EFFECTS OF SAND AND CHIPPING DUST ON GEOTECHNICAL PROPERTIES OF LATERITIC SOIL

BY

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CERTIFICATION

This is to certify that the project topic titled "Effects of Sand and Chipping Dust on Geotechnical Properties of Laterite" was done by Chidi Timothy with registration number (NAU/2017224012) in the Department of Civil Engineering, Nnamdi Azikiwe University, Awka, Anambra State.

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APPROVAL PAGE

This research work "Effects of Sand and Chipping Dust on Geotechnical Properties of Laterite" has been assessed and approved by department of civil engineering Nnamdi Azikiwe University.

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DEDICATION

This work is dedicated to Almighty God for the gift of life and also for guiding me through school. I also want to dedicate this work to my father Mr Chidi Ani who served as a real source of inspiration toward my academic pursuit.

ACKNOWLEDGEMENT

Special thanks go to Almighty God for giving me the strength to complete this work and also for His guidance and protection throughout my stay in Nnamdi Azikiwe University.

Also I will like to express my profound gratitude to my dad; Mr Chidi Ani for his moral support, constant prayers throughout my stay in school, special thanks goes also to my siblings Amaka and David for their encouragement during trying times of my academic pursuit.

I want to thank in a very special way, my project supervisor in the person of Engr. Dr. V. O. Okonkwo for his time and guidance in the accomplishment of this project. May the lord rain blessing from heaven for him and his family and may he also protect your family.

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ABSTRACT

The need to ensure that lateritic soils used for the purpose of construction meets the necessary geotechnical requirements for civil engineering application formed the basis for the study. The study was undertaken to evaluate the effect of sand and chipping dust on geotechnical properties of laterite. Laterite was stabilized with sand in an increasing order of 2.5%, 5%, 7.5% and 10% by weight of laterite, the laterite to sand mixture was thereafter stabilized with chipping dust in an increasing order of 2.5%, 5%, 7.5% and 10% by weight of laterite. The specimen was subjected to series of laboratory testing. Some of the tests conducted are: sieve analysis test, specific gravity test, compaction test, atterberg limit (liquid and plastic limit) test and CBR test. Results obtained from sieve analysis test revealed that the chipping dust, laterite and sand were classified as A-2-6, A-6 and A-2-4 according to AASHTO Soil Classification System, SM, CL and SC according to Unified Soil Classification System, the specific gravity of sand, chipping dust and laterite was 2.55, 2.76 and 2.66, the liquid limit, plastic limit and plasticity index of laterite was found to decrease on addition of sand and chipping dust, the maximum dry unit weight of laterite was found to increase on addition of sand and chipping dust while the optimum moisture content was found to decrease on consistent addition of sand and chipping dust to laterite. Results obtained from CBR test revealed that the CBR of laterite increased on consistent addition of sand and chipping dust with the laterite satisfying the criterion for use as sub-base type 1 and 2 material for pavement construction.

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LIST OF SYMBOL & ABBREVIATION

BLA—Bamboo Leaf Ash

BN—Bentonite

LAT--Laterite

G_S – Specific Gravity

AASHTO – American Association of State Highway and Transportation Officials

USCS – Unified Soil Classification System

ASTM – American Society for Testing and Material

BSL – British Standard Light

BSH – British Standard Heavy

MDUW- Maximum Dry Unit Weight

OMC – Optimum Moisture Content

LL – Liquid Limit

PL – Plastic Limit

SL – Shrinkage Limit

PI – Plasticity Index

D_{10} – Particle Size such that 10% is finer than the Size

D_{30}- Particle Size such that 30% is finer than the Size

D_{60}- Particle Size such that 60% is finer than the Size

C_U – Coefficient of Uniformity

C_C – Coefficient of Curvature

SC – Clayey Sand

SM – Silty Sand

GM – Silty Gravel

GC—Clayey Gravel

GW—Well Graded Gravel

GP—Poorly Graded Gravel

SP—Poorly Graded Sand

SW—Well Graded Sand

CL – Inorganic Clay of Low Plasticity (lean clay)

CH—Inorganic Clay of High Plasticity (fat clay)

ML- Silt of low Plasticity

MH – Silt of High Plasticity

LIST OF APPENDICES

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

During the last decade, the global demand for indigenous lateritic soil has continued to increase (Osinubi, 2004). This growing demand has generated interest in the use of this red tropical soil as a road construction material especially in developing countries like Nigeria. There have been innumerable cases of pavement failures in Nigeria roads, which have been largely attributed to the use of laterite as a road construction material. Hence improvement of certain undesirable properties of laterite became necessary as the only cost effective means for better utilization in construction sites. Some of the benefits associated with soil improvement include: increased stability and strength of the soil, reduced compressibility and void ratio. Among various alternative of soil improvement the only economically viable means is the use of suitable material known as stabilizer.

The red tropical soil which is in abundant supply in Nigeria pose a unique challenge as there are instances where this soil may contain substantial amount of clay minerals that it strength and stability cannot be guaranteed under load especially in the presence of moisture. However, the use of this soil as a road construction material is encouraged by the following advantages and they include:

1. Vast abundance of the soil.
2. The relative cheapness of the soil.
3. Reduction in the foreign exchange used in buying imported road construction material.
4. It enhances high rate of road construction.

Despite these advantages, the use of this soil as a road construction material has not been fully utilized. This is simply because there have not been extensive research into ways by which the bearing strength of the soil can be effectively improved and also due to the overdependence on the utilization of industrially manufactured soil improving additives (cement, lime) which have kept the cost of construction of stabilized road financially high.

The increasing growth in population and the corresponding increase in demand for road construction in Nigeria during the last decade have generated increased interest into ways by which the properties of laterite can be improved.

Disposal of waste is a challenge for all developing countries (Nigeria inclusive) mainly due to the increasing generation of waste, the high costs associated to its management and the lack of understanding over a diversity of factors that affect the different stages of waste management Naman, (2015). Chippings dust is also a solid waste material that is generated from stone crushing industry during production of coarse aggregate Naganathan, Ghataora, Chaddock and Blackman, (2017). It is a by-product from crushing process during crushing activities. It is commonly used as sand to make concrete, which are believed to be stronger and more durable than the regular concrete material (Gibson, 2016). Quarry dust have variety of application, it is used as substitute for sand in improving the properties of lateritic soil Soosan, Jose and Abraham, (2001). Sand is natural material with particles sizes up to 2mm. Natural sand are collected in water ways and conform to (BSI, 1992). It does not contain more than a total of 5% by weight of the followings: shale, silt and structurally weak particles (Grow, 1938). Natural sand is readily available and as a result, guarantees economy when used as a stabilizing agent.
In other to improve certain undesirable properties of laterite and tackle problem regarding waste disposal, this study will therefore evaluate the effect of chipping dust and sharp on geotechnical properties of laterite as a road construction material.

1.2 Statement of Problem

In Nigeria, laterite are the most common and effective material used for building, highway pavement and earth dam construction. Lateritic soil ranges in performance from excellent to poor based on their shear strength, reduced compressibility etc. A poor performing laterite will posses low shear strength, high void ratio, low resistance to compressibility (swelling and shrinkage), high permeability and reduced soil density. Pavement distresses have been observed on the road mainly due to the use of poor lateritic material for road construction.

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Naman, (2015). Research on the effect of chipping dust and sharp sand on laterite was only done to a certain extent (as separate entity and not collective) and knowledge gap is one of the problems hampering detailed research work on the use of chipping dust and sharp sand as an additive for improving certain properties of laterite. Therefore this study will sought to find out how laterite stabilized with chipping dust and sharp sand will be beneficial to geotechnical studies and projects.

1.3 Aim and Objectives

The aim of the study is assess the effect of chipping dust and sharp sand on geotechnical properties of laterite. The objectives of the work are:

1. Evaluate the natural properties of laterite
2. Determine the feasibility and efficacy of using chipping dust and sharp sand as an additive for stabilization of laterite.
3. Characterize (classify) the additives (chipping dust and sharp sand) to be used for stabilization of laterite.
4. Study the effect of chipping dust and sharp sand on properties of laterite.
5. Determine the maximum amount of chipping dust and sharp sand required for optimum improvement of laterite.
6. Assess the suitability of the specimen (improved laterite sample) for use as sub-grade, sub-base and base course material respectively.
7. Draw conclusion and make recommendation based on findings.

1.4 Scope of Study

The scope of this study is essentially centered on the use of chipping dust and sharp sand as an additive for improving the geotechnical properties of lateritic soils. The study is limited to analysis of laterite sample collected from ugwuoba and Agu-Awka respectively. The laboratory test to be conducted for both the sample and specimen include: particle size analysis, specific gravity, Atterberg (liquid and plastic limits), compaction and California bearing ratio. During the course of the laboratory testing certain percentage of chipping dust will be varied during the stabilization of laterite sample obtained from different location so as to optimally improve the sample.

1.5 Significance of Study

The need for this study is to provide means for optimum improvement certain undesirable properties of laterite. The findings obtained are however important in the following ways:

1. Provide a lasting solution to constant pavement distresses experienced in highways.
2. Tackle waste disposal problem resulting from high volume of chipping dust produced during quarrying activities.
3. Tackle knowledge gap in material selection for cost effective improvement of lateritic soils.
4. Provide and promote cost effective means of enhancing lateritic soils.
5. Foster infrastructural development through frequent and high level of road construction.
6. Valuable as reference material for geotechnical studies and construction works.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Definition and Origin of Laterite

Lateritic soils are highly weathered and altered residual soils formed by the in-situ weathering and decomposition of parent rocks under tropical and subtropical climatic conditions Aginam, Nwakaire and Nwajuaku, (2015).This weathering process primarily involves the continuous chemical alteration of minerals, the release of iron and aluminum oxides and the removal of bases and silica in the rocks. Lateritic soils are void or nearly void of bases primarily silicates, but may contain substantial amount of quartz and kaolinite (Alexander & cady, 1962). They are formed in hot, wet tropical regions with an annual rainfall of at least 1200mm and a daily temperature in excess of 25^oC and typically occur in humid tropical climate with 30^{o}N and 30^{o}S of the equator (Madu, 1975).They are also composed entirely of iron and aluminum oxide. They are reddish in colour and are the least soluble of rock weathering in tropical climate (Plummer, et al 2001). Laterite is also described as a product of in-situ weathering in igneous, sedimentary and metamorphic rocks commonly found under unsaturated conditions Rhardjo, Aung, Leong and Rezam, (2004). Lateritic soil is one of the most common and important material used in earth work engineering construction in the tropics and subtropics where it is in abundance.

The name laterite was coined by an English surgeon Francis Buchanan in 1807 in India from a Latin word “later” meaning brick. In the 19th century, He coined the term laterite when he wrote “What I have called indurate clay is one of the most valuable material for building. It is diffused in immense masses without any appearance of stratification and is placed over the granite that forms the bases of Malayala. It is full of cavities and pores and contains a very large quantity of quartz in the form of yellow and red ochres In the masses, while excluded from the air It is so soft, that any iron instrument readily cut it, and it is dug up in square masses with a pick-axle, and immediately cut into shape wanted with a trowel or large knife. It very soon become as hard as brick, and resists the air and water much better than materials made from bricks. The most proper English name would be laterite, from lateritis, the appellation that may be given to it in sciences”. Since then lot of researches have been carried out on laterite and a lot of terms referring to many soil types have been produced. There is a tendency to apply the term to any red soil and rocks in the tropics (Abebaw, 2005). Nearly all kind of rock can be deeply decomposed by action of high rainfall and elevated temperature. The percolating rainwater causes dissolution of primary rock material and a decrease of soluble elements such as sodium, potassium, calcium and magnesium. As a result, there remain a residual concentration of insoluble element predominantly iron and aluminum. In geosciences, only those weathered products that are most strongly altered geochemically and mineralogically are termed laterite.

2.2 Formation of Laterite

Tuncer and Lohnes, (1987) described the genesis of laterite as the weathering process which involves leaching of silica, formation of colloidal oxide and precipitation of the oxide with increasing crystallinity and dehydration as the soil is weathered. The major processes of weathering are physical, chemical and biological process. The physical weathering is predominant in the dry climate while the extent and rate of chemical weathering is largely controlled by the availability of moisture and temperature (Abebaw, 2005). As the disintegration of underlying rock occurs, the primary element are broken down by the process of physical and chemical weathering to simple ionic form. The silica and bases in the weathered material such as sodium, potassium, calcium and magnesium are washed out by the percolated rain water (verdose water), boxides and hydroxides of sesquioxide are accumulated thereby enriching the soil and giving the soil it's characteristic red colour. This process is termed laterization and it depends on the nature and extent of chemical weathering.

Laterization is the weathering process by which the rock is transformed into laterite. It is a gradual process which must be active for centuries. In tropical countries the "verdose water" is at high temperature and as a result they may contain more carbonic acids, alkaline, carbonates and organic matter. This element explains why rocks that are leached by verdose water are commonly found in tropical countries than in temperate ones. After weathering, dehydration occurs. Dehydration (either partial or complete) alters the composition and distribution of the sesquioxide rich material in a manner which is generally not reversible over wetting (Abebaw, 2005). It leads to the formation of strongly cemented soil with a unique granular soil structure. The topography and drainage of an area also influences the rate of weathering because to some extent, it determines the amount of water available for laterization to occur and the rate at which it moves through the weathering zone. The rate at which weathered material is eroded is also controlled.

Deep weathering cannot occur on steep slopes this is because the surface run-off on steep slopes is greater than the rate of infiltration thereby increasing the rate of erosion. Hence lateritic soils tend to be found on slopes (sometimes locally termed ridge gravel), to a lesser extent on uplands and rarely in poorly drained areas (Jiregna, 2008). The structure of Lateritic soil varies with the type of parent rock from which it was formed ,the location (i.e where it was formed),and also the weathering process that lead to its formation. Studies in some lateritic soils shows that they have porous granular structure consisting of iron impregnated clayey material in minute spherical aggregation (Hamilton, 1964).The aggregation derives its strength from the film found within the micro-joints of the elementary clay particles, which in addition coats the particles (Gidigasu, 1988).Thus the film found the micro joints of the elementary clay particles and as coatings over particles provides the strength of aggregation. Viewing carefully prepared thin sections of laterite under the optical microscope has shown that these soils contain rough materials with sizes tending from silt to fine sand spread throughout the soil with very finely-divided iron oxide, and a porous structure of peds or clay clusters which are usually not cemented by coatings of iron oxide but rather, they are weakly bonded. The surface of laterite soil initially exists as a gelatinous coating. After losing moisture, it becomes denser but retains its non-crystalline structure after which it crystallizes slowly into different forms, which gives them strongly cemented surfaces covered by iron oxides (Sergeyev et al, 1978). The structural development depends on the deposition of iron oxides at different stages of weathering process.

Lateritic soil chemistry and mineralogy as shown by studies greatly influence the geotechnical properties, and in certain circumstances, significantly affects the economic potential in the construction industry (Ogunsanwo, 1995). Studies by (Tuncer and Lohnes, 1977) also revealed that the degree of weathering is very well connected with the mineralogy of laterite, as the kaolinite content is high in the early stage of weathering and decrease with increase in weathering ,where as the amount of sesquioxide increases. The soil profile of laterite is defined as that in which laterite horizon exists or is capable of developing under favorable conditions (Ikiensinma, 1998). The alteration of rock by the processes of chemical weathering take place progressively through a series of events and stages which result in a profile of weathering.

Lateritic gravels stand out as low humps in the terrain. They consist of gravel sized concretionary nodules in a matrix of silt and clay. They may take up an area of several hectares and a thickness of between 1 to 5m (Jiregna, 2008).

2.3 Properties of Laterite

2.3.1 Chemical Properties

(Mallet, 1883) was perhaps the first to introduce the chemical concept for establishing the ferruginous and aluminum nature of lateritic soils. (Fermor, 1990) defined various forms of lateritic soils on the basis of the relative contents of the so-called lateritic constituents (Iron, Aluminum, Titanium, and Manganese) in relation to silica. Also, (Lacroix1998) divided laterite into:-true laterite, silicate laterite, and lateritic clays depending on the relative content of the hydroixides. There are other several attempts by the researchers to classify laterite in terms of their chemical compositions, but (Fox, 1986) has demonstrated that such classification are inadequate, other than in relations to deposits that may be exploited for their mineral content, classification based on chemical composition cannot be used to distinguish between indurate and softer formations.

The high content of the sesquioxides of iron or aluminum relative to other components is a feature of laterite. These essential components are mixed in variable proportions. Some laterite may contain more than 80% of Fe_2O_3 and little of Al_2O_3, While others may contain up to 60% of Al_2O_3 and a little of Fe_2O_3. Although alkali and alkaline bases are almost entirely absent in most cases, this is not an absolute criterion. In particular, some ferruginous tropical soils may contain significant amounts of alkaline bases. Combined silica content is low in sesquioxides. This combined silica is predominantly in the form of Kaolinite, the characteristic clay mineral of most tropical formation.

2.3.2 Physical Properties

The physical properties of residual soils, commonly known as the index properties, vary from region to region due to their heterogeneous nature and highly variable degree of weathering controlled by regional climate and topographic conditions, and the nature of bedrock, (Nnadi, 1988). It also varies with the depth of the soil and can be determined by simple laboratory tests. Studies on the effect of weathering on the physical properties of lateritic soil by (Tuncer et al, 1977 and Rahardjo, 2004) have revealed the following:

1 Pore-size distribution varies with the degree of weathering.
2 Higher pore volume and larger range of pore-size distribution indicates advancement in the weathering stage.
3 Soil classification and Atterberg limits do not show any correlation to weathering.
4 High specific gravity is a good indication of advanced degree of weathering.
5 Soil aggregation increases with increasing weathering.
6 Position in the topographical site, and depth of soil in the profile.
7 Genesis and pedological factors (parent material, climate, vegetation, period of time in which the process has operated).

2.3.3 Plasticity

Textural lateritic soils are very variable and may contain all fractions sizes; boulders, cobbles, gravel, sand, silt, and clay as well as concretionary rocks. The interaction of the soil particles at the micro scale is reflected in the atterberg limits of the soil at micro scale level. Knowledge of the atterberg limits may provide the following information:

1. A basis for identification and classification of a given soil texture.
2. Strength and compressibility characteristics swell potential of the soil or the water holding capacity.

Atterberg limit depends on:

1. The clay content**:** plasticity increases with increase in clay content (Piaskowski, 1963).
2. Nature of soil minerals**:** only minerals with sheet-like or plate-like structures exhibit plasticity. This is attributed to the high specific surface areas and hence the increased contact in the shaped particles.
3. Chemical composition of the soil environment**:** the absorptive capacity of the colloidal surface of the actions and water molecules decrease as the ratio of silica to sesquioxides decreases (Baver, 1980).

