UNIVERSITY OF MINES AND TECHNOLOGY, (UMaT)
TARKWA

FACULTY OF MINERAL RESOURCES TECHNOLOGY
DEPARTMENT OF GEOLOGICAL ENGINEERING

A PROJECT REPORT ENTITLED

IMPROVING THE GEOTECHNICAL PROPERTIES OF SPENT ORE WITH LATERITE FOR ROAD PAVEMENT CONSTRUCTION

BY
BERNARD OFOSU

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN
GEOLOGICAL ENGINEERING

PROJECT SUPERVISOR

…………………………………………
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TARKWA, GHANA
MAY, 2019

DECLARATION

I declare that this thesis is my own work. It is being submitted for the Degree of Masters in Geological Engineering in University of Mines and Technology (UMaT), Tarkwa. It has not been submitted for any degree or examination in any other University.

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(Signature of Student)

Submitted this ……………day of …………Year.

ABSTRACT

Heap leaching generate large volume of spent ore and due to its potential toxic nature, it is contained and not exposed to the environment. The spent ore can be reused as a construction material especially for road construction. However, due to its granular nature, it is difficult to compact the materials to achieve the required strength for geotechnical purposes. The geotechnical properties of the spent ore can be improved by addition of other materials. Laterite was used to improve the geotechnical properties of spent ore for the construction of base and subbase of road pavement. The laterite was added to the spent ore in range of 10% to 50% to form composites. Physical and engineering laboratory tests including, Atterberg Limits, Compaction and Californian Bearing Ratio (CBR) were conducted on the composites in accordance with British Standards. The results showed that addition of laterite from 10% to 20% resulted in Liquid Limit (LL) between 20% and 22%, the values are within the specifications for the Ministry of Transport specification for base and subbase materials. The compaction test on the composites resulted in Maximum Dry Density (MDD) between 1.3 g/cm^3 and 2.01 g/cm^3. The soaked CBR values fell between 32% and 62%, the unsoaked values were between 31% and 64%. The composite 70% Spent Ore and 30% Laterite recorded the highest soaked and unsoaked CBR value of 62% and 64% respectively. The results showed that, 30% addition of the laterite would improve the spent ore for only subbase construction. Further studies is recommended for the improvement of the geotechnical properties of spent ore for base construction.

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CHAPTER 1

INTRODUCTION

1.1 Background

Mining operations generate large volume of waste material and due to its potential toxic nature, it is contained and not exposed to the environment. Mining companies are required to provide disposal plan for the waste after decommissioning as part of the environmental impact assessment. Huge funds are required to ensure that, the waste are contained and not allowed into the environment during mining and after closure. Arhinful and Agyei (2017) estimated the cost of closing a waste dump at Iduapirem Mine in Tarkwa and reported that, the total closure and reclamation cost was estimated to be US$ 581 488.18. Some mining companies in Ghana have therefore considered the reutilisation of the waste material due challenges in disposal after decommissioning.

Several research have been conducted into the reuse mine waste for construction and other purposes all over the world (Gaonkar, et al, 2010), (Lottermorser, 2011), (Aravind and Das, 2012), (Nunes *et al.*, 1996) and (Sherwood, 1995). Mahmood (2010) investigated the use of mine tailings for unpaved road base and concluded that, the tailings if stabilized with cement can be used for road construction. Cesare et al (2016) also used alkali activated based methods to improve mine wastes for road pave applications, the research shows that large volumes of mine waste could be recycled in the industrial production of pre-cast segments for civil engineering construction purposes, in particular for transportation infrastructures.

The forgoing literature review shows that extensive research into reutilization of mine waste has been ongoing and it can be established that it is a potential road construction material if the appropriate additives are used to improve the geotechnical properties.

1.2 Problem Statement

Road construction in the country is gradually depleting natural road construction materials and other resources. It is therefore necessary to find other alternative road construction materials to minimise the depleting of the natural materials. Spent ore which is a byproduct of heap leaching is produced in large quantities in some mining companies in Ghana. These materials are potential road construction materials that can be used to reduce the depleting of natural materials for road construction. However, spent ore is granular in nature and therefore it is difficult to compact the materials to achieve the required strength for engineering design. Soils with low to intermediate plasticity can be used to improve the geotechnical properties of the spent ore for road pavement construction.

Laterite is found abundantly in the Ghana and mostly used for construction purposes. Research on most lateritic soils in Ghana by Gidigasu (1972) shows that, laterite consist of soils with clay and silt fraction that are plastic. The addition of laterite to the spent ore will provide the needed plasticity that will make it compactable for engineering purposes. This will enable laboratory tests such as Atterberg Limits, compaction, and California Bearing Ratio (CBR) to be conducted on the spent ore to determine its suitability for road subbase or base construction. It is against this background that this research intends to determine the composite properties of spent ore and the laterite for road pavement construction.

1.3 Objective of Research

The objective of the research is to determine the composites of spent ore and laterite that can be used for the construction of base and subbase of road pavement and includes:

- determination of the physical and engineering properties of the spent ore and the laterite, and
- determination of the physical and engineering properties of spent ore and laterite composites

1.4 Expected Outcomes

- Mix ratio of laterite and spent ore to obtain optimum geotechnical properties
- Moisture density relationship of each ratio

- Optimum mix ratio for road base and subbase construction.

1.5 Methods to be Used

The approach that would be used to achieve the objectives includes:

- Literature review of relevant documents.
- Bulk sampling of spent ore and laterite.
- Laboratory tests on raw spent ore and laterite.
- Laboratory tests on various composites of the spent ore and laterite.
- Analysis

1.6 Facilities to be used for Research

- Libraries and Geotechnical Laboratories at University of Mines and Technology (UMaT) and Building and Road Research Institute (BRRI).

1.7 Organisation of the Thesis

The thesis has been organised into six Chapters, the various Chapters are presented in the following details:

- Chapter One presents the synopsis of the thesis.
- Chapter Two presents an overview of the study area.
- Chapter Three consists of the review of the relevant information governing the thesis.
- Chapter Four presents the methods used for the thesis.
- Chapter Five includes results and analysis.
- Chapter Six gives the conclusions and recommendations of the thesis.

CHAPTER 2

RELEVANT INFORMATION ABOUT THE STUDY AREA

2.1 Study Area

Tarkwa is located in the Western Region of Ghana and is between Latitude 4^{o}5′ and Longitude 5^{o}5′. It is about 300 km from Accra and 85 km from Takoradi. Tarkwa hosts AngloGold Ashanti and Goldfields Ghana Limited, Tarkwa Mine. Tarkwa is the administrative capital of the District and subsistence farming is the main occupation of the people and mining being the main industrial activity (Avotri et al., 2002). The Tarkwa area lies within the Ashanti Gold Belt of Ghana that stretches from Axim in the southwest, to Konongo in the northeast (Kortatsi, 2004). The location of the study area is presented in Figure 2.1

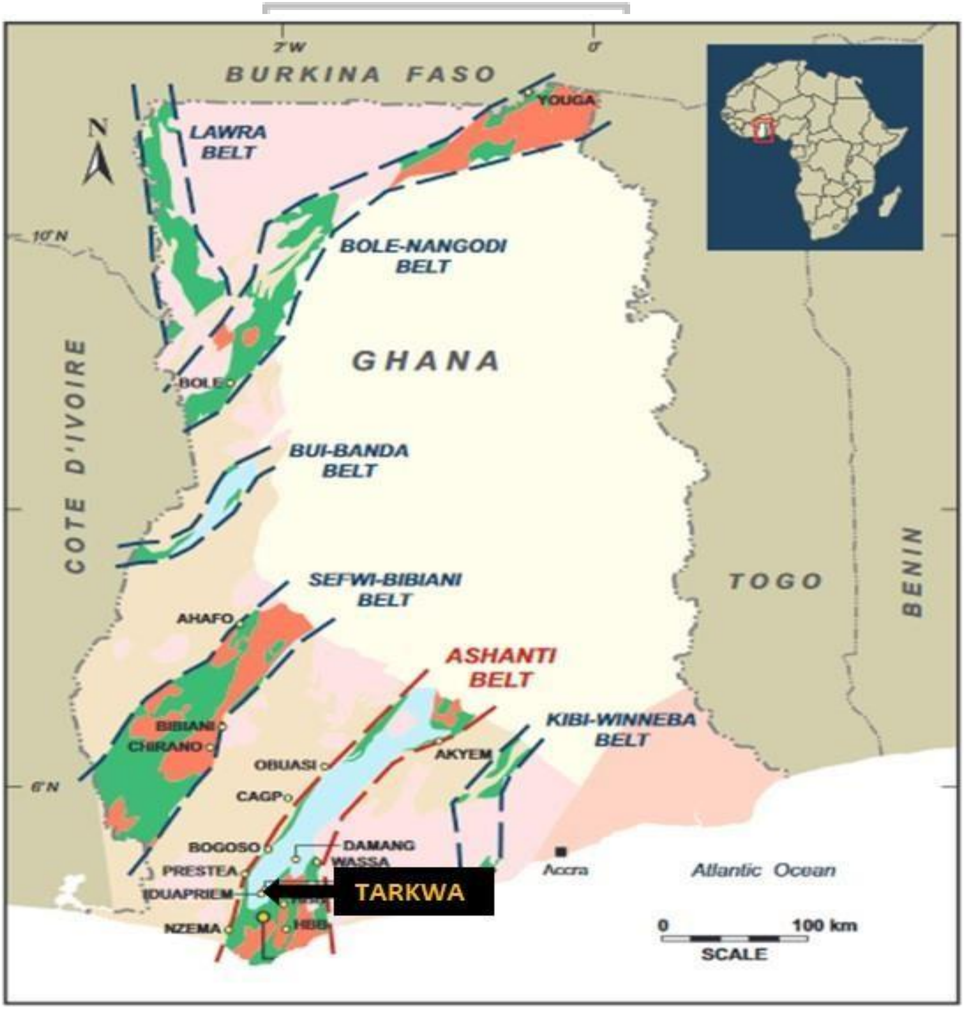


Figure 2.1 Location of the Study Area (Anon, 2016)

2.1.1 Topography

The topography of the Tarkwa area is generally described as a remarkable series of ridges and valleys parallel to one another and a true reflection of the pitching fold structures of the Banket Series of the Tarkwaian System (Seidu, 2004). The ridges are formed by the Banket and Tarkwa phyllite whereas Upper quartzite and Huni Sandstone are present in the valleys. Surface gradients of the ridges are generally very close to the Banket and Tarkwa phyllite (Seidu, 2004).

2.1.2 Climate and Vegetation

Tarkwa area has a South-Western Equatorial Climate with seasons influenced by the moist South-West Monsoon Winds from the South Atlantic Ocean and the North-East Trade Winds. The mean rainfall is approximately 1500 mm with peaks of more than 1700 mm in June and October. Between November and February, the rainfall pattern decreases to between 20 and 90 mm. The mean annual temperature is approximately 25 degrees Celsius with small daily temperature variations. Relative humidity varies from 61 % in January to a maximum of 80 % in August and September (Forson, 2006). The heavy rainfall coupled with the high temperature and humidity promote relatively deep residual soil profiles over the rocks in this region (Dickson and Benneh, 1980).

The vegetation within study area comprises of tropical rain forest with rich undergrowth of shrubs of different heights. Generally the height of trees within the study area range between 15 m and 45 m (Dickson and Benneh, 1980). There has been a rapid reduction in the density of trees in areas due to mining activities. Akabzaa and Darimani, (2001) attributed lack of protection from mining and lumber activities as the primary responsibility for the poor vegetation in the area for example in areas where mining has taken place, the vegetation mainly comprise of ferns and other shrubs which grow copiously on the hilly slopes.

2.2 Geology of the Study Area

The study area falls within the Banket Series of the Tarkwaian geological unit (Figure 2.2)

2.2.1 Tarkwaian

According to Kesse (1985) rocks of the Tarkwaian Group are concentrated mainly at the south-western part of Ghana in the Tarkwa area where they outcrop in a NE-SW trending belt. The belt stretches from near Axim to the edge of the Voltaian basin near Agogo, a distance of about 250km. The Tarkwaian rocks consist of thick series of argillaceous and arenaceous sediments (mainly arenaceous) in the lower members of the system. The Tarkwaian Group is considered to be of shallow water continental origin derived from the Birimian and associated granites (Kesse, 1985). The Tarkwaian is thought to rest unconformably on the Birimian, though in some places, the metasedimentary Birimian and the Tarkwaian are inter-folded due to post Tarkwaian orogenic activity. The common minerals are chlorite, sericite, zoisite, calcite, quartz, limonite and chloritoid (Kesse, 1985). The sediments must be regarded as integral part of the Eburnean orogenic cycle of which they represent the final molasse stage. The Tarkwain is divided into five main series, Kawere Group, Banket Series, Tarkwa Phyllites, Huni Sandstone and Dompim Phyllites (Kesse, 1985).

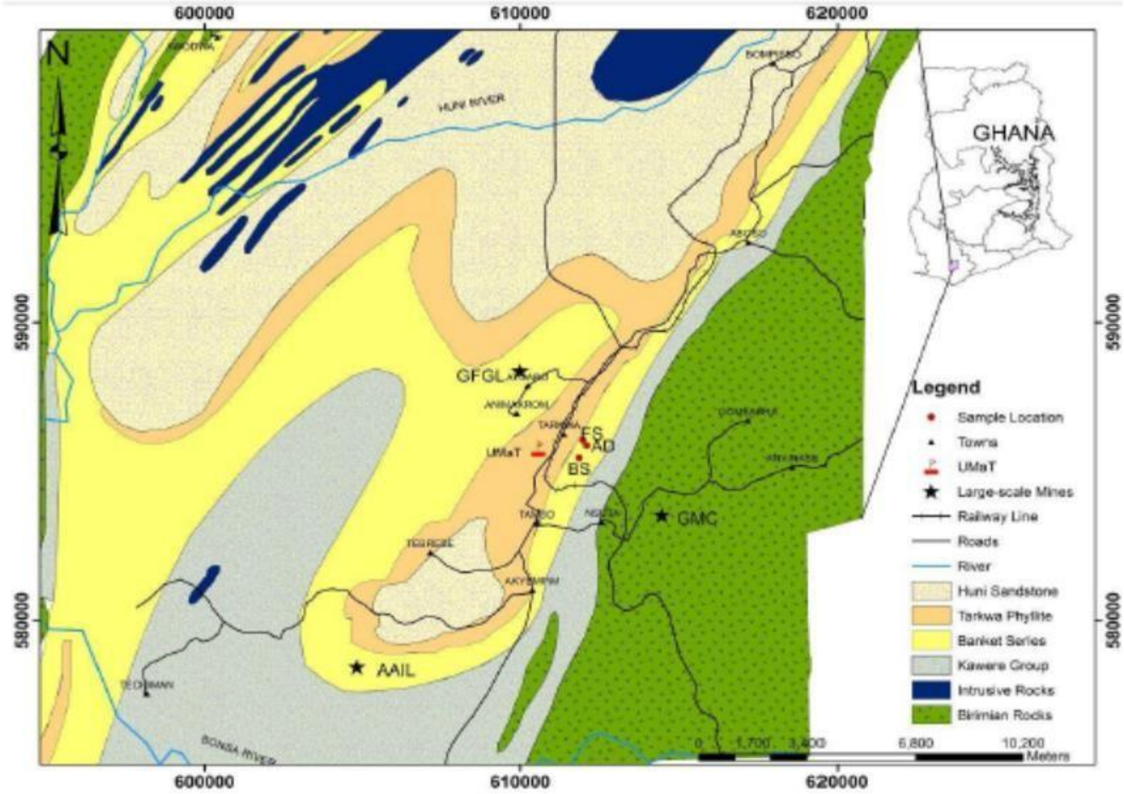


Figure 2.2 Geology of the Study Area (Arhinful and Agyei (2017)

2.2.2 The Banket Series

Banket Series represents a fluviatile series with a thickness varying between 120-600 m being greater south and west of Tarkwa. It is essentially an accumulation of high energy, coarse clastics, represented by conglomerates, grits, quartzites, which have suffered low-grade metamorphism (Kesse, 1985). Four reefs or conglomerate bands have been identified typical in the western and southern parts of the Tarkwa Goldfields namely (Kesse, 1985):

- Breccia Reef
- Quartzite and grit
- Middle Reef
- Quartzite and grit
- Basal or Main Reef
- Quartzite and grit
- Sub-basal Reef

Three of the units are persistent i.e. breccia reef, middle reef and a unit of basal conglomerates. The Basal or Main reef is the most persistent conglomerate bed in the area and is by far the richest in gold. Furthermore, it is generally better sorted than the other reefs and more uniform in thickness, composition, size and in distribution of pebbles (Kesse, 1985). The matrix of the conglomerates consists principally of quartz and sand (mainly hematite with ilmenite, magnetite and rutile), minor constituents are sericite, chlorite, tourmaline, garnet, zircon and gold. Epidote and pyrite are rare except near dykes, faults and quartz veins. A typical geological section of the Banket Series is shown in Figure 2.3.

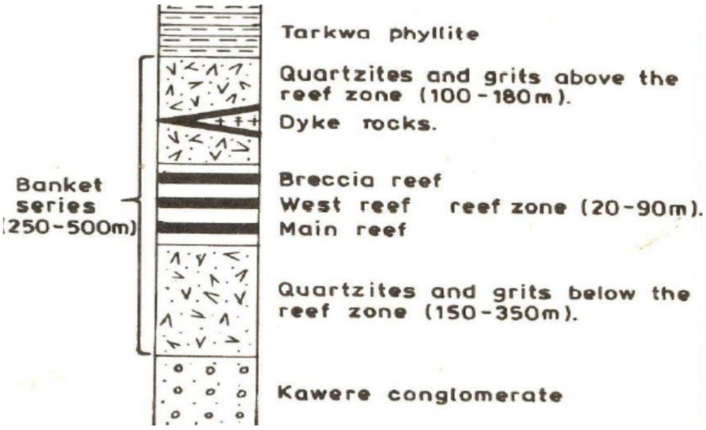


Figure 2.3 Typical Geological Section of the Banket Series (Kesse, 1985)

CHAPTER 3

LITERATURE REVIEW

3.1 Previous Research on Reuse of Mine Wastes in Ghana

Hammond (1986) conducted an extensive research into the possibility of using mining and quarry waste for construction purposes in Ghana. The objective of the research was to evaluate the chemical, mineralogical, physical, mechanical, geotechnical and engineering properties of the mining wastes. The potential of the waste materials as health and environmental contaminants was also evaluated. The research was conducted on waste from Prestea, Obuasi, Tarkwa, Dunkwa, Nsuta, Akwatia, Awaso and Konongo. The study revealed that there are about 136 million tons of mining waste in Ghana covering an area of 109 km^2 during the period of the research. He concluded that, the wastes were chemically and mineralogical stable. They contain no deleterious water soluble substances that would leach out. From the soundness test, the alkali-aggregate reaction, sulphate resistance, it was evident that the waste materials are suitable for road construction subject to the specifications and environmental requirements. Hammond (1986) recommended for the intensification of the use of waste materials in construction, monitoring of the performance of project constructed with mining waste and proposing a specification for such materials in construction.

Agyeman and Ampadu (2015) also evaluated the engineering properties of mine waste to determine its suitability for use as road pavement material. Samples of mine rock waste, derived from the granitic and granodioritic intrusive units overlying the gold-bearing metavolcanic rock and volcano-clastic sediments were obtained from three mine rock waste disposal facilities and subjected to laboratory tests to determine their physical, mechanical, geotechnical, geometrical and durability properties. The overall conclusion was that the mine rock waste met all the requirements of the Ghana Ministry of Transportation specifications for use as aggregates for crushed rock subbase, base and as surface dressing chippings for road pavements. The recommendation is to process it into the required sizes for the various applications.

Literature on the reuse of mine waste for road construction in Ghana shows that research into the reutilization of mine waste for road construction and other purposes has been ongoing and based on the work conducted by Hammond (1986) and Agyeman and Ampadu

(2015), mine wastes are potential road construction materials, however, the research did not address mine wastes that do not meet the requirements for road construction and how they can be improved.

3.2 Types of Mine Wastes

Mine waste includes all materials that must be removed to gain access to the ore. It also includes materials generated during the extraction, beneficiation, and processing of the mineral ores. The type, amount, and properties of mine waste produced at different mines vary depending on the resource being mined, process technology used, and geology at the mine site (Arhinful and Agyei, 2017). In mining, each of the mining and ore processing steps can generate waste (Figure 3.1). This waste generally has different physical and chemical properties, resulting in different potential environmental impacts (Hudson-Edwards, *et al.*, 2011).

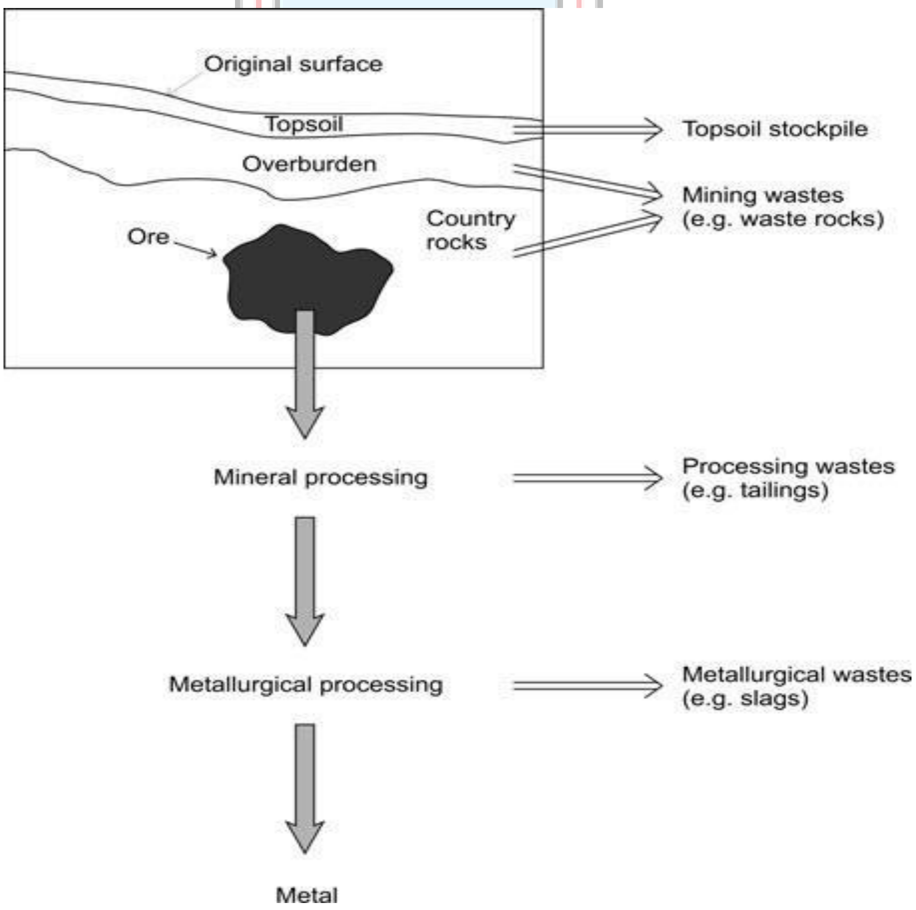


Figure 3.1 Schematic Representation of Mine Waste Generation (Hudson- Edwardds, *et al.*, 2011)

3.2.1 Mining Waste

Mining wastes are materials that do not contain any ore of any economic value depending on the specific economic condition. The cut-off grade is used as the criterion for the separation of waste rock from ore and for the classification of materials as economic or noneconomic. It is based on the concentration of the ore element in each unit of mined rock and on the cost of mining that unit. Mining wastes include overburden and waste rocks excavated and mined from surface and underground operations. Mining wastes are heterogeneous geological materials and may consist of sedimentary, metamorphic or igneous rocks, soils, and loose sediments. The physical and chemical characteristics of mining wastes vary according to their mineralogy and geochemistry, type of mining equipment, particle size of the mined material, and moisture content (Hassinger 1997).

3.2.2 Processing Wastes

Mineral processing techniques which are used in extracting mineral of interest from ore results in wastes which are referred to as tailings. The physical and chemical characteristics of the tailings vary according to the mineralogy and geochemistry of the ore, type of processing technology, particle size of the crushed material, and the type of process chemicals. The particle size for processing wastes can range in size from colloidal size to fairly coarse, gravel size particles. Most processing wastes accumulate in solution or as a sediment slurry. These tailings are generally deposited in a tailings dam or pond which has been constructed using mining or processing wastes or other earth materials available on or near the mine site (Hassinger 1997).

3.2.3 Metallurgical wastes

Processing of metal and industrial ores produces an intermediate product, a mineral concentrate, which is the input to extractive metallurgy. Extractive metallurgy is largely based on hydrometallurgy (e.g. Au, U, Al, Cu, Zn, Ni, P) and pyrometallurgy (e.g. Cu, Zn, Ni, Pb, Sn, Fe), and to a lesser degree on electrometallurgy (Warhurst, 2000). Hydrometallurgy involves the use of solvents to dissolve the element of interest. For example, at gold mines leaching of the ore with a cyanide solution is a common hydrometallurgical process to extract the gold. The process chemical dissolves the gold particles and a dilute, gold-laden solution is produced which is then processed further to recover the metal. In contrast, pyrometallurgy is based on the breakdown of the crystalline structure of the ore mineral by heat whereas electrometallurgy uses electricity. These metallurgical processes destroy the chemical combination of elements and result in the production of various waste products including atmospheric emissions, flue dust, slag, roasting products, waste water, and leached ore. (Lottermoser, 2010)

3.2.4 Mine Wastes Storage Facilities

Storage facilities for mine wastes depends on the type of waste under consideration, mine tailings are impounded in Tailings Storage Facility (TSF). It is constructed with earth materials and the basin is design to prevent leachate of the waste from contaminating the groundwater beneath the footprint of the facility and surroundings. Mine waste rock are store on engineered ground.

3.2.5 Heap Leach Waste

Heap Leaching is a technique where run-of-mine or crushed agglomerated ores are stacked over an engineered impermeable pad, chemicals are introduce at the top of heap under atmospheric conditions and leachate are collected for metal recovery processes. Because percolation of the chemical solution through the ore is achieved under gravity and atmospheric conditions, completion of metal recovery requires longer time periods. Schematic diagram of a heap leaching process is presented in Figure 3.2. Upon completion of heap leaching, the processed ore stack is generally decommissioned in place; therefore, this technique does not require use of a tailings disposal (spent ore repository) facility (Zanbak, 2014).

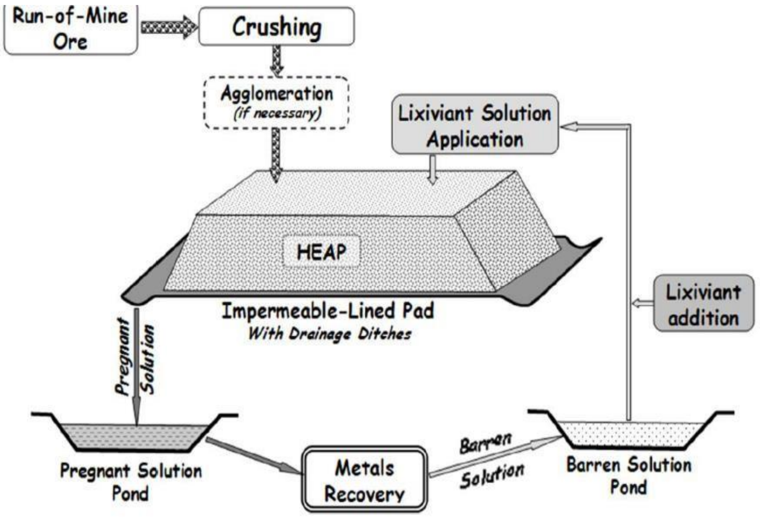


Figure 3.2 Schematic Representation of Heap Leach Process (Zanbak, 2014)

Design Component

The objective of the “heap leaching process” is to chemically dissolve the metals out of “run of mine or crushed ore, stacked on an impermeable lined pad, into a solution where metals are recovered through further chemical processing. Agglomeration may be applied on the crushed ore prior to stacking in order to enhance stacked ore permeability characteristics and subsequent percolation of chemical solution within the heap (Zanbak, 2014).

Agglomeration

Maintaining contact of leaching solution with crushed ore particles in the heap is important in increasing leach efficiency. In practice, crushing generates fine particles of rocks in addition to the clayey materials in the ore. The presence of excessive amounts of fine particles causes clogging of the pores between the larger ore particles and leads to uneven distribution of the leaching solution and can result in under leached zones in the heap. Agglomeration of crushed ore, analogous to sintering of fine iron ore, provide coarser grains that generate a more porous heap. Portland cement and lime binders are used for gold ore to prevent agglomerates from breaking up as leaching solution percolates through the heap (Lewandoski and Kawatra, 2009).

Leach Pad

The leach pad is a general term for the overall foundation of the heap (ore stack) that will be subject to leaching process. Depending on land availability, the pads are constructed either on large, relatively flat surfaces or in topographic valleys (Zanbak, 2014).

Leach Pad Bottom (Ground Surface)

The ideal site location for a leach pad is open land with smooth ground features and relatively flat (1-2% slope) ground surface without flooding potential. However; in practice leach pads are built in available spaces contoured with some earthwork. In the absence of large open flat areas, “Valley Fill” type pads can also be built in topographical valleys upslope from a constructed earthen embankment that function as a retaining structure. Another category of heap leach pad is the “on/off pads” where relatively flat pads, built with additional liner protection material are used to leach one lift of ore at a time with the spent heap material off-loaded from the leach pad at the end of the leach cycle for disposal (Zanbak, 2014).

