ASSESSMENT OF LATERITIC SOIL STABILIZED WITH ASHES FROM COCOA PODS AND PALM KERNEL SHELLS AS PARTIAL REPLACEMENT OF CEMENT

BY

DADA, MICHAEL OJO
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FEDERAL UNIVERSITY OF TECHNOLOGY,
AKURE, ONDO STATE.

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CERTIFICATION

(a) BY STUDENT: This work to the best of my knowledge has not been presented elsewhere for the award of a degree or other purpose.

Candidate's Name: Dada Michael Ojo

Signature .... **Date** ...19-02-2010

(b) BY SUPERVISOR: This is to certify that this research work was carried out by Dada Michael Ojo in the department of Civil Engineering of the Federal University of Technology, Akure, Ondo State Nigeria.

Engr. (Dr.) A. O. Owolabi MNSE, R.Eng. COREN

MAJOR SUPERVISOR **Signature** .... **Date**...19-02-2010

Engr. (Prof) S. A. OLA FNSE, R.Eng. COREN

CO-SUPERVISOR **Signature** .... **Date**...19/2/10

ABSTRACT

The assessment of the properties of lateritic soil stabilized with ashes from cocoa pods and palm kernel shells as partial replacement of cement was carried out. Samples of lateritic soil were collected at varying depths from 0.5m and 1.5m at a borrow pit after the top soil had been removed. The samples were air-dried and thoroughly mixed to ensure a homogenous sample. Each of the cocoa pods and palm kernel shells collected dried with respective inherent moisture content of 0.5% and 0.1% and was oven dried to 0% moisture content at a temperature of 110^{0}C and further heated in an open top kiln to a temperature of 800^{0}C for cocoa pods and 1000^{0}C for palm kernel shells when appreciable ashes began to appear in the furnace. Varying proportions of cement and ashes from cocoa pods and palm kernel shells used were expressed as percentage of the dry weight of the soil samples. The total additive contents used were 2%, 4%, 6% and 8% for each test carried out on the samples. Some geotechnical parameters such as: classification (specific gravity, moisture content, grain size distribution and consistency limit); Compaction; California Bearing Ratio; Chemical compositions of the additives were determined. The cost analyses of the additives were also conducted. The result of the consistency limit of the natural soil gave liquid limit of 34.0% and plasticity index of 16.2%, the soil thus classified in group A-2-6(0) and generally the results of the treated samples showed significant decrease in the plasticity index when compared with the natural soil samples and most significant in C. The maximum dry density and the C.B.R. of the treated samples increased above the natural soil in all cases, exceeding 2000kg/m^3 and 80% respectively at 6% which are the minimum permisable for unsoaked C.B.R values for base course. The results of the chemical analysis of the additives used also showed that the ashes have Fe, Mg, Na and K which compared favourably with cement but palm kernel shell ash was deficient in calcium (Ca) which is the major constituent of cement. Cocoa pods and palm kernel shells were treated as wastes, their use for this purpose will be of economic benefit since they served as suitable partial replacement when stabilizing with cement, usually an expensive commodity.

DEDICATION

This report is dedicated to the following.

(i) My Lord Jesus Christ whose grace, strength, wisdom and knowledge gave me the ability to produce this report.

(ii) Members of my family

- Esther Dada (Better half)
- Emmanuel, Precious and Victor (Children)

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CHAPTER ONE

1.0 INTRODUCTION

Research investigations have been carried out to determine the usefulness of lateritic soils in the Nigerian construction industry. It is noted that in South-Western Nigeria, the top soil consists of a high degree of humus which need to be removed before any meaningful construction work can be carried out. Lateritic soils also have wide applications not only as foundation for structures but, more importantly, as construction materials.

Lateritic soils possess geotechnical, mineralogical and physical characteristics that make them rank as fair to good engineering materials. Their properties may need to be improved upon in some cases by soil stabilization.

Soil stabilization is the alteration of any property of a soil to improve its engineering performance. Soil improvements by stabilization provide increased strength – for pavement grade, reduced compressibility – for foundation structure, reduced permeability – for dam foundation. Soil improvement can be classified according to the nature of the process involved, material added and the desired result. A satisfactory stabilizing agent must provide the required qualities and, in addition, must satisfy the following criteria: compatibility with soil material, easy handling and processing and low cost.

In this research, assessment of lateritic soil stabilized with ashes from cocoa pods and palm kernel shells as partial replacement of cement was considered because of the high cost of cement. This involves the mixture of pulverized soil and measured amounts of Portland cement, ashes from cocoa pod, ashes from palm kernel shell and water compacted to a high unit weight and protected against moisture loss.

1.1 AIM OF THE STUDY

The aim of the research is to assess the properties of lateritic soil stabilized with ashes from cocoa pods and palm kernel shells as partial replacement of cement.

1.2 SPECIFIC OBJECTIVES OF THE RESEARCH

The specific objectives are to:

(a) assess the geotechnical properties of lateritic soil stabilized with cement;

(b) determine the geotechnical properties of lateritic soil stabilized with mixture of cement and ashes from cocoa pods and palm kernel shells; and

(c) evaluate the structural and economic benefits of applying the composite.

1.3 JUSTIFICATION FOR THE STUDY

Previous studies have pointed out beneficial results of the use for pure cement, lime, fly ash and bitumen for soil stabilization. Record however do not show the applicability of ashes from cocoa pods and palm kernel shell for soil stabilization. Hence, this study intends to investigate the properties of lateritic soil stabilized with ashes from cocoa pods and palm kernel shells as partial replacement of cement to possibly reduce cost.

Cocoa pods and palm kernel shells are abundantly available in South Western Nigeria for this purpose. In the end, the improvement that is envisaged from the stabilization process using the lateritic soil with less cement content and ashes from cocoa pod with palm kernel shell is to supplement cement without undermining the strength requirement.

1.4 LIMITATION TO THE USE OF THE ADDITIVES

There is no doubt that the use of the additives would be affected by some factors. The factors are:

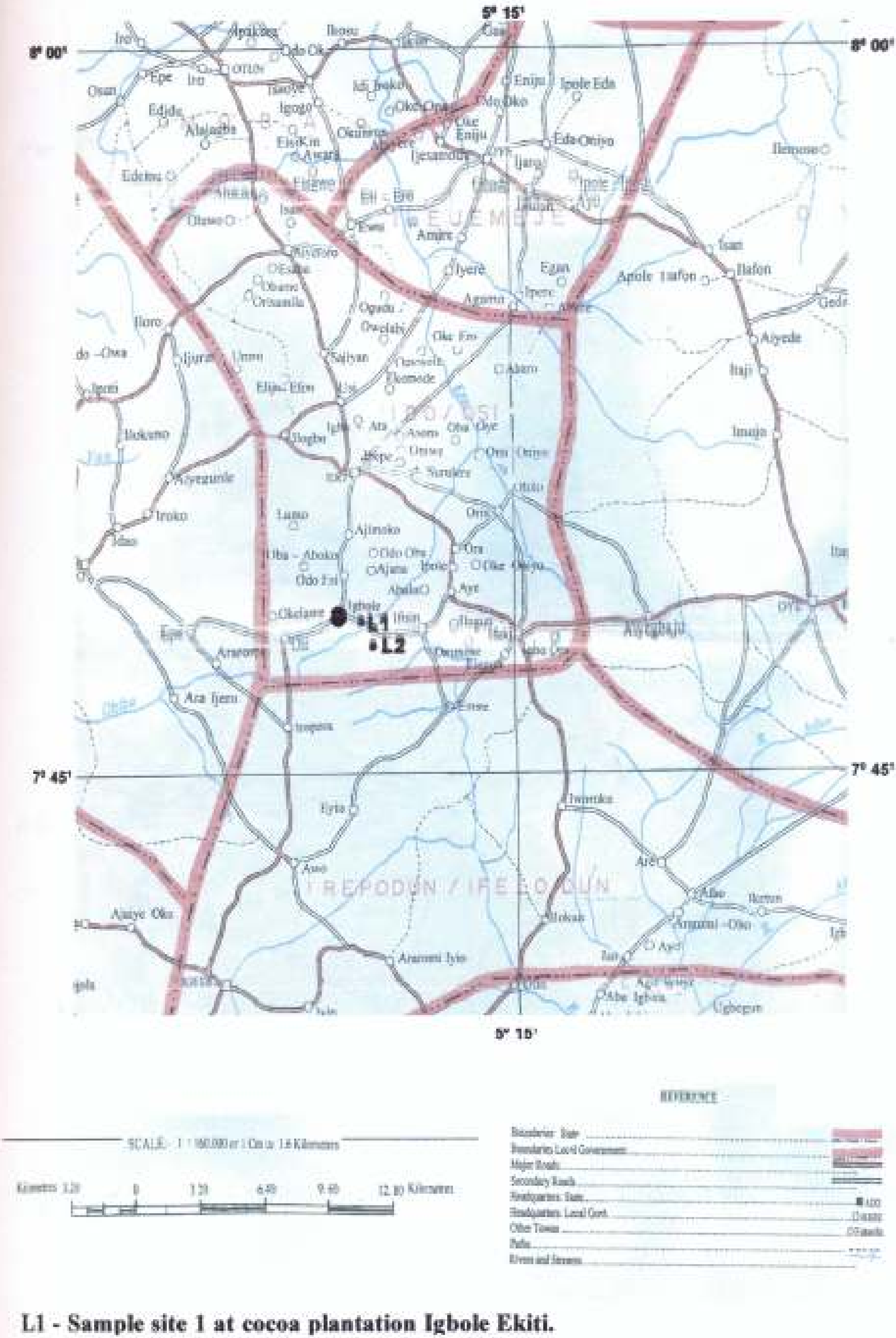
- Rate of use may outweigh the rate of accumulation (availability) especially in the case of competitors. The availability is also dependent on some natural factors (natural disasters such as fire outbreak, drought) which may affect farm produce.

1.5 EXPECTED CONTRIBUTION TO KNOWLEDGE

The research is expected to provide information on the properties and performance of cocoa pod and palm kernel shell ashes as alternative materials for soil stabilization.

1.6 LOCATION OF THE STUDY AREA

The study area is located along Olujoda – Moferere road (Ado-Ikere), Ado-Ekiti, the capital city of Ekiti State and Igbole Ekiti in Ido/Osi Local Government area of Ekiti State, South Western Nigeria. The towns are located between latitude $07^{0}\ 30^{1}$ and $07^{0}\ 49^{1}$ of the equator and longitude $05^{0}\ 07^{1}$ and $05^{0}\ 27^{1}$ east of the Greenwich Meridian (Ebisemiju, 1993; Ekiti State Surveys, 2002). The soil samples were collected from a borrow pit, 1.4km away from Olujoda Hotel along Ado – Ikere road while palm kernel shells and cocoa pods were obtained from a local oil palm processing center (Eku) and cocoa plantation respectively at Igbole-Ekiti in Ido/Osi Local Government area where they were abundantly available.



L1 - Sample site 1 at cocoa plantation Igbole Ekiti.
L2 - Sample site 2 at local palm produce (Eku) Igbole Ekiti.

Fig. 1.1A: Administrative Map of the Study Area (Ido/Osi & Environs)

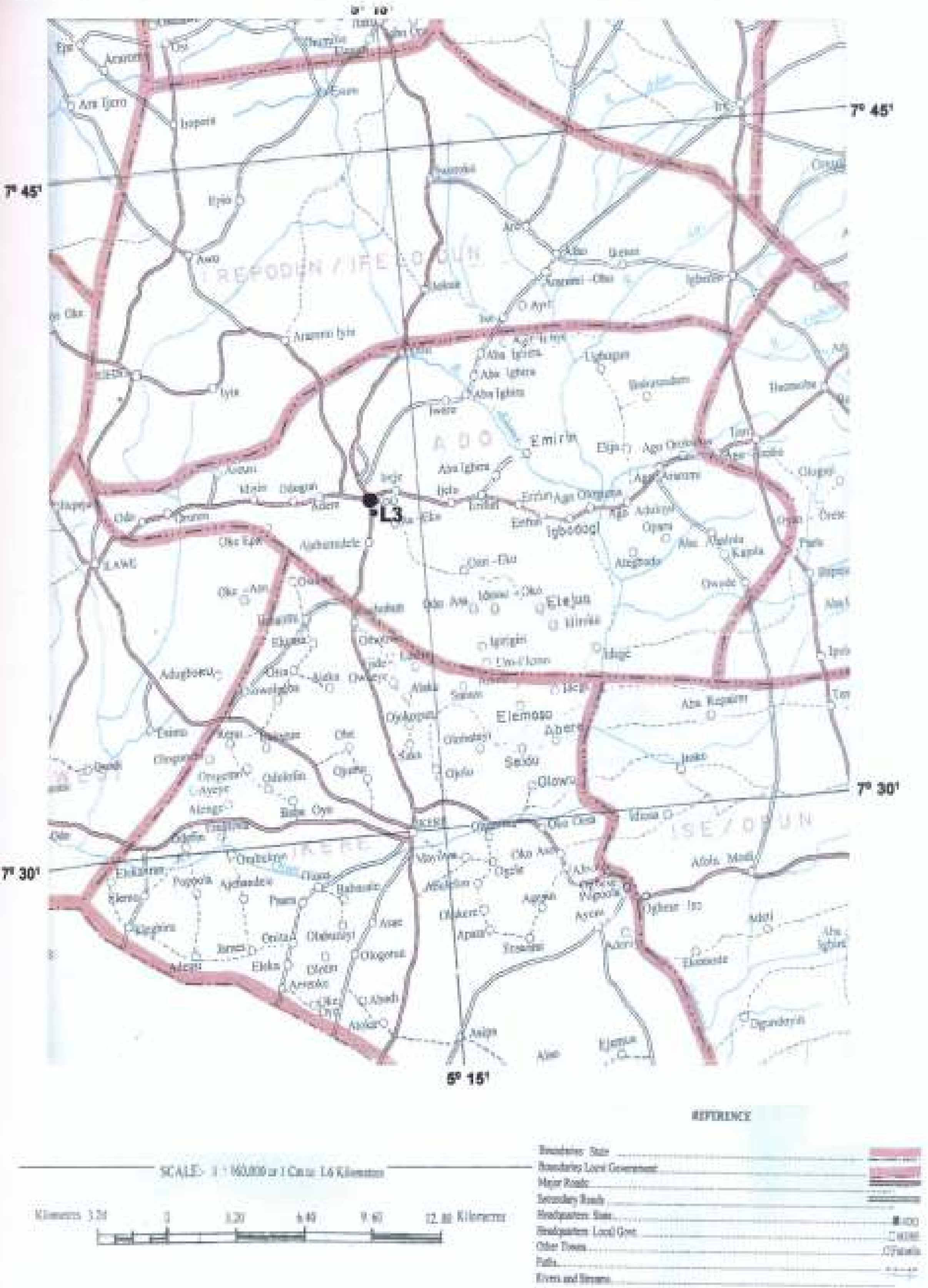


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Fig. 1.1B: Administrative Map of the Study Area (Ado-Ekiti & Environs)

Note: Figures 1.1A & B are extract from administrative map of Ekiti State

1.7 REGIONAL GEOLOGY

The geology of Ado-Ekiti is dominated by crystalline rocks of the basement complex of southwestern, Nigeria (Fig. 1.2). The rock sequence in the area is as follows:- pegmatites and aplites series, gneisses and migmatites. The rock generally trend north-south in direction. The granitic rocks are found in the western and Northern parts of the area while the charnokitic rocks are located within a narrow belt of intrusive within the granitic rocks. The mignatites are found in the eastern part. The quartzite rock type are located in the western and central area as elongated bodies within the granitic and charnokitic rocks.

The lateritic soils found within Ado-Ekiti are abundant and are the bi-product of rocks mentioned above. The nature and type of laterite soils found in the area depends greatly on the parent rock from which they have been derived. They vary from highly clayey lateritic soils for charnokite-derived from gneissic silty soils for those derived from gneissic and migmatitic rocks. The gravelly lateritic soils are those derived from the elongated bodies of quartzite. The gravelly texture is a product of partial weathering resulting from the relatively resistant quartzite bodies.

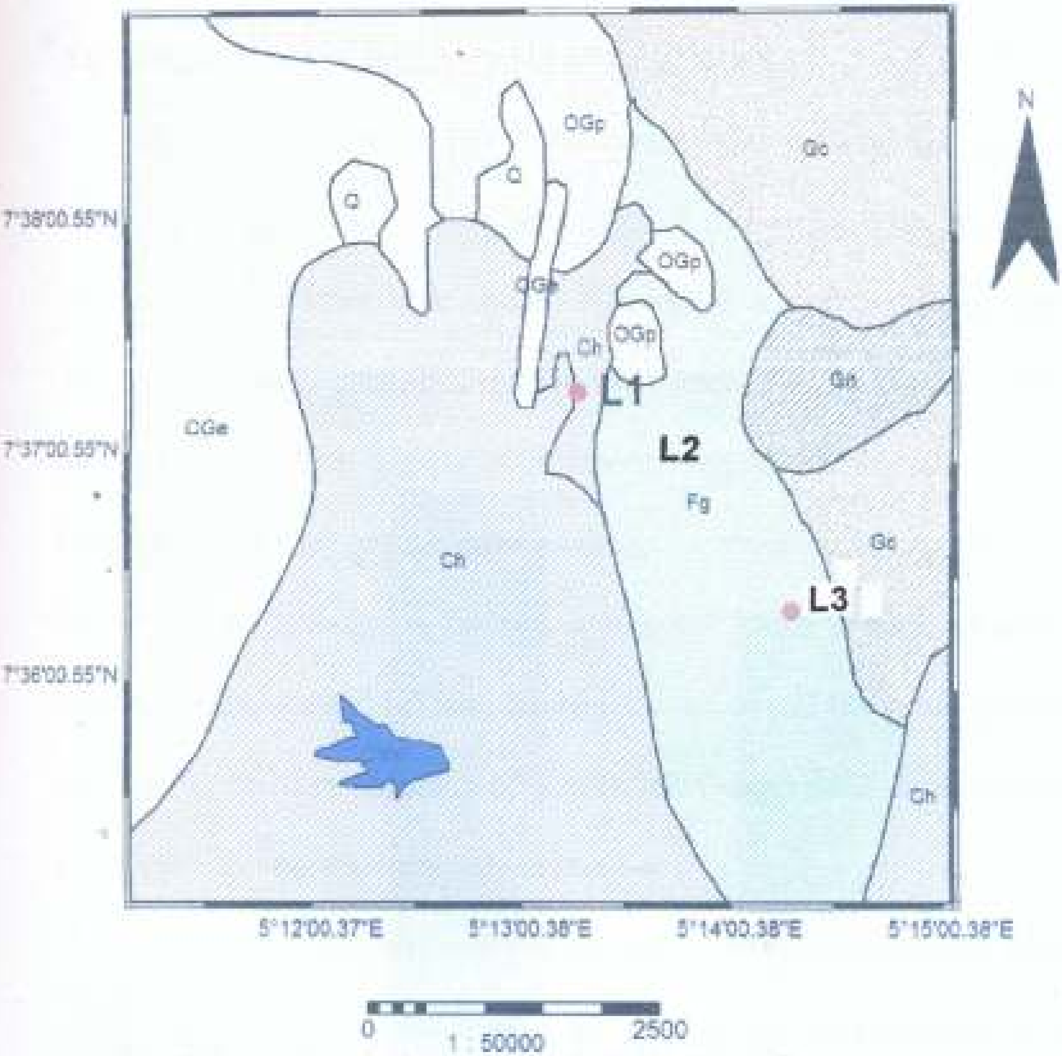

Fig. 1.2: Geological Map of the Study Area (Modified after Geology of Nigeria Akure Sheet 61)

Ch: Charnockite (coarse grained)
OGp: Coarse porphyritic biotite & biotite-hornblende
Fg: Fine Grained Charnockite
OGf: Fine to medium grained biotite and biotite-muscovite
Gc: Gneissic Charnockite
Gn: Granite gneiss
OGe: Medium grained biotite-granite
Q: Quartzites
Dam: Ureje Dam

KEY:
L1 - LOCATION 1
L2 - LOCATION 2
L3 - SAMPLE SITE 3 AT ADO-EKIT

CHAPTER TWO

2.0 REVIEW OF RELATED LITERATURE

Considerable work has been carried out on lateritic soils in many countries over the years. The attention given to lateritic soils by soil engineers is as a result of their wide-spread distribution and engineering applications. The most common materials used in the construction or rehabilitation of rural access roads in the tropics in Southern Nigeria are lateritic soils. This is because: (a) as they are the most common naturally occurring materials; (b) in the tropics weathering is intense, and hence there is lack of good quality crushed aggregate and (c) long haulage distances and the associated high costs involved in the transportation of good quality aggregates, make the utilization of lateritic gravels economically attractive.

Some lateritic soils and gravels make good materials for subbase and base construction of roads as they are easy to win and to apply on the road surface. They also have naturally stable grading with a suitable proportion of clayey materials to act as binder. However, in most parts of the tropics, there is only a limited choice of sufficiently hard concretionary laterite aggregates to be used in road surface dressing and often the significant silt and clay contents render the material moisture sensitive.

Soil stabilization occurs when additive is added to a reactive soil to generate long-term strength gain through a pozzolanic reaction e.g Lime and Cement. This reaction produces stable calcium silicate hydrates and calcium aluminate hydrates as the calcium from the lime reacts with the aluminates and silicates from the clay. The key to pozzolanic reactivity and stabilization is a reactive soil a good mix design protocol and reliable construction practices. In the soil stabilization or modification, the clay surface mineralogy is altered, producing the following benefits: plasticity reduction, reduction in moisture holding capacity (drying) swell reduction, improved stability (i.e continued strength gain with time, even after periods of environmental load damage) and the ability to construct a solid working platform (National Lime Association, 2001).

2.1 DEFINITIONS OF LATERITE BY VARIOUS AUTHORS

Bell, 1994 works on chemical compositions of lateritic soils defined laterite soils in terms of the silica alumina ratio ($Si\ O_2 : Al_2\ O_3$) as

* True laterites (those with silica-alumna ratio less than 1.33
* Lateritic soils (those with ratio between 1.33 and 2.00)
* Non-lateritic (with a ratio greater than 2.00).

Also, a chemical approach based on the silica to sesquioxide ratio i.e $SiO_2/(Fe_2O_3 + Al_2O_3)$ of less than 1.33 are indicative of laterites (Ola 1983).

Laterite is any group of deposits consisting of residual insoluble deposit of ferric and aluminium oxides formed by weathering of rocks in tropical regions (Collins English Dictionary).

Alexander & Cady 1992 defined laterite as a highly weathered material that is rich in secondary oxides of Fe, Al or both, nearly void of bases and primary silicates, but it may largely contain quartz and kaolinite. It is either hard or capable of hardening on exposure to alternate wetting and drying.

A good number of studies of several investigations revealed that laterite is a weathered product of various materials including crystalline igneous rock sediments and volcanic ash.

From the various definitions above, it can be concluded that lateritic soils contain aluminium, iron and silica in varied proportions and based on the constituent components of laterite.

2.2 ORIGIN AND FORMATION OF LATERITES

Laterites is a residual soil formed from the weathering of igneous rock under conditions of high temperature and high rainfall such as those typically occurring in tropical regions, where the decomposition process results in a soil leached of silica (SiO_2) and calcium (IV) oxide but retaining high concentration of iron and aluminium sesquioxides (Fe_2O_3, Al_2O_3). The resulting concentration of iron and aluminium oxides sharply differentiate laterization from temperate climate weathering in which the end product is largely clay minerals. As a result of heavy rainfall during the wet season, followed by the dry seasonal high temperature and rapid evaporation of the tropics, plants draw water far below the ground to replenish the ones lost to the atmosphere; as long as the supply holds. The weak solution produced by leaching of the rocks during the wet season thus become concentrated by evaporation and dissolved minerals are deposited. This leads to the accumulation of iron and aluminium hydroxides which are insoluble and are not re-dissolved during raining season and are therefore left at or near the surface where they form a thick red to black soil called laterite.

Gidigasu (1976), identified three stages in the process of laterization. The first stage, (decomposition) is characterized by physico-chemical breakdown of primary minerals and the release of constituent elements. The second involves the leaching under appropriate drainage conditions of combined silica and bases and the relative accumulation or enrichment from outside sources. Absolute accumulation of oxides and hydroxides of sesquioxides (mainly Al_2O_3 and Fe_2O_3, the most resistant components to leaching). The third stage (dehydration or desiccation) involves partial or complete dehydration sometimes involving hardening of the sesquioxide rich materials and secondary minerals.

Under tropical conditions of high temperature and rainfall, the clay minerals tend to decompose into various forms of alumina and iron oxides in relation to the nature of weathering conditions. The free iron oxide content and the degree of dehydration and/or hardening as well as the unique granular structure of some lateritic soils are believed to underlie the difference in engineering behaviour of some lateritic soils from the temperate soils. It was suggested that contemporary lateritic soils have developed at mean annual temperature of about 25^0C, hence lateritic soils are believed to always correspond to tropical climate (Gidigasu 1976).

The most significant differences in the temperate soils and lateritic soils are:

- The significant proportions of irons and aluminium oxides found in lateritic soils which tend to cement the soil particles to form a coarse grained weakly bonded particulate material and
- The relatively high temperature of laterite formation which is a feature of tropical climate (Ola 1983).

2.2.1 DISTRIBUTION AND MORPHOLOGY OF LATERITES

Laterites are found all over the world especially in inter-tropical regions of Africa, Australia, South-East Asia, India and South America. Their extension show that their formation is favoured by some conditions at one time or the other in the history of the world but not necessarily simultaneous at all points. Laterite profiles are generally of three types, those in which the crust is derived from; they are: the overlaying soil (downward transport/leaching, from underlying weathered rock (upward transport) and those in which the crust forming material is detrital (that is transported and deposited and/or precipitated. The laterite profiles that develop in-situ have a number of horizons. The horizons vary in thickness; hardness and colour depending upon the degree of development and preservation of the profile.

Carthy (1993) opined that deposits of laterites are found in a hard or cemented state particularly in areas where vegetation is sparse or has been removed. Also as hardened occurrences, laterite extends beyond sub-humid tropical climate to desert regions where there are indications of humidity in the past.

Abundance of laterite gravels and soils are located in the Precambrian basement complex area in the northern part of Nigeria. They are found in large quantities in the southern part of Nigeria and constitute about 50-70% of the total soil. Laterites can be associated with a characteristic profile forming the following level in descending order as shown in the figure below.

* A surface zone with ferruginous encrustation and concreting.
* A lateritic bed
* A zone of primary alteration to kaolinite
* A fresh zone of unaltered rock.

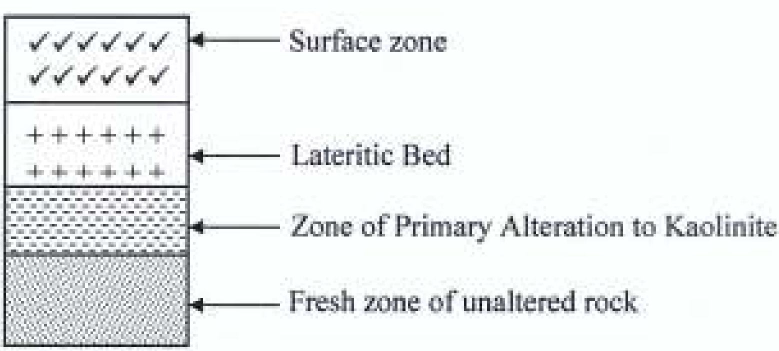

Fig 2.1: Typical lateritic soil profiles

(Source: Nigerian Educational Research and Development Council, 1999)

2.2.2 PROPERTIES AND COMPOSITION OF LATERITIC SOIL

The behaviour of laterites in pavement structures have been found to depend on their particle size characteristics, the nature and strength of gravel particles, the degree of which the soil has been compacted; the traffic volume and the climate. When the grading of lateritic gravel is close to a mechanically stable particle size distribution, the material performs satisfactorily both as unstabilized base and/or subbase in light-trafficked gravel roads (Thagessen, 1996). A satisfactory performance of laterite pavements has generally been reported on laterite gravels that possess adequate drainage.

Geotechnical characteristics and field performance of lateritic soils as well as their reaction to different stabilizing agents may be interpreted in the light of all or some of the following parameters: genesis and pedological factors (parent material, climate, topography, vegetation, period of time in which weathering processes have operated); degree of weathering (decomposition, sesquioxide enrichment and clay-size content, degree of leaching) and position in the topographic site (Ola, 1983).

Particle size distribution may provide the following information: a basis for identification and classification of soils, the compatibility characteristics, permeability, swellability and a rough idea of deformation characteristics of the soil mass. Texturally, lateritic soils are very variable and may contain all fraction sizes like boulders, cobbles, gravel, sand, silt and clay as well as concretionary rocks. Quartzitic gravels, which are formed from the alteration of quartz rich parent rocks, are generally well graded with 20% of silt and clay size fraction. Concretionary laterites have a higher content fines ranging between 35% to 40% foot slope concretionary laterite gravels are coarse and gap graded (less sand), compared to high level gravels (Gidigasu, 1976).

Pretesting preparations of lateritic soils for sieve analysis may have the following effects on the size distribution: remoulding and removal of free iron oxide increases the content of fines between 35% to 65% (this will be a function of the dispersing agent), degree of drying and time of mixing of the sample prior to testing influence the degree of dispersion of laterite soils and cementing effect of sesquioxides which bind clay and silt fractions into coarser fraction (Thagessen, 1996).

Plasticity characteristics of laterite soils: the interaction of the soil particles at the microscale level is reflected in the consistence limits or atterberg limits of the soil at microscale level. Knowledge of the Atterberg limits provides the following information: a basis for identification and classification of a given soil, texture, strength and compressibility characteristics and swell potential of the soil or the water holding capacity.

Atterberg limits depend on: the clay content, plasticity increases with increase in clay content (Filipovski, Ciric 1969); nature of soil materials, only minerals with sheet-like or plate-like structures exhibit plasticity. This is attributed to the high specific surface area and hence the increased contact in plate shaped particles, chemical composition of the soil environment; the absorptive capacity of the colloidal surface of cations and water molecules decrease as the ratio of silica to sesquioxides decrease. Plasticity tests may be affected by pre-test preparation, degree of moulding and time of mixing, drying and rewetting, and irreversible changes in plasticity on drying. Drying drives off absorbed water which is not completely regained on re-wetting (this is the case in both oven and air drying) (Fookes, 1997). Distilled water should always be used to minimize the effect of ion exchange on plasticity. Soils which contain hydrated oxides of iron and aluminium may become less plastic on drying. This is partly because hydration of sesquioxides creates a strong bond between the particles, which resists penetration by water. This process can not be reversed by re-wetting but is more pronounced on oven drying at higher temperature (Fookes, 1997).

Bowels (1985) gave the following classification for soils with various specific gravity values as shown in Table 2.1.

Table 2.1: Typical Specific Gravity Values

Type of Soil	*Specific Gravity (Gs)*
Sand	2.65 – 2.67
Silty sand	2.67 – 2.70
Inorganic clay	2.70 – 2.80
Soils with micasand iron	2.75 – 3.00
Organic soils	Variable, but under 2.00

He observed that the higher the degree of laterization, the greater the specific gravity. Specific gravity of laterites vary in relation to their chemical composition, increasing with iron content and decreasing with alumina; the coarser the soil fraction, the higher the specific gravity. The looser the soil structure, the lower the specific gravity. The specific gravity of oxidized forms is higher than that of hydrated forms.

Lateritic soils seem to be typified by a gap grading existing with a prevalence of gravel sized and clay materials but having limited sand and silt-sized particles. The pH value of laterite is dependent on the exchangeable cation of the soil. The cation type that can exist in a particular soil depends on

(i) Mineralogy of the parent material

(ii) Organic proportion present in the soil

Kaolinite, the predominant mineral in Nigeria lateritic soils has low cation exchangeable cation and the pH value does not deviate much from 7. Soils that have high cation exchangeable cation have their value in the alkaline range. Most laterite soils have sodium as exchangeable cation and the pH value is slightly acidic to neutral (5-7).

The mechanical grain sizes of the lateritic soil will affect its reaction under load. If the laterite is more of sandy soil, its properties will exhibit low compressibility, high permeability, high friction and low cohesion, but if it is more of clay soils, its properties will exhibit high compressibility, low permeability, high cohesion and low friction. Laterites generally have granular structure, therefore they have fairly large internal angle of friction. The higher the angle of friction, the higher the strength of the soil.

Another property of laterites is the tendency of expansiveness or compressiveness of the soils depending on the specific surface area of the constituent particles. Kaolinites that have low specific surface area have low expansiveness or compressiveness but montmorillonites have high specific surface area have high expansiveness or compressiveness. The mineralogical composition of most laterites are kaolinite, goethite, gibbsite, heamatite, microcline, illite, halloysite, attapulgite and quartz.

2.2.3 WATER CONTENT OF SOILS

The amount of water in a soil is important when stabilizing a soil. There is an optimum water or moisture content that will allow for optimum soil workability and provide the maximum density in the soil for the compact effort applied. Generally, as the percentage of fine-grained material in a soil increases, as the amount of clay versus silt increases, the optimum water content will increase-maximum density and best result will occur if the water content is near the optimum value. Water contents that vary widely from the optimum amount will hinder or prevent compaction and proper stabilization (Air Force Handbook 1998).

2.3 SOIL STABILIZATION

Stabilization in a broad sense, incorporates the various methods employed for modifying the properties of a soil to improve its engineering performance. The highway engineer is continually faced with the problem of increasing the strength and stability of the natural soil in order to improve its bearing properties.

Solidification/Stabilization (S/S) treatment generally consists of mixing of chemical binders with sludge with addition of water prior to dry curing of the cementitions mixture for several days. Established S/S binders include cement and water which contain high amount of calcium oxide (CaO), an ingredient essential to increase the pH of the mixture to facilitate precipitation. Research on S/S of industrial sludge are abundant (Qian et al, 2006; Diet et al, 1998; Singh and Pant, 2006; Phenrat et al, 2005).

Winterkorn (1972) opined that the chief objectives of stabilization are to improve soil strength, bearing capacity and durability under cyclical conditions such as varying moisture content or repeated application of stress. In the developing countries like India, soil stabilization methods with locally available materials have considerable scope in reducing the initial construction cost of highway pavement and for stage construction (Bindra, 1981). According to him, soil stabilization for highway purpose can be divided into the following main groups. They are: mechanical stabilization, cement stabilization, lime stabilization and bituminous stabilization. Other methods of stabilization may include chemical stabilization, thermal stabilization and electrical stabilization. He said that climate changes affect stabilization requirements.

Soil stabilization has been in the building of roads, aircraft runways, earth dams, embankments, in erosion control and in the reduction of frost heaving the possibility of employing stabilized soil for the building of houses at low cost in undeveloped region of the world has been considered by the United Nations Organisation and by others (Rawi and Toma, 1989).

2.4 CHEMICAL STABILIZATION

Various chemical compounds, including those listed below, have also been used, often on an experimental basis, as stabilizers: Calcium chloride; Magnesium chloride. The use of chemicals, may possibly provide short-term advantages by acting as a dust suppressant and providing binding action to form a hard running surface. However, the long-term advantages appear to be limited as a result of leaching of the stabilizer from the pavement. Because of the life expectancy, and possible adverse effects from using some chemicals, their use in the treatment of pavement materials is not recommended as a long-term solution to materials instability. The benefits and costs of using chemicals compared to a bituminous seal or stabilization by mechanical means or using lime or cement needs to be analyzed in the light of relevant experience. This experience to date appears to indicate that the benefits from using chemical stabilization may be short-lived due to the effects of leaching of the chemical from the treated material.

In addition to the chemicals listed above, several proprietary brands of stabilizers are available. These products are generally by-products of manufacturing processes such as pulp and wood processing, and to date appear to perform similarly to the chemical discussed above, particularly with respect to their life span and effectiveness. Nevertheless, authorities have used such products with varying degrees of success depending on the function to be performed or the problem to be overcome (Air Force Handbook 1998).

High costs attributed to costs of cement and lime usually indicate that industrial waste sludge generators have to incur significant costs for S/S treatment. As such, most of them refuse to do so and opt to illegally storing sludge within their premises or dispose sludge in nearby areas. This problem is especially rampant in developing countries. Therefore, S/S research in recent years have been focused on sage of recyclable waste materials to substitute cement and lime. In order to enable a more cost-effectiveness S/S treatment design, S/S specialists often substitute portions of S/S binder with industrial wastes such as incinerator bottom ash. (Qian et al, 2000) and coal fly ash (Singh and Pant, 2006).

2.4.1 CHOICE OF ADDITIVES FOR TYPES OF SOIL

Cement is described as a material with adhesive and cohesive properties that make it capable of bonding material fragments into a compact whole. For constructional purposes, the meaning of the term cement is restricted to the binding materials used with stone, bricks, and sandcrete blocks. The principal constituents of cement are components of lime, clay and other materials. (New Standard Encyclopedia, 1982).

The most famous use of cementitious material dates back to more than 25 centuries to the Roman Construction of aqueducts and the Appian way. Very little was known of these early cementing materials until 1956, when John Smeaton, an English government employee, discovered that a mixture of limestone and clay would harden into a solid mass when burned.(Ingines and Metcalf, 1992) Cement affects soils in two ways. First, by surface chemical action, it reduces the moisture affinity of clays. Second, it promotes cementation (the process of impregnation of soils with cement to strengthen them and make them water tight) thereby producing a semi rigid soil framework.

2.4.2 ORDINARY PORTLAND CEMENT

Cement stabilization processes have different names in literature. They these names include soil-cement, cement-stabilized soils and stabilized aggregates. Soil cement stabilization is a method of construction in which cement is mixed with pulverized soil to form a material which when compacted and allowed to harden, possesses appreciable and considerable resistance to weathering. Studies (Ashworth 1976) revealed that this form of construction method was first introduced in Great Britain in the year 1917. Report also shows that the greatest proportion of soil cement construction was carried out in the U.S.A. from 1935 and later in South Africa and in Germany (Karmuzzaman, 2002).

Portland cement is the chemical most successfully used in soil stabilization for road construction. Almost all soils respond to treatment with cement. However, chemical conditions of some soils (by interfering in the hydration of cement) and high plasticity of others (by preventing an intimate mixture) have limited the use of Portland Cement. Below is the table that shows the chemical analysis of Portland Cement.