4. Nature of exchangeable actions**:** this has a considerable influence upon the soil plasticity (Hough, 1989).

Pre-test preparation, degree of molding and time of mixing, dry and re-wetting, and irreversible changes may affect the plasticity of soil. Drying drives off absorbed water, which is not completely regained, on re-wetting (Fookes, 1997).Studies on the relationship between the natural moisture content, liquid limits and plastic limits of laterite have shown that generally the natural moisture contents is less than the plastic limit in normal lateritic soils (Vargas, 1953). However, the lateritic soil from high rain fall areas may have moisture contents as high as the liquid limit (Hirashima, 1979).

2.3.4 Particle Size Distribution

Consequently great importance has also been accorded to particle-size distribution in dealing with lateritic soils. Recent studies have revealed that lateritic soils are strikingly different from temperate zone soils in terms of genesis and structure. Their concretionary structure as compared to the dispersed temperate zone soils has necessitated modifications to mechanical or grading tests (Remillion, 1967; 1955). Consistent reports of variations in the particle-size distribution with methods of pretreatment and testing have been widely reported on laterite soils. Schofield (1957) found out that wet sieving increased the silt and clay fraction from 7 to 20% as compared to the dry sieving. It has been found that sodium hexametaphosphate generally gives better dispersion of the fine fractions. It was also found, for example, that using sodium oxalate on a halloysitic clay from Kenya gave between 20 and 30% clay fraction, while the sodium hexametaphosphate gave as high as between 40 to 50% clay fraction for the same soil (Quinones, 1963).

Another factor which has been found to affect the sedimentation test is the method of drying. Oven-dried lateritic soils were found to give the least amount of clay fraction, as compared to air-dried (Mohr and Mazhar, 1969). The decrease in the clay content was accompanied by an increase in silt and sand fraction contents as a result of the cementation and coagulation of the clay particles by free iron oxide into clusters (Terzaghi, 1958). The variation in the grading of lateritic gravels with the method of manipulation is also widely reported (Novais-Ferreira and Correia 1965 and Nascimento et al., 1959). In the study of the particle-size distribution of lateritic soils, three sources of confusion were noted. The first confusion arises from the belief by some authors, e.g. Bawa (1957), opined that lateritic soils represent a group of materials that can be defined within a specific range of particle-size distribution. The second source of confusion seems to arise out of attempts by some authors to confine the word laterite to concretionary lateritic gravels. The third source of confusion arises out of the attachment of unnecessary importance to the soil colour. (Nascimento et al. 1959) have suggested an interesting lithological classification of lateritic soils as follows:

Lateritic clays <0.002 mm

Lateritic silts =0.002 - 0.06 mm

Lateritic sands ~0.06- 2 mm

Lateritic gravel =2 - 60 mm

Laterite stones and cuirasse ≥ 60 mm

Studies on lateritic gravels by de Graft-Johnson and Bhatia, (1969) among others have shown that the grading, though important for identification purposes, cannot alone form the basis for grouping lateritic gravels in terms of mechanical properties. The strength of the aggregates was found to be an important factor. Studies of lateritic aggregates in Nigeria, has also established that the strength of the aggregates is mainly a function of the degree of maturity of the lateritic concretionary particles and the predominant sesquioxide in the aggregates (Novais-Ferreira et al, 1993).

2.3.5 Compaction Characteristics

The compaction characteristics of lateritic soils are determined by their grading characteristics and plasticity of fines. Most lateritic soils contain a mixture of quartz and concretionary coarse particles, which may vary from very hard to very soft. The strength of these particles has major implications in terms of field and laboratory compaction results and their subsequent performance in civil engineering construction projects. Placement variables (moisture content, amount of compaction, and type of compaction efforts) also influence the compaction characteristics. Varying each of these placement variables has an effect on permeability, compressibility, strength and stress-strain characteristics of the soil.

2.3.6 Shear Strength Characteristics

Shear strength is a term used in soil mechanics to describe the magnitude of the shear stress that a soil can sustain. The shear strength of a lateritic soil is a function of the friction and interlocking of particles (soil angle of internal friction) and possibly cementation or bonding at particle contact relative to total and effective stress. Due to cohesion, particulate materials may expand or contract in volume as it is subject to shear strains. If soil expands in volume, the density of particles will decrease and the strength will decrease likewise the shear strength.

The cohesion is attributable to the resultant of inter particle forces which are mainly associated with the clay-size particle of soils and will vary with the particle size and the distance separating them. The angle of internal friction included the effect of interlocking. The interlocking effect is affected to some degree by the shape of particles and the grain–size distribution. The two parameters cohesion (**c**) and angle of friction (ø) depends on the grading, particle shape and void ratio factors of the soil. Cohesion also depends on degree of saturation, while angle of internal friction does not (Gidigasu, 1976).

The shear strength characteristics of lateritic soils have been found to depend significantly on the parent materials, and the degree of weathering which in turn depends on the position of the sample in the soil profile and compositional factors as well as the pretest preparation of the samples Lohnes, Fish and Demirel, (1971).

2.3.7 Compressibility and Consolidation Characteristics

When a soil mass is subjected to a compressive force, its volume decreases. The property of the soil due to which it decrease in volume occurs under compressive force is known as the compressibility of soil. The compression of soil can occur due to;

1. Compression of solid particles and water in the void
2. Compression and expulsion of air in the void
3. Expulsion of water in the voids

The compression of saturated soil under a steady static pressure is known as consolidation. It is entirely due to expulsion of water from the voids. The consolidation characteristics of lateritic soils is generally moderate with the modulus of compressibility ranging between 1 x 10^{-3} to 1×10^{-2} sq. ft./ton.

2.3.8 Specific Gravity

The available data indicate that specific gravities vary not only with the textural soil groups but also within different fractions. In the first place lateritic soils have been found to have very high specific gravities of between 2.6 to 3.4 (de Graft-Johnson and Bhatia, 1969). For the same soil, gravel fractions were found to have higher specific gravities than fine fractions due to the concentration of iron oxide in the gravel fraction. While alumina is concentrated in the silt and clay fractions (Nascimento et al., 1959; Novais-Ferreira and Correia, 1965). It is common to find specific gravities reported for the gravel and fines separately. The average of the two values can be assumed to be more representative of the specific gravity for the whole soil.

2.4 Stabilization

Soil stabilization is not new, but man has sought to accomplish it by various means almost since the first roads were built, but it is only in recent years that scientific methods has been applied to soil stabilization. Soil stabilization may be defined as the alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of a soil.

Stabilization, in a broad sense, incorporates the various methods employed for modifying the properties of a soil to improve its engineering performance. Soil stabilization refers to the procedure in which a special soil, cementing material, or other chemical materials are added to a natural soil to improve one or more of its properties. It may also be defined as the process of blending and mixing materials with a soil so as to improve certain properties of the soil. A stabilized material may be considered as a combination of binder soil and aggregates preferably obtained at or near the site of stabilization manipulated and treated with or without admixtures, and compacted so that it will remain in its compacted state without detrimental change in shape or volume under applied force or exposure to weather.

One may achieve stabilization by mechanically mixing the natural soil and stabilizing material together so as to achieve a homogeneous mixture or by adding stabilizing material to an undisturbed soil deposit and obtaining interaction by letting it permeate through soil voids Perloff, (1976). Soil stabilizing additives are used to improve the properties of less-desirable rood soils. When used these stabilizing agents can improve and maintain soil moisture content, increase soil particle cohesion and serve as cementing and water proofing agents Janathan, Sandersand and Chernerd, (2004). A difficult problem in civil engineering works exists when the sub-grade is found to be clay soil. Soils having high clay content have the tendency to swell when their moisture content is allowed to increase (Chen, 1981). Many research have been done on the subject of soil stabilization using various additives, the most common methods of soil stabilization of clay soils in pavement work are cement and lime stabilization. The high strengths obtained from cement and lime stabilization may not always be required, however, and there is justification for seeking cheaper additives which may be used to alter the soil properties. Lime or calcium carbonate is oldest traditional chemical stabilizer used for soil stabilization..

2.4.1 Methods of Soil Stabilization

In road construction projects, soil or gravelly material is used as the road main body in pavement layers. To have required strength against tensile stresses and strains spectrum, the soil used for constructing pavement should have special specification. Through soil stabilization, unbound materials can be stabilized with cementitious materials (cement, lime, fly ash, bitumen or combination of these). The stabilized soil materials have a higher strength, lower permeability and lower compressibility than the native soil (Keller, 2011). The method can be achieved in two ways, namely:

1. In-situ soil stabilization
2. Ex-situ soil stabilization

Stabilization is not necessary a magic wand by which every soil properties can be improved for better. The decision to technological usage depends on which soil properties have to be modified. The chief properties of soil which are of interest to engineers are volume stability, strength, compressibility, permeability and durability (Sherwood, 1993: Altabba and Evans, 2005). Some stabilization technique includes mechanical and chemical stabilization.

2.4.1.1 Mechanical Stabilization

Mechanical Stabilization is the process of improving the properties of the soil by changing its gradation. This process includes soil compaction and densification by application of mechanical energy using various sorts of rollers, rammers, vibration techniques and sometime blasting. The stability of the soil in this method relies on the inherent properties of the soil material. Two or more types of natural soils are mixed to obtain a composite material which is superior to any of its components. Mechanical stabilization is accomplished by mixing or blending soils of two or more gradations to obtain a material meeting the required specification.

2.4.1.2 Chemical Stabilization

In order to improve the properties of expansive soil, a combination of chemical stabilizers such as cement, fly ash, and lime with chloride or individually can be used. About replacing soil particles to meet more stable soil structure, there are two main methods. Firstly, increasing the particle size by cementation to produce an increment in shear strength, reduction in plasticity index, and reduction in expansion potential. Secondly, improve the compaction and physical properties of the soil by using absorption and chemical binding of moisture (Onyelowe & Chibuzor, 2012).

2.4.1.3 Types of Additives used in Soil Stabilization

There are many additives that have been used to improve the engineering properties of expansive soil. These additives can be classified as waste materials such as dust, agricultural wastes, synthetic wastes, and organic wastes to enhance the economic cost.

Table 2.1: Additives Employed in Soil Stabilization (Salem, 2018).

Industrial Solid Waste	Agricultural Solid Waste	Domestic Solid Waste	Mineral Solid Waste
Fly Ash	Rice Husk Ash	Incinerator Ash	Quarry Dust, Stone Dust or Chipping Dust
Cement Kiln Ash	Bagasse Ash	Waste Tire	Marble Dust
Silica Fume	Groundnut Shell Ash	Egg Shell Powder	Limestone Dust
Copper Slag	Plantain Peel Ash	Grain Storage Dust	Granite Dust
Granulated Blast Furnace Slag	Banana Leaf Ash	Glass Cullet	Mine Tailings
	Concob Ash		Baryte

Phosphogypsum			
Ceramic Dust	Wheat Husk		
Brick Dust	Olive Cake Residue		

2.5 Chippings Dust

Chipping dust, also referred to as mechanical sand is defined as residue, tailing or other non-voluble waste material after the extraction and processing of rocks from quarries to form fine particles with less than 4.75mm diameter. Out of the different chipping wastes, chipping dust is produced in abundance; making up about 25% of the output of each crusher unit (Sarvade and Nayak, 2014). Chipping dust is a byproduct from the crushing process of stone (blue metal) which is found abundantly from rock quarries at low cost. They are residue left after the extraction and processing of rocks to form fine particles less than 4.75mm Ilangovan, Mahaendran and Nagamani, (2008). Chippings dust has been proposed as an alternative to river sand that gives additional benefit to concrete as it is known to increase the strength of concrete over concrete made with equal quantities of river sand, thou it causes a reduction in the workability of concrete Ukpata, Ephraim and Akeke, (2012). Chipping dust which is considered as a waste material causes an environmental due to disposal problem. As a result of foregoing problem, the use of chipping dust as an additive for the stabilization of laterite became necessary as this will reduce the environmental load thereby enhancing environmental sustainability and ensuring a cost effective means of road construction which will invariably enhance high rate of flexible pavement construction.

2.5 Studies on Effect of Chipping Dust on Properties of Laterite

Roobhakhshan and Kalantari (2013) conducted consistency limit, standard compaction test, unconfined compressive test and CBR test and deduced that there is remarkable influence on strength and CBR value at 1% lime + 6% waste stone powder for CBR and 7% lime + 6% waste stone powder for U.C.S which are optimum percentage.

Sabat (2012) conducted series of tests and concluded that addition of chipping dust decreases Liquid limit, Plastic limit, Plasticity index, Optimum moisture content, Cohesion and increases shrinkage limit, Maximum dry density, Angle of internal friction of expansive soil.

Satyanarayana, Raghu, Kumar and Pradeep, (2013) conducted plasticity, compaction and strength tests on gravel soil with various percentage of chipping dust and found that by addition of stone dust plasticity characteristics were reduced and CBR of the mixes improved. Addition of 25-35% of chipping dust makes the gravel soil meet the specification for use as sub-base material.

Ali and Koranne (2011) presented the results of an experimental programme undertaken to investigate the effect of chipping dust and fly ash mixing in different percentages on expansive soil. They observed that at optimum percentages, i.e., 20 to 30% of admixture, the swelling of expansive clay is almost controlled and there is a marked improvement in other properties of the soil as well. It is concluded by them that the combination of equal proportion of chipping dust and fly ash is more effective than the addition of stone dust/fly ash alone to the expansive soil in controlling the swelling nature.

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

Jayapal (2014) had studied the stabilization of clay with chipping dust for using in flexible pavement. The tests which were carried out in this study are sieve analysis, Atterberg limit, Modified Proctor Compaction (MPC), California Bearing Ratio (CBR) and Differential Free Swell (DFS). The proportion of chipping dust that was used was 0, 10, 20, 30, 40, 50, and 60% of soil weight. Atterberg limit results showed high decrement in liquid limit and plasticity index up to 50%, at 0% addition of chippings dust liquid limit pointed 55.3% while with addition of 60% of chipping dust pointed 24.2%, on the other hand, plasticity index with 0% addition was pointed 38.9% but with addition 60% chipping dust showed significant decrement of 2.7%. Maximum dry density (MDD) was increased from 1.87 to 2g/cc at addition of 0 to 60%

respectively; furthermore, the optimum moisture content was decreased from 12.7% to 8.75% at addition of 0% to 60% respectively. For California Bearing Ratio and Differential Free Swell at 0, 10, 20, 30, 40, 50 and 60 % of addition chipping dust the California Bearing Ratio value increased respectively from 4.9% at 0% addition to 22.84% at 60% addition, on the other hand, Differential Free Swell decreased from 58.70 at 0% to 17.75% at 60% portion additives.

Jayapal and Sanders, (2014) had studied the stabilization of expansive soil by using three mixtures consisting of chipping dust, fly ash, and lime. The tests that were used are Atterberg limits, Modified Proctor Compaction (MPC), California Bearing Ratio (CBR) and Deferential Free Swelling (DFS). When chipping dust of 10, 20, and 30% were added there was a reduction in plasticity index, on the other hand when fly ash added with the same percentage plasticity index was reduced too. For modified Proctor compaction by adding quarry dust at 10, 20, and 30% the Maximum Dry Density (MDD) was increased and the Optimum Water Content (OWC) was decreased. For CBR and DFS when the soil was in its natural status CBR value was 5.29% and DFS was 93.3%, furthermore, when quarry dust was added the value of CBR was increased respectively according to the percentages used and reached 18.55% at 30% addition, on the other hand, DFS were decreased respectively according to the percentage used and reached 35.6% at 30% addition.

Shanker and Ali (1992) studied the engineering properties of chipping dust and reported that chipping dust can be employed as alternative material to river sand in concrete based on grain size analysis. Rao and Anda, (1996) discovered improved compaction characteristics of rockcrete consisting of chipping dust and coarse aggregate (rock chips) over river sand moulds (sandcrete). Soosan and Jose, (2011) observed that chipping dust exhibit high shear strength which improves the geotechnical properties of moulds in which they are employed. Sridharan, Soosan and Babu, (2006) conducted studies on the shear strength of soil-chipping dust mixtures. The results showed that the chipping dust proved to be a promising substitute for sand and can be used to improve the engineering properties of soils. The dry density increased with the addition of chipping dust with attendant decrease in the optimum moisture content.

Sridharan and Soosan, (2005) also conducted another study on the effect of chipping dust on the geotechnical properties of soil used in highway construction and concluded that the CBR value steadily increased with increase in percentage of chipping dust.

2.6 Fine Aggregate (Sand)

Aggregates are generally divided into two groups: Fine and Coarse. Fine aggregate consists of natural or manufactured sand with particles sizes up to 5mm. It consists of inert natural sand conforming to (BSI, 1992). It does not contain more than a total of 5% by weight of the followings: shale, silt and structurally weak particles (Grow, 1938).

Aggregates make up or occupy 60% to 80% of concrete volume making its selection highly important (Neville, 2000). Aggregate should consist of particles with adequate strength and resistance to exposure condition and should not contain materials that will cause deterioration of concrete. All natural aggregate particles originally formed a part of a larger parent mass. This may have been fragmented by natural processes of weathering and abrasion or artificially by crushing. Thus, many properties of the aggregate depend entirely on the properties of the parent rock, for example, chemical and mineral composition, petrologic character, specific gravity, hardness, strength, physical and chemical stability, pore structure and colour (Neville, 1981). Fine aggregates provide support function to the finer solids by producing voids of a size which do no contain or support the finer particles. Particle shape affects the behaviour of the water, harsh angular aggregates not packing well and resulting in high void content (Neville, 1979). Such aggregates may have a high surface area, but because of a lack of contact between the particles, it does not effectively control the finer particles. Smooth rounded aggregates have the disadvantage that, although theoretically it should pack together and produce low voids, this situation does not necessarily occur in a graded material of this type.

Aggregates for mortar must be clean, sharp and free from salt and organic contamination. Most natural aggregates contain a small quantity of silt or clay. A small quantity of silt improves workability. Marine or estuarine aggregate should not be used unless washed completely to remove the magnesium and sodium chloride salts which are deliquescent and attract moisture Hendry, Sinha and Davies, (1987). The most suitable aggregate would appear to be one that is well graded with a balance between rounded and angular particles and a surface texture that is not too smooth. In practice it has been found that a natural river aggregate with a grading complying with (BSI, 1992) is the most suitable. Sea-dredged and crushed aggregates produce more extreme types, either all smooth and rounded or harsh and angular and generally requiring greater care in design.

The realization of the usefulness and effect of fine aggregate on the strength of lateritic soils used as a road construction material has put into the minds of Engineers and researchers to lay more emphasis into the study of its properties and usefulness. Emphasis is made on such properties like bulk density, specific gravity, silt content and particle size distribution.