Leach Pad Liner System

The design objective of the leach pad liner is to contain and prevent the loss of solutions generated in the overlying ore that will be subject to leaching process for both economic and environmental reasons. In current heap leach practice, the most preferred leach pad liner is the composite liner system. Composite liners are made up of a sequence of (starting from bottom): a compacted low permeability subgrade soil/clay liner or a geosynthetic clay liner laid over the natural ground surface, a leak-detection/collection system a geomembrane liner HDPE/LLDPE (geotextile may be placed over for protection from gravels above it), an overlying drain cover fill (gravel and drain pipes). Geosynthetic clay liners (GCL) are also used in leach pad construction, in lieu of low permeability subgrade soil/clay liners (CCL), as they become commercially available in global markets (Zanbak, 2014).

3.3 Geotechnical Properties of Soils Required for Road Construction

3.3.1 Moisture Content

The natural moisture content is the amount of water that exist in the soil samples as taken from the field. It is very important parameter since it can be used to predict the behavior of fine grain soils (clay and silts) in geotechnical applications during preliminary investigations when little or no laboratory data is available.

3.3.2 Specific Gravity

The specific gravity of a given soil is defined as the ratio of the weight of a given volume of the soil to the weight of an equal volume of distilled water. In soil mechanics, the specific gravity of soil solids (which is often referred to as the specific gravity of soil) is an important parameter for calculation of the weight-volume relationship and determination of the particle size of fine grain soil in the hydrometer classification tests (Das , 2002).

3.3.3 Particle Size Distribution

Most soils consist of a graded mixture of particles from two or more size ranges. For example, clay is a type of soil possessing cohesion and plasticity which normally consists of particles in both the clay size and silt size ranges. Soil behavior always depends to some extent on particle size (Table 3.1). Particle size distribution is used to select the appropriate materials for road bases since the grain size must meet a particular grading specification (Head, 2006). With coarse-grained materials, it is found that engineering properties are closely related to particle size and hence particle size is the dominant criterion used in evaluating and classifying these soils (Wesley, 2009). Grading is used to determine the particle size of coarse grain soils (sand and gravel) and the hydrometer or sedimentation is used to determine the particle size of fine grained soils.

Table 3.1 Soil Particle Sizes

Soil Type	**Minimum (mm)**	**Maximum (mm)**
Clay		0.002
Silt	0.002	0.063
Sand	0.063	2
Gravel	2	60

(Source: Wesley, 2009)

Sieve analysis or grading

In order to classify a soil for engineering purposes, one needs to know the distribution of the size of grains in a given soil mass. Sieve analysis is a method used to determine the grain size distribution of coarse soils. It involves determining the percentage by mass of particles within the different size ranges. The soil sample is passed through a series of standard test sieves having successively smaller mesh sizes. The mass of soil retained in each sieve is determined, and the cumulative percentage by mass passing each sieve is calculated. (Knappet and Craig, 2012).

Hydrometer Tests

Hydrometer analysis is the procedure generally adopted for determination of the particle-size distribution in a soil for the fraction that is finer than No. 200 sieve size (0.075 mm). In hydrometer analysis, a soil specimen is dispersed in water. In a dispersed state in the water, the soil particles will settle individually. This method is based on Stokes' law, which governs the velocity at which spherical particles settle in a suspension: the larger the particles are the greater is the settling velocity, and vice versa. The soil sample is pretreated with hydrogen peroxide to remove any organic material. The sample is then made up as a suspension in distilled water to which a deflocculating agent has been added to ensure that all particles settle individually, and placed in a sedimentation tube. From Stokes' law it is possible to calculate the time, *t*, for particles of a certain 'size', *D* (the equivalent settling diameter), to settle to a specified depth in the suspension (Knappet and Craig, 2012).

Particle Size Distribution Curves

Murthy (2002) established that the shape of the particle size curve indicates the type of the soil, based on the curve the soil can be classified as:

- Uniformly graded or poorly graded.
- Well graded.
- Gap graded.

Uniformly graded soil; uniformly graded soils are represented by nearly vertical lines as shown by the curve in Figure. 3.2. Uniformly graded soils have particles of almost the same diameter.

Well graded soil; a well graded soil, indicated in Figure 3.3 has particles that contain all the soil particle sizes ranging from gravel to clay size particles.

Gap graded soil; a gap graded soil shown in Figure 3.3 lack some of the particle sizes, some sizes of the particles are missing.

The grain size distribution curves can be used to understand certain characteristics of soils. To determine whether a material is uniformly graded or well graded, the following equation can be used (Murthy 2002):

$$C_u = \frac{D_{60}}{D_{10}}$$

D_{60} is the diameter of the particle at 60 per cent finer on the grain size distribution curve and D_{10} is effective grain size which correspond to 10% finer particles. The uniformity coefficient, Cu, is about one if the grain size distribution curve is almost vertical, and the value increases with gradation. For all practical purposes, the following values for granular soils can be considered;

$Cu > 4$ for well graded gravel

$Cu > 6$ for well graded sand

$C < 4$ for uniformly graded soil containing particles of the same size

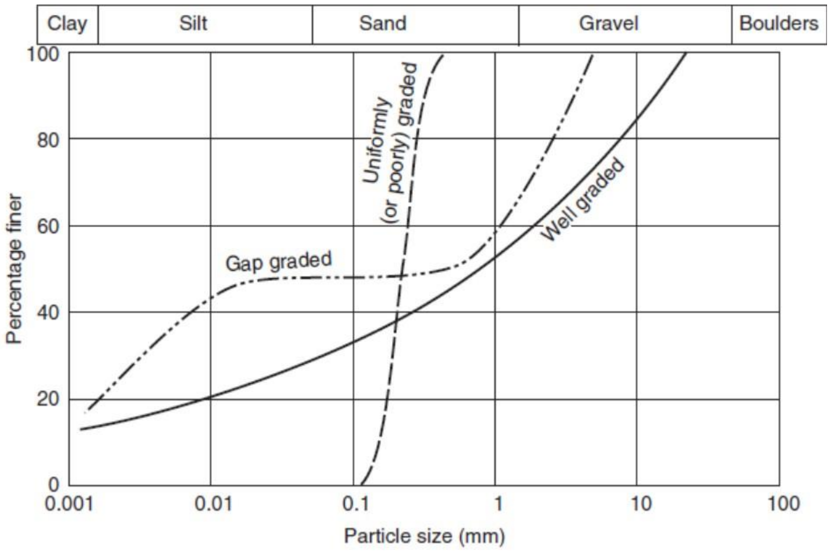


Figure 3.3 Particle Size Distribution Curves (Murthy, 2002)

3.3.4 Atterberg Limits

The behavior of cohesive soils at different moisture contents are referred to as the Atterberg limits. The moisture content (in percent) at which the cohesive soil will pass from a liquid state to a plastic state is called the Liquid Limit (LL) of the soil. Similarly, the moisture contents (in percent) at which the soil changes from a plastic to a semisolid state and from a semisolid state to a solid state are referred to as the Plastic Limit (PL) and the Shrinkage Limit (SL), respectively. The difference between the Liquid Limit and Plastic Limit is referred to as the Plasticity Index (PI) (Das, 2002). The Atterberg Limits are used with the particle size distribution in the classification of soils and also determine the effect of moisture content on the engineering behavior of cohesive soils. It can also be used to predict the engineering properties of soils for design.

3.3.5 Compaction

Wesley (2010) defined Compaction as a mechanical process in which dynamic energy is used to make the soil more compact; it squeezes air out of the void spaces and thus pushes the soil particles closer together. It does not involve the removal of any water from the soil during the compaction process itself, although drying or wetting the soil may be done prior to commencement of the compaction operation.

Compaction is carried out in the laboratory and also in the field. The results obtained from the laboratory tests are used as quality control and quality assurance during field compaction. Compaction of soil in the field is conducted with various types of equipment which includes smooth wheeled rollers, pneumatic-tyred rollers, sheepsfoot rollers, and grid rollers. In the laboratory, two compaction test are conducted, proctor test and the modified tests American Association of State Housing and Transportation Official (AASHTO), the soil is normally compacted in metal mould using falling weight of a rammer of known dimensions (Wesley, 2010). Details of the mould, hammer, and number of layers in the two tests are given in Table 3.2

Table 3.2 Details of Standard (Proctor) and Modified Compaction Tests

Description	Standard Proctor Test	Modified Tests
Mould diameter (cm)	10.5	10.5
Mould Height (cm)	11.55	11.55
Mould Volume (cm^3)	1000	1000
Number of Layers	3	5
Weight of Rammer (kg)	2.5	4.5
Fall Height of Rammer (cm)	30	45
Blows per layer	27	55

(Source: Wesley, 2010)

Principles of Compaction

The degree of compaction of a soil is measured by the dry unit weight of the skeleton. The dry unit weight correlates with the degree of packing of the soil grains. The more compacted a soil is, the smaller its void ratio and the higher its dry unit weight.

Compaction Behavior of Soils

The behavior of soils during the compaction process is best understood by considering the laboratory tests normally used to measure compaction characteristics. These tests are generally referred to as the standard Proctor test and the modified (or heavy) compaction test (Wesley, 2010). The tests involve compacting the soil in a cylindrical container (compaction mould) of known dimensions using a specified number of layers and hammers of known weight and fall height. The tests are carried out on a series of samples of the soil prepared at different water contents with approximately equal increments between them.

The effect of Compaction on Soil

- Increased Shear Strength.
- Reduced Compressibility.
- Reduced Permeability; this inhibits soils' ability to absorb water, and therefore reduces the tendency to expand/shrink and potentially liquefy.
- Reduce Liquefaction Potential
- Control Swelling & Shrinking

3.3.6 California Bearing Ratio

The California bearing ratio (CBR) is a penetration test for evaluation of the mechanical strength of natural ground, subgrades and base courses beneath new carriageway construction (Bharathi, 2017). The CBR test was originally developed by the California Department of Transportation and was subsequently incorporated by the Army Corps of Engineers for the design of flexible pavements (Taskiran, 2010). The CBR tests can be determined in laboratory or on the field with the Dynamic Cone Penetrometer, Transport and Road Laboratory version.

Laboratory Determination of CBR

The soil is compacted in a standard mould and the CBR is determined on either the unsoaked compacted soil or after 96 hours of soaking in water. According to the Ministry of Roads and Transport, material for base construction must have a CBR of 80% or more and 60% or more for subbase material (MoT, 2007).

3.4 Structure of the Road Pavement

Mathew (2009) defined road pavement as a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, its primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable light reflecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the sub-grade. The structure of a typical flexible road pavement structure is presented in Figure 3.4.

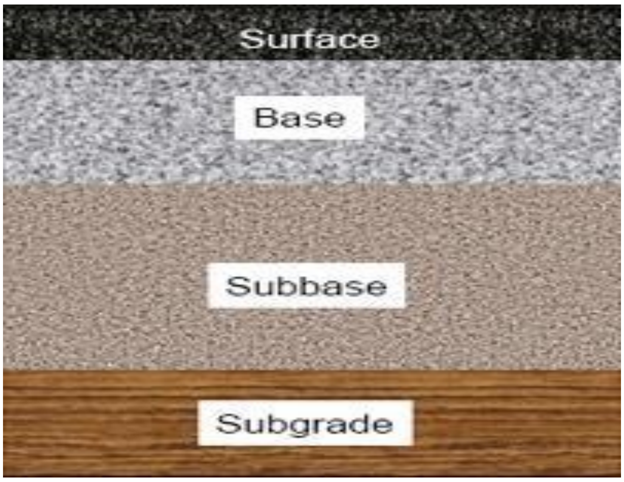


Figure 3.4 Road Pavement Structure (Mathew, 2009)

3.4.1 Wearing Surface

Wearing surface is the topmost layer of the road pavement structure and it is designed to be impermeable to the entry of water, have an even running surface, be durable and have great resistance to skidding. It is also designed to bear and transmit loads by the allowable vehicular traffic. The wearing surface is mostly made of hot rolled asphalt (Mathew and Rao, 2007).

3.4.2 Base

The base course is the layer of material immediately beneath the wearing surface and it provides additional load distribution and contributes to the sub-surface drainage. It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials. (Mathew, 2009)

3.4.3 Subbase

The subbase course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the subgrade in the pavement structure. If the base course is open graded, then the subbase course with more fines can serve as a filler between subgrade and the base course. A subbase course is not always needed or used. For example, a pavement constructed over a high quality, stiff subgrade may not need the additional features offered by a subbase course. In such situations, subbase course may not be provided (Mathew, 2009).

3.4.4 Subgrade

The subgrade is the foundation of the road pavement. It is the in-situ or native material where the in-situ materials meet the specifications or transported or stabilized material if the in-situ materials are not suitable. The thickness of the various layers of a road pavement depends on the strength of the subgrade material. The strength of the subgrade can be measured in-situ with the Dynamic Cone Penetration (DCP).

3.5 Soil Stabilisation

Soil stabilization is the process of improving the physical and engineering properties of a soil to obtain some predetermined targets. This technique is done in order to render the material suitable and satisfactory for use as foundation or subgrade, subbase and base material. According to Bell (1993), the objectives of mixing additives with soil are to improve volume stability, strength and stress-strain properties, permeability, and durability. The development of high strength and stiffness is achieved through reduction of void space, by bonding particles and aggregates together, by maintenance of flocculent structures, and by prevention of swelling. The permeability is altered through modification of pore size and distribution. The following are some of the methods used in soil stabilisation.

3.5.1 Mechanical Stabilisation

This is the process of altering soil properties by changing the gradation through mixing with other soils, densifying the soils using compaction energies, or undercutting the existing soils and replacing them with granular material. (Markwick, 1944).

a) Blending

Blending involves the mixing of materials that have different properties (typically particle size distribution and/or plasticity) to form a material with characteristics that improve upon the limitations of the source materials. Improving strength or plasticity is usually the primary reason for implementing mechanical stabilization. In most instances, blending will involve adding coarse aggregates to the finer in situ material (Jones *et al.*, 2010).

3.5.2 Chemical Stabilisation

Chemical stabilization includes the use of admixtures (chemicals and emulsions) as cementing agents, modifiers, water proofing, and water retaining and to improve the engineering properties of undesirable soils. The behaviour of each of these admixtures differs vastly from the others; each has its particular use and conversely each has its own limitations (Gidigasu, 1976). Traditional stabilizers such as Portland cement, lime and bitumen are used to stabilise soil. However, there are a variety of non-traditional additives available from the commercial sector such as polymer emulsions, acids, lignin derivatives, enzymes, tree resin emulsions, and silicates. Inorganic salts such as sodium chloride and calcium chloride have long been used in stabilization. Their chief function is to reduce plasticity and facilitate densification (Gillot, 1987).

3.5.3 Cement Stabilisation

Soil which is stabilized with cement is known as cement-soil stabilization. The chemical reaction between cement and soil during hydration process will produce binding force. Cement stabilization is suitable for inorganic soil. When soils are sandy, mixing of cement and soil can be carried out at or slightly about optimum moisture content but with clayey soils mixing is most readily achieved with moisture slightly below optimum. (Bergado *et al.*, 1996).

3.5.4 Lime Stabilisation

Lime stabilization refers to the stabilization of soil with the addition of burnt limestone products in the form of calcium oxide or calcium hydroxide (Bell, 1993). In lime-soil reaction, lime chemically reacts with the clay fraction of the soil to form cementitious compounds (Little, 1995).

Lime stabilisation is a two stage process, the first involves cation exchange to produce calcium clays and the second involves removal of silica and alumina from the clay fraction. The chemical reactions produce cementitious products that contribute to the strength of lime stabilized soil layers (Anon, 2004).

3.5.5 Bitumen Stabilisation

This method enhances the strength of the soil by making it waterproof, forms binding among the soil particles and maintain low moisture content of soil. Osinubi (2001) reported that bituminous soil stabilization has been most successfully employed in the stabilization of non-cohesive or mildly cohesive soils particularly in warm dry climates where the soil has low moisture content.

3.5.6 Industrial and Agricultural Wastes Stabilisation

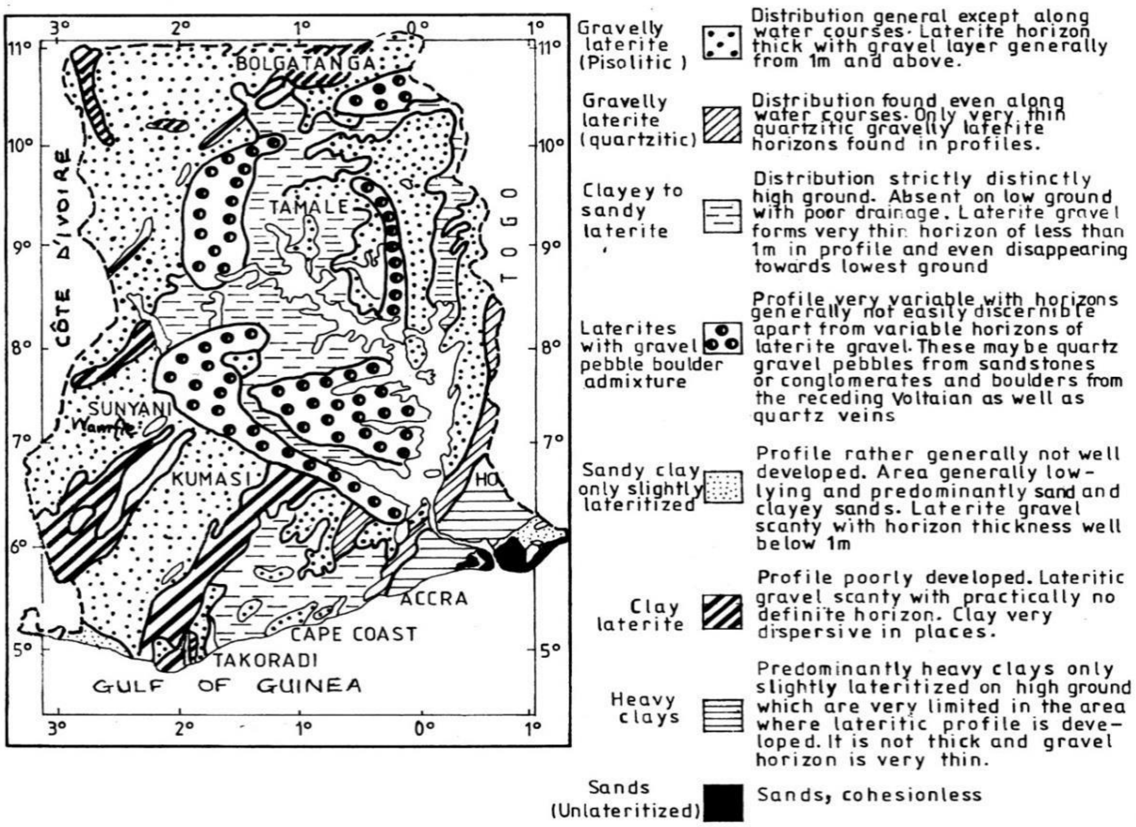
The rising cost of conventional soil stabilizers coupled with the need to reduce the cost of waste disposal as well as the need for the economical utilization of industrial and agricultural waste have prompted an investigation into the stabilizing potential of industrial and agricultural wastes. Yohanna (2014) has shown that industrial and agricultural wastes could be used for the stabilization or modification of problematic soils. The materials have been used as admixtures in lime or cement treatment for the improvement of the engineering properties of expansive soils as reported by Osinubi and Toro (1997).

3.6 Laterite

Gidigasu (1976) defined laterite as reddish residual and non-residual tropically weathered soils which generically form a chain of materials from decomposed rock through clays to sesquioxides-rich crusts. Charman (1988) also defined laterite as a highly weathered natural material formed by the concentration of the hydrated oxides of iron or aluminum. This concentration may be by residual accumulation of solution, movement and chemical precipitation. In all cases it is the result of secondary physio-chemical processes and not of the normal primary processes of sedimentation, metamorphism, volcanism or plutonism. The accumulated hydrated oxides are sufficiently concentrated to affect the character of the deposit in which they occur. They may be present alone in an unhardened soil; as a hardened layer; or as a constituent such as concretionary nodules in a soil matrix or a cemented matrix enclosing other materials. Any soil containing a clay fraction with a molecular silica-sesquioxides (SiO_2/R_2O_3) ratio of less than 2 and displaying a low expansibility is classified as lateritic soil.

3.6.1 Distribution of Laterite in Ghana

According to Gidigasu (1976) Laterite are found practically over most rock types (igneous, metamorphic, and sedimentary). The relative content of the main soil fractions of the laterite is a function of the degree of weathering and nature of the parent rock. The parent rock type and the other factors mentioned above may impart to the different engineering properties such as the particle size distribution, plasticity and strength. Figure 3.5 shows the engineering soils map of laterite in Ghana.



Gravelly laterite (Pisolitic)	⁘	Distribution general except along water courses. Laterite horizon thick with gravel layer generally from 1m and above.
Gravelly laterite (quartzitic)	▨	Distribution found even along water courses. Only very thin quartzitic gravelly laterite horizons found in profiles.
Clayey to sandy laterite	☰	Distribution strictly distinctly high ground. Absent on low ground with poor drainage. Laterite gravel forms very thin horizon of less than 1m in profile and even disappearing towards lowest ground
Laterites with gravel pebble boulder admixture	⦿	Profile very variable with horizons generally not easily discernible apart from variable horizons of laterite gravel. These may be quartz gravel pebbles from sandstones or conglomerates and boulders from the receding Voltaian as well as quartz veins
Sandy clay only slightly lateritized	░	Profile rather generally not well developed. Area generally low-lying and predominantly sand and clayey sands. Laterite gravel scanty with horizon thickness well below 1m
Clay laterite	▨	Profile poorly developed. Lateritic gravel scanty with practically no definite horizon. Clay very dispersive in places.
Heavy clays	☰	Predominantly heavy clays only slightly lateritized on high ground which are very limited in the area where lateritic profile is developed. It is not thick and gravel horizon is very thin.
Sands (Unlateritized)	■	Sands, cohesionless

Figure 3.5 Engineering Soils Map of Laterite Soils in Ghana
(Ayetey and Frempong, 1996)

3.6.2 Formation of Laterite

Laterisation involve chemical and physical alteration and/or transformation of primary rock forming minerals into materials rich in clay minerals and laterite constituent elements (Fe, Al, Ti and Mn). Gidigasu (1976) describes the formation of laterite as a three stage process as follows.

a) Decomposition of the underlying parent rock

Decomposition of the underlying parent rock characterized by physico-chemical break down of primary minerals and the release of constituent elements (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, etc.)

The second stage involves the leaching, under appropriate drainage conditions, of combined silica and bases and the relative accumulation or enrichment from outside sources of oxides and hydroxides of sesquioxides (mainly Al_2O_3, Fe_2O_3 and TiO_2). The soil conditions under which the various elements are rendered soluble and removed through leaching or combination with other substances depend on the pH and drainage condition.

Under conditions of low physico-chemical weathering activity, weathering does not continue beyond the clay forming stage, and tends to produce end products consisting of clay minerals, predominantly kaolinite and occasionally by hydrated or anhydrous oxides of iron and aluminium. Under conditions of intense and prolonged physico-chemical weathering, the clay minerals are destroyed and silica is leached, leaving aluminium oxides or hydrous iron oxides.

b) Dehydration and desiccation

The third stage involves the partial or complete dehydration of the sesquioxides-rich materials and secondary minerals. In this process, there is loss of water and concentration and crystallization of the amorphous iron colloids into dense crystalline iron minerals.

3.6.3 Geotechnical Properties of Laterite

Laterite hardens on exposure to air which could be attributed to a change in the hydration of iron and aluminium oxides. It commonly contains all size fractions from clay to gravel and sometimes even larger material. Common properties of laterite are given in Table 3.3. Such soils are of low to medium plasticity. Gidigasu (1976) identified that the geotechnical properties of laterite soil are influenced by their genesis, degree of weathering, morphology, chemical and mineralogical composition and also on the environmental factors. These factors are responsible for their variability and inhomogeneity.

Table 3.3 Geotechnical Properties of some Laterite

Item	Property	Value
1.	Moisture Content (%)	10 – 49
2.	Liquid Limit (%)	33 – 90
3.	Plastic Limit (%)	13 – 31
4.	Clay (%)	15 – 45
5.	Dry Unit Weight (KN/m^3)	15.2 – 17.3
6.	Cohesion c_u (kPa)	466 - 782
7.	Angle of Internal friction (^{o})	28 – 35
8.	Unconfined Compressive Strength (kPa)	220 - 625
9.	Compression Index	0.0186
10.	Coefficient of consolidation (m^2/year)	262 – 599*
11.	Young’s Modulus (kPa)	5.63 x 10^4

(Source: Bell, 1993)

3.7 Ministry of Transportation Standard Specifications for Road Base and Subbase Materials

The Ministry of Transportation (MoT) standard specifications for road and bridgeworks (2007) defines the standard, quality of materials and workmanship to be used in the construction of roads and bridges in the Republic of Ghana. Section 12 of the standard specifies the requirements for materials for road base and subbase. Table 3.4 shows the specification of natural gravel for road base and subbase construction. The Atterberg Limits, grading and the CBR are parameters in selecting materials for road construction.

Table 3.4 Requirements for Base and Subbase Materials (MoT, 2007)

Material properties	**Material Class**			
	G80	**G60**	**G40**	**G30**
CBR (%)	80	60	40	30
CBR Swell (%)	0.25	0.5	0.5	1.0
Grading				
% Passing Sieve Size (mm)				
75	100	100		
37.5	80 - 100	80 - 100		
20	60 - 85	75 - 100		
10	45 - 70	45 - 90		
5.0	30 - 55	30 - 75		
2.0	20 - 45	20 - 50		
0.425	8 - 26	8 - 33		
0.075	5 – 15	5 – 22		
Grading Modulus (min)	2.15	1.95	1.5	1.25
Maximum size (mm)	53.0	63.0	75.0	2/3rd layer thickness
Atterberg Limits				
Liquid Limit (%) (max)	25	30	30	35
Plasticity Index (%) (max)	10	12	14	16
Linear Shrinkage (%) (max)	5	6	7	8
Plasticity modulus (max)	200	250	250	250
Other properties				
10%Fines (kN) (min)	80	50	-	-
Ratio dry/soaked 10%Fines (min)	0.6	0.6		
Notes:				

All CBR’s will be determined at the field density specified for the layer in which the material is used.

All grading specifications are applicable after placing and compaction. Grading curves shall be smooth curves within the specified envelopes and approximately parallel to the envelopes.

Grading Modulus (GM) = 3 – (percentage passing 2.0 + 0.425 + 0.075 mm sieves) ÷ 100

Plasticity modulus = Plasticity Index x percentage passing 0.425 mm sieve

(Source: MoT, 2007)

CHAPTER 4

MATERIALS AND TEST METHODS

4.0 Introduction

The materials used for the research includes spent ore and laterite from Tarkwa area, the main aim of the research is to determine the composites of the spent ore and laterite that can be used for base or subbase construction in Ghana. The materials and methods used to achieve the results are presented in this chapter.

4.1 Sampling

4.1.1 Spent Ore

The spent ore was obtained from Anglogold Ashanti Iduapirem Limited in Tarkwa. 200kg of the spent ore were sampled randomly from the bulk spent ore. The samples were bagged and labeled and transported to the BRRI Geotechnical Laboratory in Kumasi.

4.1.2 Laterite

The laterite samples were obtained from the Tarkwa area by excavation with pick and shovel at a base of a road cut about 2.5 below the ground surface. Bulk samples were taken from the excavation. The samples were bagged and labeled and transported to the BRRI Geotechnical Laboratory in Kumasi. Figure 4.1 shows the excavation of the laterite at the base of the road cut.

Figure 4.1 Excavation of Laterite Sample

4.2 Laboratory Tests

The following laboratory tests were conducted in accordance with British Standards at the BRRI Geotechnical Laboratory and KNUST Laboratory.

- Moisture Content (BS 1377 P1:1990)
- Particle size distribution (BS 1377 P2:1990)
- Atterberg limits (BS 1377 P2:1990)
- Compaction characteristics (BS 1377 P4:1990)
- California Bearing Ratio – CBR (BS 1377 P4:1990)
- Chemical tests for sulphates and organic matter.

4.2.1 Flow Chart of Methodology

The flow chart of the tests conducted on the raw samples and the composites are presented in Figure 4.2.

