory Test

The purpose of the Laboratory Test for this study is to investigate the effects of addition of Gypsum, Brewery Spent Grain ash and Gypsum blend with BSG ash on Atterberg limits, Linear shrinkage, Compaction, California Bering ratio (CBR) and CBR swell of an expansive clay soil.

3.7.1 Analysis of Grain Size Distribution

The particle size analysis is a method of separation of soils into different fractions based on the sizes of particles present in soil. The particle size analysis maybe **mechanical (sieve)** analysis or **sedimentation** analysis.

Sieve analysis is used to separate the coarse-grained fraction of soil, i.e. the fraction of soil whose particle size is greater than No.200 (75µm) based on ASTM D422 standard. Sedimentation analysis, which is based on the principles of dispersion and sedimentation, is used for the analysis of fine-grained soil (silt and clay) whose particle size is less than No.200 (0.075 mm). Sedimentation analysis is performed either by **pipette** method or **hydrometer** analysis (Dr. Arora, 2004).

Mechanical Sieving

A gradation curve contains points corresponding to a particular grain size and a corresponding percent by mass of the soil grains. It is performed on material retained on 75µm sieve as per ASTM D422 standard but not consider the particles which pass through 75µm sieve. The result from these analyses are in the classification of soil specifically for sand, gravel and also estimation of engineering characteristics of these types of soils (Farrta, et al., 2007). The percentage of material by weight retained on the various sieves is computed as follows:

$$\text{Percent Retaind on the i}^{\text{th}}\text{ seive} = \frac{\text{weight of retained on sieve i}}{\text{total weight of oven dry sample}} * 100$$

Hydrometer Analysis

The soil particle which pass through #200 (75µm) sieve is not used by mechanical sieving test because the particles to be small and cannot pass through the screens individually. Those particles are performed by hydrometer Analysis as per ASTM D1140 standard. This test is done by soil mixed with water and sodium hexametaphosphate (as a dispersing agent) for 24hr to create a slurry of dispersed soil particles. The soil particles are initially suspended in the liquid mixture, but settle over time.

3.7.2 Specific Gravity

Specific gravity of solids is the ratio of weight in air of a given volume of soil particles at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature. It is the heaviness of soil particles are determined the pycnometer method using a soil sample passing #10(2mm) sieve as per ASTM D854 standards.

The specific gravity Gs, of a soil is calculated as follows:

$$G_S = \frac{\mathrm{W}_s}{\mathrm{W}_s + \mathrm{W}_{fw} - \mathrm{W}_{fws}}$$

Where: -

W_s = Weight Dry sample, W_{fw} = Weight Flask filled with water only, W_{fws} = Weight of flask filled with water and sample and K = correction factor based on the density of water at 20 C. The specific gravity at a standard temperature of 20^{o}C.

$$G_{S20} = k * Gs = \frac{\mathrm{k} * \mathrm{W}_s}{\mathrm{W}_s + \mathrm{W}_{fw} - \mathrm{W}_{fws}}$$

$$k = \frac{Relative\ Densty\ water\ @T\ ℃}{Relative\ Densty\ water\ @20\ ℃}$$

3.7.3 Atterberg limits

This is the basic test for the determination of plasticity index of soil which the key parameter for AASHTO and USCS soils classification in accordance with ASTM D2487. Soil plasticity is quantified in terms of Atterberg limits. liquid limit and plastic limit tests provide information regarding the effect of water content (w) on the mechanical properties of soil.

3.7.3.1 Liquid Limit Test

liquid limit (LL), defines the transition between the liquid and plastic states. Two standard methods of testing are used to determine the liquid limit of fine-grained soils. Cassagrand method and Drop-Cone method. These methods are:

i. Cassagrand methods
ii. Drop Cone methods

Both tests are carried out on remolded soil, the fraction passing through No.40 (0.425mm) sieve being used. The cone method may not be any quicker to perform, but it is fundamentally more satisfactory as the mechanics of the test depend directly on the static shear strength of the soil. The cassagrand method on the other hand, introduces a dynamic component not related to the shear strength in the same way for all soils.

Cassagrand Method

The liquid limit test determines the liquid limit of a soil. By convention, the liquid limit is defined as water content at which the groove cut into the soil pal in the standard liquid limit device requires 25 blows to close along a distance of 13mm ASTM D4318-93.

The line passing through n data points (log Ni, W i) is determined by linear regression,

$$\mathrm{w} = \mathrm{A}\log N + B$$

where the slope A and intercept B are

$$A = \frac{n\sum_{i=1}^{n} w_i\ logN_i - \sum_{i=1}^{n} w_i\ \sum_{i=1}^{n} logN_i}{n\sum_{i=1}^{n}(logN_i)^2\ - (\sum_{i=1}^{n} logN_i)^2}$$

$$B = \frac{\sum_{i=1}^{n} w_i\ \sum_{i=1}^{n}(logN_i)^2\ -\ \sum_{i=1}^{n} logN_i \sum_{i=1}^{n} w_i\ logN_i}{n\sum_{i=1}^{n}(logN_i)^2\ - (\sum_{i=1}^{n} logN_i)^2}$$

Where: - N_i = Number of blows, w_i = Water Content and n = Number of Trials It is recommended that the water content be adjusted to obtain two specimens between 15 and 25 blows, and two others between 25 and 35 blows. Material left over in the mixing dish should be preserved for the plastic limit test.

The liquid limit corresponds to N = 25 blows on the line w = A log N + B

$$\mathrm{LL} = \mathrm{A}\log(25) + B$$

Drop Cone methods

This test is based on the measurement of penetration into the soil of a standardized cone of specified mass. Take liquid limit at cone penetration of 20mm. The liquid limit is defined as the water content at which a polished stainless-steel cone of a specific weight (80 g) and an angle of 30^o will penetrate a specific distance when allowed to free fall for 5 seconds.

Liquid limit test	Drop cone method
	

Figure 3. 5 Photographs for liquid limit test

3.7.3.2 Plastic Limit

The transition between the plastic and semi-solid states defines the plastic limit. Plastic limit test is used to determine the lowest moisture content at which the soil behaves plastically. It is carried out only on the soil fraction passing #40 (0.425 mm) sieve and is usually performed in conjunction with the liquid limit test. By convention, the plastic limit of a soil is defined as the water content at which the soil begins to crumble when rolled into a thread 3 mm in diameter.

3.7.3.3 Plasticity Index

Plasticity Index is the difference between liquid limit and plastic limit value of sub-grade soil.

3.7.4 Linear Shrinkage

Shrinkage limit of a soil is the water content, expressed as a percentage of the weight of the oven-dried soil, at which further loss in moisture will not cause a decrease in its volume. The linear shrinkage is defined as the decrease in one dimension of a soil mass, expressed as a percentage of the original dimension, when the water content is reduced from a given value to the shrinkage limit.

The linear shrinkage ratio LS characterizes the change in length induced by drying a cylindrical sample of soil initially about its liquid limit LS is where L_O is Original length sample at about the liquid limit (140mm for standard mold) and L_D is Length of the sample after dried.

$$Ls = \frac{\mathrm{Lo} - L_D}{L_O} * 100$$

Figure 3. 6 photograph for linear shrinkage limit

3.7.5 Compaction Tests

laboratory compaction test, a soil at a known water content is placed in a specified manner in a mold of given dimensions and subjected to a compactive effort of controlled magnitude after which the resulting unit weight of the soil is determined. The procedure is repeated at various water contents until a relation between water content and unit weight of the soil is established.

Table 3. 2 Compaction standard table

Test	Standard ASTM D698 /AASHTO T-99			Modified ASTM D1557/AASHTO T-180		
Method	A	B	C	A	B	C
Material	≤20% retained on #4	>20% retained on #4 & ≤20% retained by 3/8”	>20% retained on 3/8” & <30% retained by 3/4”	≤20% retained on #4	>20% retained on #4 & ≤20% retained by 3/8”	>20% retained on 3/8” & <30% retained by 3/4”
Passing sieve	#4	3/8”	3/4”	#4	3/8”	3/4”
Mold. Día (cm)	30.5		15.24	10.16		15.24
Mold. Vol. (cm^3)	944		2124	944		2124
Hammer weight	2.49kg			4.54kg		
Drop height (cm)	30.5			45.7		
Compaction effort	600kN-m/m^3			2700kN-m/m^3		
No. of layers	3	3	3	5	5	5
No. of blows/layer	25	25	56	25	25	56

Soil is a porous medium consisting of soil solids and water. Dry unit weight of soil γ_d is defined as:

$$\gamma_d = \frac{\mathrm{Ms}}{\mathrm{V}} * g = \frac{\mathrm{Gs} * \gamma_w}{1 + (\frac{\mathrm{wGs}}{\mathrm{S}})}$$

Where: - Ms is the mass of soil solids in a volume of soil V, **g** gravitational acceleration constant, Gs specific gravity of soil solids, γ_w unit weight of water and S is the degree of saturation.

3.7.6 California Bearing Ratio (CBR) and CBR Swell

The strength of sub-grade is the main factor to select the required thickness of flexible pavement. This strength of sub-grade which resist the load applied on it is expressed by California Bearing Ratio value.

The CBR teste in this study is conducted by taking air dried sample which pass through sieve No.4 (4.75mm) for natural soil, different percent of gypsum (5%, 10%, 15%. &20%), different G: BSG ash ratio (1:1, 1:2, 1:3 &1:4) and different percent of BSG ash added to natural soil then compacted with their corresponding density and Optimum Moisture content as per ASTM D1883 standard. For each sample take 5kg of natural soil only and the mixture of soil with different percent off additives at their respective optimum moisture content compacted by 56 blows for five layers. The compacted samples of the CBR mold are soaked for 96 hours in a water bath to the anticipated worst case on the field.

The CBR test measures the shearing resistance of a soil under controlled moisture and density conditions. This value is computed by taken the ratio of load required at the depth of penetration (2.45mm and 5.08mm) in to a soil specimen compacted at a given OMC and MDD corresponds to the load required to obtain the same depth of penetration on a standard sample of crushed stone.

CBR= (test load on the sample/ standard load on the crushed stone) *100

CBR Swell

Road pavement structural design is usually based on 4-days soaked CBR values, to simulate the anticipated “worst-case” soil condition on the field. It measured by placing the tripod with the dial indicator on the top of soaked CBR mold. The compacted soil samples of the CBR mold are soaked for 96 hours in a water bath to get the CBR swell of the soil. The initial dial reading of the soil of the dial indicator on the soaked CBR of mold is taken just after soaking the sample. At the end of 96 hours the final dial reading of the dial indicator is taken hence the swell percentage of the initial sample length is 116.43mm.

CBR Swell = (Change in Length in mm during soaking /116.43) *100%

Figure 3. 7 Photographs for CBR test

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

The results are analyzed and discussed to give the insight of the research in terms of engineering properties of expansive soil in relation to the use. Investigation involved the evaluation of both natural and stabilized soil samples separately by performing the following tests; Gradation, specific gravity, Atterberg limits (Liquid limit, plastic limit, plasticity index and linear shrinkage) conducted form 24hr cured sample, free swell, moisture density relationship (compaction), take 4 days cured sample for CBR and CBR swell. The stabilizing agent were taken for Gypsum with the percent of (5%, 10%, 15% & 20%), for blending of BSG ash and Gypsum with the ratio of G: BSG (1:1, 1:2, 1:3, 1:4) and for BSG ash with the percent of (5%, 10%, 15% & 20%)

4.2 Chemical Composition of Proposed Material

4.2.1 Brewery Spent Grain Ash

The XRF spectroscopy data of the BSG ashes put in evidence the presence of phosphorus, silicon, calcium, magnesium and potassium as major oxide and other as a minor amount were also detected Table 4.1.

Table 4. 1 Chemical Composition of BSG Ash by X-Ray Fluorescence

Oxide Composition		Elemental Composition	
Oxide	Value	Element	Value
P_2O_5	39.46%	Zn	2,080.2 ppm
SiO_2	33.69%	Cu	665.2 ppm
CaO	14.12%	Sr	214.5 ppm
MgO	9.44%	Ba	193.7 ppm
K_2O	2.20%	Mo	33.2 ppm
Fe_2O_3	0.63%	Cr	26.9 ppm
MnO	0.16%	Rb	12.0 ppm
TiO_2	0.03%	Sc	7.4 ppm
Na_2O	0.02%	Ni	4.9 ppm
Al_2O_3	0.01%	Pb	3.7 ppm
LOI	0.02%	U	1.2 ppm

Chemical analysis indicated that the combined percent composition of SiO_2, Al_2CO_3 and Fe_2O_3 of the ash was not fulfill pozzolanic property according to ASTM C618 – 12 (ASTM 2012) standards for pozzolanic reaction. Although, it denies the pozzolanic behavior, it has different heavy cationic element like Zn, Cu, Ba … and others which used for stabilization through cation exchange, flocculation and agglomeration process by reduce the space in clay surface.

4.3 Descriptive test result for Sub-grade soil

4.3.1 Grain size distribution

The gradation of the soil sample was conducted both mechanical (sieve) and hydrometer tests. The gradation analysis to be done through mechanical sieve for the material retained on No. 200 sieves and hydrometer analysis for material pass through No. 200 sieves. The hydrometer test was conducted by taking 50gm of soil sample which passing No.200 sieve and soaked for 24 hours in chemical solution (Sodium hexa-meta phosphate) to disintegrate the large particle.

The lab result for mechanical sieve and hydrometer test shows that the sample sub grade soil contains 6% of sands, 31% of silt particles and 63% of clay particles. The experimental data as shown in appendix A and the particle size distribution curve as given in Figure 4.1

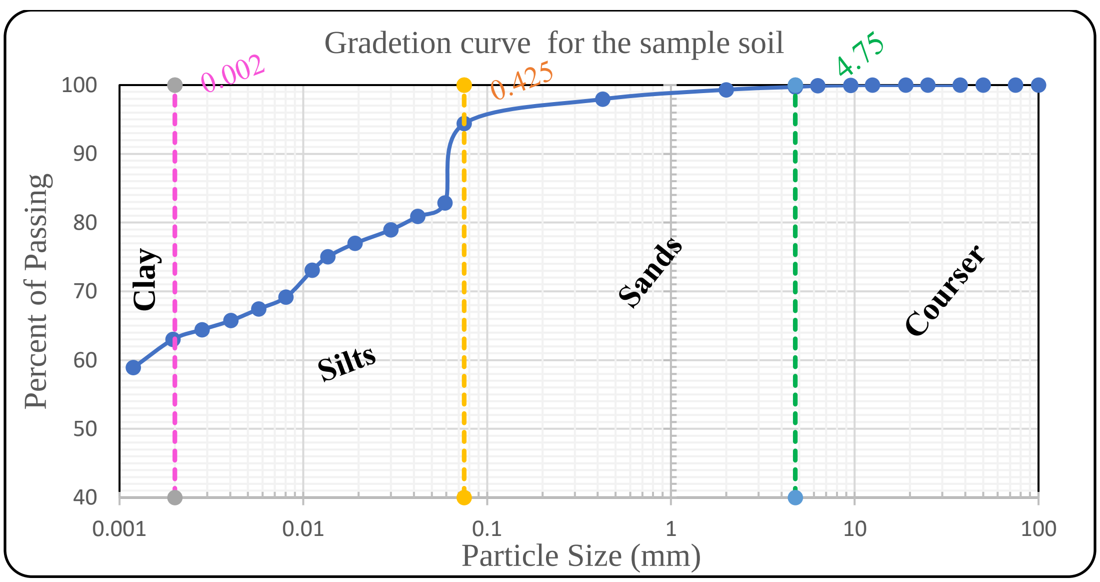


Figure 4. 1 Grain size distribution curve for sample soil

4.3.2 Atterberg's Limits of Sub-grade Soil

Drop cone methods was used for the determination of liquid limit of soil while plastic limit was determined by making threads 1/8" (3mm) thickness as per ASTM requirements. Liquid limit, plastic limit and Plasticity index of the expansive clay soil was determined as 84.48%, 32.29% and 52.29% respectively see in Appendix A. As result of Plastic Index, the sample was poor sub grade material.

4.3.3 Soil classification

Based on gradation and Atterberg limit of the sample soil was classified **CH** as per USCS system in Figure 4.2 and **A-7-5 as** per AASHTO classification system in Figure 4.3. This indicated that the sub-grade soil was clay, highly expansive material, Week sub-grade and it required treatment to be used as a sub-grade material.

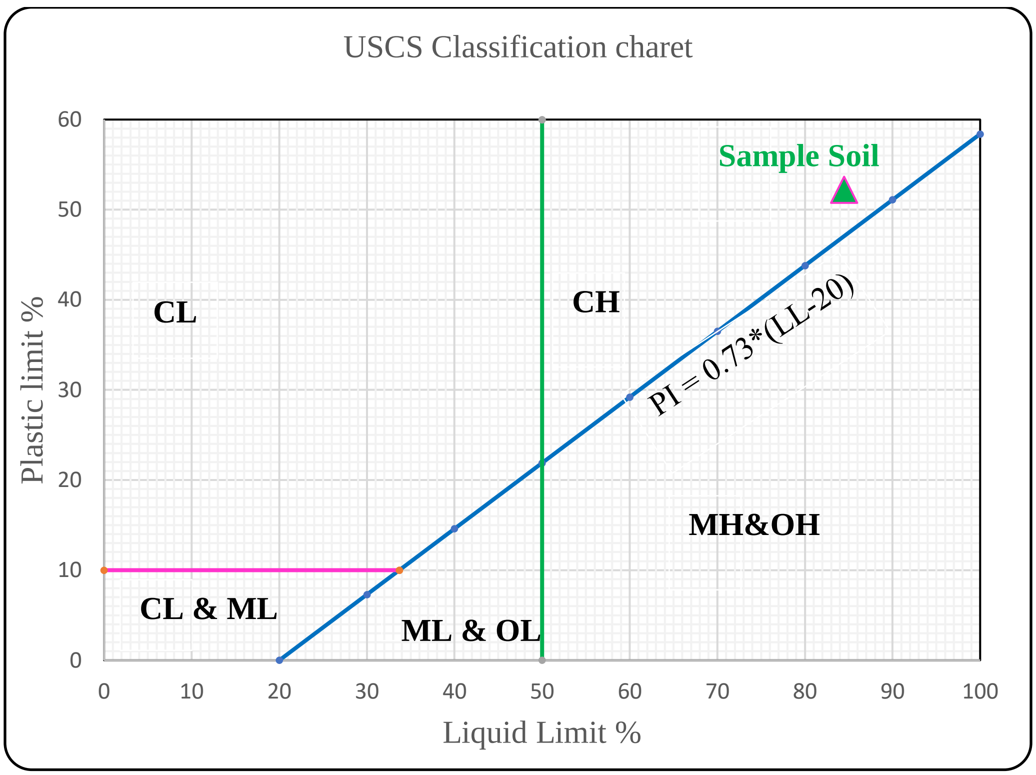


Figure 4. 2 USCS classification of natural soil

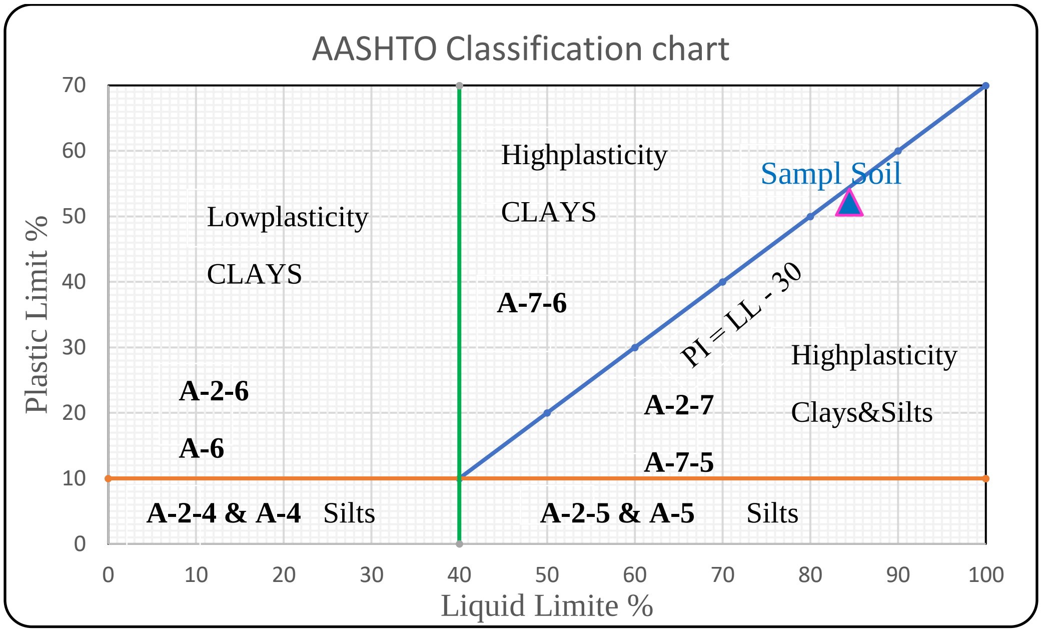


Figure 4. 3 AASHTO Classification of natural soil

4.3.4 Specific Gravity Gs of Soil

The specific gravity of CH was determined as per ASTM D 854 standard. Specific gravity for CH was 2.71.

Table 4. 2Specific gravity of natural soil

Relative Density water @20◦c	0.99823	Sample	Soil	
		Trial No.	1	2
Mass of oven dry sample (Wo) g			10	10
Mass of density bottle and water (Wa) g			99.6	100.5
Mass of density bottle, soil and water (Wb) g			105.6	107.1
Test temperature of water (T◦c)			24	24
Relative Density water @ (T◦c)			0.99732	0.99732
Specific gravity of soil at T◦c (Gs @ T◦c)			2.5	2.941176471
Specific gravity of soil at T◦c (Gs @ 20◦c)			2.49772	2.938495254
Average Gs @ 20◦c			**2.71**	

4.3.5 Compaction Characteristics of Soil

The Dry density and Optimum moisture content were determined by modified proctor test as per ASTM D1557 method A. MDD and OMC for the sample of natural soil were 1.387 g/cm3 and 35% as shown in figure 4.4 below.

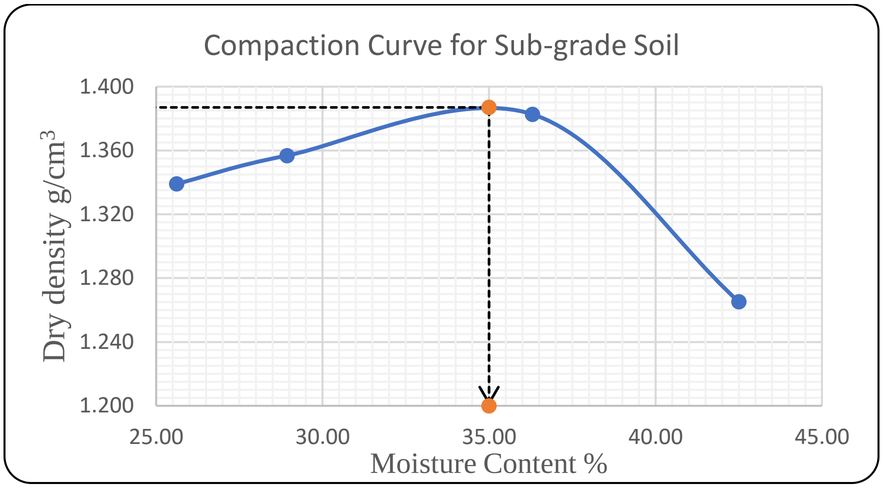


Figure 4. 4 Compaction Curve for natural Sub-grade Soil

4.3.6 California Bearing Ratio (CBR) And CBR Swell of natural soil

Samples were soaked for 96 hours, CBR and CBR swell determined as per ASTM standard. The sample had CBR and CBR swell were 1.98% and 6.02% respectively. Based on CBR value, the material was classified as poor materials.