2.6.1 Previous Works on Effect of Sand on Properties of Laterite

Azu, (2018) conducted a study on evaluation of the strength of sand stabilized laterite. The laterite used for the study was stabilized with 2%, 4%, 6% and 8% sharp sand by weight of the soils. The results obtained shows an improvement in CBR values for sample A and the optimum sharp sand content should be 2% of weight of dry soil while that of sample B is 4% of dry weight of soil with CBR of 31.08% and 36.10% respectively.

Osinubi, (2004) conducted an experimental study on effect of sand on geotechnical properties of laterite. From the findings, it was deduced that the maximum dry density (MDD) and California Bearing Ratio (CBR) improved.

This study will explore the use of sharp sand as an additive in improving the properties of laterite by varying the percentage of sharp sand so as to establish optimum level at which there is a visible improvement in undesirable properties of laterite.

CHAPTER THREE

MATERIALS AND METHODS

The section describes the material, sampling procedure, preservation and methods employed to achieve the research goal. The samples were obtained in accordance with sampling procedure described in clause 5.2 of BS 812-102: 1984 while the test was conducted in accordance with BS 1377 (1990). Below is a description of sampling procedures, preparation and methods.

3.1 Collection and Preparation of Sample

Natural reddish brown lateritic soil samples designated as LAT were obtained at consistent depth from borrow pits at Enugu-Agidi located in Anambra State, Nigeria, along Enugu-Onitsha Express way. The chipping dust was obtained at Infrastructure Development Company (IDC) located along Enugu to Onitsha Express way. Sharp Sand designated as SS was collected at a construction site in Nnamdi Azikiwe University Campus, Awka Anambra State Nigeria. The choice of sites for collection of the laterite sample was justified by the fact that it is a borrow pits where most construction companies situated in Anambra State obtain their materials for building and road construction .The laterite sample was collected with the aid of a digger and a shovel at a depth of 300mm.The samples passed all the physical test that could classify them as lateritic soils in that, it is reddish-brown in colour, fine grained in texture and could become hard during the dry season. These samples were collected in four cement bags each and were conveyed school laboratory for various laboratory testing. The in-situ moisture content of the sample on arrival was determined using oven-dried method before air-drying for a period of two weeks in an open area using corrugated roofing sheets (commonly known as zinc) so as to ensure complete and even dissipation of moisture from the samples. Upon drying, the sample was segregated by means of crushing. The crushing was done through the use of wooden mortar and pestle. Enough care was exercised to ensure that the individual particles were not crushed into smaller sizes. This was achieved by pressing the pestle on the sample agglomerate and not pounding the soil with the pestle.

The chippings dust sample passed all the necessary physical test in that, it has high crushing strength, it is relatively small in size (less than 4.75mm) and is a representative of granite (finer fraction) while sharp sand was gritty when touched with the individual particles been visible to the naked eyes. The chippings dust and sharp sand was collected in one and half cement bag respectively and were conveyed to the Civil Engineering Department Laboratory, Nnamdi Azikiwe University Awka, Anambra State, Nigeria. The additives (sand and chipping dust) were also air-dried using corrugated roofing sheet so as to expel any moisture present.

3.2 Mix Proportion

The natural laterite sample obtained from Enugu-Agidi was stabilized by adding sand by weight at intervals of 2.5%, 5%, 7.5% and 10% by dry weight of laterite while chipping dust will be added at similar intervals by weight of dry laterite sample cumulating to a total of twenty-five mix combinations. The specimen (natural laterite samples stabilized with sand and chipping dust) will be subjected to Atterberg limit (liquid and plastic limit) test, Compaction and California bearing ratio test. Table 3.1 present the percentage replacement of natural laterite samples using sand and chipping dust.

Table 3.1: Mix proportion of Laterite stabilized with Sand and Chipping Dust.

% of Sand/% of Chipping Dust	0	2.5	5	7.5	10
0					
2.5					
5					
7.5					
10					

3.3 Methods of Study

The research demands a series of Civil Engineering Testing that would aid in evaluating the effect of sand and chipping dust on geotechnical properties of laterite. The tests were conducted in accordance with BS 1377 (1990). The index properties of the natural laterite sample, chipping dust and sand will be determined while laterite stabilized with sand, chipping dust and a blend of sand and chipping dust will be subjected to compaction and California bearing ratio test. The lists of civil engineering test to be conducted are as follows

3.3.1 Particle Size Distribution (Sieve Analysis)

Sieve analysis is a procedure used to assess the particle size distribution of a granular material (sand, gravel). The size distribution is often of critical importance to the behaviour of the material during use. Sieve analysis can performed on any type of non-organic or organic granular material including sand, crushed rock, clay, granite, feldspar and a wide range of manufactured powders, grains and seed down to minimum size depending on the exact method. The standard grain size analysis test determines the relative proportion of different grain sizes as they are distributed among certain size ranges.

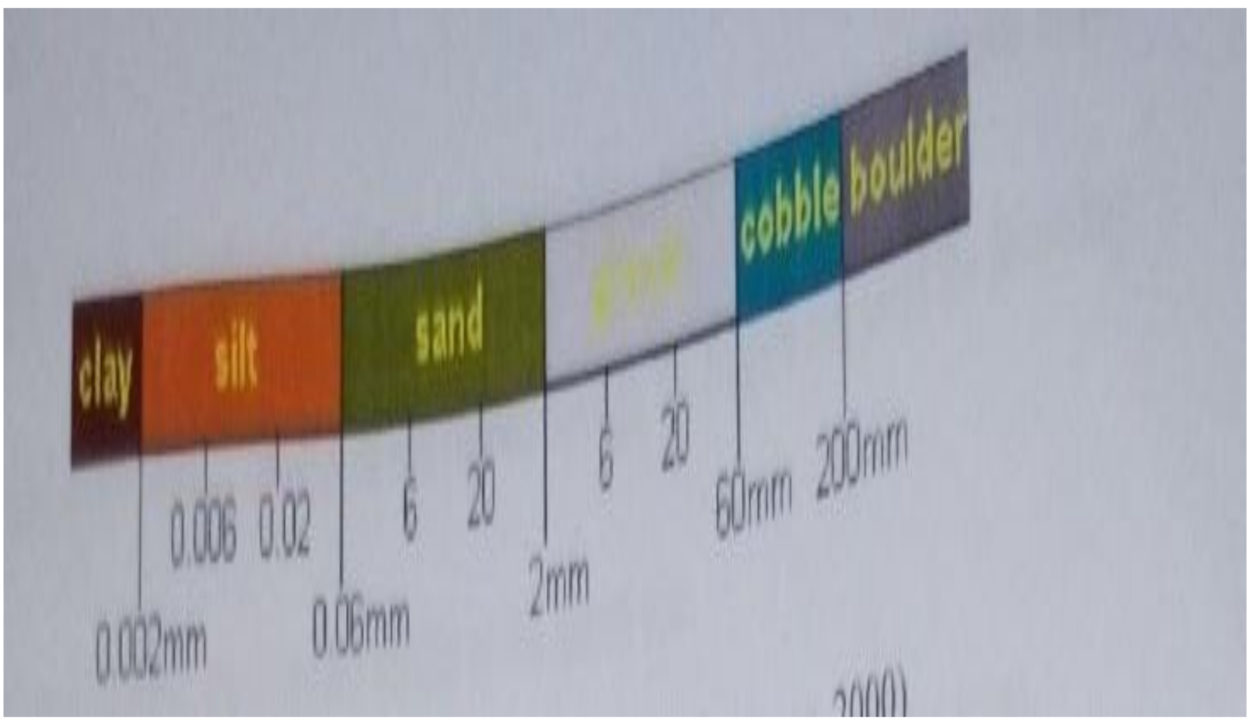

Plate 3.1 Ranges for grain Sizes of different Soil type (Courtesy of Atkinson, 2000).

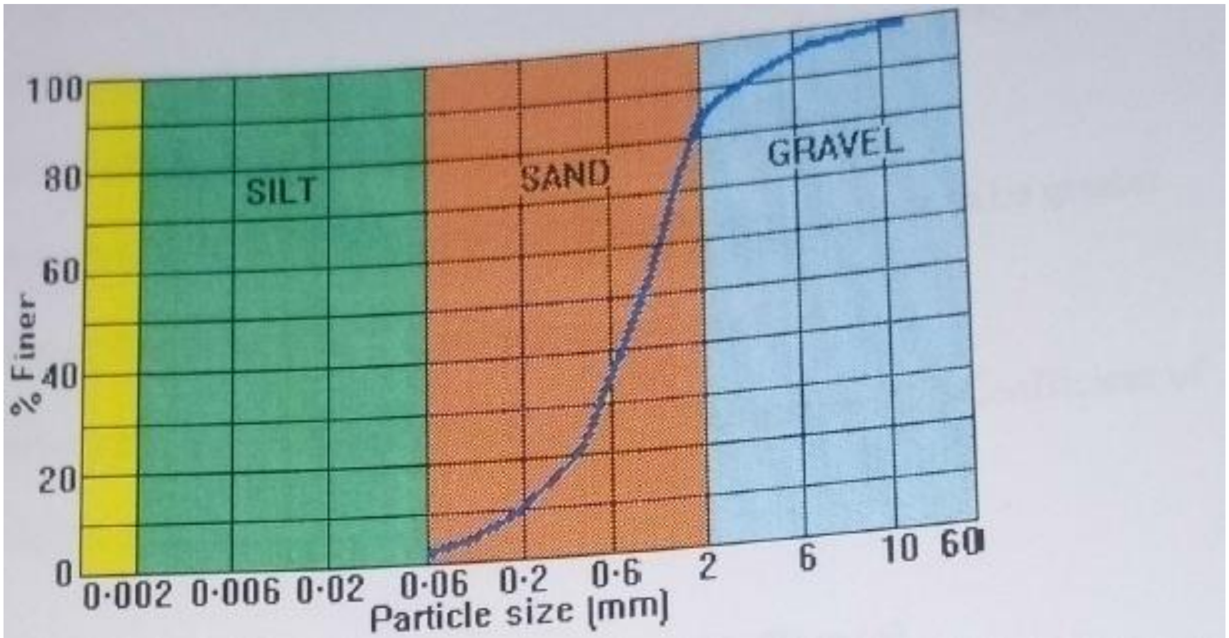

Plate 3.2 Grading Curve Ranges for Different Soil Types (Courtesy of Atkinson, 2000).

Soil posses a number of physical characteristics which can be used as aid to identify it sizes in the field. A handful of soil rubbed through the finger can yield the following:

1. Sand and other coarser particle are visible to the naked eye.
2. Silt particle becomes dusty and are easily brushed off.
3. Clay particle are greasy and sticky when wet and hard when dry and have to be scrapped or washed off hand and boot

For a soil to be well graded the value of coefficient of uniformity (Cu) has to be greater than 4 and 6 for gravel and sand respectively, while the Coefficient of Curvature (C_v) should be in the range of 1 to 3.

The apparatus needed for this experiment is listed below:

1. Stack of sieves including pan and cover.
2. Mechanical sieve shaker.
3. Weighing balance of 0.01g sensitivity.
4. Hand brush
5. Mortar and pestle (Used for crushing if the sample is conglomerated or lumped)

6. Thermostatically controlled Oven (With temperature of about $80^{O}C$-$110^{O}C$).
7. Masking tape for identification of sample.
8. Exercise book and pen for recording of result.
9. The calculation for attaining Coefficient of uniformity and Coefficient of curvature are outlined below.

Percentage retained (%) = $\frac{mass\ of\ soil\ retained\ in\ the\ sieve(g)}{total\ mass\ of\ soil\ sample(g)} \times 100$

Cumulative percentage retained = $\sum Percentage\ retained$ (%)

Cumulative Percentage Finer (%) = 100-Cummulative percentage retained.

Coefficient of Curvature = $\frac{D60}{D10}$

Coefficient of Uniformity = $\frac{(D30)2}{D10 \times D60}$

Where

D10= particle size such that 10% of the soil is finer than the size

D30= particle size such that 30% of the soil is finer than the size.

D60= particle size such that 60% of the soil is finer than the size**.**

Test Procedure

1. The stack of sieves to be used for the experiment was properly cleaned using hand brush.
2. About 500g of air-dried soil sample was weighed with the aid of a weighing balance.
3. The weighed soil sample was poured into 75um sieve and wash under a steady supply of water until clear water start coming out from the sieve after passing through the soil sample.
4. After washing pour the washed soil sample into a pre-weighed plate and dry it inside the thermostatically controlled oven at a controlled temperature of 80-$110^{O}C$ for 16-24hrs.
5. The sample was removed from the oven and the weight was determine (net weight) by deducting the weight of plate from the weight of plate and soil.

6. The stacks of sieve was arranged in the ascending order, placed in a mechanical sieve shaker, and thereafter the sample was poured and connected to the shaker for about 10-15 minute.
7. The sieve shaker was disconnected and the mass retained on each of the sieve sizes was determined.
8. The percentage retained, Cumulative percentage retained and Cumulative percentage finer was determined.
9. The graph of sieve Cumulative percentage finer against sieve sizes was plotted.
10. D10, D30 and D60 were determined from the plotted graph.
11. The Coefficient of Curvature and Coefficient of Uniformity was determined and used to classify the soil adopting the American Association of State Highway and Transportation Official (AASHTO) and Unified Soil Classification System (USCS) respectively.

Plate 3.0: Arrangement of Stacks of Sieve on a Mechanical Sieve Shaker

3.3.2 Specific Gravity Test

Specific gravity is the ratio of mass of unit volume of soil at a stated temperature to mass of equal volume of gas-free distilled water at the same temperature (Krishna, 2002). Also as defined by (Braja, 2006), Specific gravity can be defined as the ratio of unit weight of a material to unit weight of water. The specific gravity of soil solids is often needed for various calculations in soil mechanics. It can be determined accurately in the soil laboratory.

The apparatus employed for this experiment includes:

1. Density bottle of 50ml capacity and a stopper.
2. Desiccator containing anhydrous silica gel.
3. Thermostatically controlled oven with temperature of about 80-110^{O}C.
4. Weighing balance of 0.01g sensitivity.
5. Mantle heater.
6. Plastic wash bottle.
7. Distilled water.
8. Funnel
9. Thin glass rod for stirring.
10. 425um Sieve.
11. Dry piece of cloth for cleaning.
12. Masking tape for identification of sample.
13. Exercise book and pen for recording of results.

Test Procedure

1. The density bottle properly cleaned and rinsed with distilled water, thereafter oven- dried and then cooled it in a desiccator so as to remove any moisture present.
2. The empty clean and dry density bottle was weighed and recorded as (M_1).
3. About 10-15g of soil passing through 425um sieve was placed inside the density bottle, weigh and the weight of density bottle +dry soil + stopper was recorded as (M_2).
4. Distilled water was added to fill about half to three-fourth of the density bottle, and then the sample was soaked for 24hrs (The time stated is to enable complete settlement of the soil particle which is evident when clear water appears above the submerged soil).

5. The density bottle was gently stirred using thin glass rod and thereafter connected to a mantle heater to de-air the sample, the sample was not allowed to boil over.
6. After agitation, the sample was allowed to cool at room temperature and then filled with distilled water up to the specified mark (at lower meniscus level), the exterior surface of the density bottle was cleaned with a clean dry cloth and the weight of the density bottle + stopper +soil filled with water was determined and recorded as (M_3).
7. The density bottle was emptied, cleaned and rinsed with distilled water, then filled with distilled water up to the same mark. The exterior surface of the density bottle was cleaned with a clean dry cloth and the weight of the density bottle filled with distilled water + stopper was determined and recorded as (M_4).
8. The test procedure was repeated for two more trials and the average specific gravity value was obtained from the total no of trial, the variation in the specific gravity result obtained for each trial must not exceed 2%, otherwise repeat the experiment.

The Procedure for Computation of result obtained is as follows:

Specific gravity (G_S) = $\frac{(M2-M1)}{(M2-M1)-(M3-M4)}$

Where M_1= weight of density bottle + stopper

M_2= Weight of density bottle + air-dried soil + stopper.

M_3= Weight of density bottle filled with water + wet soil + stopper.

M_4= Weight of density bottle filled with water + stopper

3.3.3 Atterberg Limit Test.

The behavior of soils especially fine grained soils differs considerably in the presence of water. Clay in the presence of water may almost take a liquid or can be quite hard. Consistency is the property of soil that offers resistance to deformation, it denote the degree of firmness of a soil and can be explained in terms of plasticity and stickiness of soil. Stickiness is the ability of soil especially fine grained soil to adhere to other materials while plasticity on the other hand is the ability of soils to undergo a change in shape under the action of an impressed force without a change in volume.

Stickiness of soils especially fine grained soils can be identified practically by mixing of an air-dried soil with a given quantity of water and then interposing the soil between the thumb and the fore finger (index finger), thereafter the following inference are made as it regards to the observation and this includes:

1. **Non-Sticky:** If the wet soil falls freely between the thumb and the forefinger without leaving any remain or without stretching.
2. **Slightly Sticky:** If the wet soil falls slowly with an infinitesimal traces of remains but without stretching.
3. **Sticky:** If the wet soil falls quite slowly with visible remains and apparent stretching.
4. **Very Sticky:** If the wet soil stretches between the thumb and the fore finger without falling.

The plasticity of soils can be identified practically by rolling a known weight of wet soil into a 3mm uniform diameter thread and the following inferences based on the observation are made and they are as follows:

1. **Non-Plastic:** If the wet soil cannot be rolled into thread.
2. **Slightly Plastic:** If the wet soil can be rolled into thread but crumbles easily under application of little pressure.
3. **Plastic:** If the wet soil can be rolled into 3mm thread but crumbles under intense application of pressure and cannot be reformed.
4. **Very Plastic:** If the wet soil can be rolled into 3mm diameter thread but crumbles under intense application of pressure and can be reformed.

The atterberg limit is a limit characterized by visible transition of soil (especially fine grained soils) from liquid-plastic-semi-solid-solid state consequent upon the variation of moisture content. This test was developed by Albert Atterberg a Swedish agricultural scientist in 1911. This test is divided into three limits namely:

1. Liquid Limit (LL)
2. Plastic Limit (PL)
3. Shrinkage Limit

3.3.3.1 Liquid Limit Test

It is the water content at which the soil has a small shear strength that it flows to close a groove of standard width when jarred in a specified manner. It is the minimum water content at which the soil tends to flow like a liquid. When a soil is mixed with an excessive amount of water, it will be in a liquid state and flow like a viscous liquid. When the viscous liquid dries gradually due to loss of moisture it will pass into a plastic state. With further loss of moisture, the soil will pass into a semi-solid state. With even further reduction of moisture, the soil will pass into a solid state. The moisture content (%) at which a cohesive soil will pass from liquid state to plastic state is referred to as the liquid limit of the soil.