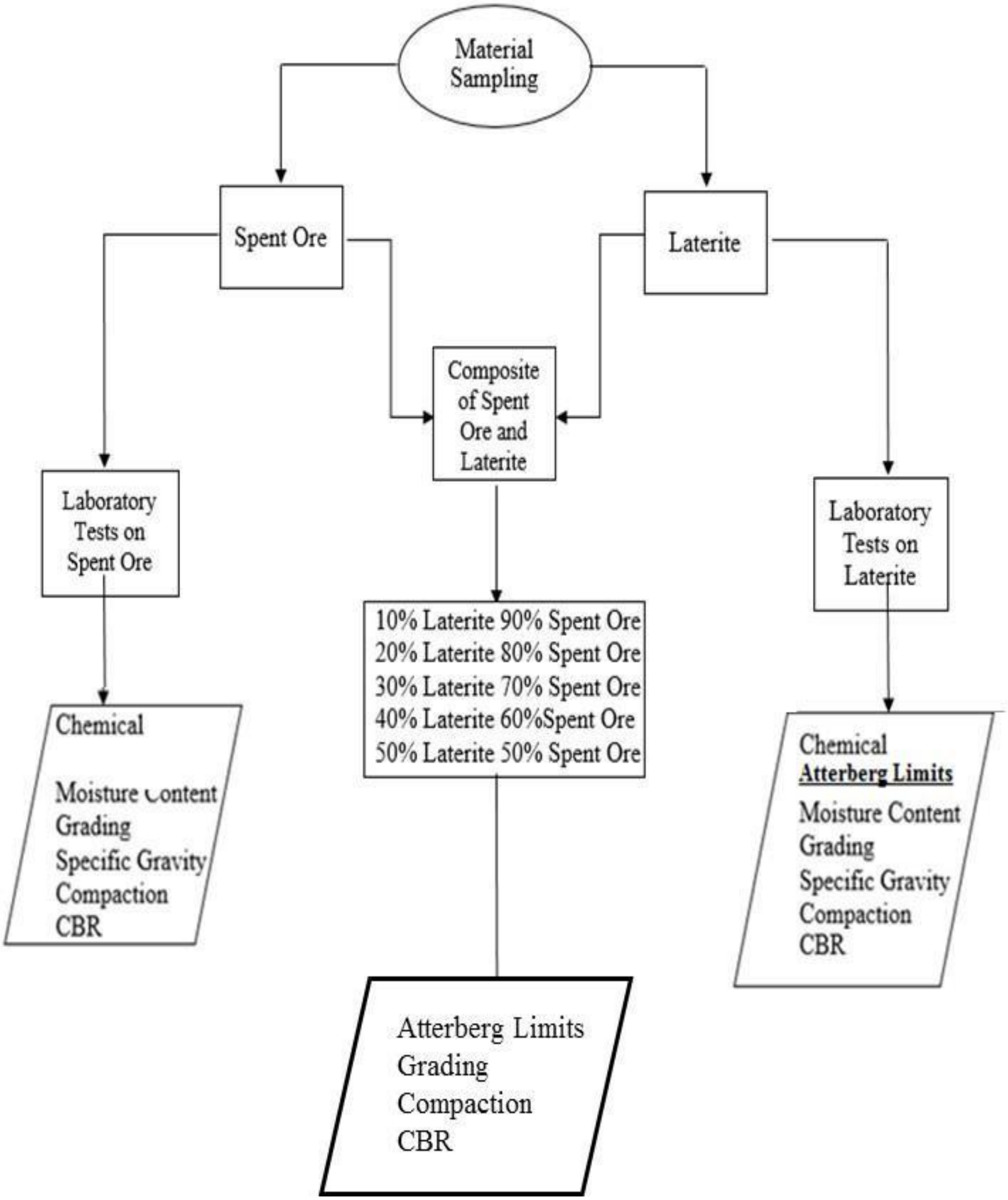


Figure 4.2 Flowchart of Methodology

4.3 Sample Preparation and Testing Procedures

4.3.1 Sample Preparation

Representative samples were taken from the sample bags for the determination of the natural moisture content. The remaining samples were spread out for air-drying in an enclosed area at a temperature of about 25^{o}C (Figure 4.3). Lumps or aggregations of soil samples were crushed with a rubber headed pestle and mortar taking care not to reduce the size of the particles.

Figure 4.3 Air Drying of Samples

4.3.2 Moisture Content

The moisture content of the soil sample was measured by the oven drying method in accordance with BS 1377-2, 1990. About 30 g of the soil samples were weighed to a precision of 0.1 g. Oven dried at 105 ^{o}C overnight then weighed, the moisture content was calculated by expressing the mass of water in the soil as a percentage of the mass of dried soil.

4.3.3 Particle Size Distribution Test

The required air-dried mass needed for the test was measured out by successive riffling of the bulk sample. 2 kg each of the spent ore and laterite were sieved through the 20 mm aperture

BS standard sieve and the mass retained noted. The fraction passing the 20 mm sieve was soaked in water in a bucket overnight. After which the material was washed through the 63 µm sieve, a little at a time. The portion retained on the sieve was dried in the oven for 24 hours after which it was sieved through a nest of BS standard sieves and the different weights of material retained on each sieve recorded.

The hydrometer method of the sedimentation test was used to quantitatively determine the particle size distribution of the finer particles. 50 g each of the samples passing the 0.075 mm sieve (No. 200) were weighed and used for the hydrometer test as provided in section 9.5 of BS 1377-2.

4.3.4 Consistency Limit Tests

Liquid Limit (LL)

B.S 1377 (1990) describes the procedure for the determination of liquid limit test of a soil which was adopted for this work. In this test, 200 g of the sample material passing BS No. 40 sieve (425 µm aperture) was placed on a clean glass plate. The soil was thoroughly mixed with water on this flat glass plate, using palette knife and spatula to form a homogenous paste. A proportion of the paste was placed in Casagrande apparatus and level parallel to the base of the chip and divided by drawing the grooving tool through the paste along diameter passing the centre of the hinge. The crank was turned to lift-drop the cup at the rate of 2 revs per second, noting the number of blows (falls) that would make the bottom two parts of the groove come together. . The liquid limit tests were determined at various moisture contents from drier states to the wetter states. The moisture content was plotted against the respective number of blows on the semi logarithm paper. The liquid limit was deduced as the moisture content corresponding to 25 blows.

Plastic limit (PL)

The plastic limit test was conducted on 25 g of the sample, the sample was mixed with distill water to form a paste. The paste was allowed to dry on the glass plate until it could be shaped into a ball. The sample was formed into a thread of about 6 mm diameter in the palms. The thread was rolled between the fingers and the glass plate until the diameter of the thread approached 3 mm. If the thread shears longitudinally and transversely, the sample is placed in a tray and the moisture content determined. If not, the thread is remolded into a ball and the procedure repeated. The moisture content of the sample at the shearing point is the plastic limit.

Plasticity Index (PI)

This was obtained as the difference between the liquid and plastic limits.

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

4.3.5 Compaction of the Raw Spent Ore and Laterite

The compaction test measures the maximum density a soil can achieve through mechanical compaction and the water content at which this occurs. 60 kg of the air dried soil samples were passed through the 19 mm sieve and riffled to obtain eight portions of 7 kg each for the compaction test. An amount of water equivalent to about 3% of the weight of the sample was added to the 7 kg portion and mixed thoroughly and compacted. A 4.5 kg hammer with a drop of 457 mm, the compaction mould of dimensions 152mm diameter and 179 mm height, were used in the test. Five soil layers, each compacted by 55 blows were applied. The density of the compacted sample was determined and samples were taken for moisture content determination. The remaining four portions were similarly treated but with increasing moisture contents of about 2 % for successive samples. The dry densities of each of the two samples and the compacting moisture content which gave the densities were determined. The resulting maximum dry densities (MDD) and optimum moisture contents (OMC) were determined from a plot of the moisture content against the dry density.

4.3.6 Laboratory Tests on the Spent Ore and Laterite Composites

Table 4.1 shows the various percentages of laterite that was added to the spent for the laboratory test. The percentages ranges from 10 % to 50 %, these percentages were selected because the laterite is inert and requires higher amount to affect the geotechnical properties of the spent ore.

Table 4.1 Composites of Spent Ore and Laterite

Item	Spent Ore (S) %	Laterite (L) %
1	90	10
2	80	20
3	70	30
4	60	40
5	50	50

4.3.7 Compaction of Spent Ore and Laterite Composites (S: L)

7 kg of the spent ore was obtained by successive riffling, after sieving the air dried samples through the 19 mm BS sieve. The initial percentage of 10 % of the 7 kg of laterite was added to the spent ore and mixed thoroughly to bring the material to a uniform consistency. An amount of water equivalent to about 3 % of the weight of the sample was added to the mixture (10% Laterite and 90 % Spent Ore) mixed thoroughly and compacted. A 4.5 kg hammer with a drop of 457 mm, the compaction mould of dimensions 152 mm diameter and 179 mm height, were used in the test. Five soil layers, each compacted by 56 blows with increasing water content of 2% were applied, compaction of the composites is presented in Figure 4.4. The density of the compacted sample was determined and samples were taken for moisture content determination. The remaining percentages of 20 %, 30 %, 40 % and 50 % of the laterite were added to the spent ore and were similarly treated but with increasing moisture contents of about 2% for successive compactions. The dry densities of each of the spent ore percentages and the compacting moisture content which gave the densities were determined. The resulting maximum dry densities (MDD) and optimum moisture contents (OMC) were determined from a plot of the moisture content against the dry density.

Figure 4.4 Compaction of Laterite and Spent

4.3.8 California bearing ratio (CBR) of Raw Spent Ore and Laterite

For the CBR test, 7 kg soil samples passing the 19 mm test sieve were used. The amount of water to be added to the 7 kg soil sample was determined as the difference between the optimum moisture content less the air dried moisture content. The sample was mixed with the required amount of water, mixed to a uniform consistency and compacted. A 4.5 kg hammer with a drop of 457 mm, the CBR mould of dimensions 152 mm diameter and 179 mm height, were used in the test. Compaction was in five layers with each layer receiving 55 blows. Portions from the mixed sample were taken before and after the compaction to determine the moisture content of the compacted sample. The compacted samples were soaked in water for 4 days in a water bath after which the penetration test was conducted. The soaked and unsoaked CBR for samples and the percentage swell of the soaked samples were recorded.

4.3.9 California bearing ratio (CBR) of Spent Ore and Laterite Composites

For the California bearing ratio of the spent ore and laterite composites, the amount of water to be added to the 7 kg soil sample was determined as the difference between the optimum moisture content less an amount equal to the sum of the air dried moisture content. The composites and water were mixed to a uniform consistency. The mixture was compacted as described above for the natural soil. Portions from the mixed sample were taken before and after the compaction to determine the moisture content of the compacted sample. The CBR test was conducted on the compacted samples. The compacted samples were soaked in water for 4 days in a water bath after which the penetration test was conducted. The soaked and unsoaked CBR for each of the two samples and the percentage swell of the soaked samples were recorded.

Figure 4.5 shows the soaking of the compacted samples and measuring of swell.

Figure 4.5 Soaking of CBR Samples and Measuring of Swell

4.3.10 Chemical Analysis of Samples

Chemical analyses of the spent ore were performed as received from site without further exposure to sunlight. Major oxides and other constituent determinations were performed by X-Ray Fluorescence. Chemical analysis were also conducted on the laterite to determine its reactivity with cement.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.0 Introduction

This chapter presents the results of the laboratory tests on the raw samples, the composites, the interpretations of the results and discussions of the results as to its suitability for road construction purposes. The chapter is presentation based on the following

- Physical and Chemical Properties of the raw samples
- Engineering properties of the composites samples.

5.1 Physical Properties of the Spent Ore

The summary of the results of the physical laboratory tests conducted on the raw spent ore are presented in Table 5.1, the laboratory data and graphs are presented in Appendix A.

Table 5.1 Summary of Properties of Spent Ore

Property	**Value**	**MoT Requirements**	
		Base	**Subbase**
LL (%)	-	25 max	30 max
PI (%)	-	10 max	12 max
Max size (mm)	38.40	53	63
Max Fines Content	3.70	15	22
OMC (%)	10.0	-	-
MDD (g/cm^3)	1.30	-	-
CBR (%)	5.2	80 min	60 min
Soaked CBR (%)	4.1	80 min	60 min
Swell (%)	0	0.25 max	0.5 max
Specific Gravity	2.70	-	-
Gravel%	42.0	-	-
Sand%	47.7	-	-
Silt%	10.3	-	-
Clay%	0	-	-

5.1.1 Grading Properties

The laboratory test results indicate that, the spent ore consists predominantly of sand and gravel with minor silt content. The spent ore is poorly graded soil with less fines and does not meet the requirement for base and subbase material. The material is non plastic with a specific gravity of 2.7. Figures 5.1 and 5.2 show the spent ore curve that is superimposed on the MoT grading envelope. It can be observed from both graphs that the grading curves of the spent ore falls outside the grading envelopes for the base material but partially within the grading envelope for subbase material.

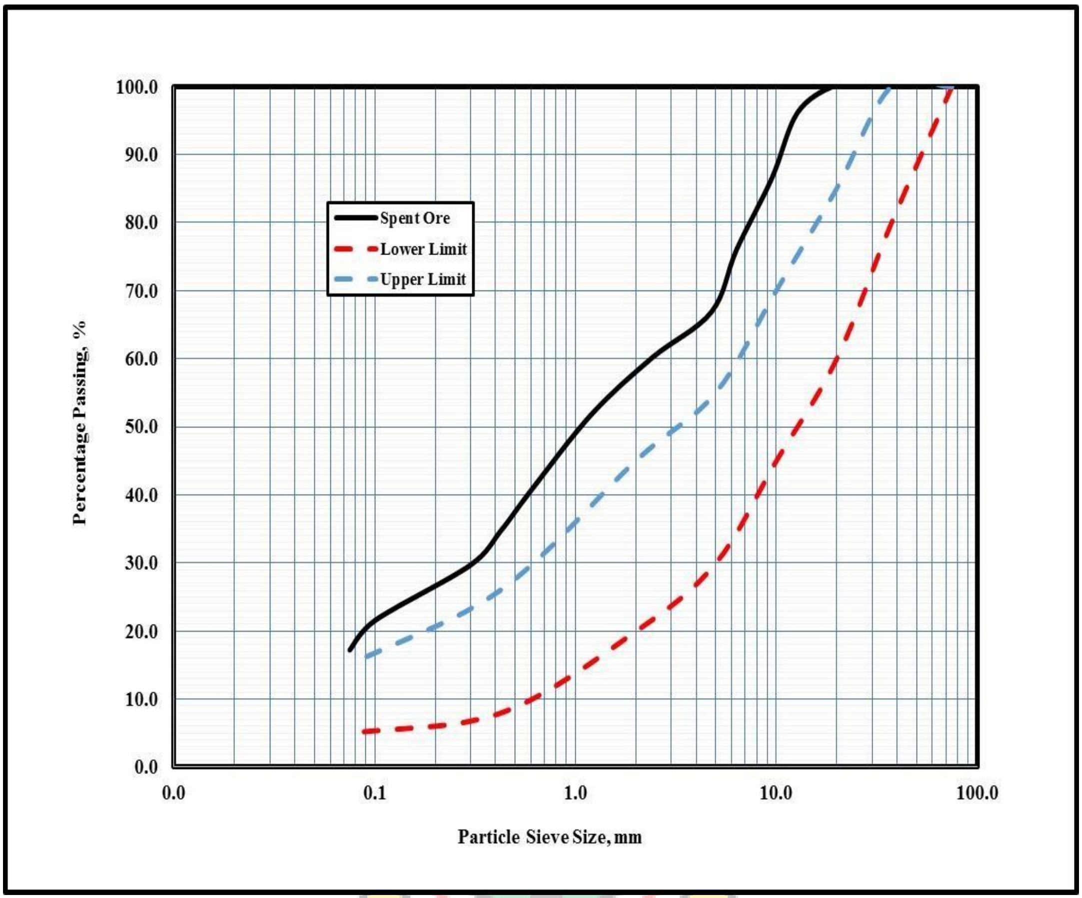


Figure 5.1 Grading Curve of Spent Ore superimposed on Grading Envelope for Base Material

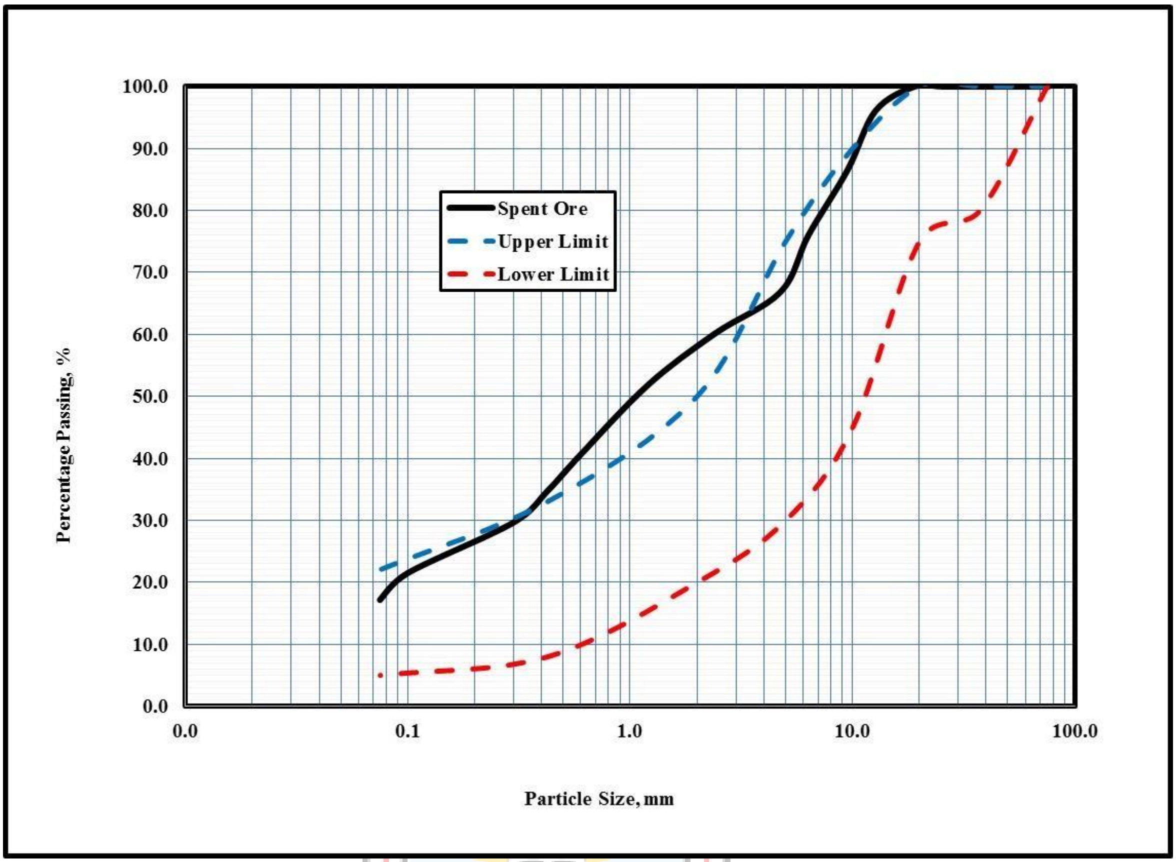


Figure 5.2 Grading Curve of Spent ore superimposed on Grading Envelope for Subbase Material

5.1.2 Chemical Properties of Spent Ore

The sodium sulphate soundness and alkali-silica reactivity test results are presented in Table 5.2. The results indicate that the materials are generally free from deleterious materials which would not cause expansive reactions in concrete. The level of cyanide measured ranged between 0.14 – 0.30 mg/L (Table 5.3). The residual cyanide content is below the maximum allowable content of 40 mg/kg in soil per international best practices (Anon, 2012).

Table 5.2 Sodium Sulphate Soundness and Alkali Silica Test Results

	TEST		
Sample	**Sodium Sulphate Soundness**	**Alkali Silica Expansion, %**	**Remarks**
Spent Ore 1	10.8	0.05	Passed both
Spent Ore 2	10.2	0.04	Passed both
Spent Ore 3	11.0	0.04	Passed both

Table 5.3 Chemical Composition of Spent Ore

Constituent	Unit	Sample 1	Sample 2
SiO_2	%	71.22	72.30
Al_2O_3	%	19.84	19.20
Fe_2O_3	%	2.75	2.78
$SiO_2+Al_2O_3+Fe_2O_3$	%	93.81	94.28
MgO	%	3.17	3.30
CaO	%	3.56	3.50
Na_2O	%	5.45	4.95
K_2O	%	3.50	3.36
Na_2O eq	%	7.837	7.242
CN^-	mg/kg	0.28	0.18
Cl	%	0.0035	0.0018
SO_4	%	0.0001	BDL

5.1.3 Physical Properties of the Laterite

Summary of the properties of the laterite are presented in Table 5.4, the graphs of the laboratory tests are presented in Appendix B. The laboratory test results indicate that, the laterite consists predominantly of silt and clay with some sand. The liquid limit is 42% with a plasticity index of 25%. This is classified as clayey soils with low plasticity.

Table 5.4 Summary of Properties of Laterite

Property	Value	MRT Requirements	
		Base	**Subbase**
LL (%)	42	25 max	30 max
PL (%)	17	-	-
PI (%)	25	10 max	12 max
PM	-	200 max	250 max
Max size (mm)	0.43	53	63
Max Fines Content	0.001	15	22
OMC (%)	5.3	-	-
MDD (g/cm^3)	1.52	-	-
CBR (%)	10.6	80 min	60 min
Soaked CBR (%)	5.2	80 min	60 min
Swell (%)	0.08	0.25 max	0.5 max
Specific Gravity	2.6	-	-
Gravel%	0	-	-
Sand%	11.1	-	-
Silt%	62.9	-	-
Clay%	26.8	-	-

5.1.4 Chemical Analysis of Laterite

The laterite sample was subjected to chemical analysis to determine the chloride, pH and sulfate levels, the results are presented in Table 5.5. The results show that, pH values are within the permissible limits, the sulphate values are below detection, the chloride levels are also below the permissible levels and the laterite will not react with concrete for construction.

Table 5.5 Chemical Analysis of Laterite

Sample Type	**pH**	**Chloride%**	**Sulphate%**
Laterite	6.0 @ 28 ^{0}C	0.0113597	Below Detection
Standard	BS 1377 – 3	ASTM D 1411	BS 1377 -3
Permissible Level	**6.0 @ 28 ^{0}C**	**0.01%**	**0.01%**

5.2 Engineering Properties

5.2.1 Compaction and CBR of Spent Ore

The results of the compaction and CBR tests conducted on the spent ore are presented in Figure 5.3 and Appendix C. Based on the compaction and CBR tests conducted on the spent ore, the maximum dry density (MDD) is 1.30 g/cm^3 with optimum moisture content (OMC) of 10.0%. The low MDD value can be attributed to the lack of fines to fill the voids in the coarse particles during the compaction process to decrease the void ratio and increase the density. The unsoaked CBR and soaked CBR are 5.2% and 4.1% respectively, the swell value is 0%. The results indicates that, the spent ore does meet the MoT requirements for base and subbase materials. It is therefore required that the spent ore is stabilized to improve the engineering properties for base and subbase construction.

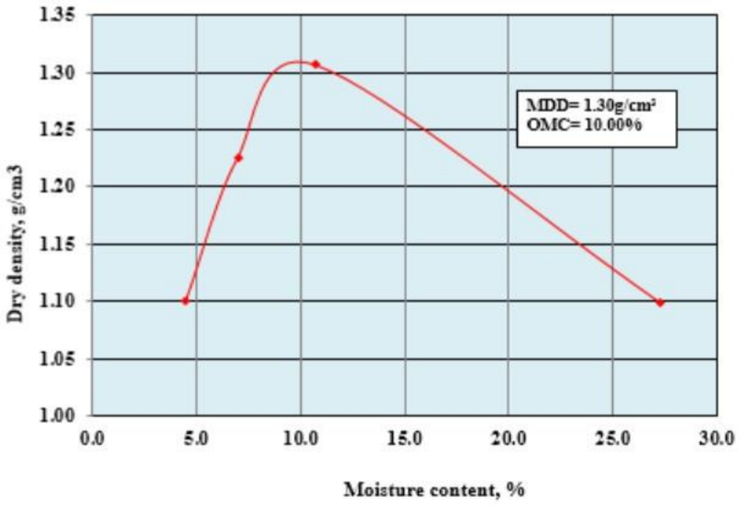


Figure 5.3 Compaction Curve for Spent Ore

5.2.2 Compaction and CBR of Laterite

The compaction and the CBR results are presented in Table 5.2, the laboratory data is presented in Appendix D. The compaction test on the laterite sample resulted in MDD of 1.5 g/cm^3 and OMC of 5.3%, the compaction curve of the laterite is presented in Figure 5.4. The CBR test also resulted in 10.6% with an unsoaked CBR of 5.2%. The swell value is also 0.08.

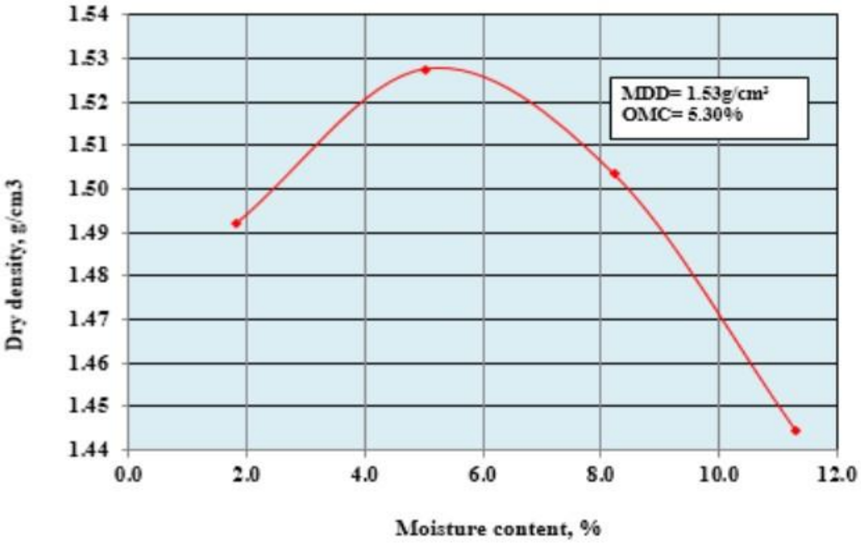


Figure 5.4 Compaction Curve for Laterite

5.3 Atterberg Limits of the Composite Materials

The summary of the results of the Atterberg Limits conducted on the composites are presented in Table 5.6 and the laboratory data are presented in Appendix E. The results show a gradual increase in the Atterberg Limits of the composite materials. The effect of the laterite on the Atterberg Limits of the spent ore is presented in subsequent paragraphs.

Table 5.6 Summary of Atterberg Limits

Item	Composite %	LL%	PL%	PI%
1	100 Spent Ore 0 Laterite	0	0	0
2	90S10L	20	17.1	2.9
3	80S20L	22	17.6	4.4
4	70S30L	36	29.1	6.9
5	60S40L	38	30.1	7.4
6	50S50L	40	31.1	8.9

5.3.1 Liquid Limits (LL) of the Composite Materials

The Liquid Limit is the moisture content at which the soils moves from the solid state into the liquid state with addition of water. Fine grain soils such as clay and silt have high LL due to their ability to absorbed water, coarse grain soils however have less LL due to its free draining nature. Figure 5.5 shows a graph of the LL of the composites. The graph shows a direct increase in the liquid limit (LL) of the composites with the addition of the laterite from 10% to 50%. The results show that addition of laterite from 10% to 20% resulted in LL between 20% and 22%, the values are within the specifications for the MoT standards for base and subbase materials.

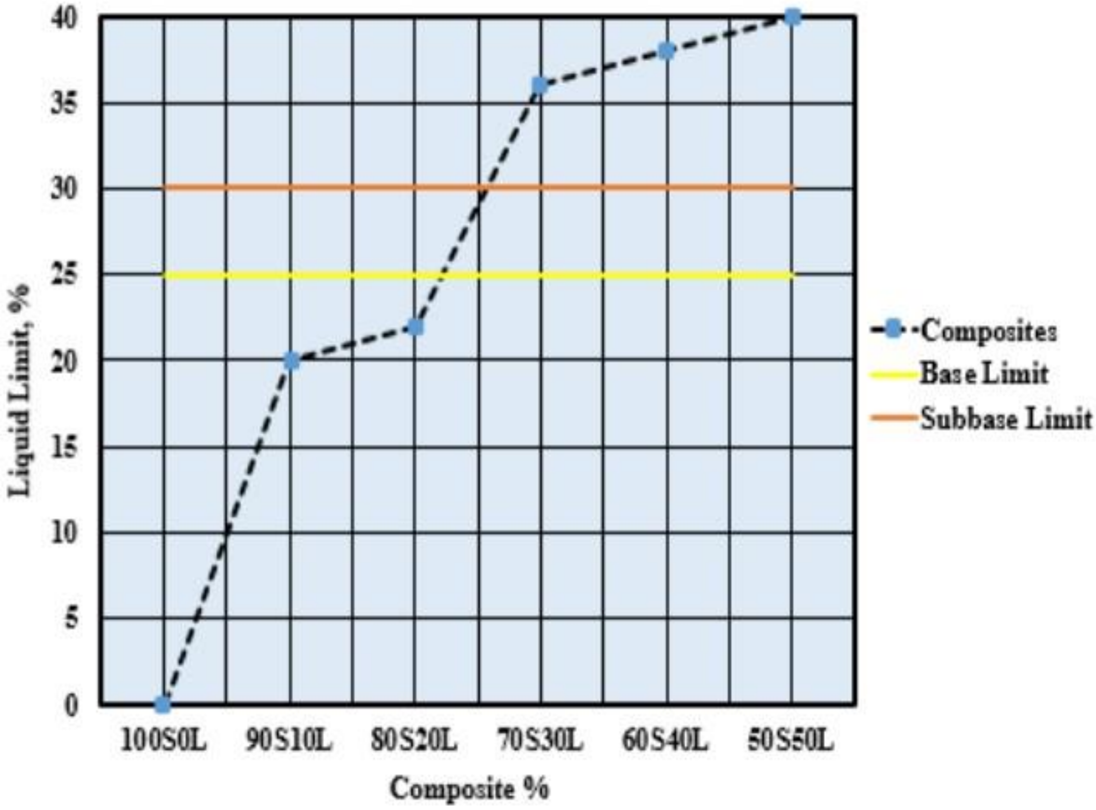


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Figure 5.5 Plot of LL of Composite Material

5.3.2 Plastic Limits (PL) of the Composite Materials

The effect of the laterite on the Plastic Limits of the spent ore is presented in Figure 5.6, the graph shows an increment in the PL of the spent ore. PL is an indication of the moisture content at which the soil moves from the liquid state to the plastic state with the addition of water, the PL of the composites is due to the clay fractions in the laterite.