Table 2.2: Chemical Analysis of Portland Cement by absorption spectroscopy (optimum conditions for each element in the concentration as percentage of their oxides)

Element	Concentration ranges (percentage of their oxide)
Ca as CaO	60 – 66
Al as Al_2O_3	0 – 0.7
S_i as SiO_{20}	18.5 – 24
Fe as Fe_2O_3	0 – 4.5
Mg as MgO	0 – 4.0
Na as Na_2O	0 – 0.7
K as K_2O	0 – 0.7

Source: Ademoroti (1996)

Non-plastic soils are readily liable to cement stabilization. Cement can be used to stabilize materials ranging from cohesionless sands and gravels to silts and plastic clays. Most soil types are suitable for soil cement except those containing an appreciable amount of active organic matter and also coarse-grained soils with materials exceeding 50mm size which may damage the mixing or pulverizing equipment of machinery. Any cement may be used for stabilization. If a special type of cement is used, it is important to determine the effects of the changes by the laboratory tests. Rapid-Hardening cements may be justified for soil containing organic matter. Calcium chloride additions can also assist in the stabilization of organically contaminated soils. In soil-cement stabilization, the cement content required to produce a good job varies between 5 and 15% of the dry weight of the soil depending on the type of soil and is determined by the strength requirements of the mix.

When making the initial laboratory tests to determine the required cement content, it is important that the specimens are prepared at the same moisture content and compacted to the same density as will be achieved in the actual stabilized layers since strength is a function of these factors as well as cement content. The mixture content of the stabilized material will be determined by the vibrating method. The preliminary trial should be carried out at least ten days before the main work of stabilization is started. Regular site control testing of the cement stabilized material should be carried out to ensure that the compacted material is capable of achieving the specified strength requirements.

Studies have shown that the compressive strength of soil-cement mixtures will increase with time of curing as does that of concrete. Soils with similar physical properties but different chemical properties may vary largely in compressive strengths when stabilized with equal amount of cement. Similarly, for soil cement (design on the basis of durability or strength after 7 days of curing), it is observed that the strength increases with age.

Economy plays an important role in soil-cement stabilization process, hence the decrease in cement is much to be desired. Additionally, it may also reduce shrinkage and the resulting cracking of the soil-cement pavements under service load. However, it should be noted that the quality of the compacted stabilized soil depends on

(i) Breakdown and mixing

(ii) The quality and quantity of water used for mixing and curing

(iii) Compaction

(iv) Curing conditions

2.4.3 CEMENT STABILIZATION

Depending on the soil type, 3% to 10% of cement by weight of dry soil is mixed with the soil to cause it to harden into a compact mass, which will not soften in the presence of water. Cementation is based on hydration of water. The major hydration products are a series of calcium silicate hydrates (CHS) and hydrated lime, $Ca(OH)_2$ (Joint Departments of Army and Air Force 1994).

2.4.4 CEMENT STABILIZATION MECHANISM

Kamruzzaman 2002 opined that cement has been found effective in stabilizing a wide variety of soils, including granular materials, silts and clays. Cement – stabilized materials generally fall into two classes – soil – cement and cement modified soil. Soil – cement is a mixture of pulverized soil material and/or aggregates, measured amounts of Portland cement, and water that is compacted to a high density. Enough cement is added to produce a hardened material with the strength and durability necessary to serve as the primary structural base layer in a flexible pavement or as a subbase for rigid pavements. Cement-treated aggregate base and recycled flexible pavement are considered soil-cement products.

Cement-modified soil is a soil of aggregate material that has been treated with a relatively small proportion of Portland cement (less cement than is required to produce hardened soil cement) with the objective of altering undesirable properties of soils or other materials so that they are suitable for use in construction. Cement-modified soil is typically used to improve subgrade soils or to amend local aggregates for use as base in lieu of more costly transported aggregates.

Portland cement is composed of calcium silicates and calcium aluminates that, when combined with water, hydrate to form the cementing compounds. Portland cement may be successful in stabilizing both granular and fine-grained soils, as well as aggregates and miscellaneous materials. Pozzolanic reaction between the calcium hydroxide release during hydration and soil alumina and soil silical occurs in fine-grained clay soils and is an important aspect of the stabilization of these soils. The permeability of cement stabilized material is greatly reduced. The result is a moisture-resistant material that is highly durable and resistant to leaching over the long term.

Cement stabilization of clayey materials results from the complex combination of mechanical and chemical bonds which depend on reactions between cement and soil particle surface (Chew et al, 2004).

In all practical cases, the primary ingredient necessary for stabilizing soils is calcium. In addition to plasticity reduction, Portland cement by its inherent nature of producing strength developing hydration products provide improved strength and durability. Therefore, the effectiveness of stabilization is based on the time (curing-soaking time) of reactions provided by cation exchange and flocculation processes. These are related with the number of positions of exchangeable ions. (Type of clay minerals – active or inactive) of a clay and the amount of librated ions from cement (% of cement) which influence the durability (bonding effect) and unconfined compressive strength (bearing capacity).

Concerning the amount of stabilizer for each soil, the choice depends on the availability, the costs and the economic conditions of the concerned area and time of construction. The amount of cement required to improve the quality of the soil through modification is determined by the trial and error approach. If it is desired to reduce the PI of the soil, successive samples of soil-cement mixtures must be prepared at different treatment levels and the PI of each mixture is determined. The general range of additive (% of total mass) for cement is between 5 and 11; lime is 1.5-8; for Bitumen 1-10 and fly-ash mixture is 10-20 variable with gradation. (Joint Departments of the Army and

Air Force 1994). Studies (Ola 1983) recommended the percentage of cement for road construction as: 3 percent for A1 and A2 soils, 5% for A4 soils and 7% for A6 and A7 soils.

Table 2.3: Cement Requirements for various soils

Soil classification	*Initial estimated cement content percent dry weight*
- GW, SW	5
- GP, GW-GC, GW-GM, SW-SC, SW-SM	6
- GC, GM, GP-GC, GP-GM, GM-GC, SC, SM, SP-SC, SP-SM, SM-SC,	7
- GL, ML, MH	9
- CH	11

Source: Joint Departments for Army and Air Force (1994)

Cement – Stabilization of clay soils within the time constraints usually in the field (e.g in transportation engineering products – road pavements, embankments, temporary support of excavations, shallow foundations etc) provides that curing time (the time of development reactions by cation exchange and flocculation processes) plays a vital role to the achievement of efficient cement stabilization. In particular, curing time influences strongly the engineering properties such as strength and durability of cement stabilized soil mass as well as the construction and usage time of infrastructural soil works (Kamruzzaman, 2002).

The first controlled soil cement construction was a road built in 1935 near Johnsonville, South Carolina, U.S.A. Since then, soil cement has been increasingly used as a satisfactory base, sub-base and to improve the subgrade for modern, highway and air field pavements (Suphi, 2005).

2.4.5 LIME STABILIZATION

Lime stabilization is achieved with calcium oxide (quick lime) or calcium hydroxide (slaked lime). The stabilization mechanism of lime is similar to that of cement. Lime acquires silica or other pozzolans in the soil to form calcium silicate hydrates (CHS) gel. Cement contains silica initially. Lime reduces plasticity by replacing troublesome cations such as sodium with calcium. At the same time, coagulation takes place and the coarse lime particles absorb a good deal of free water resulting in dehydration by weight of dry soil are typical improvement of plastic and expansive soils (Mitchell, 1982).

2.4.6 SOIL STABILIZATION USING FLY ASH

Soil stabilization involves the addition of fly ash to improve the engineering performance of a soil. This is typically used for a soft, clayey subgrade beneath a road that will experience many repeated loadings. Improvement can be done with both class C and class F fly ashes. If using a

Class F fly ash, an additive (such as lime or cement) is needed whereas the self-cementing nature of class C fly ash allows it to be used alone.

Flu ash is also used as a component in the production of flowable fill (also called controlled low strength material or CLSM), which is used as self leveling, self-compacting back fill material in liew of compacted earth or granular fill. Fly ash can replace either the Portland cement or fine aggregate (in most cases, contents mixes contain nearly all fly ash, with a small percentage of Portland cement and enough water to make the mix flowable. Low fly ash content mixes contain a high percentage of filler material, and a low percentage of fly ash, Portland cement and water. Class F fly ash is best suited for high fly ash content mixes, where as Class C fly ash is almost used in low fly ash content mixes (Hennis & Frishette 1993).

The hydrophobic nature of fly ash gives pavements better resistance to stripping. Fly ash has been shown to increase the stiffness of the asphalt matrix, improving rutting resistance and increasing mix durability. (U. S. Federal Highway Administration). More recently, fly ash has been used as a component in geopolymers, where the reactivity of the fly ash glasses is used to generate a binder comparable to a hydrated Portland cement in appearance and properties, but with dramatically reduced CO_2 emissions. (Duxson, et al., 2007).

The lower the plasticity index of a soil, the better the soil for construction purposes. Ola (1983) listed some factors that affect plasticity and there are parent material, degree of laterization, clay size content, type of clay mineral and topographic conditions.

2.4.7 LIME-FLY ASH STABILIZATION

Use of lime and cement may be extended by the addition of pulverized fly ash, (PFA) according to Bell, (1994). The three predominant elements in PFA produced by burning coals are silicon, aluminium and iron, the oxides of which together account for 75-95% of the material (Sherwood, 1995). Such ashes are known as alumino-silicate fly ash. There is another variety, known as sulpho-calcitic fly ash, which is produced by the combustion of coal with a high limestone and sulphur content. PFA therefore has pozzolanic properties, and can be used with lime to form cementitious gels. It has been reported that mixtures of cement or lime do not give as good results as when lime and cement are used on their own. However, Bell (1994) remarks that, it may be worth making some sacrifices in soil improvement in cost that the use of PFA brings.

As land is a very precious commodity and landfill are fast dwindling in most highly urbanized cities, the disposal of the ash generated from MSW the municipalities, a viable solution to the disposal problems would be the reuse of MSW ash for Civil Engineering application. A research study of the properties of the incinerator fly ash derived from MSW incineration indicated that fly ash is a potential source of jet-grouting admixture for soil improvement. The fly ash exhibits a likelihood of pozzolanic reaction due to its chemical composition and physical characteristics. The use of fly ash as an admixture in the stabilization of a soft marine clay resulted in stabilized samples with an improved strength more that 75 times that of the untreated clay (Kuan, Joo, Anthony (2003).

Afsin-Elbistan (AE) coal fly ashes obtained by burning coal samples from top, middle and bottom sections of the AE coal seam were characterized and their properties were compared. Chemical analysis of the AE coal fly ashes showed that they are mainly composed of CaO, S_iO_2, Fe_2O_3 and Al_2O_3 (Suphi 2005).

2.4.8 BITUMEN STABILIZATION

In bituminous stabilization, bitumen materials or road tars are mixed with soil so as to water proof the particles and/or provide the additional cohesion necessary for stabilization. The amount of binder normally ranges between 4% and 7% (Joint Departments of Army and Air force 1994).

2.5.0 THE USES OF ASHES

Many countries have the problems of shortage of conventional cementing materials. Recently, there are considerable efforts worldwide of utilizing indigenous and waste materials in concrete. One of such materials is the rice husk which under controlled burning, and if sufficiently ground, the ash that is produced can be used as a cement replacement material in concrete. (Anwar, Miyagawa, Gaweesh (2000)). High costs attributed to costs of cement and lime usually indicate that industrial waste sludge generators have to incur significant costs for S/S treatment. As such, most of them refuse to do so and opt to illegally store their sludge within their premises or dispose their sludge at nearby areas. This problem is especially rampant in developing countries. Therefore, S/S research in recent years have been focused on sage of recyclable waste materials to substitute cement and lime. In order to enable a more cost-effective S/S treatment design, S/S specialists often substitute portions of S/S binder with industrial wastes such as incinerator bottom ash. (Qian et al, 2000) and coal fly ash (Singh and Pant., 2006). Ashes from cocoa pods are found to be one of the active ingredients in our black soap (Prweb, 2008). It is also found useful in this research as an admixture.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 MATERIALS

The materials used in this research were cement, water, ashes from both cocoa pods and palm kernel shells, and laterites. Below are the sources of these materials.

* **Cement**

The cement used for this research was an ordinary Portland cement (Elephant) purchased from retailers in Ado-Ekiti and Akure.

* **Water**

The water used was collected from one of the bore-holes that serve the Federal University of Technology (Akure), precisely the one that serves Obanla Community.

* **Cocoa Pod Ash**

The cocoa pods ash were obtained from a plantation at Igbole-Ekiti (Location L_1 of fig 1.1A) in Ekiti State where they were abundantly available. They were collected at average inherent moisture content of 0.5%. This was oven dried to 0% moisture content at a temperature of 110^0C. The oven dried samples were further heated in an open-top kiln to a temperature e of 610^0C at which the material ignited spontaneously with large supply of oxygen. Appreciable ashes began to appear in the furnance at a temperature of 800^0C.

The test was conducted at the Science Technology Laboratory of the Federal Polytechnic, Ado – Ekiti.

* **Palm Kernel Shell Ash**

The palm kernel shells were obtained from a local palm produce (Eku location L_2 of fig 1.1A) at Igbole-Ekiti in Ekiti state where they were abundantly available. They were collected dry at average inherent moisture content of 0.1%. This was oven dried to 0% moisture content at a temperature of 110^0C at which the material ignited spontaneously with large supply of oxygen. Appreciable ashes began to appear in the furnance at a temperature of 1000^0C. This test was also conducted at the Science Technology Laboratory of the Federal Polytechnic, Ado – Ekiti.

* **Laterite**

Samples of lateritic soils used in this research were collected at varying depths from 0.5m to 1.5m on a major borrow pit along Ikere Road after the top soil had been removed. The soil sample is brownish red in colour. The material was air dried and thoroughly mixed to ensure a true representation of the sample. The soil sample properties and effect of mixing cement, ashes from cocoa pod and palm kernel shell were to be determined experimentally. The total additives content used were 2%, 4%, 6% and 8% for each test carried out on the samples. These proportions are generally acceptable for cement soil stabilization.

3.2 TESTING PROCEDURES

The procedures used in carrying out the underlisted tests for this research work were in accordance to British Standard Methods (BS 1377) and AASTHO specification.

The following tests were carried out on the soil sample used.

Classification test which include particle size distribution, Atterberg limits, specific gravity and natural moisture content.

Compaction test to determine the moisture-density relations of the sample.

California Bearing Ratio (CBR) tests

The chemical additive used for stabilizing the soil were

* Cement;
* Ashes from cocoa pods;
* Ashes from palm kernel shells.

3.3 PRE-TREATMENT OF SAMPLES

The materials used for this research were collected and treated for analysis as indicated below

* **Laterite**

When the sample was taken to the laboratory, organic debris materials such as roots, leaves were removed. The sample was air-dried, broken down with mortal and pestle.

* **Ashes from Cocoa Pods and Palm Kernel Shell Treated**

The standard procedure used in carrying out the chemical composition (metal concentration) of the materials for this work was in accordance to the Stiward Methods (described by Official Analytical Methods of Association of Official Analytical Chemist) 1990., Ademoroti; 1996 and Rowel, 1993).

To compare relative effects of the additives on performance of sample, varying proportions of cement and the Ashes from cocoa pods and palm kernel shells were used to prepare mixtures.

The amount of additives used are expressed as percentage of the dry weight of the sample. The total additives content used were 2%, 4%, 6%, 8%. These proportions were generally acceptable for cement soil stabilization. (Joint Department of Army and Air Force 1994).

Table 3.1: Material Proportions for Sample Preparation

Experimental No (Label)	*Soil Sample*	*Cement %*	*Cocoa Pod Ash %*	*Palm Kernel Shell Ash %*
A	98.0	2.0	-	-
	96.0	4.0	-	-
	94.0	6.0	-	-
	92.0	8.0	-	-
B	98.0	1.5	0.5	-
	96.0	3.0	1.0	-
	94.0	4.5	1.5	-
	92.0	6.0	2.0	-
C	98.0	1.5	-	0.5
	96.0	3.0	-	1.0
	94.0	4.5	-	1.5
	92.0	6.0	-	2.0
D	98.0	1.5	0.25	0.25
	96.0	3.0	0.5	0.5
	94.0	4.5	0.75	0.75
	92.0	6.0	1.0	1.0
F	98.0	-	2.0	-
	96.0	-	4.0	-
	94.0	-	6.0	-
	92.0	-	8.0	-
G	98.0	-	-	2.0
	96.0	-	-	4.0
	94.0	-	-	6.0
	92.0	-	-	8.0
E	100	-	-	-

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Mixing samples with additives was done manually at the optimum moisture content of natural sample as obtained from compaction tests.

The test carried out in this research covered the following areas using;

- Soil only;
- Soil – cement
- Soil – cocoa pod ash
- Soil – palm kernel shell ash
- Soil – cement with cocoa pod ash
- Soil – cement with palm kernel shell ash
- Soil – cement with ashes from both cocoa pod and palm kernel shell.

They were hand mixed after they were weighed prior to the mixing in water at required proportions.

The specimen used for the tests are uncured samples.

The results are discussed in the next chapter (chapter four) with the following relations shown.

* Particle size distribution curve.
* Moisture-density relations for natural and treated sample with varying percentages.

* Optimum moisture content versus mixture of (a) cement and ash from cocoa pod (b) cement and ash from palm kernel shell (c) cement and ashes from both the cocoa pod and palm kernel shell.
* CBR versus the additives.

The chemical composition for the additive used were also determined.

The structural economic benefits of applying the composite admixtures were evaluated.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter presents the results of various geotechnical and chemical tests carried out on all the samples. Tables and graphs were also plotted for each test. Properties such as grain size distribution, Compaction and California Bearing Ratio of the samples were determined.

The natural moisture content of the soil was determined as 3.5%.

4.1 TEXTURE AND CONSISTENCY LIMIT OF NATURAL SOIL

The grain size analysis showed that the soil in its natural state has percentage of gravel of fractions varying between 62% and 66%, sand fractions ranging between 33% and 37% with the silt and clay fractions being less than 1.0%. The result of the consistency limit of the natural soil gave liquid limit of 34.0% and plasticity index of 16.2%. The soil thus classified in group A-2-6(0). Table 4.1.2 show the results of the grain size distribution of treated and untreated samples and fig 4.1.1 to fig 4.1.4 show the particle size distribution curves of the samples. Appendix 6 also show the AASHTO classification system table.

Table 4.1.2: Results of the grain size distribution of treated and untreated samples.

Sample Type	*% additive contents*	*Specific Gravity (S.G.)*	*Group index*	*Coarse material*	*Clay percentage passing*	*Liquid limit*	*Plastic limit*	*Plasticity index*
A	2.0	3.13	0.0	99.0	1.0	42.0	27.0	15.0
	4.0	3.33	0.0	96.5	3.5	44.0	30.0	14.0
	6.0	3.52	0.0	96.0	4.0	40.0	28.0	12.0
	8.0	3.50	0.0	97.0	3.0	46.0	34.5	11.5
B	2.0	2.63	0.0	98.5	1.5	34.3	19.7	14.8
	4.0	2.78	0.0	97.0	3.0	35.0	20.4	14.6
	6.0	2.94	0.0	97.0	3.0	37.0	23.2	13.8
	8.0	3.05	0.0	95.5	4.5	38.0	21.6	11.9
C	2.0	2.63	0.0	97.0	3.0	35.0	23.0	12.0
	4.0	2.63	0.0	97.0	2.5	39.0	31.0	7.33
	6.0	2.63	0.0	97.0	3.0	42.0	36.0	5.65
	8.0	2.78	0.0	96.5	3.5	47.0	41.0	6.0
D	2.0	2.78	0.0	97.5	2.5	41.0	25.8	15.2
	4.0	2.78	0.0	97.5	2.5	43.0	29.0	14.0
	6.0	2.78	0.0	98.0	2.0	45.0	32.7	12.3
	8.0	2.94	0.0	96.5	3.5	47.0	36.3	10.7
E	0.0	2.57	0.0	99.5	0.5	34.0	17.8	16.20

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.1.3: Uniformity Coefficient (C_u) of Samples

Samples	*% additive contents*	D_{60} *(mm)*	D_{10} *(mm)*	$Cu = {}^{D60}/_{D10}$ *(Uniformity coefficient)*
A	2.0	3.0	0.30	10.70
	4.0	3.0	0.20	15.00
	6.0	3.8	0.20	19.00
	8.0	4.0	0.20	20.00
B	2.0	4.0	0.50	8.00
	4.0	3.0	0.20	15.00
	6.0	4.0	0.30	13.30
	8.0	3.0	0.20	15.00
C	2.0	5.0	0.60	8.30
	4.0	4.4	0.50	8.80
	6.0	4.0	0.30	13.30
	8.0	3.0	0.16	18.80
D	2.0	3.3	0.25	13.20
	4.0	3.0	0.30	10.00
	6.0	5.5	0.30	18.30
	8.0	3.0	0.15	20.00
E	0.0	5.0	0.65	7.70

The particle size distribution curves are plotted for sample A – E with their respective subscript. The sizes D_{10} and D_{60} are read from the curves and the values of Cu are calculated as shown in table 4.1.3.`

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

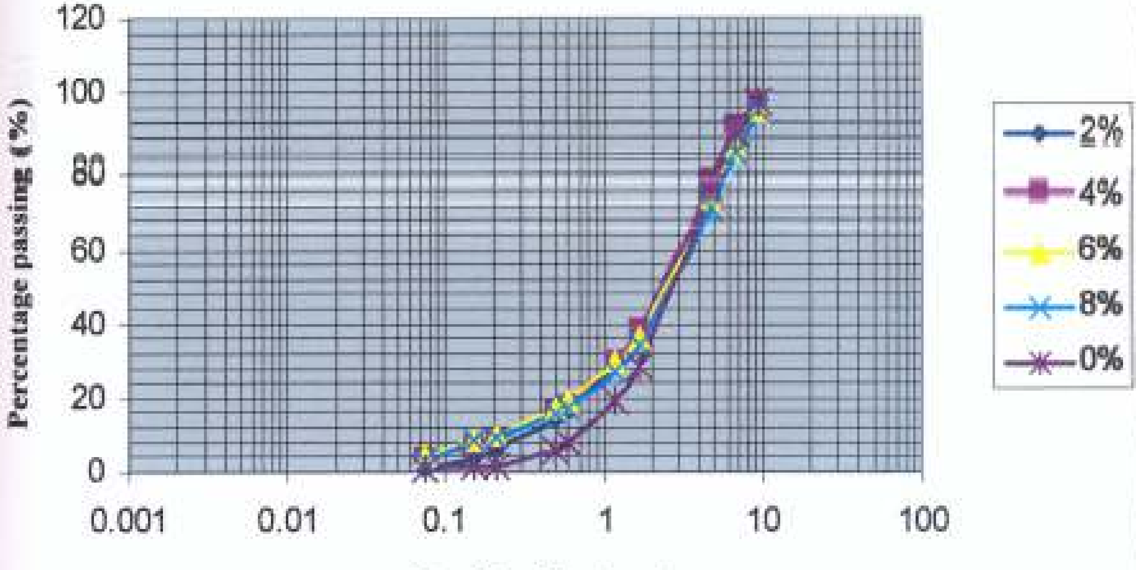

Fig 4.1.1: particle size distribution curves for samples A and E

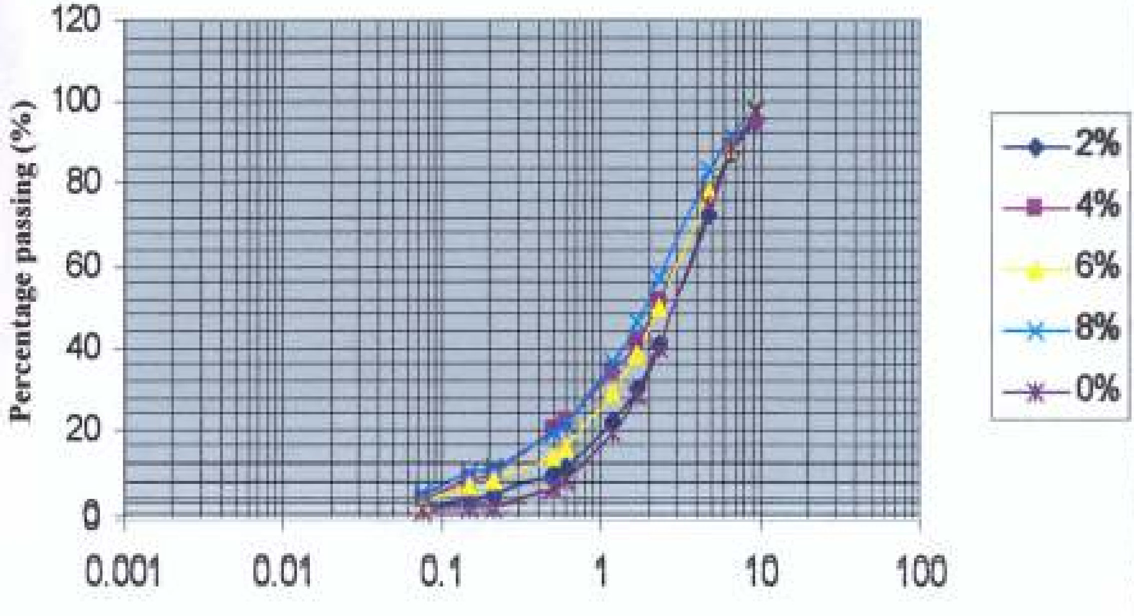

Fig 4.1.1: particle size distribution curves for samples B and E

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

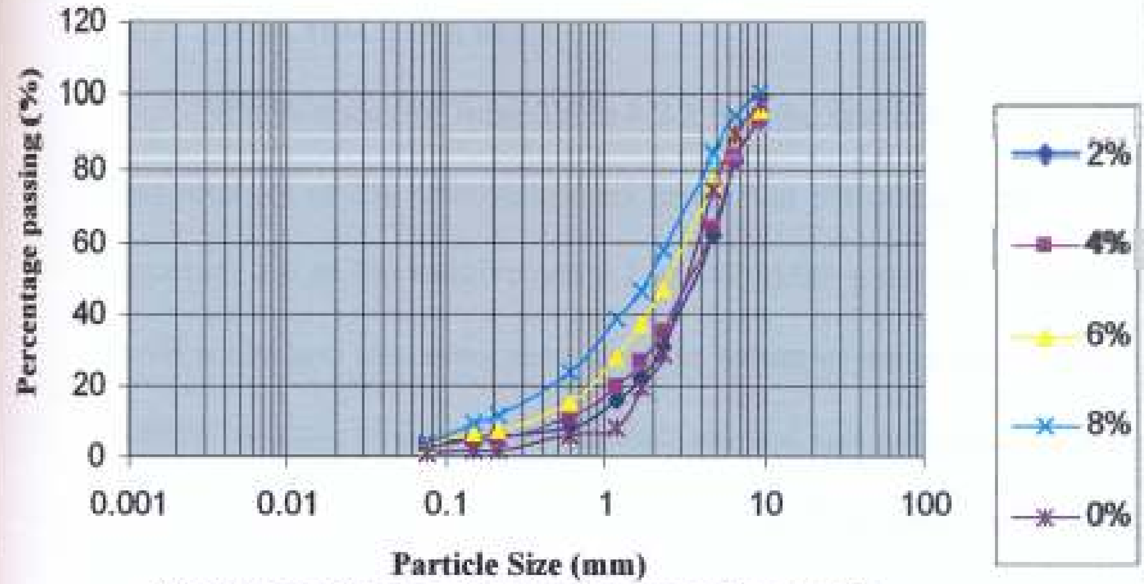

Fig 4.1.1: particle size distribution curves for samples C and E

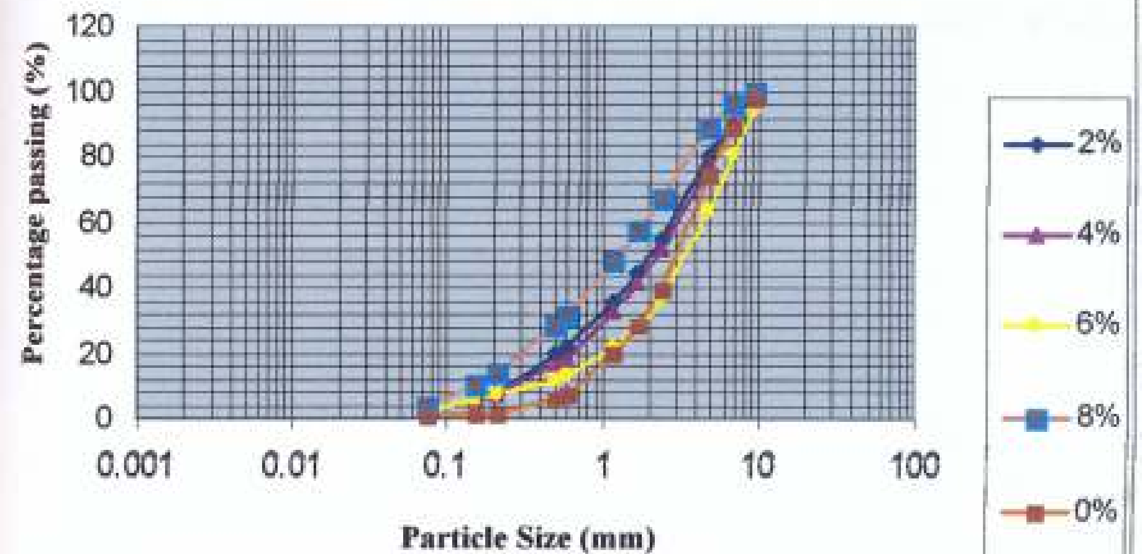

Fig 4.1.1: particle size distribution curves for samples D and E

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

4.2 SPECIFIC GRAVITY

It was observed from Table 4.2.2 that the specific gravity value ranged between 3.1 at 2% additive content and 3.5 at 8% additive for soil – cement mixture, 2.6 at 2% additive and 3.1 at 8% additive for soil – cement mixture with cocoa pod ash. Also, the respective values of the specific gravity for soil cement mixture with palm kernel shell ash and soil –cement mixture with the ashes from cocoa pod and palm kernel shell at 2% additive content are 2.6 and 2.7 and at 8% additive contents are 2.7 and 2.8.

On the other hand the specific gravity of cement, cocoa pod ash, palm kernel shell ash and the natural soil are 3.6, 2.6, 2.6 and 2.5 respectively. The results indicated that the use of these additives gave higher specific gravities than the natural soil.

Table 4.2.2: **Result of Specific Gravity Tests for the Samples and Additives used**

	SAMPLE A				SAMPLE B				SAMPLE C				SAMPLE D				E (Soil sample only control)	Cement used	Ashes from pod	Ashes from palm kernel shell
	2%	4%	6%	8%	2%	4%	6%	8%	2%	4%	6%	8%	2%	4%	6%	8%				
S. G.	3.13	3.33	3.52	3.50	2.63	2.78	2.94	3.05	2.63	2.63	2.63	2.78	2.78	2.78	2.78	2.94	2.57	3.57	2.63	2.63

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

4.3 CONSISTENCY LIMIT OF THE TREATED SAMPLES

In the case of the consistency limits of the treated samples, the liquid limit ranged between 42% at 2% additive content and 46% at 8% additive while the plasticity index ranged between 11.5% at 8% additive to 15.0% at 2% additive content for soil-cement mixture (A) (table 4.3.3A). Similarly, the liquid limit ranged between 34.3% at 2% additive content and 38.0% at 8% additive content while the plasticity index ranged between 11.9% at 8% additive content and 14.8% at 2% additive content for soil-cement mixture with cocoa pod ash (B) (table 4.3.3.B).

On the other hand, the liquid limit ranged between 35% at2% additive content and 47.0% at 8% additive content while the plasticity index ranged between 5.65% at 6% additive content and 12.0% at 2% additive content for soil-cement mixture with palm kernel shell ash (C) (table 4.3.3C) and for the mixture of soil-cement with the ashes from cocoa pod and palm kernel shell, that is sample D, the liquid limit ranged between 41.0% and 47.0% at 2% and 8% additive content respectively while the plasticity index ranged between 10.7% at 8% additive content and 15.2% at the 2% additive content (table 4.3.3D).

Generally, lateritic soils with high plasticity index are not usually recommended for both sub-grade and sub-base materials since they often result in roads failure due to plastic flow. It is for this reason that such soils are usually stabilized (Joint Department of the Army and Airforce 1994). The results of this research show that the use of palm kernel shell ash as a modifier alone had positive effect on the soil-cement mixture (sample C). Its addition reduced the plasticity range of the soil-cement mixture. It is seen that the addition of cocoa pod ash to soil-cement, that is sample B and a mixture of all three additives (cement, cocoa pod ash and palm kernel shell ash) with soil (that is sample D) did not significantly alter its properties. Hence a mixture of all three additives (D) and cocoa pod ash (B) may not be encouraged. All these are shown on fig 4.3.1 – fig. 4.3.4.

Table 4.3.3 Results of Consistency Limit test for Treated and Untreated Samples

Table 4.3.3A Results of the consistency limit test for Sample A

Soil Sample + Cement

Additive Content (%)	*Liquid Limit (%)*	*Plastic Limit (%)*	*Plasticity Index (%)*
0.0	34.3	17.8	16.2
2.0	42.0	27.0	15.0
4.0	44.0	30.0	14.0
6.0	40.0	28.0	12.0
8.0	46.0	34.5	11.5

Table 4.3.3B Results of the consistency limit test for Sample B

Soil Sample + Cement + Cocoa Pod Ash

Additive Content (%)	*Liquid Limit (%)*	*Plastic Limit (%)*	*Plasticity Index (%)*
0.0	34.0	17.8	16.2
2.0	34.3	19.5	14.8
4.0	35.0	20.4	14.6
6.0	37.0	23.2	13.8
8.0	38.0	26.1	11.9

Table 4.3.3C Results of the consistency limit test for Sample C

Soil Sample + Cement + Palm Kernel Shell Ash

Additive Content (%)	*Liquid Limit (%)*	*Plastic Limit (%)*	*Plasticity Index (%)*
0.0	34.0	17.80	16.20
2.0	35.0	23.0	12.00
4.0	39.0	31.0	7.33
6.0	42.0	36.0	5.65
8.0	47.0	41.0	6.00

Table 4.3.3D Results of the consistency limit test for Sample D

Soil Sample + Cement + Cocoa Pod Ash + Palm Kernel Shell Ash

Additive Content (%)	*Liquid Limit (%)*	*Plastic Limit (%)*	*Plasticity Index (%)*
0.0	34.0	17.8	16.2
2.0	41.0	25.8	15.2
4.0	43.0	29.0	14.0
6.0	45.0	32.7	12.3
8.0	47.0	36.3	10.7

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

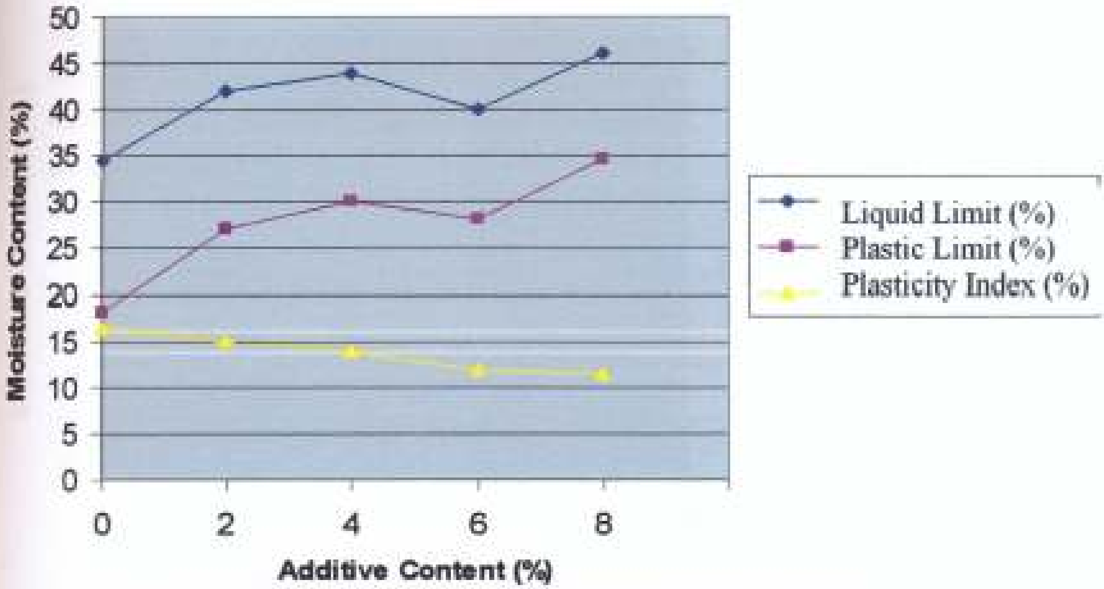

Fig 4.3.1. Variation of moisture content with additives content for samples A

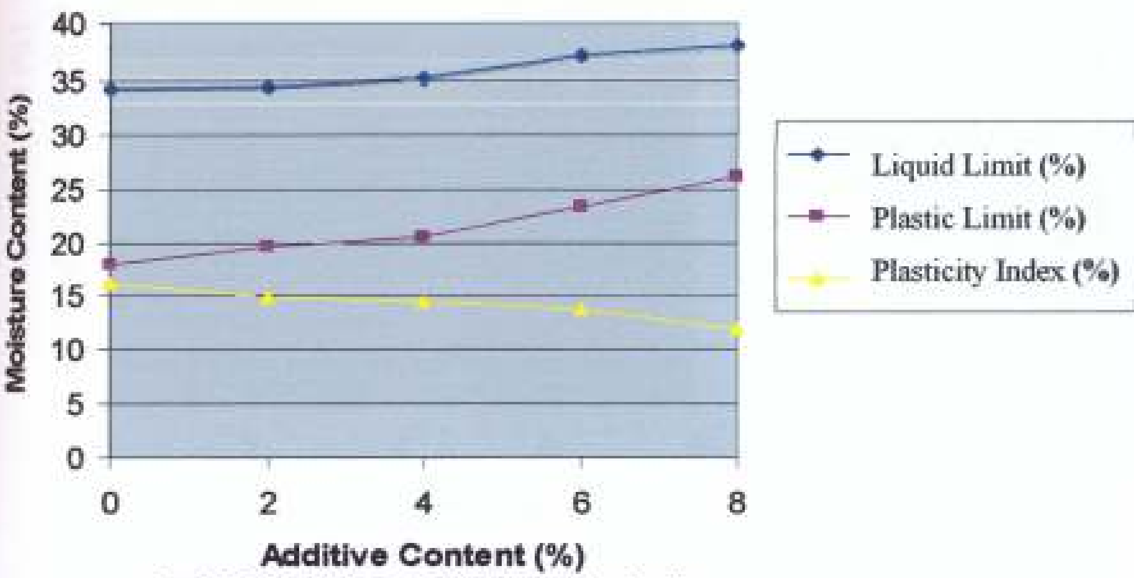

Fig 4.3.2. Variation of moisture content with additives content for samples B

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash

C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell;

E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

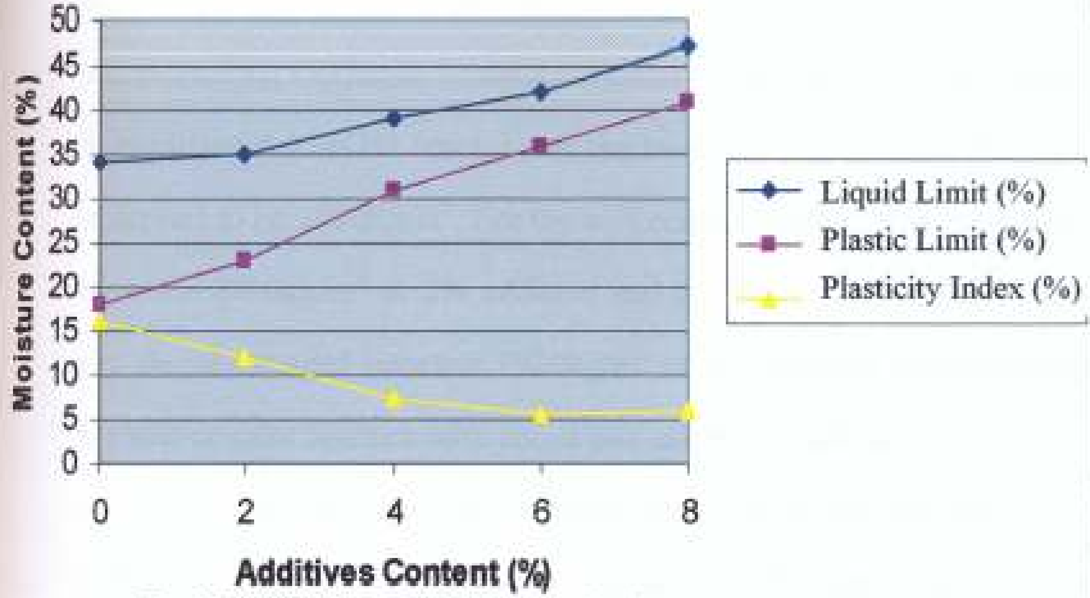

Fig 4.3.3. Variation of moisture content with additives content for samples C

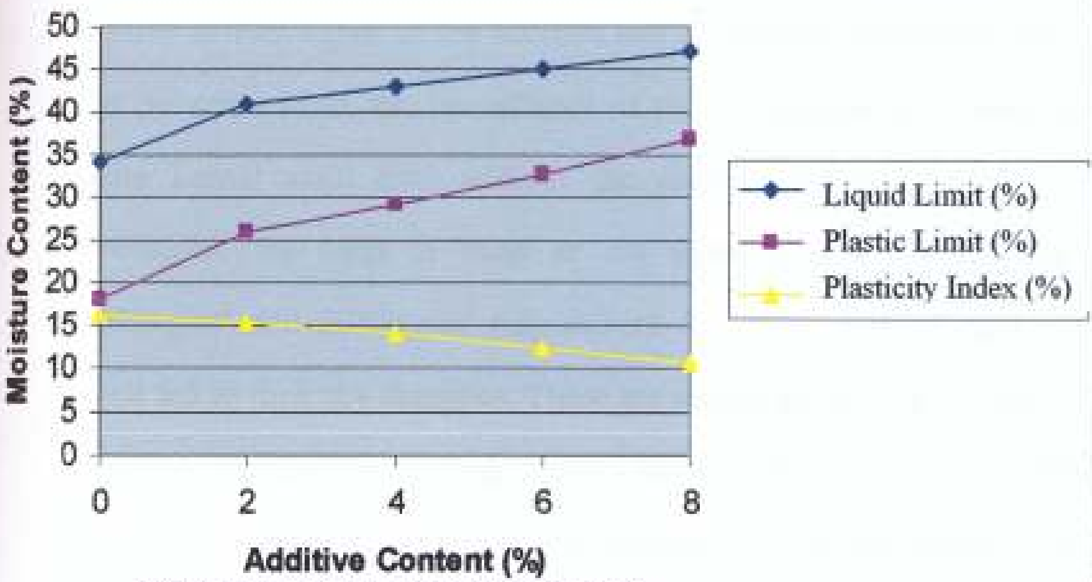

Fig 4.3.4. Variation of moisture content with additives content for samples D

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

4.4 COMPACTION CHARACTERISTICS

Table 4.4.3 shows the summary of the Maximum Dry Density and the corresponding Optimum Moisture content of the treated and untreated samples at modified AASHTO level. From the table, the dry density for natural soil is observed to be 1980kg/m^3. For the soil-cement mixture, the dry density ranged between 1990kg/m^3 at 2% additive and 2170kg/m^3 at 8% additive. Also the dry density ranged between 1920kg/m^3 at 2% additive and 2030kg/m^3 at 8% for soil-cement mixture with cocoa pod ash as a modifier.