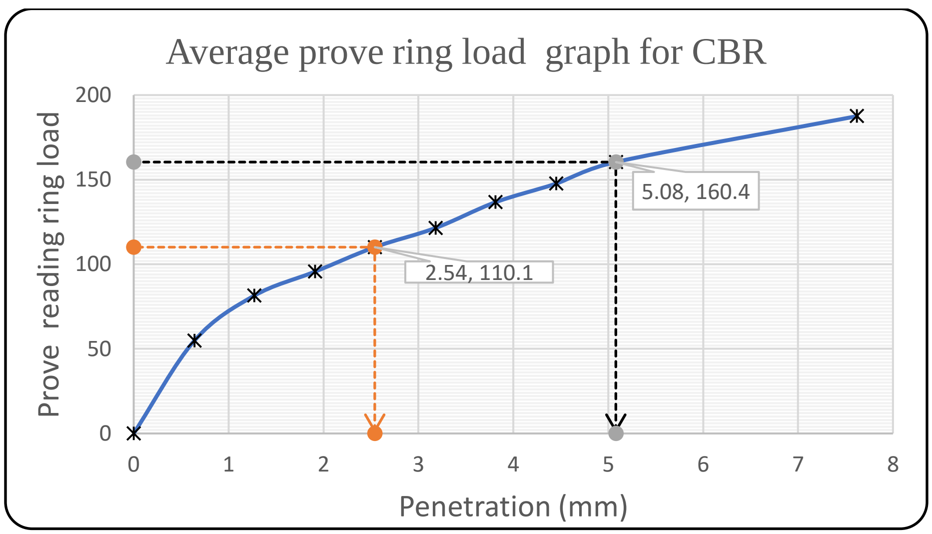


Figure 4. 5 Average prove reading load graph natural sub-grade soil for CBR

The result indicates that the soil had low bearing capacity and high plasticity index which were not satisfied the standard requirement of sub grade for highway construction. Therefore, the soil requires initial treatment and stabilization to improve its workability and engineering property.

Table 4. 3 Summary of laboratory result for untreated soil

Parameter	Laboratory result	
Percentage of Passing through No.200	**94.39%**	
Sands	6	
Silts	31	
Clays	**63**	
Liquid Limit	**84.48%**	
Plastic Limit	32.19%	
Plasticity Index	**52.39%**	
Linear shrinkage	25%	
Soil classification	USCS	**CH**
	AASHTO	**A-7-5**
Specific Gravity of Soil	2.71	
Natural Moisture Content	14.2%	
Free swell	137.5%	
Compaction test result	MDD	1.387 g/cm3
	OMC	35%
California Bearing Ratio (CBR)	**1.98%**	
CBR Swell	**6.02%**	

4.4 Descriptive test result of Sub-grade soil Stabilized by Gypsum

4.4.1 Effect of gypsum on Atterberg limit and linear shrinkage

The basic Atterberg limit lab result like liquid limit, plastic limit and linear shrinkage tests were conducted to study the effect of gypsum.

Table 4. 4 Linear shrinkage and plastic index data for gypsum treated sample

% of Gypsum	LL	PL	PI	LS	USCS Soil classification
0	84.48	32.29	52.19	25	CH
5	85.54	49.24	36.3	17.14	MH
10	77.04	43.77	33.27	16.43	MH
15	86.37	55.88	30.49	14.29	MH
20	84.04	59.07	24.93	11.43	MH

According to the results observed from the laboratory test, as the percentage of gypsum increase the plasticity index becomes to decrease. The percentage of gypsum varies from 0% - 20% the plastic index decreases from 52.19% - 24.93% and the linear shrinkage also decrease from 25% - 11.43% as shown in Table 4.4 and Figure 4.6. The reason beyond to this result, the content of calcium ions in gypsum was high that used to reduce the space in clay surface of soil by replacing the positive ions.

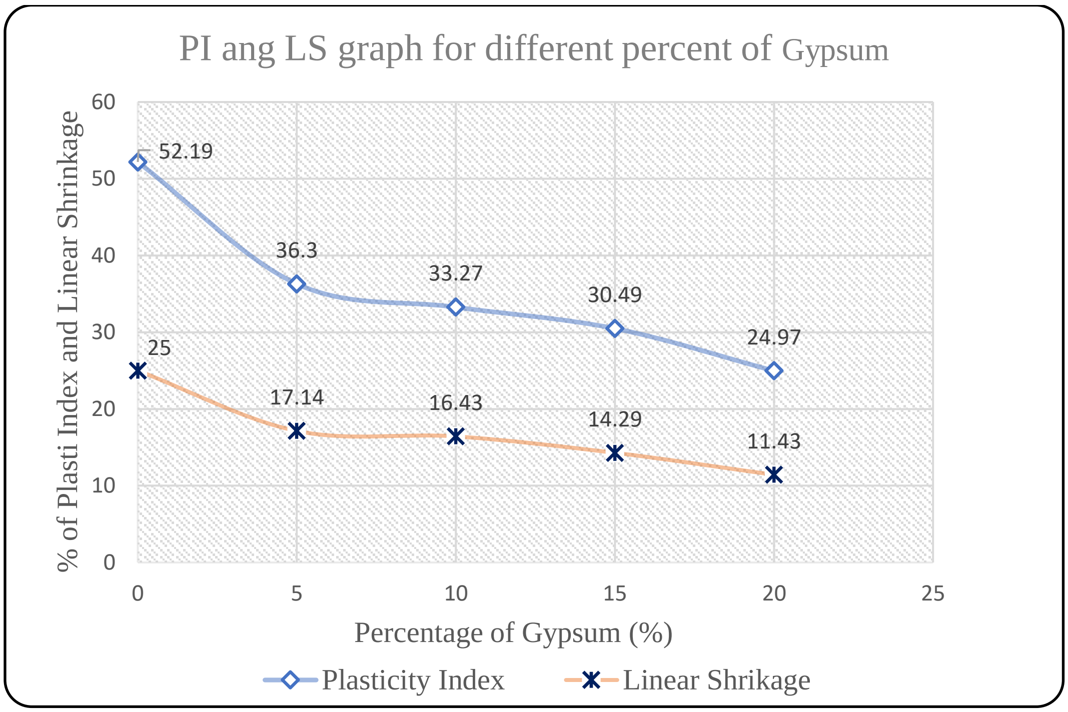


Figure 4. 6 Effect of gypsum on plastic index and linear shrinkage limit

4.4.2 Effect of Gypsum on moisture density relation

The moisture density relations are determined based on ASTM D1557 method A. Tests were conducted with different percentage (5%, 10%, 15%& 20%) of Gypsum added to the sub-grade soil. Plotted the moisture content versus dry density graph to determine MDD and OMC as shown in Figure 4.7 below. The details of the test results are attached in Appendix B.

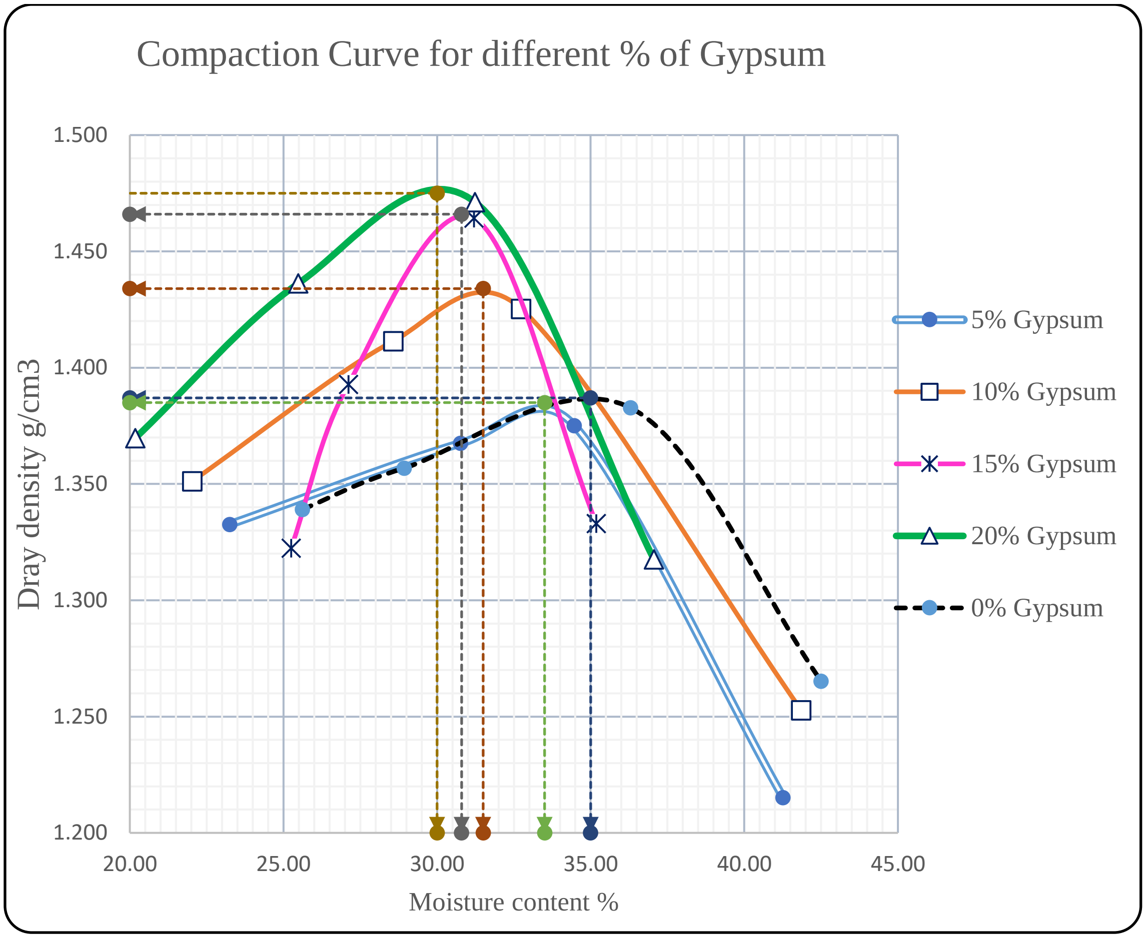


Figure 4. 7 Summary of OMC and MDD curve for gypsum treated soil sample

The result shows that as the gypsum added to the soil increase from 0% - 20% the dry density increase from 1.387 g/cm^3 – 1.475 g/cm^3 and optimum moisture content decrease from 35% - 30% as given in Figure 4.8 and the tabular data seen in Appendix B.

The reason to decrease of OMC value when the percent of gypsum add to the soil increase may be caused due to the high-water absorption nature of gypsum. The variation in optimum moisture content and dry density with varying percentage of gypsum was plotted as shown in Figure 4.8

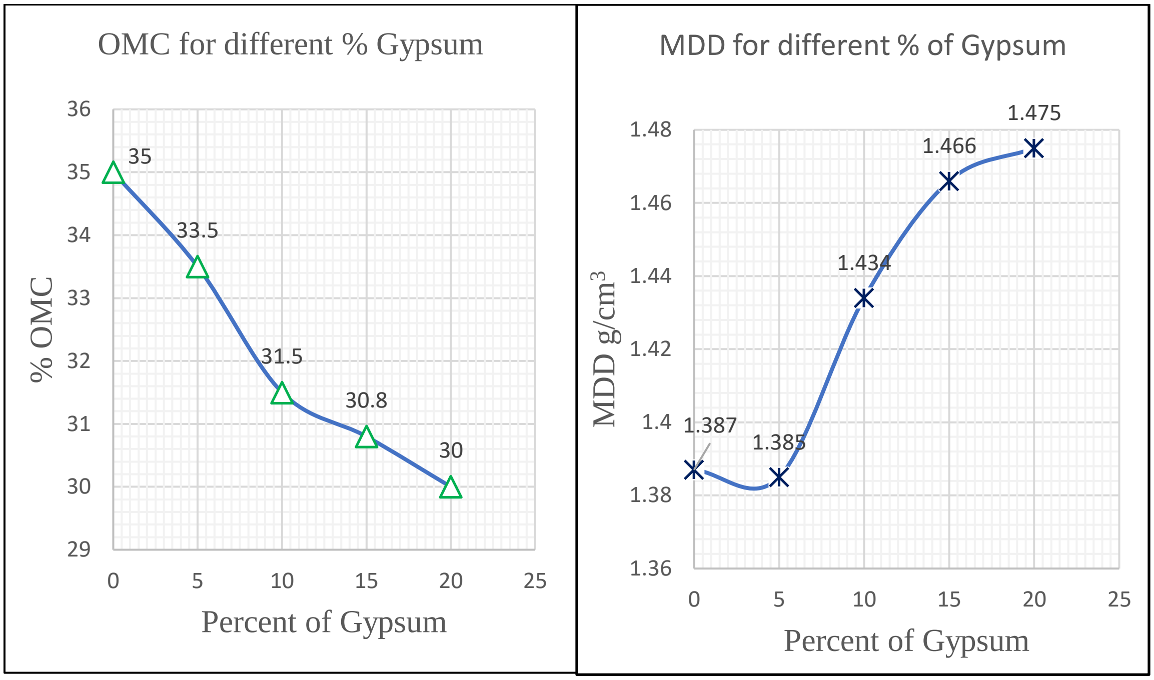


Figure 4. 8 Variation of OMC and MDD for different % of Gypsum

4.4.3 Effect of Gypsum on CBR and CBR swell

CBR test for this study was conducted by taking air dried sample which pass through sieve No.4 (4.75mm) for natural soil mixed with different percent of gypsum (5%, 10%, 15%. & 20%) and applied modified compaction. The value was determined by One-point CBR method through modified compaction with 5 layers, 56 blows and soaked for 96 hours for all samples. CBR swells also conducted after four days soaked with different percent of gypsum add to the soil.

The result shows that prove reading ring load graphs are above the natural soil, which indicated that gypsum can improve the strength of expansive sub-grade soil as seen in Figure 4.9 below.

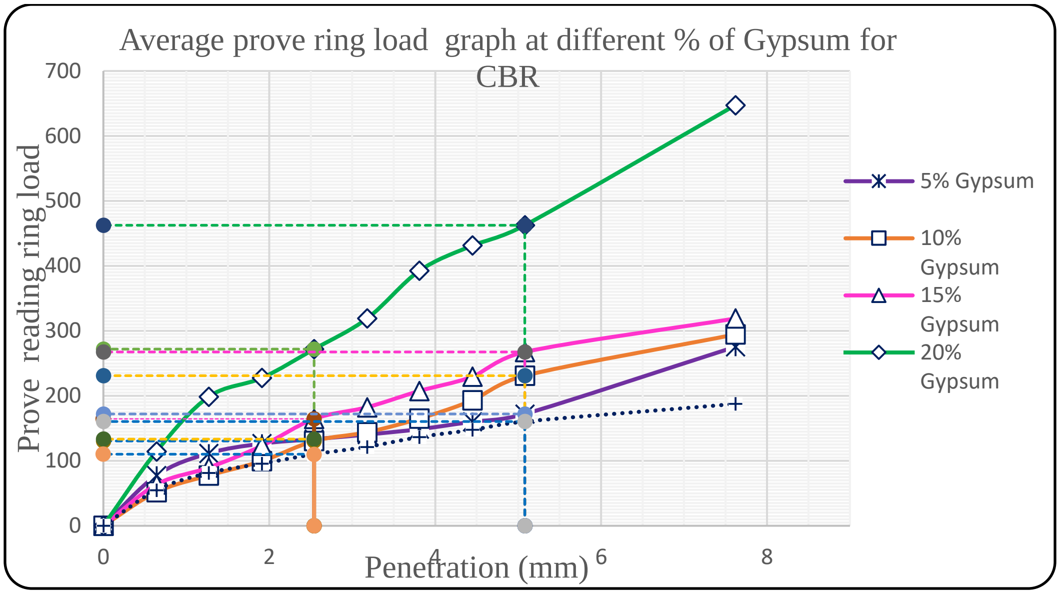


Figure 4. 9 Average prove reading load graph at different % of Gypsum for CBR

According to the laboratory test result indicated that the variations of gypsum added to the soil improve the swelling potential and the strength of weak sub-grade. The percentage of gypsum increases from 0% to 20% the CBR value changes from 1.98% to 5.51% and also CBR swells decreases from 6.02% to 4.3% as seen in Table 4.5. Based on ERA specification 15 and 20 percent of gypsum satisfied the required criteria for sub-grad. The test result was summarized in Table 4.5 and the detail laboratory data as shown in Appendix-B.

Table 4. 5 CBR and CBR swell data for gypsum treated sample

% of Gypsum	% CBR swelling	Penetration (mm)	Aver. Prove ring reading load	CBR %	Max CBR %	ERA requirement	Remark
0	6.02	2.54	110.1	1.98	1.98	>3%	Poor
		5.08	160.4	1.92			
5	5.16	2.54	133.3	2.39	2.39		Poor
		5.08	172.1	2.06			
10	4.94	2.54	130.5	2.34	2.77		Poor
		5.08	231	2.77			
15	4.3	2.54	164.5	2.95	3.2		Satisfied
		5.08	267.5	3.2			
20	3.87	2.54	271.9	4.88	5.51		Satisfied
		5.08	460.5	5.51			

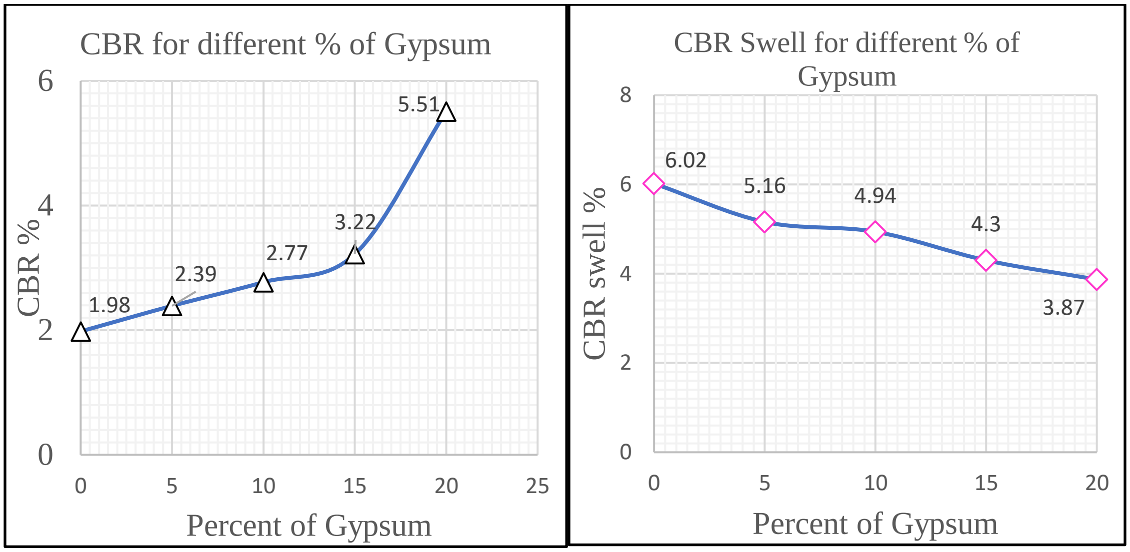


Figure 4. 10 Effect of different % of gypsum on CBR and CBR swell

Generally, the percentage of gypsum increase to (0%, 5%, 10%, 15% and 20%) the laboratory test result indicates as follow:

Table 4. 6 Summary of laboratory result for gypsum stabilized

% of gypsum	Atterberg limit			LS	Compaction		CBR	CBR swell	CBR > 3%	USCS soil classification
	LL	PL	PI		OMC	MDD				
0	84.48	32.29	52.19	25	35	1.387	1.98	6.02	poor	CH
5	85.54	49.24	36.30	17.14	33.5	1.385	2.39	5.16	poor	MH
10	77.04	43.77	33.26	16.43	31.5	1.434	2.77	4.94	poor	MH
15	86.37	55.88	30.49	14.29	30.8	1.466	3.22	4.3	Satisfied	MH
20	84.04	59.07	24.98	11.43	**30**	**1.475**	**5.51**	**3.87**	Satisfied	MH

The soil class changes from highly plastic clay to high plastic silts as per USCS for all proposed percentage of stabilizer.

Therefore, based on the value of plasticity index, linear shrinkage, CBR and CBR swell, the highest strength happens at 20% which is taken as the optimum percentage.

4.5 Descriptive test result of Sub-grade soil Stabilized by Brewery Spent Grain ash

4.5.1 Effect of BSG ash on Atterberg limit and linear shrinkage

The Atterberg limit lab result like liquid limit, plastic limit and plastic index as well as linear shrinkage tests were conducted to study the effect of brewery spent grain ash with different percentage 5%, 10%, 15% and 20% added to the natural soil. The sample of natural soil was air dried which pass through No.40 sieve mixed with BSG ash by then take 300g for each sample and socked with plastic cover for 24 hours to distribute the moisture in sample uniformly as well as to give sufficient time for chemical reaction.

As a result, observed from the laboratory test, the percentage of BSG ash added to the soil increase 5%, 10%, 15% and 20% the plasticity index of treated sample varies 36.3%, 50.71%, 51.69% & 48.52% as well as the linear shrinkage also varies 15%, 12.86%, 11.43% & 7.86% respectively as shown in Figure 4.11 & Appendix C. According to the result, the percent of BSG ash added to soil increase, the plasticity index increase some else then decrease, but decrease for all compared with natural soil and high reduction of PI observed at 5% of BSG ash added. The linear shrinkage decreases as the percent of BSG ash added to the soil increase.

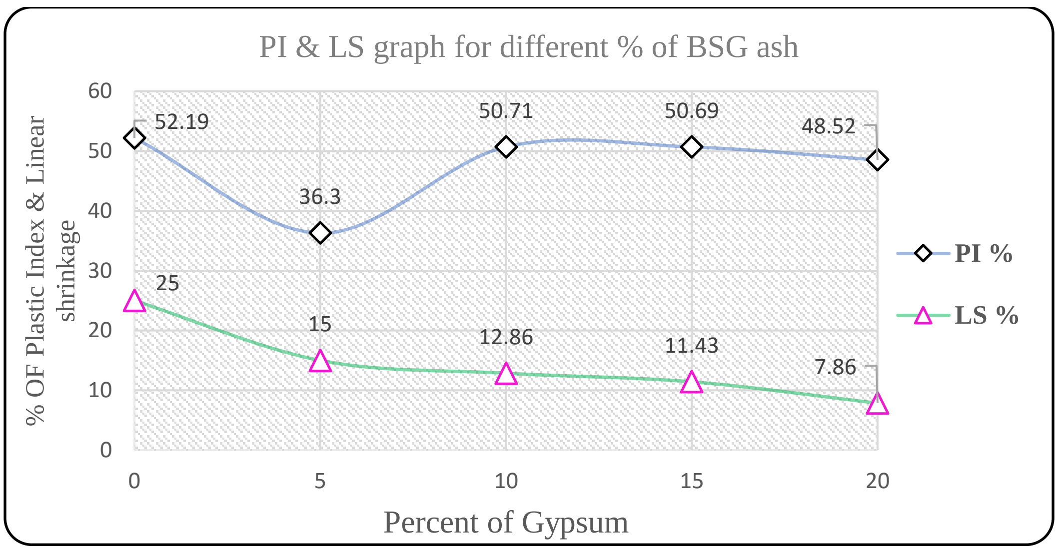


Figure 4. 11 Effect of BSG ash on plastic index and linear shrinkage limit

4.5.2 Effect of BSG ash on moisture density relation

Compaction tests for this study were conducted to study the effect for different percent of BSG ash added to the sub grade soil on moisture density relation. This test indicated that the effect of proposed percentage of BSG ash stabilizer on maximum dry density and its corresponding optimum moisture content from the compaction curve in Figure 4.12 and the tabular data as seen in Appendix C.