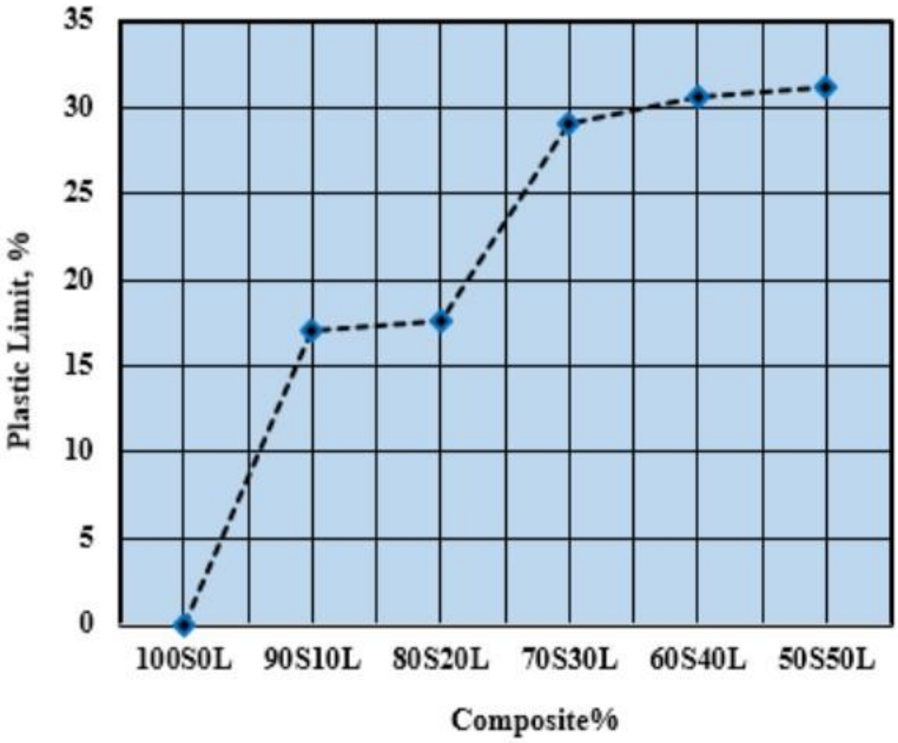

Figure 5.6 Plot of PL of Composite Material

5.3.3 Plasticity Index (PI) of the Composite Materials

The PI is the difference between the LL and the PL, the PI is a very important parameter of soil since it directly affect the engineering behavior of soils. The PI is related to the type and fraction of clay particles and minerals in a particle soil mass. The effect of the laterite on the PI of the composites are presented in graphical form in Figure 5.7. It can be observed from the graph that, the PI of the composites increase with increment in the percentage of the laterite. The higher the percentage of the laterite, the higher the PI. The results show that, the addition of laterite from 10% to 50% resulted in PI values that are within the MoT specification for PI values for based and subbase materials. (10% maximum for base and 12% maximum for subbase materials.

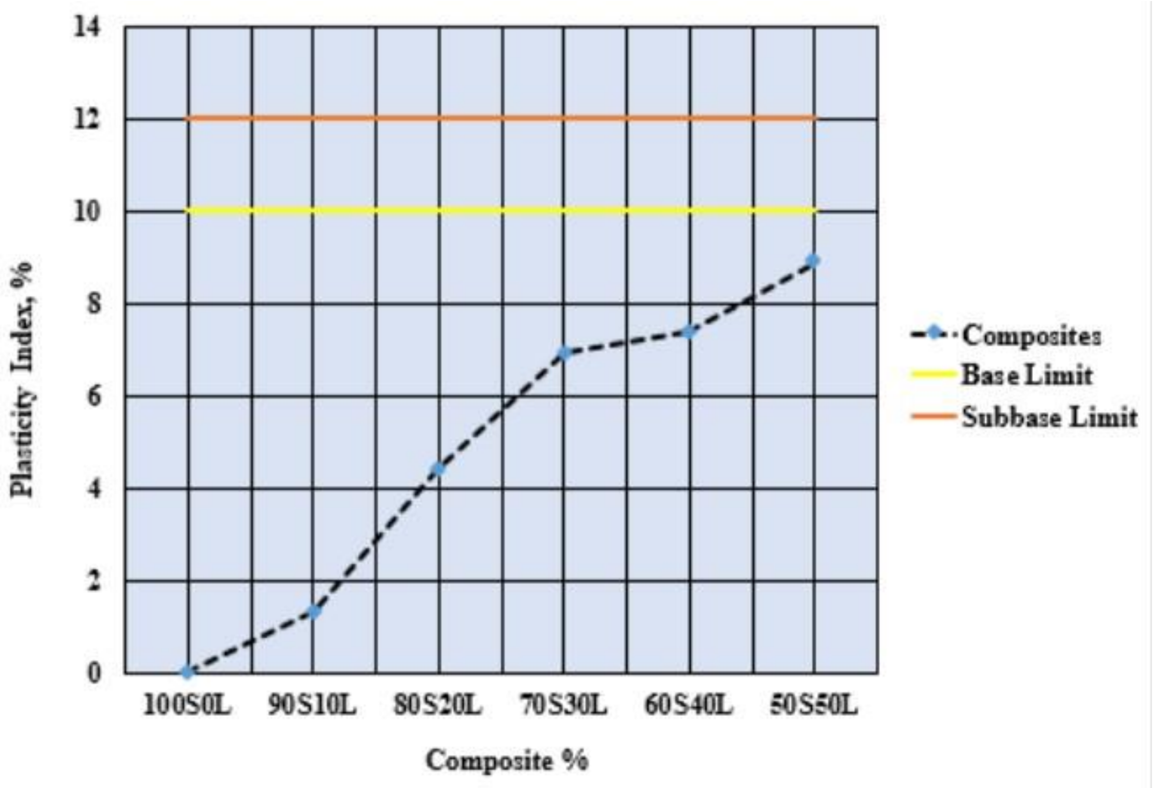

Figure 5.7 Plot of PI of Composite Material

5.4 Compaction Properties of the Composite Materials

The results of the compaction tests conducted on the composite material are summarized and presented in Table 5.7, the laboratory data are presented in Appendix F.

Table 5.7 Summary of Compaction Tests on Composite Materials

Item	Composite %	MDD (g/cm^3)	OMC (%)
1	100S0L	1.30	10.0
2	90S10L	1.48	5.0
3	80S20L	1.59	7.4
4	70S30L	2.01	7.5
5	60S40L	1.56	8.4
6	50S50L	1.55	9.6

5.4.1 Maximum Dry Density (MDD) of the Composite Materials

The graph presented in Figure 5.8 shows the effect of the laterite on MDD of the composites. The graph shows a gradual increase in the MDD of the spent ore with addition of the laterite, the MDD ranges from 1.3 g/ cm^3 to 2.01 g/cm^3. The composite 70S:30L resulted in the highest MDD of 2.01 g/cm^3. The trend in the results can be attributed to increasing laterite content in the composites, compaction is a densification process where air is expelled from the soils by applying loads which result in the rearrangement of the soil particles. The grading of the spent ore indicates that, the material consist of gravelly sand which is coarse grained, the laterite is also made up of clayey silts which is fine grained. The addition of the laterite to the spent ore is a blend of coarse grained soils. Fine grained soils, the fine grained particles will fill in the voids spaces between the coarse particles which when compacted at the optimum moisture content would results in higher MDD. The trend as presented in Figure 5.8 shows an increment in the MDD up to composite 70S30L and decrease to composite 10%S90%L. It means that, the optimum amount of the laterite to produce the highest MDD is 30% and any subsequent increment in the laterite content will amount to excess fines in the composites that will decrease the MDD.

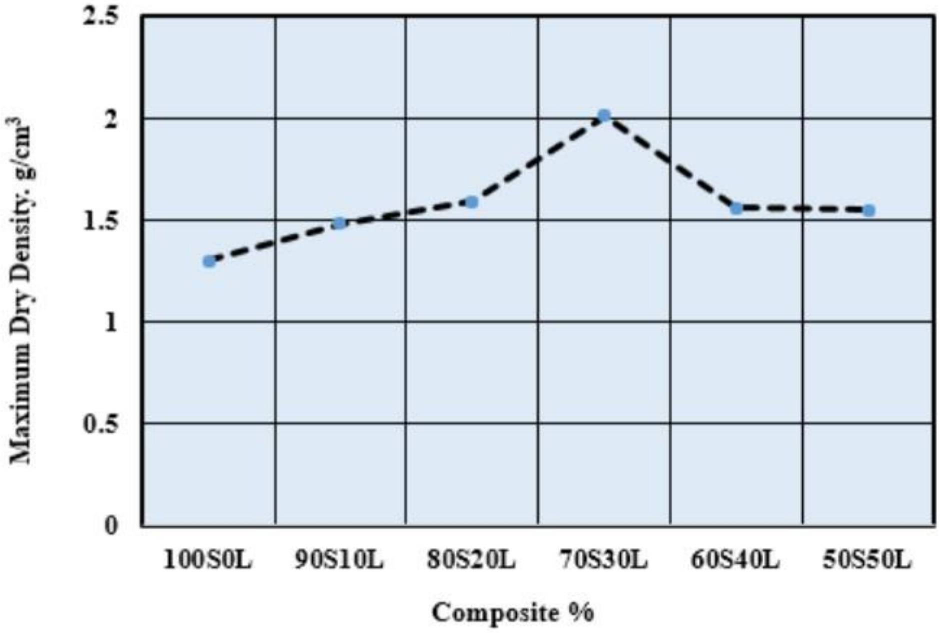

Figure 5.8 Plot of MDD of Composite Material

5.4.2 Optimum Moisture Content (OMC) of the Composite Materials

The effect of the laterite on the OMC of the composites is presented in Figure 5.9, the results showed direct increase in the OMC of the composites with the laterite content. The least OMC was recorded by composites 90S10L and the highest was by 50S50L. The amount of water added during the compaction process is very important since it acts as a lubricant and aids the soil particles to slide over each for effect compaction.

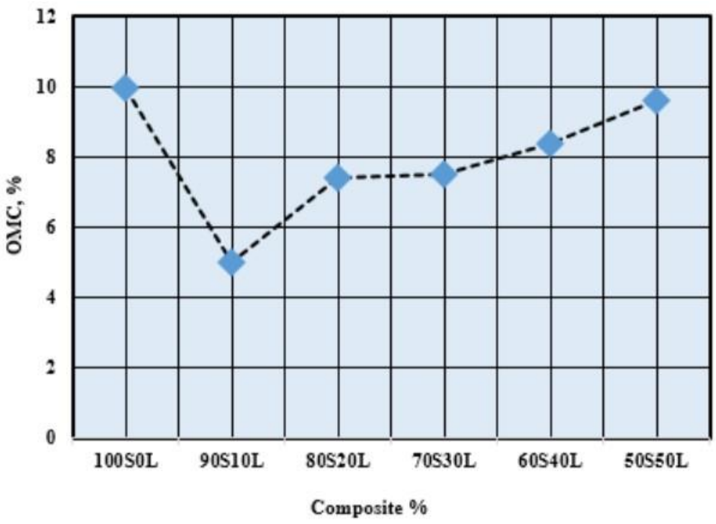

Figure 5.9 Plot of OMC of Composite Material

5.5 California Bearing Ratio of the Spent Ore of the Composite Materials

Summary of the CBR results of the composites are presented in Table 5.8 and the laboratory data are shown in Appendix G. Table 5.8 shows the soaked and unsoaked CBR values with the corresponding swell values of the composites.

Table 5.8 Summary of CBR Tests

Item	Composite %	CBR %		Swell
		Soaked	Unsoaked	
1	100S0L	4.1	5.2	0
2	90S10L	35	41	0.01
3	80S20L	39	46	0.02
4	70S30L	62	64	0.06
5	60S40L	23	34	0.07
6	50S50L	14	31	0.08

5.5.1 Swell values of the Composite Material

The swell values of the composites are show in Figure 5.10, the graph shows a gradual increase in the swell value with the increment in the laterite percentage. The Composite 50%S50%L resulted in the highest swell value of 0.08. The swell value relates to the clay content in the laterite, as the laterite is increased, the amount of clay in the composite also increased and accounted for the trend observed in the results presented in Figure 5.7. Based on the results, the addition of laterite between 10% and 50% will result in swell values that are within the MRT Specifications.

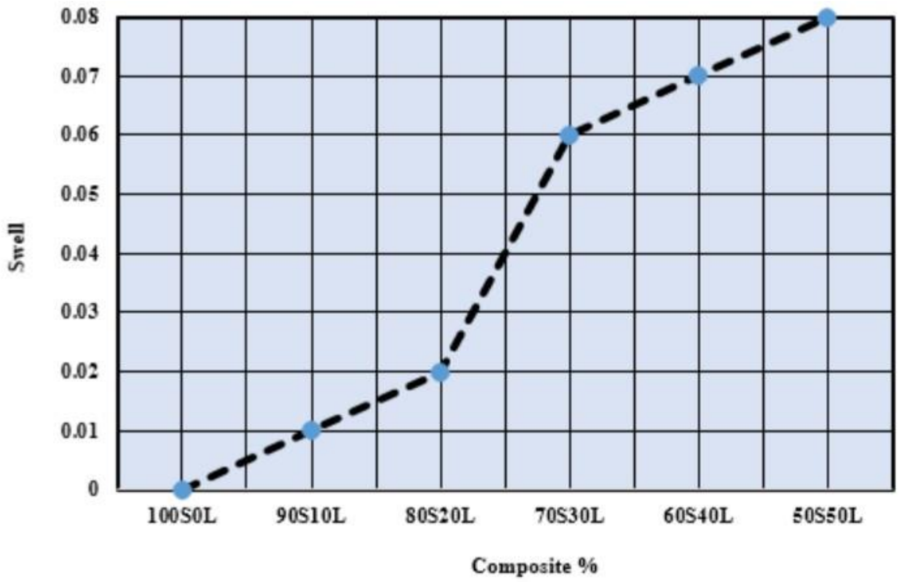

Figure 5.10 Plot of Swell of Composite Material

5.5.2 CBR values of the Composite Materials

The effect of the laterite on the CBR values of the composites are presented in graphical form in Figure 5.11, the results shows variations in the CBR values with the various composites. It can also be observed that, the unsoaked CBR values are higher than the soaked CBR. The composites 70S30L recorded the highest soaked and unsoaked CBR values. This results is expected because it recorded the highest MDD for the compaction tests. Based on the results and the MoT Standards, the composite 70S30L can be used as a subbase material for road construction.

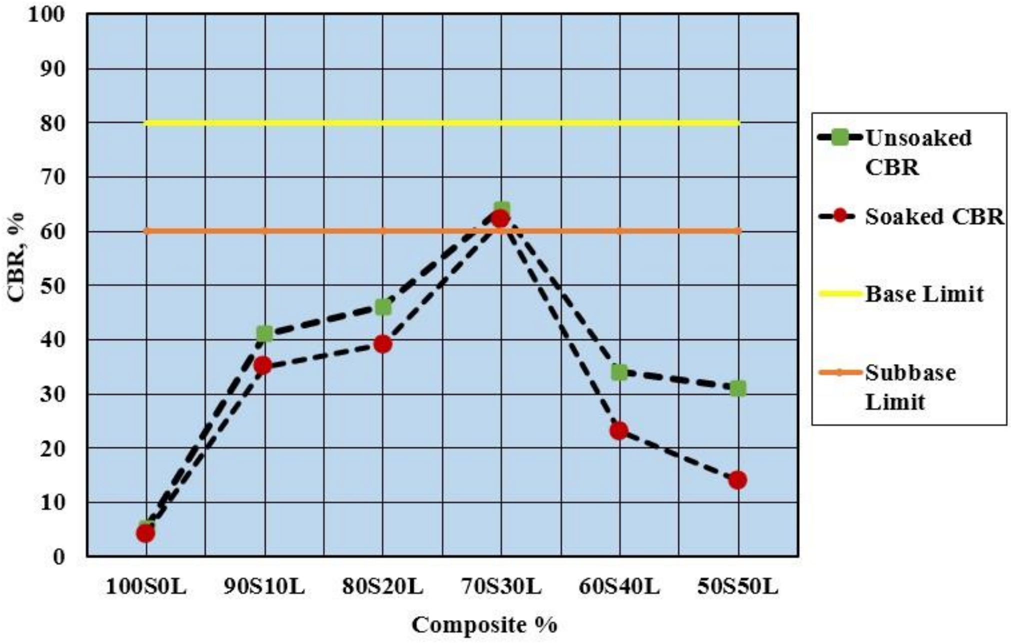

Figure 5.11 Plot of CBR of Composite Material

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the laboratory tests conducted on the raw and composite materials the following conclusions and recommendation have been formulated.

1. The spent ore consists predominantly of sand and gravel with minor silt content. The spent ore is non-plastic with a specific gravity of 2.7.
2. The soaked and unsoaked CBR value of the spent ore are 5.2% and 4.1% respectively, the spent ore does not meet the requirements for base and subbase material as specified by the MoT standards.
3. The chemical analysis of the spent ore showed that, cyanide content ranged from 0.14 – 0.30 mg/L. The residual cyanide content is below the maximum allowable content of 40 mg/kg per international best practices. The spent ore is free from deleterious materials.
4. The laterite is made up of predominantly of silt and clay with some sand. The liquid limit (LL) is 42% with a Plasticity Index (PI) of 25%. This is classified as clayey soils with low plasticity on the plasticity chart.
5. The Atterberg Limit tests conducted on the composite materials show a general increase in the LL, PL and the PI with increasing percentage of the laterite. The results show that addition of laterite from 10% to 20% resulted in LL between 20% and 22%. The values are within the specifications for the MoT standards for base and subbase materials.
6. The compaction test on the composite materials resulted in MDD between 1.3 g/cm^3 and 2.01g/cm^3. The composite material 70S30L recorded the highest MDD of 2.01g/cm^3.
7. The soaked CBR values of the composite material were between 32% and 62%, the unsoaked values were between 31% and 64%. The composite 70S30L recorded the highest soaked and unsoaked CBR value of 62% and 64%.

8. Combination of 70% of the spent ore and 30% of the laterite would produce a composite material that can be used as subbase material for road construction.

6.2 Recommendations

1. Since the results of the studies indicated that, the composites did not meet the requirement for base material, it is recommended that, further research is conducted on the improvement of spent ore for base construction. The possibility of using other additives can be investigated.

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APPENDICE

APPENDIX A

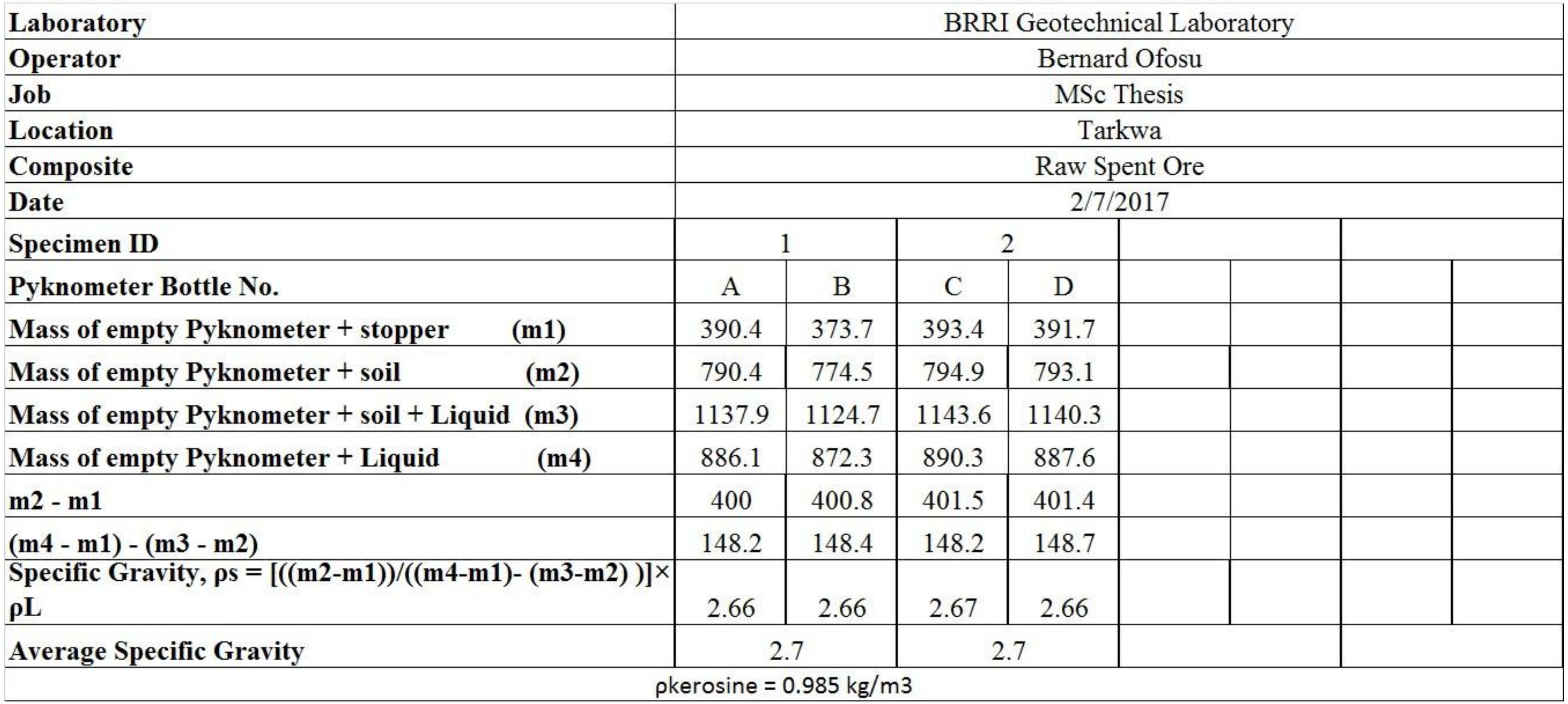
PHYSICAL PROPERTIES OF SPENT ORE

LABORATORY DATA AND GRAPHS

MOISTURE CONTENT (SPENT ORE)

Laboratory					BRRI Geotechnical Laboratory				
Operator					Bernard Ofosu				
Job					MSc Thesis				
Location					Tarkwa				
Composite					Spent Ore				
Date					**02/07/2017**				
Container No.	342		987						
Mass of wet soil + Container, W1, (g)	102.8	84	83.2	108.3					
Mass of dry soil + Container, W2, (g)	96.5	78	78.5	100.6					
Mass of Container, W3, (g)	10.5	16.7	16.5	9.3					
Mass of Moisture, W4 = W1-W2, (g)	6.3	6	4.7	7.7					
Mass of dry soil, W5 = W2-W3, (g)	86	61.3	62	91.3					
Moisture Content, [(W4/W5)*100], (%)	7.325581	9.787928	7.580645	8.433735					
Ave. Moisture Content	**8.30**								

SPECIFIC GRAVITY (SPENT ORE)



Laboratory	BRRI Geotechnical Laboratory							
Operator	Bernard Ofosu							
Job	MSc Thesis							
Location	Tarkwa							
Composite	Raw Spent Ore							
Date	2/7/2017							
Specimen ID	1		2					
Pyknometer Bottle No.	A	B	C	D				
Mass of empty Pyknometer + stopper (m1)	390.4	373.7	393.4	391.7				
Mass of empty Pyknometer + soil (m2)	790.4	774.5	794.9	793.1				
Mass of empty Pyknometer + soil + Liquid (m3)	1137.9	1124.7	1143.6	1140.3				
Mass of empty Pyknometer + Liquid (m4)	886.1	872.3	890.3	887.6				
m2 - m1	400	400.8	401.5	401.4				
(m4 - m1) - (m3 - m2)	148.2	148.4	148.2	148.7				
Specific Gravity, ρs = [((m2-m1))/((m4-m1)- (m3-m2))]× ρL	2.66	2.66	2.67	2.66				
Average Specific Gravity	2.7		2.7					
ρkerosine = 0.985 kg/m3								

PARTICLE SIZE DISTRIBUTION

APPENDIX B

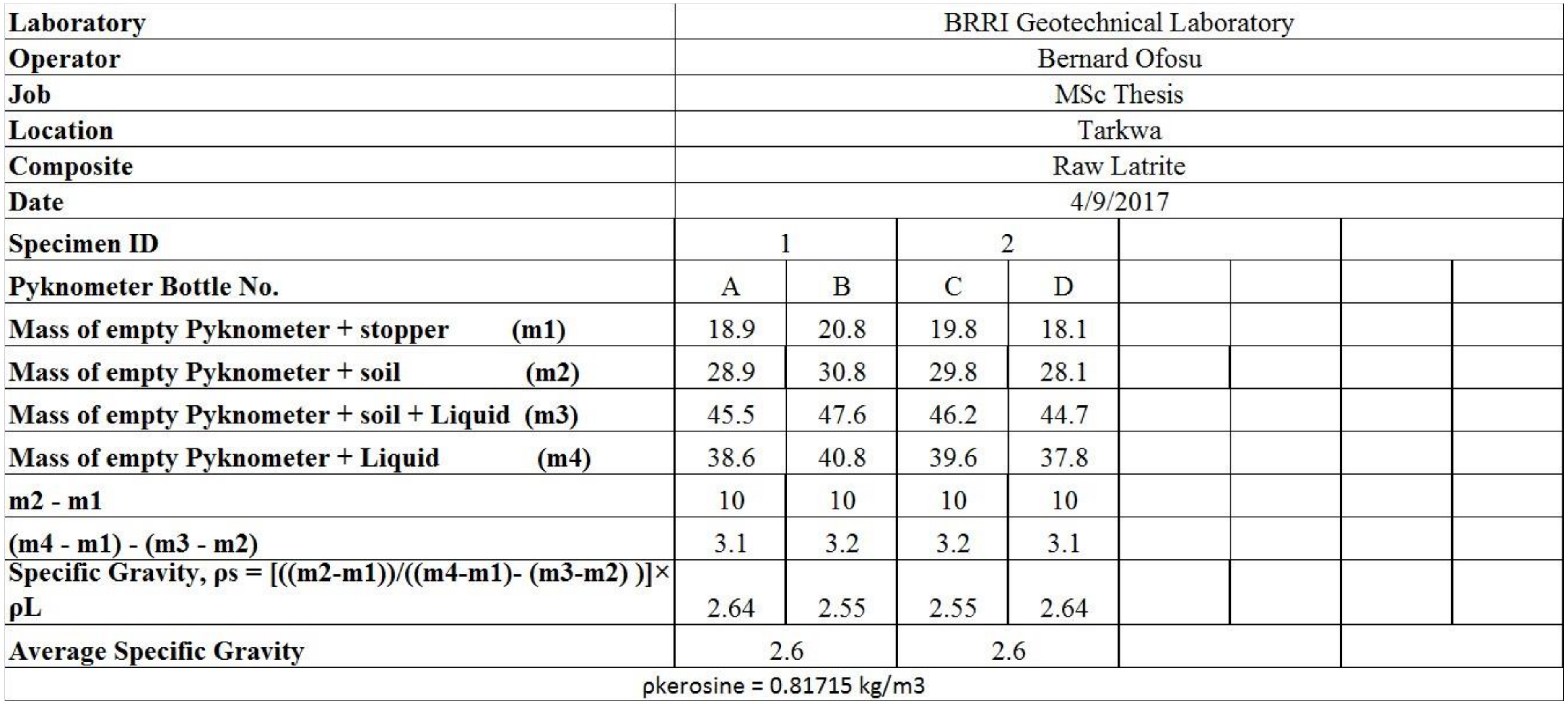
PHYSICAL PROPERTIES OF LATERITE

LABORATORY DATA AND GRAPHS

MOISTURE CONTENT (RAW LATERITE)