In a similar way, when the palm kernel shell ash was used as a modifier with soil-cement mixture, the dry density of 1950kg/m^3 at 2% additive and 2060kg/m^3 at 8% additive were obtained and when the two modifiers (cocoa pod ash and palm kernel shell ash) are used with soil-cement mixture, the dry density of 1960kg/m^3 at 2% additive and 2040kg/m^3 at 8% were also obtained. On the other hand, the use of each of these modifiers (i.e. cocoa pod ash or palm kernel shell ash) without the addition of cement gave values of 1900kg/m^3 for each of them at 2% additive and a maximum value of 2020kg/m^3 and 2040kg/m^3 respectively for cocoa pod ash and palm kernel shell ash as their dry densities. These are shown on fig. 4.4.1 to fig. 4.4.6.

A comparison of these results showed that each of the additives had positive effect on the soil as they all improved on the dry density of the natural soil. However, the best result was obtained at 8% cement only given a value of 2170kg/m^3. If however, any of the other two modifiers is to be considered, palm kernel shell ash will be a better replacement since a higher dry density was obtained with its use over that of cocoa pod ash.

Table 4.4.3 **Results of compaction tests for the treated and untreated samples with the additives**

Additive Content	A		B		C		D		E		F		G	
	MDD	OMC	MDD	OMC	MDD	OMC	MDD	OMC	MDD	OMC	MDD	OMC	MDD	OMC
2%	19.9	13.9	19.2	14.0	19.5	8.0	19.8	8.0	18.9	11.8	19.0	8.0	19.2	14.0
4%	20.4	12.5	19.5	14.0	20.0	7.0	19.7	11.0			19.3	12.5	19.4	14.0
6%	20.8	11.1	20.2	11.0	20.2	12.0	19.9	11.0			20.1	11.8	19.8	13.0
8%	21.7	13.0	20.3	11.0	20.6	11.0	20.4	8.0			20.2	9.5	20.4	12.2

Note: The OMC were used in the C.B.R. Tests
M.D.D. = Maximum Dry Density
O.M.C = Optimum Moisture Content.

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

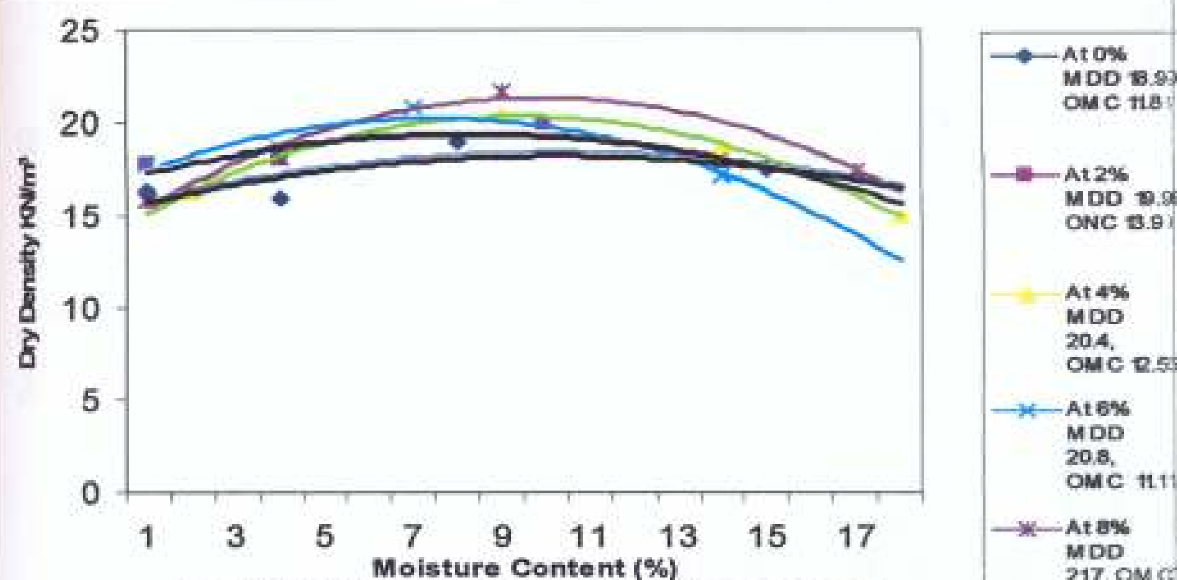

Fig 4.4.1: Variation of dry density with percentage moisture content for samples A and E

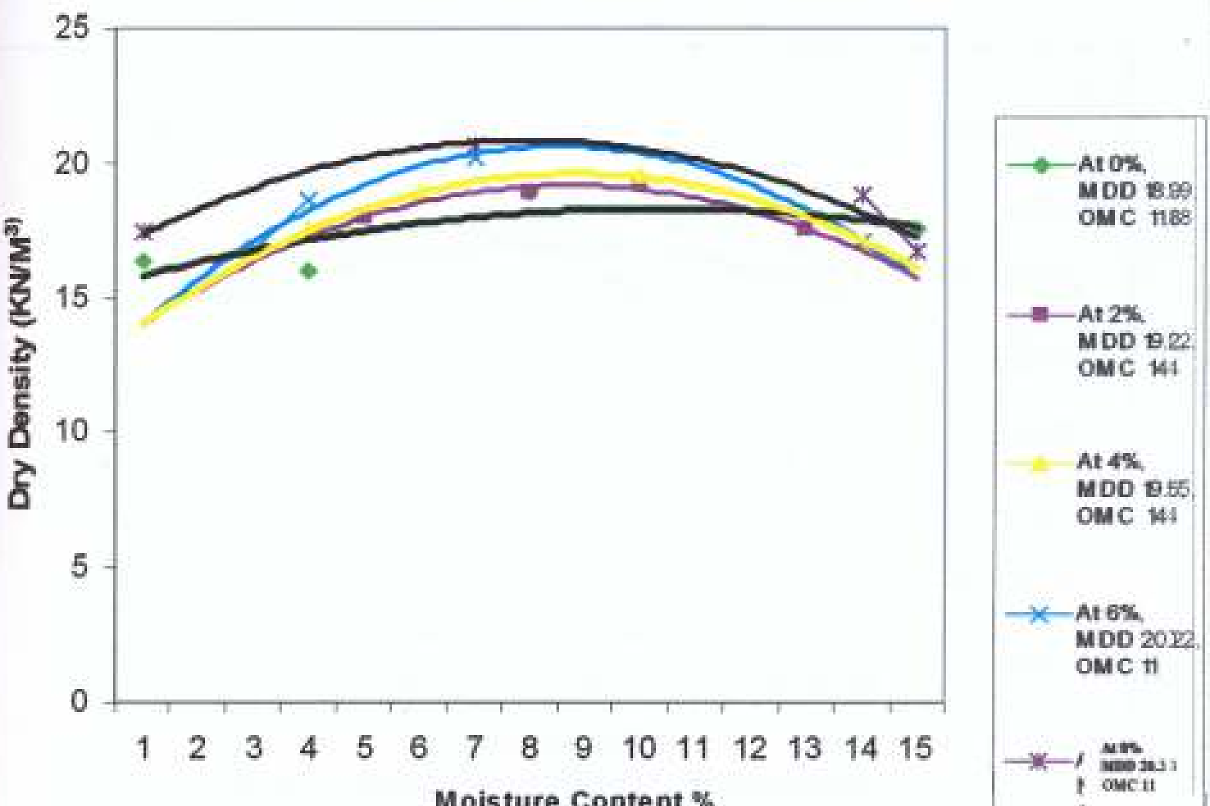

Fig 4.4.2: Variation of dry density with percentage moisture content for samples B and E

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

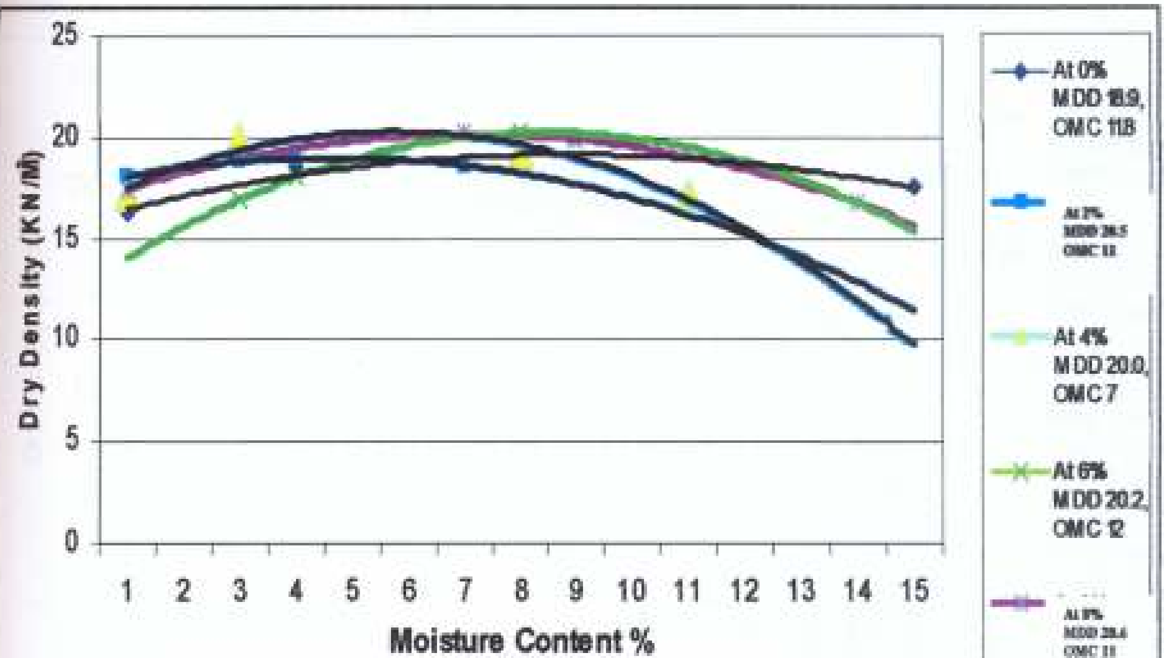

Fig 4.4.3: Variation of dry density with percentage moisture content for samples C and E

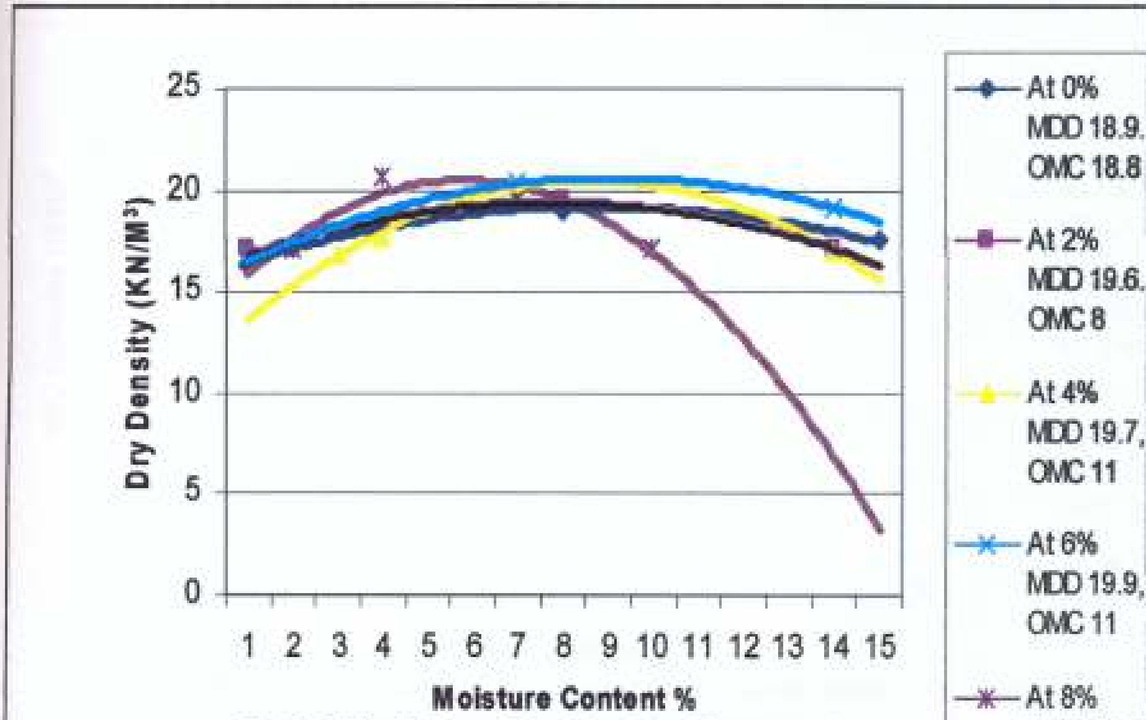

Fig 4.4.4: Variation of dry density with percentage moisture content for samples D and E

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

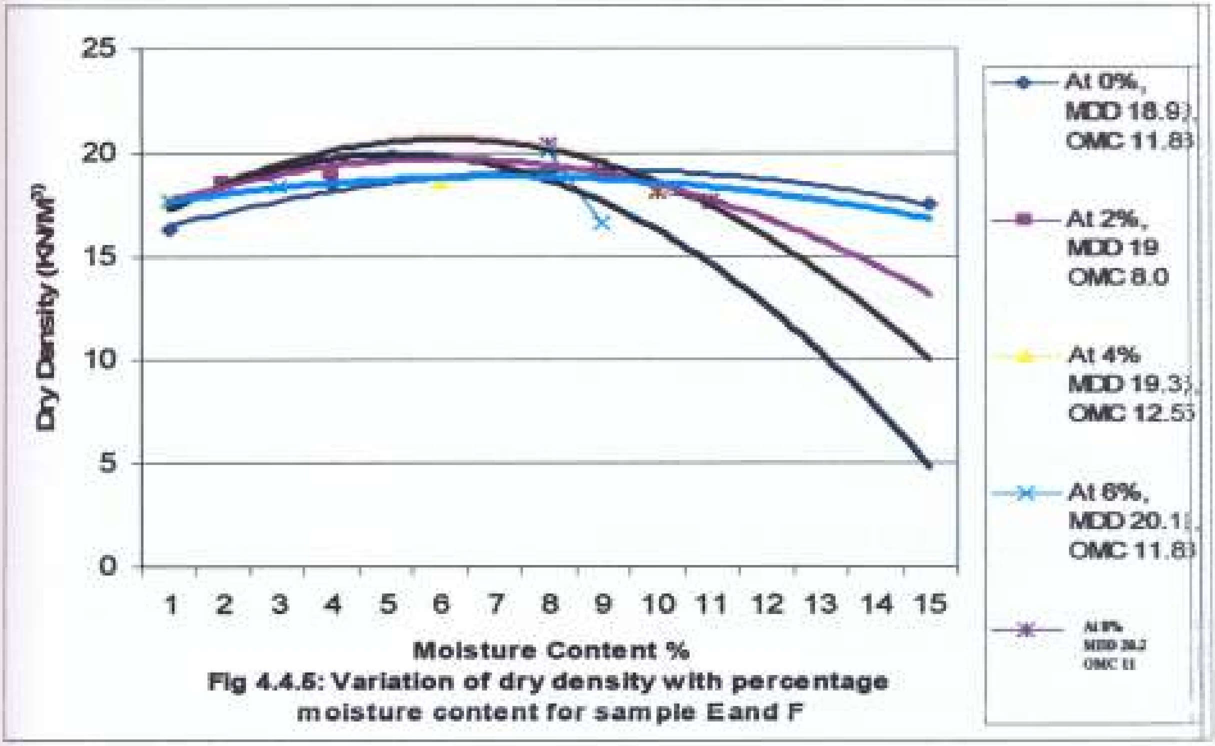

Fig 4.4.5: Variation of dry density with percentage moisture content for sample E and F

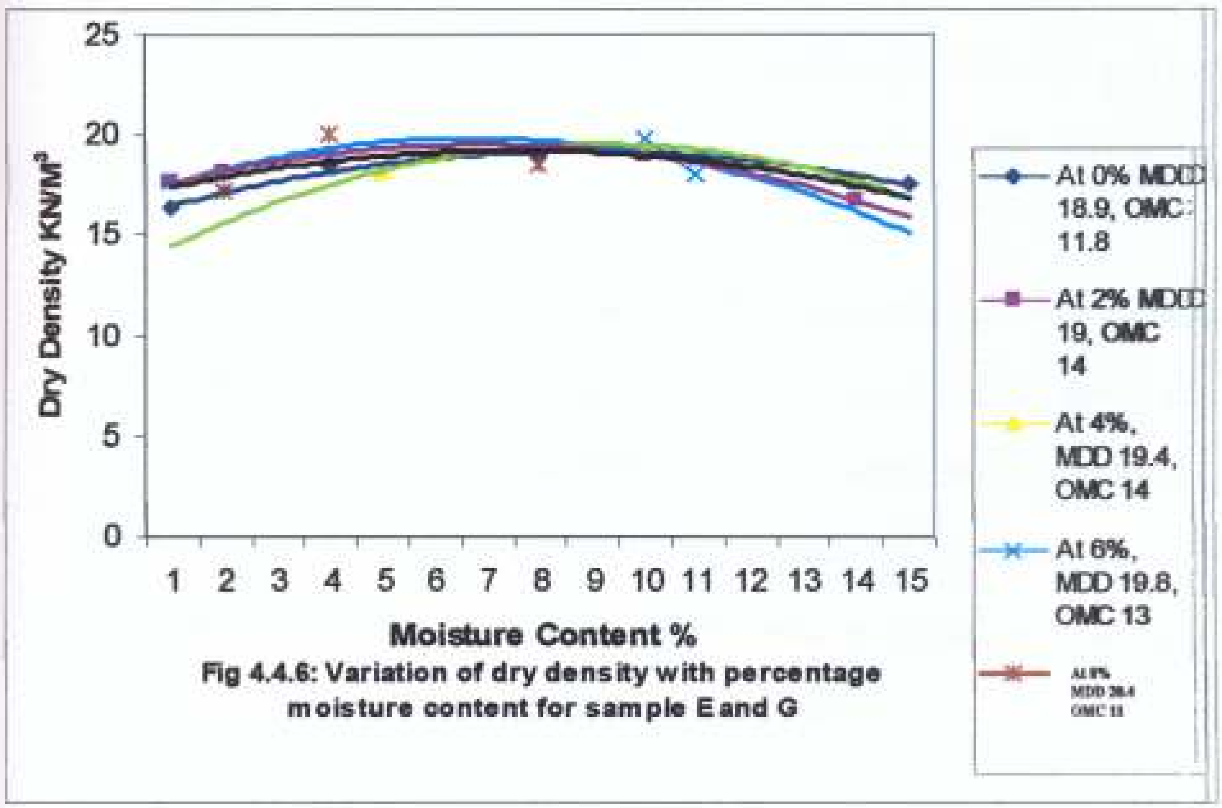

Fig 4.4.6: Variation of dry density with percentage moisture content for sample E and G

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

4.5 CALIFORNIA BEARING RATIO (CBR)

The unsoaked C.B.R was used in this research and the compactive effort used was 3.06KN-m/cm^3. From Table 4.5.3 the CBR value of the untreated soil sample gave 21%. In the case of treated sample, the CBR values ranged between 35.0% at 2% additive and 115.0% at 8% additive for soil-cement mixture (that is sample A); 69% at 2% additive and 127% at 8% additive for soil-cement mixture with cocoa pod ash (Sample B). On the other hand, the values ranged between 59% at 2% additive and 150% at 8% additive for soil-cement mixture with palm kernel shell ash (sample C) and 110% at 2% additive and 128% at 8% additive for the soil-cement mixture with ashes from cocoa pod and palm kernel shell (sample D). Also the CBR. values ranged between 35% at 2% additive and 110% at 8% additive for soil-cocoa pod ash mixture and between 34.1% at 2% additive and 100.7% at 8% additive for soil-palm kernel shell ash.

Generally the CBR values of the treated samples increased with increase in the additives (Table 4.5.3 and fig 4.5.2). All the treated samples gave CBR for based course values exceeding 80% which is the minimum permissible for unsoaked CBR. (General Specification Requirements for Roads and B ridges 1992: Appendix 7). Therefore, these additives may be considered as suitable replacement of cement in the ratio given in Table 3.1.

Table 4.5.3: **Result of the CBR test for the treated and untreated samples with additives.**

Additive content (%)	*Sample A (%)*	*Sample B (%)*	*Sample C (%)*	*Sample D (%)*	*Sample E (%)*	*Sample F (%)*	*Sample G (%)*
0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
2	37.0	69.0	59.0	110.0		35.0	34.1
4	89.0	102.0	97.0	114.0		84.2	75.6
6	95.0	116.0	106.0	125.0		95.2	86.2
8	115.0	127.0	150.0	128.0		110.2	100.7

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

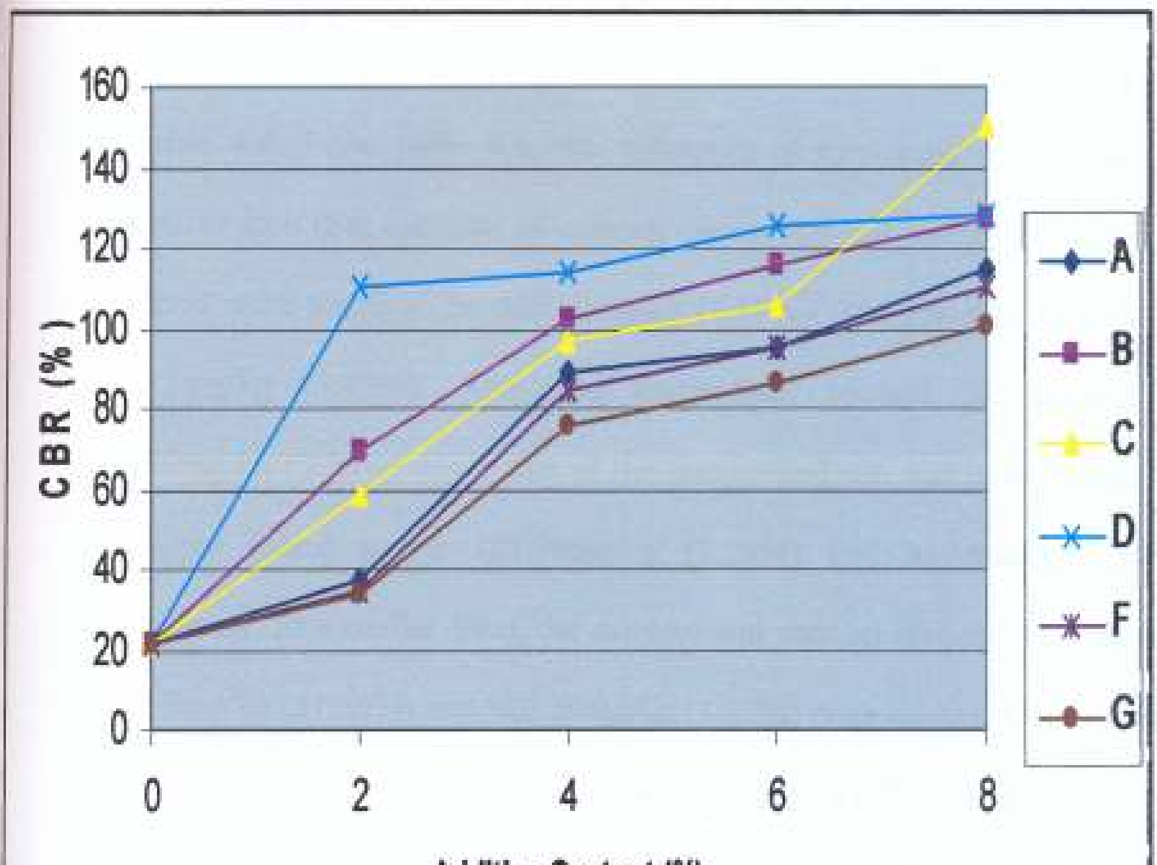

Fig 4.5.2. Variation California Bearing Ratio with additive content for all samples (A-G)

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

4.6 CHEMICAL ANALYSIS

The results of the chemical analysis of the additives used are presented in Table 4.6. From table 4.6, the following observations were made. The respective iron (Fe) contents of cement, cocoa pod ash and palm kernel shell ash used were found to be 400.10mg/kg (4.10%), 320.35mg/kg (3.25%) and 345.15mg/kg (3.45%). Also, the magnesium content for cement was 360.50mg/kg (3.56%) while that of the cocoa pod ash and palm kernel shell ash were found to be 327.98mg/kg (3.28%) and 319.8mg/kg (3.19%) respectively. In a similar form, the calcium and sodium content for cement are 5160.0mg/kg (51.50%) and 120.20mg/kg (1.22%) respectively. Cocoa pod ash has 4647mg/kg (46.48%) of calcium and 90.30mg/kg (0.93%) of sodium while the values for calcium and sodium contents in the palm kernel shell ash were respectively 647.5mg/kg (6.48%) and 85.80mg/kg (0.86%). The potassium content in cement, cocoa pod ash and palm kernel shell used were 90.01mg/kg (0.90%), 76.50mg/kg (0.77%) and 63.20mg/kg (0.63%) in that order. Also found in the analysis were manganese and zinc having their respective values in cement as 11.11g/kg (0.11%) and 56.40mg/kg (0.56%), cocoa pod ash as 8.83mg/kg (0.083%) and 56.40mg/kg (0.56%), cocoa pod ash as 8.83mg/kg (0.083%) and 36.8mg/kg (0.37%) and palm kernel shell ash as 2.50mg/kg (0.025%) and 45.85mg/kg (0.049%). Comparing this with the standard values, in table 2.2, the result showed that cocoa pod ash has iron (Fe), Magnesium (Mg), Calcium (Ca), Sodium (Na), and Potassium (K) values which compared favoutably with cement. In a similar form, the result showed that the palm kernel shell ash has Fe, Mg, Na, and K which also compared favorably with cement but deficient in calcium (Ca) which is the major constituent of cement. However, cocoa pod ash will be a better replacement since a higher percentage of calcium which is the major constituent of cement was found in it (Ademoroti ,1996).

Table 4.6: Results of the chemical analysis of the additives used

Metals	*Cement*		*Cocoa pod ash*		*Palm kernel shell ash*		*Standard values (%)*
	mg/kg	*%*	*Mg/kg*	*%*	*mg/kg*	*%*	
Iron (Fe)	400.10	4.10	320.35	3.23	345.15	3.45	0-4.5
Manganese (Mn)	11.11	0.11	8.83	0.083	2.50	0.025	-
Magnesium (Mg)	360.50	3.65	327.98	3.28	319.8	3.19	0-4.0
Calcium (Ca)	5160.00	51.56	4647	46.48	647.5	6.48	60-66
Sodium (Na)	120.20	1.22	90.30	0.93	85.80	0.86	0-0.7
Potassium (K)	90.01	0.90	76.50	0.77	63.20	0.63	0-0.7
Zinc (Zn)	56.40	0.56	36.8	0.37	4.85	0.049	-

4.7 COST ANALYSIS OF THE ADDITIVES

The cost analysis of the additives in Naira per cubic metre ₦/m^3 is a relative cost deduced from a market survey of cement and other related conditions. It was observed that when considering the use of 8% of the additive in the ratio given in Table 3.1.

The cost of using 8% cement was ₦406/m^3, while 2% cocoa pod ash with 6% cement resulted into ₦315/m^3. The cost implication of using 2% palm kernel shells ash and 6% cement was ₦332/m^3. Considering the use of 6% cement, 1% cocoa pod ash and 1% of palm kernel shell ash gave the cost of ₦324/m^3. It was observed from Table 4.7.2 that the use of 2% cocoa pod ash with 6% cement has the least cost/m^3.

Table 4.7.2 Cost Comparison of the Addutive used

% Additive used	*Cost /m^3 (₦/m^3)*
8% Cement	406.00
2% Cocoa pod ash + 6% cement	315.00
2% Palm kernel shell ash + 6% cement	332.00
1% Cocoa pod ash + 1% Palm Kernel Shell ashes + 6% cement	324.00

Table 4.8: **Summary of Results for Geotechnical Properties of the Treated and Untreated Samples**

Property of the natural and stabilized samples	A = Soil – cement (% by weight)				B = Soil – cement with cocoa pod ash (% by weight)				C = Soil – cement with palm kernel shell ash (% by weight)				D = Soil – cement with ashes from both cocoa pod and palm kernel shell (% by weight)				F = Soil – cocoa pod ash (% by weight)				G = Soil – palm kernel shell ash (% by weight)				Cement (% by weight)	E = Soil only (% by weight)
	(2/98)%	(4/96)%	(6/94)%	(8/92)%	(1.5/0.5/98)%	(3/1/96)%	(4.5/1.5/94)%	6/2/92%	(1.5/0.5/98)%	(3/1/96)%	(4.5/1.5/94)%	6/2/92%	(1.5/0.25/0.25/98)%	(3/0.5/0.5/96)%	(4.5/0.75/0.75/94)%	(6/1/1/92)%	(2/98)%	(4/96)%	(6/94)%	(8/92)%	(2/98)%	(4/96)%	(6/94)%	(8/92)%	-	0%
L.L%	42.00	44.00	40.00	48.00	34.3	35.00	37.00	38.0	35.00	38.00	42.0	47.00	41.0	43.0	45.0	47.0	-	-	-	-	-	-	-	-	-	34.3
P.L%	27.00	30.00	28.00	34.50	19.5	28.80	23.20	26.1	23.00	31.00	36.00	41.00	25.8	29.0	32.7	36.3	-	-	-	-	-	-	-	-	-	17.8
P.I.%	15.00	14.00	12.00	11.50	14.8	14.60	13.80	11.9	12.00	7.33	5.65	6.00	15.2	14.0	12.3	10.7	-	-	-	-	-	-	-	-	-	16.2
S.G	3.13	3.33	3.52	3.50	2.63	2.760	2.940	2.50	3.05	2.63	2.63	2.78	2.78	2.78	2.94	-	2.63	-	-	-	2.63	-	-	-	3.5	2.57
OMC %	13.9	12.50	11.10	13.50	14.00	14.00	11.00	11.0	8.00	7.00	12.00	11.00	8.00	11.0	11.0	11.0	11.8	12.6	11.8	11.8	14.0	14.0	13.0	8.2		11.8
MDD KN/m³	19.9	20.40	20.80	21.70	19.20	19.50	20.20	20.6	19.60	20.0	20.20	20.30	19.6	19.7	19.9	20.4	19.0	19.3	20.1	20.4	19.0	19.4	19.8	20.2		18.9
C.B.R %	37.0	89.00	95.00	115.00	69.00	102.00	116.0	127.0	59.0	97.0	106.00	150.0	110.0	114.0	125.0	128.0	35.0	84.2	95.2	110.2	34.1	75.8	88.2	100.7	-	21.0
CU = D60/D10	10.7	15.00	19.00	20.00	8.00	15.00	13.30	15.0	8.30	8.80	13.30	18.80	13.2	10.00	18.30	20.00	-	-	-	-	-	-	-	-	-	7.70

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only. F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In the assessment of the geotechnical properties of lateritic soil stabilized with cement, mixture of cement with ashes from cocoa pods and palm kernel shells as partial replacement for cement, it was observed that:

- The maximum dry density of the treated samples increased above the natural soil in all cases exceeding 2000kg/m^3 at 6% which is the minimum dry density often specified for base-course material (General Specification Requirements for Roads and Bridges 1992: Appendix 7).
- The C.B.R values of the treated samples generally increased with increase in additives and the values exceeded 80% which is also the minimum value specified for unsoaked C.B.R for base course (General Specification Requirements for Roads and Bridges: Appendix 7).
- Considering the fact that both cocoa pod and palm kernel shells are treated as wastes, their use for this purpose will be of economic benefit since they will serve as suitable partial replacement when stabilizing with cement usually an expensive commodity.
- The chemical analysis of the metals of the additives used showed that cocoa pod ash would be a better replacement materials for cement as the palm kernel shell ash was deficient of calcium which is the major constituent of cement

5.2 RECOMMENDATIONS FOR FURTHER RESEARCH

On the basis of test results, observations and conclusion, the following recommendations are being made.

- Unconfined Compression Test should be conducted on the soil-cement with ashes from cocoa pod and palm kernel shell to determine the compressive strength for the assessment of their structural use as base course material.
- Tests should be conducted in-situ to assess the durability of roads constructed with ashes from cocoa pods and palm kernel shells

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APPENDIX 1:

Results of Grain size analysis of the samples.