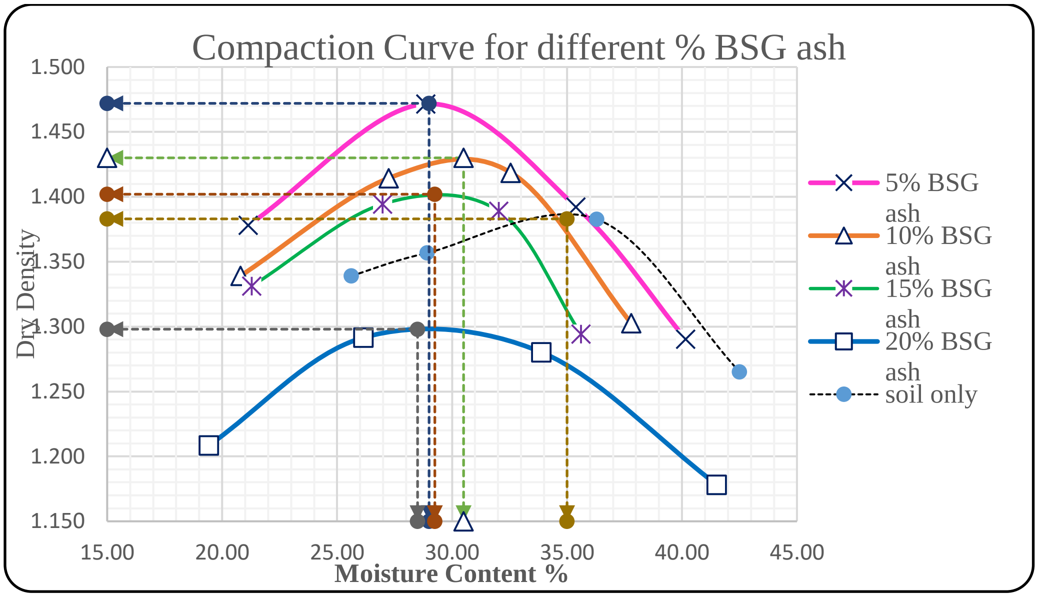


Figure 4. 12 Summary of OMC and MDD curve for BSG ash treated soil sample

According to the laboratory result as shown in figure 4.13. The percent of brewery spent grain ash added to the soil increase, the maximum dry density becomes decrease. The optimum moisture content also decreases compared with natural sub-grade soil which indicated that brewery spent grain ash had water absorbent behavior.

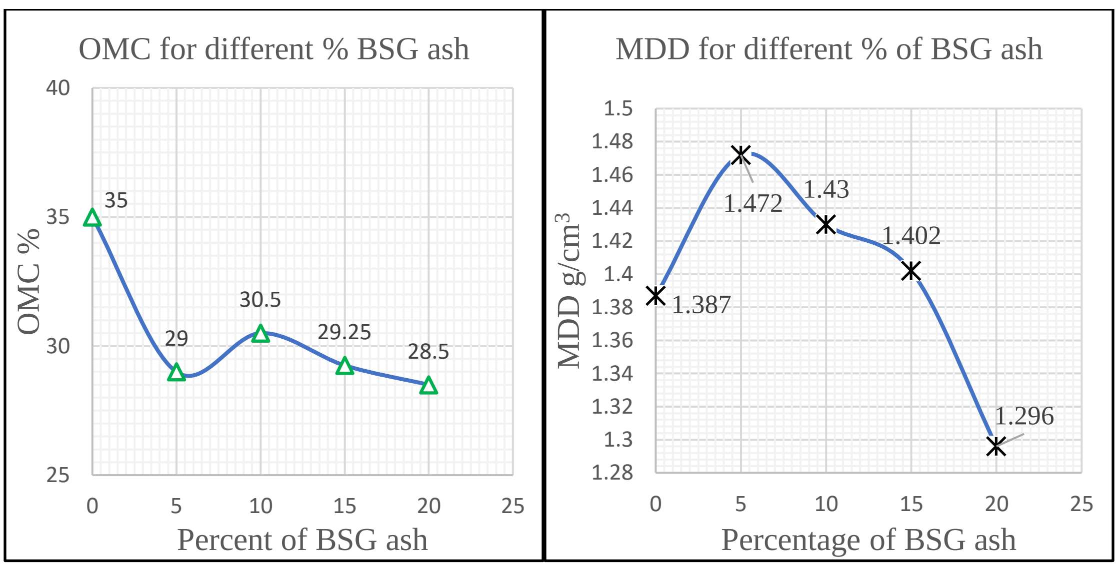


Figure 4. 13 Variation of OMC and MDD for different % of BSG ash

4.5.3 Effect of BSG ash on CBR and CBR swell

CBR teste for this study was conducted by taking air dried sample which pass through sieve No.4 (4.75mm) for natural soil mixed with different percent of 5%, 10%, 15% and 20% BSG ash through modified compaction. The value was determined by One-point CBR method through modified compaction with 5 layers, 56 blows and soaked for 96 hours for all samples.

CBR swells also determined after four days soaked for each percentage of BSG ash add to the soil. The prove reading ring load graphs are above the natural soil, which indicated each proposed percentage of BSG ash used to improve the engineering properties of sub-grade soil.

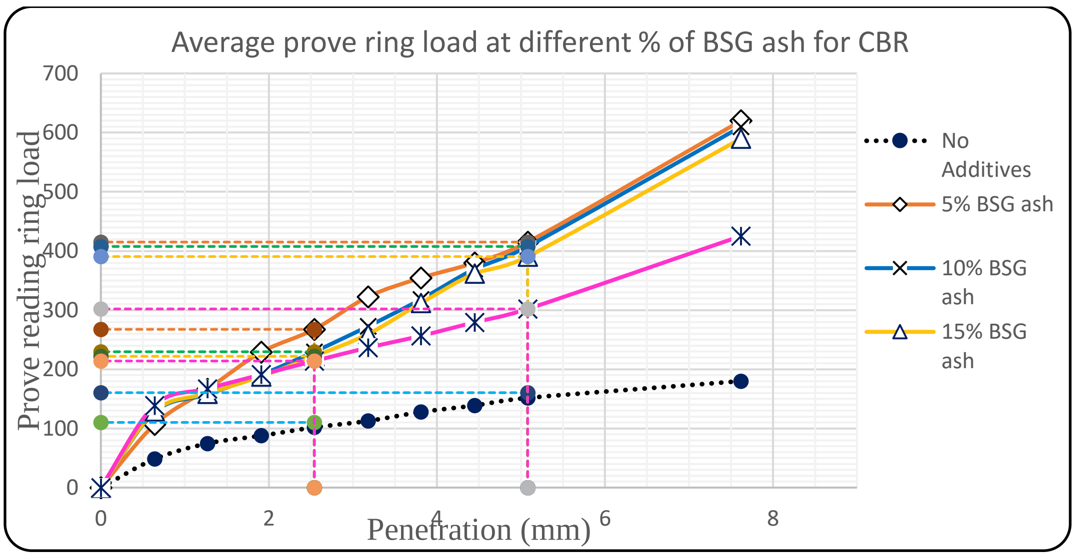


Figure 4. 14 Average prove reading load graph at different % of BSG ash for CBR

According to the laboratory result, the percentage of BSG ash increase from 5% to 20%, the CBR value decrease as 4.97%, 4.88%, 4.67% & 3.84% and also the CBR swell increases as 4.08%, 4.51%, 5.16% & 5.8% for their respective proposed percentage of BSG ash as shown in figure 4.15 and table 4.7 below. For all sample the laboratory result of CBR value was more than 3% that satisfied ERA subgrade specification. The CBR swell increase as the percent of BSG ash increase. Generally, the result indicated that brewery spent grain ash used as a stabilizer however as the percent add to the soil increase the effect due to this stabilizer becomes decrease. The detail tabular data put in Appendix C.

Table 4. 7 CBR and CBR swell data for BSG ash treated sample

% of BSG ash	% CBR Swelling	Penetration (mm)	Aver. Prove ring reading load	CBR %	Max CBR%	ERA requirement for subgrade	Remark
0	6.02	2.54	110.1	1.98	1.98	>3%	Poor
		5.08	160.4	1.92			
5	4.08	2.54	267.5	4.80	4.97		Satisfied
		5.08	415	4.97			
10	4.51	2.54	229.6	4.12	4.88		Satisfied
		5.08	407.5	4.88			
15	5.16	2.54	222	3.99	4.67		Satisfied
		5.08	390.5	4.67			
20	5.8	2.54	214	3.84	3.84		Satisfied
		5.08	302	3.62			

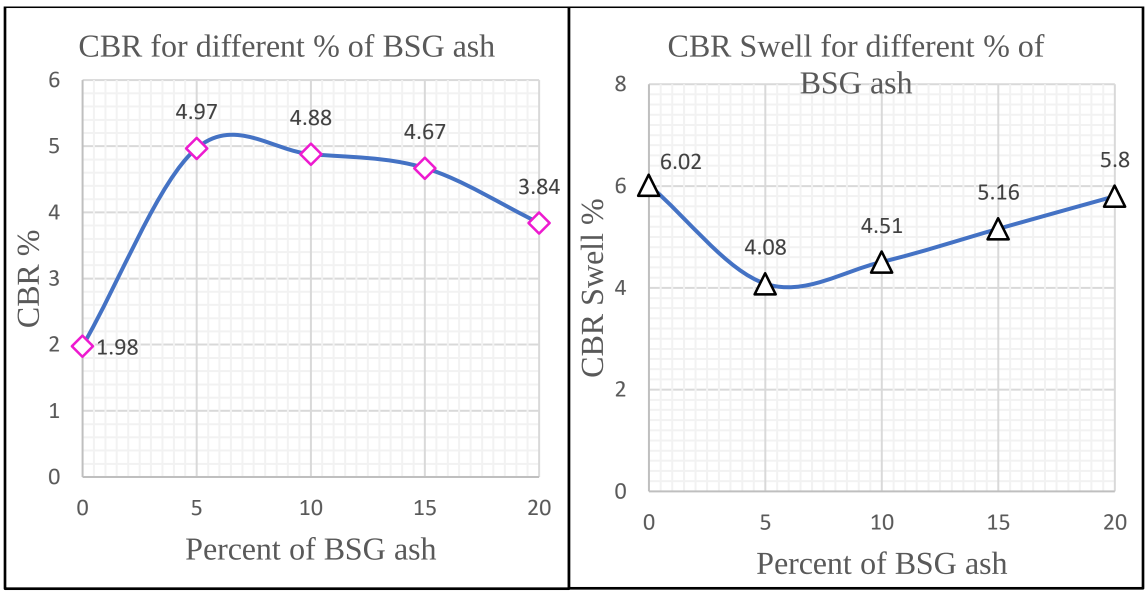


Figure 4. 15 Effect of different % of BSG ash on CBR and CBR swell

Generally, the effect of BSG ash added to weak sub-grade soil with the proposed percentage 5%, 10%, 15% and 20% as a stabilizer. After conducted the required laboratory tests and summarized as below in Table 4.8.

Table 4. 8 Summary of laboratory result for BSG ash stabilized

% of BSG ash	Atterberg limit			LS	compaction		CBR	CBR swell	CBR > 3%	USCS soil classification
	LL	PL	PI		OMC	MDD				
0	84.48	32.29	52.19	25	35	1.387	1.98	6.02	Poor	CH
5	95.8	49.24	36.3	15	**29**	**1.472**	**4.97**	**4.08**	satisfied	MH
10	87.64	36.93	50.71	12.86	30.5	1.43	4.88	4.51	satisfied	CH
15	87.36	36.67	50.69	11.43	29.25	1.402	4.67	5.16	satisfied	CH
20	86.52	38	48.52	7.86	28.5	1.296	3.84	5.8	satisfied	CH

The soil class changes from highly plastic clay to highly plastic silts as per USCS at 5% BSG ash, but not change for others percentage.

4.6 Blending effect of Gypsum and Brewery spent grain ash for sub-grade stabilization

The basic aim of this study was to evaluate the effect of brewery spent grain ash on liquid limit, plastic limit, plasticity index, linear shrinkage, moisture density relation, CBR and CBR swell for partial replacement of gypsum. All laboratory tastes were conducted by taking different proportion of G: BSG ash ratio (1:1, 1:2, 1:3 and 1:4) with the cumulative percentage value of gypsum and brewery spent grain ash taken as the optimum percent of gypsum 20%.

Table 4. 9 Percent of Gypsum and BSG ash for the proposed blending ratio

Additive ratio (G: BSG ash)	Cumulative value of blending Additive (20%)	
	% of Gypsum (G)	% of Brewery spent grain ash (BSG ash)
1:1	10	10
1:2	6.7	13.3
1:3	5	15
1:4	4	16

4.6.1 Blending effect of Gypsum and BSG ash on Atterberg limit and linear shrinkage

The Atterberg limit lab result like liquid limit, plastic limit and plastic index as well as linear shrinkage tests were conducted to study the blending effect of gypsum and brewery spent grain ash with different ratio 1:1, 1:2, 1:3 and 1:4 added to the natural soil. The sample of natural soil was air dried which pass through No.40 sieve mixed with different ratio of (G: BSG ash) by then take 300g for each sample and socked with plastic cover for 24 hours to distribute the moisture in sample uniformly as well as to give sufficient time for chemical reaction.

According to the results observed from the laboratory test, as the percentage of gypsum add decrease from 10% to 4% and the present BSG ash add increase from 10% to 16% for their corresponding mix ratio the plasticity behavior of sub grade soil and also linear shrinkage becomes slightly decrease as shown in Figure 4.16 and Appendix D. The reason beyond to this result, the content of calcium ions in gypsum was high that used to reduce the space in clay surface of soil by replacing the sodium ions.

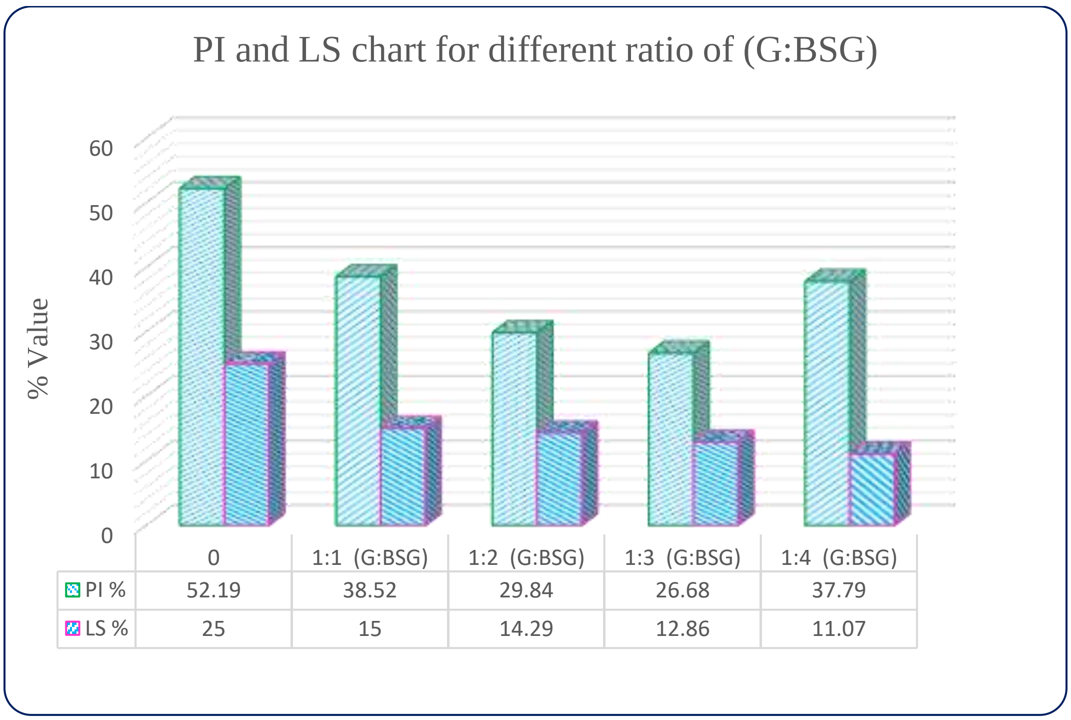


Figure 4. 16 PI and LS chart for different ratio of (G: BSG ash)

4.6.2 Effect of Gypsum and BSG ash on moisture density relation

Compaction tests were conducted with different blending ratio of (G: BSG ash) as shown in Table 4.9 added to the sub grade soil which pass through No.40 sieve to study of moisture density relationship. This test indicated that the effect of different blending ratio of proposed stabilizer on maximum dry density and its corresponding optimum moisture content from the compaction curve as shown in Figure 4.17 and the tabular data as seen in Appendix-D.

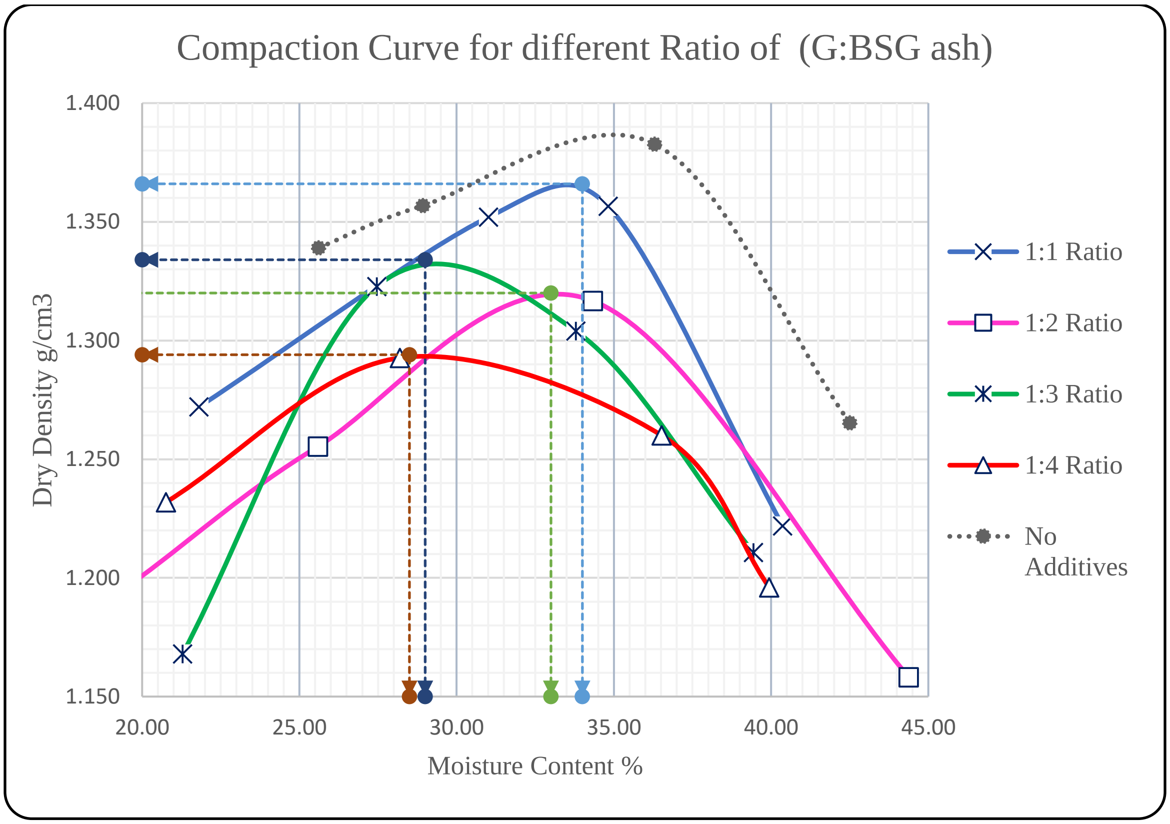


Figure 4. 17 Compaction curves for different ratio of (G: BSG ash)

According the laboratory test result, the gypsum and brewery spent grain ash added to the natural sub-grade soil with different mix ratio 1:1, 1:2, 1:3 and 1:4 as seen in Table 4.9, the dry density varies 1.387 g/cm^3, 1368 g/cm^3, 1.32 g/cm^3, 1.334 g/cm^3 & 1.294g/cm^3 and optimum moisture content also varies 35%, 33.5%, 33%, 29.5 & 28.5% for their respective mix ratio as shown in figure 4.18 and the detailed tabulated data attached in Appendix D.

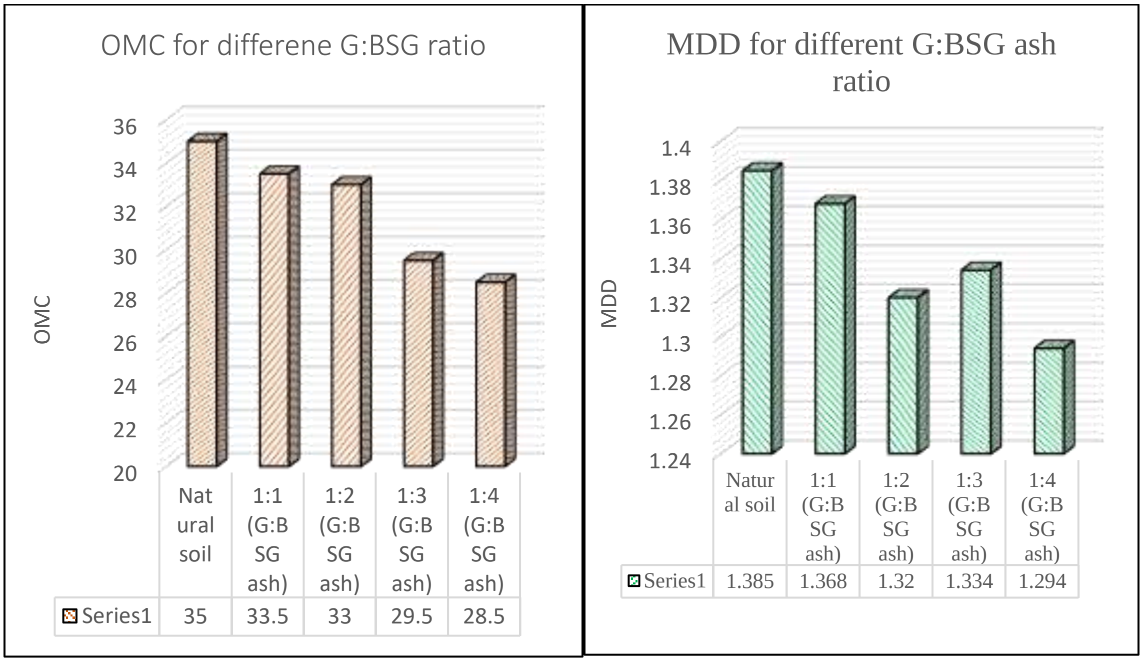


Figure 4. 18 MDD and OMC chart for different G: BSG ash ratio

4.6.3 Effect of Gypsum and BSG ash on CBR and CBR swell

CBR test for this study was conducted by taking air dried sample which pass through sieve No.4 (4.75mm) for natural soil mixed with different blending proportion of (G: BSG ash) ratio and applied modified compaction. The value was determined by One-point CBR method through modified compaction with 5 layers, 56 blows and soaked for 96 hours for all samples.

CBR swells also determined after four days soaked for each blending ratio add to the soil. The prove reading ring load graphs are above the natural soil, which indicated each proposed blending ratio used to improve the engineering properties of sub-grade soil as seen in Figure 4.19 below.

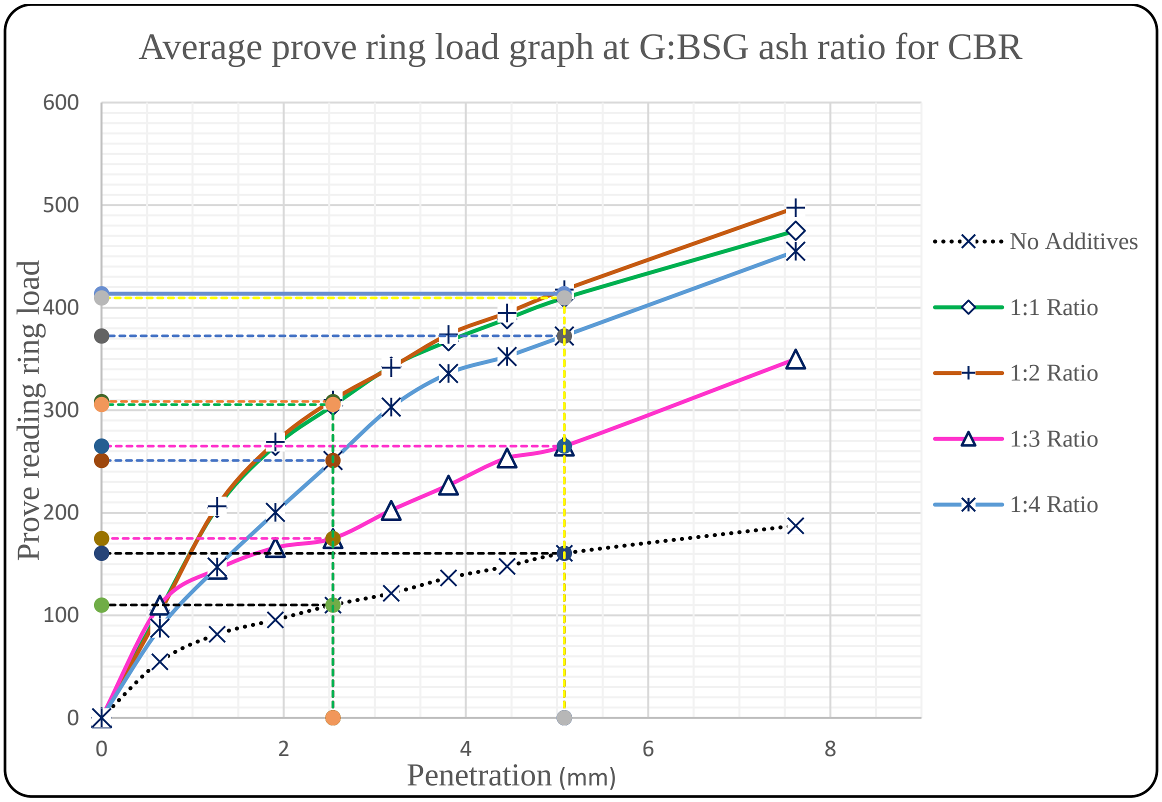


Figure 4. 19 Average prove reading load graph at different (G: BSG ash) ratio for CBR

The California bearing ratio value slightly decrease when the percent of gypsum added decrease and the percent of brewery spent grain ash increase in the proposed mix ratio in table 4.9. According to the laboratory test result the CBR value for all proposed ratio of 1:1, 1:2, 1:3 and 1:4 were 5.47%, 5.54%, 5.49% & 4.51% as shown in Table 4.10 and Figure 4.19 respectively. The CBR swell value of stabilized sub-grade soil also decrease compared with the natural sub-grade soil. Specially for 1:2 (G: BSG ash) ratio that contains 6.7% of gypsum and 13.3% of BSG ash, the CBR and CBR swell values are 5.53% & 3.65% respectively which satisfied ERA sub-grade specification. Indirectly the result due to this ratio had a related effect for stabilization due to the optimum percent gypsum because of partial replacement of gypsum by BSG ash through replacement of non-plastic material, flocculation and agglomeration due to cation exchange resulting into increase of soil density. The detail tabular data shown in Appendix D.