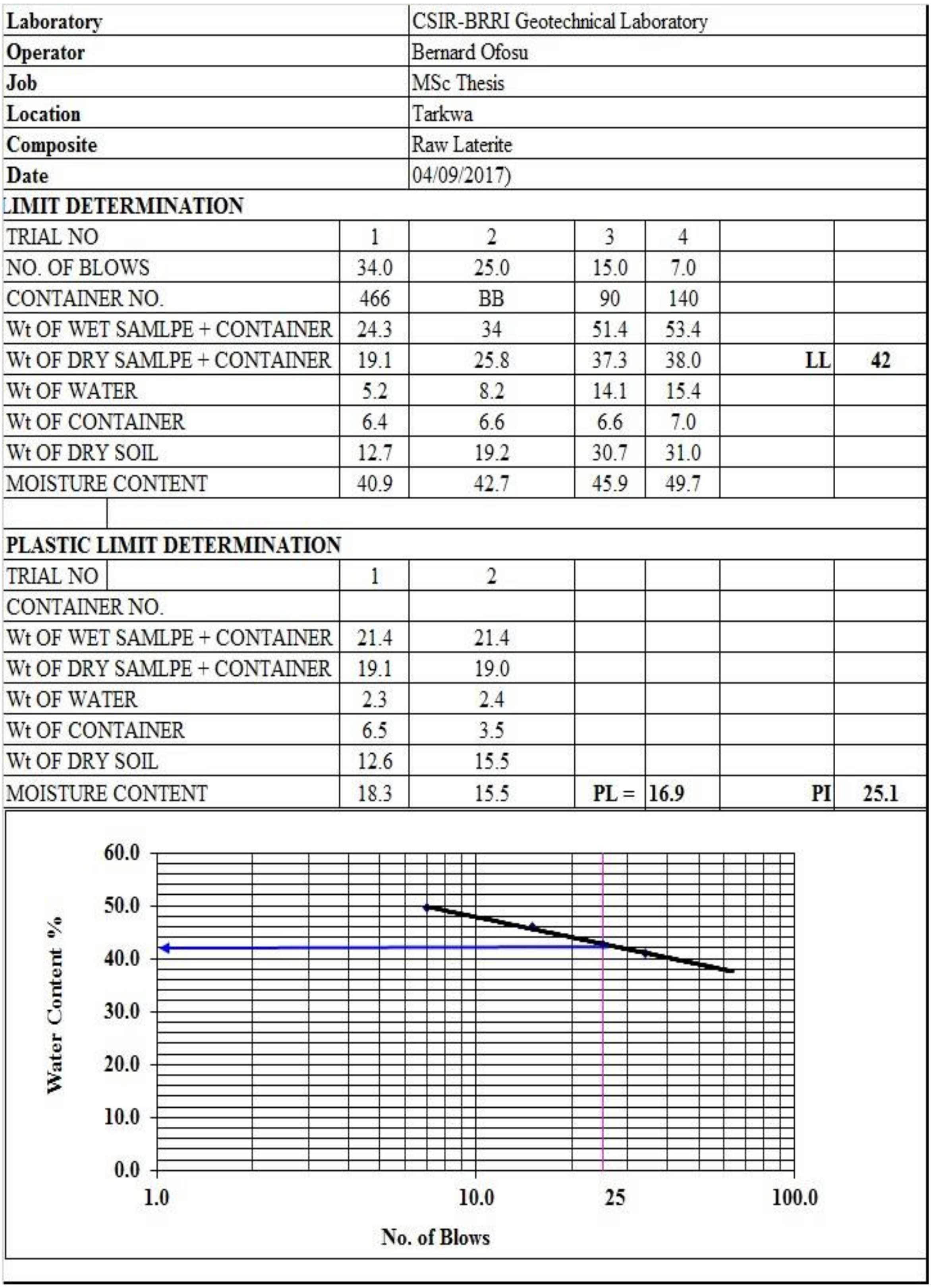
Laboratory					BRRI Geotechnical Laboratory				
Operator					Bernard Ofosu				
Job					MSc Thesis				
Location					Tarkwa				
Composite					Raw Laterite				
Date					04/09/2017				
Container No.	124		147						
Mass of wet soil + Container, W1, (g)	115	114.5	116	115.8					
Mass of dry soil + Container, W2, (g)	98.5	97.8	100	99.5					
Mass of Container, W3, (g)	10.5	11	12	10.9					
Mass of Moisture, W4 = W1-W2, (g)	16.5	16.7	16	16.3					
Mass of dry soil, W5 = W2-W3, (g)	88	86.8	88	88.6					
Moisture Content, [(W4/W5)*100], (%)	18.75	19.23963	18.18182	18.39729					
Ave. Moisture Content	**18.6**								

SPECIFIC GRAVITY



Laboratory	BRRI Geotechnical Laboratory							
Operator	Bernard Ofosu							
Job	MSc Thesis							
Location	Tarkwa							
Composite	Raw Latrite							
Date	4/9/2017							
Specimen ID	1		2					
Pyknometer Bottle No.	A	B	C	D				
Mass of empty Pyknometer + stopper (m1)	18.9	20.8	19.8	18.1				
Mass of empty Pyknometer + soil (m2)	28.9	30.8	29.8	28.1				
Mass of empty Pyknometer + soil + Liquid (m3)	45.5	47.6	46.2	44.7				
Mass of empty Pyknometer + Liquid (m4)	38.6	40.8	39.6	37.8				
m2 - m1	10	10	10	10				
(m4 - m1) - (m3 - m2)	3.1	3.2	3.2	3.1				
Specific Gravity, ρs = [((m2-m1))/((m4-m1)- (m3-m2))]× ρL	2.64	2.55	2.55	2.64				
Average Specific Gravity	2.6		2.6					
ρkerosine = 0.81715 kg/m3								

ATTERBERG LIMITS (RAW LATERITE)



Laboratory	CSIR-BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	Raw Laterite
Date	04/09/2017)

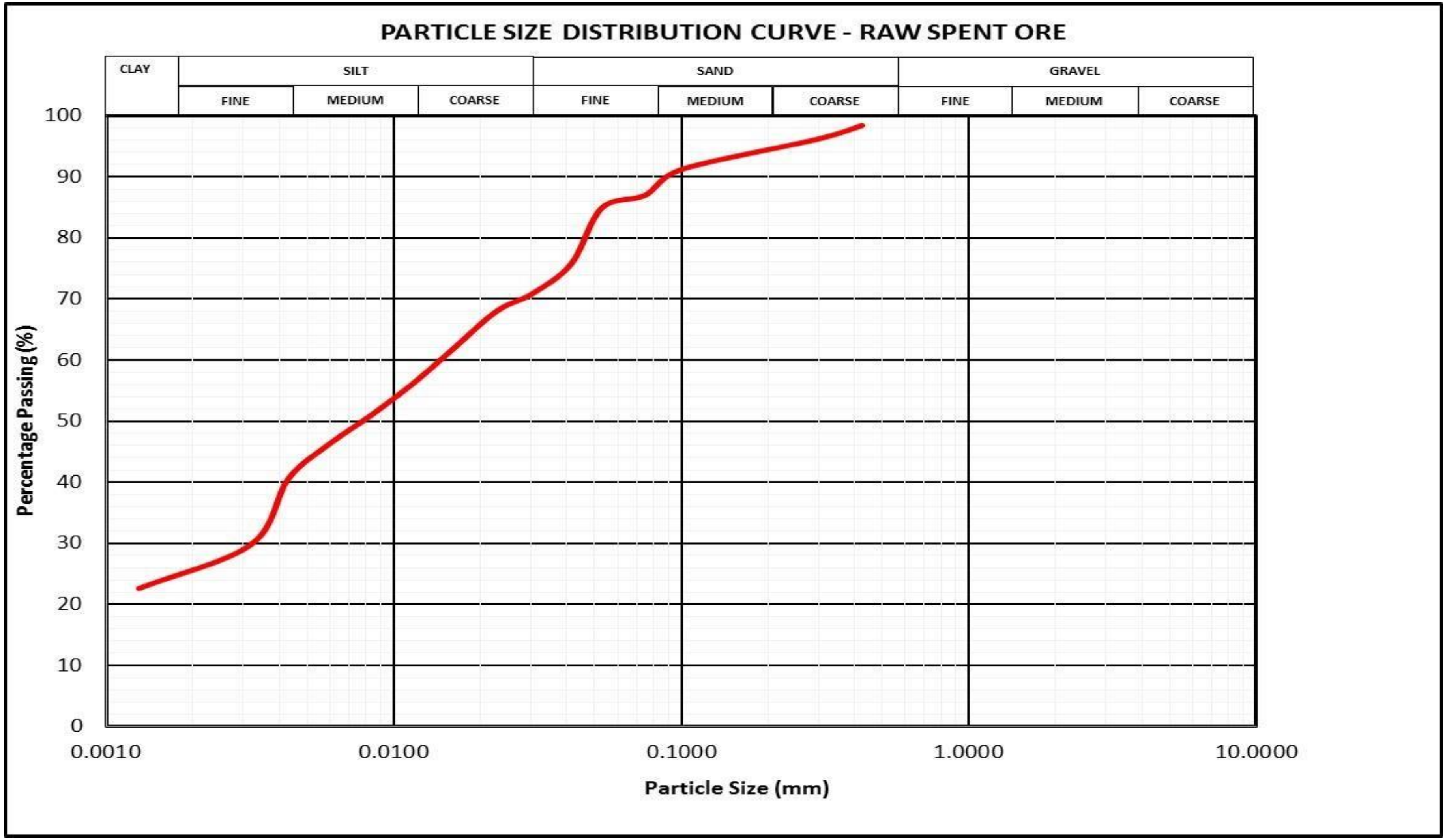
LIMIT DETERMINATION

TRIAL NO	1	2	3	4		
NO. OF BLOWS	34.0	25.0	15.0	7.0		
CONTAINER NO.	466	BB	90	140		
Wt OF WET SAMLPE + CONTAINER	24.3	34	51.4	53.4		
Wt OF DRY SAMLPE + CONTAINER	19.1	25.8	37.3	38.0	**LL**	**42**
Wt OF WATER	5.2	8.2	14.1	15.4		
Wt OF CONTAINER	6.4	6.6	6.6	7.0		
Wt OF DRY SOIL	12.7	19.2	30.7	31.0		
MOISTURE CONTENT	40.9	42.7	45.9	49.7		

PLASTIC LIMIT DETERMINATION

TRIAL NO	1	2				
CONTAINER NO.						
Wt OF WET SAMLPE + CONTAINER	21.4	21.4				
Wt OF DRY SAMLPE + CONTAINER	19.1	19.0				
Wt OF WATER	2.3	2.4				
Wt OF CONTAINER	6.5	3.5				
Wt OF DRY SOIL	12.6	15.5				
MOISTURE CONTENT	18.3	15.5	**PL =**	**16.9**	**PI**	**25.1**

PARTICLE SIZE DISTRIBUTION (RAW LATERITE)

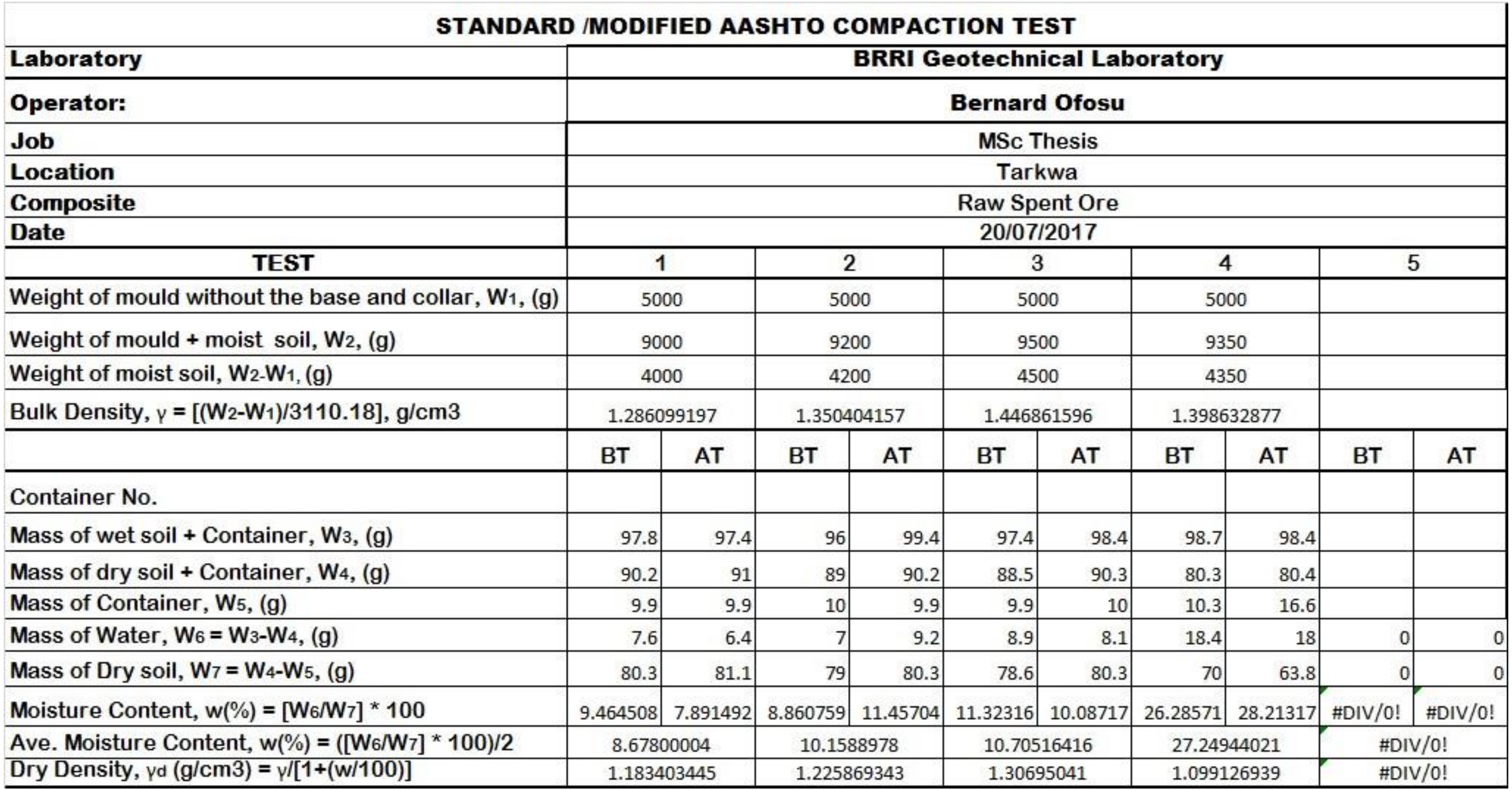


APPENDIX C

ENGINEERING PROPERTIES OF SPENT ORE

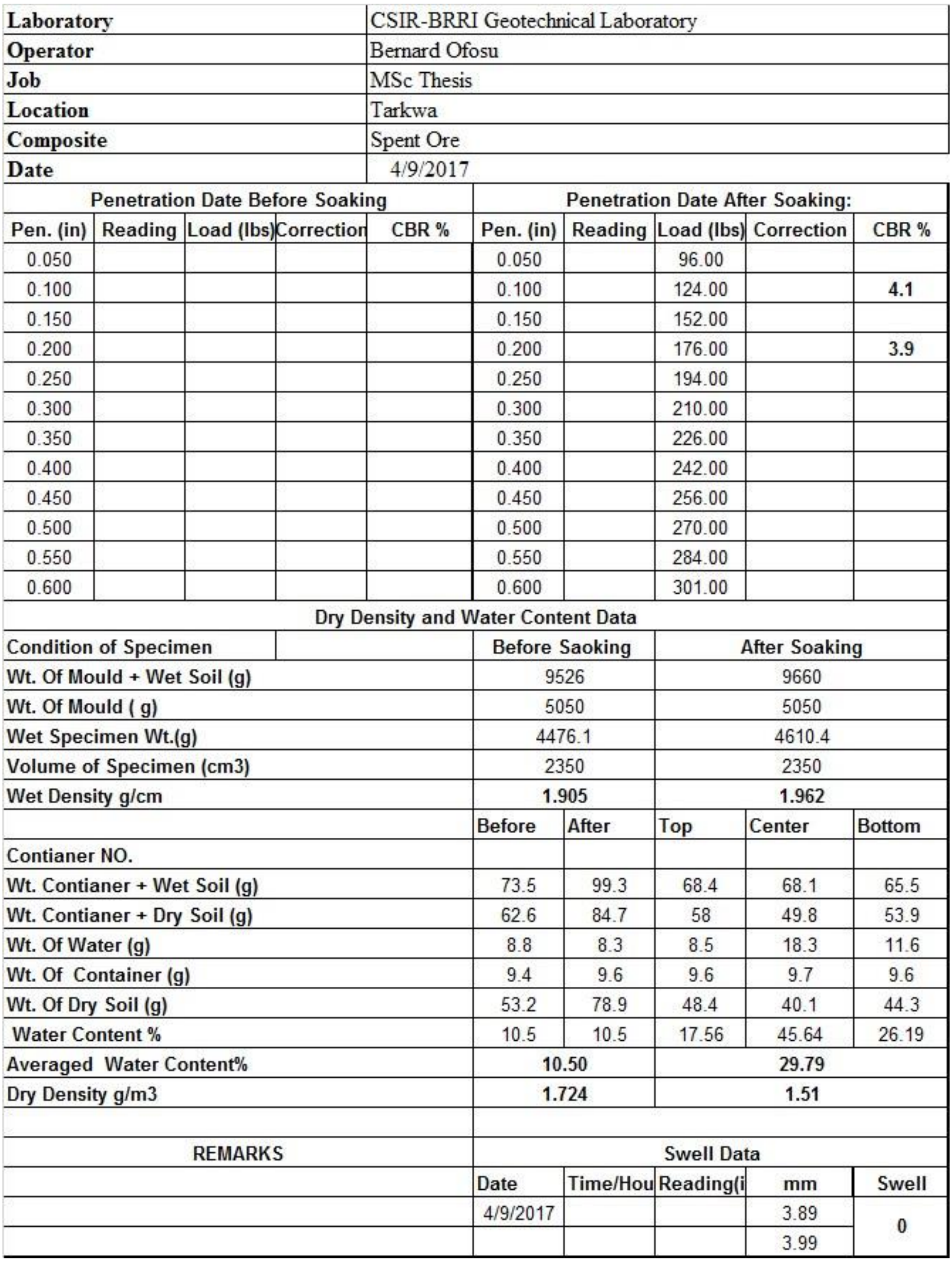
LABORATORY DATA AND GRAPHS

COMPACTION (SPENT ORE)



STANDARD /MODIFIED AASHTO COMPACTION TEST										
Laboratory	**BRRI Geotechnical Laboratory**									
Operator:	**Bernard Ofosu**									
Job	MSc Thesis									
Location	Tarkwa									
Composite	Raw Spent Ore									
Date	20/07/2017									
TEST	1		2		3		4		5	
Weight of mould without the base and collar, W_1, (g)	5000		5000		5000		5000			
Weight of mould + moist soil, W_2, (g)	9000		9200		9500		9350			
Weight of moist soil, W_2-W_1, (g)	4000		4200		4500		4350			
Bulk Density, $\gamma = [(W_2-W_1)/3110.18]$, g/cm3	1.286099197		1.350404157		1.446861596		1.398632877			
	BT	AT	BT	AT	BT	AT	BT	AT	BT	AT
Container No.										
Mass of wet soil + Container, W_3, (g)	97.8	97.4	96	99.4	97.4	98.4	98.7	98.4		
Mass of dry soil + Container, W_4, (g)	90.2	91	89	90.2	88.5	90.3	80.3	80.4		
Mass of Container, W_5, (g)	9.9	9.9	10	9.9	9.9	10	10.3	16.6		
Mass of Water, $W_6 = W_3-W_4$, (g)	7.6	6.4	7	9.2	8.9	8.1	18.4	18	0	0
Mass of Dry soil, $W_7 = W_4-W_5$, (g)	80.3	81.1	79	80.3	78.6	80.3	70	63.8	0	0
Moisture Content, $w(\%) = [W_6/W_7] * 100$	9.464508	7.891492	8.860759	11.45704	11.32316	10.08717	26.28571	28.21317	#DIV/0!	#DIV/0!
Ave. Moisture Content, $w(\%) = ([W_6/W_7] * 100)/2$	8.67800004		10.1588978		10.70516416		27.24944021		#DIV/0!	
Dry Density, γ_d (g/cm3) = $\gamma/[1+(w/100)]$	1.183403445		1.225869343		1.30695041		1.099126939		#DIV/0!	

CBR (SPENT ORE



Laboratory	CSIR-BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	Spent Ore
Date	4/9/2017

Penetration Date Before Soaking					Penetration Date After Soaking:				
Pen. (in)	Reading	Load (lbs)	Correction	CBR %	Pen. (in)	Reading	Load (lbs)	Correction	CBR %
0.050					0.050		96.00		
0.100					0.100		124.00		**4.1**
0.150					0.150		152.00		
0.200					0.200		176.00		**3.9**
0.250					0.250		194.00		
0.300					0.300		210.00		
0.350					0.350		226.00		
0.400					0.400		242.00		
0.450					0.450		256.00		
0.500					0.500		270.00		
0.550					0.550		284.00		
0.600					0.600		301.00		

Dry Density and Water Content Data

Condition of Specimen	Before Saoking	After Soaking
Wt. Of Mould + Wet Soil (g)	9526	9660
Wt. Of Mould (g)	5050	5050
Wet Specimen Wt.(g)	4476.1	4610.4
Volume of Specimen (cm3)	2350	2350
Wet Density g/cm	**1.905**	**1.962**

	Before	After	Top	Center	Bottom
Contianer NO.					
Wt. Contianer + Wet Soil (g)	73.5	99.3	68.4	68.1	65.5
Wt. Contianer + Dry Soil (g)	62.6	84.7	58	49.8	53.9
Wt. Of Water (g)	8.8	8.3	8.5	18.3	11.6
Wt. Of Container (g)	9.4	9.6	9.6	9.7	9.6
Wt. Of Dry Soil (g)	53.2	78.9	48.4	40.1	44.3
Water Content %	10.5	10.5	17.56	45.64	26.19
Averaged Water Content%	**10.50**		**29.79**		
Dry Density g/m3	**1.724**		**1.51**		

REMARKS	Swell Data				
	Date	Time/Hou	Reading(i	mm	Swell
	4/9/2017			3.89	**0**
				3.99	

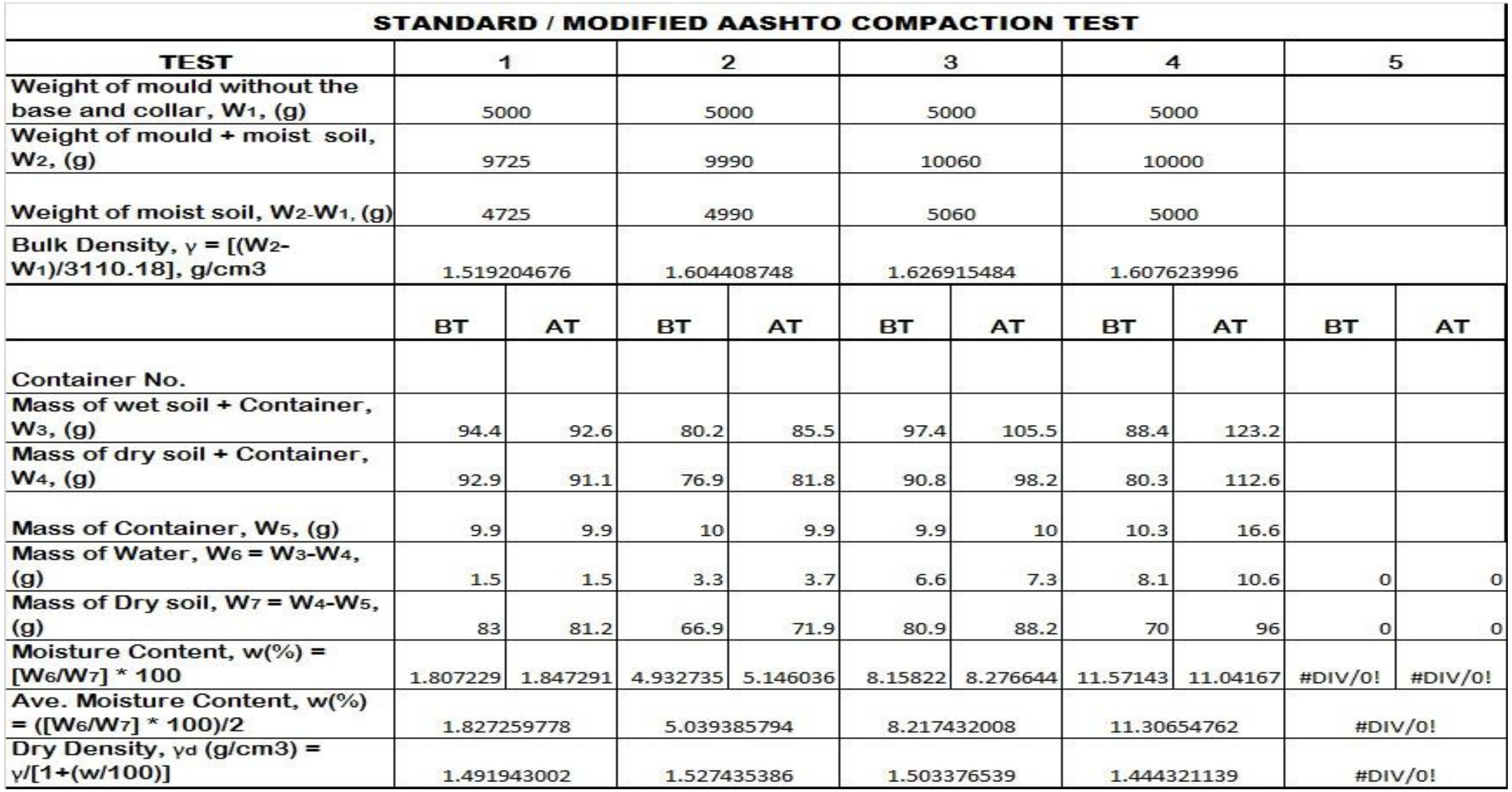
)

APPENDIX D

ENGINEERING PROPERTIES OF LATERITE

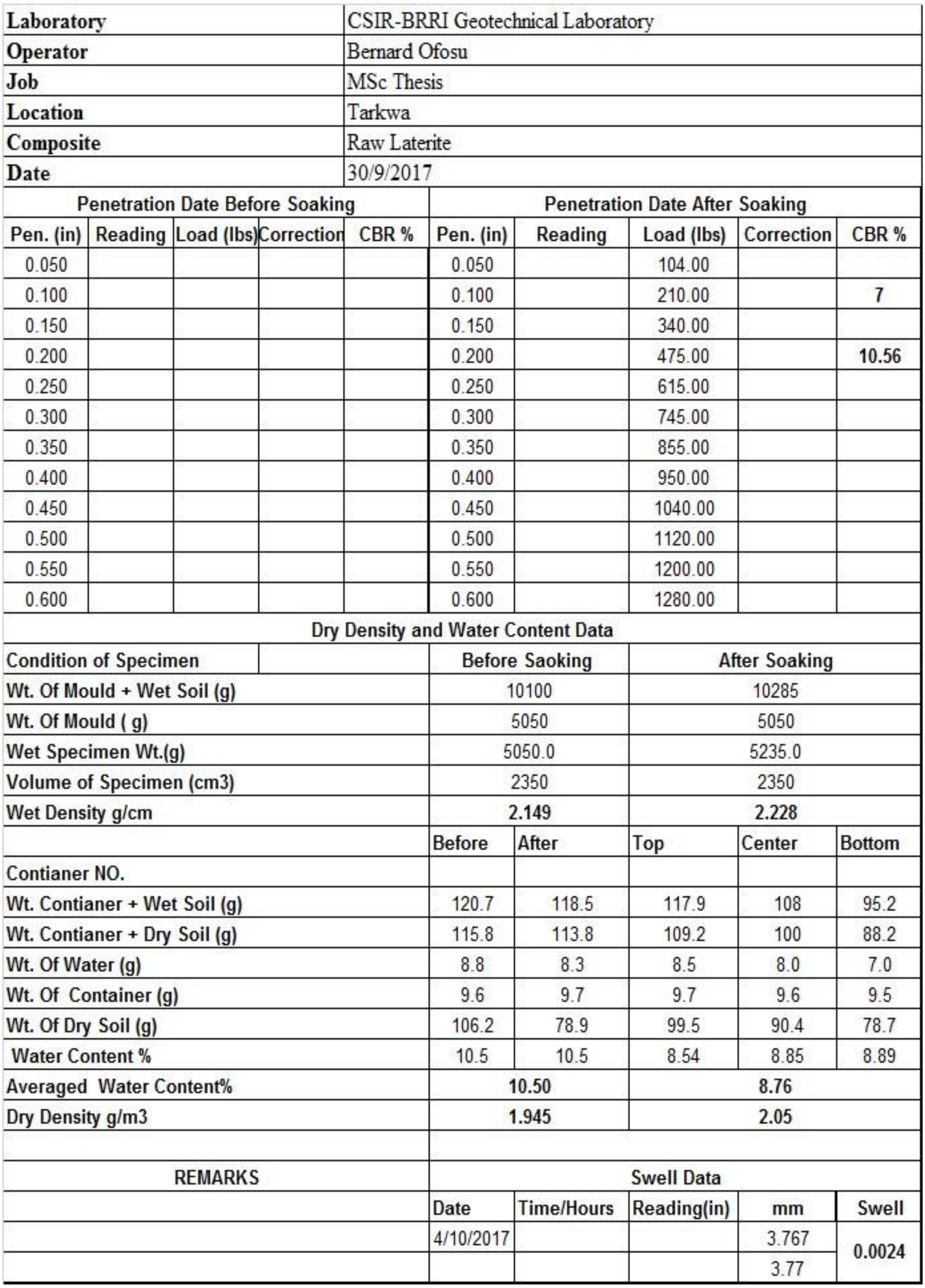
LABORATORY DATA AND GRAPHS

COMPACTION (RAW LATERITE)



STANDARD / MODIFIED AASHTO COMPACTION TEST										
TEST	**1**		**2**		**3**		**4**		**5**	
Weight of mould without the base and collar, W_1, (g)	5000		5000		5000		5000			
Weight of mould + moist soil, W_2, (g)	9725		9990		10060		10000			
Weight of moist soil, W_2-W_1, (g)	4725		4990		5060		5000			
Bulk Density, $\gamma = [(W_2-W_1)/3110.18]$, g/cm3	1.519204676		1.604408748		1.626915484		1.607623996			
	BT	**AT**	**BT**	**AT**	**BT**	**AT**	**BT**	**AT**	**BT**	**AT**
Container No.										
Mass of wet soil + Container, W_3, (g)	94.4	92.6	80.2	85.5	97.4	105.5	88.4	123.2		
Mass of dry soil + Container, W_4, (g)	92.9	91.1	76.9	81.8	90.8	98.2	80.3	112.6		
Mass of Container, W_5, (g)	9.9	9.9	10	9.9	9.9	10	10.3	16.6		
Mass of Water, $W_6 = W_3$-W_4, (g)	1.5	1.5	3.3	3.7	6.6	7.3	8.1	10.6	0	0
Mass of Dry soil, $W_7 = W_4$-W_5, (g)	83	81.2	66.9	71.9	80.9	88.2	70	96	0	0
Moisture Content, w(%) = $[W_6/W_7]$ * 100	1.807229	1.847291	4.932735	5.146036	8.15822	8.276644	11.57143	11.04167	#DIV/0!	#DIV/0!
Ave. Moisture Content, w(%) = $([W_6/W_7]$ * 100)/2	1.827259778		5.039385794		8.217432008		11.30654762		#DIV/0!	
Dry Density, γ_d (g/cm3) = $\gamma/[1+(w/100)]$	1.491943002		1.527435386		1.503376539		1.444321139		#DIV/0!	