APPENDIX 1

4.1 RESULTS OF PARTICLE SIZE DISTRIBUTION OF THE TREATED AND UNTREATED SAMPLE

Table 4.1.A1: Result of Particle Size Distribution of Sample A1

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	9.0	9.0	4.5	95.5
6.7mm	18.0	27.0	9.0	86.5
4.75mm	27.0	54.0	13.5	73.0
2.36mm	50.0	104	25.0	48.0
1.70mm	19.0	123.0	9.5	38.5
1.18mm	18.0	1.41	9.0	29.5
0.600μm	27.0	168.0	13.5	16.0
500μm	4.0	172.0	2.0	14.0
225μm	5.0	177.0	2.0	14.0
212μm	12.0	189.0	6.0	515
150μm	4.0	193.0	2.0	3.5
75μm	5.0	198.0	2.5	1.0
43μm				
PAN	2	200	1.0	-

Mass of sample used = 200g

Table 4.1.A2: Result of Particle Size Distribution of Sample A2

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	5.0	5.0	2.5	97.5
6.7mm	13.0	18.0	6.5	91.0
4.75mm	28.0	4.6	14.0	77.0
2.36mm	58.0	104.0	29.0	48.0
1.70mm	20.0	124.0	10.0	38.0
1.18mm	17.0	141.0	8.5	29.5
0.600μm	24.0	165.0	12.0	17.5
500μm	3.0	168.0	1.5	16.0
225μm	5.0	173.0	2.5	13.5
212μm	10.0	183.0	5.0	8.5
150μm	3.0	186.0	1.5	7.0
75μm	7.0	193.0	3.5	3.5
43μm				
PAN	7.0	200.0	3.5	-

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.1.A3: **Result of Particle Size Distribution of Sample A3**

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	10.0	10.0	5.0	95.0
6.7mm	1.9	29.0	9.5	85.5
4.75mm	25.0	54.0	12.5	73.0
2.36mm	55.0	109.0	27.5	45.5
1.70mm	18.0	127.0	9.0	36.5
1.18mm	14.0	141.0	7.0	29.5
0.600μm	21.0	162.0	10.5	19.0
500μm	4.0	166.0	2.0	17.0
225μm	4.0	170.0	2.0	15.0
212μm	10.0	180.0	5.0	10.0
150μm	3.0	183.0	1.5	8.5
75μm	9.0	192.0	4.5	4.0
43μm				
PAN	8.0	200.0	4.0	-

Table 4.1.A4: **Result of Particle Size Distribution of Sample A4**

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	10.0	10.0	5.0	95.0
6.7mm	22.0	32.0	11.0	84.0
4.75mm	27.0	59.0	13.5	70.5
2.36mm	55.0	144.0	27.5	43.0
1.70mm	18.0	132.0	9.0	34.0
1.18mm	14.0	146.0	7.0	27.0
0.600μm	20.0	166.0	10.0	17.0
500μm	3.0	169.0	1.5	15.5
225μm	4.0	173.0	2.0	13.5
212μm	8.0	181.0	4.0	9.5
150μm	2.0	183.0	1.0	8.5
75μm	11.0	194.0	5.5	3.0
43μm				
PAN	6.0	200.0	3.0	-

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.1.B1: **Result of Particle Size Distribution of Sample B1**

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	10.0	10.0	5.0	95.0
6.7mm	15.0	25.0	7.5	87.5
4.75mm	30.0	55.0	15	72.5
2.36mm	64.0	19.0	32	40.5
1.70mm	21.0	140.0	10.5	30.0
1.18mm	16.0	156.0	8.0	22.0
0.600µm	22.0	178.0	11.0	11.0
500µm	3.0	181.0	1.5	9.5
225µm	4.0	185.0	2.0	7.5
212µm	7.0	192.0	3.5	4.0
150µm	2.0	194.0	1.0	3.0
75µm	3.0	197.0	1.5	1.5
43µm				
PAN	3.0	200.0	1.5	-

Table 4.1.B2: Result of Particle Size Distribution of Sample B2

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	10.0	10.0	5.0	95.0
6.7mm	13.0	23.0	6.5	88.5
4.75mm	22.0	45.0	11.0	77.5
2.36mm	53.0	98.0	26.5	51.0
1.70mm	19.0	117.0	9.5	41.5
1.18mm	15.0	132.0	7.5	34.0
0.600µm	24.0	156.0	12.0	22.0
500µm	4.0	160.0	2.0	20.0
225µm	6.0	166.0	3.0	17.0
212µm	15.0	181.0	7.5	9.5
150µm	4.0	185.0	2.0	7.5
75µm	9.0	194.0	4.5	3.0
43µm				
PAN	6.0	200.0	3.0	-

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.1.B3: **Result of Particle Size Distribution of Sample B3**

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	3.0	3.0	1.5	98.5
6.7mm	19.0	22.0	9.5	89.0
4.75mm	22.0	44.0	11.0	78.0
2.36mm	56.0	100.0	28.0	50.0
1.70mm	23.0	123.0	11.5	38.5
1.18mm	19.0	142.0	9.5	29.0
0.600µm	27.0	169.0	13.5	15.5
500µm	4.0	173.0	2.0	13.5
225µm	5.0	178.0	2.5	11.0
212µm	7.0	185.0	3.5	7.5
150µm	2.0	187.0	1.0	6.5
75µm	7.0	194.0	.5	3.0
43µm				
PAN	6.0	200.0	3.0	-

Table 4.1.B4: **Result of Particle Size Distribution of Sample B4**

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	4.0	4.0	2.0	98.0
6.7mm	13.0	17.0	6.5	91.5
4.75mm	17.0	34.0	8.5	83.0
2.36mm	52.0	86.0	26.0	57.0
1.70mm	22.0	108.0	11.0	46.0
1.18mm	19.0	127.0	9.5	36.5
0.600µm	30.0	157.0	15.0	21.5
500µm	4.0	161.0	2.0	19.5
225µm	6.0	167.0	3.0	16.5
212µm	11.0	178.0	5.5	11.0
150µm	*3.0*	*181.0*	*1.5*	*9.5*
75µm	10.0	191.0	5.0	4.5
43µm				
PAN	9.0	200.0	4.5	-

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.1.C1: **Result of Particle Size Distribution of Sample C1**

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	15.0	15.0	7.5	92.5
6.7mm	20.0	35.0	10.0	82.5
4.75mm	42.0	77.0	21	61.5
2.36mm	62.0	139.0	31	30.5
1.70mm	17.0	156.0	8.5	22.0
1.18mm	13.0	169.0	6.5	15.5
0.600µm	15.0	184.0	7.5	8.0
500µm	2.0	186.0	1.0	7.0
225µm	1.0	187.0	0.5	6.5
212µm	2.0	189.0	1.0	5.5
150µm	1.0	190.0	0.5	5.0
75µm	4.0	194.0	2.0	3.0
43µm				
PAN	6.0	200.0	3.0	-

Table 4.1.C2: **Result of Particle Size Distribution of Sample C2**

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	15.0	15.0	7.5	92.5
6.7mm	20.0	3.5	10	82.5
4.75mm	37.0	7.2	18.5	64.0
2.36mm	57.0	129.0	28.5	35.5
1.70mm	18.0	147.0	9.0	26.5
1.18mm	14.0	161.0	7.0	19.5
0.600µm	18.0	179.0	9.0	10.5
500µm	3.0	182.0	1.5	9.0
225µm	3.0	185.0	1.5	7.5
212µm	5.0	190.0	2.5	5.0
150µm	1.0	191.0	0.5	4.5
75µm	4.0	195.0	2.0	2.5
43µm				
PAN	5.0	200.0	2.5	-

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.1.C3: **Result of Particle Size Distribution of Sample C3**

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	9.0	9.0	4.5	95.5
6.7mm	14.0	23.0	7.0	88.5
4.75mm	23.0	46.0	11.5	77.0
2.36mm	60.0	106.0	30	47.0
1.70mm	20.0	126.0	10.0	37.0
1.18mm	18.0	144.0	9.0	28.0
0.600μm	26.0	170.0	13.0	15.0
500μm	3.0	173.0	1.5	13.5
225μm	5.0	178.0	2.5	11.0
212μm	8.0	186.0	4.0	7.0
150μm	1.0	187.0	0.5	6.5
75μm	7.0	194.0	3.5	3.0
43μm				
PAN	6.0	200.0	3.0	-

Table 4.1.C4: Result of Particle Size Distribution of Sample C4

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	-	-	-	100.0
6.7mm	12.0	12.0	6.0	94.0
4.75mm	20.0	32.0	10.0	84.0
2.36mm	53.0	85.0	26.5	57.5
1.70mm	22.0	107.0	11.0	46.5
1.18mm	17.0	124.0	8.5	38.0
0.600μm	29.0	153.0	14.5	23.5
500μm	4.0	157.0	2.0	21.5
225μm	6.0	163.0	3.0	18.5
212μm	14.0	177.0	7.0	11.5
150μm	4.0	181.0	2.0	9.5
75μm	12.0	193.0	6.0	3.5
43μm				
PAN	7.0	200.0	3.5	-

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.1.D1: **Result of Particle Size Distribution of Sample D1**

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	6.0	6.0	3.0	97.0
6.7mm	15.0	21.0	7.5	89.5
4.75mm	19.0	40.0	9.5	80.0
2.36mm	51.0	91.0	25.5	54.5
1.70mm	20.0	111.0	10.0	44.5
1.18mm	18.0	129.0	9.0	35.5
0.600µm	27.0	156.0	13.5	22.0
500µm	5.0	161.0	2.5	19.5
225µm	7.0	168.0	3.5	16.0
212µm	17.0	185.0	8.5	7.5
150µm	4.0	189.0	2.0	5.5
75µm	6.0	195.0	3.0	2.5
43µm				
PAN	5.0	200.0	2.5	-

Table 4.1.D2: **Result of Particle Size Distribution of Sample D2**

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	5.0	5.0	2.5	97.5
6.7mm	16.0	2.1	8.0	89.5
4.75mm	21.0	4.2	10.5	79.0
2.36mm	54.0	96.0	27.0	52.0
1.70mm	21.0	117.0	10.5	41.5
1.18mm	18.0	135.0	9.0	32.5
0.600µm	28.0	163.0	14.0	18.5
500µm	4.0	167.0	2.0	16.5
225µm	6.0	173.0	3.0	13.5
212µm	13.0	186.0	6.5	7.0
150µm	3.0	189.0	1.5	5.5
75µm	6.0	195.0	3.0	2.5
43µm				
PAN	5.0	200.0	2.5	-

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.1.D3: **Result of Particle Size Distribution of Sample D3**

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	11.0	11	5.5	94.5
6.7mm	28.0	39	14	80.5
4.75mm	35.0	74	17.5	63.0
2.36mm	53.0	127	26.5	36.5
1.70mm	16.0	143	8.0	28.5
1.18mm	13.0	156	6.5	22.0
0.600µm	17.0	173	8.5	13.5
500µm	3.0	176	1.5	12.0
225µm	3.0	179	1.5	10.5
212µm	7.0	186	3.5	7.0
150µm	2.0	188	1.0	6.0
75µm	8.0	196.0	4.0	2.0
43µm				
PAN	4.0	200.0	2.0	-

Table 4.1.D4: **Result of Particle Size Distribution of Sample D4**

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	1.0	1.0	0.5	99.5
6.7mm	7.0	8.0	3.5	96.0
4.75mm	14.0	22.0	7.0	89.0
2.36mm	44.0	66.0	22	67.0
1.70mm	19.0	85.0	9.5	57.3
1.18mm	19	104.0	9.5	48.0
0.600µm	33.0	137.0	16.5	31.5
500µm	6.0	143.0	3.0	28.5
225µm	9.0	152.0	4.5	24.0
212µm	21.0	173.0	10.5	13.5
150µm	7.0	180.0	3.5	10.0
75µm	13.0	193.0	6.5	3.5
43µm				
PAN	7.0	200.0	3.5	-

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.1.E: **Result of Particle Size Distribution of Sample E**

Sieve size	*Weight Retained*	*Cum. Wt Retained*	*% Retained*	*% Passing*
9.5mm	5.0	5.0	2.5	97.5
6.7mm	17.0	22.0	8.5	89.0
4.75mm	29.0	51.0	14.5	74.5
2.36mm	70.0	121.0	35	39.5
1.70mm	22.0	143.0	11	28.5
1.18mm	18.0	161.0	9	19.5
0.600μm	24.0	185.0	12	7.5
500μm	3.0	188.0	1.5	6.0
225μm	4.0	192.0	2.0	4.0
212μm	5.0	197.0	2.5	1.5
150μm	7.0	197.7	0.35	1.15
75μm	1.3	199.0	0.65	0.5
43μm				
PAN	1.0	200.0	0.5	-

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

APPENDIX 2:

Results of the Consistency limit tests of the treated and untreated samples

APPENDIX 2

4.3.1 CONSISTENCY LIMITS TESTS OF THE TREATED AND UNTREATED SAMPLES

Table 4.3.1.A1: Consistency Limits tests of Sample A1

Additive Content: 2% Cement + 98% Soil Sample

	1	2	3	4			
No of blows	45	39	33	20	PL		
Can No	A11	A12	A13	A14	A1X	A1Y	A1Z
Mass of wet soil + can ($W_{ws} + W_c$)	32.7	33.3	33.86	31.94	15.45	17.0	16.0
Mass of dry soil + can ($W_{ds} + W_c$)	32.0	32.0	32.86	31.00	15.15	16.8	15.8
Mass of can (W_c)	29.0	29.0	30.00	29.00	14.00	15.0	15.0
Mass of dry soil (W_{ds})	3.0	3.3	2.86	2.00	1.15	1.0	0.8
Mass of moisture (W_w)	0.7	1.0	1.00	0.94	0.30	0.3	0.2
Moisture content % (M_c)	23.6	30.3	35.0	47.0	26.0	30.0	25.0
PL					27.0		

Table 4.3.1.A2: Consistency Limits tests of Sample A2

Additive Content: 4% Cement + 96% Soil Sample

	1	2	3	4			
No of blows	45	39	21	17	PL		
Can No	A21	A22	A23	A24	A2X	A2Y	A2Z
Mass of wet soil + can ($W_{ws} + W_c$)	33.45	33.94	33.56	34.23	16.83	16.0	16.0
Mass of dry soil + can ($W_{ds} + W_c$)	32.45	32.94	32.00	32.73	16.63	15.6	15.8
Mass of can (W_c)	29.00	30.00	29.00	30.00	16.00	15.0	15.0
Mass of dry soil (W_{ds})	3.45	2.94	3.00	2.73	0.63	0.6	0.8
Mass of moisture (W_w)	1.00	1.00	1.56	1.50	0.20	0.4	0.2
Moisture content % (M_c)	29.0	34.0	52.0	55.0	31.7	33.3	25.0
PL					30.0		

Note:

$$MC = \left(\frac{Ww}{Wds} \times 100 \right) \%$$

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.3.1.A3: Consistency Limits tests of Sample A3

Additive Content: 6% Cement + 94% Soil Sample

	1	2	3	4			
No of blows	45	33	29	14	PL		
Can No	A31	A32	A33	A34	A3X	A3Y	A3Z
Mass of wet soil + can (W_{ws} + W_c)	34.18	32.43	33.95	31.56	32.8	17.2	16.1
Mass of dry soil + can (W_{ds} + W_c)	33.80	31.70	32.95	31.0	22.0	17.0	16.0
Mass of can (W_c)	30.00	29.00	30.0	30.0	15.0	16.0	15.0
Mass of dry soil (W_{ds})	3.80	2.70	2.95	1.0	7.0	1.0	1.0
Mass of moisture (W_w)	0.38	0.73	1.0	0.56	2.4	0.2	0.3
Moisture content % (M_c)	10.0	27.0	34.0	56.0	34.2	20.0	30.0
PL					28.0		

Table 4.3.1.A4: Consistency Limits tests of Sample A4

Additive Content: 8% Cement + 92% Soil Sample

	1	2	3	4			
No of blows	46	35	20	15	PL		
Can No	A41	A42	A43	A44	A4X	A4Y	A4Z
Mass of wet soil + can (W_{ws} + W_c)	33.45	32.84	34.56	32.12	16.57	17.0	16.0
Mass of dry soil + can (W_{ds} + W_c)	32.45	32.0	33.0	31.0	16.37	16.8	15.8
Mass of can (W_c)	29.0	29.0	30.0	29.0	16.00	16.8	15.0
Mass of dry soil (W_{ds})	3.45	3.0	3.0	2.0	0.37	0.8	0.8
Mass of moisture (W_w)	1.0	0.84	1.56	1.12	0.20	0.2	0.2
Moisture content % (M_c)	29	38.0	52.0	56.0	53.5	25.0	25.5
PL					34.5		

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.3.1.B1: Consistency Limits tests of Sample B1

Additive Content: 0.5% Cocoa Pod Ash + 1.5% Cement + 98% Soil Sample

	1	2	3	4			
No of blows	30.0	28.0	24.0	20.0		PL	
Can No	B11	B12	B13	B14	B1X	B1Y	B1Z
Mass of wet soil + can (W_{ws} + W_c)	30.6	33.75	35.4	33.72	17.0	16.0	17.1
Mass of dry soil + can (W_{ds} + W_c)	30.3	32.75	33.7	32.72	16.8	15.8	16.9
Mass of can (W_c)	29.0	29.0	29.0	30.00	16.0	14.0	16.0
Mass of dry soil (W_{ds})	1.3	3.75	4.7	2.72	0.8	1.8	0.9
Mass of moisture (W_w)	0.3	1.0	1.7	1.00	0.2	0.2	0.2
Moisture content % (M_c)	23.0	27.0	36.0	44.00	25.0	11.1	22.2
PL						19.5	

Table 4.3.1.B2: Consistency Limits tests of Sample B2

Additive Content: 1% Cocoa Pod Ash + 3% Cement + 96% Soil Sample

	1	2	3	4			
No of blows	40.0	36.0	28.0	17.0		PL	
Can No	B21	B22	B23	B24	B2X	B2Y	B2Z
Mass of wet soil + can (W_{ws} + W_c)	33.92	33.84	33.63	34.53	16.3	16.0	17.76
Mass of dry soil + can (W_{ds} + W_c)	33.00	33.00	32.63	33.00	16.1	15.6	17.50
Mass of can (W_c)	29.00	30.00	30.00	30.00	15.0	14.0	16.00
Mass of dry soil (W_{ds})	4.00	3.00	2.63	3.00	1.04	1.6	1.50
Mass of moisture (W_w)	1.92	1.84	1.00	1.53	0.2	0.4	0.26
Moisture content % (M_c)	23.00	28.00	38.00	51.00	19.2	25.0	17.00
PL						20.40	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.3.1.B3: Consistency Limits tests of Sample B3

Additive Content: 1.5% Cocoa Pod Ash + 4.5% Cement + 94% Soil Sample

	1	2	3	4			
No of blows	45.0	33.0	20.0	15.0		PL	
Can No	B31	B32	B33	B34	B3X	B3Y	B3Z
Mass of wet soil + can (W_{ws} + W_c)	32.44	33.9	34.17	37.2	16.0	15.7	15.9
Mass of dry soil + can (W_{ds} + W_c)	32.00	33.0	33.00	35.0	15.8	15.6	15.7
Mass of can (W_c)	30.00	30.0	30.00	30.0	15.0	15.0	15.0
Mass of dry soil (W_{ds})	2.00	3.0	3.00	5.0	0.8	0.6	0.7
Mass of moisture (W_w)	0.44	0.9	1.17	2.2	0.2	0.1	0.2
Moisture content % (M_c)	22.00	30.0	39.00	44.0	25.0	16.0	28.6
PL						23.2	

Table 4.3.1.B4: Consistency Limits tests of Sample B4

Additive Content: 2% Cocoa Pod Ash + 6% Cement + 92% Soil Sample

	1	2	3	4			
No of blows	35.0	30.0	23.0	16.0		PL	
Can No	B41	B42	B43	B44	B4X	B4Y	B4Z
Mass of wet soil + can (W_{ws} + W_c)	35.08	35.0	20.68	33.02	16.75	15.76	16.77
Mass of dry soil + can (W_{ds} + W_c)	34.08	34.0	19.00	32.00	16.40	16.40	16.39
Mass of can (W_c)	30.00	31.0	15.00	30.00	15.00	15.00	15.00
Mass of dry soil (W_{ds})	4.00	3.0	4.00	2.00	1.40	1.40	1.39
Mass of moisture (W_w)	1.08	1.0	1.68	1.02	3.50	3.60	0.38
Moisture content % (M_c)	27.00	33.0	42.00	51.00	25.00	25.7	27.3
PL						26.0	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.3.1.C1: Consistency Limits tests of Sample C1

Additive Content: 0.5% Palm Kernel Shell Ash + 1.5% Cement + 98% Soil Sample

	1	2	3	4			
No of blows	45.0	35.0	21.0	18.0	PL		
Can No	C11	C12	C13	C14	C1X	C1Y	C1Z
Mass of wet soil + can ($W_{ws} + W_c$)	32.66	35.16	35.90	35.5	16.4	17.3	16.2
Mass of dry soil + can ($W_{ds} + W_c$)	32.0	34.00	34.00	35.0	16.0	17.0	16.0
Mass of can (W_c)	30.0	30.00	29.00	30.0	14.0	16.0	15.0
Mass of dry soil (W_{ds})	2.0	4.00	5.00	5.0	2.0	1.0	1.0
Mass of moisture (W_w)	0.66	1.16	1.90	2.0	0.4	0.3	0.2
Moisture content % (M_c)	23.0	29.00	38.00	40.0	20.0	29.0	20.0
PL					23.0		

Table 4.3.1.C2: Consistency Limits tests of Sample C2

Additive Content: 1% Palm Kernel Shell Ash + 3% Cement + 96% Soil Sample

	1	2	3	4			
No of blows	40.0	37.0	25.0	16.0	PL		
Can No	C21	C22	C23	C24	C2X	C2Y	C2Z
Mass of wet soil + can ($W_{ws} + W_c$)	33.75	36.45	35.95	36.4	16.43	16.45	17.3
Mass of dry soil + can ($W_{ds} + W_c$)	33.0	35.00	34.00	34.0	16.00	16.01	17.0
Mass of can (W_c)	30.0	30.00	29.00	29.0	15.00	15.09	16.0
Mass of dry soil (W_{ds})	3.0	5.00	5.00	5.0	1.00	1.00	1.0
Mass of moisture (W_w)	0.75	1.45	1.95	2.4	0.30	0.31	0.3
Moisture content % (M_c)	25.0	29.00	39.00	48.0	30.0	33.00	30.0
PL					31.0		

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.3.1.C3: Consistency Limits tests of Sample C3

Additive Content: 1.5% Palm Kernel Shell Ash + 4.5% Cement + 94% Soil Sample

	1	2	3	4			
No of blows	42.0	32.0	20.0	16.0	PL		
Can No	C31	C32	C33	C34	C3X	C3Y	C3Z
Mass of wet soil + can ($W_{ws} + W_c$)	35.1	36.7	37.45	34.62	17.73	14.74	18.0
Mass of dry soil + can ($W_{ds} + W_c$)	34.0	35.0	35.00	33.0	17.53	14.54	17.0
Mass of can (W_c)	29.0	30.0	30.00	30.0	17.00	14.00	14.0
Mass of dry soil (W_{ds})	5.0	5.0	5.00	3.00	1.53	0.54	3.0
Mass of moisture (W_w)	1.1	1.7	2.45	1.62	0.20	0.20	1.0
Moisture content % (M_c)	22.0	34.0	49.00	54.00	37.70	37.00	33.3
PL					36.0		

Table 4.3.1.C4: Consistency Limits tests of Sample C4

Additive Content: 2% Palm Kernel Shell Ash + 6% Cement + 92% Soil Sample

	1	2	3	4			
No of blows	37.0	27.0	20.0	13.0	PL		
Can No	C41	C42	C43	C44	C4X	C4Y	C4Z
Mass of wet soil + can ($W_{ws} + W_c$)	36.7	35.4	37.7	38.1	16.4	17.43	17.4
Mass of dry soil + can ($W_{ds} + W_c$)	35.0	33.0	35.0	35.0	16.0	16.70	17.0
Mass of can (W_c)	30.0	30.0	30.0	30.0	15.0	16.00	16.0
Mass of dry soil (W_{ds})	5.0	3.0	5.0	5.0	1.0	1.00	1.0
Mass of moisture (W_w)	1.7	2.4	2.7	3.1	0.4	0.43	0.4
Moisture content % (M_c)	34.0	48.0	54.0	62.0	40.0	43.00	40.0
PL					41.0		

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.3.1.D1: Consistency Limits tests of Sample D1

Additive Content: 0.25% Cocoa Pod Ash + 0.25% Palm Kernel Shell Ash + 1.5% Cement + 98% Soil Sample

	1	2	3	4			
No of blows	44.0	35.0	23.0	18.0	PL		
Can No	D11	D12	D13	D14	D1X	D1Y	D1Z
Mass of wet soil + can ($W_{ws} + W_c$)	34.68	37.15	37.15	37.7	17.77	17.0	17.0
Mass of dry soil + can ($W_{ds} + W_c$)	34.0	35.00	35.0	35.0	16.17	16.8	16.8
Mass of can (W_c)	30.0	29.00	30.0	29.0	16.39	16.0	16.0
Mass of dry soil (W_{ds})	4.0	6.00	5.0	6.0	1.39	0.8	0.8
Mass of moisture (W_w)	0.68	1.74	2.15	2.7	0.38	0.2	0.2
Moisture content % (M_c)	17.0	29.00	43.0	45.0	27.4	25.0	25.0
PL						25.8	

Table 4.3.1.D2: Consistency Limits tests of Sample D2

Additive Content: 0.5% Cocoa Pod Ash + 0.5% Palm Kernel Shell Ash + 3% Cement + 96% Soil Sample

	1	2	3	4			
No of blows	37.0	30.0	22.9	16.0	PL		
Can No	D21	D22	D23	D24	D2X	D2Y	D2Z
Mass of wet soil + can ($W_{ws} + W_c$)	36.45	36.85	36.35	36.16	16.32	16.0	16.32
Mass of dry soil + can ($W_{ds} + W_c$)	35.0	35.00	34.00	34.00	16.22	15.8	16.22
Mass of can (W_c)	30.0	30.00	29.00	30.00	16.00	15.0	16.00
Mass of dry soil (W_{ds})	5.0	5.00	5.00	4.00	0.32	0.8	0.32
Mass of moisture (W_w)	1.45	1.85	2.35	2.16	0.10	0.2	0.10
Moisture content % (M_c)	29.0	37.00	47.00	54.00	31.20	25.0	30.80
PL						29.0	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.3.1.D3: Consistency Limits tests of Sample D3

Additive Content: 0.75% Cocoa Pod Ash + 0.75% Palm Kernel Shell Ash + 4.5% Cement + 98% Soil Sample

	1	2	3	4			
No of blows	45.0	40.0	25.0	20.0	PL		
Can No	D31	D32	D33	D34	D3X	D3Y	D3Z
Mass of wet soil + can ($W_{ws} + W_c$)	36.0	34.08	36.02	39.12	16.32	16.40	15.07
Mass of dry soil + can ($W_{ds} + W_c$)	35.0	33.00	35.0	36.0	16.22	16.01	14.80
Mass of can (W_c)	30.0	29.00	29.0	30.0	16.00	15.09	14.00
Mass of dry soil (W_{ds})	5.0	4.00	6.0	6.0	0.32	1.0	0.80
Mass of moisture (W_w)	1.0	1.08	1.02	3.12	0.1	0.31	0.27
Moisture content % (M_c)	20.0	27.0	34.0	52.0	31.2	33.0	33.8
PL						32.7	

Table 4.3.1.D4: Consistency Limits tests of Sample D4

Additive Content: 1% Cocoa Pod Ash + 1% Palm Kernel Shell Ash + 6% Cement + 92% Soil Sample

	1	2	3	4			
No of blows	40.0	30.0	20.0	14.0	PL		
Can No	D41	D42	D43	D44	D4X	D4Y	D4Z
Mass of wet soil + can ($W_{ws} + W_c$)	37.74	37.52	38.24	38.66	17.23	18.0	16.45
Mass of dry soil + can ($W_{ds} + W_c$)	36.00	35.0	35.00	35.00	17.00	15.7	16.00
Mass of can (W_c)	30.00	29.0	29.00	29.00	16.00	14.0	15.09
Mass of dry soil (W_{ds})	6.00	6.00	6.00	6.00	0.99	3.0	1.00
Mass of moisture (W_w)	1.74	2.52	3.24	3.66	0.30	1.0	0.45
Moisture content % (M_c)	29.00	42.00	54.0	61.00	30.3	33.3	45.00
PL						36.3	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.3.1.E: Consistency Limits tests of Sample E

Additive Content: 0% Cement + 100% Soil Sample

	1	2	3	4			
No of blows	43.0	39.0	25.0	15.0		PL	
Can No	E11	E12	E13	E14	E1X	E1Y	E1Z
Mass of wet soil + can ($W_{ws} + W_c$)	35.0	35.0	37.0	37.5	15.7	14.5	17.9
Mass of dry soil + can ($W_{ds} + W_c$)	34.0	34.0	35.0	35.0	15.6	14.4	17.8
Mass of can (W_c)	29.0	30.0	29.0	29.0	15.0	14.0	17.0
Mass of dry soil (W_{ds})	5.0	4.0	6.0	6.0	0.6	0.4	0.8
Mass of moisture (W_w)	1.0	1.0	2.0	2.5	0.1	0.1	0.1
Moisture content % (M_c)	20.0	25.0	33.3	41.6	16.0	25.0	12.5
PL						17.8	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

Table 4.3.2 **SUMMARY OF RESULTS SHOWING MOISTURE CONTENTS AND NO OF BLOWS FOR BOTH TREATED AND TREATED SAMPLES**

SAMPLE	A				B				C				D				E			
TEST NO	2%	4%	6%	8%	2%	4%	6%	8%	2%	4%	6%	8%	2%	4%	6%	8%	2%	4%	6%	8%
0% Additive Content																				
No of blows																	43.0	39.0	25.0	15.0
Moisture content %																	20.0	25.0	33.3	41.6
2% Additive Content																				
No of blows	45.0	39.0	33.0	20.0	30.0	28.0	24.0	20.0	45.0	35.0	21.0	18.0	44.0	35.0	23.0	18.0				
Moisture content %	23.6	30.0	35.0	47.0	23.0	27.0	36.0	44.0	23.0	29.0	38.0	40.0	17.0	29.0	43.0	45.0				
4% Additive Content																				
No of blows	45.0	39.0	21.0	17.0	40.0	36.0	28.0	17.0	40.0	37.0	25.0	16.0	37.0	30.0	22.0	16.0				
Moisture content %	29.0	34.0	52.0	55.0	23.0	28.0	38.0	51.0	25.0	29.0	39.0	48.0	29.0	37.0	47.0	54.0				
6% Additive Content																				
No of blows	45.0	33.0	29.0	14.0	45.0	33.0	20.0	15.0	42.0	32.0	20.0	16.0	45.0	40.0	35.0	20.0				
Moisture content %	10.0	27.0	34.0	56.0	22.0	30.0	39.0	44.0	22.0	34.0	49.0	54.0	20.0	27.0	34.0	52.0				
8% Additive Content																				
No of blows	46.0	35.0	20.0	15.0	35.0	30.0	23.0	16.0	37.0	27.0	20.0	13.0	40.0	30.0	20.0	14.0				
Moisture content %	29.0	38.0	52.0	56.0	27.0	33.0	42.0	51.0	34.0	48.0	54.0	62.0	29.0	42.0	54.0	61.0				

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

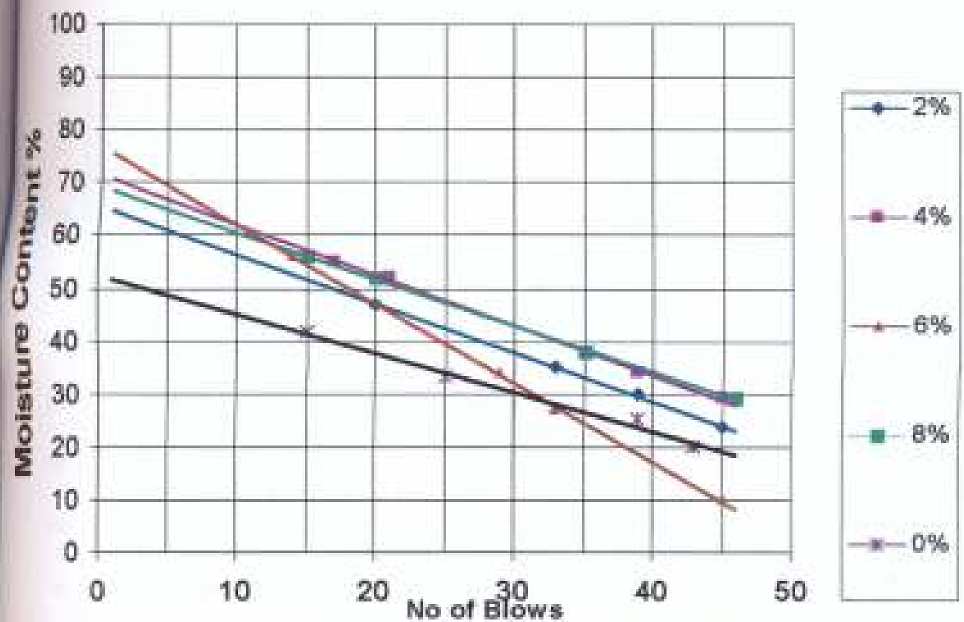


Fig 4.3.A: Graphs of Moisture Content Against No of Blows of Samples A and E

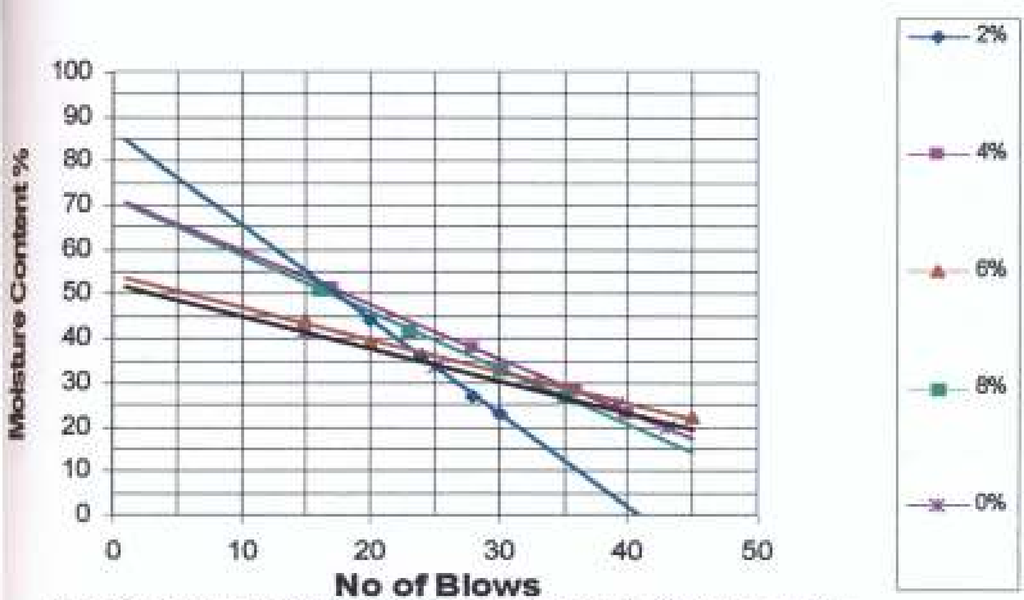


Fig 4.3.B: Graphs of Moisture Content against No of Blows of samples B and E

LEGEND

ioil + Cement; B = Soil + Cement + Cocoa Pod Ash

ioil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell;

il Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

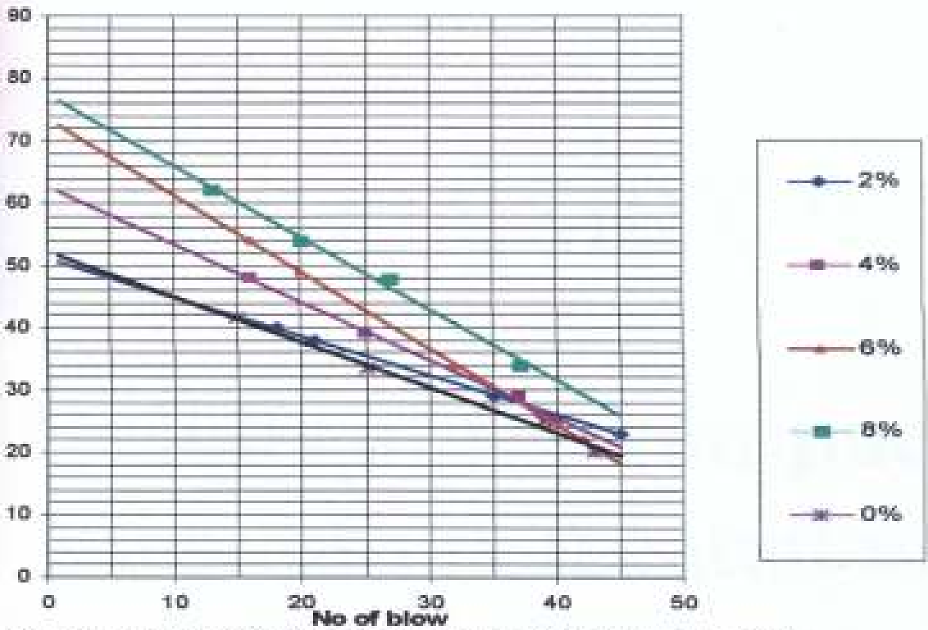


Fig 4.3.C : Graphs of moisture content against no of blows of samples C and E

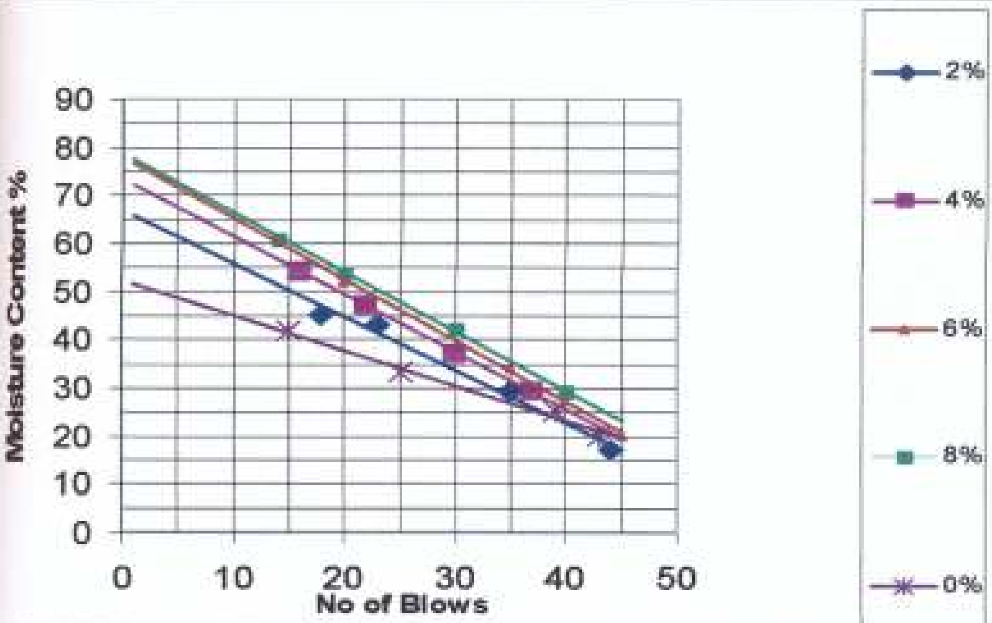


Fig 4.3.D: Graphs of Moisture Content Against No of Blows for samples D and E

LEGEND

Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + ent + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = + Palm Kernel Shell Ash

APPENDIX 3:

Results of the compaction test of the treated and untreated samples

APPENDIX 3

TABLE 4.4: RESULTS OF COMPACTION TEST FOR BOTH ADDITIVE TREATED AND UNTREATED SOIL SAMPLES

Table 4.4.1.A1: Compaction test of Sample A1

Additive Content: 2% Cement + 98% Soil Sample

Test No	1		2		3		4		5		6		7	
of Cyl. And wet Sample (kg)	2.75		3.85		3.85		4.15		4.06		4.10		4.00	
of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
of wet sample (kg)	1.10		2.00		1.99		2.30		2.21		2.25		2.15	
Density (KN/M^3)	18.60		19..60		19.5		22.60		21.89		22.10		21.10	
ainer No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
of Cont. and wet Sample (g)	34.0	34.0	35.0	48.0	35.0	35.0	36.0	36.0	36.0	37.0	35.0	26.0	36.0	38
of Cont. and dry Sample (g)	33.0	33.0	34.0	47.0	3.0	34.0	35.0	35.0	24.0	34.0	33.0	23.0	33.0	35
of Moisture (g)	10.0	1.0	1.0	1.0	2.0	1.0	2.0	2.0	2.0	3.0	2.0	3.0	3.0	3.
of Container (g)	14.0	14.0	15.0	17.0	15.0	15.0	16.0	16.0	16.0	16.0	15.0	7.0	16.0	16
of Dry Sample (g)	19.0	19.0	19.0	18.0	18.0	19.0	18.0	18.0	18.0	18.0	18.0	16.0	17.0	17
isture content %	5.3	5.3	5.3	56.0	11.0	5.3	11.1	11.1	11.1	16.7	11.0	18.8	17.6	17
erage moisture content %	5.3		5.5		8.2		11.1		13.9		15.0		17.6	
y Density (KN/m^3)	17.7		18.6		18.0		19.9		19.2		19.2		17.9	