In order to study the liquid limit of the soil Casagrande test was conducted. liquid limit is generally determined by the mechanical method using Casagrande apparatus or the standard liquid limit test apparatus. With respect to this method, the liquid limit is defined as the moisture content at which 25 blows or drop in standard liquid limit apparatus will just close a groove of standardized dimension cut into sample by a grooving tool at a specified amount (Aroja, et al 2017).

The apparatus used for liquid limit determination is outlined below:

1. Liquid limit device (Cassagrande type)
2. Grooving tool
3. Moisture content tins
4. Porcelain evaporating dish
5. Spatula or pellet knife
6. Thermostatically controlled oven
7. Weighing balance sensitive to 0.01g
8. Plastic wash bottle containing distilled water
9. Paper towels
10. Masking tape for identification of tin.

11. Exercise book and pen for recording of data
12. 425um Sieve
13. Airtight container

Test Procedure

1. The sample was prepared by weighing about 150g of soil and passing it through 425um sieve, the sample was mixed with distilled water in a glass plate with the aid of pellet knife, during the mixing operation, coarse particle was removed by hand and mixed the sample was mixed to form a thick homogenous paste, thereafter, the mixed soil was placed in an airtight container and leave to mature for 24hrs.
2. The mass of four moisture content tins was determined and recorded as (W_1)
3. The matured sample was placed on an evaporating dish with little water added to it using the plastic squeeze bottle; the soil was properly mixed to ensure uniform distribution of moisture.
4. A portion of the paste (mixed soil) was placed on the liquid limit device and then the mixture was leveled so as to obtain a maximum depth of 1cm.
5. The grooving tool was used to cut a groove along the symmetrical axis of the cup holding the tool perpendicular to the cup.
6. The handle of the crank of the liquid limit device was rotated at the rate of 2 revolution per second and the no of blows required to close the groove at a distance of 13mm was counted. Closing of the groove should be as a result of plastic flow of the soil and not by sliding, if sliding occurs repeat the test.
7. About 10g of soil in the closed groove was taken and placed in the moisture content tins for moisture content determination, the sample was weighed and recorded as (W_2)
8. The rest of the soil in the cup was removed and paper towel was used to clean the cassagrande cup properly.
9. The water content of the soil was altered and the process was repeated to obtain the required no of blows in the range of 15-40 blows.
10. The graph of moisture content against the log of no of blows was plotted and the moisture content corresponding to 25 blows on the abscissa gives the value of the liquid limit.

The Procedure employed for the Computation of the Result obtained is as Follows:

Moisture content = $\frac{\text{Weight of water}}{\text{weight of dry soil}} \times 100 = \frac{W2-W3}{W3-W1} \times 100$

Where W_1 = Weight of empty tin.

W_2 = Weight of tin + wet soil.

W_3 = Weight of tin + oven-dried

3.3.3.2 Plastic Limit Test

The plastic limit of a soil is the moisture content expressed as a percentage of the weight of oven-dried soil at the boundary between the plastic and the semi-solid state of consistency. It is the moisture content at which a soil will just begin to crumble when rolled into a uniform 3mm diameter thread using a glass plate or other recommended surface for rolling. Soil used for Atterberg limit test can be classified based on the plasticity index of the soil. The plasticity index is the amount of water required to change a soil from its plastic limit to liquid limit, in other word it is the numerical difference between the liquid limit and the plastic limit of soil. Table 3.2 is used to classify soil based on the ranges of it plasticity index.

Table 3.4: Plasticity Ratings for Fine grained Soil (Braja, M.Das, 2002).

Plasticity Index	Plasticity
0	Non-Plasticity
<7	Low Plasticity
7-17	Medium Plasticity
17-35	High Plasticity
>35	Very High Plasticity

1. The apparatus used for this experiment includes:
2. A smooth glass plate about 300mm square and 10mm thick.
3. A palette knife or spatula
4. A short length of 3mm metal rod

5. Moisture content tins
6. Plastic squeeze bottle
7. Weighing balance with 0.01g sensitivity
8. Veneer caliper
9. Masking tape for tin identification
10. Exercise book and pen for recording of result.

Test Procedure

1. The sample was prepared by the method described in the liquid limit using the sample passing 425um sieve.
2. The empty moisture content tins was identified, weighed and recorded as (W1).
3. About 20g of the prepared soil paste was placed on a porcelain evaporating dish and water was added using the plastic squeeze bottle, the soil was mix thoroughly until the paste is plastic enough to be rolled into a ball.
4. A portion of the ball was taken and rolled on a glass plate with the palm of the hand into a thread of uniform diameter throughout its length by rolling forward and backward.
5. The rolling and remolding continued until the thread just start to crack at a distance of 3mm.
6. The small crumbed pieces was collected and placed in a moisture content tin a weighed and recorded as (W2).
7. The tin was placed in the oven at a constant temperature of 80-110^{O}C for a period of 16-24hrs.
8. After 24hrs, the tin was removed from the oven and the weight of the dry soil plus the tin was determined and recorded as (W_3).
9. The test procedure was repeated for at least two trials and take the average plastic limit value for all the trials.

The Computation for Plastic Limit is as follows:

Plastic limit = $\frac{Weight\ of\ water}{Weight\ of\ oven{-}dried\ soil} \times 100\ = \frac{W2-W3}{W3-W1} \times 100$

Where W_1 = Weight of empty tins.

W_2 = Weight of tin plus wet soil

W3 = Weight of tin plus oven-dried soil

3.3.4 Compaction Test

Compaction is the process of increasing the bulk density of the soil by driving out air. It involves the densification of soils by mechanical means thereby increasing the dry density of the soil. According to (Shruthi, 2017) Compaction of soil is the process by which the soil solid are packed more closely together by mechanical means, thus increasing it dry density. It could also be stated as the process of packing the soil particle more closely together usually by tamping, rolling or other mechanical means, thus increasing the dry density of the soil. It is achieved through the reduction of the volume of air void in the soil with little or no reduction in water content. The process must not be confused with consolidation in which water is squeezed out under the action of steady static load. Consolidation is a natural process and result in dense packing of the soil.

In civil engineering practice soil compaction is essential for the following reasons:

1. Increasing the bearing strength of foundation
2. Provide stability to slope and foundation.
3. Prevention of undesirable settlement of structures
4. Reduction of water seepage from structure

The compaction methods to be adopted for this research are British Standard Light for natural laterite samples and laterite stabilized with sand, chipping dust and blend of sand and chipping dust.

Details of British Standard Compaction Process

Table 3.5: Details of Compaction Mould.

Type	Diameter (mm)	Height (mm)	Volume(cm^3)
British Standard	**105**	**115.5**	**1000**

Table 3.6: Details of Compaction Procedure.

Type of test	Mould (cm^3)	Rammer(kg)	Drop (mm)	No of layers	Blow per layer
BS light	**1000**	**2.5**	**300**	**3**	**27**
BS heavy	**1000**	**4.5**	**450**	**5**	**27**

The mechanical energy applied in each type of British Standard in term of work done is given as follows:

British Standard Light

Mechanical energy = $\frac{Weight\ of\ rammer \times no\ of\ layers \times no\ of\ blows \times height\ of\ drop}{Volume\ of\ mould}$

$=\frac{2.5g\times 3layers\times 27blows\times 300mm}{1000}$ **= 60.75kgm =60.75× 9.81Nm=596j**

Work done per unit volume of soil $=\frac{596}{1000}$ **=596kj/m^3**

The apparatus used for the test are as follows:

1. Compaction mould with a detachable base plate and removable extension collar.
2. Metal rammer (either 2.5kg or 4.5kg)
3. Measuring Cylinder 200ml or 500ml
4. Large Metal tray (600mm×600mm ×600mm)
5. Balance up to 10kg readable to 1g
6. Small tools such as palette knife, steel straight edge about 300mm long.
7. Drying oven temperature of 105-110^{O}C
8. Apparatus for moisture content determination

Test Procedure

1. The mould, extension collar and base plate was cleaned and dried. The dimension was measured and weigh to the nearest 1kg check if the rammer falls freely.
2. The internal surface of the mould was greased.
3. The extension collar was attached to the mould.
4. About 3kg of the soil sample was weighed on a weighing balance.
5. About 4% water was added to the soil sample, mixing it thoroughly and separating the soil into three layers for British Standard Light and five layers for British Standard Heavy.
6. The wet soil was poured into the mould and compacted thoroughly by applying the required no of blow using either a 2.5kg or 4.5kg rammer falling freely from a height of 300mm. The blow was distributed uniformly over the surface of the mould.
7. After completion of the compaction operation, the extension collar was removed and the top of the mould was carefully leveled by means of a straight edge.
8. The mould with the compacted soil to the nearest 1kg was weighed and recorded as W_2.
9. The moisture content of the representative sample of the specimen was determined and recorded as M.
10. The procedure was repeated and 8%, 12%, 16% and 20% of water was added and the value obtained was recorded.
11. The graph of dry density against moisture content was plotted and the maximum dry density (MDD) of the soil at the corresponding optimum moisture content (OMC) was determined.

The Computation of the result obtained is as follows:

Determination of Dry Density (P_d).

Wt of mould (kg) = W_1

Wt of mould + wet soil (kg) = W_2

Wt of wet soil (kg) = W_2-W_1

Volume of mould (M^3) = W_4

Bulk Density (kg/m^3) = $\frac{Wt\ of\ wet\ soil\ (\text{kg})}{\text{Vol of mould (m3)}}$ =$\frac{\text{W2}-\text{W1}}{\text{W4}}$

Moisture Content (%) = $\frac{\text{mosture content (top)+ moisture content (bottom)}}{2}$

Dry Density (kg/m^3) = $\frac{\text{Bulk density}}{\text{1+moisture content (\%)}} = \frac{\text{Pb}}{1+\text{w}/100}$

Determination of Moisture Content (w) for top and bottom respectively.

Wt of tin (kg) = W_1

Wt of tin + wet soil = W_2

Wet of wet soil (kg) = W_3 = W_2-W_1

Wt of tin + dry soil (kg) = W_4

Wt of dry soil (kg) = W_5= W_4-W_1

Wt of water (kg) =W_6 = W_3-W_5

Moisture Content (%) = $\frac{\text{Wt of water}}{\text{Wt of dry soil}} \times 100 = \frac{\text{W6}}{\text{W5}} \times 100$

Plate 3.1: Compaction of Natural Laterite Soil

3.3.5 California Bearing Ratio Test

The California bearing ratio test was originally developed by the California division of highway in 1938, for the design of highway thickness. The test is used for evaluating the suitability of materials used in sub-grade, sub-base and base course respectively. The test result has been correlated with the thickness of various materials required for flexible pavement construction. The test may be conducted on a prepared specimen in a mould or on the soil in-situ condition.

In the test the load required to push a plunger into a soil specimen at a controlled rate is measured, then the load on the plunger at a certain depth is recorded as a percentage of a standardized load. The load necessary to push a plunger to a certain depth into the soil is expressed as a percentage of the load required to force the same plunger to the same depth into a standard sample of compacted crush stone. The construction of highway pavement requires a California Bearing Ratio value for 2.5mm and 5mm penetration respectively, with that of 2.5mm penetration being comparatively higher than that of 5mm penetration. The Federal Ministry of work Standard Specification for roads and bridges (1997) state that road construction material should have a CBR value of 10%, 20% and 80% for use as sub-grade, sub-base and base course respectively. The material to be used for the test will be subjected to 48 hours soaking in other to ascertain it behavior under worst condition (flooding as a result of intense rainfall).

Table 3.7: Standard load adopted for different penetration on a standard material with CBR value of 100%.

Penetration of plunger (mm)	Standard Load (kg)
2	1150
2.5	1320
4	1760
5	2000
6	2220
7.5	2630
8	2650
10	3180
12.5	3600

1. The apparatus used for the test are outlined below:
2. A cylindrical corrosion resistant mould 152mm×127mm having a diameter of 150-152mm with a detachable base plate and a removable extension collar.
3. A compressive device for static compaction of applying a force of at least 300KN
4. Metal plugs 150mm $\pm$ 0,5mm and 50mm thick.
5. Metal rammer 2.5kg or 4.5kg.
6. Dial gauge of 0.01g sensitivity.
7. Soaking tank.
8. A steel rod of about 16mm diameter and 600mm long and a straight edge of 300mm steel stripe and 3mm thick with one beveled edge.
9. Weighing balance of 25kg accuracy and a spatula.
10. Filter paper
11. Apparatus for moisture content determination.
12. Masking tape used for identification of moisture content tins.
13. Exercise book and pen for recording.

Test Procedure

The methods used for California Bearing Ratio Test are:

1. Compression with tamping.
2. Recompaction with known maximum dry unit weight (MDUW) and optimum moisture content (OMC).
3. For this course of study the method for recompacted sample with known maximum dry unit weight (MDUW) and optimum moisture content (OMC) is to be adopted and the procedure is outlined below:
4. Carry out Compaction test using 6kg of soil sample, varying the moisture content at a particular percentage say 4%, determine the maximum dry density and optimum moisture content.
5. Clean properly and grease the internal surface of the CBR mould.
6. Weigh 6kg of soil mixing with the optimum moisture content determined from compaction test.

7. Divide the soil into 5 equal layer (CBR Heavy) and seal in an airtight container until requested for use.
8. Stand the mould assembly in a solid base, place the first soil portion and compact using 4.5kg rammer for 62 even blows.
9. Repeat using the remaining four portion of soil in turn so that the level of the soil is not more than 6mm above the top of the mould body.
10. Remove the collar and trim the soil flush with mould with the scrapper or knife edge.
11. Weigh the mould, soil and base plate to the nearest kg.

Preparation for Soaking

Soil may soften when load is placed on it due to flooding or increase in moisture content. Soaking of the sample is done primarily to determine the strength (load bearing strength) of the soil under worst condition (rainy season).Below are the list of apparatus used for CBR Soaking:

1. Perforated base plate fitted to CBR mould in place of normal base plate.
2. Perforated swell plate with an adjustable stem to provide a sealing for the stem of the dial gauge.
3. Tripod mounting to support dial gauge
4. Soaking tank
5. Annular Surcharge discs with internal diameter of 52-54mm and external diameter of 145mm to 150mm.
6. Petroleum jelly.
7. The Soaking procedures are enumerated as follows:
8. Remove the base plate and replace with perforated base plate.
9. Fit the collar to the other end of the mould, pack the screw thread with petroleum jelly to make it water tight.
10. Place the mould assembly in soaking, place the filter paper in the sample, the perforated swell plate, and then annular surcharge disc.
11. Mount dial gauge on top of the extension collar, secure the dial gauge in place and adjust the stem in the perforated base plate to give zero.

12. Fill the immersion tank with water just below the extension collar. Start the timer when water has just covered the base plate.
13. Record the time taken for water to appear at the top of the sample if it does occur within two days. Flood the top of the sample and leave to soak for a day.
14. Plot the swelling against elapsed time or square root of time. Flattening curve indicates that swelling is complete.
15. Take off the dial gauge and its support; remove the mould assembly and leave to drain for 15min.
16. Remove the Surcharge discs, perforated plate and collar, then fit the other base plate.
17. Weigh the sample + mould + base plate if density is required after soaking is completed.
18. If the sample has swollen, trim it to the level of the mould and reweigh
19. Test the sample by adjusting the dial gauge to start at zero and take the reading at interval of 0.5mm for every 30seconds till 7mm penetration.
20. Record the load at penetration of 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5 and 7.0mm and express this force as percentage of the standard load.
21. Calculate the CBR for 2.5 and 5mm penetration; repeat the same procedure for top and bottom, the higher CBR value will be used as the CBR for the material.
22. Plot the graph of force (KN) against penetration (mm).
23. The normal curve is convex upward, but if the initial part is concave upward applies the necessary correction to the curve.

Mathematically it is expressed as $\frac{\text{test load}}{\text{standard load}} \times 100$

CBR2.5mm = $\frac{\text{test load}}{1320} \times 100$

CBR5mm = $\frac{\text{test load}}{2000} \times 100$

Where

Test load = dial gauge reading × proof ring constant

CHAPTER FOUR

RESULTS AND DISCUSSION

This section presents key findings valuable in evaluating the effect of sand and chipping dust on geotechnical properties of laterite. Below is a presentation of the research findings:

4.1 Results

The results obtained from the study which will be considered for analysis include the following:

1. Sieve Analysis Test Results
2. Specific Gravity Test Results
3. Atterberg Limit Test Results
4. Compaction Test Results
5. CBR Test Results

Below is a detailed discussion on the effect of sand and chipping dust on geotechnical properties of laterite based on the experimental results obtained from the test listed above:

4.1.1 Sieve Analysis Test

Table 4.1: Sieve Analysis Test Results for Chipping Dust

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cum % Retained	Cum % Finer
4.75	7.96	1.59	1.59	98.41
2	138.46	27.69	29.28	70.718
1.18	70.72	14.14	43.43	56.574
0.85	33.57	6.71	50.14	49.86
0.6	30.85	6.17	56.31	43.69
0.425	25.78	5.16	61.47	38.534
0.3	20.9	4.18	65.65	34.354
0.15	38.8	7.76	73.41	26.594
0.075	34.44	6.89	80.29	19.706
Tray	40.4			

Table 4.2: Sieve Analysis Test Results for Laterite

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cum % Retained	Cum % Finer

2	**21.3**	**4.26**	**4.26**	**95.74**
1.18	**37.9**	**7.58**	**11.84**	**88.16**
0.85	**40.6**	**8.12**	**19.96**	**80.04**
0.6	**48.9**	**9.78**	**29.74**	**70.26**
0.425	**45.8**	**9.16**	**38.90**	**61.1**
0.3	**50.4**	**10.08**	**48.98**	**51.02**
0.15	**42.7**	**8.54**	**57.52**	**42.48**
0.075	**12.67**	**2.53**	**60.05**	**39.946**
Tray	**4.56**			

Table 4.3: Sieve Analysis Test Results for Sand

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cum % Retained	Cum % Finer
2	**7.97**	**2.66**	**2.66**	**97.34**
1.18	**9.98**	**3.33**	**5.99**	**94.01**
0.85	**11.73**	**3.91**	**9.90**	**90.10**
0.6	**27.95**	**9.32**	**19.21**	**80.79**
0.425	**44.02**	**14.67**	**33.89**	**66.11**
0.3	**53.69**	**17.90**	**51.78**	**48.22**
0.15	**112.1**	**37.37**	**89.15**	**10.85**
0.075	**8.46**	**2.82**	**91.97**	**8.03**
Tray	**2.8**			