Table 4. 10 CBR and CBR swell data for G: BSG ash blending stabilization

G:BSG ash ratio	% value		% CBR Swell	Penetration (mm)	Aver. Prove ring reading load	CBR %	Max CBR%	ERA requirement	Remark
	G	BSG ash							
0	0	0	6.02	2.54	110.1	1.98	1.98	>3%	Poor
				5.08	160.4	1.92			
1:1	10	10	3.87	2.54	305.5	5.47	5.47		Satisfied
				5.08	409.5	4.90			
1:2	6.7	13.3	3.65	2.54	308.5	5.54	5.54		Satisfied
				5.08	413.6	4.95			
1:3	5	15	4.3	2.54	175	5.44	5.49		Satisfied
				5.08	265	5.49			
1:4	4	16	4.73	2.54	251	4.51	4.51		Satisfied
				5.08	372.5	4.46			

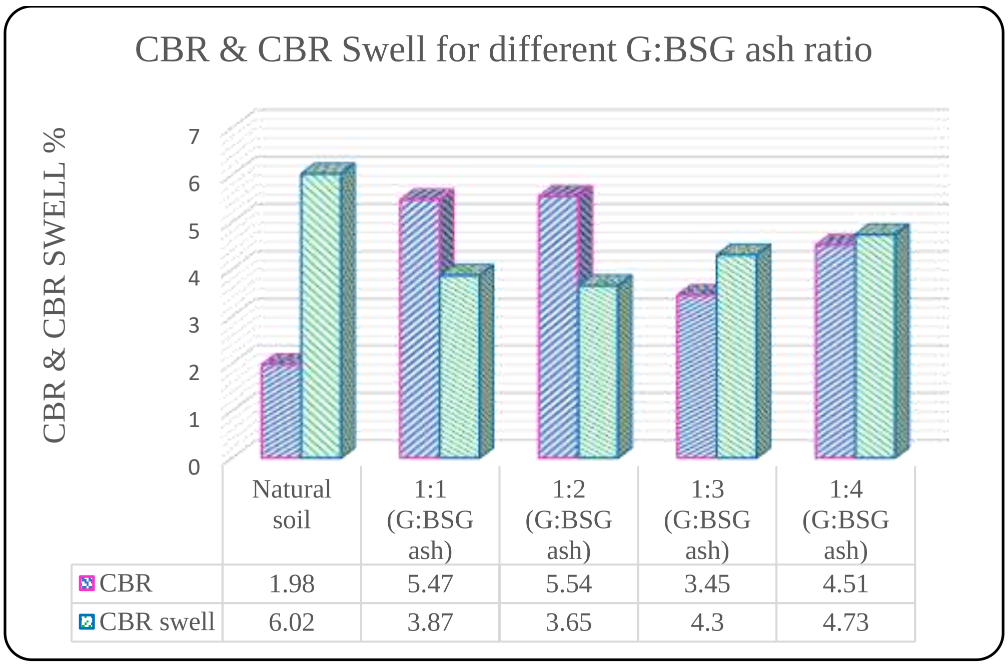


Figure 4. 20 CBR and CBR swell for different (G: BSG ash) ratio

Generally, the blending effect of (G: BSG ash) ratio of 1:1, 1:2, 1:3 and 1:4 which contains (10%, 6.7%, 5% & 4%) of gypsum and (10%, 13.3%, 15% & 16%) of BSG ash for the respective ratio. All laboratory test results were summarized as shown in Table 4.11 below:

Table 4. 11 Summary of laboratory result for blending stabilized

Blending G: BSG ash stabilizer			Atterberg limit			LS	Compaction		CBR	CBR swell	CBR > 3%	USCS soil classification
Ratio	G	BSG ash	LL	PL	PI		OMC	MDD				
0:0	0	0	84.48	32.29	52.19	25	35	1.385	1.98	6.02	poor	CH
1:1	10	10	78.02	39.5	38.52	15	33.5	1.368	5.47	3.87	satisfied	MH
1:2	6.7	13.3	76.51	46.67	29.84	14.29	**33**	**1.32**	**5.54**	**3.65**	satisfied	MH
1:3	5	15	78.76	52.08	26.68	12.86	29.5	1.334	3.45	4.3	satisfied	MH
1:4	4	16	76.58	48.33	28.25	12.14	28.5	1.294	4.51	4.73	satisfied	MH

The soil class was highly clay (CH) as per USCS and A-7-5 as per AASHTO for natural sub grade. After stabilized through blending of each proposed ratio the soil class change from highly plastic clay (CH) to highly plastic silts (MH) as per USCS, but it was not change as per AASHTO.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The following conclusions can be drawn from the results of investigation carried out within the scope of the study.

- BSG ash was denied the pozzolanic property but, it contains heavy cationic element that used for stabilization through cation exchange.
- The plasticity index and linear shrinkage reduced 52.19% to 24.93% and 25% to 11.43% respectively, when the percent of gypsum added to the soil increase from 0% to 20% with 5% range of variation. The optimum moisture content decreased from 35% to 30%, maximum dry density increased from 1.387 g/cm^3 to 1.475 g/cm^3, California bearing ratio value increased from 1.98% to 5.51% and CBR swells reduced from 6.02% to 3.87% as the percent of gypsum increase from 0% to 20%. According to ERA sub-grade specification 15% & 20% are satisfied however, based on the strength CBR and CBR swell value 20% gypsum taken as the optimum percentage from the proposed amount for stabilization.
- The plastic index, linear shrinkage and optimum moisture become reduce compared with the natural soil for the proposed percentage of BSG ash added to soil. The California bearing ratio and maximum dry density were reduced from 4.97% to 3.84% and 1.472g/cm^3 to 1.296g/cm^3 respectively. CBR swell increased from 4.08% to 5.8% as the percentage of BSG ash added to soil increase from 5% to 20% with 5% range. Therefore at 5% BSG ash the values of OMC, MDD, CBR and CBR swell were 29%, 1.472g/cm^3, 4.97% and 4.08% respectively which has higher strength than others percentage.
- The blending of the two additives had the great effect on the strength of sub grade stabilization at the proposed ratio compared with individual additives. As the percent of gypsum decrease and BSG ash increase in the respective mix ration, the plastic index and linear shrinkage become to decrease. The optimum effect happens

at 1:2 (G: BSG ash) ratio which contains 6.7% of gypsum and 13.3% of BSG ash. Therefore at 1:2 ratio the values of PI, LS, OMC, MDD, CBR and CBR swell were 29.84%, 14.29%, 33%, 1.32%, 5.54% & 3.65% respectively. This indicated that BSG ash used as a partial replacement of gypsum for stabilization.

Generally, The California bearing ratio values for gypsum at 20%, for BSG ash at 5% and for the blending of (G: BSG ash) ratio at 1:2 (6.7%G:13.3%BSG ash) were 5.51%, 4.97% and 5.54% respectively. Therefore, the blending of the two additives with 1:2 ratio use as a stabilizer was preferable due to cost minimization through partial replacement of gypsum by BSG ash and to improve the engineering property of natural sub-grade soil.

5.2 Recommendation

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

- Brewery spent grain ash investigated in this research work can be used as a stabilizer of expansive sub grade soil in combination with gypsum. Therefore, concerned bodies like Beer industries, higher education sectors and government entities should be made aware about this potential soil stabilizing material and promote its standardized production and usage.
- The Beer factories in collaboration with higher education should work together to be done more research for further study of BSG ash as a soil stabilizing material and to preserve the environmental impact and suitable waste treatment.
- The following topics are recommended for future studies
    - Investigate the effect of BSG ash by mixing with other stabilizers like cement, lime, flay ash.
    - The BSG ash used in the study was obtained from an uncontrolled burning; Studies should be made using controlled burning at different temperature and the detail chemical composition should be done.
    - This study was conducted by taking limited parameter. I recommended to added other parameters like mineralogical tests and unconfined compressive strength with different curing period should be performed.

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APPENDIXES

Appendix A: - Laboratory analysis data for expansive clay soil

A.1 Hydrometer analysis data

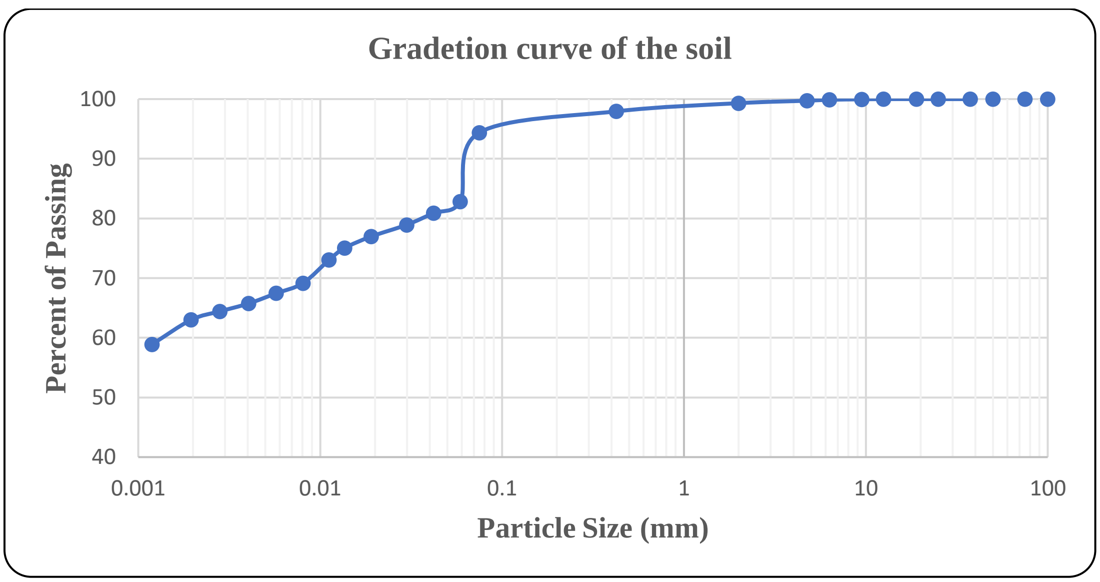
t(min)	Ra	T °C	C_t	Rm	L(cm)	Factor K	D(mm)	R_P	%P	%P_A
0.5	41	25	1.4	41.5	9.5	0.0135	**0.0589**	42.4	87.77	**82.84**
1	40	25	1.4	40.5	9.65	0.0135	**0.0420**	41.4	85.70	**80.89**
2	39	25	1.4	39.5	9.8	0.0135	**0.0299**	40.4	83.63	**78.93**
5	38	25	1.4	38.5	10	0.0135	**0.0191**	39.4	81.56	**76.98**
10	37	25	1.4	37.5	10.15	0.0135	**0.0136**	38.4	79.49	**75.02**
15	36	25	1.4	36.5	10.3	0.0135	**0.0112**	37.4	77.42	**73.08**
30	34	25	1.4	34.5	10.65	0.0135	**0.0080**	35.4	73.28	**69.16**
60	33	25.5	1.525	33.5	10.8	0.0135	**0.0057**	34.525	71.47	**67.45**
120	32	26	1.65	32.5	11	0.0134	**0.0040**	33.65	69.65	**65.74**
240	31	27.3	1.975	31.5	11.15	0.0131	**0.0028**	32.975	68.26	**64.43**
480	30	28.4	2.25	30.5	11.3	0.0127	**0.0020**	32.25	66.76	**63.01**
1440	29	24	1.15	29.5	11.45	0.0134	**0.0012**	30.15	62.41	**58.91**

Where: -
Ra= Actual hydrometer reading, **t=** elapsed lime (min), **T °C**= test temperature,
Tem. Correction Ct= 0.25*T - 4.85, Hyd.reading for effective length **R_M= R_a + C_M**,
Meniscus correction C_M=0.5, Effective length **L= 16.3 - 0.1641*Rm**, **Factor K** take from table as a function of (T, Gs), Particle Size **D=K*(L/t) ^0.5,** Hyd.reading for % finer **R_P= Ra + Ct**, Factor **A**= (G_S*1.65)/((G_S-1) *2.65), **G_S**= Specific gravity of the sample soil, Percent Finer **P= A*(R_P/M_D) *100**, Dry mass of soil for hydrometer test **M_D**=50g,
Adjusted percent Finer **P_A= P*(F_{200}/100)** and **F_{200}**= Percent of passing at sieve N_O.200

A.2 Gradation data for both Mechanical Sieve and Hydrometer analysis

Mechanical (Sieve) Method					Hydrometer Method	
Amount of oven dried sample Before Wash (gm)				2041.2		
Amount of oven dried sample After Wash (gm)				114.6		
Sieve Size		Weight of retained (gm)	% Retained	% Passing	Particle size, D(mm)	%Finer(P)
inch (in)	(mm)					
4"	100	0	0.00	100.00	0.0589	71.74
3"	75	0	0.00	100.00	0.0420	69.74
2"	50	0	0.00	100.00	0.0191	65.76
1 1/2"	37.5	0	0.00	100.00	0.0136	63.77
1"	25	0	0.00	100.00	0.0112	61.77
3/4"	19	0	0.00	100.00	0.0080	57.79
1/2"	12.5	0	0.00	100.00	0.0057	55.80
3/8"	9.5	0.80	0.04	99.96	0.0040	54.80
1/4"	6.3	1.40	0.07	99.89	0.0028	54.80
No.4	4.75	3.40	0.17	99.73	0.0020	54.80
No.10	2	8.40	0.41	99.31	0.0012	48.82
No.40	0.425	27.90	1.37	97.95		
No. 200	0.075	72.70	3.56	94.39		
	Pan	1926.60	94.39	0.00		
	Total	**2041.20**				

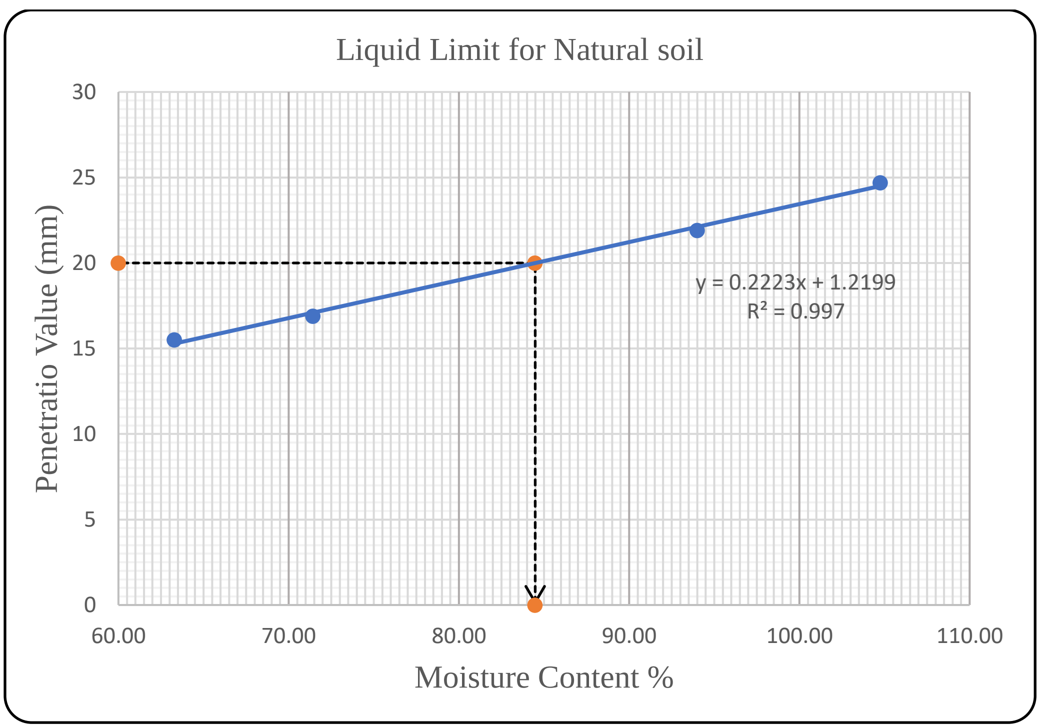
Gradation curve



A.3 Determination of PI using drop cone method for expansive soil without additive

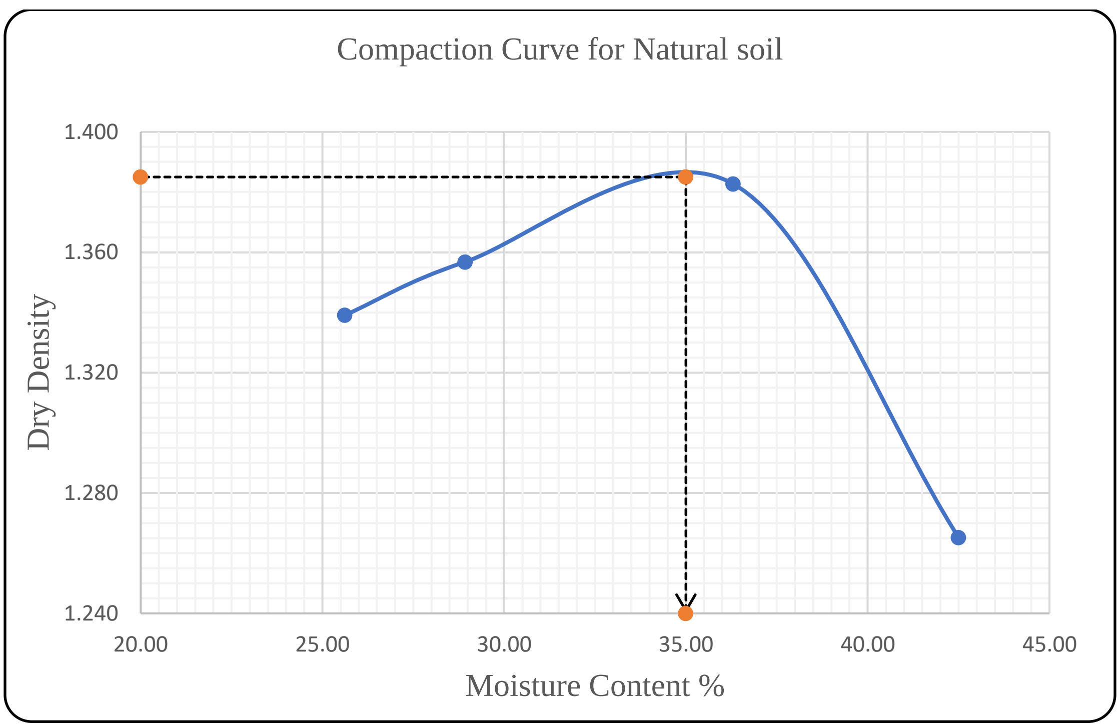
List of Data	**Liquid Limit (LL)**				**Plastic Limit (PL)**	
Can No.	A12	A1	A2	H	1000	527
Mass of Can M1 (g)	38	35.7	37	37.2	37.1	35.6
Mass of (wet soil + can) M2 (g)	68.7	66.9	69.4	71.6	39.2	37.2
Mass of (dry soil + can) M3 (g)	56.8	53.9	53.7	54	38.7	36.8
Moisture content = ((M2-M3)/(M3-M1))*100	**63.30**	**71.43**	**94.01**	**104.76**	**31.25**	**33.33**
Penetration (mm)	**15.5**	**16.9**	**21.9**	**24.7**		

		Summary of Result		**Description of sample preparation**
Linear shrinkage (LS)		**LL**	**84.48**	* The sample should pass through No.200 (0.425mm) * Oven dried the sample them soaked for 24hr * use drop cone method for LL determination
Initial Length (mm)L_o	14	**PL**	**32.29**	
Final Length (mm) L_D	10.5	**PI**	**52.19**	
LS = 100*(1-L_D/L_O)	25.00	**LS**	**25.00**	



A.4 Compaction data for natural soil

Mould weight	2910.6	**Compaction for Free soil 0% Additives**			
Mould Volume	944	Trial 1	Trial 2	Trial 3	Trial 4
CAN No.		938	936	565	930
Mass of CAN (gm)		36.1	36.2	36	35.9
Mould + Compacted soil (gm)		4498.5	4561.9	4689.7	4612.6
Mass of (CAN + wet soil) (gm)		87.1	98.6	92.7	110
Mass of (CAN+ Dry soil) (gm)		76.7	84.6	77.6	87.9
Mass of wet soil (gm)		1587.9	1651.3	1779.1	1702
Bulck Density		1.682	1.749	1.885	1.803
Moisture Content %		**25.62**	**28.93**	**36.30**	**42.50**
Dry Density		**1.339**	**1.357**	**1.383**	**1.265**
Summary		***Maximum Dry Density (MDD)***			**1.385**
		Optimum Moisture Content (OMC)			**35**



A.5 CBR data

CBR for Natural Soil)

Penetration in mm	Trial 1 Load/Div.	Trial 2 Load/Div.	Average
0	0	0	0.0
0.64	62	48	54.9
1.27	88	75	81.4
1.91	104	88	95.6
2.54	119	102	110.1
3.18	130	113	121.4
3.81	146	128	136.6
4.45	157	139	147.6
5.08	169	152	160.4
7.62	195	180	187.5

Standard stresses in Kg & Kg/cm2

Penetration mm	Standard load kg.	Unit standard load, kg/cm^2
2.54	1370	70
5.08	2055	105

Summary of CBR Value %

Corrected CBR Value @ 2.54mm	1.98
Corrected CBR Value @ 5.08mm	1.92
CBR Taken as Max. (@2.54,@5.08)	1.98