Table 4.4.1.A2: Compaction test of Sample A2

Additive Content: 4% Cement + 96% Soil Sample

Test No	1		2		3		4		5		6		7	
Wt. of Cyl. And wet Sample (kg)	3.70		3.60		3.95		4.07		4.20		4.10		3.71	
Wt. of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
Wt of wet sample (kg)	1.85		1.75		2.10		2.22		2.35		2.25		1.86	
Wet Density (KN/M^3)	18.13		17.2		20.60		21.80		32.50		22.07		18.26	
Container No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
Wt. of Cont. and wet Sample (g)	34.0	36.0	35.0	36.0	34.0	35.0	35.0	36.0	36.0	36.0	35.0	36.0	36.0	3
Wt. of Cont. and dry Sample (g)	33.0	35.0	34.0	35.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	32.0	32.0	3
Wt. of Moisture (g)	1.0	1.0	1.0	1.0	1.0	2.0	2.0	3.0	3.0	3.0	2.0	4.0	4.0	4.
Wt. of Container (g)	14.0	16.0	15.0	17.0	14.0	15.0	17.0	9.0	16.0	16.0	15.0	16.0	13.6	1
Wt. of Dry Sample (g)	19.0	19.0	19.0	18.0	19.0	18.0	16.0	24.0	17.0	17.0	18.0	16.0	18.4	1
Moisture content %	5.3	5.3	5.3	5.3	5.13	11.1	12.5	12.5	17.6	17.6	11.1	25.0	21.7	2
Average moisture content %	5.3		5.5		8.2		12.5		17.6		18.1		21.7	
Dry Density (KN/m^3)	17.2		16.3		19.0		20.4		20.0		18.7		17.1	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.4.1.A3: Compaction test of Sample A3

Additive Content: 6% Cement + 94% Soil Sample

Test No	1		2		3		4		5		6		7	
Wt. of Cyl. And wet Sample (kg)	3.75		3.80		3.90		4.00		4.05		4.12		3.95	
Wt. of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
Wt. of wet sample (kg)	1.90		1.95		2.05		2.15		2.20		2.27		2.10	
Wet Density (KN/M^3)	18.60		19.10		20.10		21.10		21.16		22.22		20.60	
Container No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
Wt. of Cont. and wet Sample (g)	36.0	36.0	36.0	36.0	34.0	35.0	35.0	36.0	34.0	37.0	35.0	36.0	35.0	36.0
Wt. of Cont. and dry Sample (g)	35.0	35.0	35.0	35.0	33.0	33.0	33.0	35.0	33.0	35.0	33.0	34.0	32.0	33.0
Wt. of Moisture (g)	1.0	1.0	1.0	1.0	1.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	3.0	3.0
Wt. of Container (g)	16.0	16.0	16.0	17.0	14.0	15.0	15.0	17.0	14.0	18.0	15.0	16.0	15.0	16.0
Wt. of Dry Sample (g)	19.0	19.0	19.0	18.0	19.0	18.0	18.0	18.0	19.0	17.0	18.0	18.0	17.0	17.0
Moisture content %	5.3	5.3	5.3	5.6	5.3	11.1	11.1	5.6	5.3	11.8	11.1	11.1	17.6	17.6
Average moisture content %	5.3		5.5		8.2		8.4		8.6		11.1		17.6	
Dry Density (KN/m^3)	17.7		18.1		18.6		18.5		19.9		20.8		17.5	

Table 4.4.1.A4: Compaction test of Sample A4

Additive Content: 8% Cement + 92% Soil Sample

Test No	1		2		3		4		5		6		7	
Wt. of Cyl. And wet Sample (kg)	3.75		3.85		3.90		3.95		4.00		3.73		4.05	
Wt. of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
Wt. of wet sample (kg)	1.90		2.00		2.05		2.10		2.15		1.88		2.20	
Wet Density (KN/M^3)	16.60		19.60		20.10		20.60		21.10		18.40		21.60	
Container No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
Wt. of Cont. and wet Sample (g)	26.0	26.0	35.0	35.0	25.0	30.0	35.0	36.0	30.0	34.0	35.0	36.0	35.0	30.0
Wt. of Cont. and dry Sample (g)	25.0	25.0	34.0	33.0	23.0	29.0	32.0	34.0	28.0	32.0	33.0	33.0	32.0	27.0
Wt. of Moisture (g)	1.0	1.0	1.0	2.0	2.0	1.0	3.0	1.0	2.0	2.0	2.0	3.0	3.0	3.0
Wt. of Container (g)	6.0	6.0	15.0	5.0	5.0	11.0	15.0	15.0	11.0	16.0	15.0	15.0	15.0	10.0
Wt. of Dry Sample (g)	19.0	19.0	19.0	18.0	18.0	18.0	17.0	19.0	17.0	16.0	18.0	18.0	17.0	17.0
Moisture content %	5.3	5.3	5.3	11.1	11.1	5.6	17.6	5.3	11.8	12.5	11.1	16.7	17.6	17.6
Average moisture content %	5.3		8.2		8.4		11.5		12.2		13.9		17.6	
Dry Density (KN/m^3)	15.8		18.1		18.5		18.5		18.8		21.7		18.4	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.4.1.B1: Compaction test of Sample B1

Additive Content: 0.5% Cocoa Pod Ash + 1.5% Cement + 98% Soil Sample

Test No	1		2		3		4		5		6		7	
Wt. of Cyl. And wet Sample (kg)	3.70		3.75		3.80		3.85		4.00		3.59		3.95	
Wt. of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
Wt. of wet sample (kg)	1.85		1.90		1.95		2.00		2.15		1.74		2.10	
Wet Density (KN/M^3)	18.1		18.1		19.10		19.60		21.10		17.05		20.60	
Container No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
Wt. of Cont. and wet Sample (g)	35.0	36.0	36.0	35.0	35.0	35.0	36.0	36.0	36.0	34.0	36.0	36.0	36.0	36.0
Wt. of Cont. and dry Sample (g)	34.0	35.0	35.0	34.0	34.0	33.0	34.0	35.0	33.0	33.0	34.0	33.0	33.0	33.0
Wt. of Moisture (g)	1.0	1.0	1.0	1.0	1.0	2.0	2.0	1.0	3.0	1.0	2.0	3.0	3.0	3.0
Wt. of Container (g)	15.0	16.0	17.0	15.0	16.0	15.0	17.0	16.0	16.0	14.0	16.0	16.0	15.0	15.0
Wt. of Dry Sample (g)	19.0	19.0	18.0	18.0	17.0	19.0	17.0	19.0	17.0	19.0	18.0	17.0	18.0	18.0
Moisture content %	5.3	5.3	5.6	5.3	5.6	11.1	11.8	5.3	17.6	5.3	11.1	17.6	16.7	16.7
Average moisture content %	5.3		5.5		8.4		8.6		11.5		14.4		16.7	
Dry Density (KN/m^3)	17.2		17.6		17.6		18.0		18.9		19.2		17.7	

Table 4.4.1.B2: Compaction test of Sample B2

Additive Content: 1% Cocoa Pod Ash + 3% Cement + 96% Soil Sample

Test No	1		2		3		4		5		6		7	
Wt. of Cyl. And wet Sample (kg)	3.75		3.80		3.85		3.78		3.95		4.15		3.90	
Wt. of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
Wt. of wet sample (kg)	1.90		1.95		2.00		1.93		2.10		2.30		2.05	
Wet Density (KN/M^3)	18.60		19.10		19.60		18.92		20.60		22.60		20.10	
Container No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
Wt. of Cont. and wet Sample (g)	48.0	37.0	35.0	35.0	35.0	35.0	36.0	35.0	36.0	37.0	36.0	36.0	36.0	36.0
Wt. of Cont. and dry Sample (g)	47.0	36.0	34.0	34.0	34.0	34.0	35.0	34.0	34.4	35.0	34.0	33.0	33.0	33.0
Wt. of Moisture (g)	1.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0	1.5	2.0	2.0	3.0	3.0	3.0
Wt. of Container (g)	27.0	16.0	16.0	15.0	17.0	17.0	16.0	16.5	16.0	17.0	16.0	16.0	16.0	16.0
Wt. of Dry Sample (g)	20.0	20.0	19.0	18.0	17.0	17.0	19.0	18.5	18.0	18.0	18.0	17.0	17.0	17.0
Moisture content %	5.0	5.0	5.3	5.6	5.9	5.9	10.5	5.6	8.1	11.1	11.1	17.6	17.6	17.6
Average moisture content %	5.0		5.5		5.9		8.1		9.6		14.4		17.6	
Dry Density (KN/m^3)	17.7		18.1		18.1		17.5		18.8		19.5		17.1	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.4.1.B3: Compaction test of Sample B3

Additive Content: 1.5% Cocoa Pod Ash +4.5% Cement + 94% Soil Sample

Test No	1		2		3		4		5		6		7	
t. of Cyl. And wet Sample (kg)	3.65		3.75		3.80		3.87		3.90		3.69		3.90	
t. of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
t of wet sample (kg)	1.80		1.90		1.95		2.02		2.09		1.84		2.05	
t Density (KN/M^3)	17.70		18.60		19.10		19.83		20.10		18.00		20.10	
ontainer No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
t. of Cont. and wet Sample (g)	34.0	36.0	35.0	49.0	35.0	50.0	49.0	35.0	36.0	34.0	35.0	36.0	34.0	50.0
t. of Cont. and dry Sample (g)	33.0	35,0	34.0	48.0	34.0	48.0	48.0	33.0	24.0	32.0	33.0	34.0	32.0	47.0
t. of Moisture (g)	1.0	1.0	1.0	1.0	1.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0
t. of Container (g)	14.0	16.0	15.0	30.0	15.0	18.0	34.0	5.6	6.0	12.0	15.0	16.0	14.0	30.0
t. of Dry Sample (g)	19.0	19.0	19.0	18.0	19.0	20.0	14.0	27.4	18.0	20.0	18.0	18.0	17.0	17.0
isture content %	5.3	5.3	5.3	5.6	5.3	10.0	7.1	7.3	11.1	10.0	11.1	11.1	17.6	17.6
erage moisture content %	5.3		5.5		7.7		7.2		10.6		11.1		17.6	
y Density (KN/m^3)	16.8		17.6		17.7		18.1		18.2		20.2		17.7	

Table 4.4.1.B4: Compaction test of Sample B4

Additive Content: 2% Cocoa Pod Ash + 6% Cement + 92% Soil Sample

Test No	1		2		3		4		5		6		7	
t. of Cyl. And wet Sample (kg)	3.53		3.80		3.85		3.80		4.15		3.76		3.85	
t. of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
t of wet sample (kg)	1.68		1.95		2.00		1.95		2.30		1.91		2.00	
t Density (KN/M^3)	16.5		19.10		19.60		19.17		22.60		18.78		19.60	
ontainer No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
t. of Cont. and wet Sample (g)	30.0	34.0	30.0	23.0	37.0	49.0	40.0	50.0	24.0	26.0	30.0	30.0	35.0	25.0
t. of Cont. and dry Sample (g)	29.0	33.0	29.0	22.0	35.0	48.0	38.0	48.0	21.0	25.0	28.0	28.0	32.0	22.0
t. of Moisture (g)	1.0	1.0	1.0	1.0	2.0	1.0	2.0	2.0	3.0	1.0	2.0	2.0	3.0	3.0
t. of Container (g)	10.0	14.0	10.0	4.0	14.0	29.0	10.0	30.0	4.0	6.0	11.0	11.0	15.0	5.0
t. of Dry Sample (g)	19.0	19.0	19.0	18.0	21.0	21.0	18.0	18.0	17.0	19.0	17.0	17.0	17.0	17.0
oisture content %	5.3	5.3	5.3	5.6	9.5	5.0	11.0	11.0	17.6	15.3	11.8	11.8	17.6	17.6
erage moisture content %	5.3		5.5		7.3		11.1		11.5		11.8		17.6	
y Density (KN/m^3)	17.4		18.1		18.3		20.3		20.0		19.8		16.7	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.4.1.C1: Compaction test of Sample C1

Additive Content: 0.5% Palm Kernel Shell Ash + 1.5% Cement + 98% Soil Sample

Test No	1		2		3		4		5		6		7	
t of Cyl. And wet Sample (kg)	3.75		3.80		3.80		3.85		3.67		4.15		3.95	
t of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
t of wet sample (kg)	1.90		1.95		1.95		2.00		1.82		2.30		2.10	
t Density (KN/M³)	18.6		19.10		19.10		19.60		17.81		22.60		20.60	
ntainer No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
t of Cont. and wet Sample (g)	36.0	36.0	35.0	35.0	25.0	36.0	34.0	35.0	35.0	34.0	34.0	35.0	35.0	35.0
t of Cont. and dry Sample (g)	35.5	35.5	34.0	34.5	34.0	35.0	32.0	34.0	33.0	33.5	32.5	33.5	33.0	33.0
t of Moisture (g)	0.5	0.5	1.0	0.5	1.0	1.0	2.0	1.0	2.0	0.5	1.5	1.5	2.0	2.0
t of Container (g)	16.0	16.0	15.0	15.0	15.0	16.0	14.0	15.0	15.0	12.0	14.0	15.0	15.0	15.0
t of Dry Sample (g)	19.5	19.5	19.0	19.5	19.0	19.0	18.0	19.0	18.0	21.5	18.5	18.5	18.0	18.0
isture content %	2.5	2.3	5.3	2.6	5.3	5.3	5.6	5.3	11.1	2.3	8.1	8.1	11.1	11.1
erage moisture content %	2.5		4.0		5.3		5.5		6.7		8.1		11.1	
y Density (KN/m³)	18.1		18.4		18.1		18.6		19.0		19.5		18.6	

Table 4.4.1.C2: Compaction test of Sample C2

Additive Content: 1% Palm Kernel Shell Ash + 3% Cement + 96% Soil Sample

Test No	1		2		3		4		5		6		7	
t of Cyl. And wet Sample (kg)	3.70		3.75		3.75		3.95		4.05		3.95		3.85	
t of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
t of wet sample (kg)	1.85		1.90		1.90		2.1		2.2		2.1		2.0	
t Density (KN/M³)	18.1		18.6		18.64		20.6		21.6		20.6		19.6	
ntainer No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
t of Cont. and wet Sample (g)	36.0	25.0	36.0	34.0	30.0	49.0	49.0	34.0	34.0	49.0	35.0	50.0	35.0	50.0
t of Cont. and dry Sample (g)	35.0	24.0	35.0	33.0	28.0	47.0	47.0	32.0	32.0	47.0	33.0	47.0	32.0	48.0
t of Moisture (g)	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0
t of Container (g)	16.0	5.0	17.0	14.0	7.0	29.0	29.0	14.0	15.0	30.0	12.0	3.0	15.0	30.0
t of Dry Sample (g)	19.0	19.0	18.0	19.0	21.0	20.0	18.0	18.0	17.0	17.0	21.0	17.0	17.0	18.0
isture content %	5.3	5.3	5.6	5.3	9.5	5.0	11.1	11.1	11.8	11.8	9.5	17.8	17.8	11.1
erage moisture content %	5.3		5.5		7.3		11.1		11.8		13.7		14.5	
y Density (KN/m³)	17.2		17.6		20.0		18.5		19.3		18.1		17.1	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.4.1.C3: Compaction test of Sample C3

Additive Content: 1.5% Palm Kernel Shell Ash + 4.5% Cement + 94% Soil Sample

Test No	1		2		3		4		5		6		7	
of Cyl. And wet Sample (kg)	3.65		3.70		3.56		3.00		3.69		4.00		3.85	
of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
of wet sample (kg)	1.80		1.85		1.70		2.05		1.84		2.15		2.00	
Density (KN/M³)	17.70		18.10		16.67		21.10		18.67		21.10		19.60	
tainer No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
of Cont. and wet Sample (g)	3.0	23.0	36.0	35.0	34.0	34.0	30.0	26.0	34.0	35.0	35.0	29.0	50.0	36.0
of Cont. and dry Sample (g)	29.0	22.0	34.0	34.0	32.0	33.0	28.0	24.0	32.0	33.0	33.0	27.0	47.0	33.0
of Moisture (g)	1.0	1.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0
of Container (g)	10.0	3.0	13.0	15.0	14.0	14.0	10.0	2.0	15.0	16.0	15.0	15.0	17.0	17.0
of Dry Sample (g)	19.0	19.0	21.0	19.0	18.0	19.0	18.0	20.0	17.0	17.0	18.0	15.0	17.0	17.0
sture content %	5.3	5.3	9.5	5.3	11.1	15.3	11.1	10.0	11.8	11.8	11.1	13.3	17.6	17.6
erage moisture content %	5.3		7.4		8.2		10.2		11.8		12.2		17.6	
y Density (KN/m³)	16.8		16.9		18.0		18.2		20.2		18.8		16.7	

Table 4.4.1.C4: Compaction test of Sample C4

Additive Content: 2% Palm Kernel Shell Ash + 6% Cement + 92% Soil Sample

Test No	1		2		3		4		5		6		7	
t. of Cyl. And wet Sample (kg)	3.65		3.70		3.47		4.05		4.10		3.90		3.80	
t. Of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
t of wet sample (kg)	1.80		1.85		1.62		2.20		2.25		2.05		1.95	
et Density (KN/M³)	1.70		18.10		15.90		21.60		22.10		20.10		19.10	
ontainer No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
t. of Cont. and wet Sample (g)	50.0	36.0	35.0	50.0	30.0	50.0	35.0	39.0	34.0	50.0	49.0	34.0	49.0	35.0
t. of Cont. and dry Sample (g)	49.0	35.0	34.0	49.0	28.0	49.5	33.0	38.0	32.0	47.0	47.0	32.0	46.0	32.0
t. of Moisture (g)	1.0	1.0	1.0	1.0	2.0	0.5	2.0	1.0	2.0	2.0	2.0	2.0	3.0	3.0
t. of Container (g)	20.0	16.0	15.0	30.0	10.0	30.0	15.0	19.0	14.0	30.0	30.0	15.0	29.0	15.0
t. of Dry Sample (g)	19.0	19.0	18.0	19.0	18.0	19.5	18.0	19.0	18.0	18.0	17.0	17.0	17.0	17.0
oisture content %	5.3	5.3	5.6	5.3	11.1	2.6	11.1	5.3	11.1	11.1	11.8	11.8	17.6	17.6
verage moisture content %	5.3		5.5		6.9		8.2		11.1		11.8		17.6	
ry Density (KN/m³)	16.8		17.5		17.0		20.0		20.6		18.0		16.2	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.4.1.D1: Compaction test of Sample D1

Additive Content: 0.25% Cocoa Pod Ash + 0.25% Palm Kernel Shell Ash + 1.5% Cement + 98% Soil Sample

Test No	1		2		3		4		5		6		7	
W. of Cyl. And wet Sample (kg)	3.68		3.70		3.75		3.80		3.63		4.05		3.90	
W. Of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
W. of wet sample (kg)	1.83		1.85		1.90		1.95		1.78		2.20		2.08	
Wet Density (KN/M^3)	18.0		18.10		18.60		19.10		17.49		21.60		20.10	
Container No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
W. of Cont. and wet Sample (g)	35.0	36.0	49.0	49.0	50.0	35.0	36.0	49.0	26.0	35.0	35.0	35.0	35.0	36.0
W. of Cont. and dry Sample (g)	34.0	35.0	48.0	48.0	48.0	34.0	34.0	48.0	23.0	34.0	32.0	33.0	32.0	33.0
W. of Moisture (g)	1.0	1.0	1.0	1.0	2.0	1.0	2.0	1.0	3.0	1.0	3.0	2.0	3.0	3.0
W. of Container (g)	15.0	16.0	29.0	30.0	30.0	15.0	17.0	29.0	6.0	15.0	15.0	12.0	15.0	16.0
W. of Dry Sample (g)	19.0	19.0	19.0	18.0	18.	19.0	17.0	19.0	17.0	19.0	17.0	21.0	17.0	17.0
Moisture content %	5.3	5.3	5.3	5.6	11.1	5.3	11.8	5.3	17.6	5.3	17.3	9.5	17.6	17.6
Average moisture content %	5.3		5.5		8.2		8.6		11.5		13.6		17.6	
Dry Density (KN/m^3)	17.1		17.2		19.6		17.6		19.5		19.0		17.1	

Table 4.4.1.D2: Compaction test of Sample D2

Additive Content 0.5% Cocoa Pod Ash + 0.5% Palm Kernel Shell Ash + 3% Cement + 96% Soil Sample

Test No	1		2		3		4		5		6		7	
W. of Cyl. And wet Sample (kg)	3.65		3.70		3.80		3.90		3.71		4.10		3.90	
W. Of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
W. of wet sample (kg)	1.80		1.85		1.95		2.05		1.86		2.25		2.05	
Wet Density (KN/M^3)	17.70		18.10		19.10		20.10		18.26		22.10		20.10	
Container No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
W. of Cont. and wet Sample (g)	35.0	50.0	34.0	49.0	50.0	36.0	34.0	50.0	34.0	35.0	35.0	34.0	36.0	31.0
W. of Cont. and dry Sample (g)	34.0	49.0	32.0	48.0	48.0	35.0	32.0	48.0	32.0	33.0	33.0	32.0	33.0	28.0
W. of Moisture (g)	1.0	1.0	2.0	1.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0
W. of Container (g)	15.0	30.0	09.0	29.0	20.0	16.0	14.0	27.0	9.0	9.0	17.0	9.0	16.0	11.0
W. of Dry Sample (g)	19.0	19.0	23.0	19.0	18.0	19.0	18.0	23.0	23.0	23.0	16.0	23.0	17.0	17.0
Moisture content %	5.3	5.3	8.7	5.3	11.1	5.3	11.1	8.7	8.7	8.7	12.5	8.7	17.6	17.6
Average moisture content %	5.3		7.0		8.2		9.9		10.6		11.9		17.6	
Dry Density (KN/m^3)	16.8		16.9		17.7		18.3		19.5		19.7		17.1	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.4.1.D3: Compaction test of Sample D3

Additive Content: 0.75% Cocoa Pod Ash + 0.75% Palm Kernel Shell Ash + 4.5% Cement + 94% Soil Sample

Test No	1		2		3		4		5		6		7	
Wt. of Cyl. And wet Sample (kg)	3.65		3.70		3.75		3.85		3.72		4.05		4.00	
Wt. Of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
Wt. of wet sample (kg)	1.80		1.85		1.90		2.0		1.87		2.20		2.15	
Wet Density (KN/M^3)	17.70		18.10		18.60		19.60		18.36		21.60		21.10	
Container No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
Wt. of Cont. and wet Sample (g)	35.0	25.0	35.0	50.0	35.0	26.0	34.0	35.0	50.0	36.0	40.0	35.0	34.0	36.0
Wt. of Cont. and dry Sample (g)	34.0	24.0	34.0	49.0	33.0	25.0	32.0	34.0	48.0	34.0	38.0	32.0	31.0	33.0
Wt. of Moisture (g)	1.0	1.0	1.0	1.0	2.0	1.0	2.0	1.0	2.0	2.0	2.0	3.0	3.0	3.0
Wt. of Container (g)	15.0	5.0	16.0	31.0	10.0	6.0	14.0	15.0	29.0	15.0	20.0	14.0	14.0	16.0
Wt. of Dry Sample (g)	19.0	19.0	18.0	18.0	23.0	19.0	18.0	19.0	19.0	19.0	18.0	18.0	17.0	17.0
Moisture content %	5.3	5.3	5.6	5.6	8.7	5.3	11.1	5.3	10.5	1.5	11.1	11.1	17.6	17.6
Average moisture content %	5.3		5.6		7.0		8.2		10.5		11.1		17.6	
Dry Density (KN/m^3)	16.8		17.1		17.4		18.1		19.5		19.9		19.1	

Table 4.4.1.D4: Compaction test of Sample D4

Additive Content: 1% Cocoa Pod Ash + 1% Palm Kernel Shell Ash + 6% Cement + 92% Soil Sample

Test No	1		2		3		4		5		6		7	
Wt. of Cyl. And wet Sample (kg)	3.65		3.70		3.75		3.85		3.73		4.05		3.95	
Wt. Of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
Wt. of wet sample (kg)	1.80		1.85		1.90		2.00		1.88		2.20		2.00	
Wet Density (KN/M^3)	17.70		18.10		18.60		19.60		18.48		21.60		19.60	
Container No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
Wt. of Cont. and wet Sample (g)	36.0	35.0	35.0	50.0	50.0	34.0	50.0	30.0	30.0	49.0	49.0	30.0	35.0	23.0
Wt. of Cont. and dry Sample (g)	35.0	34.0	34.0	49.0	49.0	33.0	48.0	29.0	28.0	48.0	47.0	28.0	32.0	21.0
Wt. of Moisture (g)	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	1.0	2.0	2.0	3.0	2.0
Wt. of Container (g)	16.0	15.0	16.0	30.0	30.0	16.0	25.0	10.0	10.0	29.0	24.0	12.0	15.0	3.0
Wt. of Dry Sample (g)	19.0	19.0	18.0	19.0	19.0	17.0	23.0	19.0	18.0	19.0	23.0	16.0	17.0	18.0
Moisture content %	5.3	5.3	5.6	5.3	5.3	5.9	8.7	5.3	11.1	5.3	8.7	12.5	17.6	11.1
Average moisture content %	5.3		5.5		5.6		7.0		8.2		10.6		14.4	
Dry Density (KN/m^3)	16.8		17.2		17.6		18.3		20.4		19.5		17.1	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.4.1.E: Compaction test of Sample E

Additive Content: 100% Soil Sample + 0% Cement

Test No	1		2		3		4		5		6		7	
t of Cyl. And wet Sample (kg)	3.60		3.70		3.95		4.00		3.57		4.20		3.97	
t. Of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
t of wet sample (kg)	1.75		1.85		2.10		2.15		1.72		2.35		2.12	
e Density (KN/M^3)	17.20		18.10		20.60		21.10		16.91		23.10		20.79	
ontainer No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
t. of Cont. and wet Sample (g)	35.0	36.0	36.0	39.0	37.0	35.0	36.0	36.0	35.0	35.0	26.0	36.0	34.0	35.0
t. of Cont. and dry Sample (g)	34.0	35.0	35.0	38.0	36.0	33.0	34.0	34.0	32.0	33.0	24.0	33.0	31.0	32.0
t. of Moisture (g)	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	3.0	2.0	2.0	3.0	3.0	3.0
t. of Container (g)	15.0	16.0	17.0	18.0	17.0	15.0	17.0	17.0	8.6	17.4	6.0	17.0	15.0	16.0
t. of Dry Sample (g)	19.0	19.0	18.0	19.0	19.0	18.0	17.0	17.0	23.4	15.6	18.0	16.0	16.0	16.0
oisture content %	5.3	5.3	5.6	5.3	5.3	11.1	11.8	11.8	12.8	12.8	11.1	18.0	18.8	18.8
verage moisture content %	5.3		5.5		8.2		11.8		11.8		15.0		18.8	
ry Density (KN/m^3)	16.3		17.2		19		18.9		18.9		20.1		17.5	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.4.1.F1: Compaction test of Sample F1

Additive Content: 2% Cocoa Pod Ash + 98% Soil Sample

Test No	1		2		3		4		5		6		7	
Of Cyl. And wet Sample (kg)	3.85		3.95		4.00		3.70		4.60		3.97		3.90	
Of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
of wet sample (kg)	2.00		2.10		2.15		1.85		2.25		2.12		2.05	
Density (KN/M³)	19.60		20.60		21.10		18.17		22.10		20.79		2.01	
Container No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
of Cont. and wet Sample (g)	35.0	48.0	34.0	35.0	35.0	36.0	35.0	36.0	36.0	36.0	26.0	36.0	36.0	31.0
of Cont. and dry Sample (g)	34.0	47.0	33.0	33.0	35.0	35.0	33.0	33.0	34.0	33.0	24.0	33.0	33.0	28.0
of Moisture (g)	1.0	1.0	1.0	2.0	1.0	1.0	2.0	3.0	2.0	3.0	2.0	3.0	3.0	3.0
of Container (g)	15.0	17.0	14.0	15.0	17.0	17.0	15.0	15.0	16.0	16.0	6.0	17.0	16.0	11.0
of Dry Sample (g)	19.0	19.0	19.0	18.0	18.0	18.0	18.0	18.0	18.0	17.0	18.0	16.0	17.0	17.0
Moisture content %	5.3	5.6	5.3	11.1	11.1	5.6	11.1	16.7	11.0	17.6	11.1	18.8	17.6	17.6
Average moisture content %	5.5		8.2		8.4		13.9		14.4		15.0		17.6	
Dry Density (KN/m³)	18.6		19.0		19.0		18.9		18.4		17.5		17.1	

Table 4.4.1.F2: Compaction test of Sample F2

Additive Content: 4% Cocoa Pod Ash + 96% Soil Sample

Test No	1		2		3		4		5		6		7	
W. Of Cyl. And wet Sample (kg)	3.75		3.80		3.95		4.05		3.66		3.90		3.75	
W. Of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
W. of wet sample (kg)	1.10		1.95		2.10		2.20		1.81		2.01		2.90	
Wet Density (KN/M³)	18.60		19.10		20.00		21.60		17.78		2.10		18.60	
Container No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
W. of Cont. and wet Sample (g)	36.0	36.0	36.0	36.0	36.0	37.0	34.0	49.0	35.0	36.0	50.0	35.0	36.0	26.0
W. of Cont. and dry Sample (g)	35.0	35.0	35.0	35.0	34.0	35.0	32.0	47.0	33.0	33.0	47.0	33.0	33.0	24.0
W. of Moisture (g)	1.0	1.0	1.0	1.0	1.5	2.0	2.0	2.0	2.0	3.0	3.0	2.0	3.0	2.0
W. of Container (g)	16.0	16.0	16.0	17.0	16.0	17.0	15.0	30.0	17.0	9.0	3.0	12.0	17.0	6.0
W. of Dry Sample (g)	19.0	19.0	19.0	18.0	18.0	18.0	17.0	17.0	16.0	24.0	17.0	21.0	16.0	18.0
Moisture content %	5.3	5.3	5.3	5.6	8.1	11.0	11.8	11.8	12.5	12.5	17.6	9.6	18.8	11.1
Average moisture content %	5.3		5.5		9.6		11.8		12.5		13.7		15.0	
Dry Density (KN/m³)	17.7		18.1		18.8		19.L3		19.3		18.2		17.4	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.4.1.F3: Compaction test of Sample F3

Additive Content: 6% Cocoa Pod Ash + 94% Soil Sample

Test No	1		2		3		4		5		6		7	
Wt. Of Cyl. And wet Sample (kg)	3.75		3.80		3.95		4.05		3.72		3.80		3.75	
Wt. Of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
Wt of wet sample (kg)	1.95		1.95		2.10		2.20		1.87		1.99		1.90	
Wet Density (KN/M^3)	18.60		19.10		20.60		21.60		18.34		19.10		16.60	
Container No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
Wt. of Cont. and wet Sample (g)	48.0	37.0	30.0	35.0	34.0	49.0	34.0	35.0	49.0	34.0	35.0	29.0	35.0	30.0
Wt. of Cont. and dry Sample (g)	47.0	36.0	28.0	34.0	32.0	47.0	32.0	33.0	47.0	32.0	33.0	27.0	32.0	27.0
Wt. of Moisture (g)	1.0	1.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0
Wt. of Container (g)	27.0	16.0	7.0	14.0	14.0	29.0	15.0	16.0	30.0	15.0	15.0	15.0	15.0	10.0
Wt. of Dry Sample (g)	20.0	20.0	21.0	20.0	18.0	18.0	17.0	17.0	17.0	17.0	18.0	15.0	17.0	17.0
Moisture content %	5.0	5.0	9.5	5.0	11.1	11.1	11.8	11.8	11.8	11.8	11.1	13.3	17.6	17.6
Average moisture content %	5.0		7.3		11.1		11.8		11.8		12.2		17.6	
Dry Density (KN/m^3)	17.7		18.4		18.5		19.8		20.1		16.2		15.8	

Table 4.4.1.F4: Compaction test of Sample F4

Additive Content: 8% Cocoa Pod Ash + 92% Soil Sample

Test No	1		2		3		4		5		6		7	
Wt. Of Cyl. And wet Sample (kg)	3.70		3.85		4.0		3.74		3.37		3.85		3.85	
Wt. Of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
Wt of wet sample (kg)	1.85		2.00		2.15		1.89		1.52		2.00		1.95	
Wet Density (KN/M^3)	13.13		19.60		21.10		18.52		14.95		19.60		19.10	
Container No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
Wt. of Cont. and wet Sample (g)	35.0	36.0	35.0	35.0	37.0	35.0	49.0	34.0	35.0	50.0	35.0	26.0	50.0	36.0
Wt. of Cont. and dry Sample (g)	34.0	35.0	34.0	34.0	36.0	33.0	47.0	32.0	33.0	47.0	33.0	23.0	47.0	33.0
Wt. of Moisture (g)	1.0	1.0	1.0	1.0	1.0	2.09	2.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0
Wt. of Container (g)	15.0	17.0	17.0	17.0	15.0	30.0	15.0	12.0	3.0	15.0	7.0	17.0	17.0	17.0
Wt. of Dry Sample (g)	19.0	18.0	17.0	17.0	19.0	18.0	17.0	17.0	21.0	17.0	18.0	16.0	17.0	17.0
Moisture content %	5.3	5.6	5.9	5.9	5.3	11.1	11.8	11.8	9.5	17.8	11.1	18.8	17.6	17.6
Average moisture content %	5.5		5.9		8.2		11.8		13.7		15.0		17.6	
Dry Density (KN/m^3)	17.2		18.5		18.9		20.2		17.1		17.2		16.7	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.4.1.G1: Compaction test of Sample G1

Additive Content: 2% Palm Kernel Shell Ash + 98% Soil Sample

Test No	1		2		3		4		5		6		7	
Of Cyl. And wet Sample (kg)	3.75		3.85		3.90		3.95		3.35		3.90		3.85	
Of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
wet sample (kg)	1.10		2.10		2.05		2.10		1.70		2.00		2.00	
Density (KN/M^3)	18.60		19.60		20.16		20.00		16.70		20.10		19.60	
ner No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
Cont. and wet Sample (g)	26.0	26.0	35.0	36.0	35.0	35.0	35.0	36.0	35.0	50.0	35.0	23.0	34.0	50.0
Cont. and dry Sample (g)	25.0	25.0	34.0	35.0	34.0	33.0	32.0	34.0	33.0	47.0	32.0	21.0	32.0	47.0
Moisture (g)	1.0	1.0	1.0	1.0	1.0	2.0	3.0	1.0	2.0	3.0	3.0	3.0	3.0	3.0
Container (g)	6.0	6.0	15.0	17.0	16.0	15.0	15.0	15.0	12.0	3.0	15.0	3.0	14.0	30.0
Dry Sample (g)	19.0	19.0	18.0	18.0	17.0	19.0	17.0	19.0	21.0	17.0	17.0	18.0	17.0	17.0
ture content %	5.3	5.3	5.3	5.6	5.6	11.1	17.6	5.3	9.5	17.8	17.6	11.1	17.6	17.6
age moisture content %	5.3		5.5		8.4		11.5		13.7		14.4		17.6	
Density (KN/m^3)	17.7		18.1		18.5		18.5		19.0		18.2		16.7	

Table 4.4.1.G2: Compaction test of Sample G2

Additive Content: 4% Palm Kernel Shell Ash + 96% Soil Sample

Test No	1		2		3		4		5		6		7	
Of Cyl. And wet Sample (kg)	3.80		3.85		3.95		4.00		4.05		3.59		3.75	
Of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
wet sample (kg)	1.95		2.00		2.10		2.15		2.20		1.74		1.90	
Density (KN/M^3)	19.10		19.60		20.60		21.10		21.60		17.03		18.60	
ner No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
Cont. and wet Sample (g)	36.0	35.0	36.0	36.0	37.0	35.0	26.0	35.0	34.0	35.0	36.0	36.0	36.0	36.0
Cont. and dry Sample (g)	35.0	34.0	35.0	34.0	34.0	35.0	34.0	23.0	32.0	32.0	33.0	33.0	33.0	33.0
Moisture (g)	1.0	1.0	1.0	2.0	1.5	2.0	1.0	3.0	3.0	2.0	2.0	3.0	3.0	3.0
Container (g)	17.0	15.0	16.0	17.0	16.0	17.0	15.0	6.0	12.0	9.0	15.0	15.0	16.0	16.0
Dry Sample (g)	18.0	18.0	19.0	17.0	18.0	18.0	19.0	17.0	20.0	23.0	18.0	18.0	17.0	17.0
ture content %	5.6	5.3	5.3	11.8	8.1	11.1	5.3	17.6	15.0	8.7	11.1	16.7	17.6	17.6
age moisture content %	5.6		8.6		9.6		11.5		11.9		13.9		17.6	
Density (KN/m^3)	17.6		18.1		18.8		18.9		19.5		19.4		17.7	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.4.1.G3: Compaction test of Sample G3

Additive Content: 6% Palm Kernel Shell Ash + 94% Soil Sample

Test No	1		2		3		4		5		6		7	
f Cyl. And wet Sample (kg)	3.75		3.80		3.96		4.00		4.15		3.90		3.85	
f Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
wet sample (kg)	1.10		1.95		2.10		2.15		2.30		2.05		2.10	
Density (KN/M³)	18.60		19.10		20.60		21.10		22.60		20.10		19.60	
ainer No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
f Cont. and wet Sample (g)	34.0	34.0	35.0	36.0	35.0	34.0	36.0	35.0	35.0	35.0	35.0	50.0	25.0	25.0
f Cont. and dry Sample (g)	33.0	33.0	35.0	35.0	33.0	33.0	34.0	33.0	33.0	33.0	32.0	48.0	22.0	32.0
f Moisture (g)	1.0	1.0	1.0	1.0	2.1	1.0	2.0	2.0	3.0	2.0	3.0	3.0	3.0	3.0
f Container (g)	14.0	14.0	16.0	17.0	15.0	14.0	16.0	15.0	15.0	15.0	15.0	30.0	5.0	15.0
f Dry Sample (g)	19.0	19.0	19.0	18.0	18.0	19.0	18.0	18.0	18.0	18.0	17.0	18.0	17.0	17.0
ure content %	5.3	5.3	5.3	5.6	11.1	5.3	11.1	11.1	16.7	11.1	17.6	11.1	17.6	17.6
age moisture content %	5.3		5.3		8.2		11.1		13.9		14.5		17.6	
Density (KN/m³)	17.7		18.1		19.0		19.5		19.8		18.0		17.1	