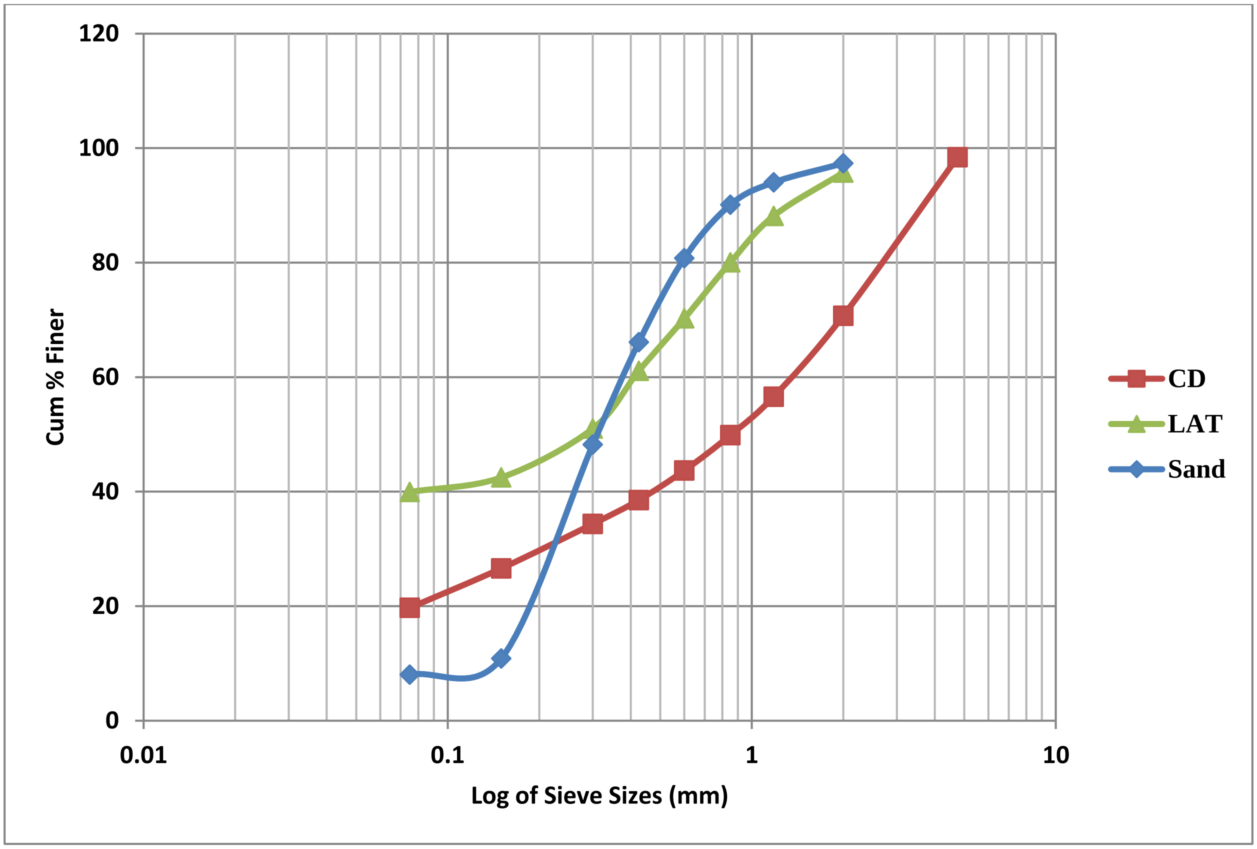

Figure 4.0: Particle Size Distribution Curve for Chipping Dust, Sand and Laterite.

Figure 4.0 depicts the particle size distribution curve for chipping dust, sand and laterite respectively. The percentage passing through sieve No 200 (0.075mm) for chipping dust, sand and laterite were 19.7%, 39.9% and 8.03% respectively. The coefficient of uniformity and coefficient of curvature for chipping dust, laterite and sand were 0,0 0,0, 2.5 and 0.76 respectively. The chipping dust, laterite and sand were classified as A-2-6, A-6 and A-2-4 according to AASHTO Soil Classification System and SM (sand mixed with silt), CL (clay of low plasticity) and SC (sand mixed with clay) according to Unified Soil Classification System. Gradation assessment of the three samples revealed that sand were poorly graded, the gradation of laterite and chipping dust could not be ascertained due to loss in some of their respective shape parameters (D10).

4.1.2 Specific Gravity Test

Table 4.4: Specific Gravity Result for Sand

Determinants	Trial 1	Trial 2	Trial 3
Wt of density bottle, W_1 (g).	24.50	25.32	25.12
Wt of bottle + dry soil, W_2 (g).	34.48	35.31	35.10
Wt of bottle + soil + water, W_3 (g).	84.43	86.39	85.03
Wt of bottle + water, W_4 (g).	78.35	80.32	78.93

Table 4.5. Specific Gravity Result For Chipping Dust.

Determinants	Trial 1	Trial 2	Trial 3
Wt of density bottle, W_1 (g).	27.66	26.83	25.02
Wt of bottle + dry soil, W_2 (g).	37.66	36.83	35.02
Wt of bottle + soil + water, W_3 (g).	88.06	85.46	85.73
Wt of bottle + water, W_4 (g).	81.81	79.22	78.50

Table 4.6. Specific Gravity Result for LAT

Determinants	Trial 1	Trial 2	Trial 3
Wt of density bottle, W_1 (g).	24.76	25.64	25.90
Wt of bottle + dry soil, W_2 (g).	34.74	35.63	35.90

Wt of bottle + soil + water, W_3 (g).	**84.33**	**85.15**	**85.79**
Wt of bottle + water, W_4 (g).	**78.07**	**78.94**	**79.56**

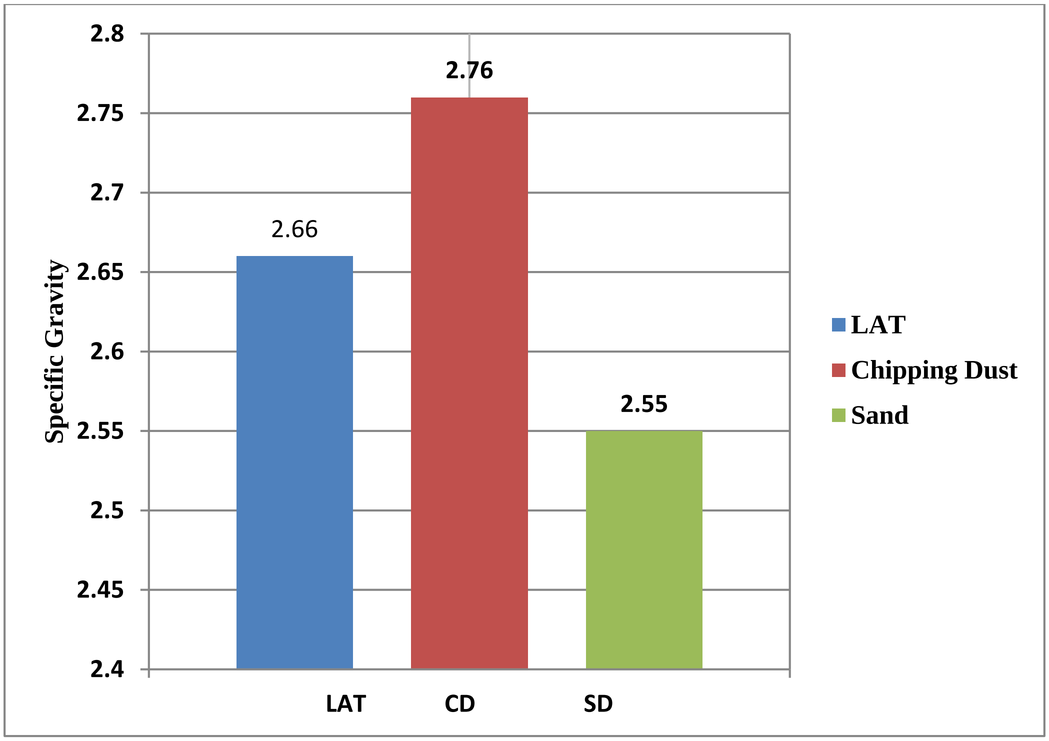

Figure 4.1: Specific Gravity Results for Laterite, Sand and Chipping Dust.

Table 4.4 to 4.6 shows the specific gravity results obtained for laterite, chipping dust and sand respectively. The specific gravity of laterite, chipping dust and sand were 2.66, 2.76 and 2.55 respectively. The results showed that chipping dust yielded the highest specific gravity value while sand yielded the lowest specific gravity value. The range of specific gravity results (2.55 - 2.76) obtained for the three samples satisfied the requirements given by Federal Ministry of Works and Housing (1999) which state that the specific gravity of materials especially materials used for road construction must lie between 2.5 to 2.75. This result therefore justifies the use of these materials for the experimental study.

4.1.3 Atterberg Limit Test

Table 4.7: Liquid Limit Results for Laterite Stabilized with Sand and Chipping Dust

% of Sand/% of Chipping Dust	0	2.5	5	7.5	10
0	42.6	36.8	35.2	33.2	26.8
2.5	36.8	26.2	24.8	-	-
5	-	-	-	-	-
7.5	-	-	-	-	-
10	-	-	-	-	-

Table 4.8: Plastic Limit Results for Laterite Stabilized with Sand and Chipping Dust

% of Sand/% of Chipping Dust	0	2.5	5	7.5	10
0	28.1	25.8	20.5	17.6	15.8
2.5	13.1	12.8	11.1	-	-
5	-	-	-	-	-
7.5	-	-	-	-	-
10	-	-	-	-	-

Table 4.8: Plasticity Index Results for Laterite Stabilized with Sand and Chipping Dust

% of Sand/% of Chipping Dust	0	2.5	5	7.5	10
0	14.5	11	14.7	15.6	11
2.5	23.7	13.4	13.7	-	-
5	-	-	-	-	-
7.5	-	-	-	-	-
10	-	-	-	-	-

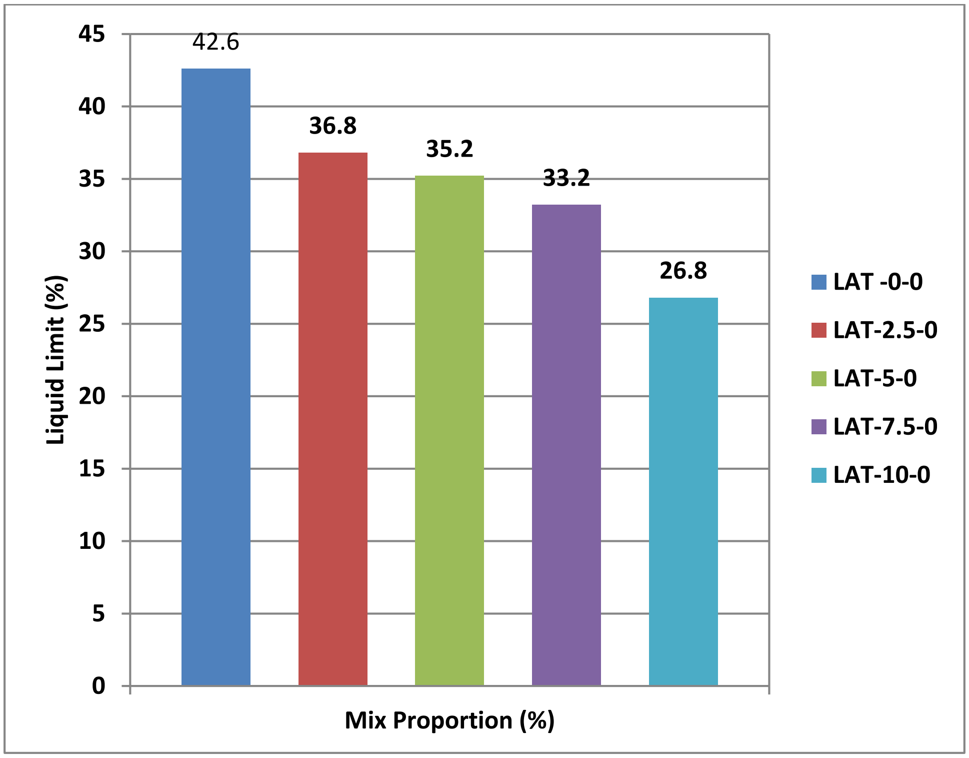

Figure 4.2: Liquid Limit Values for Laterite Stabilized with Sand

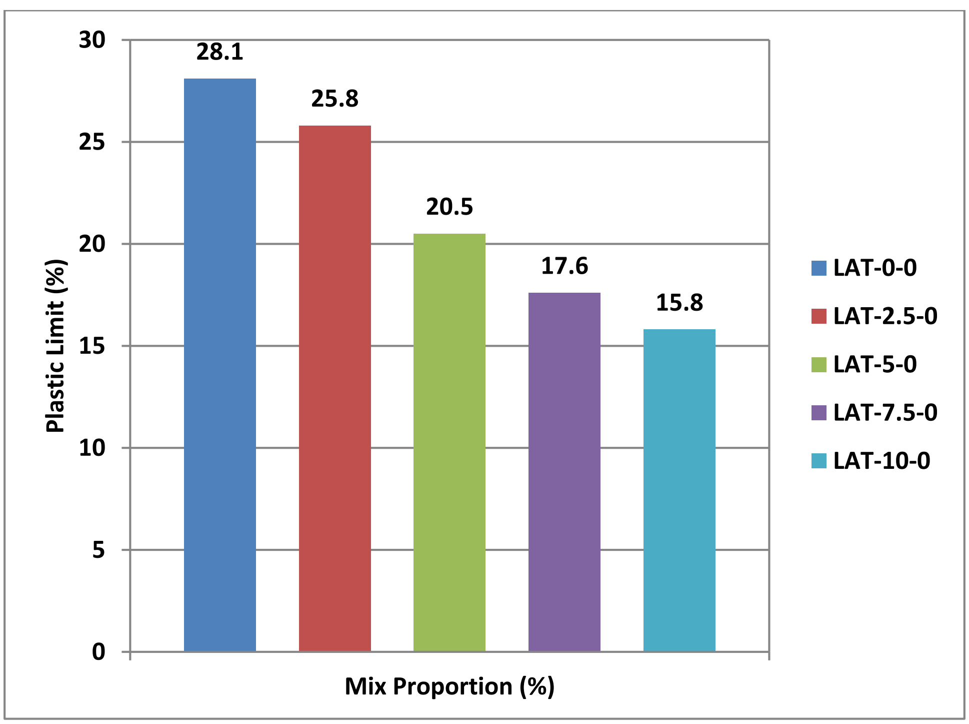

Figure 4.3: Plastic Limit Values for Laterite Stabilized with Sand

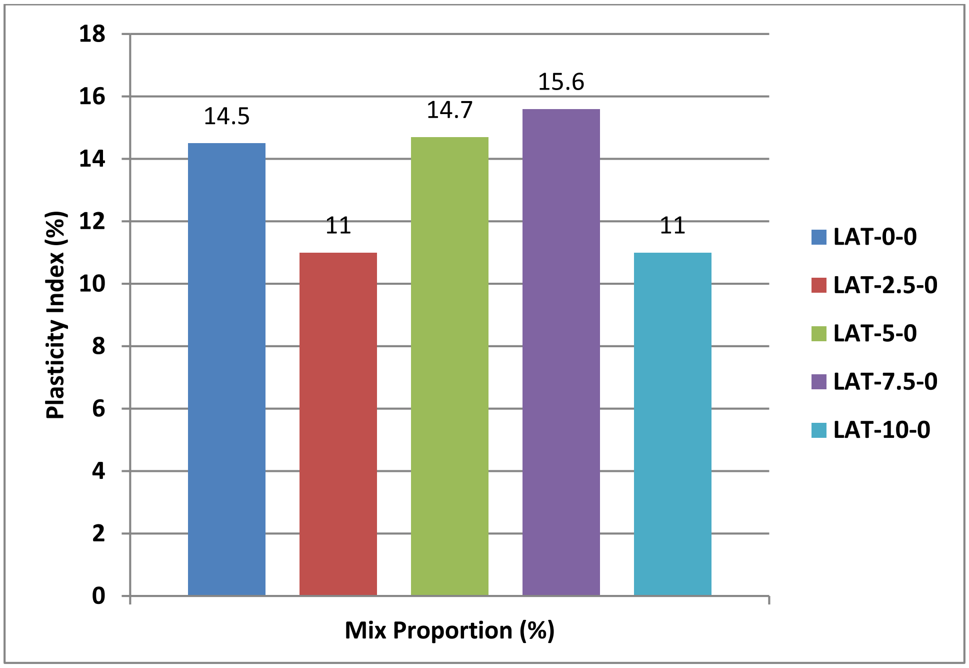

Figure 4.4: Plasticity Index Values for Laterite Stabilized with Sand

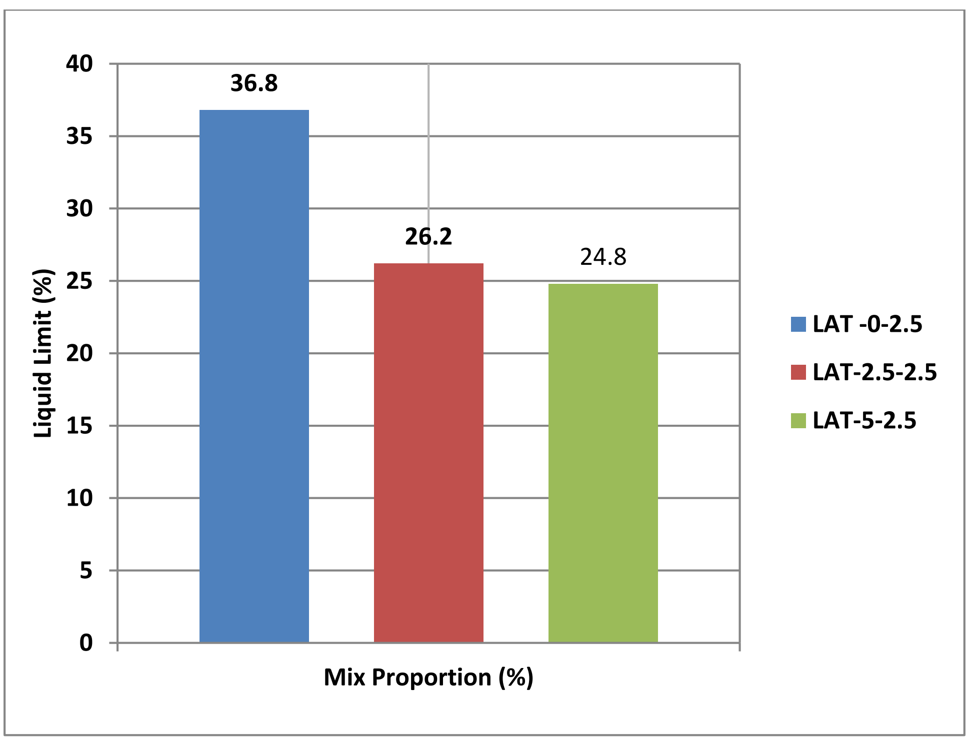

Figure 4.5: Liquid Limit Values for Laterite Stabilized with Sand and Chipping Dust