<u>Data:</u> factor **0.246**

*Optimum moisture content **=>35%**

*Maximum dry density (MDD) =>1.385gm/cm3

* Condition of test specimen =>Soaked 96hr

* 2KN Proving ring calibration factor =.0.246kg/div

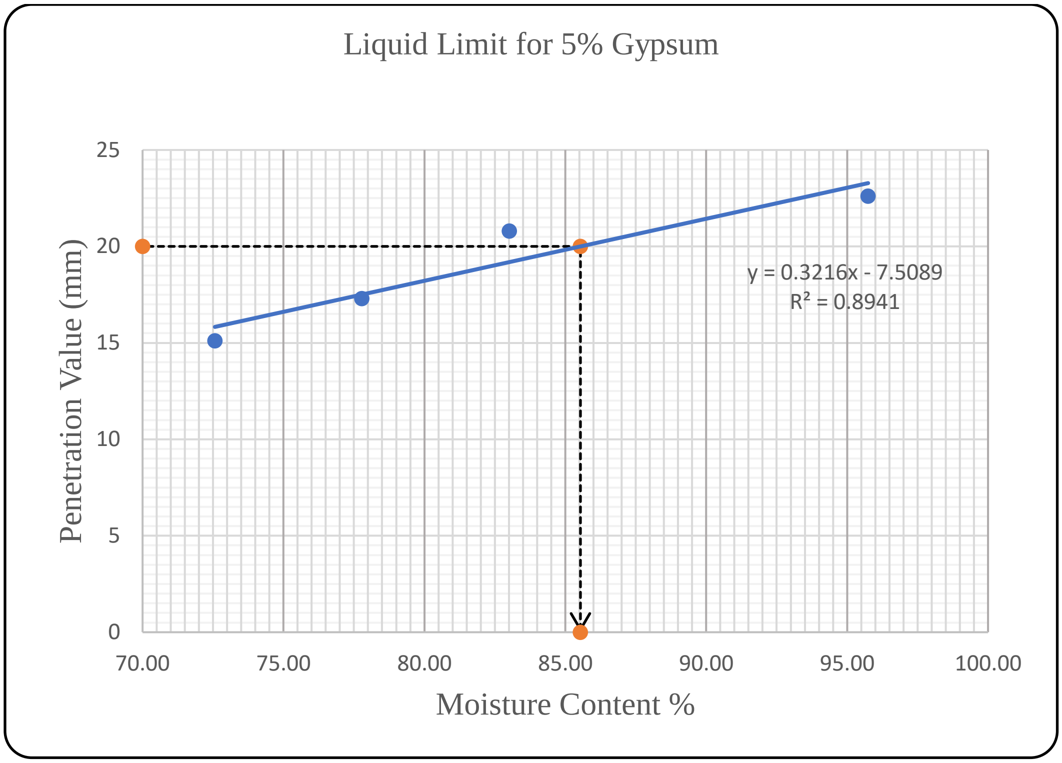
Appendix B: - Laboratory analysis data for Gypsum stabilized sub-grade

B.1 <u>5% Gypsum</u>

B.1.1 Atterberg limit data

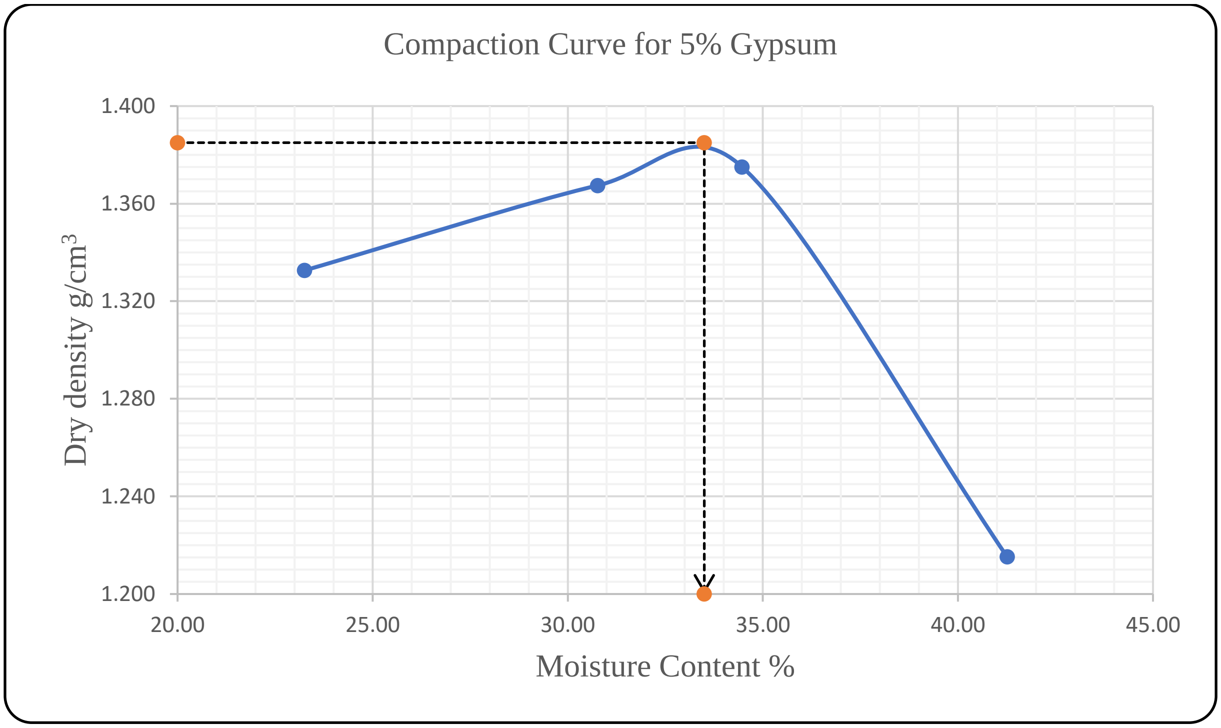
List of Data	**Liquid Limit (LL)**				**Plastic Limit (PL)**	
Can No.	564	568	566	572	447	2
Mass of Can M1 (g)	35.7	36	35.8	36.8	37.5	37.5
Mass of (wet soil + can) M2 (g)	55.2	55.2	55.2	55.2	42.4	42.6
Mass of (dry soil + can) M3 (g)	47	46.8	46.4	46.2	40.8	40.9
Moisture content = ((M2-M3)/(M3-M1))*100	72.57	77.78	83.02	95.74	48.48	50.00
Penetration (mm)	15.1	17.3	20.8	22.6		

		Summary of Result		**Description of sample preparation**
Linear shrinkage (LS)		**LL**	**85.54**	* The sample should pass through No.200 (0.425mm)
Initial Length (mm)L_o	14	**PL**	**49.24**	* Oven dried the sample them soaked for 24hr
Final Length (mm) L_D	11.8	**PI**	**36.30**	* use drop cone method for LL determination
LS = 100*(1-L_D/L_O)	15.71	**LS**	**15.71**	*



B.1.2 Compaction data

Mould weight	3349.5	Compaction for 5% Gypsum with Soil			
Mould Volume	944	Trial 1	Trial 2	Trial 3	Trial 4
CAN No.		922	575	931	921
Mass of CAN (gm)		35.9	36.4	35.6	35.3
Mould + Compacted soil (gm)		4900	5037.6	5095	4970
Mass of (Can +wet soil) (gm)		95.8	95.9	98.8	93.5
Mass of (Can +Dry soil) (gm)		84.5	81.9	82.6	76.5
Mass of wet soil (gm)		1550.5	1688.1	1745.5	1620.5
Bulck Density		1.642	1.788	1.849	1.717
Moisture Content %		23.25	30.77	34.47	41.26
Dry Density		1.333	1.367	1.375	1.215
Summary		***Maximum Dry Density (MDD)***			**1.385**
		Optimum Moisture Content (OMC)			**33.5**



B.1.3 CBR data

CBR for 5% Gypsum			
Penetration in mm	**Trial-1 Load/Div.**	**Trial-2 Load/Div.**	**Average**
0	0	0	0.0
0.64	80	75	77.5
1.27	115	108	111.5
1.91	131	122	126.5
2.54	138	128	133.3
3.18	146	135	140.4
3.81	155	143	148.7
4.45	167	154	160.3
5.08	179	165	172.1
7.62	280	258	269.1

Standard stresses in Kg & Kg/cm2		
Penetration mm	Standard load, kg.	Unit standard load, kg/cm^2
2.54	1370	70
5.08	2055	105

Summary of CBR Value %	
Corrected CBR Value @ 2.54mm	2.39
Corrected CBR Value @ 5.08mm	2.06
CBR Taken as Max. (@2.54,@5.08)	2.39

Data: factor 0.246

*Optimum moisture content **=>33.5%**

*Maximum dry density (MDD) => 1.385gm/cm3

* Condition of test specimen => Soaked 96hr

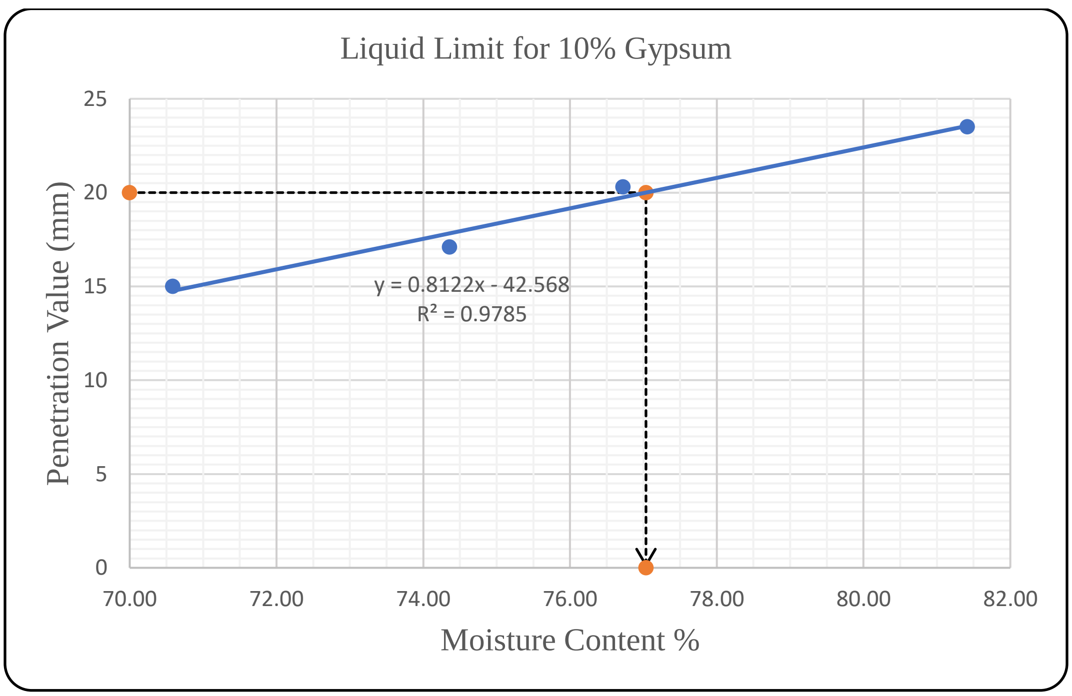
* 2KN Proving ring calibration factor =>0.246 kg/div

B.2 10% Gypsum

B.2.1 Atterberg limit data

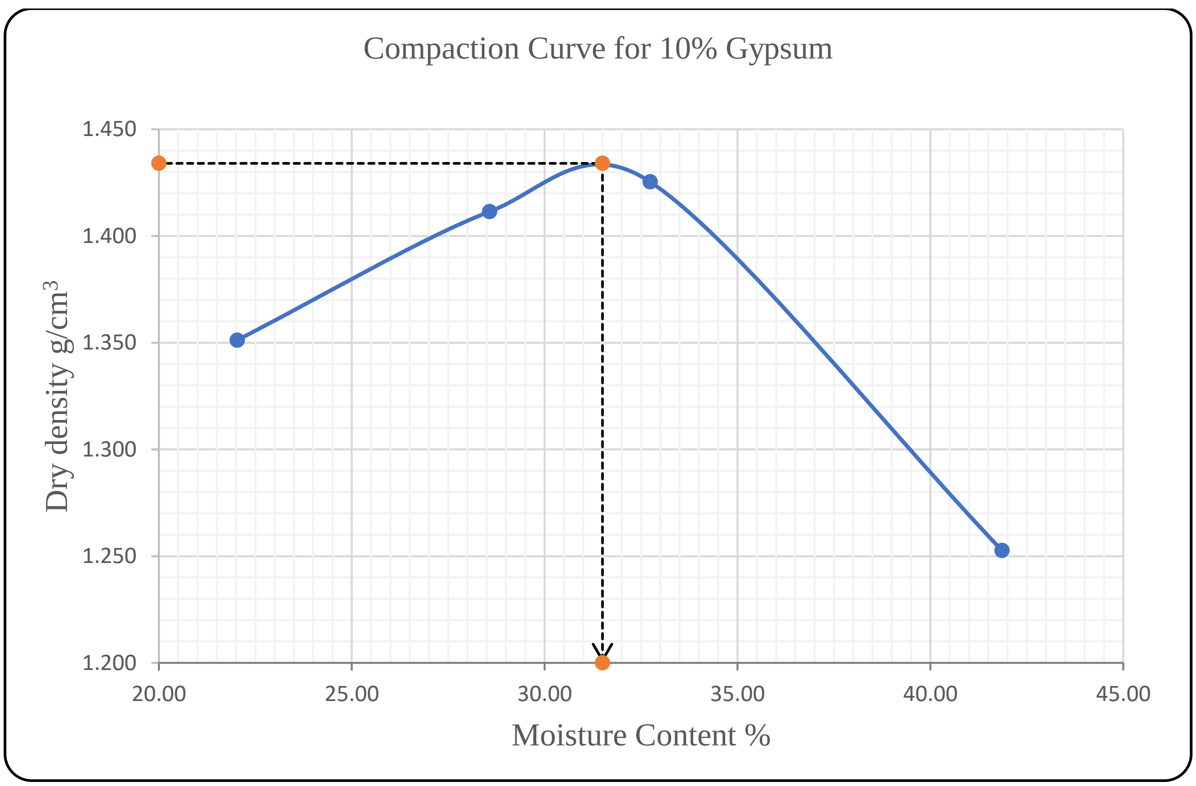
List of Data	Liquid Limit (LL)				Plastic Limit (PL)	
Can No.						
Mass of Can M1 (g)	36.2	36.1	36	36	37.8	37.3
Mass of (wet soil + can) M2 (g)	56.5	56.5	56.5	56.5	41.8	41.9
Mass of (dry soil + can) M3 (g)	48.1	47.8	47.6	47.3	40.5	40.5
Moistur content = ((M2-M3)/(M3-M1))*100	70.59	74.36	76.72	81.42	48.15	43.75
Penetration (mm)	15	17.1	20.3	23.5		

		Summary of Result		Description of sample preparation
Linear shrinkage (LS)		**LL**	**77.04**	* The sample should pass through No.200 (0.425mm)
Initial Length (mm)L_o	14	**PL**	**45.95**	* Oven dried the sample them soaked for 24hr
Final Length (mm) L_D	12	**PI**	**31.09**	* use drop cone method for LL determination
LS = 100*(1-L_D/L_O)	14.29	**LS**	**14.29**	*



B.2.2 Compaction data

Mould weight	3349.5	**Compaction for 10% Gypsum with Soil**			
Mould Volume	944	Trial 1	Trial 2	Trial 3	Trial 4
CAN No.		926	988	996	983
Mass of CAN (gm)		35.8	36.3	36.1	36.3
Mould + Compacted soil (gm)		4906	5062.5	5135.5	5027
Mass of (Can +wet soil) (gm)		112.8	107.4	103	86.8
Mass of (Can +Dry soil) (gm)		98.9	91.6	86.5	71.9
Mass of wet soil (gm)		1556.5	1713	1786	1677.5
Bulck Density		1.649	1.815	1.892	1.777
Moisture Content %		22.03	28.57	32.74	41.85
Dry Density		1.351	1.411	1.425	1.253
Summary		***Maximum Dry Density (MDD)***			**1.434**
		Optimum Moisture Content (OMC)			**31.5**



B.2.3 CBR data

CBR for 10% Gypsum			
Penetration in mm	**Trial -1 Load/Div.**	**Trial -2 Load/Div.**	**Average**
0	0	0	0.0
0.64	51	53	51.9
1.27	75	80	77.5
1.91	94	105	99.5
2.54	125	136	130.5
3.18	138	150	144.0
3.81	160	170	165.0
4.45	186	200	193.0
5.08	227	235	231.0
7.62	289	300	294.5

Standard stresses in Kg & Kg/cm2		
Penetration mm	Standard load, kg.	Unit standard load, kg/cm^2
2.54	1370	70
5.08	2055	105

summary of CBR Value %	
Corrected CBR Value @ 2.54mm	2.34
Corrected CBR Value @ 5.08mm	2.77
CBR Taken as Max. (@2.54,@5.08)	2.77

Data: factor 0.246

*Optimum moisture content **=>31.5%**

*Maximum dry density (MDD) =>1.434gm/cm3

* Condition of test specimen =>Soaked 96hr

* 2KN Proving ring calibration factor =>0.246 kg/div

B.3 15% Gypsum

B.3.1 Atterberg limit data

List of Data	Liquid Limit (LL)				Plastic Limit (PL)	
Can No.	A5	M	B	A	1	4
Mass of Can M1 (g)	37.9	37	37.7	37	37.3	37.4
Mass of (wet soil + can) M2 (g)	69	68.7	72.7	68.1	40.1	39.9
Mass of (dry soil + can) M3 (g)	56.6	55.3	55.3	51.8	39	38.9
Moisture content = ((M2-M3)/(M3-M1))*100	66.31	73.22	98.86	110.14	64.71	66.67
Penetration (mm)	15	18.7	21.9	25		

Linear shrinkage (LS)		Summary of Result	
		LL	**86.37**
Initial Length (mm)L_o	14	**PL**	**65.69**
Final Length (mm) L_D	11.8	**PI**	**20.69**
LS = 100*(1-L_D/L_O)	15.71	**LS**	**15.71**

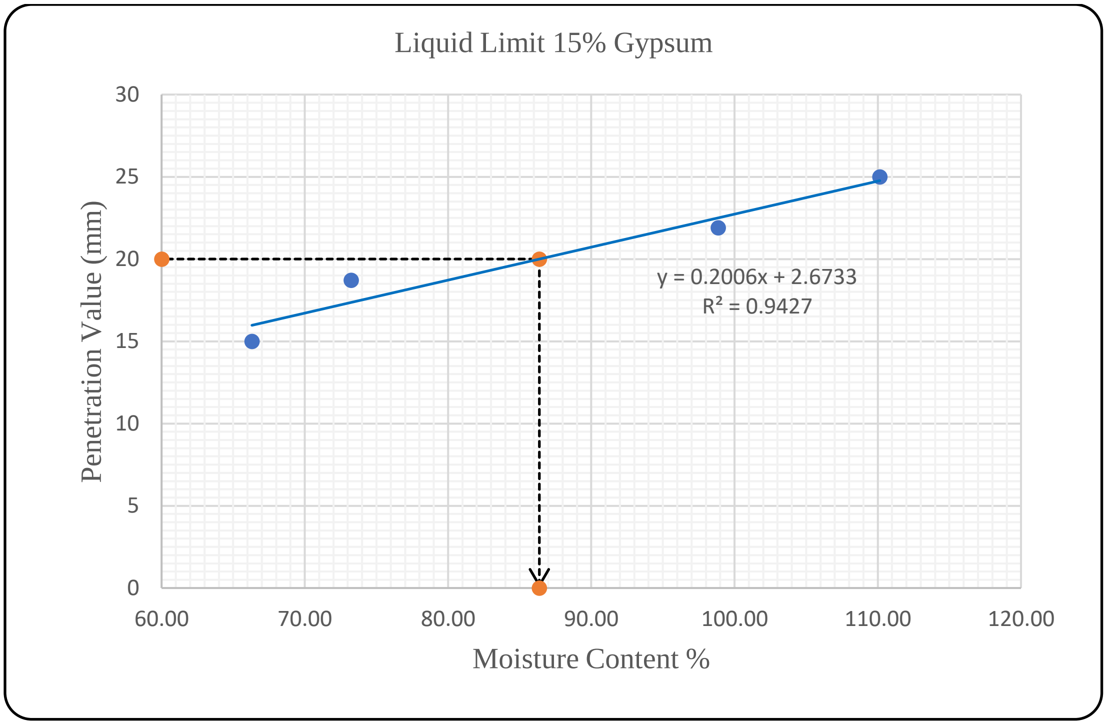
Description of sample preparation

* The sample should pass through No.200 (0.425mm)

* Oven dried the sample them soaked for 24hr

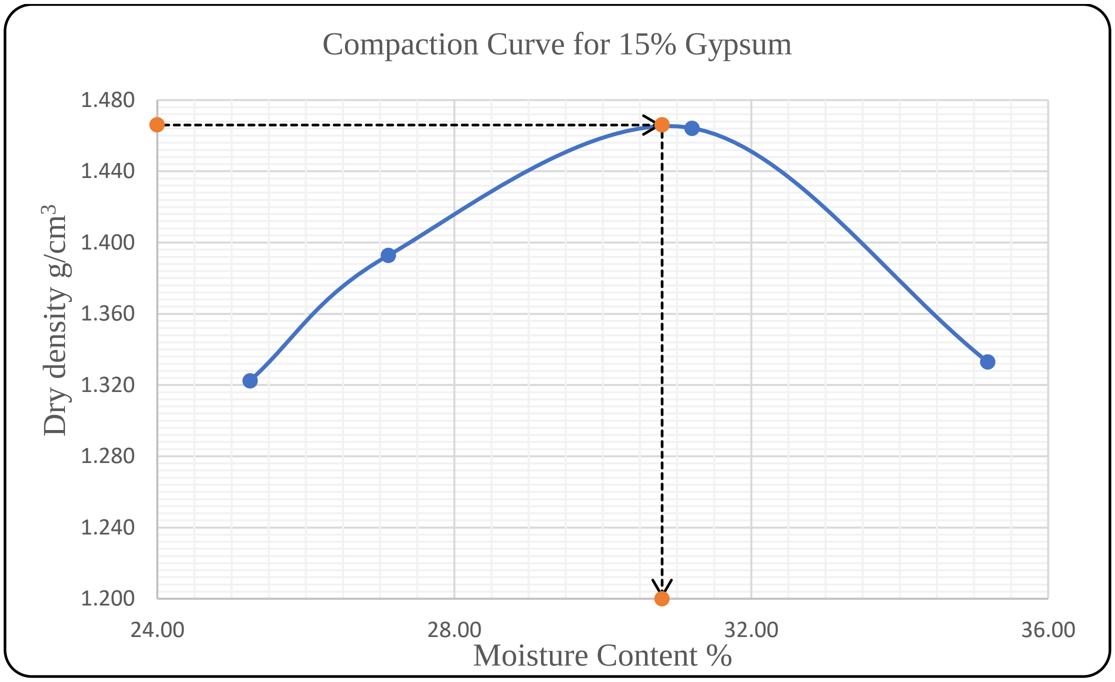
* use drop cone method for LL determination

*



B.3.2 Compaction data

Mould weight	2926	Compaction for 15% Gypsum with Soil			
Mould Volume	944	Trial 1	Trial 2	Trial 3	Trial 4
CAN No.		A	570	567	924
Mass of CAN (gm)		37.2	37.8	37.2	37.5
Mould + Compacted soil (gm)		4489.6	4597.4	4739.6	4627.1
Mass of (Can +wet soil) (gm)		125	103.9	111.2	125.1
Mass of (Can +Dry soil) (gm)		107.3	89.8	93.6	102.3
Mass of wet soil (gm)		1563.6	1671.4	1813.6	1701.1
Bulck Density		1.656	1.771	1.921	1.802
Moisture Content %		25.25	27.12	31.21	35.19
Dry Density		1.322	1.393	1.464	1.333
Summary		***Maximum Dry Density (MDD)***			**1.466**
		Optimum Moisture Content (OMC)			**30.8**



B.3.3 CBR data

CBR for 15% Gypsum

Penetration in mm	Trial -1 Load/Div.	Trial -2 Load/Div.	Average
0	0	0	0
0.64	57	70	63.5
1.27	84	95	89.5
1.91	116	130	123
2.54	155	174	164.5
3.18	175	190	182.5
3.81	198	217	207.5
4.45	218	241	229.5
5.08	260	275	267.5
7.62	311	327	319

Standard stresses in Kg & Kg/cm2

Penetration, mm	Standard load, kg.	Unit standard load, kg/cm^2
2.54	1370	70
5.08	2055	105

summary of CBR Value %

Corrected CBR Value @ 2.54mm	2.95
Corrected CBR Value @ 5.08mm	3.20
CBR Taken as Max. (@2.54,@5.08)	3.20