Table 4.4.1.G4: Compaction test of Sample G4

Additive Content: 8% Palm Kernel Shell Ash + 92% Soil Sample

Test No	1		2		3		4		5		6		7	
Of Cyl. And wet Sample (kg)	3.70		3.74		3.85		4.05		3.90		3.85		3.75	
Of Cylinder (kg)	1.85		1.85		1.85		1.85		1.85		1.85		1.85	
f wet sample (kg)	1.85		1.89		2.00		2.20		2.05		2.00		1.90	
Density (KN/M³)	18.30		18.48		19.60		21.60		20.10		19.60		18.60	
ainer No	T	B	T	B	T	B	T	B	T	B	T	B	T	B
f Cont. and wet Sample (g)	35.0	36.0	35.0	35.0	50.0	40.0	49.0	34.0	30.0	34.0	36.0	36.0	50.0	34.0
f Cont. and dry Sample (g)	34.0	35.0	34.0	33.0	48.0	38.0	47.0	32.0	28.0	32.0	34.0	33.0	47.0	32.0
f Moisture (g)	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	16.0	3.0	3.0
f Container (g)	15.0	17.0	15.0	5.0	30.0	10.0	20.0	15.0	11.0	16.0	16.0	16.0	30.0	14.0
f Dry Sample (g)	19.0	18.0	19.0	18.0	18.0	18.0	17.0	17.0	17.0	16.0	18.0	17.0	17.0	17.0
ture content %	5.3	5.9	5.3	11.1	11.0	11.0	11.8	11.8	11.8	12.5	11.1	17.6	17.6	17.6
age moisture content %	5.5		8.2		11.0		11.8		12.2		14.4		17.6	
Density (KN/m³)	17.2		20.4		18.6		19.3		18.5		18.6		17.6	

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.4.2 **SUMMARY OF RESULTS (COMPACTION) FOR THE TREATED AND UNTREATED SAMPLES**

IPLE TYPE	A				B				C				D				E				F				G		
Test No	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
2%																											
Average Moisture ontent (%)	5.3	8.2	14.0	17.9	8.6	11.5	14.4	16.7	4.0	6.7	8.1	11.1	5.3	5.5	8.0	17.6	5.3	8.2	11.6	18.8	5.6	8.4	13.9	15.0	5.3	5.5	13.7
y Density (KN/m^3)	17.7	19.5	19.9	17.9	18.0	18.9	19.2	17.7	18.1	20.7	19.5	18.6	17.1	17.2	19.8	17.1	16.3	17.0	18.9	17.5	18.6	19.0	16.8	17.5	17.7	18.1	19.2
4%																											
Average Moisture ontent (%)	5.5	12.5	18.1	21.7	8.1	9.6	14.4	17.6	5.3	7.3	11.8	14.5	7.0	8.2	10.6	17.6					5.3	9.6	12.5	13.7	8.6	9.6	13.9
y Density (KN/m^3)	16.3	20.4	16.7	15.0	17.5	18.8	19.5	17.1	17.2	20.0	19.2	17.1	16.9	17.7	19.7	17.1					17.7	18.8	19.3	18.2	18.1	18.8	19.4
6%																											
Average Moisture ontent (%)	5.3	8.2	11.1	17.6	8.3	7.2	11.1	17.6	7.4	8.2	11.8	17.6	5.3	5.6	11.1	17.6					5.0	7.3	11.8	12.2	5.3	8.2	13.9
y Density (KN/m^3)	17.7	18.6	20.8	17.2	16.8	18.6	20.2	17.1	16.9	17.2	20.2	16.7	16.8	17.1	19.9	19.1					17.7	18.4	20.1	16.6	17.7	19.0	19.8
8%																											
Average Moisture ontent (%)	5.3	8.2	13.0	21.3	5.3	11.1	16.8	17.6	5.6	6.9	11.1	17.6	5.5	8.2	10.6	14.4					5.9	11.8	13.7	15.0	5.5	8.2	12.2
y Density (KN/m^3)	15.8	18.1	21.7	17.4	17.4	20.3	19.8	16.7	17.5	18.3	20.6	16.2	17.2	20.4	19.5	17.1					18.5	20.2	18.1	17.7	17.2	20.4	18.5

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell;
E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

APPENDIX 4:

California Bearing Ratio of the treated and untreated samples with their graphs

APPENDIX 4

TABLE 4.5.1:CALIFORNIA BEARING RATIO TESTS OF THE TREATED AND UNTREATED SAMPLES

Table 4.5.A1: California Bearing Ratio of Sample A1

Additive Content: 2% Cement + 98% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	*Load*	*Corrected*	*C.B.R.%*		*Selected CBR%*	*Load*	*Corrected*	*C.B.R.*		*Selected CBR%*
			2.5mm	*5.0mm*				*2.5mm*	*5.0mm*	
0.5	7.0	0.707				11.0	1.111			
1.0	11.0	1.111				23.0	2.323			
1.5	14.0	1.414				30.0	3.030			
2.0	18.0	1.818				36.0	3.636			
2.5	22.0	2.222	18.0	23.0	23.0	43.0	4.343	33.0	37.0	37.0
3.0	35.0	2.525				50.0	5.050			
3.5	30.0	3.030				57.0	5.757			
4.0	34.0	3.434				62.0	6.262			
4.5	38.0	3.838				68.0	6.868			
5.0	44.0	4.444				70.0	7.07			
5.5	49.0	4.949				77.0	7.777			
6.0	55.0	5.555				83.0	8.383			
6.5	61.0	6.161				88.0	8.888			
7.0	67.0	6.767				105.0	10.605			

Proving ring factor = 0.101

Table 4.5.A2: California Bearing Ratio of Sample A2

Additive Content: 4% Cement + 96% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	*Load*	*Corrected*	*C.B.R.%*		*Selected CBR%*	*Load*	*Corrected*	*C.B.R.*		*Selected CBR%*
			2.5mm	*5.0mm*				*2.5mm*	*5.0mm*	
0.5	4.0	0.404				17.0	1.717			
1.0	16.0	1.616				31.0	3.131			
1.5	28.0	2.828				51.0	5.151			
2.0	39.0	3.939				71.0	7.171			
2.5	51.0	5.151	39.0	76.0	76.0	90.0	9.090	63.0	89.0	89.0
3.0	68.0	6.868				105.0	10.605			
3.5	80.0	8.080				127.0	12.827			
4.0	95.0	9.595				147.0	14.847			
4.5	115.0	11.615				164.0	16.564			
5.0	132.0	13.332				174.0	17.574			
5.5	150.0	15.150				183.0	18.483			
6.0	176.0	17.776				195.0	19.695			
6.5	201.0	20.301				206.0	20.806			
7.0	211.0	21.311				217.0	21.917			

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.5.A4: California Bearing Ratio of Sample A3

Additive Content: 6% Cement + 94% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	***Load***	***Corrected***	***C.B.R.%***		***Selected CBR%***	***Load***	***Corrected***	***C.B.R.***		***Selected CBR%***
			2.5mm	***5.0mm***				***2.5mm***	***5.0mm***	
0.5	10.0	1.010				13.0	1.313			
1.0	27.0	2.727				32.0	3.232			
1.5	39.0	3.939				43.0	4.343			
2.0	51.0	5.151				58.0	5.858			
2.5	66.0	6.666				72.0	7.272			
3.0	82.0	8.282	51.0	86.0	86.0	87.0	8.787	55.0	95.0	95.0
3.5	104.0	10.504				109.0	11.009			
4.0	127.0	12.827				136.0	13.736			
4.5	149.0	15.049				153.0	15.453			
5.0	172.0	17.372				180.0	18.180			
5.5	193.0	19.493				201.0	20.301			
6.0	229.0	23.129				238.0	24.038			
6.5	242.0	24.442				260.0	26.26			
7.0	267.0	26.967				272.0	27.472			

Table 4.5.A3: California Bearing Ratio of Sample A4

Additive Content: 8% Cement +92% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	***Load***	***Corrected***	***C.B.R.%***		***Selected CBR%***	***Load***	***Corrected***	***C.B.R.***		***Selected CBR%***
			2.5mm	***5.0mm***				***2.5mm***	***5.0mm***	
0.5	25.0	5.525				28.0	2.828			
1.0	53.0	5.353				57.0	5.757			
1.5	82.0	8.282				84.0	8.484			
2.0	104.0	10.504				110.0	11.110			
2.5	128.0	12.928				135.0	13.635			
3.0	132.0	13.332	81.0	110.0	110.0	159.0	16.059	94.0	115.0	115.0
3.5	176.0	17.776				180.0	18.180			
4.0	199.0	20.099				210.0	21.210			
4.5	209.0	21.109				215.0	21.715			
5.0	218.0	22.018				225.0	22.250			
5.5	221.0	22.321				230.0	23.230			
6.0	225.0	22.725				237.0	23.937			
6.5	246.0	24.846				256.0	25.856			
7.0	278.0	28.078				281.0	28.381			

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.5.B1: California Bearing Ratio of Sample B1

Additive Content: 0.5% Cocoa Pod Ash + 1.5% Cement + 98% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	*Load*	*Corrected*	*C.B.R.%*		*Selected CBR%*	*Load*	*Corrected*	*C.B.R.*		*Selected CBR%*
			2.5mm	*5.0mm*				*2.5mm*	*5.0mm*	
0.5	11.0	1.111				12.0	1.212			
1.0	18.0	1.818				24.0	2.424			
1.5	25.0	2.525				43.0	4.348			
2.0	33.0	3.333				54.0	5.454			
2.5	40.0	4.040				71.0	7.171			
3.0	51.0	5.151	23.0	55.0	55.0	84.0	8.484	42.0	69.0	69.0
3.5	70.0	7.070				99.0	9.999			
4.0	82.0	8.282				113.0	11.413			
4.5	93.0	9.393				125.0	12.626			
5.0	105.0	10.605				136.0	13.736			
5.5	118.0	11.918				146.0	14.746			
6.0	131.0	13.231				156.0	15.756			
6.5	145.0	14.646				164.0	16.564			
7.0	151.0	15.251				171.0	17.271			

Table 4.5.B2: California Bearing Ratio of Sample B2

Additive Content: 1% Cocoa Pod Ash + 3% Cement + 96% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	*Load*	*Corrected*	*C.B.R.%*		*Selected CBR%*	*Load*	*Corrected*	*C.B.R.*		*Selected CBR%*
			2.5mm	*5.0mm*				*2.5mm*	*5.0mm*	
0.5	24.0	2.424				19.0	1.919			
1.0	47.0	4.747				50.0	5.050			
1.5	70.0	7.070				73.0	7.373			
2.0	89.0	8.983				100.0	10.100			
2.5	105.0	10.605				124.0	12.524			
3.0	121.0	12.221	82.0	84.0	84.0	148.0	14.948	98.0	102.0	102.0
3.5	133.0	13.433				163.0	16.463			
4.0	145.0	14.645				175.0	17.675			
4.5	157.0	15.857				191.0	19.291			
5.0	163.0	16.463				202.0	20.402			
5.5	169.0	17.069				212.0	21.412			
6.0	178.0	17.978				225.0	22.725			
6.5	180.0	18.180				232.0	23.432			
7.0	192.0	19.392				235.0	-			

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.5.B2: California Bearing Ratio of Sample B3

Additive Content: 1.5% Cocoa Pod Ash + 45% Cement + 94% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	*Load*	*Corrected*	*C.B.R.%*		*Selected CBR%*	*Load*	*Corrected*	*C.B.R.*		*Selected CBR%*
			2.5mm	*5.0mm*				*2.5mm*	*5.0mm*	
0.5	15.0	1.515				34.0	3.434			
1.0	28.0	2.828				57.0	5.757			
1.5	57.0	5.757				80.0	8.080			
2.0	84.0	8.484				103.0	10.403			
2.5	114.0	11.514				127.0	12.824			
3.0	148.0	14.948	84.0	93.0	93.0	147.0	14.847	116.0	93.0	116.0
3.5	157.0	15.857				162.0	16.362			
4.0	179.0	18.079				167.0	16.867			
4.5	197.0	19.897				170.0	17.170			
5.0	215.0	21.715				175.0	17.675			
5.5	247.0	24.947				185.0	18.685			
6.0	257.0	25.957				193.0	19.493			
6.5	268.0	27.068				207.0	20.907			
7.0	274.0	27.674				228.0	23.028			

Table 4.5.B4: California Bearing Ratio of Sample B4

Additive Content: 2% Cocoa Pod Ash + 6% Cement + 92% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	*Load*	*Corrected*	*C.B.R.%*		*Selected CBR%*	*Load*	*Corrected*	*C.B.R.*		*Selected CBR%*
			2.5mm	*5.0mm*				*2.5mm*	*5.0mm*	
0.5	20.0	2.020				28.0	2.828			
1.0	41.0	4.141				45.0	4.545			
1.5	62.0	6.262				68.0	6.868			
2.0	88.0	8.888				84.0	8.484			
2.5	132.0	13.332				134.0	13.534			
3.0	161.0	16.261				167.0	16.867			
3.5	184.0	18.584	94.0	126.0	126.0	190.0	19.190	102.0	127.0	127.0
4.0	202.0	20.402				208.0	21.008			
4.5	216.0	21.816				231.0	23.331			
5.0	249.0	25.149				256.0	25.856			
5.5	271.0	27.371				280.0	28.280			
6.0	288.0	29.088				291.0	29.391			
6.5	304.0	30.704				307.0	31.007			
7.0	321.0	32.421				328.0	33.128			

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.5.C1: California Bearing Ratio of Sample C1

Additive Content: 0.5% Palm Kernel Shell Ash +1.5% Cement + 98% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	*Load*	*Corrected*	*C.B.R.%*		*Selected CBR%*	*Load*	*Corrected*	*C.B.R.*		*Selected CBR%*
			2.5mm	*5.0mm*				*2.5mm*	*5.0mm*	
0.5	10.0	1.010				12.0	1.212			
1.0	15.0	1.515				22.0	2.222			
1.5	21.0	2.121				37.0	3.737			
2.0	28.0	2.828				50.0	5.05			
2.5	34.0	3.434	40.0	56.0	56.0	62.0	6.262	44.0	59.0	59.0
3.0	41.0	4.141				73.0	7.373			
3.5	50.0	5.050				86.0	8.686			
4.0	56.0	5.656				97.0	9.797			
4.5	65.0	6.565				108.0	10.900			
5.0	73.0	7.373				118.0	11.918			
5.5	80.0	8.080				125.0	12.625			
6.0	86.0	8.686				130.0	13.130			
6.5	94.0	9.494				136.0	13.736			
7.0	102.0	10.302				147.0	14.847			

Table 4.5.C2: California Bearing Ratio of Sample C2

Additive Content: 1% Palm Kernel Shell Ash +3% Cement + 96% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	*Load*	*Corrected*	*C.B.R.%*		*Selected CBR%*	*Load*	*Corrected*	*C.B.R.*		*Selected CBR%*
			2.5mm	*5.0mm*				*2.5mm*	*5.0mm*	
0.5	7.0	0.707				11.0	1.111			
1.0	14.0	1.414				19.0	1.919			
1.5	25.0	2.525				39.0	3.737			
2.0	37.0	3.737				42.0	4.242			
2.5	53.0	5.353				57.0	5.757			
3.0	73.0	7.373	44.0	92.0	92.0	76.0	7.676	44.0	97.0	97.0
3.5	96.0	9.696				100.0	10.100			
4.0	125.0	12.625				132.0	13.332			
4.5	126.0	15.756				160.0	16.160			
5.0	188.0	18.988				189.0	19.089			
5.5	213.0	21.518				198.0	29.998			
6.0	218.0	22.018				230.0	23.230			
6.5	221.0	22.321				240.0	24.240			
7.0	230.0	23.23				247.0	24.947			

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.5.C3: California Bearing Ratio of Sample C3

Additive Content: 1.5% Palm Kernel Shell Ash + 4.5% Cement + 94% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	*Load*	*Corrected*	*C.B.R.%*		*Selected CBR%*	*Load*	*Corrected*	*C.B.R.*		*Selected CBR%*
			2.5mm	*5.0mm*				*2.5mm*	*5.0mm*	
0.5	10.0	1.01				39.0	3.939			
1.0	28.0	2.828				63.0	6.363			
1.5	45.9	4.545				87.0	8.787			
2.0	64.0	6.464				109.0	11.009			
2.5	86.0	8.686				129.0	13.029			
3.0	107.0	10.807	62.0	93.0	93.0	150.0	15.150	95.0	106.0	106.0
3.5	126.0	12.726				168.0	16.968			
4.0	147.0	14.847				184.0	18.584			
4.5	169.0	17.069				198.0	19.998			
5.0	184.0	18.584				215.0	21.715			
5.5	200.0	20.200				226.0	22.826			
6.0	213.0	21.513				235.0	23.735			
6.5	229.0	23.129				248.0	25.048			
7.0	247.0	24.947				257.0	25.957			

Table 4.5.C4: California Bearing Ratio of Sample C4

Additive Content: 2.0% Palm Kernel Shell Ash + 6.0% Cement + 92% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	*Load*	*Corrected*	*C.B.R.%*		*Selected CBR%*	*Load*	*Corrected*	*C.B.R.*		*Selected CBR%*
			2.5mm	*5.0mm*				*2.5mm*	*5.0mm*	
0.5	21.0	2.121				28.0	2.828			
1.0	33.0	3.333				57.0	5.757			
1.5	56.0	6.656				83.0	8.383			
2.0	93.0	9.393				115.0	11.615			
2.5	132.0	13.332				154.0	15.554			
3.0	173.0	17.473				191.0	19.191			
3.5	204.0	20.604	110.0	138.0	138.0	225.0	22.725	115.0	150.0	150.0
4.0	232.0	23.432				251.0	25.351			
4.5	255.0	25.755				267.0	26.961			
5.0	275.0	27.775				284.0	28.684			
5.5	294.0	29.694				320.0	32.320			
6.0	314.0	31.714				333.0	33.633			
6.5	331.0	33.430				342.0	34.542			
7.0	345.0	38.845				352.0	35.552			

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.5.D1: California Bearing Ratio of Sample D1

Additive Content: 0.25% Cocoa Pod Ash + 0.25 Palm Kernel Shell Ash + 1.5% Cement + 98% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	***Load***	***Corrected***	***C.B.R.%***		***Selected CBR%***	***Load***	***Corrected***	***C.B.R.***		***Selected CBR%***
			2.5mm	***5.0mm***				***2.5mm***	***5.0mm***	
0.5	40.0	4.040				25.0	2.525			
1.0	62.0	6.262				35.0	3.535			
1.5	80.0	8.080				65.0	6.262			
2.0	97.0	9.797				85.0	8.585			
2.5	114.0	11.514				111.0	11.211			
3.0	126.0	12.726	79.0	85.0	85.0	134.0	13.534	83.0	110.0	110.0
3.5	141.0	14.241				159.0	16.059			
4.0	152.0	15.352				180.0	18.180			
4.5	163.0	16.463				200.0	20.200			
5.0	168.0	16.968				218.0	22.018			
5.5	177.0	17.877				234.0	23.634			
6.0	181.0	18.281				248.0	23.634			
6.5	196.0	19.796				263.0	26.563			
7.0	213.0	21.513				274.0	27.674			

Table 4.5.D2: California Bearing Ratio of Sample D2

Additive Content: 0.5% Cocoa Pod Ash + 0.5 Palm Kernel Shell Ash + 3% Cement + 96% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	***Load***	***Corrected***	***C.B.R.%***		***Selected CBR%***	***Load***	***Corrected***	***C.B.R.***		***Selected CBR%***
			2.5mm	***5.0mm***				***2.5mm***	***5.0mm***	
0.5	19.0	1.919				35.0	3.535			
1.0	45.0	4.545				57.0	5.757			
1.5	67.0	6.767				79.0	7.898			
2.0	88.0	8.888				98.0	9.898			
2.5	108.0	10.908				120.0	12.120			
3.0	128.0	12.928	97.0	110.0	110.0	142.0	14.342	87.0	114.0	114.0
3.5	146.0	14.746				156.0	15.756			
4.0	166.0	16.766				182.0	18.382			
4.5	183.0	18.483				198.0	19.998			
5.0	197.0	19.897				216.0	21.816			
5.5	209.0	21.109				229.0	23.129			
6.0	244.0	2.694				240.0	24.240			
6.5	249.0	25.149				253.0	25.553			
7.0	256.0	25.856				267.0	26.967			

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.5.D3: California Bearing Ratio of Sample D3

Additive Content: 0.75% Cocoa Pod Ash + 0.75 Palm Kernel Shell Ash + 4. 5% Cement + 94% Soil Sample

Penetration (mm)	TOP					BOTTOM				
	Load	Corrected	C.B.R.%		Selected CBR%	Load	Corrected	C.B.R.		Selected CBR%
			2.5mm	5.0mm				2.5mm	5.0mm	
0.5	24.0	2.424				45.0	4.545			
1.0	45.0	4.545				73.0	7.373			
1.5	70.0	7.070				101.0	10.201			
2.0	94.0	9.494				130.0	13.130			
2.5	115.0	11.615				156.0	15.756			
3.0	139.0	14.039	87.0	105.0	105.0	180.0	18.180			
3.5	160.0	16.160				209.0	21.109			
4.0	175.0	17.615				220.0	22.220			
4.5	192.0	19.392				232.0	23.432			
5.0	207.0	20.907				244.0	24.644			
5.5	220.0	22.220				258.0	26.058			
6.0	234.0	23.634				268.0	27.068			
6.5	246.0	24.846				282.0	28.482			
7.0	260.0	26.26				304.0	30.0704			

Table 4.5.D4: California Bearing Ratio of Sample D4

Additive Content: 1% Cocoa Pod Ash + 1% Palm Kernel Shell Ash + 6% Cement + 92% Soil Sample

Penetration (mm)	TOP					BOTTOM				
	Load	Corrected	C.B.R.%		Selected CBR%	Load	Corrected	C.B.R.		Selected CBR%
			2.5mm	5.0mm				2.5mm	5.0mm	
0.5	25.0	2.525				30.0	3.030			
1.0	41.0	4.141				48.0	4.848			
1.5	60.0	6.060				71.0	7.171			
2.0	75.0	7.575				82.0	8.282			
2.5	98.0	9.898				106.0	10.706			
3.0	120.0	12.120	76.0	112.0	112.0	123.0	12.423	78.0	128.0	128.0
3.5	148.0	14.948				152.0	15.352			
4.0	175.0	17.675				183.0	18.483			
4.5	202.0	20.402				198.0	19.998			
5.0	232.0	23.432				255.0	25.755			
5.5	260.0	26.260				263.0	26.563			
6.0	294.0	29.694				300.0	30.300			
6.5	331.0	33.421				246.0	24.846			
7.0	372.0	37.572				380.0	38.380			

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.5.E: California Bearing Ratio of Sample E

Additive Content: 100% Soil Sample

	TOP					BOTTOM				
Penetration (mm)	*Load*	*Corrected*	*C.B.R.%*		*Selected CBR%*	*Load*	*Corrected*	*C.B.R.*		*Selected CBR%*
			2.5mm	*5.0mm*				*2.5mm*	*5.0mm*	
0.5	1.5	0.152				2.50	0.253			
1.0	2.0	0.202				4.00	0.404			
1.5	3.5	0.353				6.50	0.656			
2.0	4.5	0.454				8.50	0.858			
2.5	6.0	0.606				10.00	1.010			
3.0	13.5	1.364				12.00	1.212			
3.5	19.0	1.919				15.00	1.515			
4.0	25.0	2.525	8.0	21.0	21.0	17.00	1.717	5.0	11.0	21.0
4.5	29.0	2.929				18.00	1.818			
5.0	35.0	3.536				20.00	2.020			
5.5	40.0	4.040				23.00	2.323			
6.0	49.0	4.949				25.00	2.525			
6.5	55.0	5.555				26.00	2.626			
7.0	60.0	6.060				28.00	2.828			

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.5.F1: California Bearing Ratio of Sample F1

Additive Content: 2% of Cocoa Pod Ash + 98% Soil

	TOP					BOTTOM				
Penetration (mm)	*Load*	*Corrected*	*C.B.R.%*		*Selected CBR%*	*Load*	*Corrected*	*C.B.R.*		*Selected CBR%*
			2.5mm	*5.0mm*				*2.5mm*	*5.0mm*	
0.5	2.5	0.253				8.0	0.808			
1.0	5.0	0.050				16.0	1.616			
1.5	8.0	0.080				23.0	2.323			
2.0	14.0	1.414				31.0	3.131			
2.5	18.0	1.818				39.0	3.939			
3.0	21.0	2.121	19.4	21.2	21.2	46.0	4.696	29.5	35.0	35.0
3.5	26.0	2.626				53.0	5.353			
4.0	31.0	3.131				62.0	5.262			
4.5	35.0	3.535				66.0	6.666			
5.0	41.0	4.141				68.0	6.868			
5.5	47.0	4.947				74.0	7.474			
6.0	52.0	5.252				80.0	8.080			
6.5	60.0	6.06				85.0	8.585			
7.0	64.0	6.414				96.0	9.696			

Table 4.5.F2: California Bearing Ratio of Sample F2

Additive Content: 4% of Cocoa Pod Ash + 96% Soil

	TOP					BOTTOM				
Penetration (mm)	*Load*	*Corrected*	*C.B.R.%*		*Selected CBR%*	*Load*	*Corrected*	*C.B.R.*		*Selected CBR%*
			2.5mm	*5.0mm*				*2.5mm*	*5.0mm*	
0.5	3.0	0.303				13.0	1.313			
1.0	14.0	1.414				26.0	2.626			
1.5	24.0	2.424				44.0	4.444			
2.0	36.0	3.636				66.0	6.666			
2.5	48.0	4.848				82.0	8.282			
3.0	63.0	6.363				98.0	9.892			
3.5	74.0	7.474				178.0	11.918			
4.0	91.0	9.191	37.0	60.6	60.6	135.0	13.635	52.9	84.2	84.2
4.5	102.0	10.302				152.0	15.352			
5.0	122.2	12.322				167.0	16.867			
5.5	135.0	13.635				176.0	17.776			
6.0	160.0	16.160				183.0	18.483			
6.5	195.0	19.695				197.0	19.897			
7.0	200.0	20.200				205.0	20.705			

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.5.F4: California Bearing Ratio of Sample F3

Additive Content: 6% of Cocoa Pod Ash + 94% Soil

Penetration (mm)	TOP					BOTTOM				
	Load	Corrected	C.B.R.%		Selected CBR%	Load	Corrected	C.B.R.		Selected CBR%
			2.5mm	5.0mm				2.5mm	5.0mm	
0.5	8.0	0.808				10.0	1.010			
1.0	22.0	2.222				28.0	2.828			
1.5	35.0	2.535				37.0	5.353			
2.0	44.0	4.444				53.0	6.767			
2.5	56.0	5.656				67.0	7.676			
3.0	72.0	7.272				76.0	9.999			
3.5	93.0	9.393	44.6	94.2	94.2	99.0	12.827	60.4	95.2	95.2
4.0	118.0	11.918				127.0	14.241			
4.5	135.0	13.635				141.0	17.069			
5.0	161.0	16.261				169.0	19.190			
5.5	182.0	18.382				190.0	22.725			
6.0	216.0	21.812				225.0	25.250			
6.5	238.0	24.038				250.0	26.563			
7.0	251.0	25.251				263.0	27.674			

Table 4.5.F3: California Bearing Ratio of Sample F4

Additive Content: 8% of Cocoa Pod Ash + 92% Soil

Penetration (mm)	TOP					BOTTOM				
	Load	Corrected	C.B.R.%		Selected CBR%	Load	Corrected	C.B.R.		Selected CBR%
			2.5mm	5.0mm				2.5mm	5.0mm	
0.5	21.0	2.121				24.0	2.424			
1.0	47.0	4.747				48.0	4.848			
1.5	72.0	7.272				76.0	7.676			
2.0	93.0	9.393				101.0	10.201			
2.5	118.0	11.918				127.0	12.827			
3.0	127.0	12.827				145.0	14.645			
3.5	151.0	15.251	90.6	105.2	105.2	167.0	16.867	98.1	110.2	110.2
4.0	182.0	18.382				202.0	20.240			
4.5	198.0	19.998				210.0	21.210			
5.0	205.0	20.705				217.0	21.917			
5.5	210.0	21.210				226.0	22.826			
6.0	218.0	22.018				231.0	23.331			
6.5	230.0	23.230				240.0	24.240			
7.0	258.0	26.058				270.0	27.270			

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.5.G1: California Bearing Ratio of Sample G1

Additive Content: 2% Palm Kernel Shell Ash + 98% Soil

	TOP					BOTTOM				
Penetration (mm)	Load	Corrected	C.B.R.%		Selected CBR%	Load	Corrected	C.B.R.		Selected CBR%
			2.5mm	5.0mm				2.5mm	5.0mm	
0.5	2.0	0.202				6.0	0.606			
1.0	3.8	0.3838				13.0	1.313			
1.5	6.0	0.606				19.0	1.919			
2.0	10.0	1.010				24.0	2.424			
2.5	13.0	1.313				33.0	3.333			
3.0	19.0	1.919				40.0	4.040			
3.5	22.0	2.222	9.8	19.5	19.5	45.0	4.545	26.4	34.1	34.1
4.0	30.0	3.030				58.0	5.858			
4.5	33.0	3.333				62.0	6.262			
5.0	39.0	3.939				66.0	6.666			
5.5	43.0	4.343				70.0	7.070			
6.0	50.0	5.050				77.0	7.777			
6.5	58.0	5.858				82.0	8.282			
7.0	62.0	6.262				93.0	9.292			

Table 4.5.G2: California Bearing Ratio of Sample G2

Additive Content: 4% Palm Kernel Shell Ash + 96% Soil

	TOP					BOTTOM				
Penetration (mm)	Load	Corrected	C.B.R.%		Selected CBR%	Load	Corrected	C.B.R.		Selected CBR%
			2.5mm	5.0mm				2.5mm	5.0mm	
0.5	2.5	0.2525				0.9	0.909			
1.0	11.0	1.111				19.0	1.919			
1.5	19.0	1.919				33.0	3.333			
2.0	30.0	3.030				56.0	5.656			
2.5	42.0	4.242				73.0	7.373			
3.0	51.0	5.151				81.0	8.181			
3.5	66.0	6.666	37.0	50.6	50.6	118.0	11.918	53.6	75.6	75.6
4.0	80.0	8.080				126.0	12.726			
4.5	93.0	9.393				141.0	14.241			
5.0	107.0	10.807				153.0	15.453			
5.5	118.0	11.918				165.0	16.665			
6.0	140.0	14.140				174.0	17.574			
6.5	172.0	17.373				180.0	18.180			
7.0	183.0	18.483				198.0	19.998			

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.5.G4: California Bearing Ratio of Sample G3

Additive Content: 6% Palm Kernel Shell Ash + 94% Soil

Penetration (mm)	TOP					BOTTOM				
	Load	Corrected	C.B.R.%		Selected CBR%	Load	Corrected	C.B.R.		Selected CBR%
			2.5mm	5.0mm				2.5mm	5.0mm	
0.5	5.0	0.505				7.0	0.707			
1.0	18.0	1.818				23.0	2.323			
1.5	31.0	3.131				36.0	3.636			
2.0	44.0	4.444				48.0	4.848			
2.5	58.0	5.858				63.9	6.363			
3.0	71.0	7.171				79.0	7.974			
3.5	93.0	9.393				98.0	9.898			
4.0	118.0	11.918	45.3	80.2	80.2	125.0	12.625	39.1	86.2	86.2
4.5	132.0	13.332				140.0	14.140			
5.0	163.0	16.463				172.0	17.372			
5.5	185.0	18.685				190.0	19.190			
6.0	205.0	20.705				210.0	21.210			
6.5	231.0	23.331				247.0	24.647			
7.0	251.0	25.351				263.0	26.563			

Table 4.5.G3: California Bearing Ratio of Sample G4

Additive Content: 8% Palm Kernel Shell Ash + 92% Soil

Penetration (mm)	TOP					BOTTOM				
	Load	Corrected	C.B.R.%		Selected CBR%	Load	Corrected	C.B.R.		Selected CBR%
			2.5mm	5.0mm				2.5mm	5.0mm	
0.5	16.0	1.616				19.0	1.919			
1.0	37.0	3.737				37.0	3.737			
1.5	62.0	6.262				63.0	6.363			
2.0	85.0	8.585				82.0	8.282			
2.5	107.0	10.807				116.0	11.716			
3.0	117.0	11.817	79.4	100.2	100.2	129.0	13.029	83.1	100.7	100.7
3.5	140.0	14.140				147.0	14.847			
4.0	169.0	17.069				181.0	18.281			
4.5	181.0	18.281				193.0	19.493			
5.0	196.0	19.796				207.0	20.907			
5.5	204.0	20.604				218.0	22.018			
6.0	211.0	21.311				226.0	22.826			
6.5	219.0	22.119				231.0	23.331			
7.0	241.0	25.341				263.0	25.563			

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

Table 4.5.2: **C.B.R. OF THE SAMPLES TREATED AND UNTREATED WITH ADDITIVES**

Sample Type	*Additive Content %*	*Force at 2.5mm*	*Tap Force at 5.00mm*	*CRB value at 2.5mm (%)*	*CBR (%) value at 5.0mm*	*Selected CBR %*
A	2.0	4.4	7.4	33.0	37.0	37.0
	4.0	8.4	17.8	55.0	89.0	89.0
	8.0	7.3	19.0	63.0	95.0	95.0
	6.0	1.2.5	2.3	94.0	115.0	115.0
B	2.0	7.0	13.8	53.0	69.0	69.0
	4.0	13.0	18.5	116.0	93.0	102.0
	6.0	13.5	20.4	98.0	102.0	116.0
	8.0	22.0	25.6	102.0	127.0	127.0
C	2.0	5.8	19.4	44.0	97.0	59.0
	4.0	12.6	21.2	95.0	106.0	97.0
	6.0	5.8	11.8	44.0	59.0	106.0
	8.0	15.3	30.1	115.0	150.0	150.0
D	2.0	11.6	22.8	87.0	114.0	110.0
	4.0	15.0	25.0	113.0	125.0	114.0
	6.0	11.0	22.0	83.0	110.0	125.0
	8.0	10.3	25.6	78.0	128.0	128.0
E	0	1.0	4.2	5.0	21.0	21.0
F	2.0	3.9	7.0	29.5	35.0	35.0
	4.0	7.0	16.8	52.9	84.2	84.2
	6.0	13.0	22.0	98.1	110.2	95.2
	8.0	8.0	19.0	60.4	95.2	110.2
G	2.0	3.5	6.8	26.4	34.1	34.1
	4.0	7.1	15.1	53.6	75.6	75.6
	6.0	1.1	20.1	83.1	100.7	86.2
	8.0	6.5	17.2	39.1	86.2	100.7

Standard Load for 2.5mm = 13.24KN/m^2

Standard Load for 5.0mm = 19.96KN/m^2

$$\text{CRB} = \frac{\text{Force on plunger}}{\text{Standard Load}} \times 100\%$$

<u>*Note:*</u>

Take the higher value as the CBR of the samples for each additive content at 2.5mm and 5.0mm as shown above.