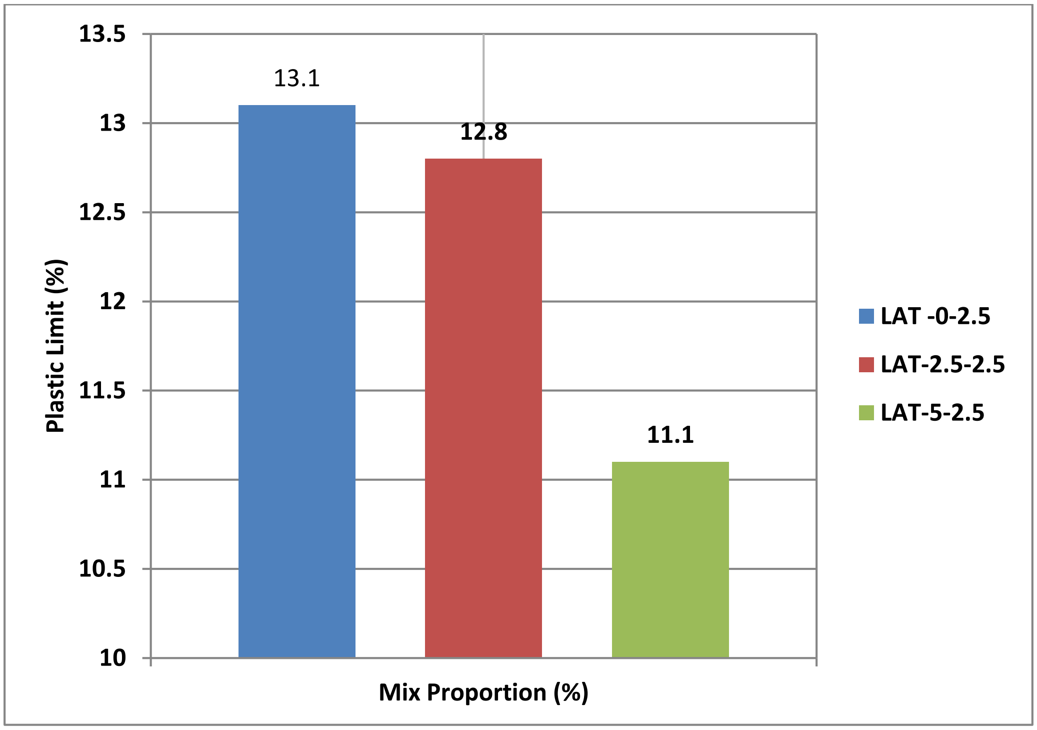

Figure 4.6: Plastic Limit Values for Laterite Stabilized with Sand and Chipping Dust

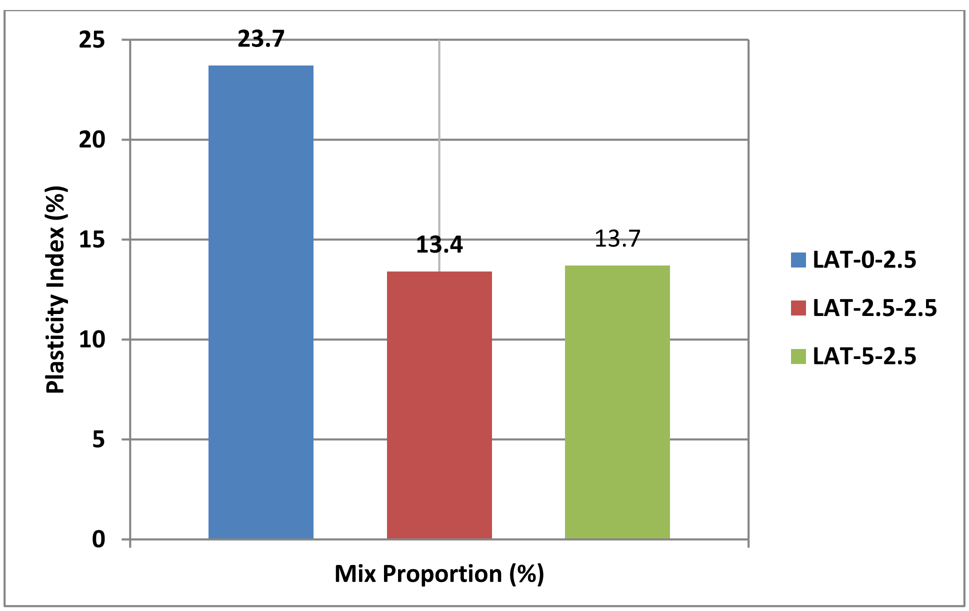

Figure 4.7: Plasticity Index Values for Laterite Stabilized with Sand and Chipping Dust

Figure 4.2 – 4.7 depicts the liquid limit, plastic limit and plasticity index results for laterite stabilized with sand and a blend of sand with chipping dust. It was observed that addition of addition of sand to laterite from 2.5% to 10% decreased the liquid and plastic limit of laterite from its natural value of 42.6% and 28.1% to 26.8% and 15.8% respectively while a fluctuating range of values was obtained for the plasticity index of the mixture. While for laterite stabilized with a blend of sand and chipping dust, it was observed that the liquid limit, plastic limit and plasticity index of laterite decreased from 42.6%, 28.1% and 14.5% to 24.8%, 11.1% and 13.7% respectively. It was also observed that beyond 5% and 2.5% addition of sand and chipping dust to laterite, the mixture became non plastic. The general decline in liquid limit, plastic limit and plasticity index of laterite on addition of sand and chipping dust could be attributed to the non-plastic nature of sand and chipping dust. The range of values obtained for the liquid limit and plasticity index satisfied the general specification given by Federal Ministry of Works and Housing, (1999) which state that the liquid limit and plasticity index of road construction material must not exceed 80% and 55% respectively.

4.1.4 Compaction Test

Table 4.9: Maximum Dry Unit Weight for Laterite Stabilized with Sand and Chipping Dust

% of Sand/% of Chipping Dust	0	2.5	5	7.5	10
0	18.3	19.3	19.8	20.28	20.73
2.5	19.8	20.3	20.8	21.2	21.2
5	21.2	21.2	21.7	21.7	22.2
7.5	21.3	22.2	22.2	22.7	22.7
10	21.7	22.1	22.7	23.2	23.7

Table 4.10: Optimum Moisture Content for Laterite Stabilized with Sand and Chipping Dust

% of Sand/% of Chipping Dust	0	2.5	5	7.5	10
0	14.6	14.5	17.8	17.1	12.9

2.5	**16.9**	**15.1**	**14.7**	**12.5**	**12.2**
5	**13.7**	**12.4**	**11.5**	**11.2**	**10.9**
7.5	**16.7**	**14.6**	**14**	**13.7**	**11.5**
10	**16.6**	**13.9**	**11.6**	**15.7**	**12.9**

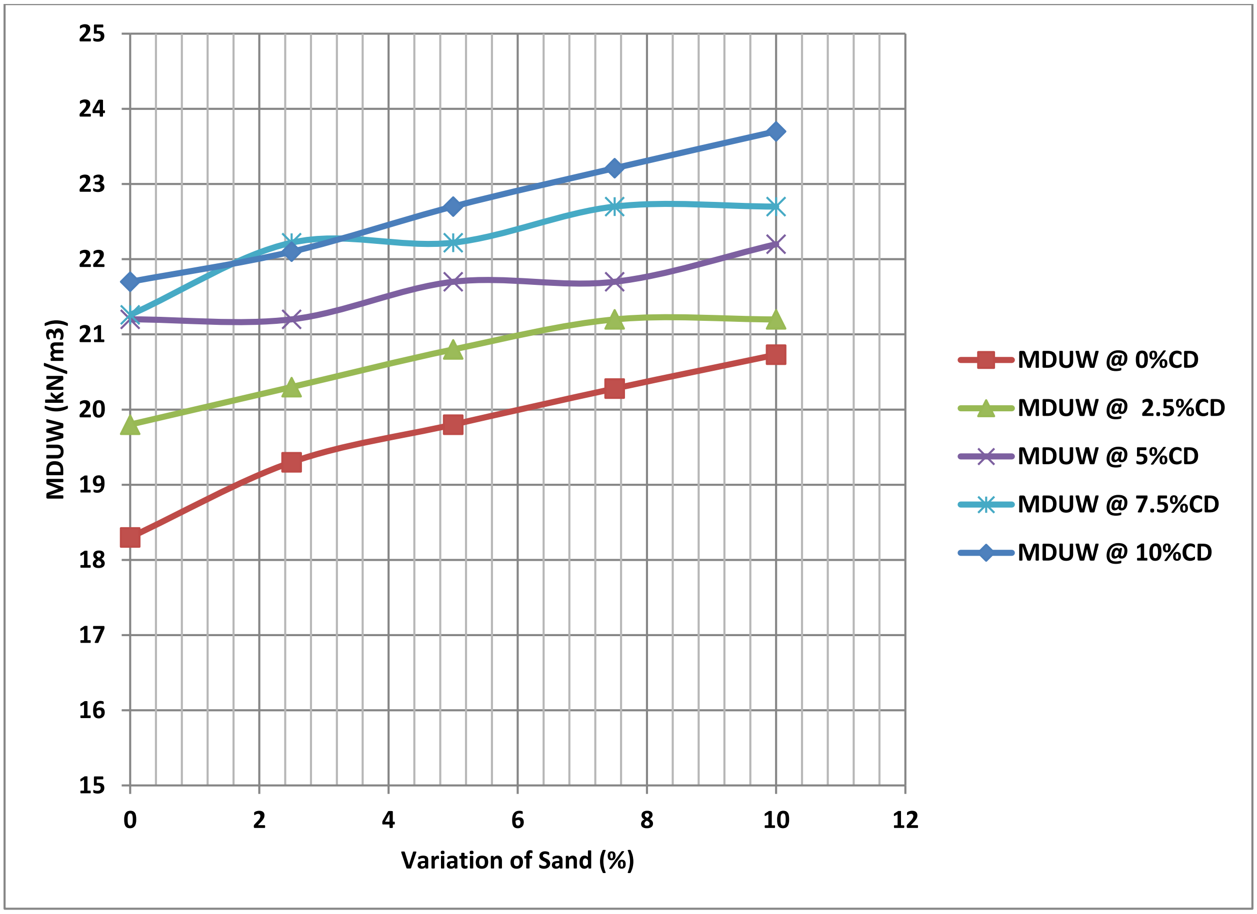

Figure 4.8: Graph Showing the Maximum Dry Unit Weight of Laterite Stabilized with Varying Percentages of Sand and Chipping Dust

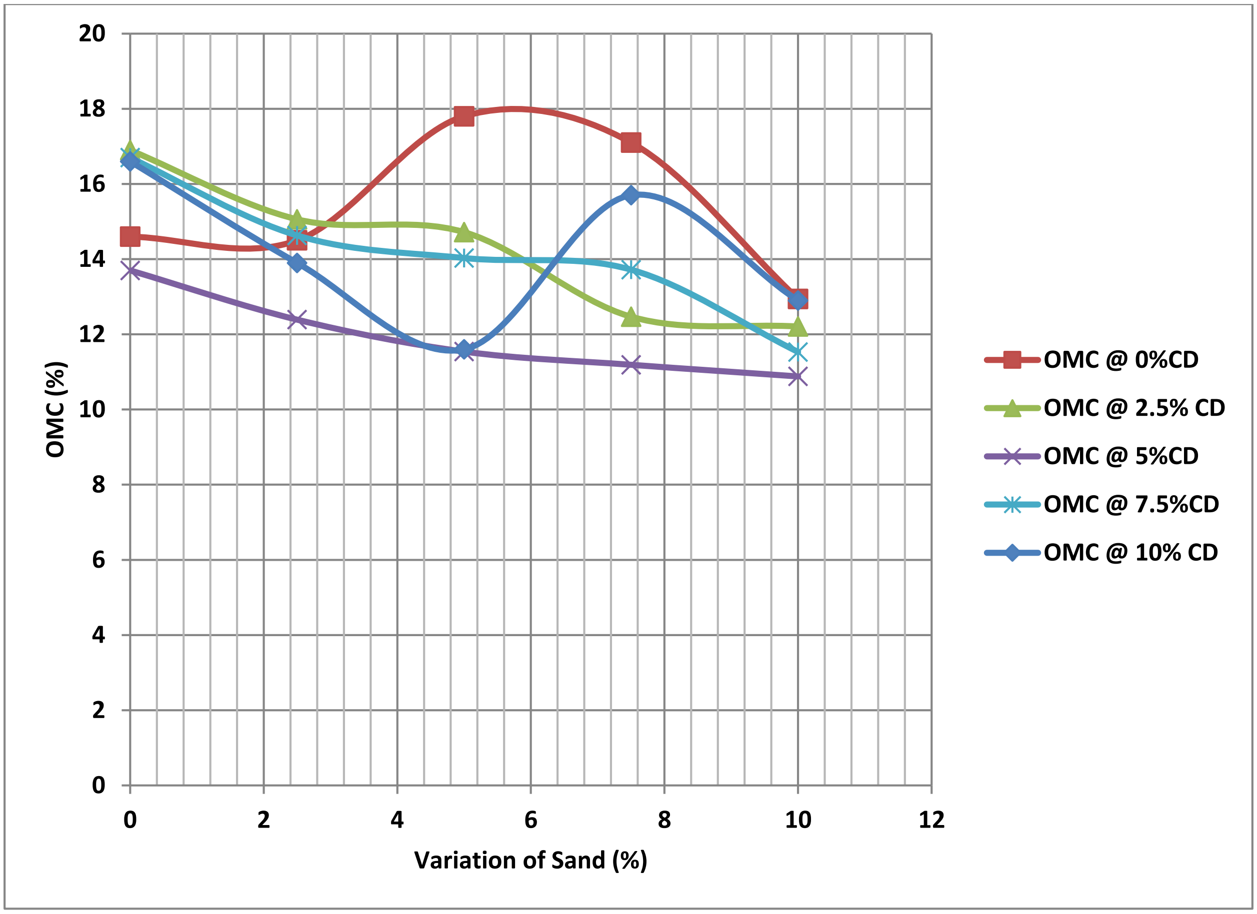

Figure 4.9: Graph Showing the Optimum Moisture Content of Laterite Stabilized with Varying Percentages of Sand and Chipping Dust

Table 4.9 – 4.10 depicts the maximum dry unit weight and optimum moisture content of laterite stabilized with sand and a blend of sand with chipping dust at varying percentages. The peak value of maximum dry unit and optimum moisture content were obtained for laterite stabilized with a blend of sand and chipping dust at 10% each while that of the optimum moisture content was obtained for laterite stabilized with 7.5% of sand. The lowest value of maximum dry unit weight and optimum moisture content was obtained for the natural laterite sample and laterite stabilized with 10% of sand and 5% of chipping dust. On addition of sand to laterite, it was observed that the maximum dry unit weight of laterite increased from its natural value of 18.3kN/m^3 to 20.73kN/m^3 while for laterite stabilized with a blend of sand and chipping dust, a general increase in maximum dry unit weight of laterite was observed. It was also observed that the optimum moisture content generally decreased as the maximum dry unit weight increased,

this implies that less water content will be required to obtain maximum dry unit weight during field compaction. These results are in agreement with the works of Okonkwo et al. (2022), Rowe, (2000) and Venkatramiaah, (2006) and other concluded research works.

4.1.5 CBR Test

Table 4.11: California Bearing Ratio Results for Laterite Stabilized with Sand and Chipping Dust

% of Sand/% of Chipping Dust	0	2.5	5	7.5	10
0	10.61	13.6	15.2	16.7	19.7
2.5	17.4	18.9	21.2	26.7	29.5
5	31.1	33.3	34.1	35.6	36.4
7.5	31.8	32.6	33.3	34.8	36.4
10	31.8	32.6	34.8	40.2	41.7

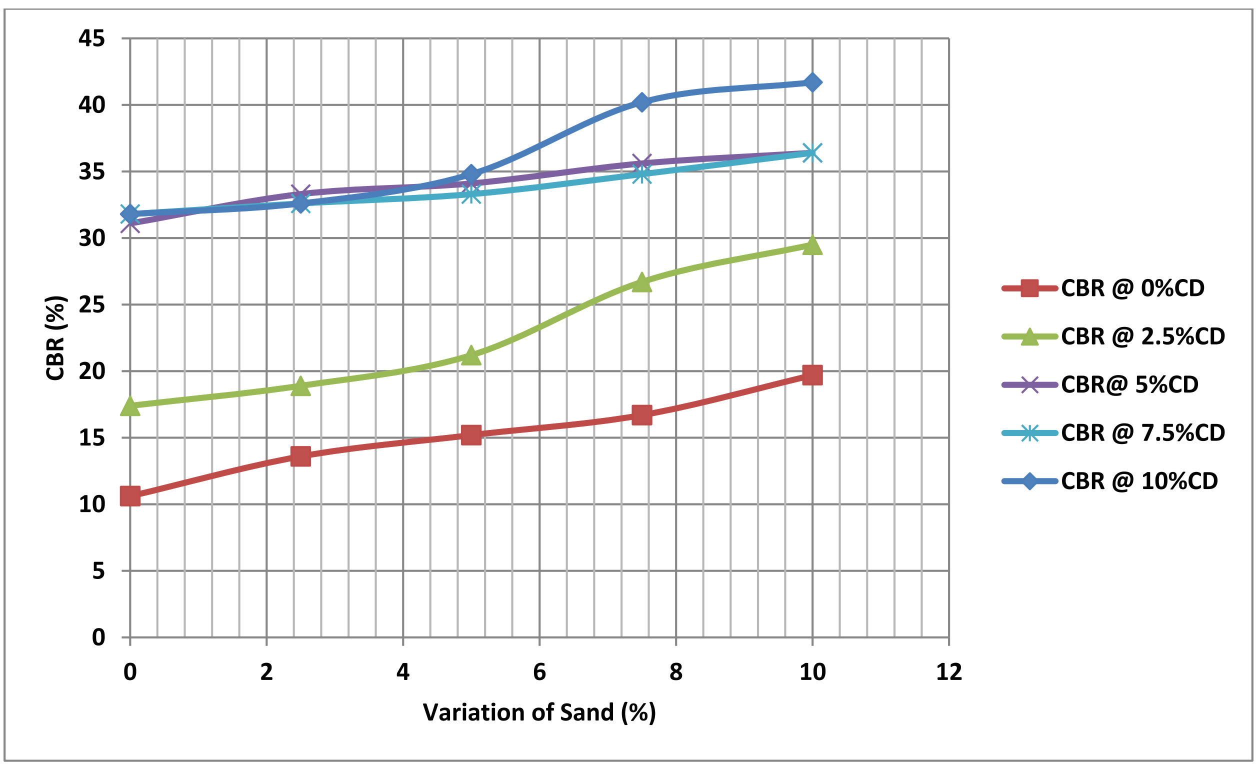

Figure 4.10: Graph Showing the CBR Values of Laterite Stabilized with Varying Percentages of Sand and Chipping Dust

Table 4.11 depicts the CBR characteristics of laterite stabilized with sand and chipping dust at varying percentages. The CBR characteristics of laterite stabilized with sand and chipping dust were similar to that of compaction. The highest CBR value was obtained for laterite stabilized with 10% sand and 10% chipping dust. The lowest CBR value was obtained for the natural laterite sample. On addition of sand and a blend of sand with chipping dust to laterite, significant improvement in CBR of the natural laterite soil was observed. The increase in CBR of the natural laterite from 10.61% to 41.7% could be attributed to the relative strength of the modifiers (sand and chipping dust). Addition of sand and chipping dust to laterite makes the laterite to satisfy the criterion for use as sub-base type 2 and 1 material for road construction. This finding is in agreement with the work of Mu azu, (2018) and Okonkwo, et al. (2022).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The following conclusion in the light of the findings obtained by the study can be drawn:

1 Grain size determination test for chipping dust, laterite and sand classified the samples as A-2-6, A-6 and A-2-4 according to AASHTO Soil Classification System and SM (sand mixed with silt), CL (clay of low plasticity) and SC (sand mixed with clay) according to Unified Soil Classification System.