Data: factor 0.246

*Optimum moisture content =>30.8%

*Maximum dry density (MDD) =>1.466gm/cm3

* Condition of test specimen =>Soaked 96hr

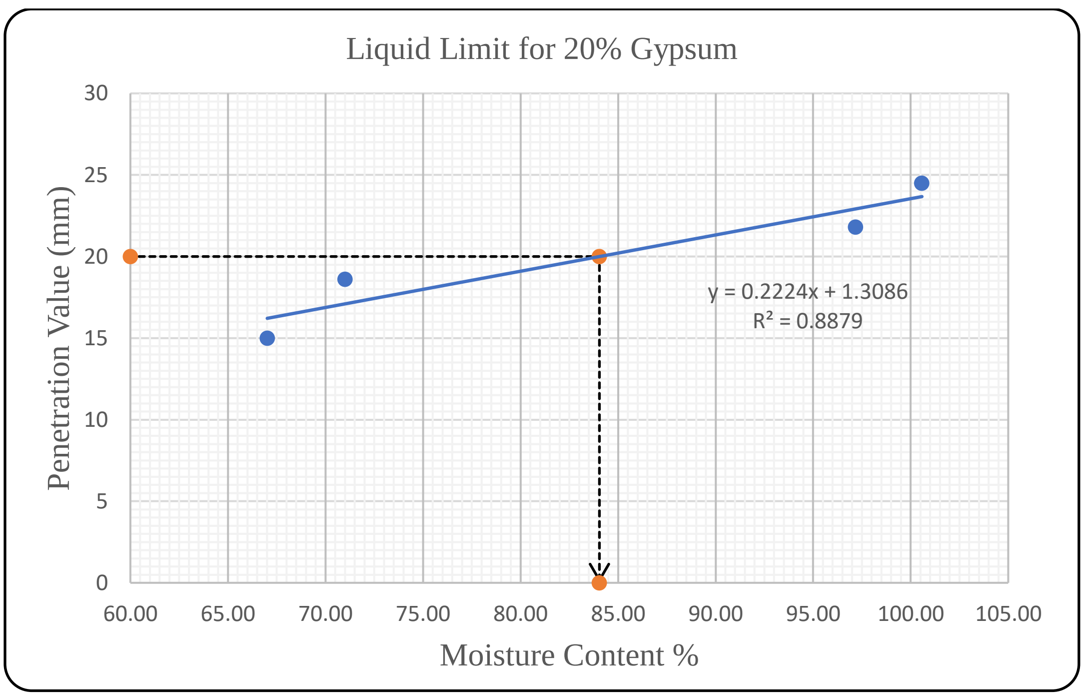
* 2KN Proving ring calibration factor =>0.246 kg/div

B.4 <u>20% Gypsum</u>

B.4.1 Atterberg limit data

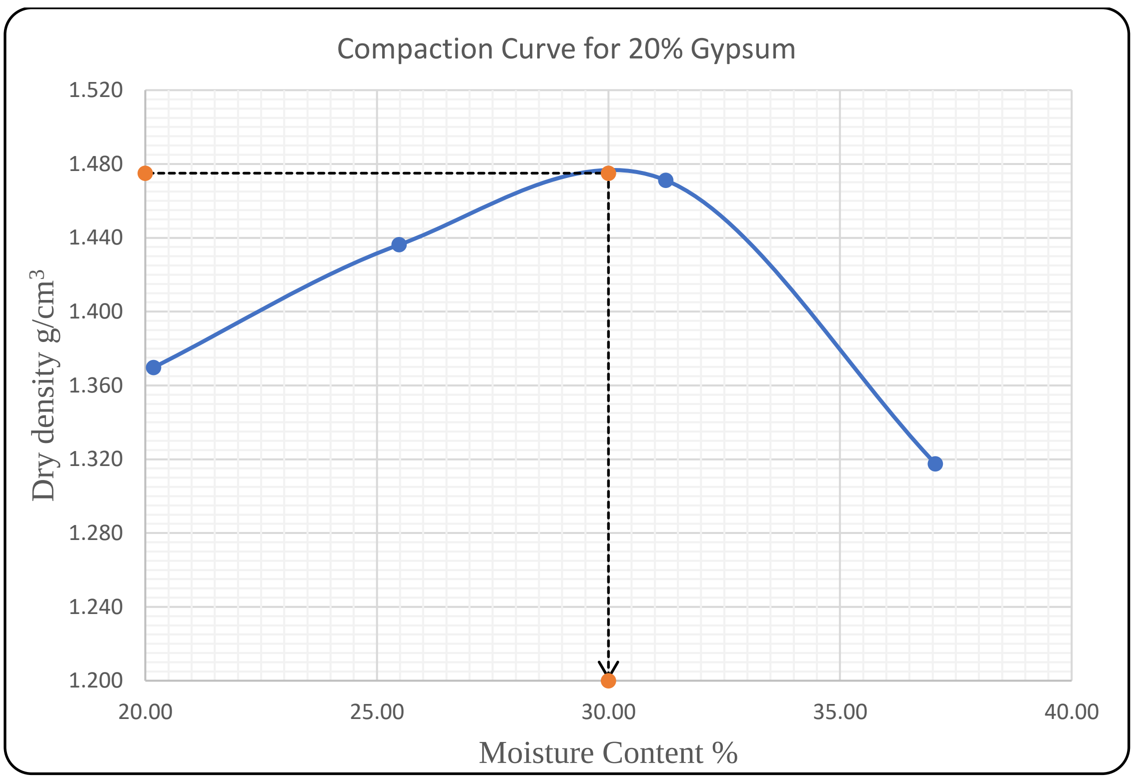
List of Data	Liquid Limit (LL)				Plastic Limit (PL)	
Can No.	A12	A1	A2	H	1000	527
Mass of Can M1 (g)	37.7	36	37.9	37.6	36.1	37.2
Mass of (wet soil + can) M2 (g)	69.6	70.2	72.8	72.5	38.1	39.5
Mass of (dry soil + can) M3 (g)	56.8	56	55.6	55	37.3	38.6
Moisture content = ((M2-M3)/(M3-M1))*100	67.02	71.00	97.18	100.57	66.67	64.29
Penetration (mm)	15	18.6	21.8	24.5		

		Summary of Result		Description of sample preparation
Linear shrinkage (LS)		**LL**	**84.04**	* The sample should pass through No.200 (0.425mm)
Initial Length (mm)L_o	14	**PL**	**65.48**	* Oven dried the sample them soaked for 24hr
Final Length (mm) L_D	11.9	**PI**	**18.57**	* use drop cone method for LL determination
LS = 100*(1-L_D/L_O)	15	**LS**	**15.00**	*



B.4.2 Compaction data

Mould weight	2926	**Compaction for 20% Gypsum with Soil**			
Mould Volume	944	Trial 1	Trial 2	Trial 3	Trial 4
CAN No.		A	570	567	924
Mass of CAN (gm)		37.4	37.1	37.2	37.8
Mould + Compacted soil (gm)		4480	4627.3	4748.6	4630.7
Mass of (Can +wet soil) (gm)		117.8	102.1	106.1	107.7
Mass of (Can +Dry soil) (gm)		104.3	88.9	89.7	88.8
Mass of wet soil (gm)		1554	1701.3	1822.6	1704.7
Bulck Density		1.646	1.802	1.931	1.806
Moisture Content %		20.18	25.48	31.24	37.06
Dry Density		1.370	1.436	1.471	1.318
Summary		***Maximum Dry Density (MDD)***			**1.475**
		Optimum Moisture Content (OMC)			**30**



B.4.3 CBR data

CBR for 20% Gypsum			
Penetration in mm	**Trial -1 Load/Div.**	**Trial -2 Load/Div.**	**Average**
0	0	0	0.0
0.64	105	123.75	114.4
1.27	191	206	198.5
1.91	220	235	227.5
2.54	260	283.75	271.9
3.18	309	329.25	319.1
3.81	380	405	392.5
4.45	418	445	431.5
5.08	446	475	460.5
7.62	635	660	647.5

Standard stresses in Kg & Kg/cm2		
Penetration, mm	Standard load, kg.	Unit standard load, kg/cm^2
2.54	1370	70
5.08	2055	105

summary of CBR Value %	
Corrected CBR Value @ 2.54mm	4.88
Corrected CBR Value @ 5.08mm	5.51
CBR Taken as Max. (@2.54,@5.08)	5.51

Data: factor 0.246

*Optimum moisture content **=>30%**

*Maximum dry density (MDD) =>1.475gm/cm3

* Condition of test specimen =>Soaked 96hr

* 2KN Proving ring calibration factor =>0.246 kg/div

B.4.4 CBR swell data

Percentage of Additives		Lf	Li	CBR swell	Avg. CBR swell
% Gypsum	0	22	14.5	6.45	6.02
		23	16.5	5.59	
	5	23	17.5	4.73	5.16
		24	17.5	5.59	
	10	24	18	5.16	4.94
		23	17.5	4.73	
	15	20	15.5	3.87	4.30
		22	16.5	4.73	
	20	23	19	3.44	3.87
		22.5	17.5	4.30	

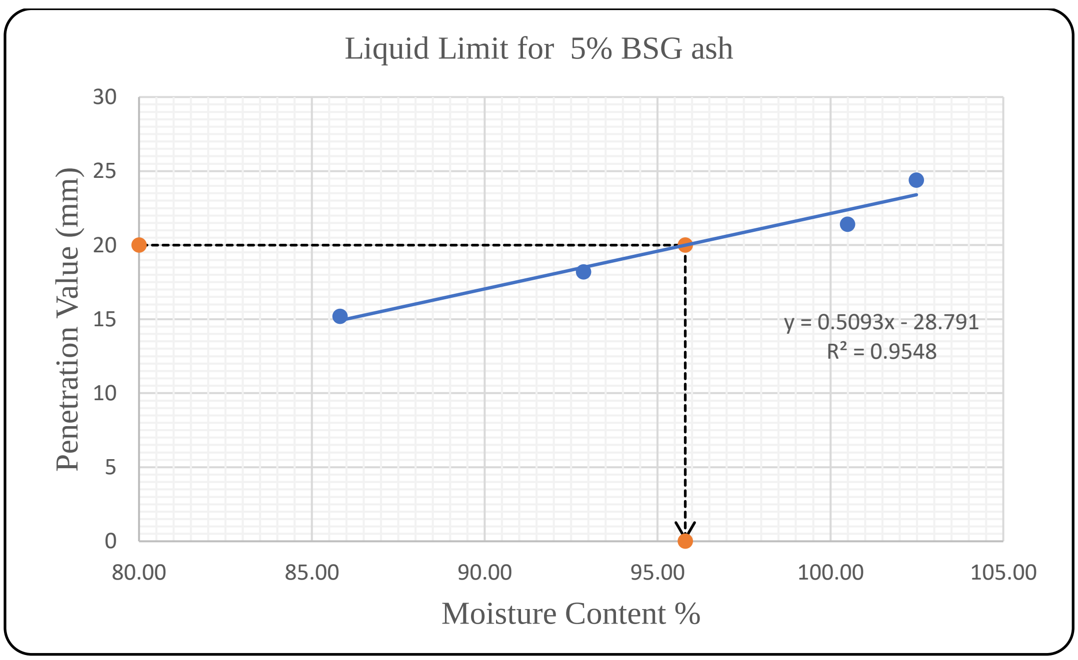
Appendix C: - Laboratory analysis data for BSG ash stabilized sub-grade

C.1 5% BSG ash

C.1.1 Atterberg limit data

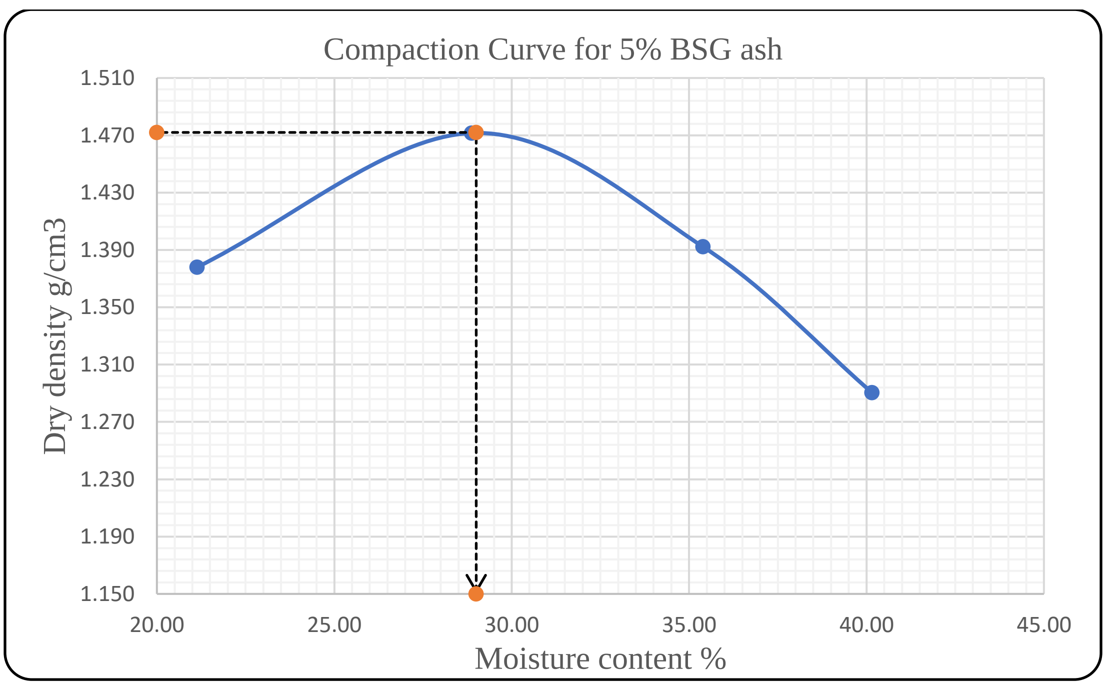
List of Data	Liquid Limit (LL)				Plastic Limit (PL)	
Can No.	924	998	938	930	A	B
Mass of Can M1 (g)	36.2	36.3	36.1	36	37	37.6
Mass of (wet soil + can) M2 (g)	63.7	60.6	76.4	76.7	46.5	47
Mass of (dry soil + can) M3 (g)	51	48.9	56.2	56.1	43.7	44.2
Moisture content = ((M2-M3)/(M3-M1))*100	85.81	92.86	100.50	102.49	41.79	42.42
Penetration (mm)	15.2	18.2	21.4	24.4		

		Summary of Result		Description of sample preparation
Linear shrinkage (LS)		**LL**	**95.80**	* The sample should pass through No.200 (0.425mm)
Initial Length (mm)L_o	14	**PL**	**49.24**	* Oven dried the sample them soaked for 24hr
Final Length (mm) L_D	11.9	**PI**	**36.3**	* use drop cone method for LL determination
LS = 100*(1-L_D/L_O)	15.00	**LS**	**15.00**	*



C.1.2 Compaction data

Mould weight	4751.6	**Compaction With 5% BSG Ash**			
Mould Volume	944	Trial 1	Trial 2	Trial 3	Trial 4
CAN No.		565	572	575	568
Mass of CAN (gm)		36	36.8	36.4	36
Mould + Compacted soil (gm)		6315.9	6530.3	6519.5	6447.4
Mass of (Can +wet soil) (gm)		74.4	80.1	102.2	106.5
Mass of (Can +Dry soil) (gm)		67.7	70.4	85	86.3
Mass of wet soil (gm)		1575.8	1790.2	1779.4	1707.3
Bulck Density		1.669	1.896	1.885	1.809
Moisture Content %		21.14	28.87	35.39	40.16
Dry Density		1.378	1.472	1.392	1.290
Summary		***Maximum Dry Density (MDD)***			**1.472**
		Optimum Moisture Content (OMC)			**29**



C.1.3 CBR data

CBR for 5% BSG Ash			
Penetration in mm	**Trial -1 Load/Div.**	**Trial -2 Load/Div.**	**Average**
0	0	0	0
0.64	97	117	106.63
1.27	150	183	166.38
1.91	207	251	228.94
2.54	245	290	267.50
3.18	310	335	322.50
3.81	344	365	354.50
4.45	370	390	380.00
5.08	400	430	415.00
7.62	605	635	620

Standard stresses in Kg & Kg/cm2		
Penetration mm	Standard load, kg.	Unit standard load, kg/cm^2
2.54	1370	70
5.08	2055	105

summary of CBR Value %	
Corrected CBR Value @ 2.54mm	4.80
Corrected CBR Value @ 5.08mm	4.97
CBR Taken as Max. (@2.54,@5.08)	4.97

Data: factor 0.246

*Optimum moisture content **=>29%**

*Maximum dry density (MDD) =>1.472gm/cm3

* Condition of test specimen =>Soaked 96hr

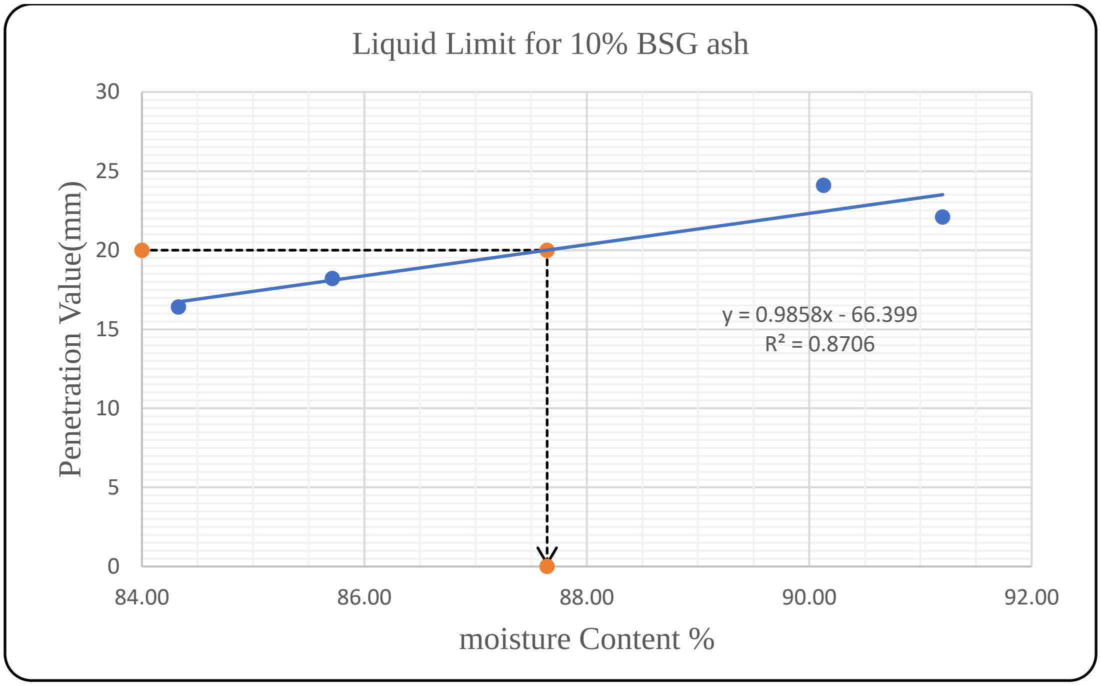
* 2KN Proving ring calibration factor =>0.246 kg/div

C.2 <u>10% BSG ash</u>

C.2.1 Atterberg limit data

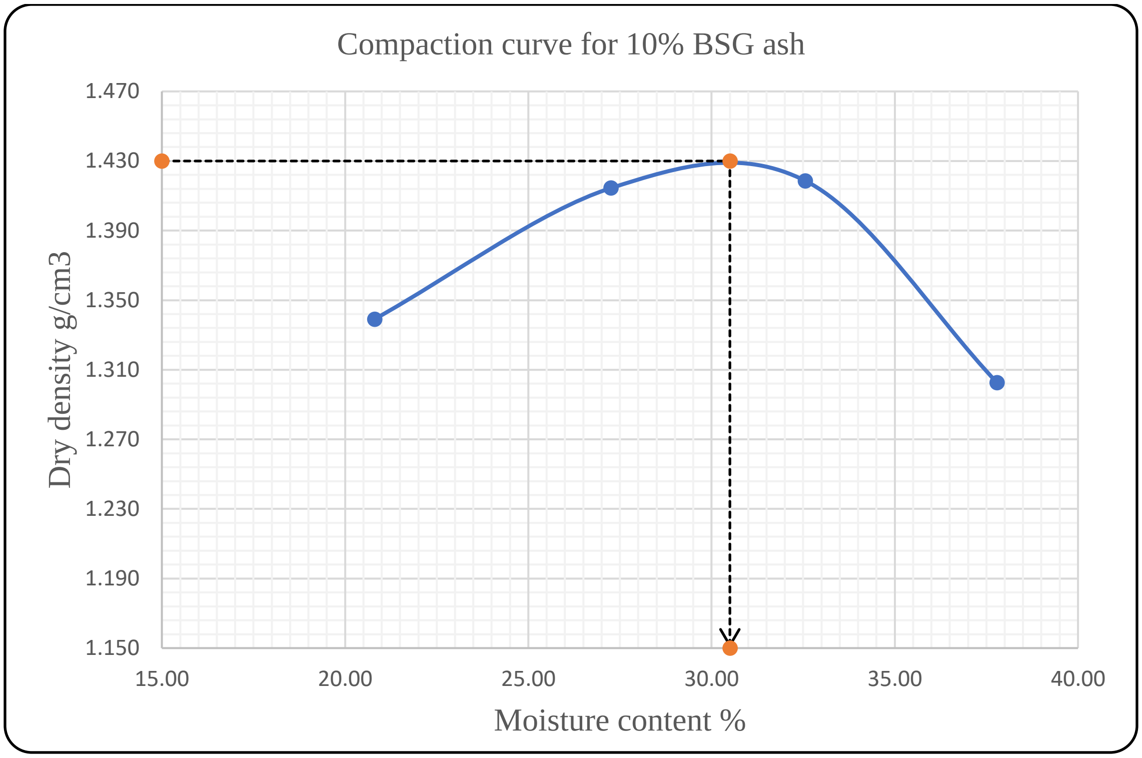
List of Data	**Liquid Limit (LL)**				**Plastic Limit (PL)**	
Can No.	927	EL/02	936	966	2	T/16
Mass of Can M1 (g)	36	35.1	36.2	36.2	37.2	36.8
Mass of (wet soil + can) M2 (g)	60.7	66.3	60.1	80.5	43.2	48.9
Mass of (dry soil + can) M3 (g)	49.4	51.9	48.7	59.5	41.6	45.6
Moisture content = ((M2-M3)/(M3-M1))*100	84.33	85.71	91.20	90.13	36.36	37.50
Penetration (mm)	16.4	18.2	22.1	24.1		

		Summary		**Description of sample preparation**
Linear shrinkage (LS)		**LL**	**87.64**	* The sample should pass through No.200 (0.425mm)
Initial Length (mm)L_o	14	**PL**	**36.93**	* Oven dried the sample them soaked for 24hr
Final Length (mm) L_D	12.2	**PI**	**50.71**	* use drop cone method for LL determination
LS = 100*(1-L_D/L_O)	12.86	**LS**	**12.86**	*



C.2.2 Compaction data

Mould weight	4751.6	**Compaction With 10% BSG Ash**			
Mould Volume	944	Trial 1	Trial 2	Trial 3	Trial 4
CAN No.		926	937	931	936
Mass of CAN (gm)		35.8	36	35.6	36.2
Mould + Compacted soil (gm)		6267.2	6439.2	6515.3	6434.4
Mass of (Can +wet soil) (gm)		86.9	91.1	98.3	94.9
Mass of (Can +Dry soil) (gm)		78.1	79.3	82.9	78.8
Mass of wet soil (gm)		1527.1	1699.1	1775.2	1694.3
Bulck Density		1.618	1.800	1.881	1.795
Moisture Content %		20.80	27.25	32.56	37.79
Dry Density		1.339	1.414	1.419	1.303
Summary		***Maximum Dry Density (MDD)***			**1.43**
		Optimum Moisture Content (OMC)			**30.5**



C.2.3 CBR data

CBR for 10% BSG Ash			
Penetration in mm	**Trial -1 Load/Div.**	**Trial -2 Load/Div.**	**Average**
0	0	0	0.00
0.64	130	126	127.75
1.27	161	154	157.63
1.91	196	186	190.88
2.54	237	222	229.63
3.18	282	263	272.63
3.81	330	307	318.25
4.45	384	356	369.75
5.08	425	390	407.50
7.62	620	600	610.00

Standard stresses in Kg & Kg/cm2		
Penetration mm	Standard load, kg.	Unit standard load, kg/cm^2
2.54	1370	70
5.08	2055	105

summary of CBR Value %	
Corrected CBR Value @ 2.54mm	4.12
Corrected CBR Value @ 5.08mm	4.88
CBR Taken as Max. (@2.54,@5.08)	4.88