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

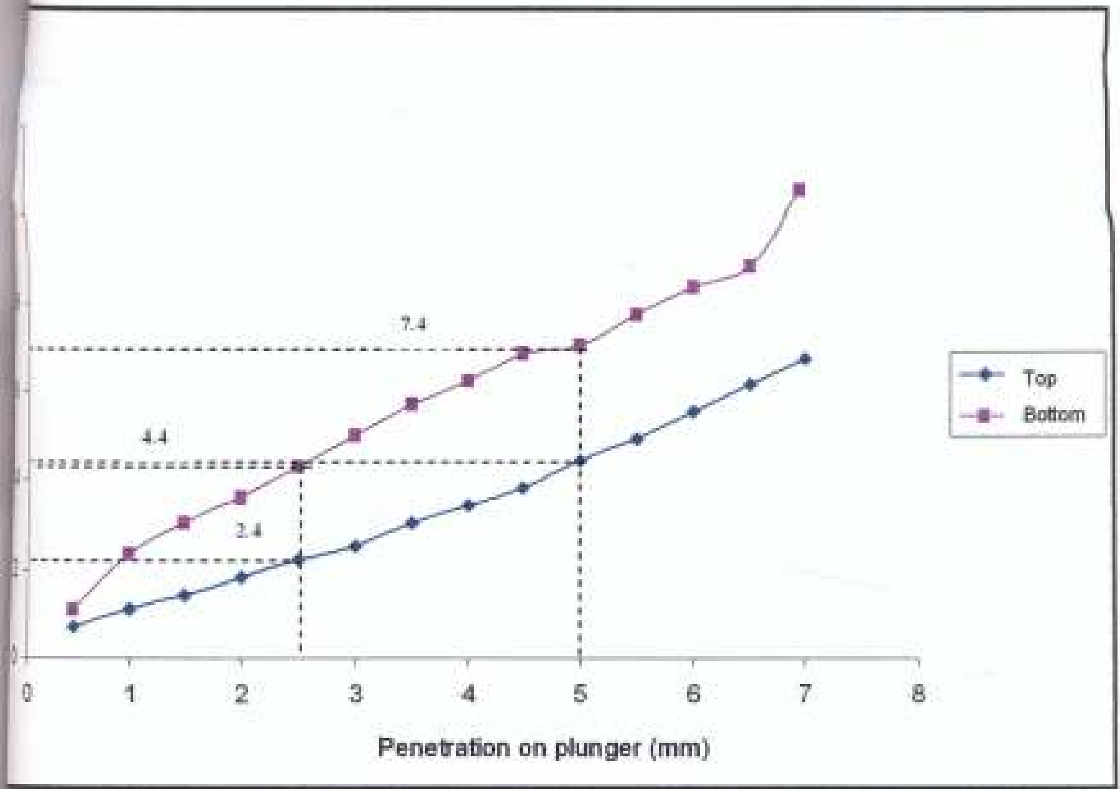


Fig 4.5.A1: California Bearing Ratio graphs for Sample A1

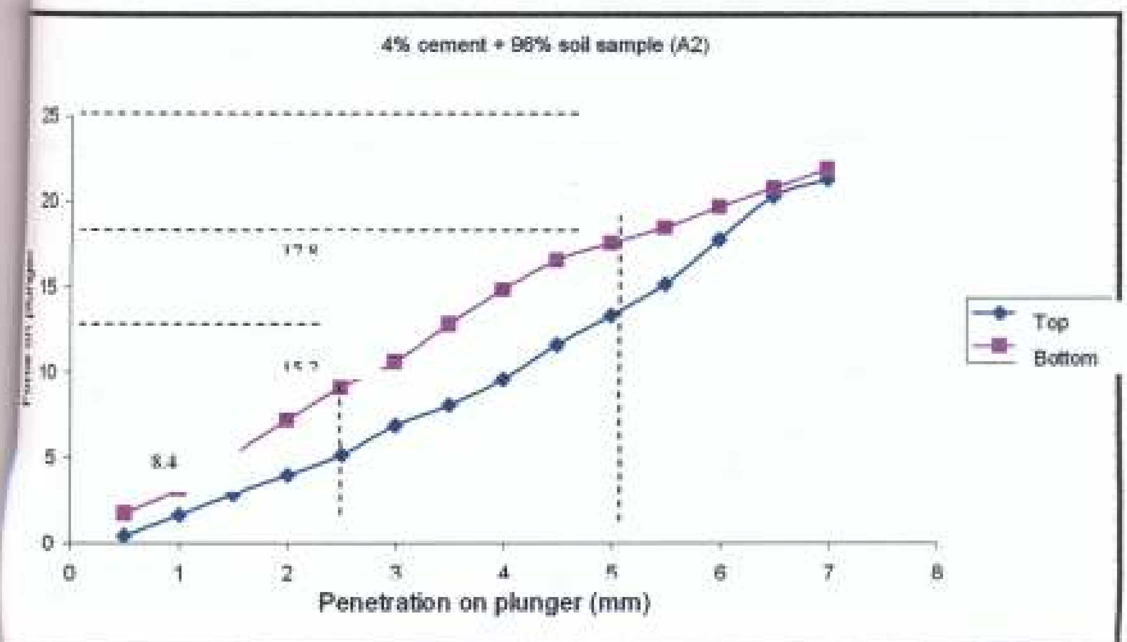


Fig 4.5.A2: California Bearing Ratio graphs for Sample A2

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash;

D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only,

F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

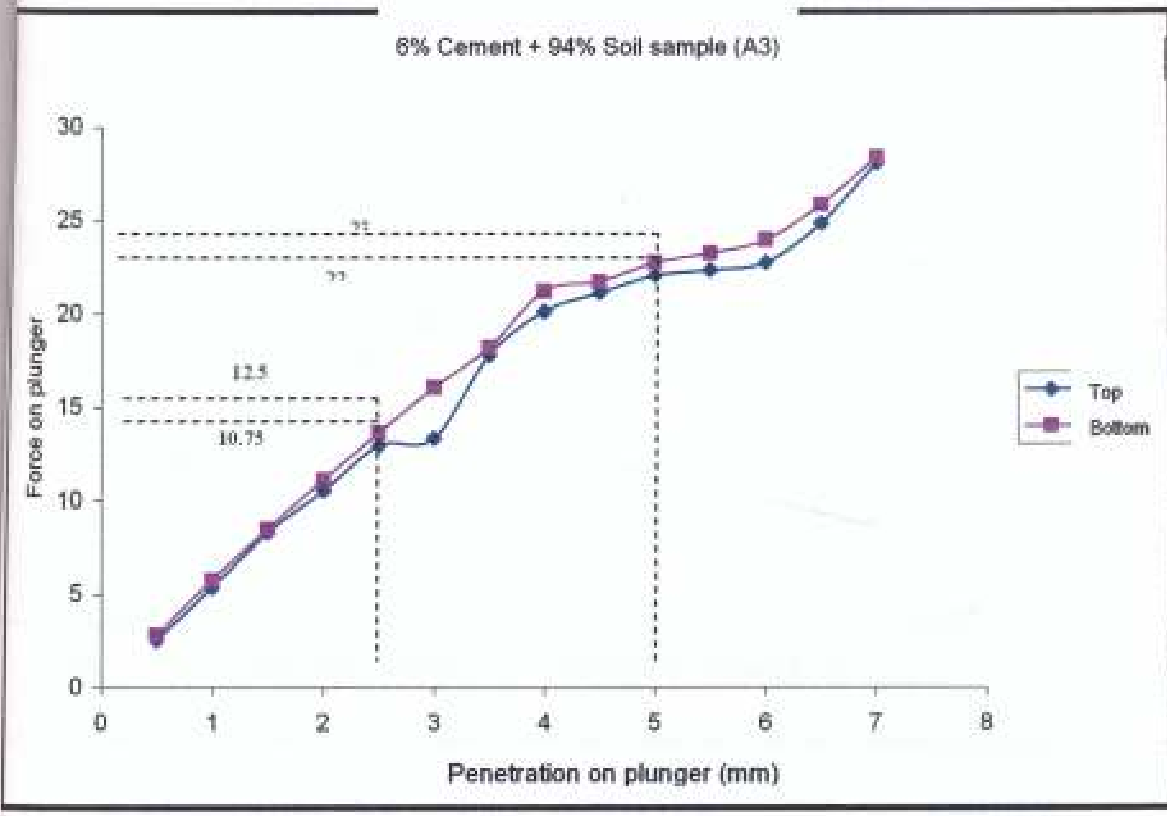


Fig 4.5.A3: California Bearing Ratio graphs for Sample A3

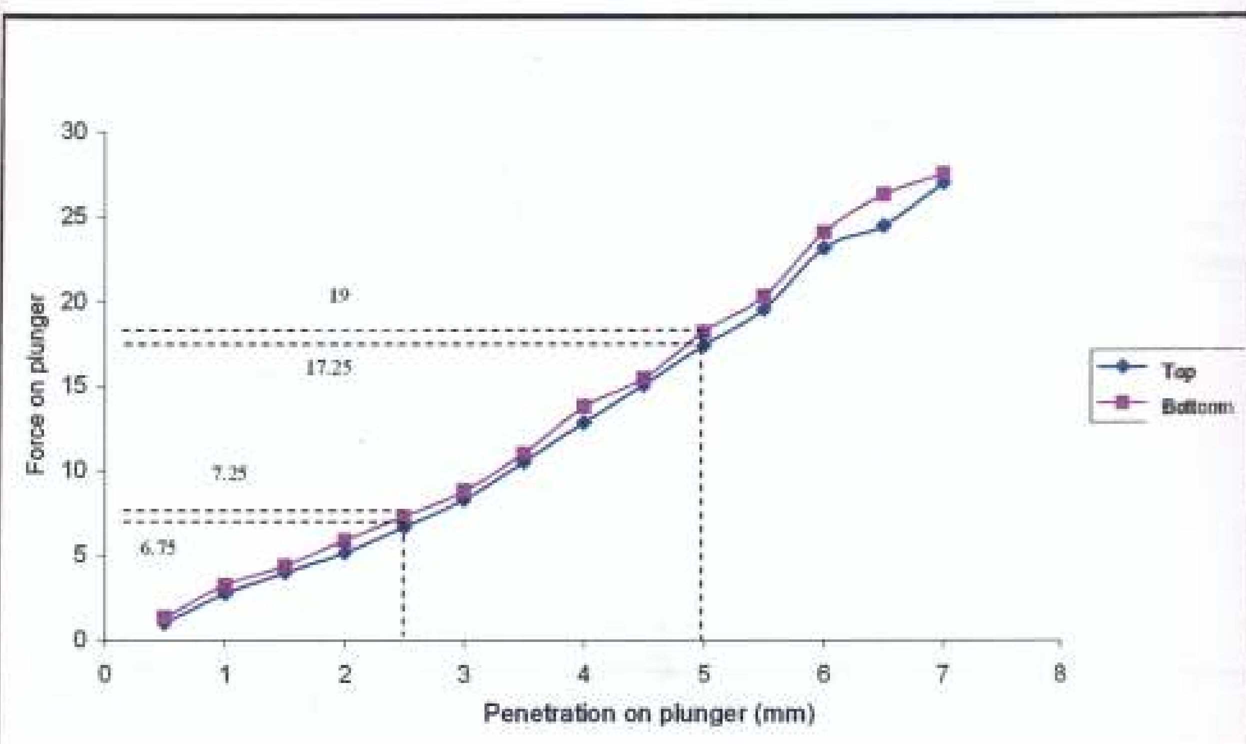


Fig 4.5.A4: California Bearing Ratio graphs for Sample A4

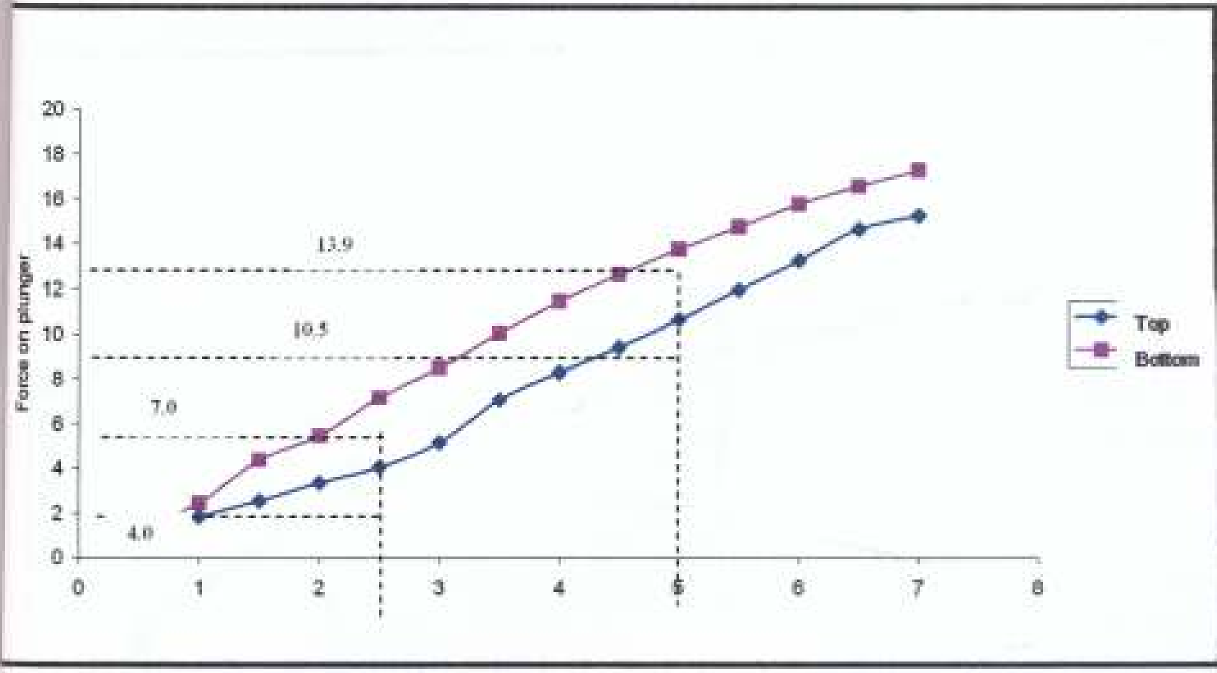
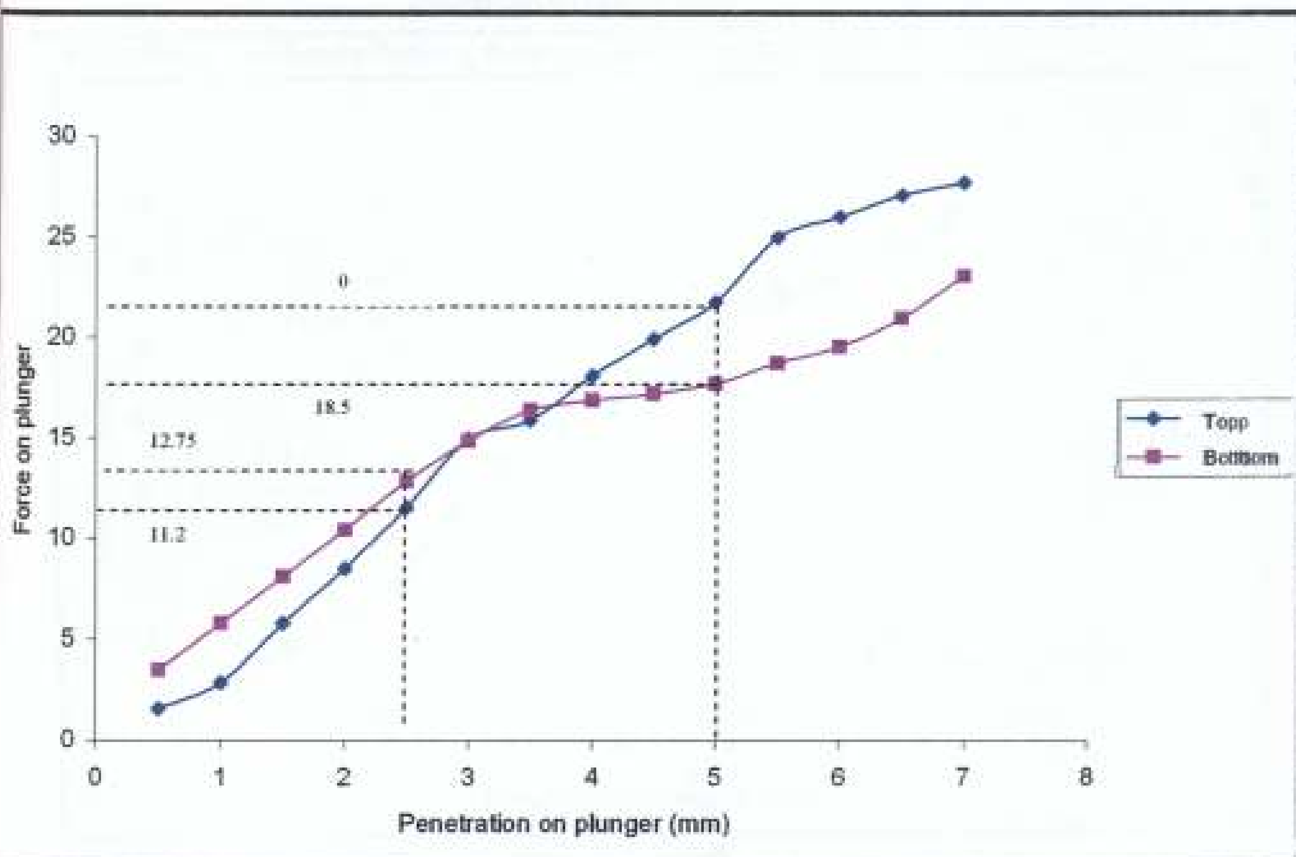


Fig 4.5.B1: California Bearing Ratio graphs for Sample B1



ig 4.5.B3: California Bearing Ratio graphs for Sample B3

EGEND

= Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod nd Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

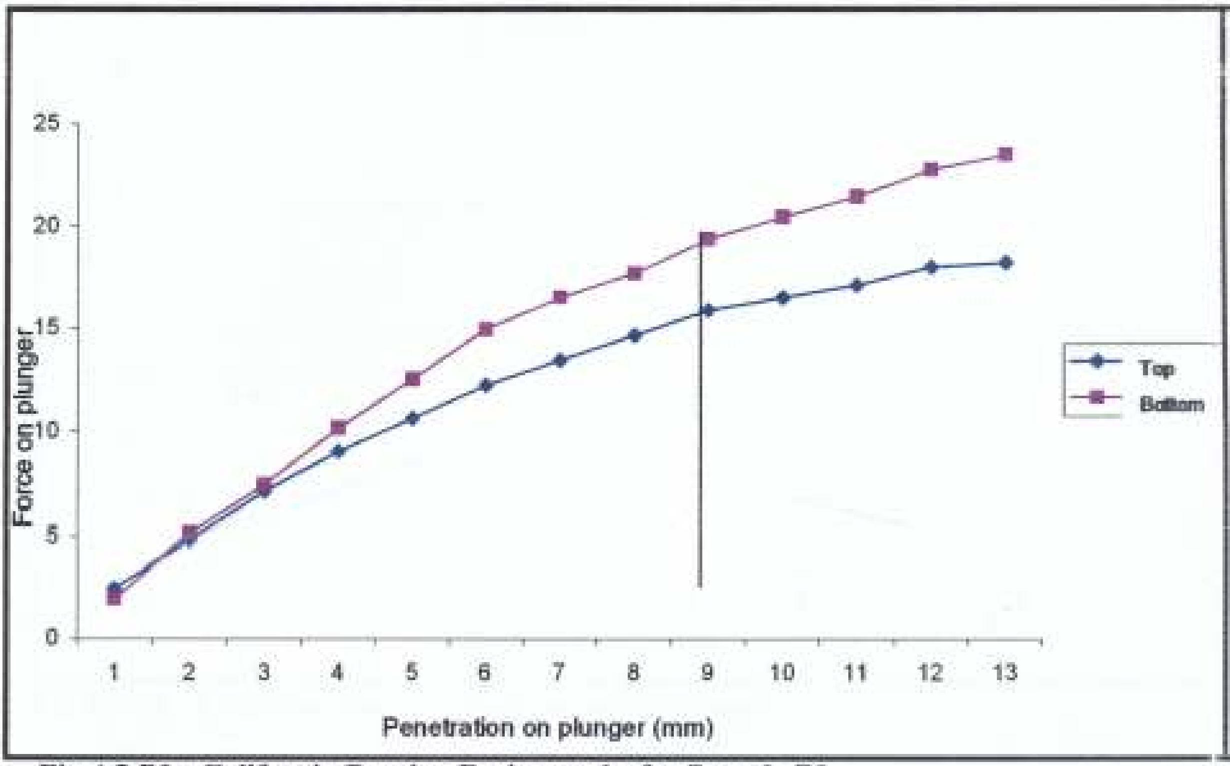


Fig 4.5.B2: California Bearing Ratio graphs for Sample B2

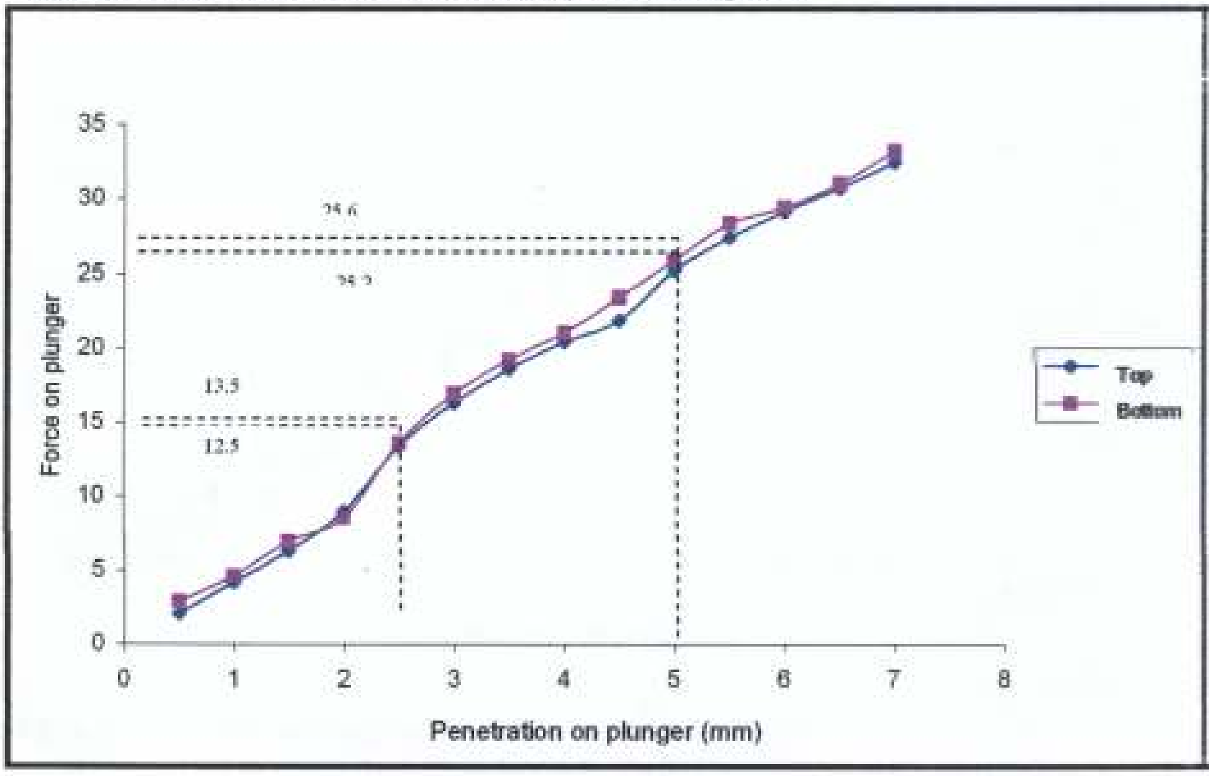


Fig 4.5.B4: California Bearing Ratio graphs for Sample B4

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash;

D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only,

F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

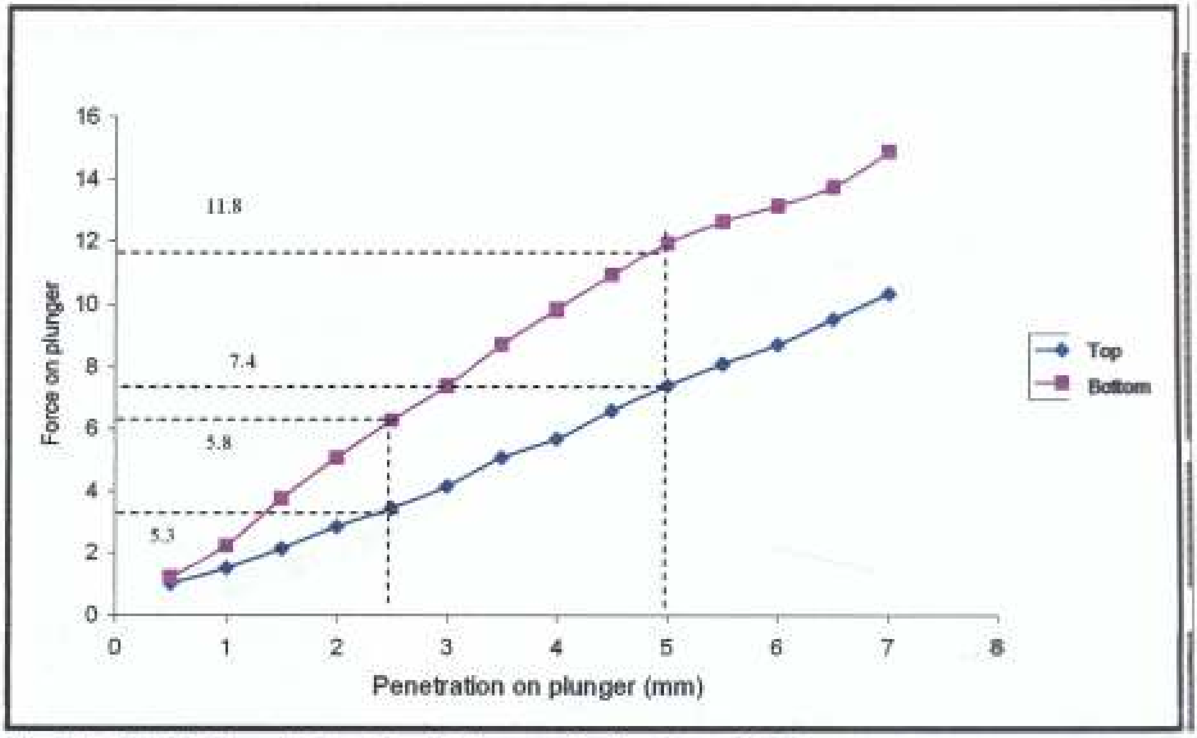


Fig 4.5.C1: California Bearing Ratio graphs for Sample C1

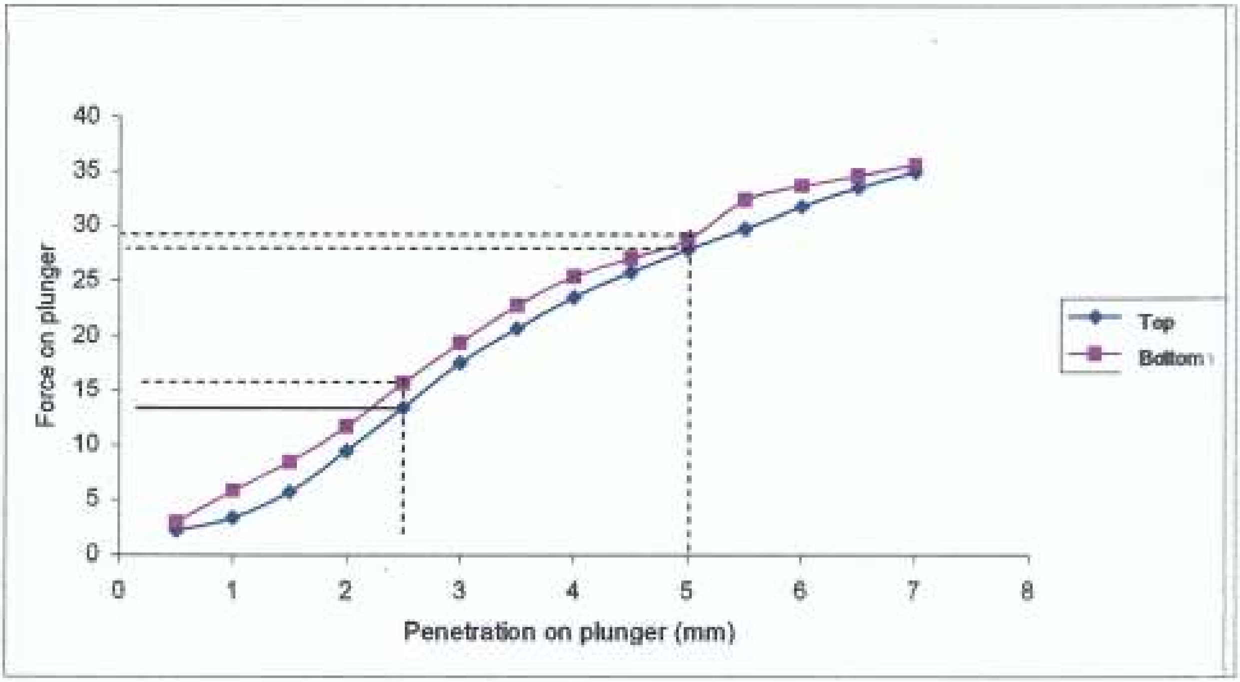


Fig 4.5.C4: California Bearing Ratio graphs for Sample C4

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash;

D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only,

F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

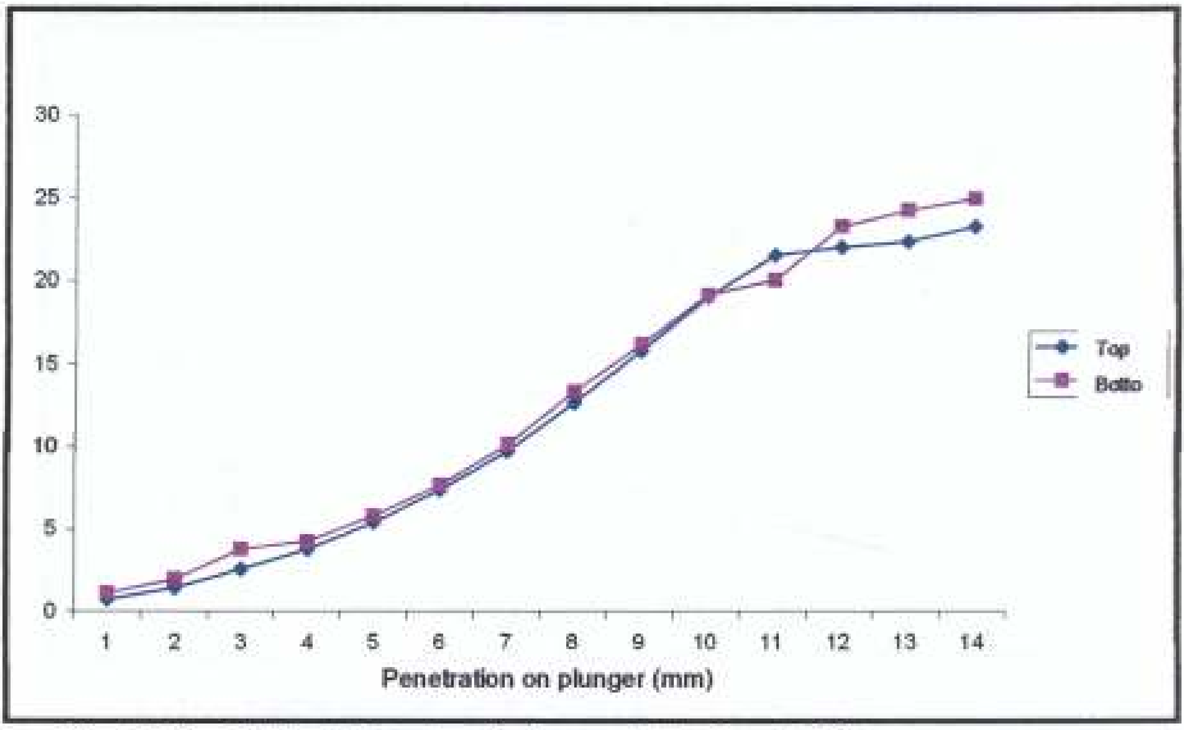


Fig 4.5.C2: California Bearing Ratio graphs for Sample C2

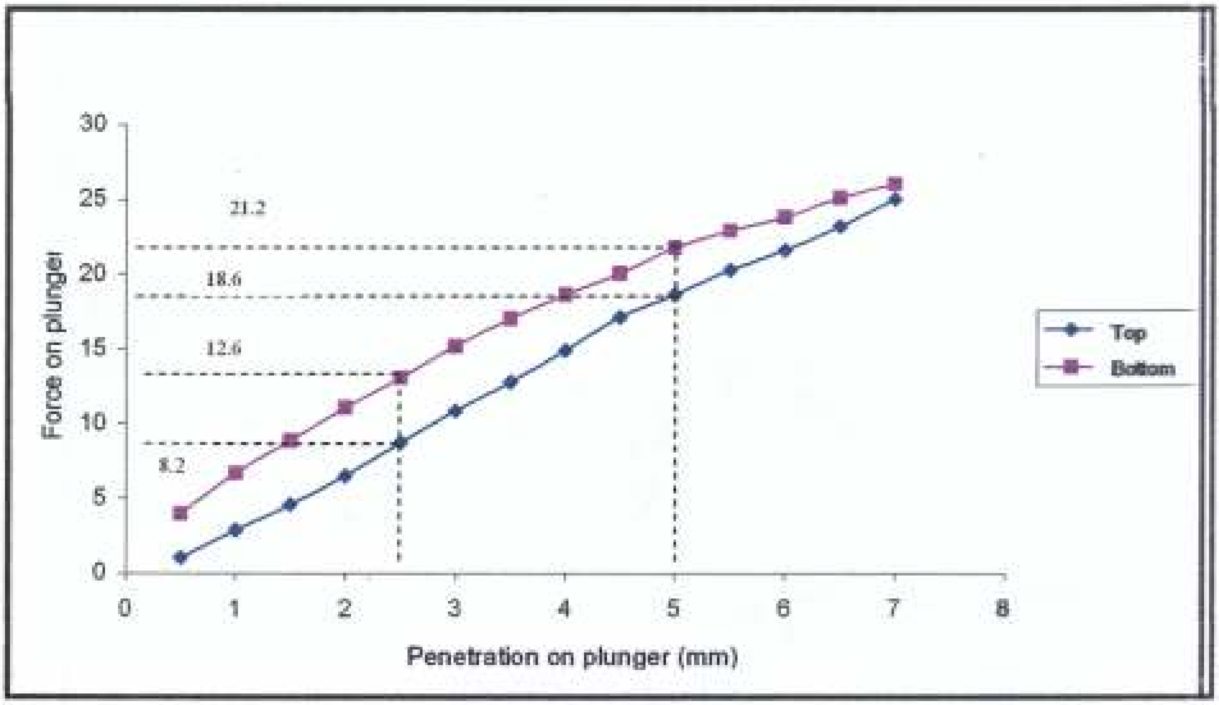


Fig 4.5.C3: California Bearing Ratio graphs for Sample C3

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash;

D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only,

F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

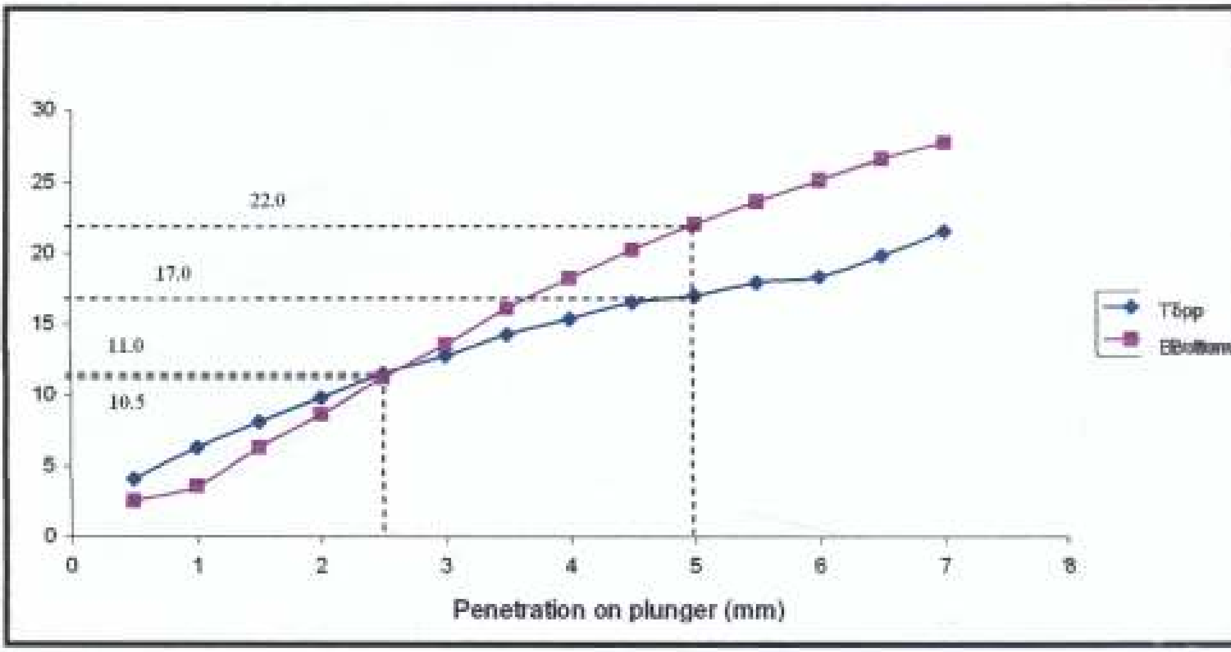


Fig 4.5.D1: California Bearing Ratio graphs for Sample D1

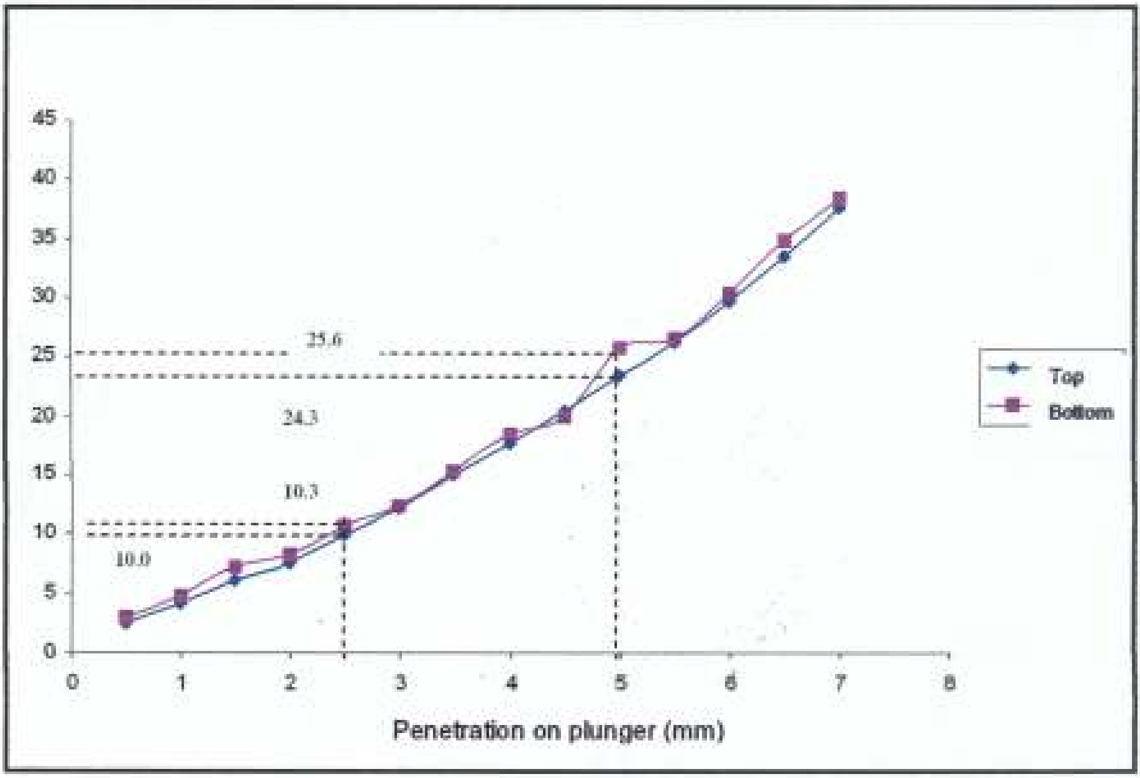


Fig 4.5.D4: California Bearing Ratio graphs for Sample D4

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash;

D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only.