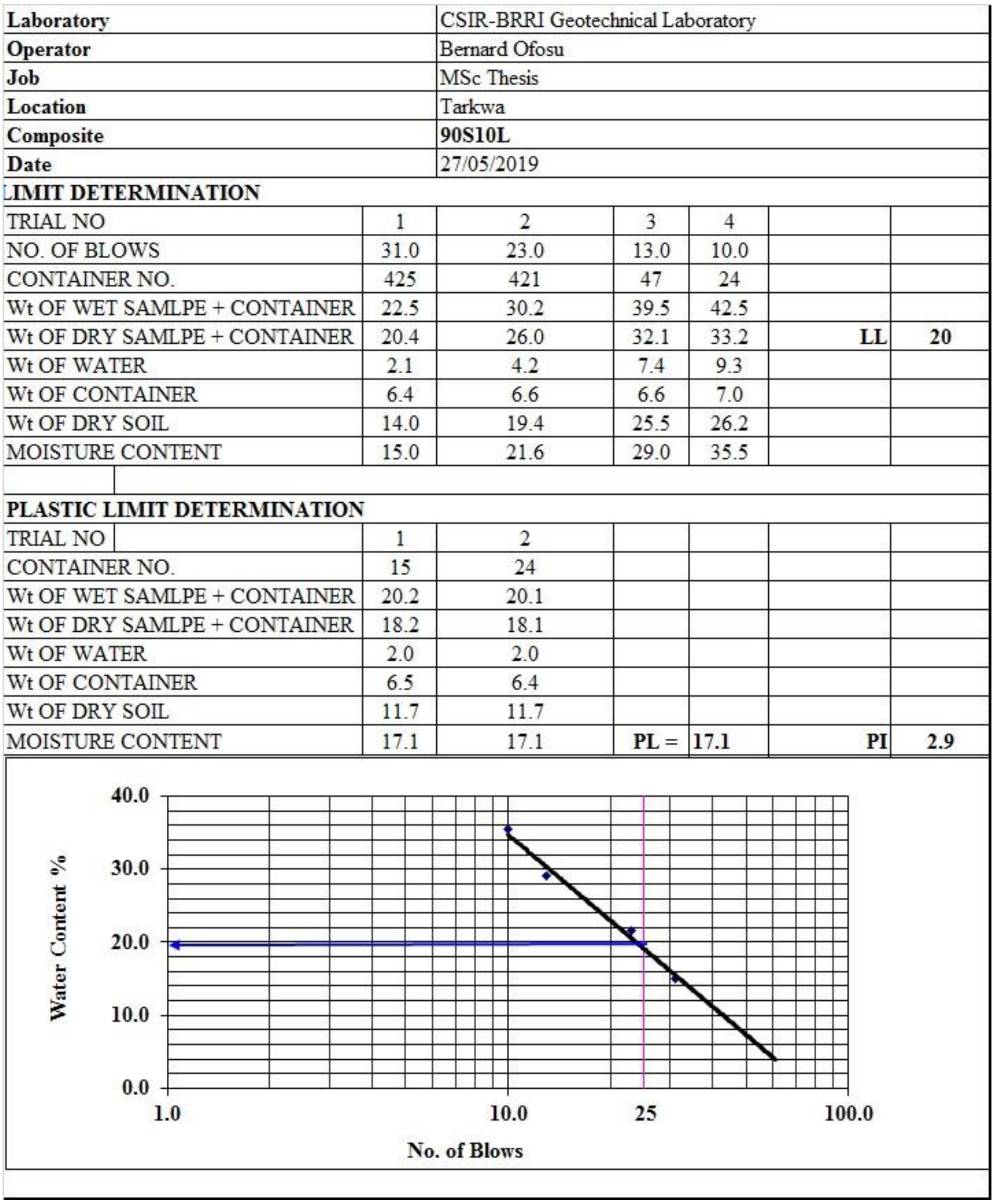
CBR (RAW LATERITE)



Laboratory	CSIR-BRRI Geotechnical Laboratory								
Operator	Bernard Ofosu								
Job	MSc Thesis								
Location	Tarkwa								
Composite	Raw Laterite								
Date	30/9/2017								
Penetration Date Before Soaking					Penetration Date After Soaking				
Pen. (in)	Reading	Load (lbs)	Correction	CBR %	Pen. (in)	Reading	Load (lbs)	Correction	CBR %
0.050					0.050		104.00		
0.100					0.100		210.00		**7**
0.150					0.150		340.00		
0.200					0.200		475.00		**10.56**
0.250					0.250		615.00		
0.300					0.300		745.00		
0.350					0.350		855.00		
0.400					0.400		950.00		
0.450					0.450		1040.00		
0.500					0.500		1120.00		
0.550					0.550		1200.00		
0.600					0.600		1280.00		
Dry Density and Water Content Data									
Condition of Specimen					Before Saoking		After Soaking		
Wt. Of Mould + Wet Soil (g)					10100		10285		
Wt. Of Mould (g)					5050		5050		
Wet Specimen Wt.(g)					5050.0		5235.0		
Volume of Specimen (cm3)					2350		2350		
Wet Density g/cm					**2.149**		**2.228**		
					Before	After	Top	Center	Bottom
Contianer NO.									
Wt. Contianer + Wet Soil (g)					120.7	118.5	117.9	108	95.2
Wt. Contianer + Dry Soil (g)					115.8	113.8	109.2	100	88.2
Wt. Of Water (g)					8.8	8.3	8.5	8.0	7.0
Wt. Of Container (g)					9.6	9.7	9.7	9.6	9.5
Wt. Of Dry Soil (g)					106.2	78.9	99.5	90.4	78.7
Water Content %					10.5	10.5	8.54	8.85	8.89
Averaged Water Content%					**10.50**		**8.76**		
Dry Density g/m3					**1.945**		**2.05**		
REMARKS					Swell Data				
					Date	Time/Hours	Reading(in)	mm	Swell
					4/10/2017			3.767	**0.0024**
								3.77	

APPENDIX E

ATTERBERG LIMITS OF COMPOSITES



Laboratory	CSIR-BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	**90S10L**
Date	27/05/2019

LIMIT DETERMINATION

TRIAL NO	1	2	3	4		
NO. OF BLOWS	31.0	23.0	13.0	10.0		
CONTAINER NO.	425	421	47	24		
Wt OF WET SAMLPE + CONTAINER	22.5	30.2	39.5	42.5		
Wt OF DRY SAMLPE + CONTAINER	20.4	26.0	32.1	33.2	**LL**	**20**
Wt OF WATER	2.1	4.2	7.4	9.3		
Wt OF CONTAINER	6.4	6.6	6.6	7.0		
Wt OF DRY SOIL	14.0	19.4	25.5	26.2		
MOISTURE CONTENT	15.0	21.6	29.0	35.5		

PLASTIC LIMIT DETERMINATION

TRIAL NO	1	2				
CONTAINER NO.	15	24				
Wt OF WET SAMLPE + CONTAINER	20.2	20.1				
Wt OF DRY SAMLPE + CONTAINER	18.2	18.1				
Wt OF WATER	2.0	2.0				
Wt OF CONTAINER	6.5	6.4				
Wt OF DRY SOIL	11.7	11.7				
MOISTURE CONTENT	17.1	17.1	**PL =**	**17.1**	**PI**	**2.9**

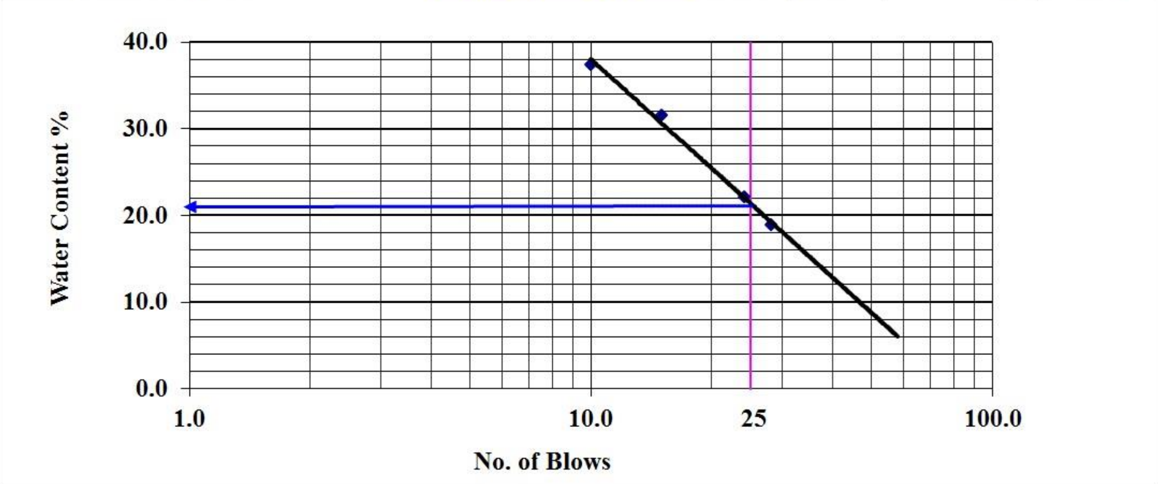
Laboratory	CSIR-BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	**80S20L**
Date	9/10/2017

LIMIT DETERMINATION

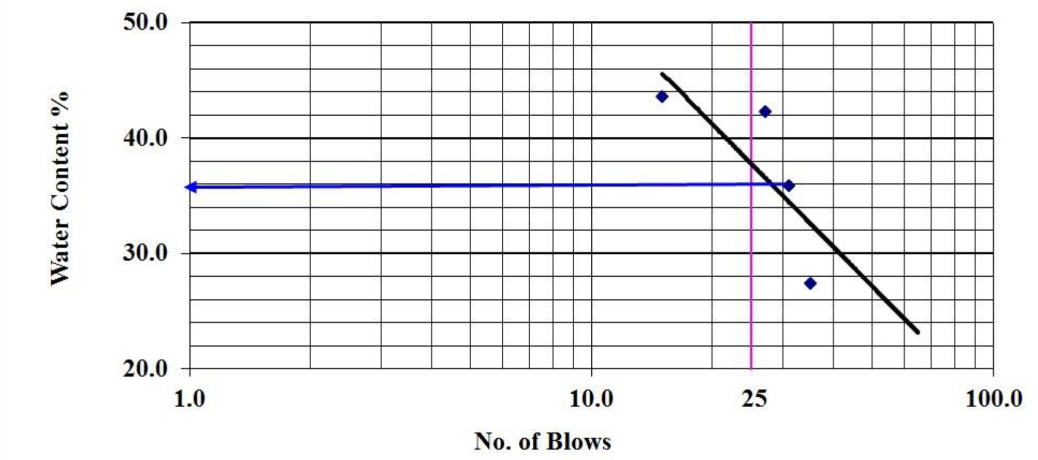
TRIAL NO	1	2	3	4		
NO. OF BLOWS	28.0	24.0	15.0	10.0		
CONTAINER NO.	18	22	102	98		
Wt OF WET SAMLPE + CONTAINER	24.2	32.1	40.2	44.5		
Wt OF DRY SAMLPE + CONTAINER	21.4	27.5	32.1	34.2	**LL**	**22**
Wt OF WATER	2.8	4.6	8.1	10.3		
Wt OF CONTAINER	6.6	6.7	6.5	6.7		
Wt OF DRY SOIL	14.8	20.8	25.6	27.5		
MOISTURE CONTENT	18.9	22.1	31.6	37.5		

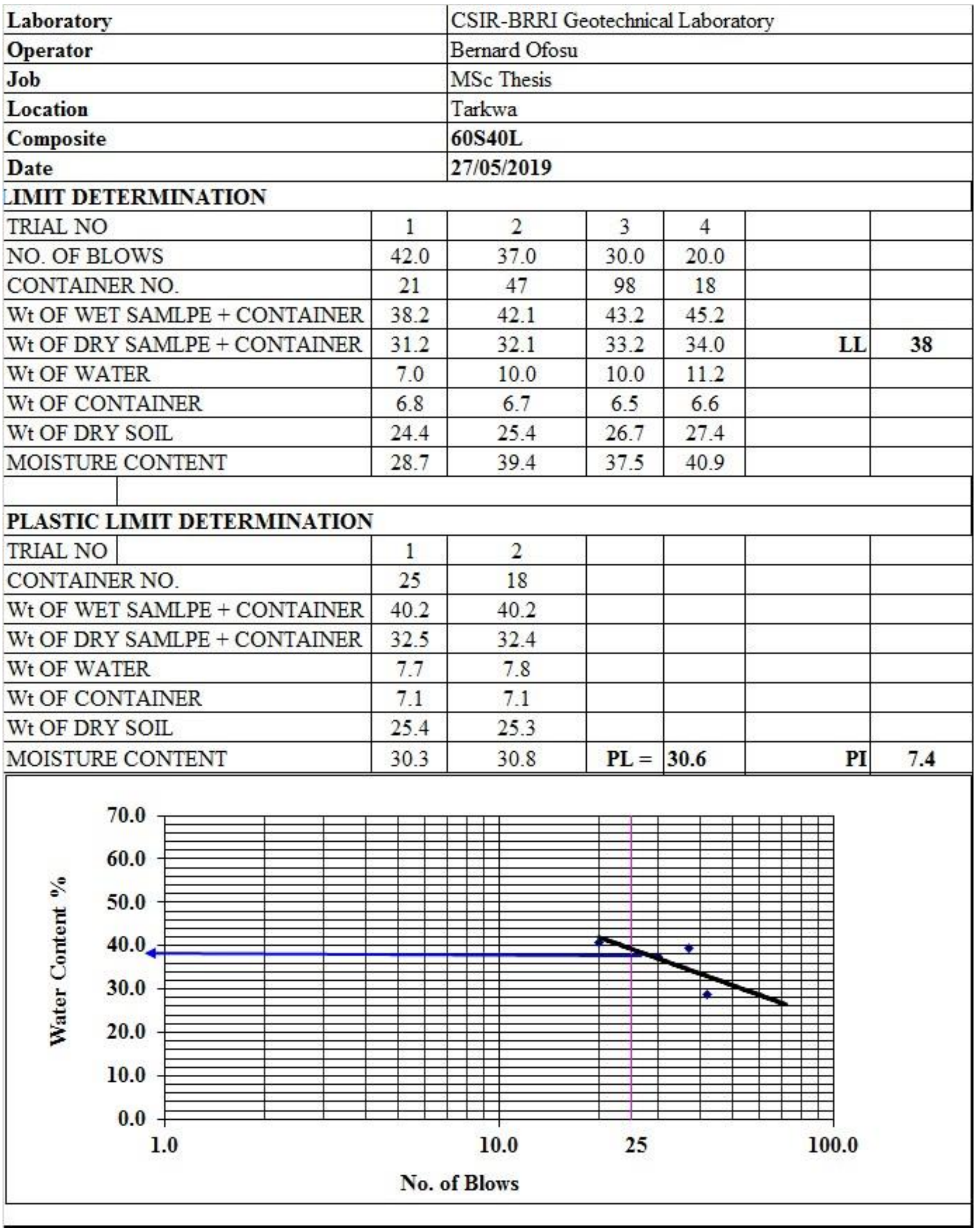
PLASTIC LIMIT DETERMINATION

TRIAL NO	1	2				
CONTAINER NO.	14	54				
Wt OF WET SAMLPE + CONTAINER	22.0	22.1				
Wt OF DRY SAMLPE + CONTAINER	19.8	19.8				
Wt OF WATER	2.2	2.3				
Wt OF CONTAINER	7.0	7.0				
Wt OF DRY SOIL	12.8	12.8				
MOISTURE CONTENT	17.2	18.0	**PL =**	**17.6**	**PI**	**4.4**



Laboratory	CSIR-BRRI Geotechnical Laboratory					
Operator	Bernard Ofosu					
Job	MSc Thesis					
Location	Tarkwa					
Composite	**70S30L**					
Date	9/10/2017					
LIMIT DETERMINATION						
TRIAL NO	1	2	3	4		
NO. OF BLOWS	35.0	31.0	27.0	15.0		
CONTAINER NO.	45	14	58	78		
Wt OF WET SAMLPE + CONTAINER	30.5	35.4	42	46.2		
Wt OF DRY SAMLPE + CONTAINER	25.4	27.8	31.5	34.2	**LL**	**36**
Wt OF WATER	5.1	7.6	10.5	12.0		
Wt OF CONTAINER	6.8	6.6	6.7	6.7		
Wt OF DRY SOIL	18.6	21.2	24.8	27.5		
MOISTURE CONTENT	27.4	35.8	42.3	43.6		
PLASTIC LIMIT DETERMINATION						
TRIAL NO	1	2				
CONTAINER NO.	48	23				
Wt OF WET SAMLPE + CONTAINER	30.5	30.5				
Wt OF DRY SAMLPE + CONTAINER	25.3	25.2				
Wt OF WATER	5.2	5.3				
Wt OF CONTAINER	7.2	7.2				
Wt OF DRY SOIL	18.1	18.0				
MOISTURE CONTENT	28.7	29.4	**PL =**	**29.1**	**PI**	**6.9**





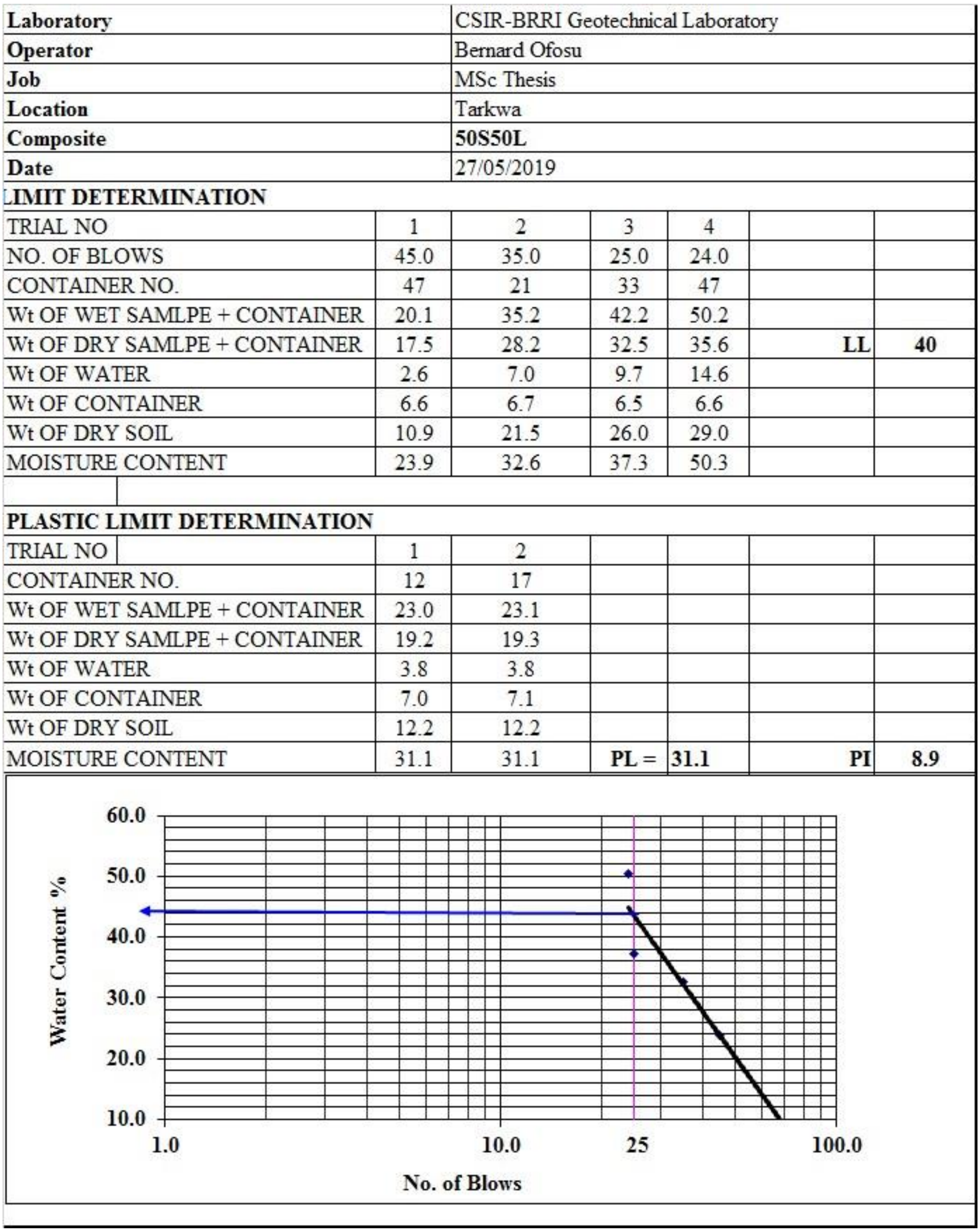
Laboratory	CSIR-BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	**60S40L**
Date	**27/05/2019**

LIMIT DETERMINATION

TRIAL NO	1	2	3	4		
NO. OF BLOWS	42.0	37.0	30.0	20.0		
CONTAINER NO.	21	47	98	18		
Wt OF WET SAMLPE + CONTAINER	38.2	42.1	43.2	45.2		
Wt OF DRY SAMLPE + CONTAINER	31.2	32.1	33.2	34.0	**LL**	**38**
Wt OF WATER	7.0	10.0	10.0	11.2		
Wt OF CONTAINER	6.8	6.7	6.5	6.6		
Wt OF DRY SOIL	24.4	25.4	26.7	27.4		
MOISTURE CONTENT	28.7	39.4	37.5	40.9		

PLASTIC LIMIT DETERMINATION

TRIAL NO	1	2				
CONTAINER NO.	25	18				
Wt OF WET SAMLPE + CONTAINER	40.2	40.2				
Wt OF DRY SAMLPE + CONTAINER	32.5	32.4				
Wt OF WATER	7.7	7.8				
Wt OF CONTAINER	7.1	7.1				
Wt OF DRY SOIL	25.4	25.3				
MOISTURE CONTENT	30.3	30.8	**PL =**	**30.6**	**PI**	7.4



Laboratory	CSIR-BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	**50S50L**
Date	27/05/2019

LIMIT DETERMINATION

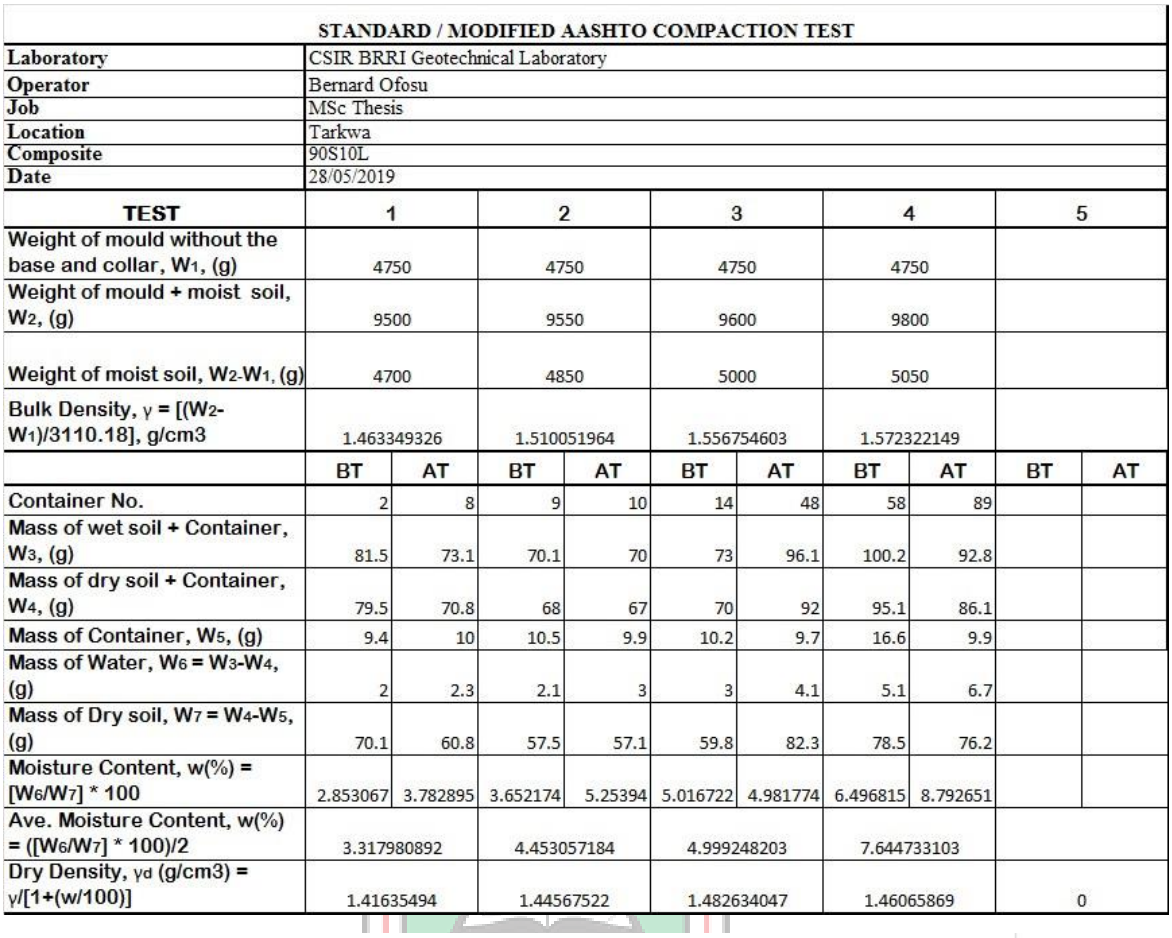
TRIAL NO	1	2	3	4		
NO. OF BLOWS	45.0	35.0	25.0	24.0		
CONTAINER NO.	47	21	33	47		
Wt OF WET SAMLPE + CONTAINER	20.1	35.2	42.2	50.2		
Wt OF DRY SAMLPE + CONTAINER	17.5	28.2	32.5	35.6	**LL**	**40**
Wt OF WATER	2.6	7.0	9.7	14.6		
Wt OF CONTAINER	6.6	6.7	6.5	6.6		
Wt OF DRY SOIL	10.9	21.5	26.0	29.0		
MOISTURE CONTENT	23.9	32.6	37.3	50.3		

PLASTIC LIMIT DETERMINATION

TRIAL NO	1	2				
CONTAINER NO.	12	17				
Wt OF WET SAMLPE + CONTAINER	23.0	23.1				
Wt OF DRY SAMLPE + CONTAINER	19.2	19.3				
Wt OF WATER	3.8	3.8				
Wt OF CONTAINER	7.0	7.1				
Wt OF DRY SOIL	12.2	12.2				
MOISTURE CONTENT	31.1	31.1	**PL =**	**31.1**	**PI**	**8.9**