Data: factor 0.246

*Optimum moisture content =>30.5%

*Maximum dry density (MDD) =>1.43gm/cm3

* Condition of test specimen =>Soaked 96hr

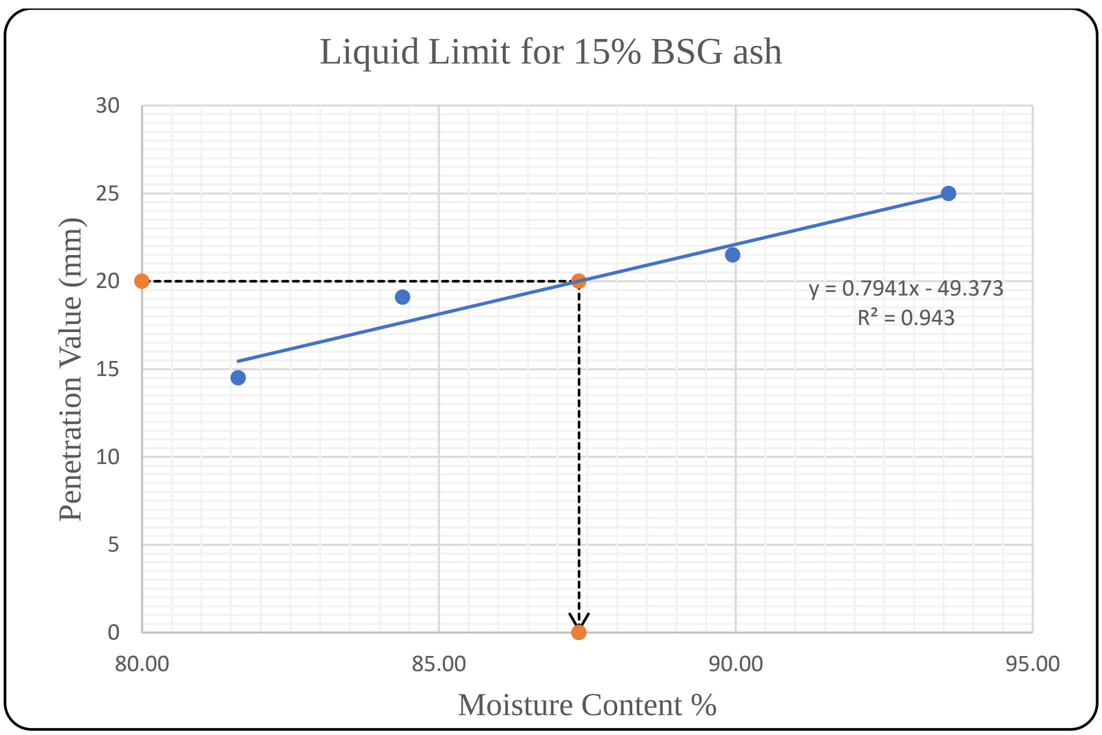
* 2KN Proving ring calibration factor =>0.246 kg/div

C.3 15% BSG ash

C.3.1 Atterberg limit data

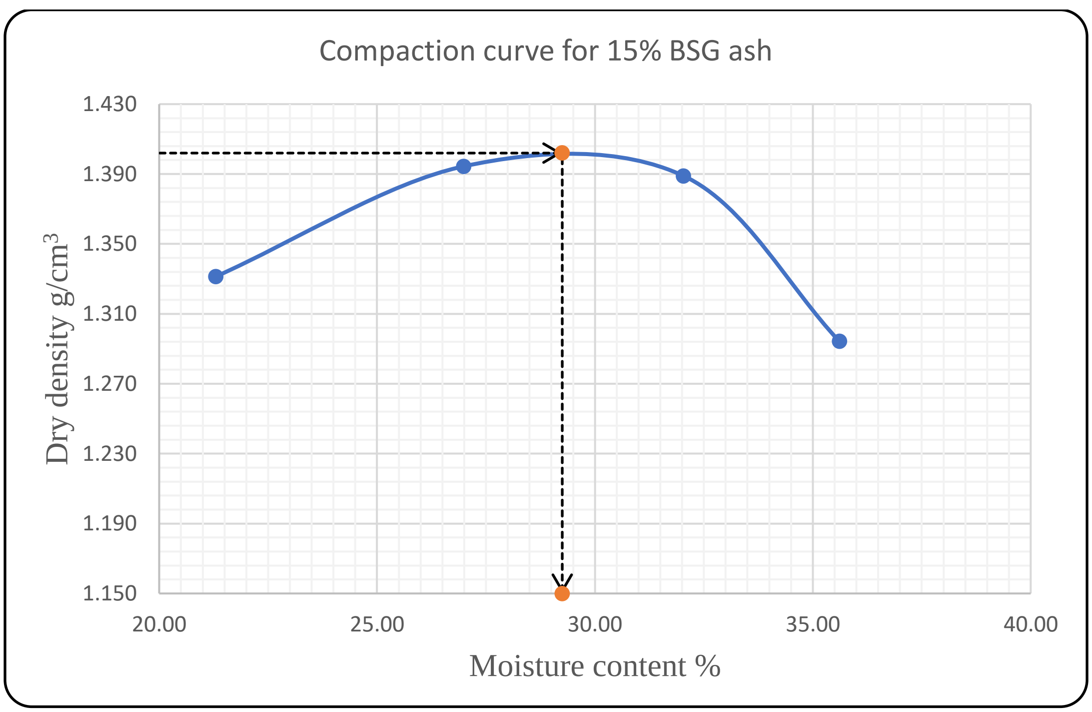
List of Data	**Liquid Limit (LL)**				**Plastic Limit (PL)**	
Can No.	566	926	931	983	575	565
Mass of Can M1 (g)	35.8	35.8	35.6	36.1	36.3	36
Mass of (wet soil + can) M2 (g)	69.4	67.7	73.4	87.4	48.9	45.7
Mass of (dry soil + can) M3 (g)	54.3	53.1	55.5	62.6	45.5	43.1
Moisture content = ((M2-M3)/(M3-M1))*100	81.62	84.39	89.95	93.58	36.96	36.62
Penetration (mm)	14.5	19.1	21.5	25		

		Summary		**Description of sample preparation**
Linear shrinkage (LS)		**LL**	**87.36**	* The sample should pass through No.200 (0.425mm)
Initial Length (mm)L_o	14	**PL**	**36.67**	* Oven dried the sample them soaked for 24hr
Final Length (mm) L_D	12.2	**PI**	**50.69**	* use drop cone method for LL determination
LS = 100*(1-L_D/L_O)	12.86	**LS**	**12.86**	*



C.3.2 Compaction data

Mould weight	4751.6	**Compaction With 15% BSG Ash**			
Mould Volume	944	Trial 1	Trial 2	Trial 3	Trial 4
CAN No.		566	966/L3	983	567
Mass of CAN (gm)		35.7	36.2	36.2	36
Mould + Compacted soil (gm)		6264.6	6411.6	6471.3	6397
Mass of (Can +wet soil) (gm)		102.9	100.2	103.8	99.6
Mass of (Can +Dry soil) (gm)		91.1	86.6	87.4	82.9
Mass of wet soil (gm)		1524.5	1671.5	1731.2	1656.9
Bulck Density		1.615	1.771	1.834	1.755
Moisture Content %		21.30	26.98	32.03	35.61
Dry Density		1.331	1.394	1.389	1.294
Summary		***Maximum Dry Density (MDD)***			**1.402**
		Optimum Moisture Content (OMC)			**29.25**



D.3.3 CBR data

CBR for 15% BSG Ash			
Penetration in mm	**Trial -1 Load/Div.**	**Trial -2 Load/Div.**	**Average**
0	0	0	0
0.64	117	141	129
1.27	140	178	159
1.91	161	215	188
2.54	190	254	222
3.18	219	300	259.5
3.81	280	344	312
4.45	325	399	362
5.08	356	425	390.5
7.62	560	620	590

Standard stresses in Kg & Kg/cm2		
Penetration mm	Standard load, kg.	Unit standard load, kg/cm^2
2.54	1370	70
5.08	2055	105

summary of CBR Value %	
Corrected CBR Value @ 2.54mm	3.99
Corrected CBR Value @ 5.08mm	4.67
CBR Taken as Max. (@2.54,@5.08)	4.67

Data: factor **0.246**

*Optimum moisture content =>29.25%

*Maximum dry density (MDD) 1.402gm/cm3

* Condition of test specimen =>Soaked 96hr

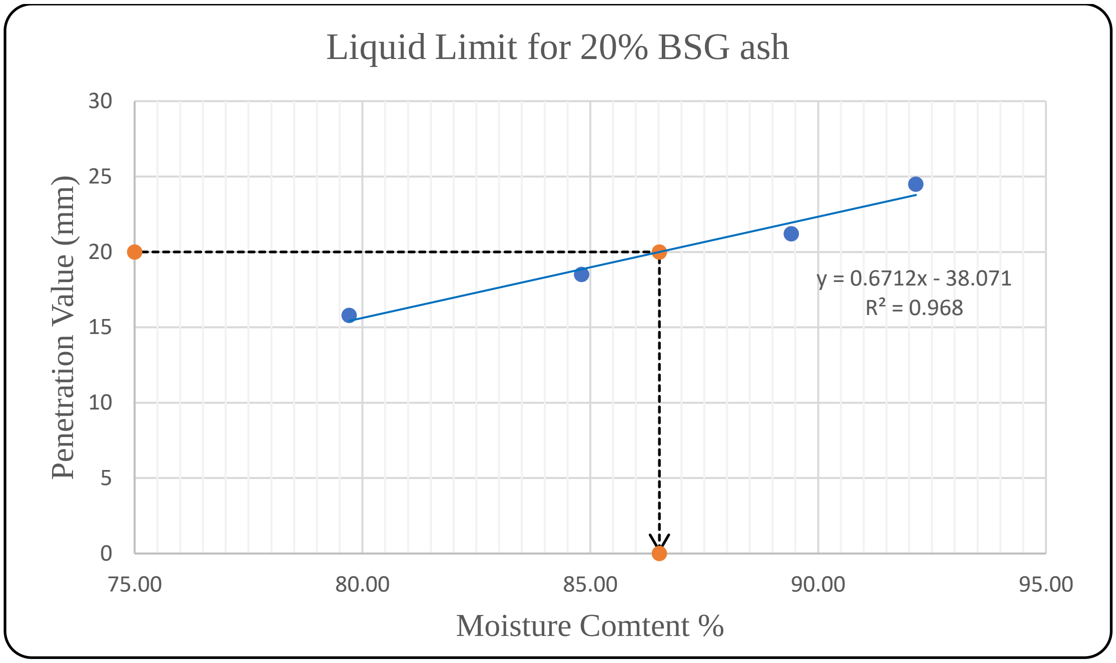
* 2KN Proving ring calibration factor =>0.246 kg/div

C.4 20% BSG ash

C.4.1 Atterberg limit data

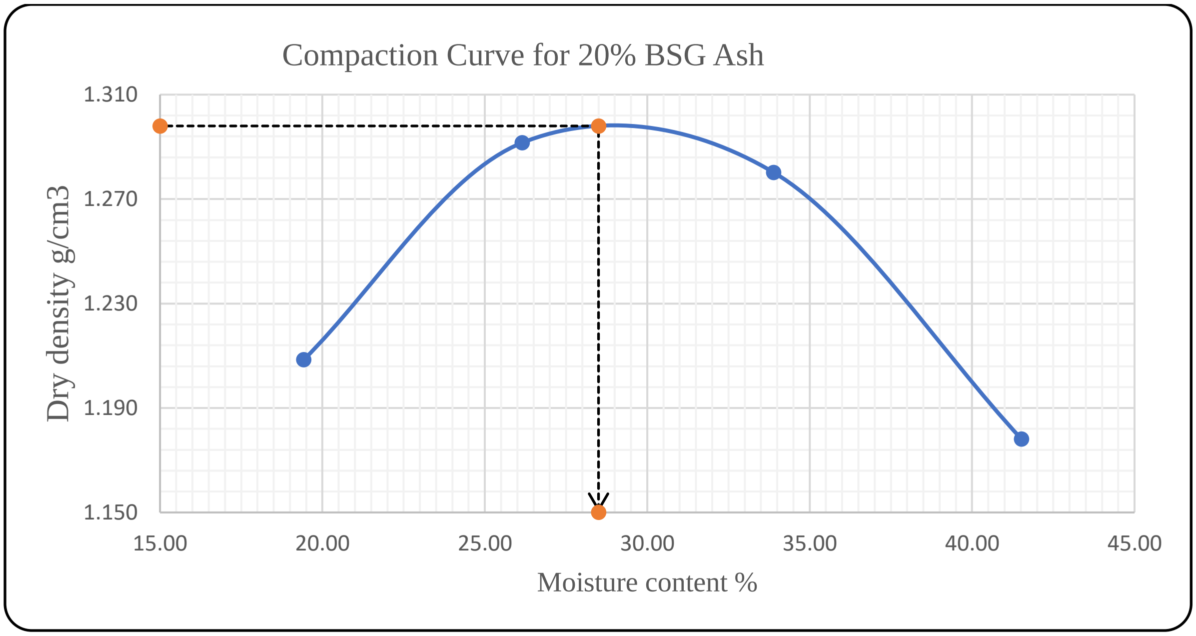
List of Data	**Liquid Limit (LL)**				**Plastic Limit (PL)**	
Can No.	998	930	924	938	A	B
Mass of Can M1 (g)	36.3	36	36.3	36	37	37.6
Mass of (wet soil + can) M2 (g)	61.1	79.8	68.5	82.5	52.5	53.7
Mass of (dry soil + can) M3 (g)	50.1	59.7	53.3	60.2	48.2	49.3
Moistur content = ((M2-M3)/(M3-M1))*100	79.71	84.81	89.41	92.15	38.39	37.61
Penetration (mm)	15.8	18.5	21.2	24.5		

		Summary		**Description of sample preparation**
Linear shrinkage (LS)		**LL**	**86.52**	* The sample should pass through No.200 (0.425mm)
Initial Length (mm)L_o	14	**PL**	**38.00**	* Oven dried the sample them soaked for 24hr
Final Length (mm) L_D	12.9	**PI**	**48.52**	* use drop cone method for LL determination
LS = 100*(1-L_D/L_O)	7.86	**LS**	**7.86**	*



C.4.2 Compaction data

Mould weight	4751.6	Compaction With 20% BSG Ash			
Mould Volume	944	Trial 1	Trial 2	Trial 3	Trial 4
CAN No.		575	565	568	572
Mass of CAN (gm)		37.4	36	36	36.8
Mould + Compacted soil (gm)		6102.5	6278.2	6358.2	6314
Mass of (Can +wet soil) (gm)		87.2	96.3	100.4	101.9
Mass of (Can +Dry soil) (gm)		79.1	83.8	84.1	82.8
Mass of wet soil (gm)		1362.4	1538.1	1618.1	1573.9
Bulck Density		1.443	1.629	1.714	1.667
Moisture Content %		19.42	26.15	33.89	41.52
Dry Density		1.208	1.292	1.280	1.178
Summary		***Maximum Dry Density (MDD)***			**1.296**
		Optimum Moisture Content (OMC)			**28.5**



D.4.3 CBR data

CBR for 20% BSG Ash			
Penetration in mm	**Trial -1 Load/Div.**	**Trial -2 Load/Div.**	**Average**
0	0	0	0
0.64	147	131	139
1.27	178	156	167
1.91	205	177	191
2.54	230	198	214
3.18	254	219	236.5
3.81	276	237	256.5
4.45	299	260	279.5
5.08	325	279	302
7.62	450	400.5	425.25

Standard stresses in Kg & Kg/cm2		
Penetration mm	Standard load, kg.	Unit standard load, kg/cm^2
2.54	1370	70
5.08	2055	105

summary of CBR Value %	
Corrected CBR Value @ 2.54mm	3.84
Corrected CBR Value @ 5.08mm	3.62
CBR Taken as Max. (@2.54,@5.08)	3.84

Data: factor 0.246

*Optimum moisture content =>28.5%

*Maximum dry density (MDD) =>1.296gm/cm3

* Condition of test specimen =>Soaked 96hr

* 2KN Proving ring calibration factor =>0.246kg/div

C.4.4 CBR swell data

Percentage of Additives		Lf	Li	CBR swell	Avg. CBR swell
% BSG ash	0	22	14.5	6.45	6.02
		23	16.5	5.59	
	5	23	17	5.16	4.08
		22	18.5	3.01	
	10	24	19.5	3.87	4.51
		23.5	17.5	5.16	
	15	11	5	5.16	5.16
		24	18	5.16	
	20	24	18.5	4.73	5.80
		24	16	6.88	

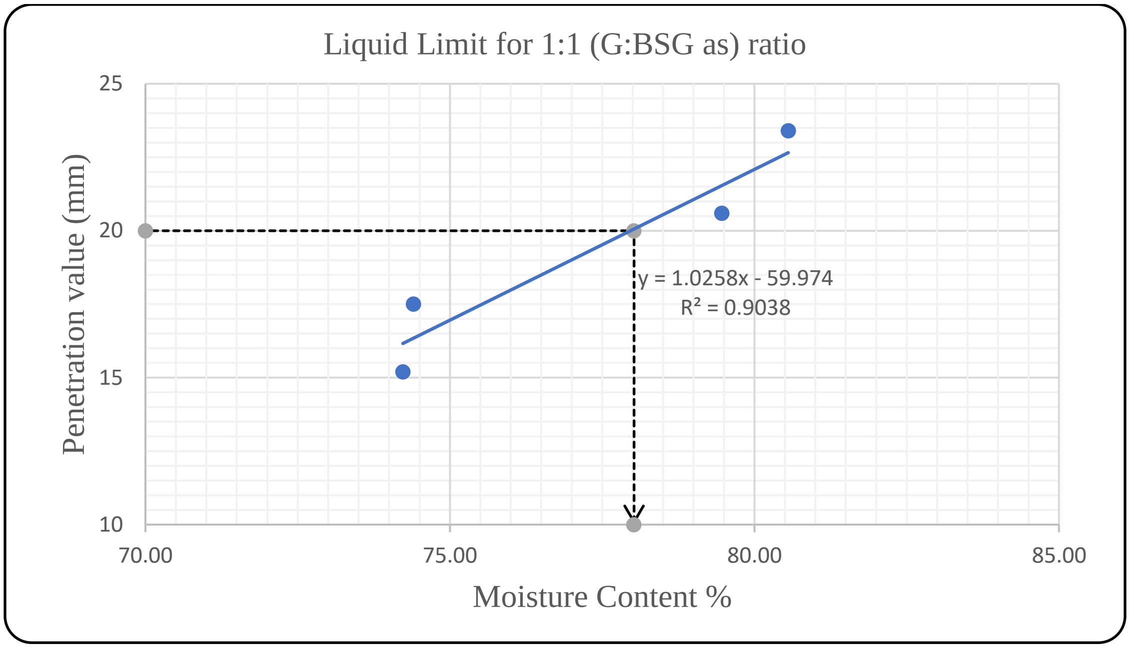
Appendix D: - Laboratory analysis data for blending stabilized of different ratio

D.1 <u>1:1 (G: BSG ash) ratio</u>

D.1.1 Atterberg limit data

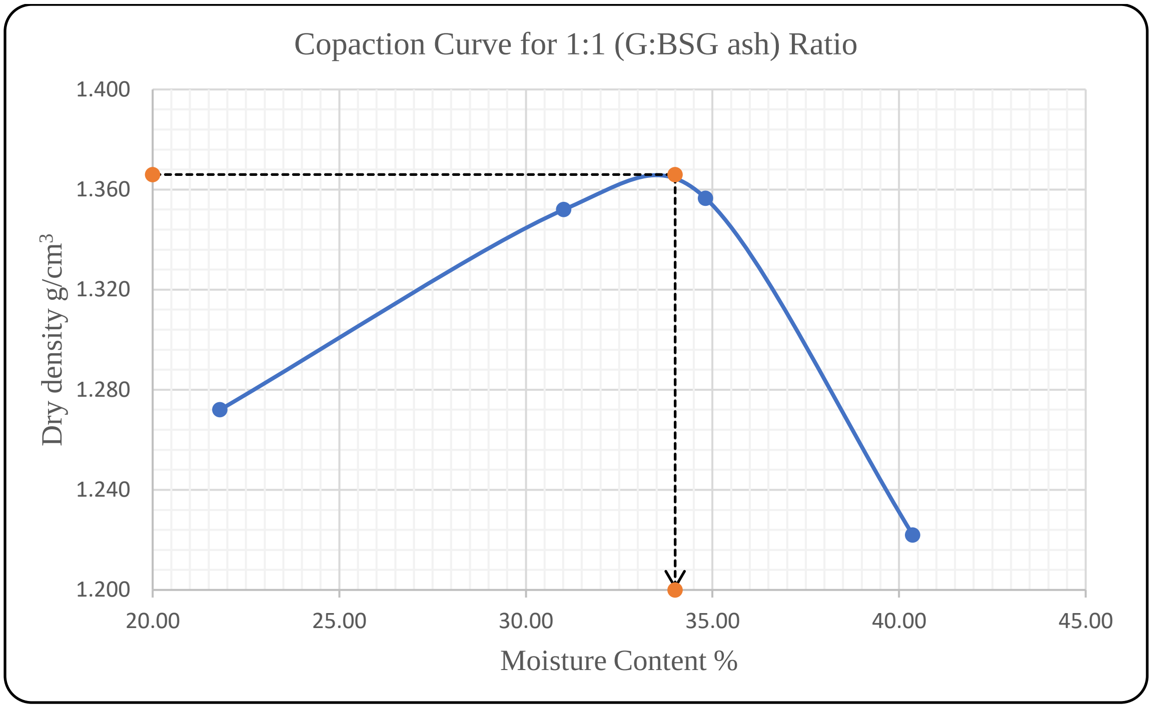
List of Data	**Liquid Limit (LL)**				**Plastic Limit (PL)**	
Can No.	938	575	926	568	921	935
Mass of Can M1 (g)	36.1	36.4	35.8	36	35.3	35.8
Mass of (wet soil + can) M2 (g)	53	58.2	55.9	55.5	38.4	38.7
Mass of (dry soil + can) M3 (g)	45.8	48.9	47	46.8	37.5	37.9
Moisture content = ((M2-M3)/(M3-M1))*100	74.23	74.40	79.46	80.56	40.91	38.10
Penetration (mm)	15.2	17.5	20.6	23.4		

		Summary of Result		**Description of sample preparation**
Linear shrinkage (LS)		**LL**	**78.02**	* The sample should pass through No.200 (0.425mm)
Initial Length (mm)L_o	14	**PL**	**39.50**	* Oven dried the sample them soaked for 24hr
Final Length (mm) L_D	12.2	**PI**	**38.52**	* use drop cone method for LL determination
LS = 100*(1-L_D/L_O)	12.86	**LS**	**12.86**	*



D.1.2 Compaction data

Mould weight	4740.1	Compaction for 1:1 (G: BSG ash) ratio			
Mould Volume	944	Trial 1	Trial 2	Trial 3	Trial 4
CAN No.		575	931	A	922
Mass of CAN (gm)		36.2	35.6	37.4	35.3
Mould + Compacted soil (gm)		6202.7	6412.3	6466.5	6359.3
Mass of (Can +wet soil) (gm)		110.5	92.2	88.9	88.5
Mass of (Can +Dry soil) (gm)		97.2	78.8	75.6	73.2
Mass of wet soil (gm)		1462.6	1672.2	1726.4	1619.2
Bulck Density		1.549	1.771	1.829	1.715
Moisture Content %		21.80	31.02	34.82	40.37
Dry Density		1.272	1.352	1.357	1.222
Summary		***Maximum Dry Density (MDD)***			**1.366**
		Optimum Moisture Content (OMC)			**33.8**



D.1.3 CBR data

CBR for 1:1 (G: BSG ash) Ratio			
Penetration in mm	**Trial -1 Load/Div.**	**Trial -2 Load/Div.**	**Average**
0	0	0	0
0.64	100	110	105
1.27	200	210	205
1.91	260	271	265.5
2.54	296	313	304.5
3.18	340	345	342.5
3.81	360	375	367.5
4.45	378	400	389
5.08	401	418	409.5
7.62	471	479	475

Standard stresses in Kg & Kg/cm2		
Penetration mm	Standard load, kg.	Unit standard load, kg/cm^2
2.54	1370	70
5.08	2055	105

summary of CBR Value %	
Corrected CBR Value @ 2.54mm	5.47
Corrected CBR Value @ 5.08mm	4.90
CBR Taken as Max. (@2.54,@5.08)	5.47