F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

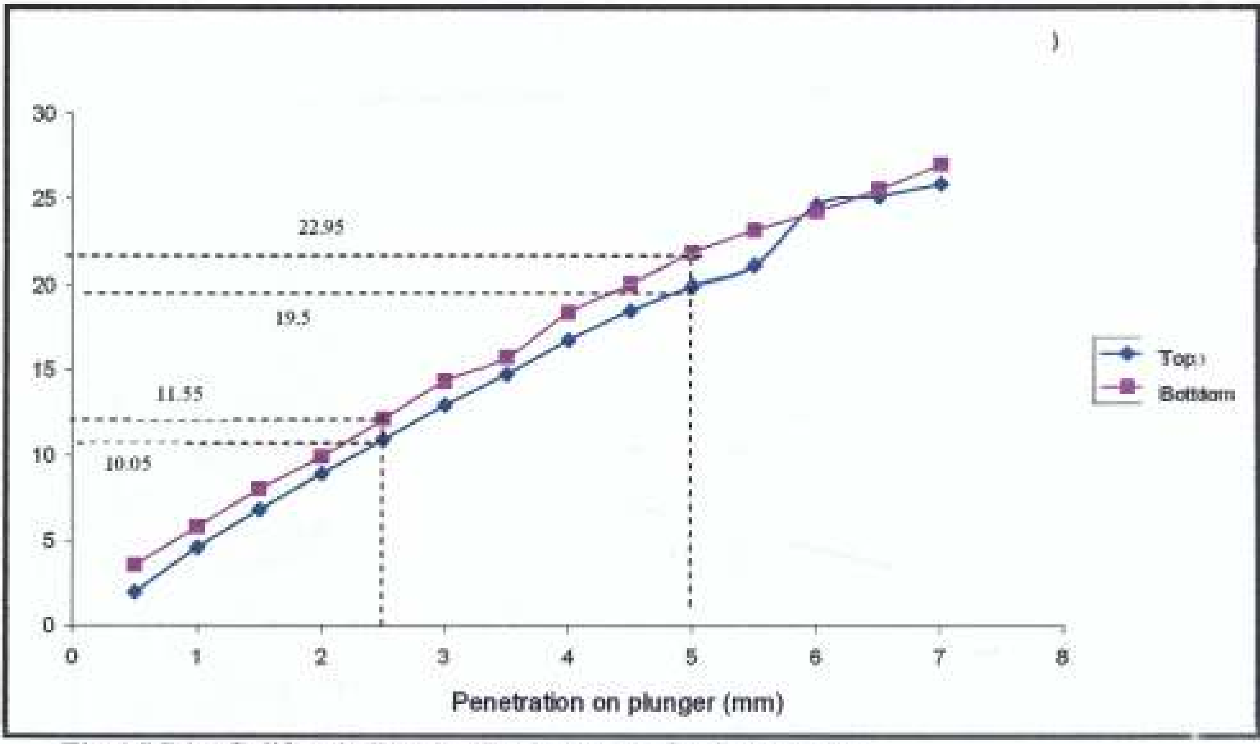


Fig 4.5.D2: California Bearing Ratio graphs for Sample D2

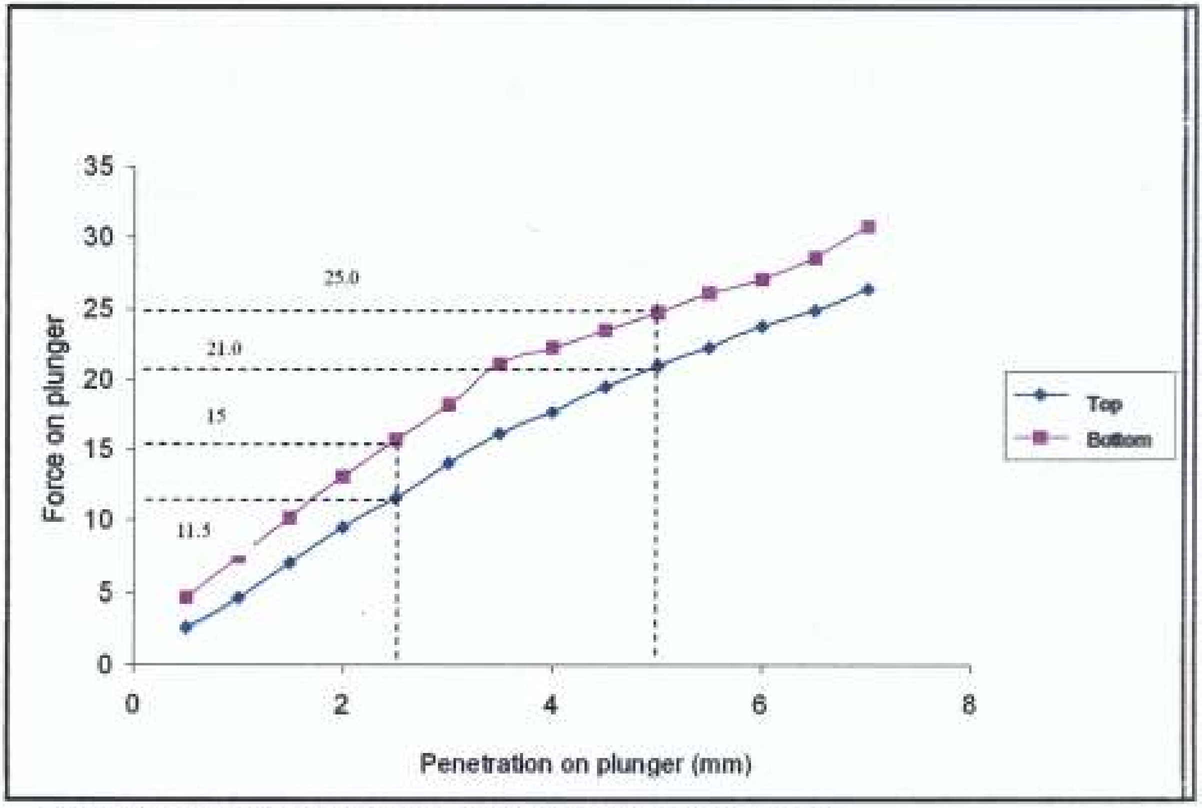


Fig 4.5.D3: California Bearing Ratio graphs for Sample D3

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash;

D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only,

F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

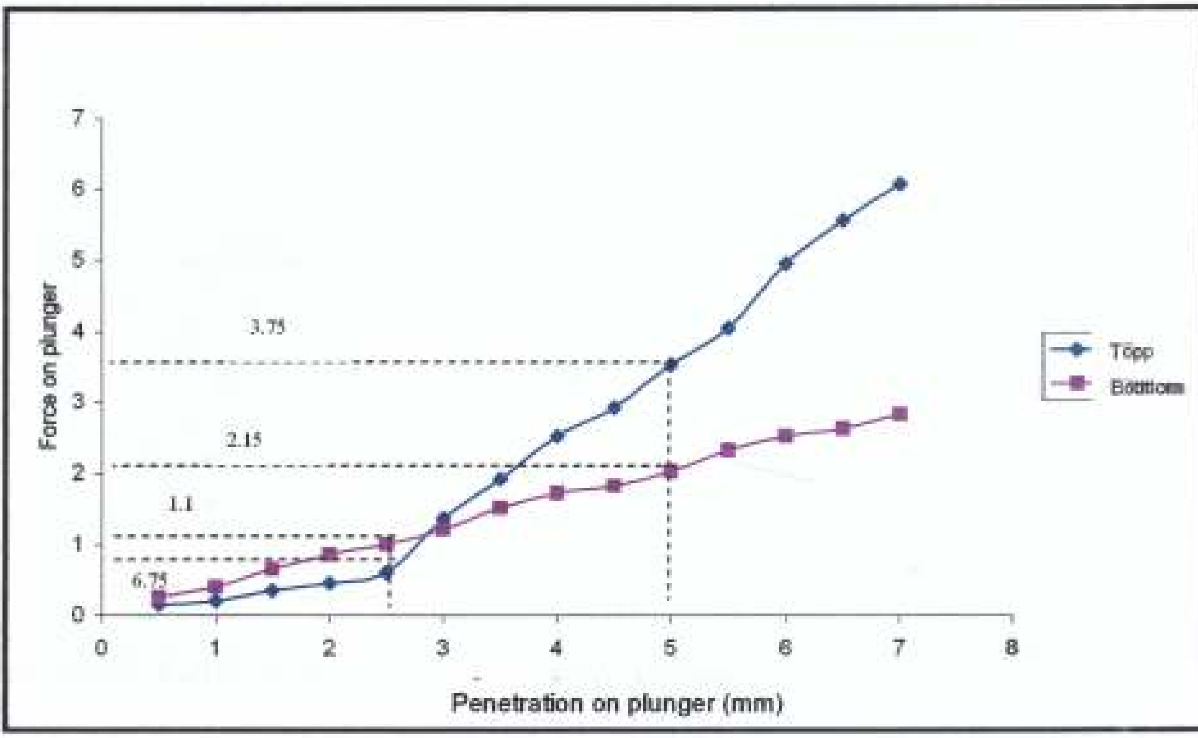


Fig 4.5.E: California Bearing Ratio graphs for Sample E

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash;

D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only,

F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

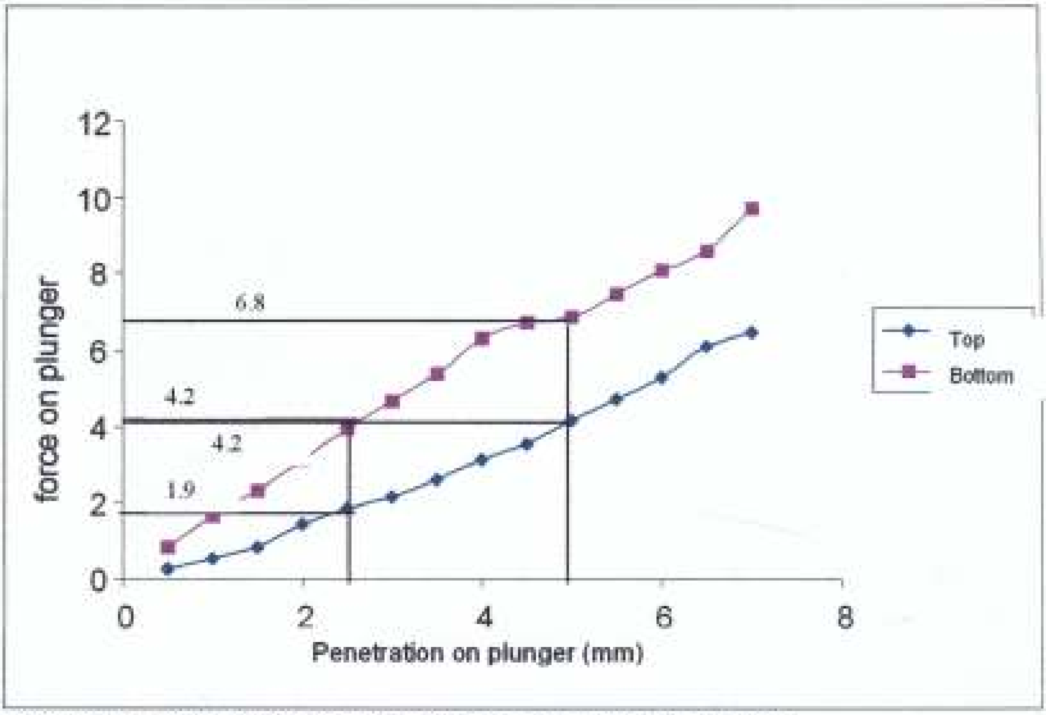


Fig 4.5.F1: California Bearing Ratio graphs for Sample F1

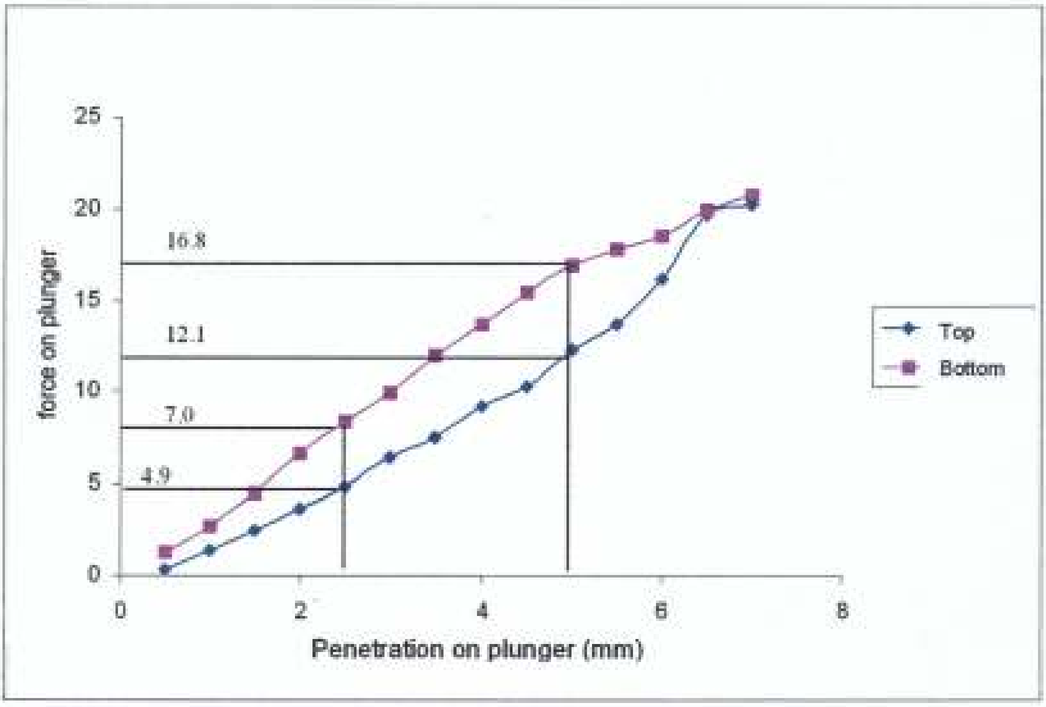


Fig 4.5.F2: California Bearing Ratio graphs for Sample F2

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash;

D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only,

F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

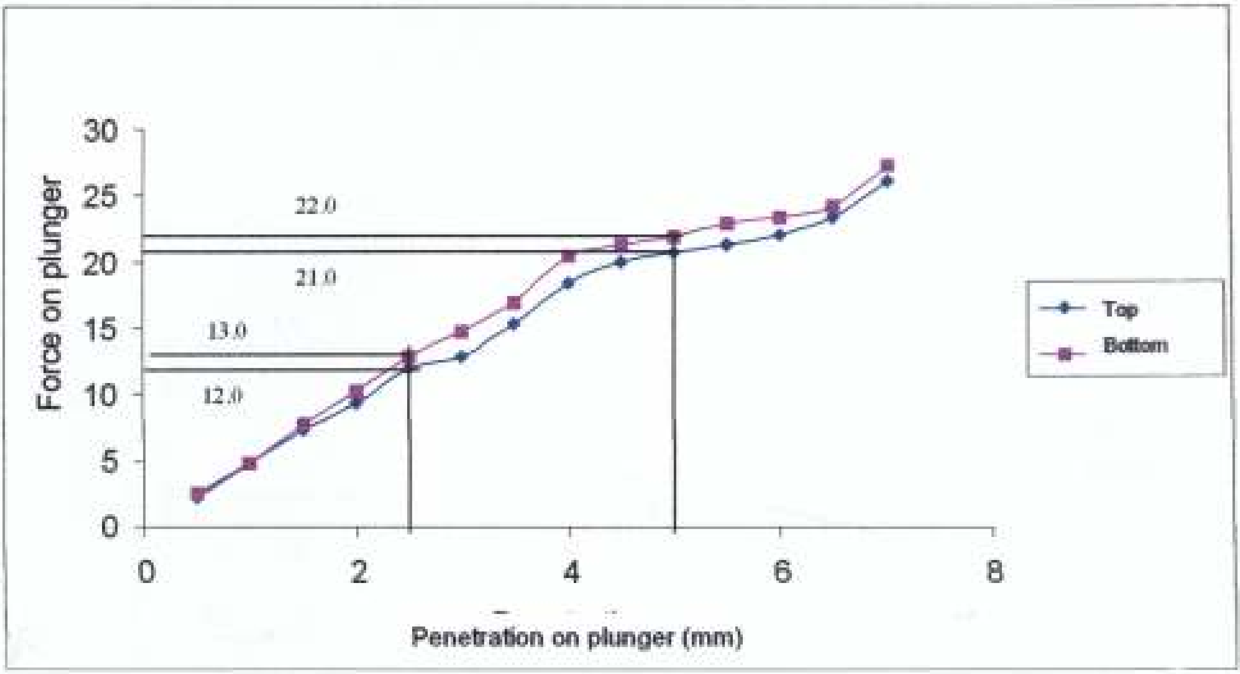


Fig 4.5.F4: California Bearing Ratio graphs for Sample F4

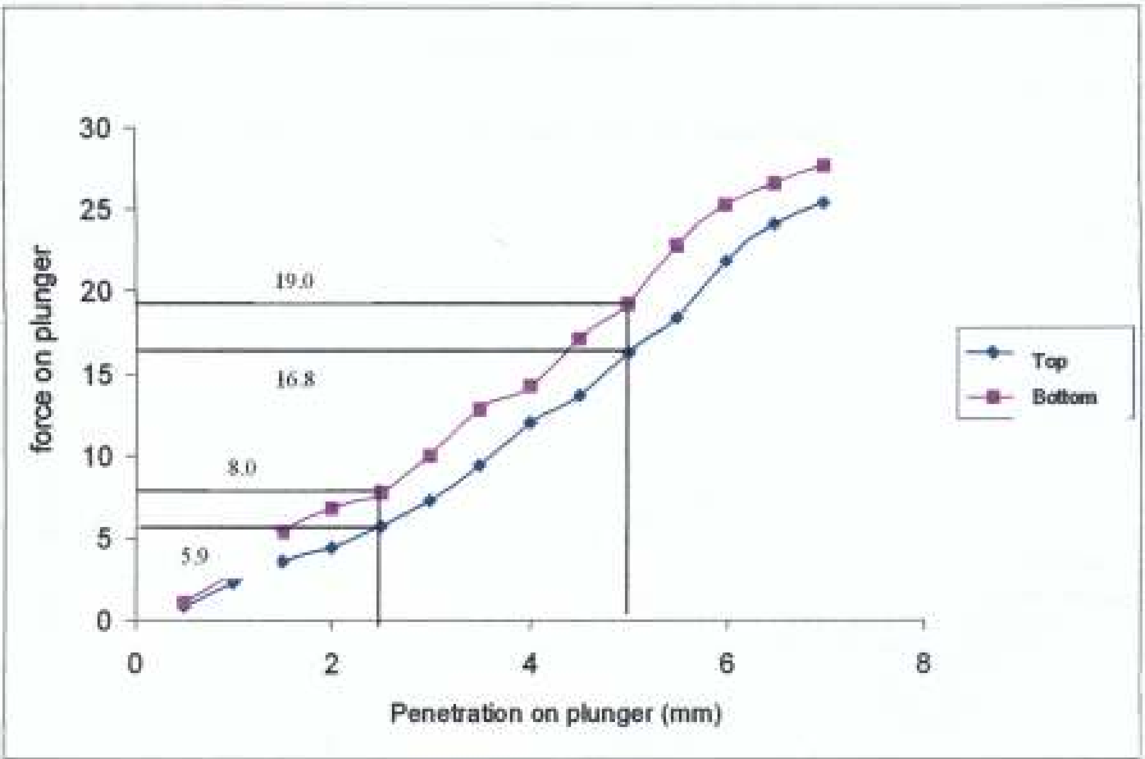


Fig 4.5.F3: California Bearing Ratio graphs for Sample F3

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash;

D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only,

F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

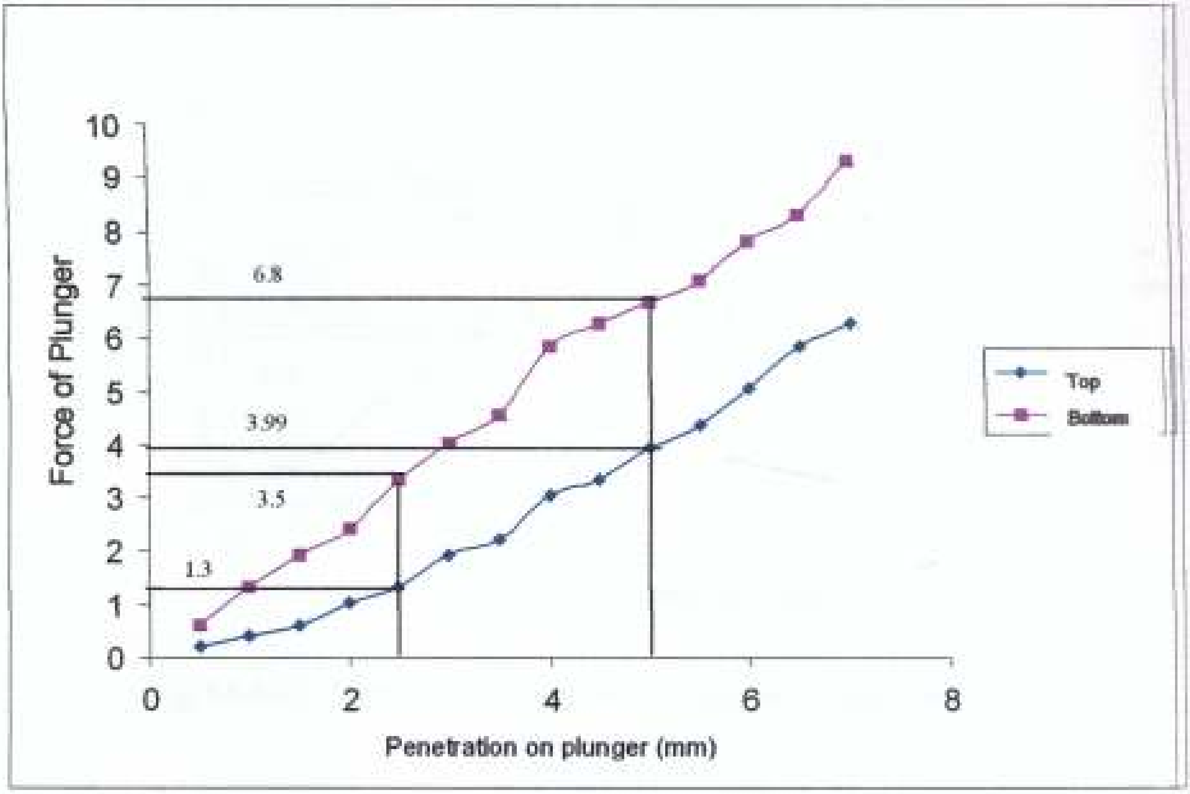


Fig 4.5.G1: California Bearing Ratio graphs for Sample G1

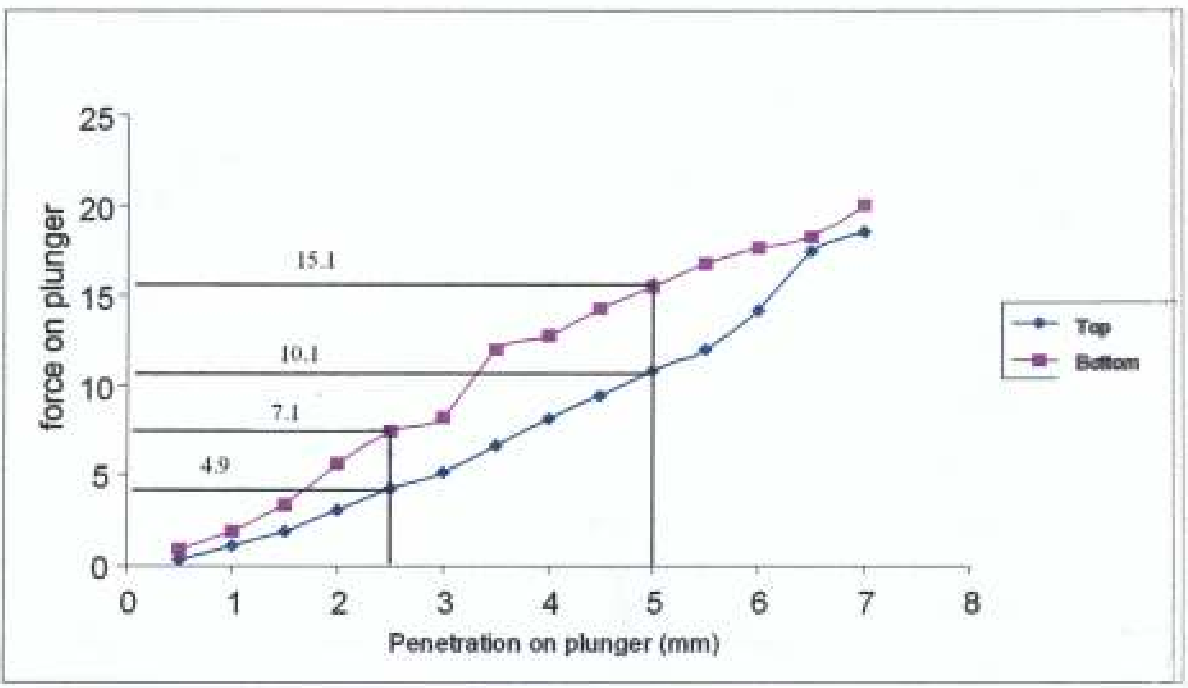


Fig 4.5.G2: California Bearing Ratio graphs for Sample G2

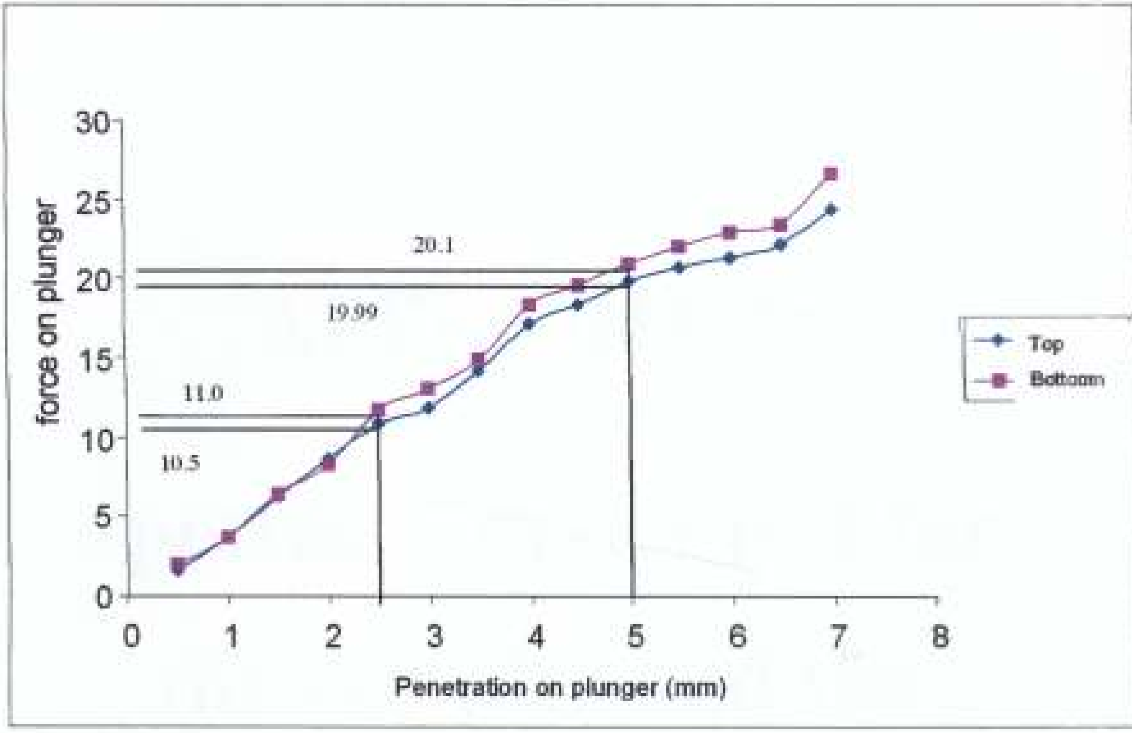


Fig 4.5.G4: California Bearing Ratio graphs for Sample G4

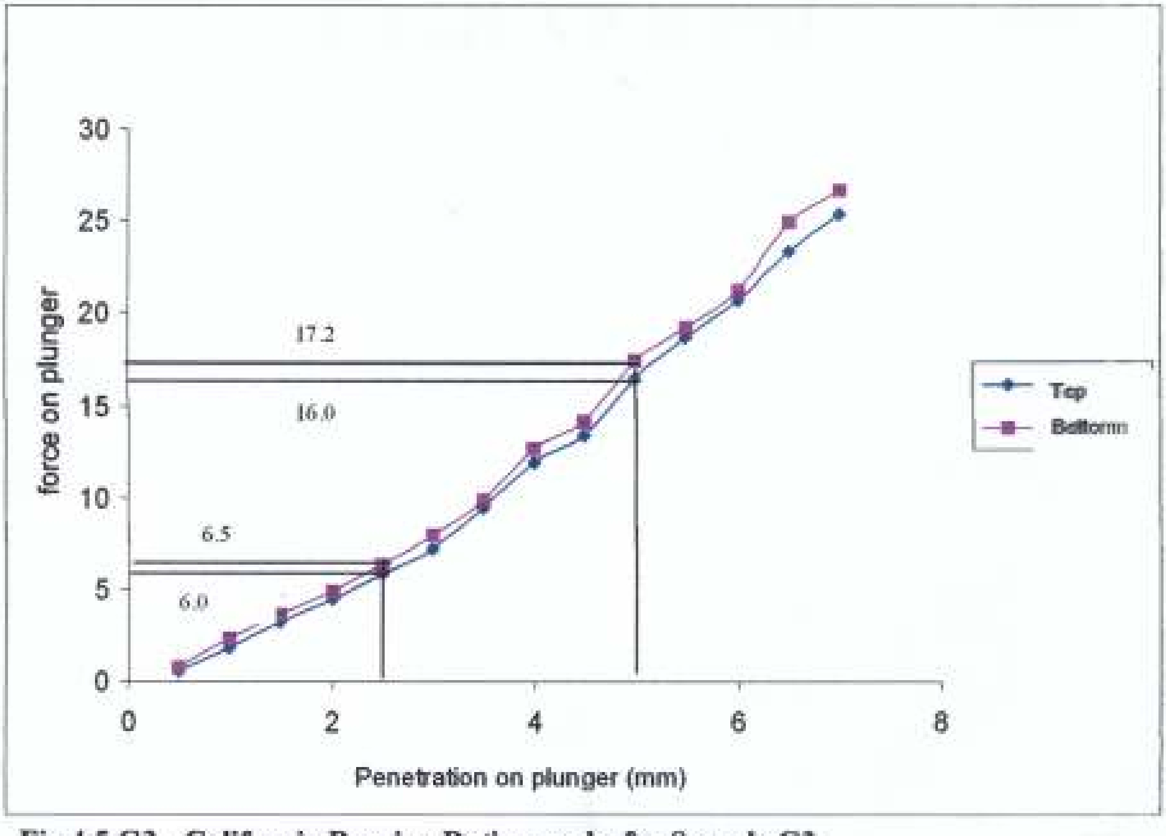


Fig 4.5.G3: California Bearing Ratio graphs for Sample G3

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash

APPENDIX 5:

Specific Gravity test for the samples and the additive used.

TABLE 4.2.1 **SPECIFIC GRAVITY TEST FOR THE SAMPLES AND ADDITIVES USED**

	SAMPLE A				SAMPLE B				SAMPLE C				SAMPLE D				E (Soil sample only control)	Cement used	Ashes from pod	Ashes from palm kernel shell
	2%	4%	6%	8%	2%	4%	6%	8%	2%	4%	6%	8%	2%	4%	6%	8%				
W_1 (g)	500.0	50.0	500.0	500.0	482.0	482.0	482.0	482.0	499.0	499.0	499.0	499.0	499.0	499.0	482.0	482.0	482.0	482.0	499.0	482.0
W_2 (g)	550.0	550.0	550.0	549.0	532.0	532.0	532.0	532.0	549.0	549.0	549.0	549.0	549.0	549.0	532.0	532.0	532.0	532.0	549.0	532.0
W_3 (g)	1044.0	1045.0	1045.5	1045.6	1043.0	1043.0	1044.0	1046.0	1047.0	1046.0	1046.0	1047.0	1047.0	1047.0	1045.0	1046.0	1045.0	1049.0	1046.0	1044.0
W_4 (g)	1010.0	1010.0	1010.0	1010.0	1013.0	1013.0	1013.0	1013.0	1015.0	1015.0	1015.0	1015.0	1015.0	1015.0	1013.0	1013.0	1013.0	1013.0	1015.0	1013.0
$W_2 - W_1$ (gm)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
$W_3 - W_2$ (gm)	494.0	495.0	485.0	511.0	511.0	511.0	512.0	514.0	498.0	397.0	497.0	498.0	498.0	498.0	513.0	514.0	513.0	517.0	497.0	512.0
$W_4 - W_1$ (gm)	510.0	510.0	510.0	495.0	531.0	531.0	531.0	531.0	516.0	516.0	516.0	516.0	516.0	516.0	513.0	531.0	513.0	513.0	516.0	531.0
S. G.	3.13	3.33	3.52	3.50	2.63	2.78	2.94	3.05	2.63	2.63	2.63	2.78	2.78	2.78	2.78	2.94	2.57	3.57	2.63	2.63

LEGEND

A = Soil + Cement; B = Soil + Cement + Cocoa Pod Ash; C = Soil + Cement + Palm Kernel Shell Ash; D = Soil + Cement + Ashes From Cocoa Pod And Palm Kernel Shell; E = Soil Sample Only, F = Soil + Cocoa Pod Ash; G = Soil + Palm Kernel Shell Ash.

APPENDIX 6:

AASHTO Classification system table

APPENDIX 6

AASHTO CLASSIFICATION SYSTEM TABLE

General classification	*Granular materials (35% or less passing 75µm sieve)*							*Silt-clay materials (More than 35% passing 75µm sieve)*			
Group classification	*A – 1*		*A – 3*	*A – 2*				*A – 4*	*A – 5*	*A – 6*	*A – 7*
	A-1-a	*A-1-b*		*A-2-4*	*A-2-5*	*A-2-6*	*A-2-7*				*A-7-5* *A-7-6*
Sieve analysis, % passing A.S.T.M. Sieve / BS sieve No. 10 2.0mm No. 40 425mm No. 200 75µm	50max. 30max. 15max.	50max. 25max.	51max. 19max.	35max.	35max.	35max.	35max.	36min.	36min.	36min.	36min.
Characteristics of fraction passing A.S.T.M. No. 40 (BS 425µm) Liquid limit Plasticity index	6 max.		N. P.	40max. 10max.	41min. 40max.	40max. 11min.	41min. 11min.	40max. 10max.	41min. 10min.	40min. 10min.	41min. 11min.
Group index	0		0	0		4max.		8max.	12max.	16max.	16
Usual significant materials	Stone fragments, gravel and sand		Fine sand Silty or clayey gravel and sand					Silty soil		Clayey soils	
General rating as subgrade	Excellent to good						Fair to poor				

Note. The A-7 group is subdivided according a plastic index criterion. When a soil has a F1 equal to or less than the liquid limit minus 30, it is placed in the A-7-5 sub-group. When the P1 is greater than LL-30, the soil falls into the A-7-6 subgroup.

The following empirical formula is used to obtain the group index of a soil:

G.I = 0.2a + 0-005ac + 0.01bd

where a = that portion of the percentage passing the 75µm sieve greater than 35 and not exceeding 75, expressed as a positive whole number from a to 40.

b = that portion of the percentage passing the 75µm sieve greater than 15 and not exceeding 55, expressed as a positive whole number from 0 to 40.

c = that proportion of the numerical liquid limit greater than 40 and not exceeding 60, expressed as a positive whole number from 0 to 20.

and d = that portion of the numerical plasticity index greater than 10 and not exceeding 30, expressed as a positive whole number between 0 and 20.

The above formula is weighted so that the maximum of each of the three variables is in the ratio of 8 for the percentage passing the 75µm sieve, 4 for liquid limit, and 8 for plasticity index. This weighting and the adopted critical ranges are based on the study of average relative evaluations placed on subgrade materials by several highway organizations in the United States which use the tests involved in this classification system.

The group index of a soil is expressed to the nearest whole number and is written in parenthesis after the group or subgroup designation, e.g A-2(3). Even if the determined value is zero, it is still given.

Source: O' Flaherty (1974)

APPENDIX 7:

General Specification Requirements for Roads and Bridges.

APPENDIX 7

FEDERAL MINISTRY OF WORK II.

GENERAL SPECIFICATION REQUIREMENTS FOR ROADS AND BRIDGES

(a) **SUBGRADE**

Clauses 6102 and 6122 of the General Specification (Roads and Buildings) Vol II 1992 stipulate that a material will be suitable for use as subgrade if the following requirements are met:

(i)	Proportion Passing BS sieve No 200	not greater than 35%
(ii)	Liquid Limit (LL)	not greater than 80%
(iii)	Plasticity Index (PL)	not greater than 55%
(iv)	Relative compaction	not less than 100%

(b) **SUB BASE**

Clause 6201 of the General Specification (Roads and Bridges) vol II 1994 stipulates that a material will be suitable for use as sub base if the following requirements are met:

(i)	Proportion Passing BS sieve No 200	not greater than 35%
(ii)	Liquid Limit (LL)	not greater than 35%
(iii)	Plasticity Index (PL)	not greater than 12%
(iv)	CBR (Soaked – 24 hours)	not less than 30%
(v)	Relative Compaction	not les than 100%

(c) **BASE COURSE**

Clause 6201 of the General Specification (Roads and Bridges) vol II 1994, stipulate that a material will be suitable for use as base course if the following requirements are met:

(i)	Proportion passing BS sieve No 200	not greater than 35%
(ii)	Liquid Limit (LL)	not greater than 35%
(iii)	Plasticity Index (PL)	not greater than 12%
(iv)	CBR (unsoaked – 24 hours)	not less than 80%
(v)	Relative compaction	not less than 100%

(c) **ASPHALTIC CONCRETE**

Clause 6374, Tables VI – 16 and VI – 17of the General specification (Roads and Bridges) vol II 1994 stipulate that a material will be suitable for use as asphaltic concrete if the following requirement are met:

Wearing Course

Optimum Bitumen content	5 – 8%
Marshall stability	350kg mm
Marshall flow	2 – 43mm
Void in Total mix	3 – 5%

APPENDIX 8:

Pictures taken at various stages of work

Plate 1: Collection of cocoa pods for the thesis at the cocoa plantation in Igbole-Ekiti, Ido/Osi Local Government Area of Ekiti State

Plate 2: Collection of palm kernel shells for the thesis at the local palm produce in Igbole Ekiti, Ido/Osi Local Government Area of Ekiti State

Plate 3: Collection of soil samples for the thesis at a borrow pit along Olujoda Moferere Road (Ikere/Ado) in Ado Ekiti, the capital city of Ekiti State

Plate 4: Preparation for the burning of the palm kernel shells and cocoa pods at the Glass Technology Laboratory of the Federal Polytechnic, Ado-Ekiti.

Soil sample being weighed before compaction at the F.U.T.A (Geotechnical Laboratory)

Plate 6: Compaction Test being performed on the samples at the Federal University of Technology Geotechnical Laboratory, Akure.

Plate 7: Compacted samples being weighed before testing at the Federal University of Technology Geotechnical Laboratory, Akure.

Plate 8: Compacted samples being taken into the oven for drying at the Federal University of Technology Geotechnical Laboratory, Akure.

Plate 9: California bearing ratio test being performed on the samples at the Federal University of Technology, Geotechnical Laboratory Akure.