APPENDIX F

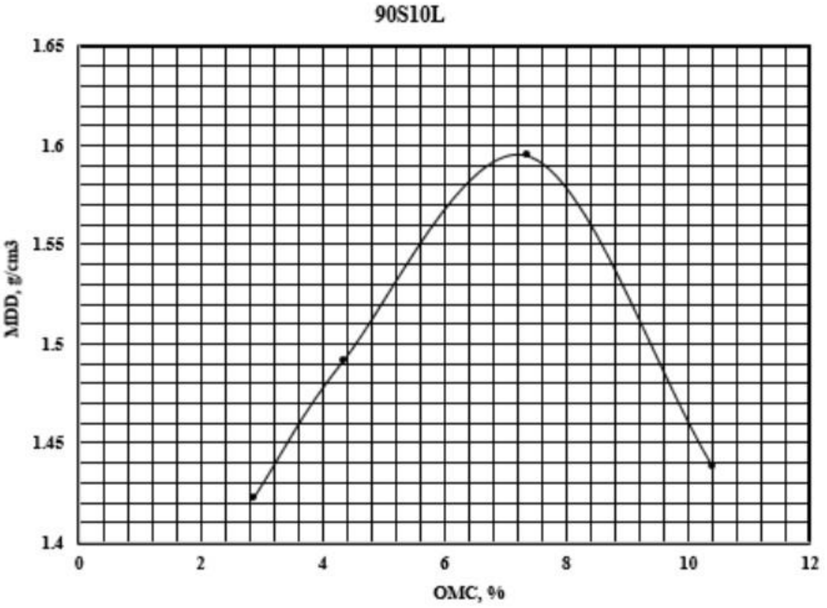
COMPACTION OF COMPOSITES

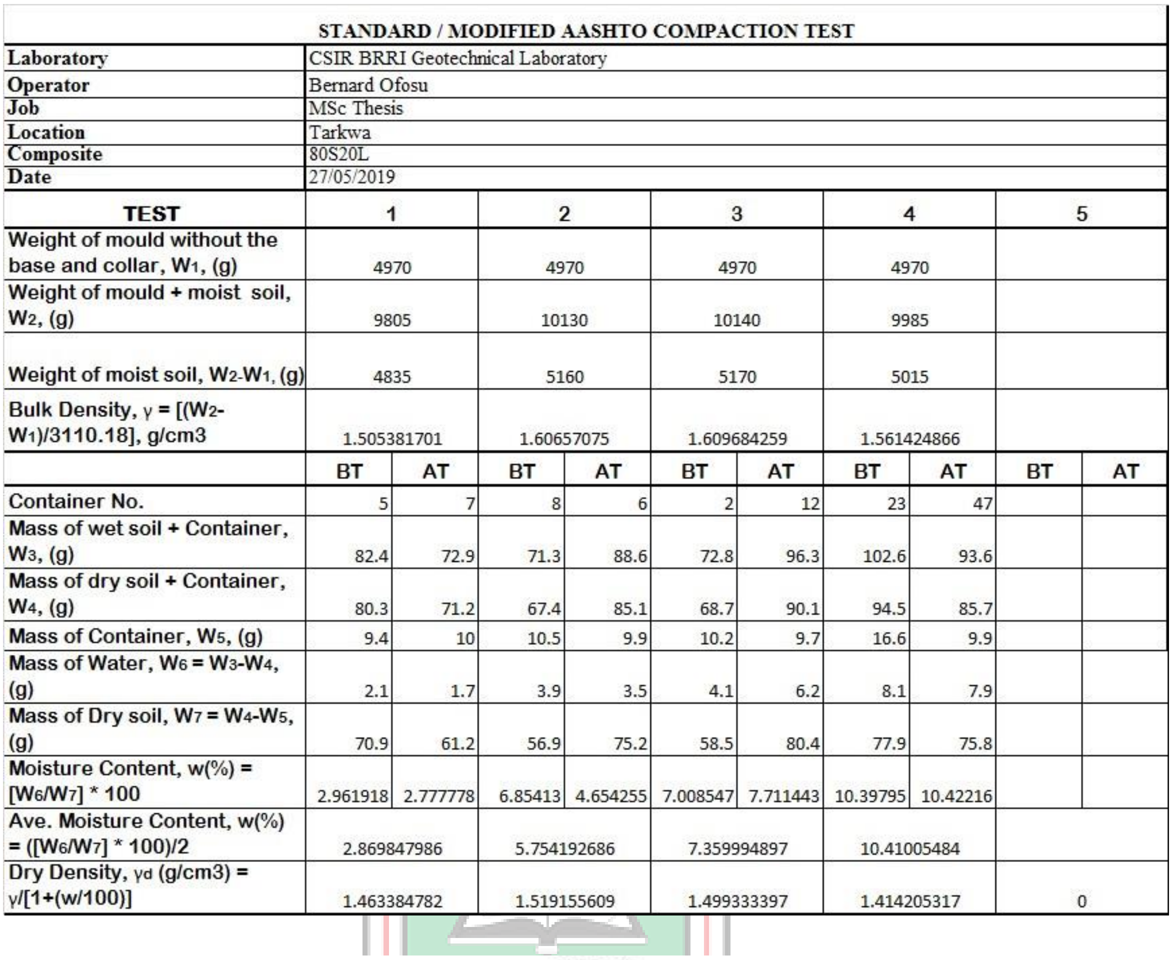


STANDARD / MODIFIED AASHTO COMPACTION TEST

Laboratory	CSIR BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	90S10L
Date	28/05/2019

TEST	1		2		3		4		5	
Weight of mould without the base and collar, W_1, (g)	4750		4750		4750		4750			
Weight of mould + moist soil, W_2, (g)	9500		9550		9600		9800			
Weight of moist soil, W_2-W_1, (g)	4700		4850		5000		5050			
Bulk Density, γ = [(W_2-W_1)/3110.18], g/cm3	1.463349326		1.510051964		1.556754603		1.572322149			
	BT	AT	BT	AT	BT	AT	BT	AT	BT	AT
Container No.	2	8	9	10	14	48	58	89		
Mass of wet soil + Container, W_3, (g)	81.5	73.1	70.1	70	73	96.1	100.2	92.8		
Mass of dry soil + Container, W_4, (g)	79.5	70.8	68	67	70	92	95.1	86.1		
Mass of Container, W_5, (g)	9.4	10	10.5	9.9	10.2	9.7	16.6	9.9		
Mass of Water, $W_6 = W_3$-W_4, (g)	2	2.3	2.1	3	3	4.1	5.1	6.7		
Mass of Dry soil, $W_7 = W_4$-W_5, (g)	70.1	60.8	57.5	57.1	59.8	82.3	78.5	76.2		
Moisture Content, w(%) = [W_6/W_7] * 100	2.853067	3.782895	3.652174	5.25394	5.016722	4.981774	6.496815	8.792651		
Ave. Moisture Content, w(%) = ([W_6/W_7] * 100)/2	3.317980892		4.453057184		4.999248203		7.644733103			
Dry Density, γ_d (g/cm3) = γ/[1+(w/100)]	1.41635494		1.44567522		1.482634047		1.46065869		0	

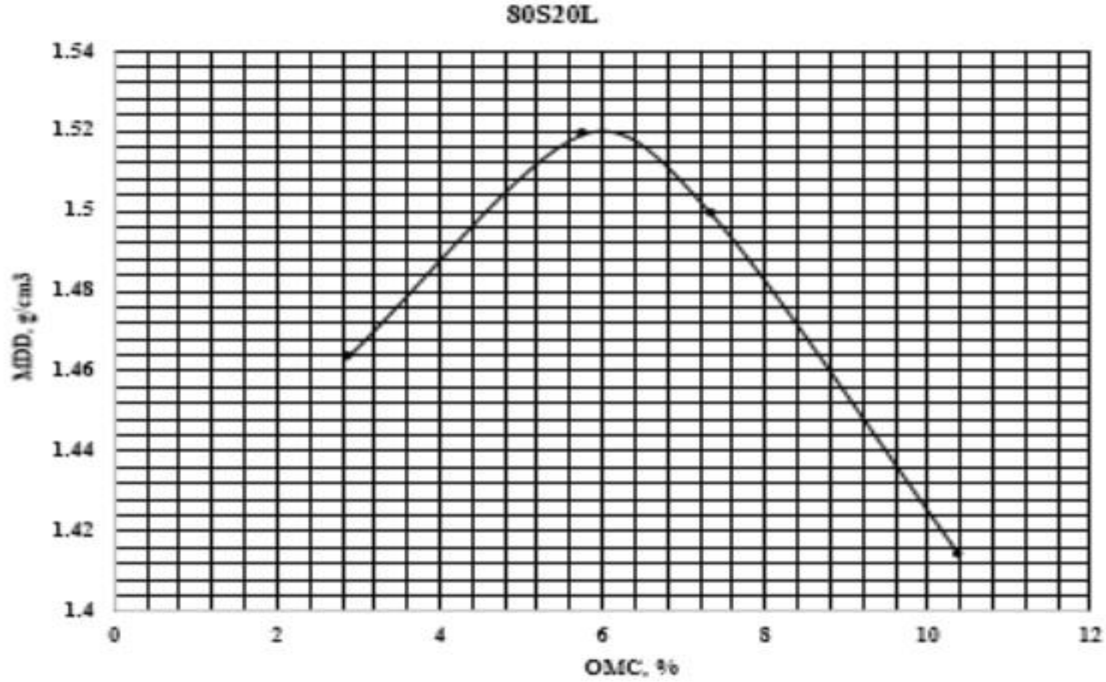




STANDARD / MODIFIED AASHTO COMPACTION TEST

Laboratory	CSIR BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	80S20L
Date	27/05/2019

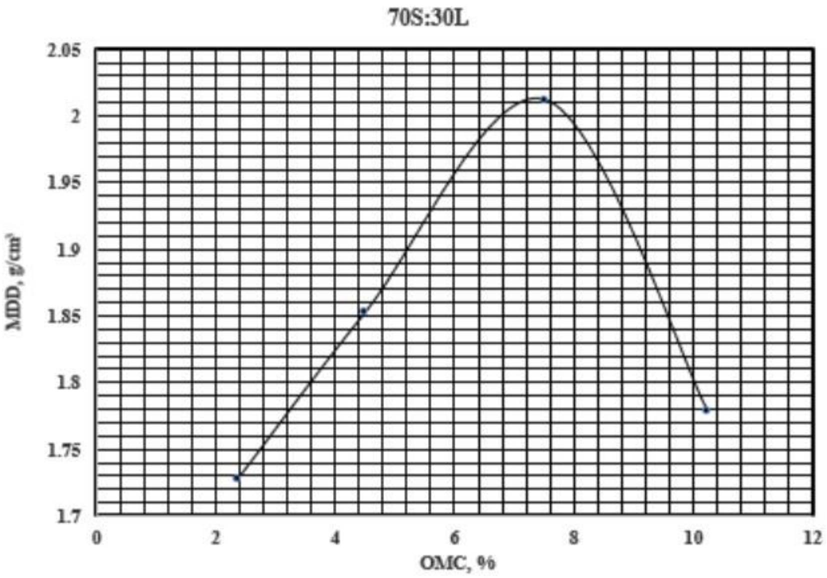
TEST	1		2		3		4		5	
Weight of mould without the base and collar, W_1, (g)	4970		4970		4970		4970			
Weight of mould + moist soil, W_2, (g)	9805		10130		10140		9985			
Weight of moist soil, W_2-W_1, (g)	4835		5160		5170		5015			
Bulk Density, γ = [(W_2-W_1)/3110.18], g/cm3	1.505381701		1.60657075		1.609684259		1.561424866			
	BT	AT	BT	AT	BT	AT	BT	AT	BT	AT
Container No.	5	7	8	6	2	12	23	47		
Mass of wet soil + Container, W_3, (g)	82.4	72.9	71.3	88.6	72.8	96.3	102.6	93.6		
Mass of dry soil + Container, W_4, (g)	80.3	71.2	67.4	85.1	68.7	90.1	94.5	85.7		
Mass of Container, W_5, (g)	9.4	10	10.5	9.9	10.2	9.7	16.6	9.9		
Mass of Water, W_6 = W_3-W_4, (g)	2.1	1.7	3.9	3.5	4.1	6.2	8.1	7.9		
Mass of Dry soil, W_7 = W_4-W_5, (g)	70.9	61.2	56.9	75.2	58.5	80.4	77.9	75.8		
Moisture Content, w(%) = [W_6/W_7] * 100	2.961918	2.777778	6.85413	4.654255	7.008547	7.711443	10.39795	10.42216		
Ave. Moisture Content, w(%) = ([W_6/W_7] * 100)/2	2.869847986		5.754192686		7.359994897		10.41005484			
Dry Density, γ_d (g/cm3) = γ/[1+(w/100)]	1.463384782		1.519155609		1.499333397		1.414205317		0	



STANDARD / MODIFIED AASHTO COMPACTION TEST

Laboratory	CSIR BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	70S30L
Date	9/10/2017

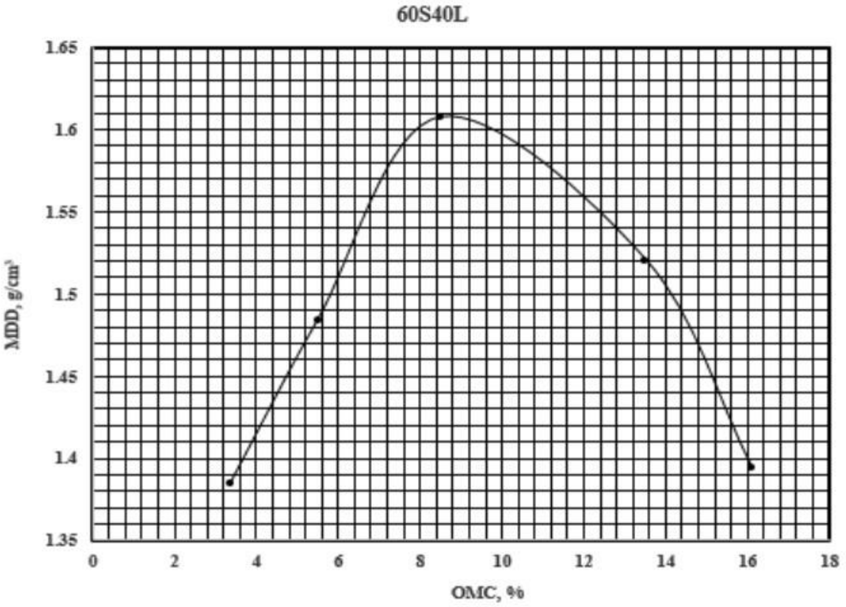
TEST	1		2		3		4		5	
Weight of mould without the base and collar, W_1, (g)	5000		5000		5000		5000		5000	
Weight of mould + moist soil, W_2, (g)	9600		9700		10100		10300		10050	
Weight of moist soil, W_2-W_1, (g)	5500		6000		6600		6100		5400	
Bulk Density, γ = [(W_2-W_1)/3110.18], g/cm3	1.768386396		1.929148795		2.122063675		1.961301275		1.736233916	
	BT	AT	BT	AT	BT	AT	BT	AT	BT	AT
Container No.	58	5	10	78	89	8	45	19	16	32
Mass of wet soil + Container, W_3, (g)	110.7	90.3	72.1	87.5	88.4	88.6	86.3	81.2	101.7	125.6
Mass of dry soil + Container, W_4, (g)	108.3	88.5	69.8	84.6	85.9	83.3	79.6	74.2	89.9	113.9
Mass of Container, W_5, (g)	9.6	10.1	16.8	10.1	16.5	10.1	10	9.5	10	16.8
Mass of Water, $W_6 = W_3$-W_4, (g)	2.4	1.8	2.3	2.9	2.5	5.3	6.7	7	11.8	11.7
Mass of Dry soil, $W_7 = W_4$-W_5, (g)	98.7	78.4	53	74.5	69.4	73.2	69.6	64.7	79.9	97.1
Moisture Content, w(%) = [W_6/W_7] * 100	2.431611	2.295918	4.339623	3.892617	3.602305	7.240437	9.626437	10.81917	14.76846	12.04943
Ave. Moisture Content, w(%) = ([W_6/W_7] * 100)/2	2.363764655		4.116120046		5.421371317		10.22280108		13.40894707	
Dry Density, γ_d (g/cm3) = γ/[1+(w/100)]	1.727551152		1.85288195		2.012934994		1.779397054		1.530949683	

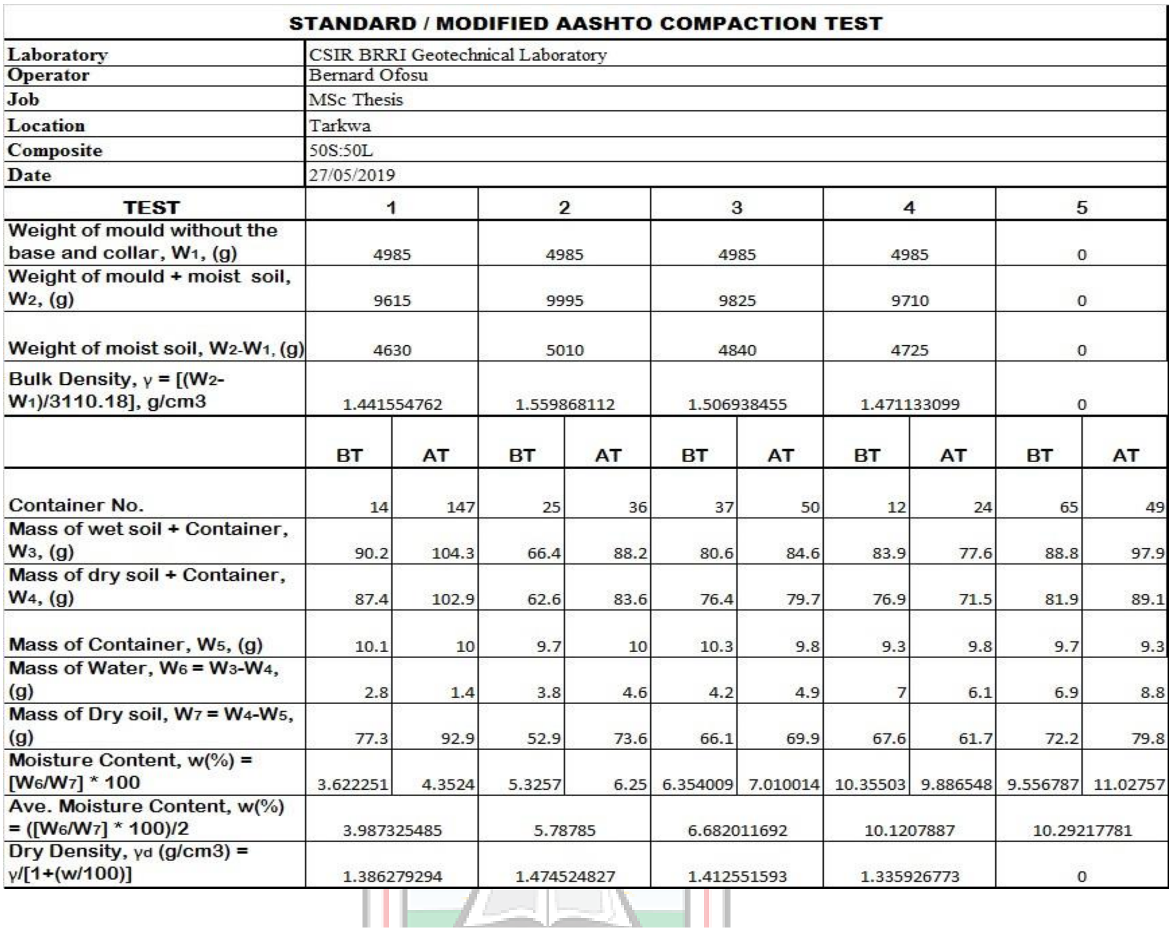


STANDARD / MODIFIED AASHTO COMPACTION TEST

Laboratory	CSIR BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	60S:40L
Date	9/10/2017

TEST	1		2		3		4		5	
Weight of mould without the base and collar, W_1, (g)	4750		4750		4750		4750		4750	
Weight of mould + moist soil, W_2, (g)	9150		9400		9900		10500		9650	
Weight of moist soil, W_2-W_1, (g)	4600		5100		5600		5400		5200	
Bulk Density, γ = [(W_2-W_1)/3110.18], g/cm3	1.432214234		1.587889695		1.743565155		1.681294971		1.619024787	
	BT	AT	BT	AT	BT	AT	BT	AT	BT	AT
Container No.	12A	3	45D	15	102	325	12B	156	108	109
Mass of wet soil + Container, W_3, (g)	79.9	80.4	84.2	88.8	90	86	33.8	58.3	84.1	101.1
Mass of dry soil + Container, W_4, (g)	77.6	78.1	79.1	83.9	86.1	78.2	31.5	53.7	73.8	89.4
Mass of Container, W_5, (g)	9.7	10	9.8	10.2	16.2	9.7	9.8	9.9	9.9	16.6
Mass of Water, W_6 = W_3-W_4, (g)	2.3	2.3	5.1	4.9	3.9	7.8	2.3	4.6	10.3	11.7
Mass of Dry soil, W_7 = W_4-W_5, (g)	67.9	68.1	69.3	73.7	69.9	68.5	21.7	43.8	63.9	72.8
Moisture Content, w(%) = [W_6/W_7] * 100	3.387334	3.377386	7.359307	6.648575	5.579399	11.38686	10.59908	10.50228	16.11894	16.07143
Ave. Moisture Content, w(%) = ([W_6/W_7] * 100)/2	3.382360256		7.003941332		8.483130228		10.55068072		16.0951822	
Dry Density, γ_d (g/cm3) = γ/[1+(w/100)]	1.385356487		1.483954399		1.607222387		1.52083638		1.39456673	

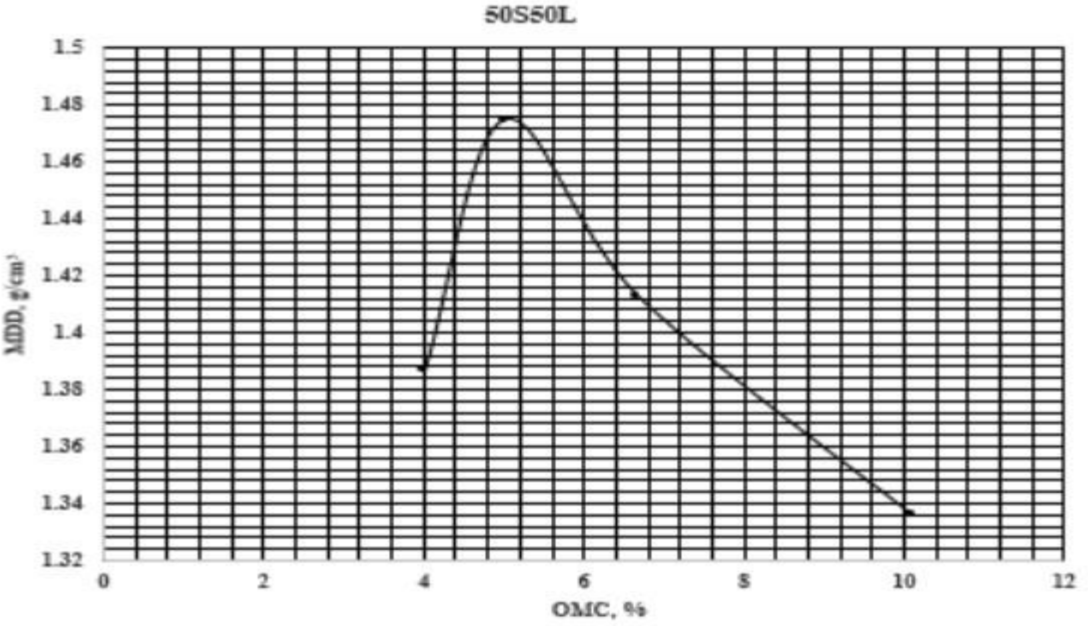




STANDARD / MODIFIED AASHTO COMPACTION TEST

Laboratory	CSIR BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	50S:50L
Date	27/05/2019

TEST	**1**		**2**		**3**		**4**		**5**	
Weight of mould without the base and collar, W_1, (g)	4985		4985		4985		4985		0	
Weight of mould + moist soil, W_2, (g)	9615		9995		9825		9710		0	
Weight of moist soil, W_2-W_1, (g)	4630		5010		4840		4725		0	
Bulk Density, γ = [(W_2-W_1)/3110.18], g/cm3	1.441554762		1.559868112		1.506938455		1.471133099		0	
	BT	**AT**	**BT**	**AT**	**BT**	**AT**	**BT**	**AT**	**BT**	**AT**
Container No.	14	147	25	36	37	50	12	24	65	49
Mass of wet soil + Container, W_3, (g)	90.2	104.3	66.4	88.2	80.6	84.6	83.9	77.6	88.8	97.9
Mass of dry soil + Container, W_4, (g)	87.4	102.9	62.6	83.6	76.4	79.7	76.9	71.5	81.9	89.1
Mass of Container, W_5, (g)	10.1	10	9.7	10	10.3	9.8	9.3	9.8	9.7	9.3
Mass of Water, W_6 = W_3-W_4, (g)	2.8	1.4	3.8	4.6	4.2	4.9	7	6.1	6.9	8.8
Mass of Dry soil, W_7 = W_4-W_5, (g)	77.3	92.9	52.9	73.6	66.1	69.9	67.6	61.7	72.2	79.8
Moisture Content, w(%) = [W_6/W_7] * 100	3.622251	4.3524	5.3257	6.25	6.354009	7.010014	10.35503	9.886548	9.556787	11.02757
Ave. Moisture Content, w(%) = ([W_6/W_7] * 100)/2	3.987325485		5.78785		6.682011692		10.1207887		10.29217781	
Dry Density, γ_d (g/cm3) = γ/[1+(w/100)]	1.386279294		1.474524827		1.412551593		1.335926773		0	



APPENDIX G

CALIFONIA BEARING RATION OF COMPOSITES

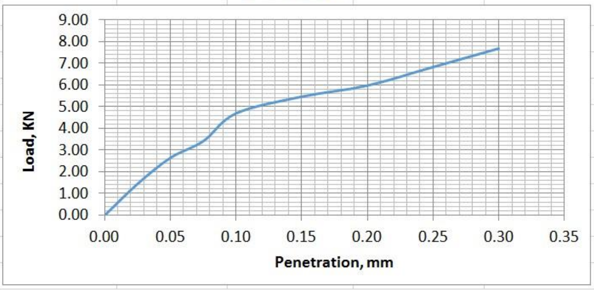
CBR (SOAKED)

Laboratory	BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	90S:10L (Soaked)
Date	30/10/2017

Penetration Data After 96hrs Soaking

Pen. (mm)	**Reading**	**Load (kN)**	**Correction**	**CBR %**
0.00	0.0	0.00		
0.03	85.0	1.45		
0.05	155.0	2.65		
0.075	200.0	3.42		
0.10	275.0	4.70	1.4	**35.48**
0.15	320.0	5.47		
0.20	350.0	5.98	1.3	**29.95**
0.25	400.0	6.83		
0.30	450.0	7.69		
CBR Value, %			1	**35**

CBR CURVE



Dry Density and Water Content Data

Condition of Specimen	**Before Saoking**		**After Soaking**		
Wt. Of Mould + Wet Soil (g)	9550.00		9625.00		
Wt. Of Mould (g)	5000		5000		
Wet Specimen Wt.(g)	4550.0		4625.0		
Volume of Specimen (cm3)	2335		2335		
Wet Density g/cm	**1.949**		**1.981**		
	Before	**After**	**Top**	**Center**	**Bottom**
Contianer NO.	ACE	42A	131	26	NAZ
Wt. Contianer + Wet Soil (g)	67.1	81	99.3	101.6	111.8
Wt. Contianer + Dry Soil (g)	63.5	77.2	92.6	94.4	101.5
Wt. Of Water (g)	3.6	3.8	6.7	7.2	10.3
Wt. Of Container (g)	9.7	10.4	10.3	9.3	10
Wt. Of Dry Soil (g)	53.8	66.8	82.3	85.1	91.5
Water Content %	6.69	5.69	8.14	8.46	11.26
Averaged Water Content%	**6.19**		**9.29**		
Dry Density g/m3	**1.835**		**1.81**		

REMARKS	**Swell Data**				
	Date	**Time/Hours**	**Reading (mm)**	**Change in Height (mm)**	**Swell**
	30/10/2017		8.77	0.01	**0.01**
			8.78		

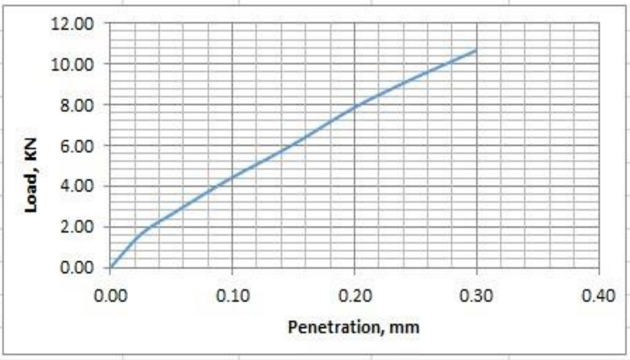
CBR (SOAKED)

Laboratory+A1:J25	BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	80S:20L (Soaked)
Date	30/10/2017

Penetration Data After 96hrs Soaking

Pen. (mm)	**Reading**	**Load (kN)**	**Correction**	**CBR %**
0.00	0.0	0.00		
0.03	96.0	1.64		
0.05	153.0	2.61		
0.075	207.0	3.54		
0.10	259.0	4.42	1.4	**33.41**
0.15	354.0	6.05		
0.20	460.0	7.86	1.3	**39.37**
0.25	546.0	9.33		
0.30	624.0	10.66		
CBR Value, %			1	**39**

CBR CURVE



Dry Density and Water Content Data

Condition of Specimen	**Before Saoking**		**After Soaking**		
Wt. Of Mould + Wet Soil (g)	9800.00		9955.00		
Wt. Of Mould (g)	5100		5100		
Wet Specimen Wt.(g)	4700.0		4855.0		
Volume of Specimen (cm3)	2335		2335		
Wet Density g/cm	**2.013**		**2.079**		
	Before	**After**	**Top**	**Center**	**Bottom**
Contianer NO.	412	259	129	322	252
Wt. Contianer + Wet Soil (g)	93.4	76.6	92.7	88.7	79.4
Wt. Contianer + Dry Soil (g)	88.5	72.3	83.6	81.4	72.8
Wt. Of Water (g)	4.9	4.3	9.1	7.3	6.6
Wt. Of Container (g)	9.7	10.4	10.3	9.3	10
Wt. Of Dry Soil (g)	78.8	61.9	73.3	72.1	62.8
Water Content %	6.22	6.95	12.41	10.12	10.51
Averaged Water Content%	**6.58**		**11.02**		
Dry Density g/m3	**1.889**		**1.87**		