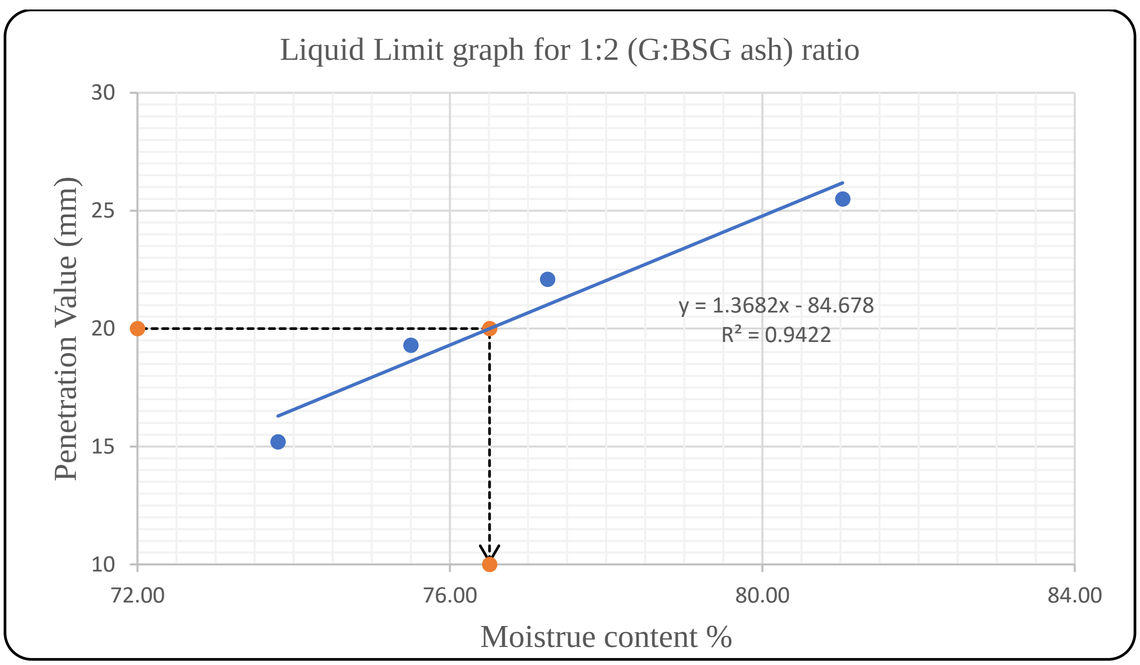
Data: factor 0.246
*Optimum moisture content =>33.5%
*Maximum dry density (MDD) =>1.368gm/cm3
* Condition of test specimen =>Soaked 96hr
* 2KN Proving ring calibration factor =>0.246 kg/div

D.2 1:2 (G: BSG ash) ratio

D.2.1 Atterberg limit data

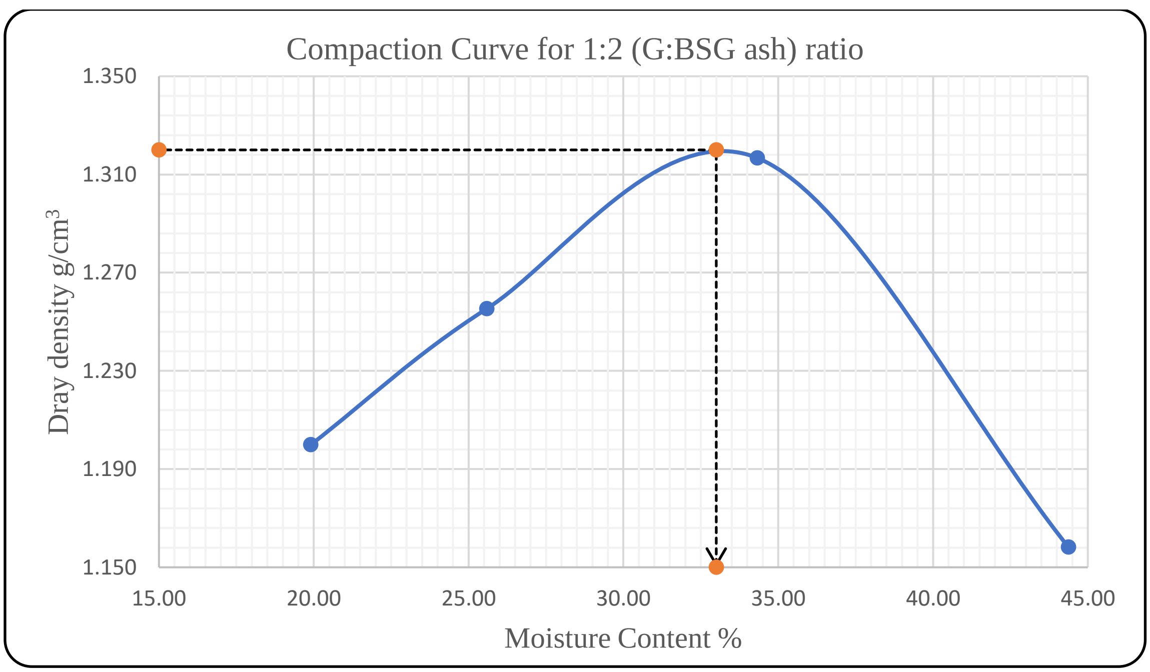
List of Data	Liquid Limit (LL)				Plastic Limit (PL)	
Can No.	A10	B7	936	13	M3	12
Mass of Can M1 (g)	38.1	37.7	36.2	37.4	37.8	37.6
Mass of (wet soil + can) M2 (g)	77.9	75.1	78.5	83.2	40.1	40.4
Mass of (dry soil + can) M3 (g)	61	59.01	60.06	62.7	39.3	39.5
Moisture content = ((M2-M3)/(M3-M1))*100	73.80	75.50	77.25	81.03	53.33	47.37
Penetration (mm)	15.2	19.3	22.1	25.5		

		Summary of Result		Description of sample preparation
Linear shrinkage (LS)		**LL**	**76.51**	* The sample should pass through No.200 (0.425mm)
Initial Length (mm)L_o	14	**PL**	**50.35**	* Oven dried the sample them soaked for 24hr
Final Length (mm) L_D	11.8	**PI**	**26.16**	* use drop cone method for LL determination
LS = 100*(1-L_D/L_O)	15.71	**LS**	**15.71**	*



D.2.2 Compaction data

Mould weight	4740.1	**Compaction for 1:2 (G: BSG ash) ratio**			
Mould Volume	944	Trial 1	Trial 2	Trial 3	Trial 4
CAN No.		928	930	12	572
Mass of CAN (gm)		35.9	35.5	35.9	36.4
Mould + Compacted soil (gm)		6156.7	6228.4	6409.8	6318.6
Mass of (Can +wet soil) (gm)		88.3	99.3	94.2	83.9
Mass of (Can +Dry soil) (gm)		79.6	86.3	79.3	69.3
Mass of wet soil (gm)		1358.3	1488.3	1669.7	1578.5
Bulck Density		1.439	1.577	1.769	1.672
Moisture Content %		19.91	25.59	34.33	44.38
Dry Density		1.200	1.255	1.317	1.158
Summary		***Maximum Dry Density (MDD)***			**1.32**
		Optimum Moisture Content (OMC)			**33**



D.2.3 CBR data

CBR for 1:2 (G: BSG ash) Ratio			
Penetration in mm	**Trial -1 Load/Div.**	**Trial -2 Load/Div.**	**Average**
0	0	0	0
0.64	100	105	102.6
1.27	198	215	206.5
1.91	261	277	269.0
2.54	300	317	308.5
3.18	335	348	341.7
3.81	365	383	374.0
4.45	380	410	395.0
5.08	405	422	413.6
7.62	490	505	497.6

Standard stresses in Kg & Kg/cm2		
Penetration mm	Standard load, kg.	Unit standard load, kg/cm^2
2.54	1370	70
5.08	2055	105

summary of CBR Value %	
Corrected CBR Value @ 2.54mm	5.54
Corrected CBR Value @ 5.08mm	4.95
CBR Taken as Max. (@2.54,@5.08)	5.54

Data: factor 0.246

*Optimum moisture content =>33%

*Maximum dry density (MDD) =>1.32gm/cm3

* Condition of test specimen =>Soaked 96hr

* 2KN Proving ring calibration factor =>0.246 kg/div

D.3 1:3 (G: BSG ash) ratio

D.3.1 Atterberg limit data

List of Data	**Liquid Limit (LL)**				**Plastic Limit (PL)**	
Can No.	12	565	927	930	572	931
Mass of Can M1 (g)	36.3	36	35.9	36	36.9	35.6
Mass of (wet soil + can) M2 (g)	55.8	55.9	58.6	59.3	39.5	39.2
Mass of (dry soil + can) M3 (g)	47.4	47.2	48.5	48.8	38.7	38.1
Moisture content = ((M2-M3)/(M3-M1))*100	75.87	77.68	80.16	82.03	44.44	44.00
Penetration (mm)	17	18.9	21.5	23		

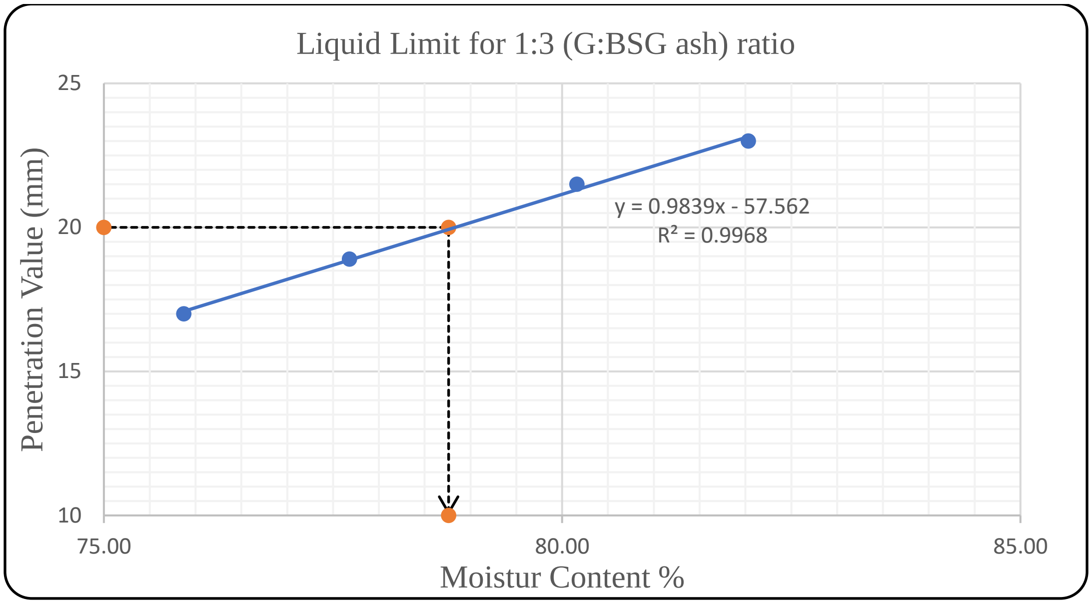
		Summary of Result	
Linear shrinkage (LS)		**LL**	**78.76**
Initial Length (mm)L_o	14.0	**PL**	**44.22**
Final Length (mm) L_D	12.5	**PI**	**34.54**
LS = 100*(1-L_D/L_O)	10.71	**LS**	**10.71**

Description of sample preparation

* The sample should pass through No.200 (0.425mm)

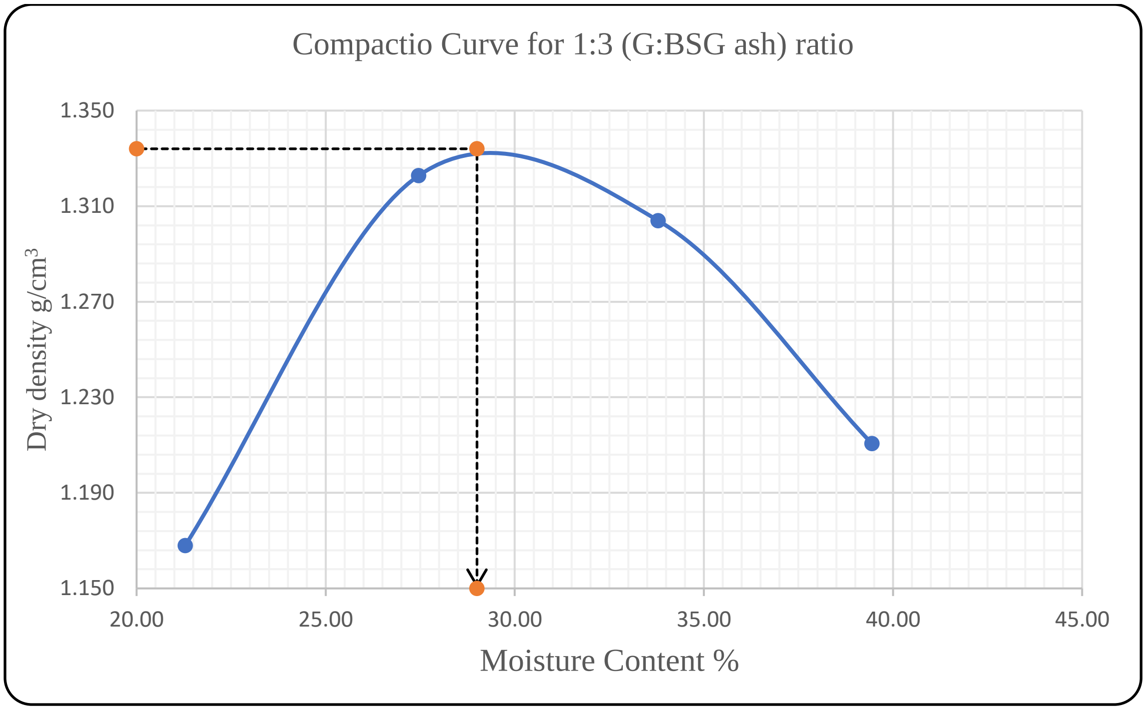
* Oven dried the sample them soaked for 24hr

* use drop cone method for LL determination



D.3.2 Compaction data

Mould weight	4740.1	Compaction for 1:3 (G: BSG ash) ratio			
Mould Volume	944	Trial 1	Trial 2	Trial 3	Trial 4
CAN No.		966	5	565	564
Mass of CAN (gm)		36.2	37	35.8	35.6
Mould + Compacted soil (gm)		6077.3	6331.7	6392.1	6333.7
Mass of (Can +wet soil) (gm)		96.6	99.2	84.9	80.5
Mass of (Can +Dry soil) (gm)		86	85.8	72.5	67.8
Mass of wet soil (gm)		1337.2	1591.6	1652	1593.6
Bulck Density		1.417	1.686	1.750	1.688
Moisture Content %		21.29	27.46	33.79	39.44
Dry Density		1.168	1.323	1.304	1.211
Summary		***Maximum Dry Density (MDD)***			**1.334**
		Optimum Moisture Content (OMC)			**29.5**



D.3.3 CBR data

CBR for 1:3 (G: BSG ash) Ratio			
Penetration in mm	**Trial -1 Load/Div.**	**Trial -2 Load/Div.**	**Average**
0	0	0	0
0.64	105	115	110
1.27	138	152	145
1.91	158	174	166
2.54	170	180	175
3.18	195	210	202.5
3.81	220	234	227
4.45	247	260	253.5
5.08	250	280	265
7.62	335	365	350

Standard stresses in Kg & Kg/cm2		
Penetration mm	Standard load, kg.	Unit standard load, kg/cm^2
2.54	1370	70
5.08	2055	105

summary of CBR Value %	
Corrected CBR Value @ 2.54mm	5.44
Corrected CBR Value @ 5.08mm	5.49
CBR Taken as Max. (@2.54,@5.08)	5.49

Data:	factor	0.426

*Optimum moisture content =>29.5%

*Maximum dry density (MDD) =>1.336gm/cm3

* Condition of test specimen =>Soaked 96hr

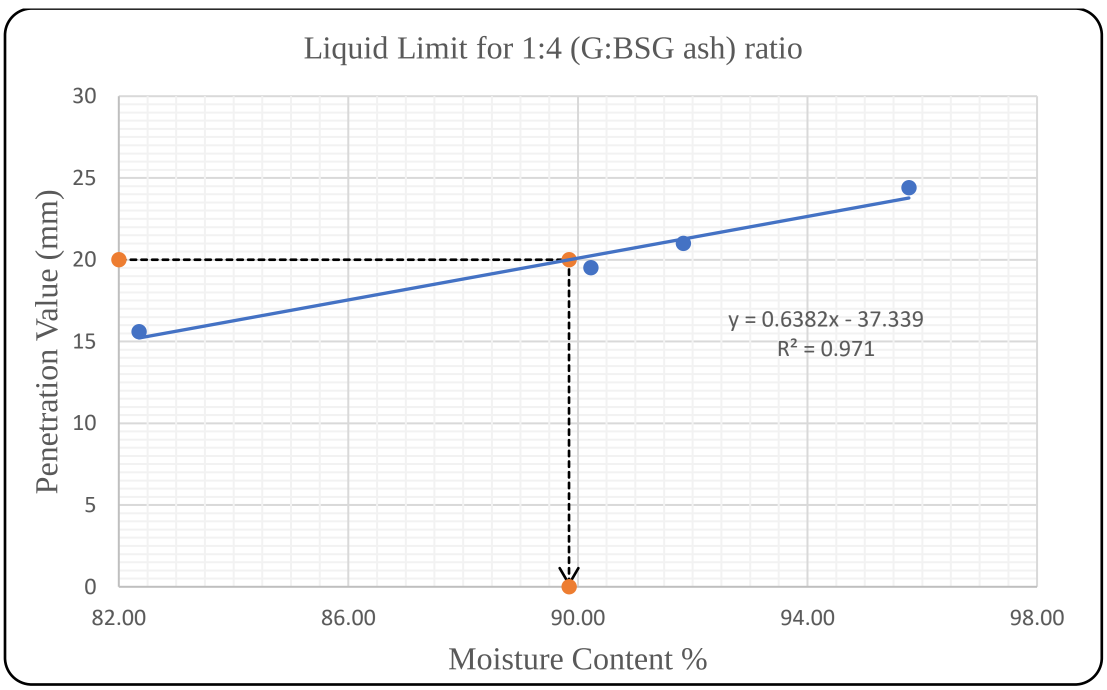
* 2KN Proving ring calibration factor =>0.246 kg/div

D.4 1:4 (G: BSG ash) ratio

D.4.1 Atterberg limit data

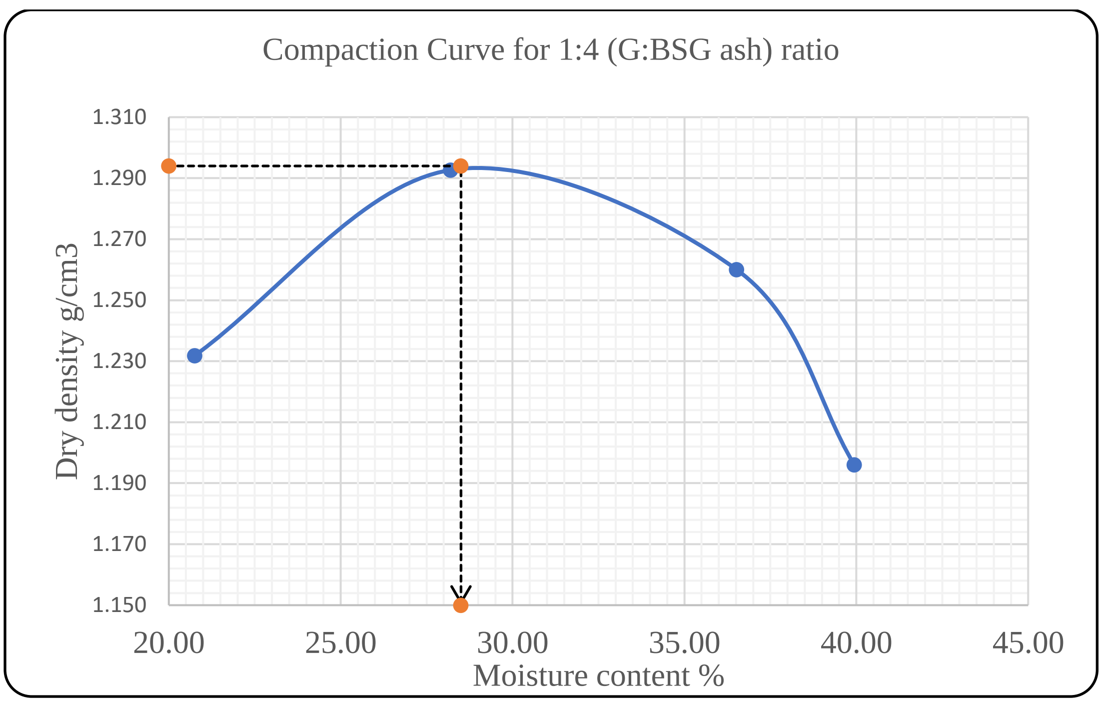
List of Data	Liquid Limit (LL)				Plastic Limit (PL)	
Can No.	935	938	936	928	568	926
Mass of Can M1 (g)	35.9	36.1	36.2	36.4	36	35.8
Mass of (wet soil + can) M2 (g)	60.7	61.4	64.4	73.4	40.9	39.7
Mass of (dry soil + can) M3 (g)	49.5	49.4	50.9	55.3	39.5	38.6
Moisture content = ((M2-M3)/(M3-M1))*100	82.35	90.23	91.84	95.77	40.00	39.29
Penetration (mm)	15.6	19.5	21	24.4		

		Summary of Result		Description of sample preparation
Linear shrinkage (LS)		**LL**	**89.84**	* The sample should pass through No.200 (0.425mm) * Oven dried the sample them soaked for 24hr * use drop cone method for LL determination
Initial Length (mm)L_o	14	**PL**	**39.64**	
Final Length (mm) L_D	12.45	**PI**	**50.20**	
LS = 100*(1-L_D/L_O)	11.07	**LS**	**11.07**	



D.4.2 Compaction data

Mould weight	4740.1	Compaction for Free soil 1:4			
Mould Volume	944	Trial 1	Trial 2	Trial 3	Trial 4
CAN No.		930	575	565	998
Mass of CAN (gm)		36	36.4	36	36.2
Mould + Compacted soil (gm)		6144.3	6304.5	6373.2	6320.1
Mass of (Can +wet soil) (gm)		87.2	85.5	83.1	84.9
Mass of (Can +Dry soil) (gm)		78.4	74.7	70.5	71
Mass of wet soil (gm)		1404.2	1564.4	1633.14	1580
Bulck Density		1.488	1.657	1.730	1.674
Moisture Content %		20.75	28.20	36.52	39.94
Dry Density		1.232	1.293	1.260	1.196
Summary		***Maximum Dry Density (MDD)***			**1.294**
		Optimum Moisture Content (OMC)			**28.5**



D.4.3 CBR data

CBR for 1:4 (G: BSG ash) Ratio

Penetration in mm	Trial -1 Load/Div.	Trial -2 Load/Div.	Average
0	0	0	0
0.64	95	80	87.5
1.27	159	135	147
1.91	212	189	200.5
2.54	260	242	251
3.18	315	291	303
3.81	349	323	336
4.45	362	343	352.5
5.08	383	362	372.5
7.62	465	445	455

Standard stresses in Kg & Kg/cm2

Penetration mm	Standard load, kg.	Unit standard load, kg/cm^2
2.54	1370	70
5.08	2055	105

summary of CBR Value %

Corrected CBR Value @ 2.54mm	4.51
Corrected CBR Value @ 5.08mm	4.46
CBR Taken as Max. (@2.54,@5.08)	4.51

Data: factor 0.246

*Optimum moisture content =>28.5%

*Maximum dry density (MDD) =>1.294gm/cm3

* Condition of test specimen =>Soaked 96hr

* 2KN Proving ring calibration factor =>0.246 kg/div

D.4.4 CBR swell data

Blending ratio of stabilizer		Lf	Li	CBR swell	Avg. CBR swell
G:BSG ratio	Natural soil	22	14.5	6.45	
		23	16.5	5.59	6.02
	1:1 (G: BSH ash)	21	16.5	3.87	
		20.5	16	3.87	3.87
	1:2 (G: BSG ash)	24	19.5	3.87	
		25	21	3.44	3.65
	1:3 (G: BSG ash)	20	15	4.30	
		19.5	14.5	4.30	4.30
	1:4 (G: BSG ash)	20	19	0.86	
		24	14	8.60	4.73