2 The specific gravity of laterite, chipping dust and sand were 2.66, 2.76 and 2.55 respectively, this materials satisfied the requirements given by Federal Ministry of Works and Housing, (1999) which state that the specific gravity of road construction materials must fall within 2.55 to 2.75.

3 The liquid, plastic and plasticity index of laterite were found to decrease on addition of sand and a blend of sand with chipping dust to laterite. It was observed that beyond 5% sand and 2.5% chipping dust, the mixture became non-plastic.

4 The maximum dry unit weight of laterite was found to increase on addition of sand and a blend of sand with chipping dust to laterite.

5 The optimum moisture content was generally found to decrease as the maximum dry unit weight increased; this implies that less water will be required to attain maximum dry unit weight during field compaction.

6 The CBR of laterite were found to increase on addition of sand and a blend of sand with chipping dust to laterite.

7 The chipping dust and sand were therefore adjudged as effective modifiers since enhancement in compaction and CBR characteristics of the natural lateritic soil was observed.

5.2 Recommendation

From the findings obtained on investigation of the geotechnical properties of laterite stabilized with sand and chipping dust, the following recommendation can be made:

1 The study recommends the use of mechanical stabilization as a cost effective means of treating poor lateritic soils encountered in the field. Weak lateritic soils should be subjected to treatment through stabilization using sand and chipping dust.

2 To achieve cost effectiveness in mechanical stabilization of poor lateritic soils, it is very pertinent to note the quantity of sand required to yield the optimum geotechnical properties in poor lateritic soils as sand is a relatively expensive chemical stabilizing agents.

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APPENDICES

APPENDIX A

CBR Test

Table A1: CBR Result for LAT+ 0%SD + 0%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	0.3	0.5	0.8	1.1	1.4	1.7	2	2.2	2.5	2.8	3.1	3.4	3.7	4
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	0.1	0.4	0.7	0.9	1.1	1.4	1.7	2.0	2.2	2.5	2.8	3.1	3.4	3.7

Table A2: CBR Result for LAT + 2.5%SD + 0%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	0.6	0.9	1.1	1.5	1.8	2.1	2.4	2.6	2.9	3.2	3.5	3.8	4.1	4.4
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	0.4	0.6	0.9	1.1	1.3	1.7	1.9	2.2	2.5	2.8	3.1	3.4	3.6	3.9

Table A3: CBR Result for LAT + 5%SD + 0%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	0.8	1.1	1.4	1.7	2	2.3	2.6	2.9	3.1	3.4	3.7	4	4.3	4.6
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	0.3	0.7	0.9	1.2	1.4	1.7	2	2.1	2.4	2.7	2.9	3.1	3.4	3.7

Table A4: CBR Result for LAT + 7.5%SD + 0%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7

Dial reading (Top)	**36**	**54**	**71**	**84**	**96**	**108**	**115**	**122**	**126**	**130**	**136**	**140**	**154**	**158**
Force (KN)	**1.1**	**1.4**	**1.7**	**2**	**2.2**	**2.5**	**2.7**	**2.9**	**3.2**	**3.4**	**3.6**	**3.8**	**4.1**	**4.3**
Dial reading (Bottom)	**10**	**25**	**38**	**52**	**67**	**82**	**99**	**110**	**126**	**137**	**148**	**157**	**166**	**174**
Force (KN)	**0.7**	**1**	**1.2**	**1.5**	**1.7**	**1.9**	**2.1**	**2.3**	**2.5**	**2.7**	**2.9**	**3.1**	**3.3**	**3.5**

Table A5: CBR Result for LAT + 10%SD + 0%CD

Penetration (mm)	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**
Dial reading (Top)	**36**	**54**	**71**	**84**	**96**	**108**	**115**	**122**	**126**	**130**	**136**	**140**	**154**	**158**
Force (KN)	**1.3**	**1.6**	**1.8**	**2.3**	**2.6**	**2.8**	**3.0**	**3.2**	**3.5**	**3.7**	**3.8**	**4.1**	**4.3**	**4.5**
Dial reading (Bottom)	**10**	**25**	**38**	**52**	**67**	**82**	**99**	**110**	**126**	**137**	**148**	**157**	**166**	**174**
Force (KN)	**0.9**	**1.2**	**1.5**	**1.8**	**2.1**	**2.4**	**2.6**	**2.9**	**3.1**	**3.3**	**3.5**	**3.7**	**3.8**	**4.0**

Table A6: CBR Result for LAT + 0%SD + 2.5%CD

Penetration (mm)	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**
Dial reading (Top)	**36**	**54**	**71**	**84**	**96**	**108**	**115**	**122**	**126**	**130**	**136**	**140**	**154**	**158**
Force (KN)	**1.2**	**1.4**	**1.7**	**2**	**2.3**	**2.7**	**2.9**	**3**	**3.2**	**3.4**	**3.7**	**4**	**4.2**	**4.3**
Dial reading (Bottom)	**10**	**25**	**38**	**52**	**67**	**82**	**99**	**110**	**126**	**137**	**148**	**157**	**166**	**174**
Force (KN)	**0.6**	**0.9**	**1.1**	**1.4**	**1.7**	**2.0**	**2.2**	**2.4**	**2.7**	**2.9**	**3.1**	**3.3**	**3.5**	**3.7**

Table A7: CBR Result for LAT+ 2.5%SD + 2.5%CD

Penetration (mm)	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**
Dial reading (Top)	**36**	**54**	**71**	**84**	**96**	**108**	**115**	**122**	**126**	**130**	**136**	**140**	**154**	**158**
Force (KN)	**1**	**1.4**	**1.8**	**2.2**	**2.5**	**2.8**	**3.2**	**3.5**	**3.7**	**4**	**4.3**	**4.6**	**4.9**	**5.2**
Dial reading (Bottom)	**10**	**25**	**38**	**52**	**67**	**82**	**99**	**110**	**126**	**137**	**148**	**157**	**166**	**174**
Force (KN)	**0.7**	**1**	**1.4**	**1.7**	**2**	**2.2**	**2.5**	**2.7**	**3**	**3.2**	**3.5**	**3.7**	**4**	**4.2**

Table A8: CBR Result for LAT+ 5%SD + 2.5%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	1.4	1.8	2.3	2.5	2.8	3.1	3.4	3.7	3.9	4.2	4.4	4.6	4.9	5.2
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	1.1	1.3	1.7	2.1	2.4	2.7	3	3.3	3.6	3.9	4.2	4.5	4.8	5.1

Table A9: CBR Result for LAT + 7.5%SD + 2.5%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	1.8	2.4	2.9	3.3	3.5	3.8	4.2	4.5	4.7	5	5.3	5.6	5.8	6.2
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	1.4	1.7	2.1	2.4	2.7	3	3.4	3.7	4	4.3	4.6	4.9	5.2	5.5

Table A10: CBR Result for LAT + 10%SD + 2.5%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	2.2	2.7	3.1	3.5	3.9	4.2	4.5	4.8	5.1	5.4	5.7	6.1	6.4	6.7
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	1.7	2	2.4	2.7	3	3.3	3.7	4	4.3	4.6	4.9	5.2	5.5	5.8

Table A11 CBR Result for LAT + 0%SD + 5%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	2.5	3	3.4	3.8	4.1	4.4	4.7	5	5.2	5.6	5.9	6.2	6.4	6.7
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	1.9	2.2	2.6	2.9	3.2	3.5	3.8	4	4.3	4.6	4.9	5.2	5.5	5.8

Table A12: CBR Result for LAT+ 2.5%SD + 5%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	2.8	3.2	3.6	4.1	4.4	4.8	5.2	5.6	5.8	6.3	6.6	6.9	7.1	7.4
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	1.5	1.8	2.2	2.7	3.0	3.4	3.8	4.2	4.6	4.8	5.1	5.4	5.7	6.1

Table A13: CBR Result for LAT + 5%SD + 5%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	2.7	3.1	3.6	4	4.5	4.8	5.2	5.5	5.7	6.1	6.5	6.8	7.1	7.3
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	2.1	2.4	2.7	3.1	3.4	3.8	4.2	4.5	4.9	5.2	5.5	5.8	6.1	6.4

Table A14: CBR Result for LAT + 7.5%SD + 5%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	3	3.4	3.7	4.2	4.7	5	5.3	5.6	5.9	6.4	6.8	7.2	7.5	7.8
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	2.4	2.7	3.1	3.5	3.8	4.1	4.5	4.8	5.2	5.6	5.9	6.2	6.5	6.8

Table A15: CBR Result for LAT + 10%SD + 5%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	3.3	3.8	4.1	4.5	4.8	5.1	5.3	5.6	6	6.6	6.9	7.2	7.5	7.8
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	2.7	3	3.3	3.5	3.8	4.2	4.5	4.9	5.2	5.6	5.9	6.2	6.5	6.8

Table A16: CBR Result for LAT + 0%SD + 7.5%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	2.6	3	3.4	3.8	4.2	4.4	4.7	5	5.2	5.6	5.9	6.2	6.4	6.7
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	2	2.3	2.6	2.9	3.2	3.5	3.8	4	4.3	4.6	4.9	5.2	5.5	5.8

Table A17: CBR Result for LAT + 2.5%SD + 7.5%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	2.8	3.1	3.4	3.8	4.3	4.5	4.7	5	5.2	5.6	5.9	6.2	6.4	6.7
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	2.1	2.4	2.7	3	3.3	3.6	3.9	4.2	4.5	4.8	5.1	5.4	5.7	6

Table A18: CBR Result for LAT + 5%SD + 7.5%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	3	3.4	3.7	4	4.4	4.8	5.1	5.4	5.7	6	6.3	6.5	6.8	7.1
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	2.4	2.7	3	3.2	3.5	3.8	4.1	4.4	4.7	5	5.4	5.7	6	6.3

Table A19: CBR Result for LAT + 7.5%SD + 7.5%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	3.2	3.6	3.9	4.3	4.6	5.1	5.4	5.7	6	6.2	6.5	6.8	7.1	7.4
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	2.6	3	3.3	3.7	4	4.3	4.6	5	5.3	5.6	5.9	6.2	6.5	6.8

Table A20: CBR Result for LAT + 10%SD + 7.5%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	3.4	3.8	4.2	4.5	4.8	5.2	5.6	5.9	6.3	6.5	6.8	7.2	7.4	7.6
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	2.9	3.1	3.3	3.7	4	4.3	4.6	5	5.3	5.6	5.9	6.2	6.5	6.8

Table A21: CBR Result for LAT + 0%SD + 10%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	2.8	3.1	3.4	3.8	4.2	4.5	4.7	5	5.2	5.6	5.9	6.2	6.4	6.7
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	2.3	2.6	2.8	3	3.3	3.6	3.9	4.2	4.5	4.8	5.1	5.4	5.7	6

Table A22: CBR Result for LAT + 2.5%SD + 10%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	3.1	3.3	3.7	4	4.3	4.6	4.8	5	5.2	5.6	5.9	6.2	6.4	6.7
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	2.6	2.8	3.1	3.4	3.7	4	4.2	4.5	4.8	5	5.3	5.6	5.8	6.1

Table A23: CBR Result for LAT + 5%SD + 10%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	3.3	3.6	4	4.3	4.6	4.9	5.1	5.3	5.5	5.8	6.1	6.4	6.7	7
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	3	3.3	3.6	3.9	4.1	4.4	4.7	5	5.3	5.5	5.7	5.9	6.1	6.3

Table A24: CBR Result for LAT + 7.5%SD + 10%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	3.6	4.1	4.5	4.9	5.3	5.6	5.9	6.2	6.4	6.8	7.1	7.3	7.5	7.8
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	3.1	3.4	3.6	3.9	4.1	4.4	4.7	5	5.3	5.5	5.7	5.9	6.1	6.3

Table A25: CBR Result for LAT + 10%SD + 10%CD

Penetration (mm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
Dial reading (Top)	36	54	71	84	96	108	115	122	126	130	136	140	154	158
Force (KN)	3.8	4.2	4.6	5.1	5.5	5.8	6	6.2	6.4	6.8	7.1	7.3	7.5	7.8
Dial reading (Bottom)	10	25	38	52	67	82	99	110	126	137	148	157	166	174
Force (KN)	3.4	3.7	4	4.4	4.7	4.9	5.1	5.3	5.7	5.9	6.2	6.5	6.7	6.9

APPENDIX B

Liquid and Plastic Limit Test

Table B1: Liquid Limit Result for LAT + 0%SD + 0%CD

BLOWS	33	28	23	17	13
Wt of empty tin (g)	15.07	15.68	15.29	17.73	14.38
Wt of tin + wet soil (g)	25.58	25.67	25.08	26.82	21.51
Wt of tin + dry soil (g)	22.96	22.79	22.05	23.78	18.85
Wt of wet soil (g)	10.51	9.99	9.79	9.09	7.13
Wt of dry soil (g)	7.89	7.11	6.76	6.05	4.47
Wt of water (g)	2.62	2.88	3.03	3.04	2.66
Moisture Content (%)	33.21		44.82	50.25	59.51

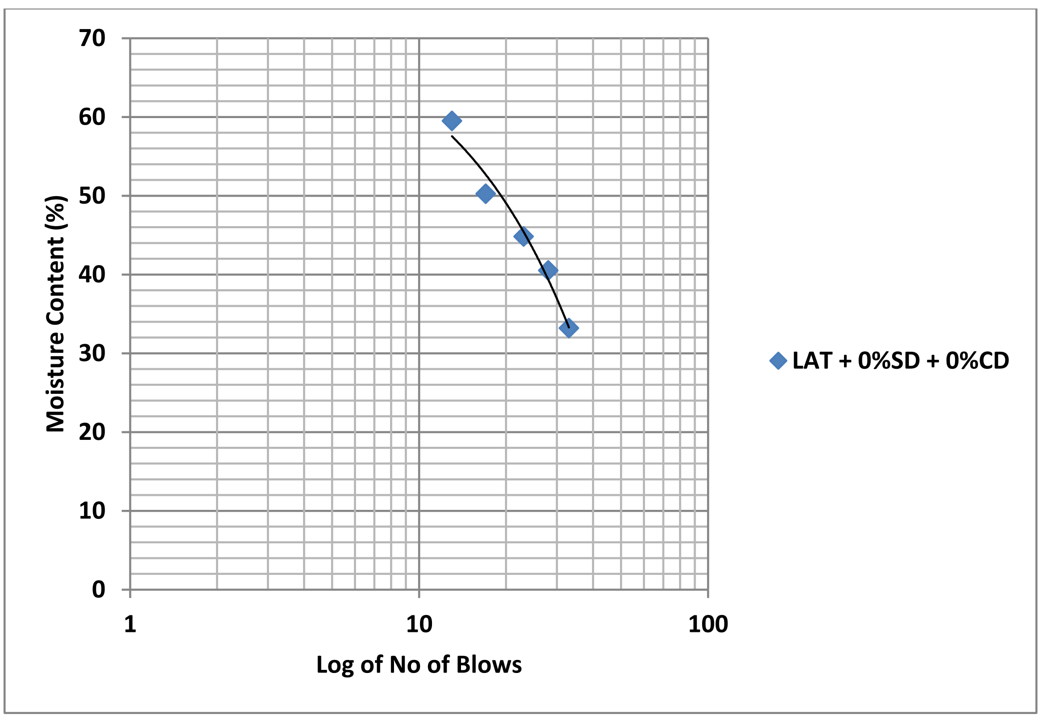

Figure B1: Liquid Limit Graph for LAT + 0%SD + 0%CD

Table B2: Liquid Limit Result for LAT + 2.5%SD + 0%CD

BLOWS	32	26	22	18	13
Wt of empty tin (g)	14.7	13.53	17.76	15.86	14.21
Wt of tin + wet soil (g)	18.62	17.94	23.04	20.38	19.45
Wt of tin + dry soil (g)	17.71	16.71	21.49	18.94	17.58
Wt of wet soil (g)	3.92	4.41	5.28	4.52	5.24
Wt of dry soil (g)	3.01	3.18	3.73	3.08	3.37
Wt of water (g)	0.91	1.23	1.55	1.44	1.87
Moisture Content (%)	30.23	38.68	41.55	46.75	55.49