REMARKS

Swell Data

Date	**Time/Hours**	**Reading (mm)**	**Change in Height (mm)**	**Swell**
30/10/2017		5.65	0.03	**0.02**
3/10/2017		5.68		

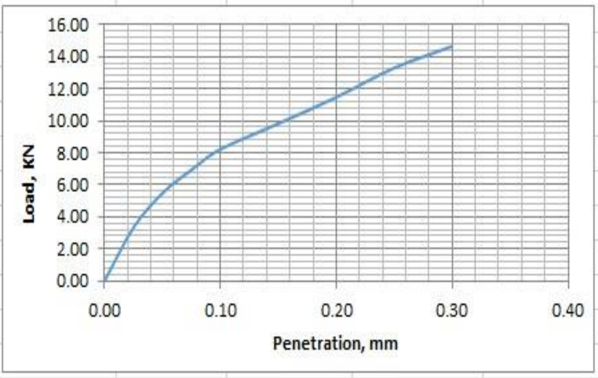
CBR (SOAKED)

Laboratory	BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	70S:30L (Soaked)
Date	30/10/2017

Penetration Data After 96hrs Soaking

Pen. (mm)	Reading	Load (kN)	Correction	CBR %
0.00	0.0	0.00		
0.03	195.0	3.33		
0.05	320.0	5.47		
0.075	405.0	6.92		
0.10	480.0	8.20	1.4	**61.93**
0.15	574.0	9.80		
0.20	670.0	11.44	1.3	**57.34**
0.25	777.0	13.27		
0.30	856.0	14.62		
CBR Value, %			1	**62**

CBR CURVE



Dry Density and Water Content Data

Condition of Specimen	Before Saoking		After Saoking		
Wt. Of Mould + Wet Soil (g)	9023.00		8950		
Wt. Of Mould (g)	4150		4150		
Wet Specimen Wt.(g)	4873.0		4800		
Volume of Specimen (cm3)	2335		2335		
Wet Density g/cm	**2.087**		**2.056**		
	Before	**After**	**Top**	**Center**	**Bottom**
Contianer NO.	34	667C	287	428	85
Wt. Contianer + Wet Soil (g)	70.8	85.9	98.9	85.4	109.5
Wt. Contianer + Dry Soil (g)	67.1	82	93.7	81.3	103.3
Wt. Of Water (g)	3.7	3.9	5.2	4.1	6.2
Wt. Of Container (g)	9.6	9	9.7	9.9	10.3
Wt. Of Dry Soil (g)	57.5	73.0	84.0	71.4	93.0
Water Content %	6.43	5.34	6.19	5.74	6.67
Averaged Water Content%	**5.89**		**6.20**		
Dry Density g/m3	**1.971**		**1.97**		

REMARKS

Swell Data

Date	Time/Hours	Reading (mm)	Change in Height (mm)	Swell
30/10/2017		4.39	0.08	**0.06**
3/10/2017		4.47		

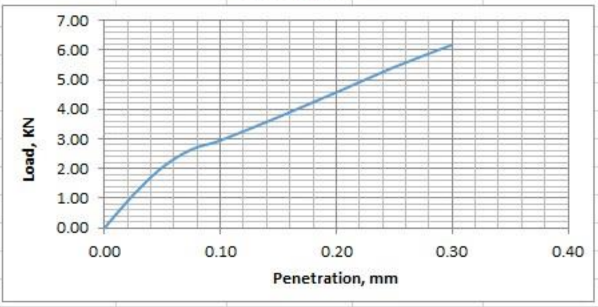
CBR (SOAKED)

Laboratory	BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	60S:40L (Soaked)
Date	30/10/2017

Penetration Data After 96hrs Soaking

Pen. (mm)	Reading	Load (kN)	Correction	CBR %
0.00	0.0	0.00		
0.03	66.0	1.13		
0.05	120.0	2.05		
0.075	155.0	2.65		
0.10	173.0	2.96	1.4	**22.32**
0.15	219.0	3.74		
0.20	268.0	4.58	1.3	**22.93**
0.25	318.0	5.43		
0.30	362.0	6.18		
CBR Value, %			1	23

CBR CURVE

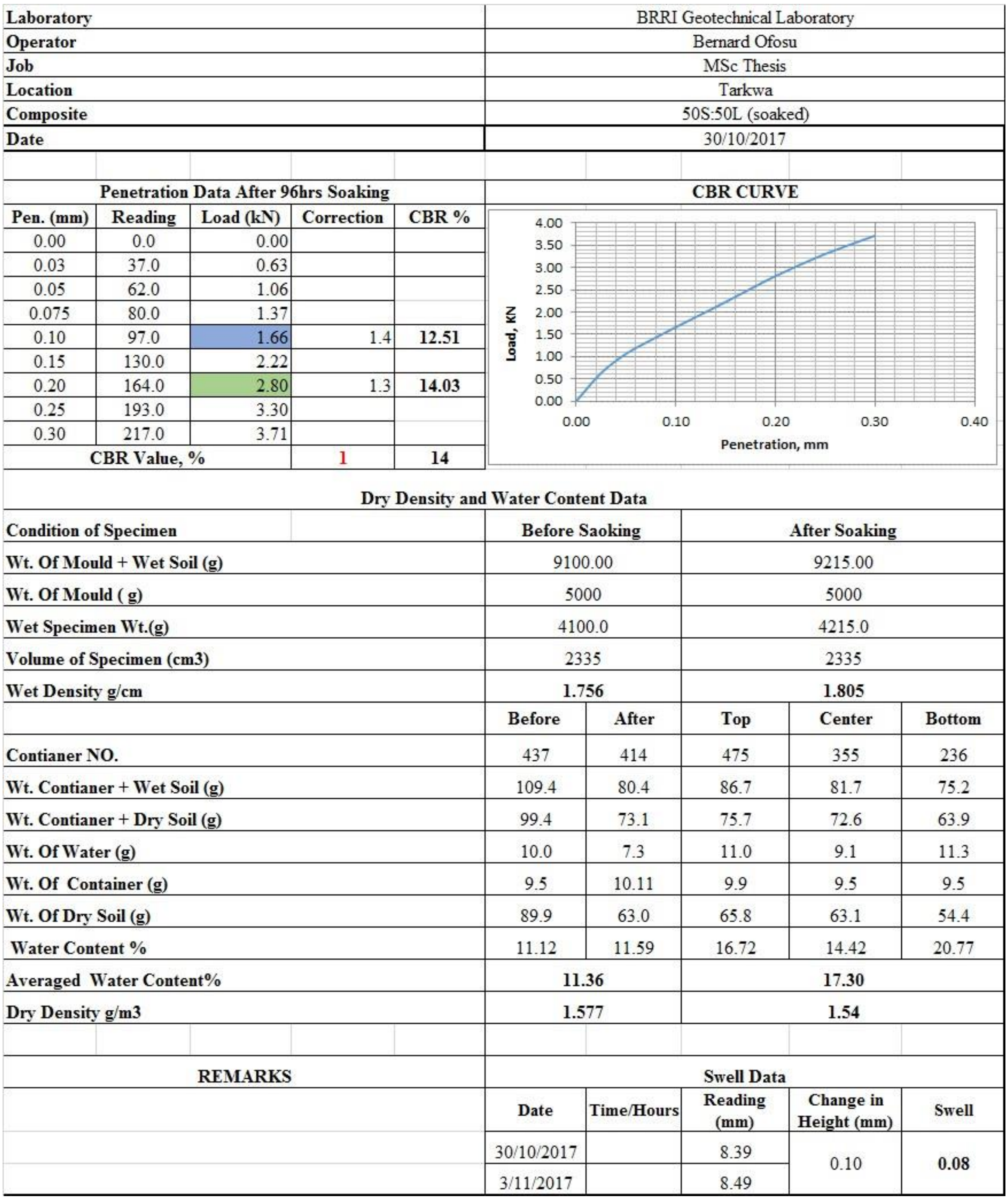


Dry Density and Water Content Data

Condition of Specimen	Before Saoking		After Soaking		
Wt. Of Mould + Wet Soil (g)	10000.00		10100.00		
Wt. Of Mould (g)	5100		5100		
Wet Specimen Wt.(g)	4900.0		5000.0		
Volume of Specimen (cm3)	2335		2335		
Wet Density g/cm	**2.099**		**2.141**		
	Before	**After**	**Top**	**Center**	**Bottom**
Contianer NO.	454	482	82	404	6
Wt. Contianer + Wet Soil (g)	93.8	92.1	75.4	88.7	99.1
Wt. Contianer + Dry Soil (g)	86.7	58.8	67.6	81.2	86.5
Wt. Of Water (g)	7.1	33.3	7.8	7.5	12.6
Wt. Of Container (g)	10.1	9.8	10.4	10.1	9.4
Wt. Of Dry Soil (g)	76.6	49.0	57.2	71.1	77.1
Water Content %	9.27	67.96	13.64	10.55	16.34
Averaged Water Content%	**38.61**		**13.51**		
Dry Density g/m3	**1.514**		**1.89**		

REMARKS	Swell Data				
	Date	**Time/Hours**	**Reading (mm)**	**Change in Height (mm)**	**Swell**
	30/10/2017		14.29	0.09	**0.07**
	3/11/2017		14.38		

CBR (SOAKED)



Laboratory	BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	50S:50L (soaked)
Date	30/10/2017

Penetration Data After 96hrs Soaking

Pen. (mm)	Reading	Load (kN)	Correction	CBR %
0.00	0.0	0.00		
0.03	37.0	0.63		
0.05	62.0	1.06		
0.075	80.0	1.37		
0.10	97.0	1.66	1.4	**12.51**
0.15	130.0	2.22		
0.20	164.0	2.80	1.3	**14.03**
0.25	193.0	3.30		
0.30	217.0	3.71		
CBR Value, %			1	**14**

CBR CURVE

Dry Density and Water Content Data

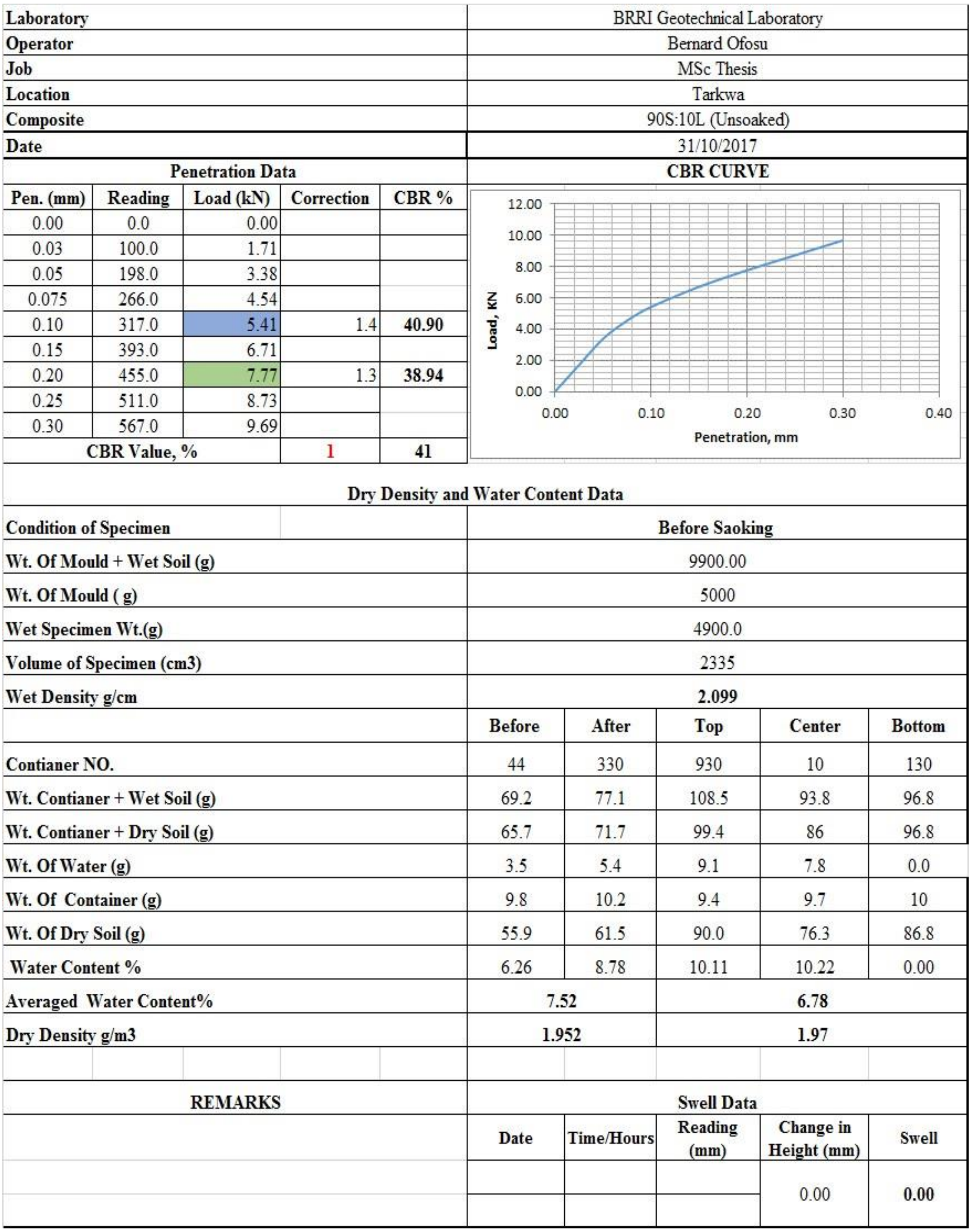
Condition of Specimen	**Before Saoking**		**After Soaking**		
Wt. Of Mould + Wet Soil (g)	9100.00		9215.00		
Wt. Of Mould (g)	5000		5000		
Wet Specimen Wt.(g)	4100.0		4215.0		
Volume of Specimen (cm3)	2335		2335		
Wet Density g/cm	**1.756**		**1.805**		
	Before	**After**	**Top**	**Center**	**Bottom**
Contianer NO.	437	414	475	355	236
Wt. Contianer + Wet Soil (g)	109.4	80.4	86.7	81.7	75.2
Wt. Contianer + Dry Soil (g)	99.4	73.1	75.7	72.6	63.9
Wt. Of Water (g)	10.0	7.3	11.0	9.1	11.3
Wt. Of Container (g)	9.5	10.11	9.9	9.5	9.5
Wt. Of Dry Soil (g)	89.9	63.0	65.8	63.1	54.4
Water Content %	11.12	11.59	16.72	14.42	20.77
Averaged Water Content%	**11.36**		**17.30**		
Dry Density g/m3	**1.577**		**1.54**		

REMARKS

Swell Data

Date	**Time/Hours**	**Reading (mm)**	**Change in Height (mm)**	**Swell**
30/10/2017		8.39	0.10	**0.08**
3/11/2017		8.49		

CBR (UNSOAKED)



Laboratory	BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	90S:10L (Unsoaked)
Date	31/10/2017

Penetration Data

Pen. (mm)	**Reading**	**Load (kN)**	**Correction**	**CBR %**
0.00	0.0	0.00		
0.03	100.0	1.71		
0.05	198.0	3.38		
0.075	266.0	4.54		
0.10	317.0	5.41	1.4	**40.90**
0.15	393.0	6.71		
0.20	455.0	7.77	1.3	**38.94**
0.25	511.0	8.73		
0.30	567.0	9.69		
CBR Value, %			1	**41**

CBR CURVE

Dry Density and Water Content Data

Condition of Specimen	**Before Saoking**
Wt. Of Mould + Wet Soil (g)	9900.00
Wt. Of Mould (g)	5000
Wet Specimen Wt.(g)	4900.0
Volume of Specimen (cm3)	2335
Wet Density g/cm	**2.099**

	Before	**After**	**Top**	**Center**	**Bottom**
Contianer NO.	44	330	930	10	130
Wt. Contianer + Wet Soil (g)	69.2	77.1	108.5	93.8	96.8
Wt. Contianer + Dry Soil (g)	65.7	71.7	99.4	86	96.8
Wt. Of Water (g)	3.5	5.4	9.1	7.8	0.0
Wt. Of Container (g)	9.8	10.2	9.4	9.7	10
Wt. Of Dry Soil (g)	55.9	61.5	90.0	76.3	86.8
Water Content %	6.26	8.78	10.11	10.22	0.00
Averaged Water Content%	**7.52**		**6.78**		
Dry Density g/m3	**1.952**		**1.97**		

REMARKS

Swell Data

Date	**Time/Hours**	**Reading (mm)**	**Change in Height (mm)**	**Swell**
			0.00	**0.00**

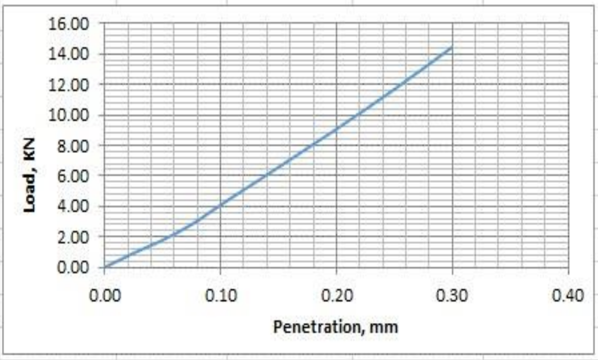
CBR (UNSOAKED)

Laboratory	BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	80S:20L (Unsoaked)
Date	31/10/2017

Penetration Data

Pen. (mm)	**Reading**	**Load (kN)**	**Correction**	**CBR %**
0.00	0.0	0.00		
0.03	55.0	0.94		
0.05	105.0	1.79		
0.075	165.0	2.82		
0.10	240.0	4.10	1.4	**30.96**
0.15	385.0	6.58		
0.20	532.0	9.09	1.3	**45.53**
0.25	685.0	11.70		
0.30	847.0	14.47		
CBR Value, %			1	**46**

CBR CURVE



Dry Density and Water Content Data

Condition of Specimen	**Before Saoking**
Wt. Of Mould + Wet Soil (g)	9525.00
Wt. Of Mould (g)	4300
Wet Specimen Wt.(g)	5225.0
Volume of Specimen (cm3)	2335
Wet Density g/cm	**2.238**

	Before	**After**	**Top**	**Center**	**Bottom**
Contianer NO.	370	396	447	930	999
Wt. Contianer + Wet Soil (g)	87	82.8	94.4	82.1	100.8
Wt. Contianer + Dry Soil (g)	81.9	78.7	89.4	77.9	94.4
Wt. Of Water (g)	5.1	4.1	5.0	4.2	6.4
Wt. Of Container (g)	9.9	10	10.1	9.6	10.1
Wt. Of Dry Soil (g)	72.0	68.7	79.3	68.3	84.3
Water Content %	7.08	5.97	6.31	6.15	7.59
Averaged Water Content%	**6.53**		6.68		
Dry Density g/m3	**2.101**		**0.00**		

REMARKS	**Swell Data**				
	Date	**Time/Hours**	**Reading (mm)**	**Change in Height (mm)**	**Swell**
				0.00	**0.00**

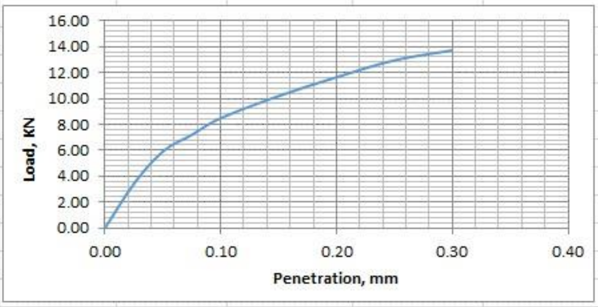
CBR (UNSOAKED)

Laboratory	BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	70S:30L (Unsoaked)
Date	30/10/2017

Penetration Data

Pen. (mm)	**Reading**	**Load (kN)**	**Correction**	**CBR %**
0.00	0.0	0.00		
0.03	200.0	3.42		
0.05	345.0	5.89		
0.075	420.0	7.17		
0.10	495.0	8.46	1.4	**63.86**
0.15	595.0	10.16		
0.20	680.0	11.62	1.3	**58.19**
0.25	756.0	12.91		
0.30	801.0	13.68		
CBR Value, %			1	**64**

CBR CURVE



Dry Density and Water Content Data

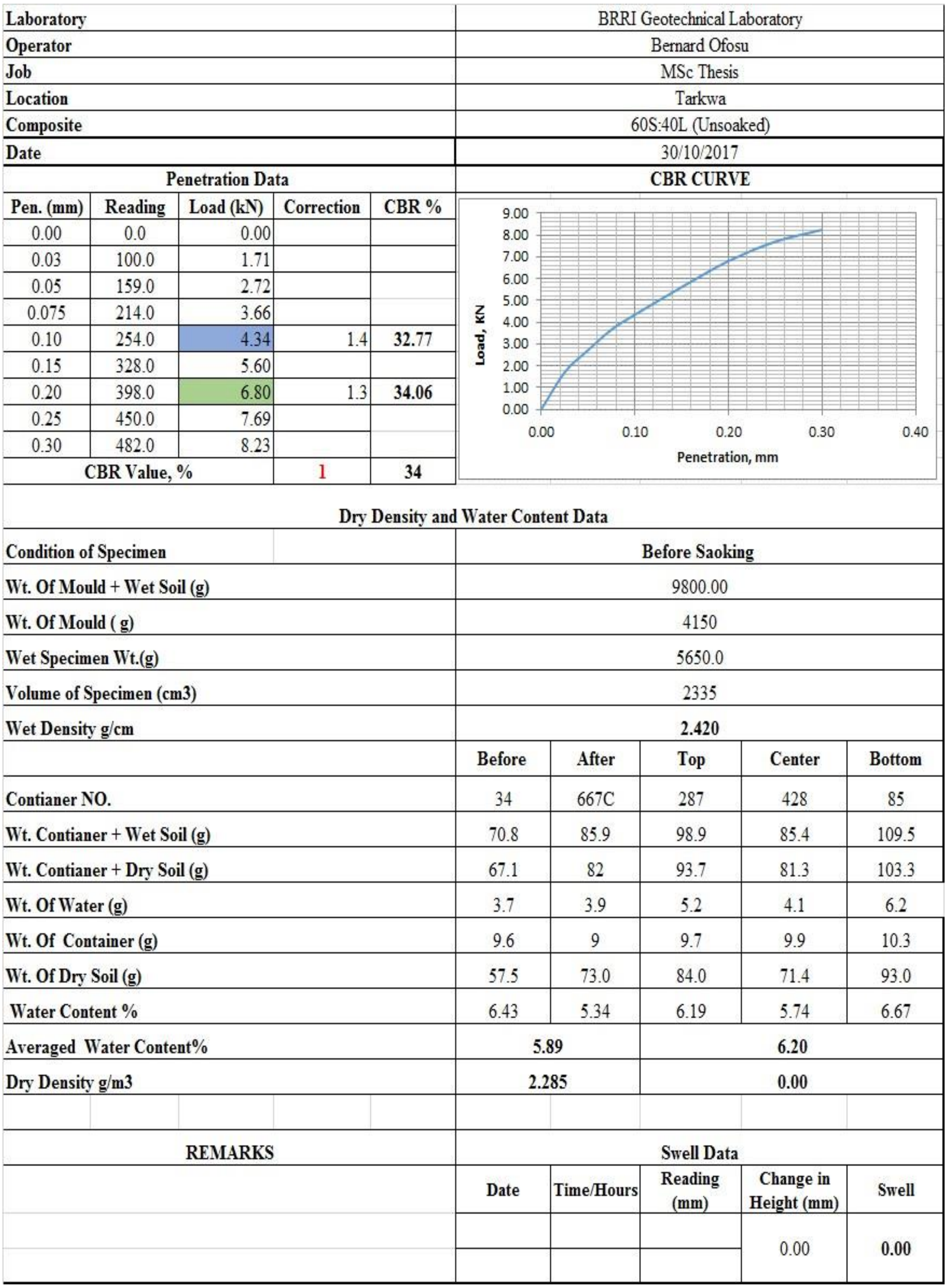
Condition of Specimen	**Before Saoking**		**After Soaking**		
Wt. Of Mould + Wet Soil (g)	9900.00				
Wt. Of Mould (g)	5000				
Wet Specimen Wt.(g)	4900.0				
Volume of Specimen (cm3)	2335				
Wet Density g/cm	**2.099**				
	Before	**After**	**Top**	**Center**	**Bottom**
Contianer NO.	44	330	930	10	130
Wt. Contianer + Wet Soil (g)	69.2	77.1	108.5	93.8	101.6
71.7	65.7	74.7	99.4	86	96.8
Wt. Of Water (g)	3.5	2.4	9.1	7.8	4.8
Wt. Of Container (g)	9.8	10.2	9.4	9.7	10
Wt. Of Dry Soil (g)	55.9	64.5	90.0	76.3	86.8
Water Content %	6.26	3.72	10.11	10.22	5.53
Averaged Water Content%	**4.99**		**8.62**		
Dry Density g/m3	**1.999**		**0.00**		

REMARKS

Swell Data

Date	**Time/Hours**	**Reading (mm)**	**Change in Height (mm)**	**Swell**
			0.00	**0.00**

CBR UNSOAKED)



Laboratory	BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	60S:40L (Unsoaked)
Date	30/10/2017

Penetration Data

Pen. (mm)	Reading	Load (kN)	Correction	CBR %
0.00	0.0	0.00		
0.03	100.0	1.71		
0.05	159.0	2.72		
0.075	214.0	3.66		
0.10	254.0	4.34	1.4	**32.77**
0.15	328.0	5.60		
0.20	398.0	6.80	1.3	**34.06**
0.25	450.0	7.69		
0.30	482.0	8.23		
CBR Value, %			1	**34**

CBR CURVE

Dry Density and Water Content Data

Condition of Specimen	Before Saoking
Wt. Of Mould + Wet Soil (g)	9800.00
Wt. Of Mould (g)	4150
Wet Specimen Wt.(g)	5650.0
Volume of Specimen (cm3)	2335
Wet Density g/cm	**2.420**

	Before	After	Top	Center	Bottom
Contianer NO.	34	667C	287	428	85
Wt. Contianer + Wet Soil (g)	70.8	85.9	98.9	85.4	109.5
Wt. Contianer + Dry Soil (g)	67.1	82	93.7	81.3	103.3
Wt. Of Water (g)	3.7	3.9	5.2	4.1	6.2
Wt. Of Container (g)	9.6	9	9.7	9.9	10.3
Wt. Of Dry Soil (g)	57.5	73.0	84.0	71.4	93.0
Water Content %	6.43	5.34	6.19	5.74	6.67
Averaged Water Content%	**5.89**		**6.20**		
Dry Density g/m3	**2.285**		**0.00**		

REMARKS

Swell Data

Date	Time/Hours	Reading (mm)	Change in Height (mm)	Swell
			0.00	**0.00**

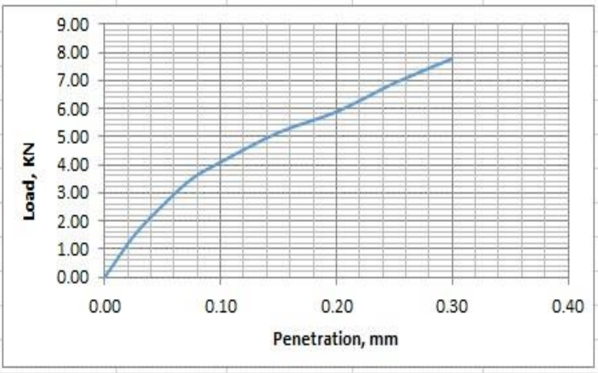
CBR (UNSOAKED)

Laboratory	BRRI Geotechnical Laboratory
Operator	Bernard Ofosu
Job	MSc Thesis
Location	Tarkwa
Composite	**50S:50L (Unsoaked)**
Date	30/10/2017

Penetration Data

Pen. (mm)	Reading	Load (kN)	Correction	CBR %
0.00	0.0	0.00		
0.03	86.0	1.47		
0.05	150.0	2.56		
0.075	205.0	3.50		
0.10	240.0	4.10	1.4	**30.96**
0.15	302.0	5.16		
0.20	345.0	5.89	1.3	**29.52**
0.25	405.0	6.92		
0.30	456.0	7.79		
CBR Value, %			1	**31**

CBR CURVE



Dry Density and Water Content Data

Condition of Specimen	**Before Saoking**				
Wt. Of Mould + Wet Soil (g)	9775.00				
Wt. Of Mould (g)	5000				
Wet Specimen Wt.(g)	4775.0				
Volume of Specimen (cm3)	2335				
Wet Density g/cm	**2.045**				
	Before	**After**	**Top**	**Center**	**Bottom**
Contianer NO.	184	166	385	247	210
Wt. Contianer + Wet Soil (g)	94.4	93.7	56.6	91.1	95.7
Wt. Contianer + Dry Soil (g)	87.6	86.7	55.1	84.3	87.5
Wt. Of Water (g)	6.8	7.0	1.5	6.8	8.2
Wt. Of Container (g)	9.8	9.4	10.3	9.8	10.2
Wt. Of Dry Soil (g)	77.8	77.3	44.8	74.5	77.3
Water Content %	8.74	9.06	3.35	9.13	10.61
Averaged Water Content%	**8.90**		**7.69**		
Dry Density g/m3	**1.878**		**1.51**		

REMARKS

Swell Data

Date	Time/Hours	Reading (mm)	Change in Height (mm)	Swell
			0.00	**0.00**