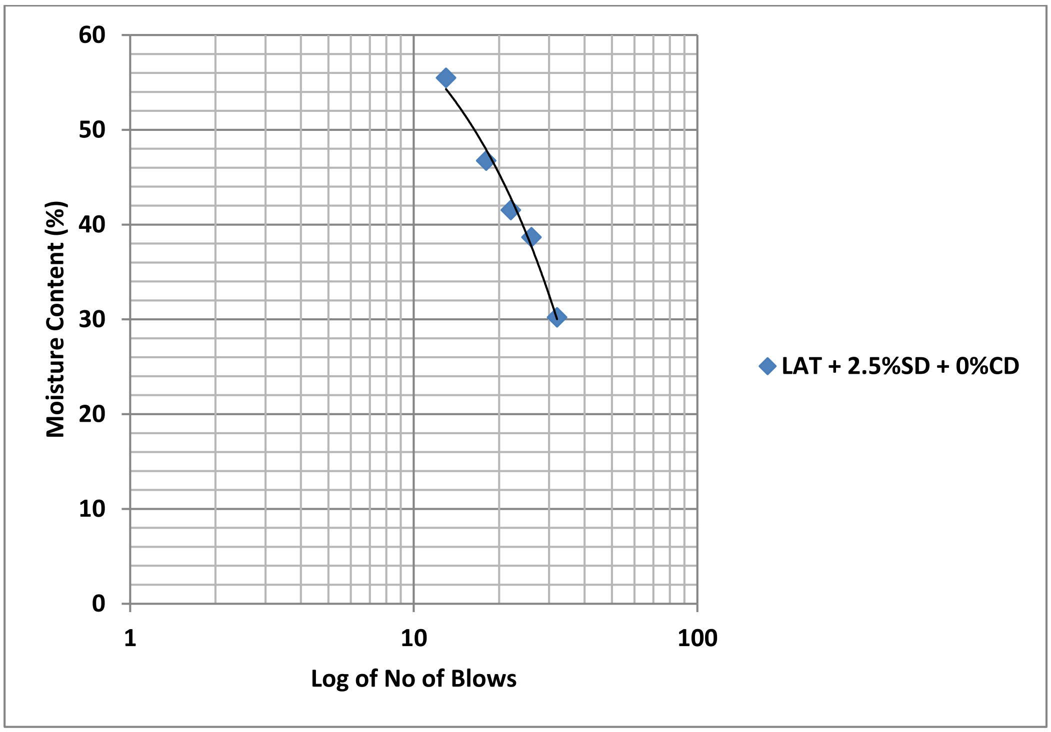

Figure B2: Liquid Limit Graph for LAT + 2.5%SD + 0%CD

Table B3: Liquid Limit Result for LAT + 5%SD + 0%CD

BLOWS	33	27	24	18	14
Wt of empty tin (g)	14.82	15.64	16.48	14.88	15.21
Wt of tin + wet soil (g)	46.24	34.62	32.28	26.94	30.66
Wt of wet soil (g)	31.42	18.98	15.8	12.06	15.45

Wt of tin +dry soil (g)	**39.14**	**29.78**	**27.78**	**23.25**	**25.67**
Wt of dry soil (g)	**24.32**	**14.14**	**11.3**	**8.37**	**10.46**
Wt of water (g)	**7.1**	**4.84**	**4.5**	**3.69**	**4.99**
Moisture Content (g)	**29.19**	**34.23**	**39.82**	**44.09**	**47.71**

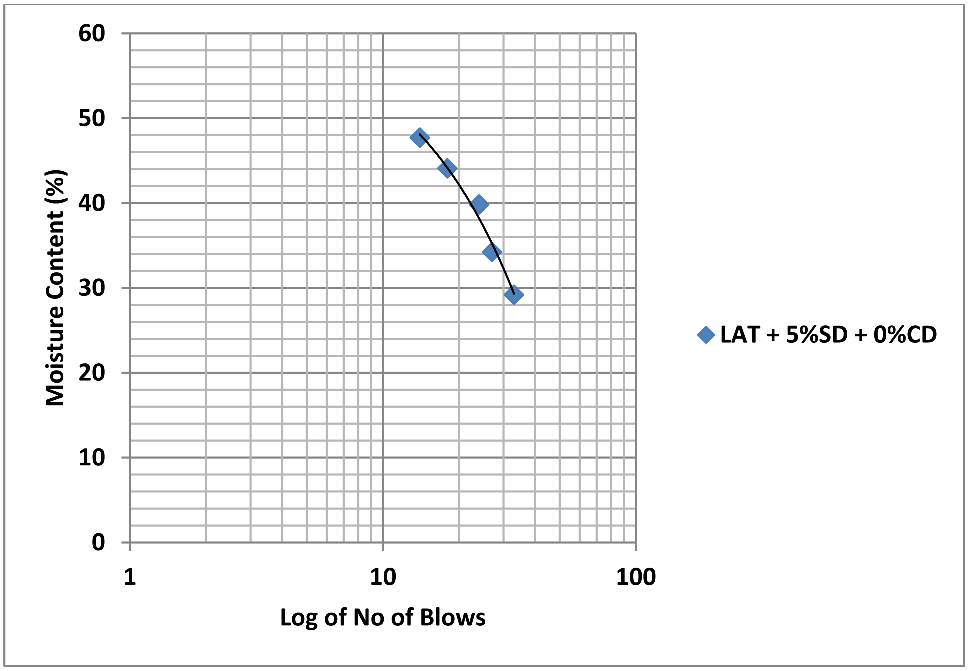

Figure B3: Liquid Limit Graph for LAT + 5%SD + 0%CD

Table B4: Liquid Limit Result for LAT + 7.5%SD + 0%CD

BLOWS	**33**	**28**	**23**	**17**	**13**
Wt of empty tin (g)	**14.18**	**16.42**	**17.16**	**15.49**	**16.04**
Wt of tin + wet soil (g)	**50.16**	**44.28**	**46.28**	**48.56**	**40.82**
Wt of wet soil (g)	**35.98**	**27.86**	**29.12**	**33.07**	**24.78**
Wt of tin +dry soil (g)	**42.68**	**37.69**	**38.59**	**39.45**	**33.67**
Wt of dry soil (g)	**28.5**	**21.27**	**21.43**	**23.96**	**17.63**
Wt of water (g)	**7.48**	**6.59**	**7.69**	**9.11**	**7.15**
Moisture Content (g)	**26.25**	**30.98**	**35.88**	**38.02**	**40.56**

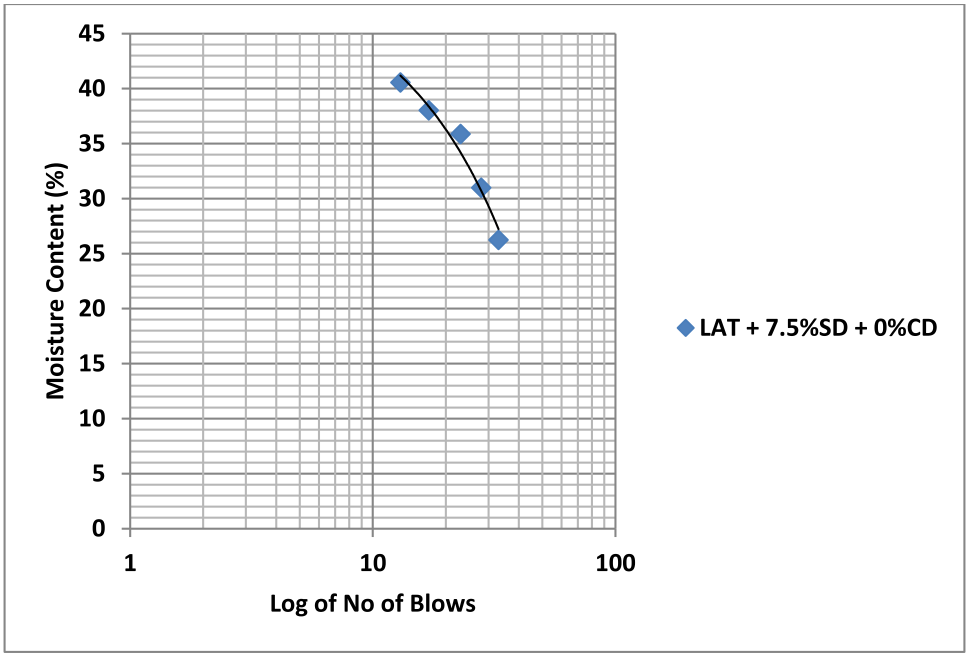

Figure B4: Liquid Limit Graph for LAT + 7.5%SD + 0%CD

Table B5: Liquid Limit Result for LAT + 10%SD + 0%CD

BLOWS	33	26	22	18	14
Wt of empty tin (g)	14.89	18.46	17.56	15.06	16.57
Wt of tin + wet soil (g)	45.05	50.57	47.44	40.93	49.21
Wt of wet soil (g)	30.16	32.11	29.88	25.87	32.64
Wt of tin +dry soil (g)	39.98	43.96	41.05	34.71	40.61
Wt of dry soil (g)	25.09	25.5	23.49	19.65	24.04
Wt of water (g)	5.07	6.61	6.39	6.22	8.6
Moisture Content (g)	20.21	25.92	27.20	31.65	35.77

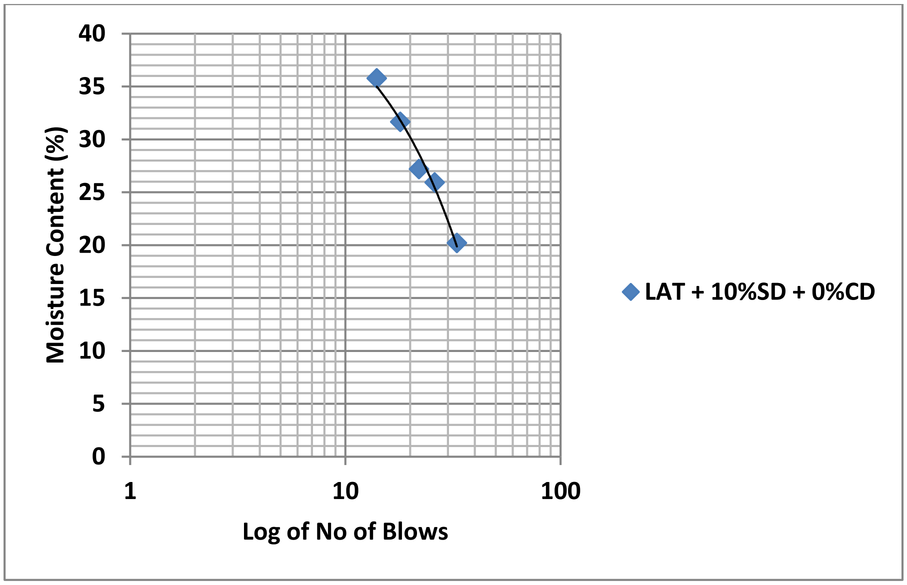

Figure B5: Liquid Limit Graph for LAT + 10%SD + 0%CD

Table B6: Liquid Limit Result for LAT + 0%SD + 2.5%CD

No of Blows	32	28	22	27	13
Wt of Empty Tin (g)	14.42	16.38	16.32	15.12	14.84
Wt of Tin + Wet Soil (g)	30.3	24.77	32.18	26.54	29.89
Wt of Wet Soil (g)	15.88	8.39	15.86	11.42	15.05
Wt of Tin + Oven-dried Soil (g)	27.13	22.74	27.76	23.27	25.21
Wt of Oven-dried Soil (g)	12.71	6.36	11.44	8.15	10.37
Wt of Water (g)	3.17	2.03	4.42	3.27	4.68
Moisture Content (%)	24.94	31.92	38.64	40.12	45.13

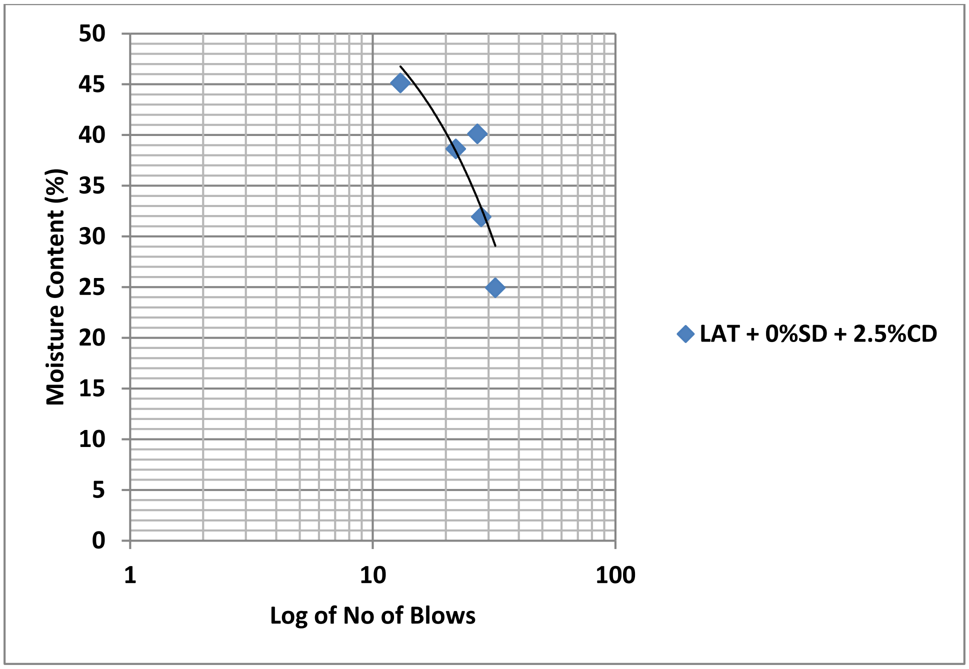

Figure B6: Liquid Limit Graph for LAT + 0%SD + 2.5%CD

Table B7: Liquid Limit Result for LAT + 2.5%SD + 2.5%CD

BLOWS	33	27	23	18	14
Wt of empty tin (g)	**14.89**	**18.46**	**17.56**	**15.06**	**16.57**
Wt of tin + wet soil (g)	**45.15**	**50.57**	**47.44**	**40.93**	**49.21**
Wt of wet soil (g)	**30.26**	**32.11**	**29.88**	**25.87**	**32.64**
Wt of tin +dry soil (g)	**39.98**	**43.97**	**41.15**	**34.71**	**40.71**
Wt of dry soil (g)	**25.09**	**25.51**	**23.59**	**19.65**	**24.14**
Wt of water (g)	**5.17**	**6.6**	**6.29**	**6.22**	**8.5**
Moisture Content (g)	**20.61**	**25.87**	**26.66**	**31.65**	**35.21**

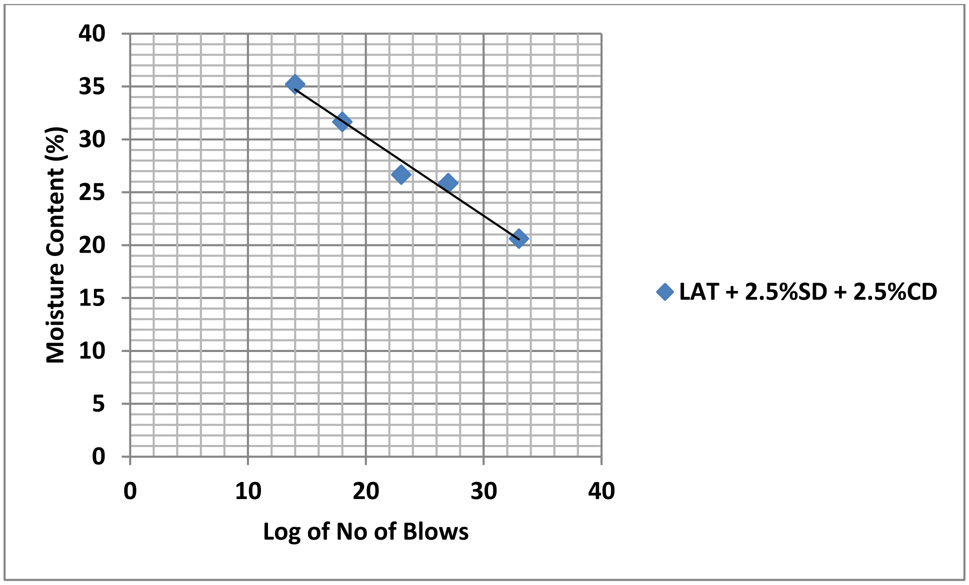

Figure B7: Liquid Limit Graph for LAT + 2.5%SD + 2.5%CD

Table B8: Liquid Limit Result for LAT + 5%SD + 2.5%CD

No of Blows	34	29	23	28	14
Wt of Empty Tin (g)	14.42	16.38	16.32	15.12	14.84
Wt of Tin + Wet Soil (g)	32.9	24.77	32.18	26.54	29.89
Wt of Wet Soil (g)	18.48	8.39	15.86	11.42	15.05
Wt of Tin + Oven-dried Soil (g)	30.04	23.24	28.96	24.07	26.21
Wt of Oven-dried Soil (g)	15.62	6.86	12.64	8.95	11.37
Wt of Water (g)	2.86	1.53	3.22	2.47	3.68
Moisture Content (%)	18.31	22.30	25.47	27.60	32.37

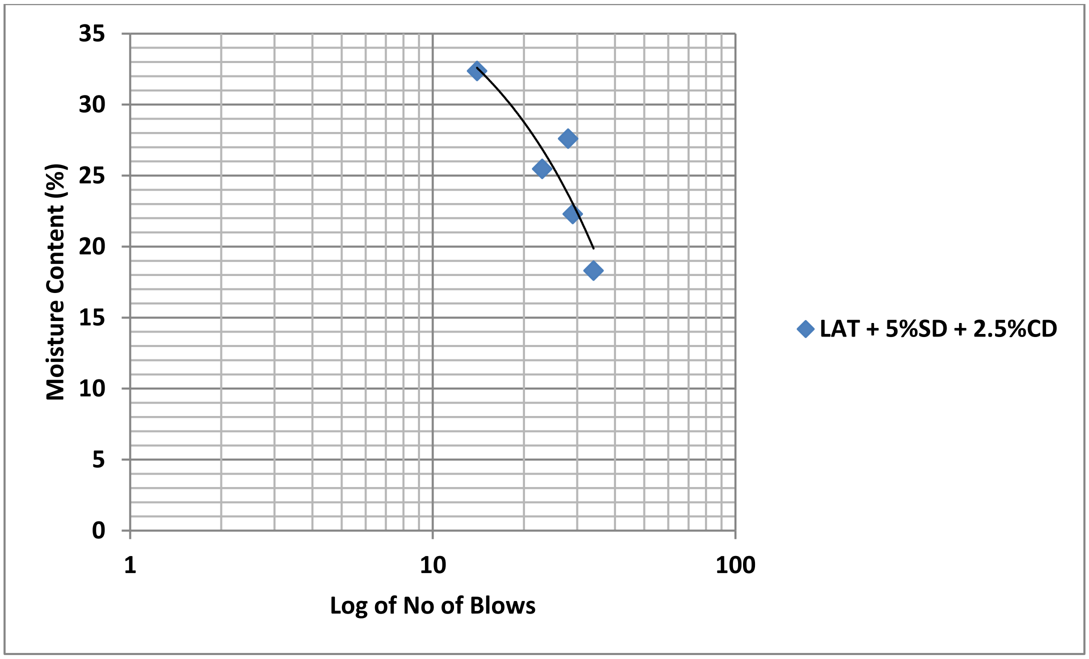

Figure B8: Liquid Limit Graph for LAT + 5%SD + 2.5%CD

Table B9: Plastic Limit Results for LAT + 0%SD + 0%CD

LAT + 0%SD + 0%CD	Test 1	Test 2	Test 3
Wt of empty tin (g)	16.28	15.68	15.27
Wt of tin + wet soil (g)	17.92	16.34	16.59
Wt of tin + dry soil (g)	17.55	16.21	16.28
Wt of wet soil (g)	1.64	0.66	1.32
Wt of dry soil (g)	1.27	0.53	1.01
Wt of water (%)	0.37	0.13	0.31
Plastic Limit (%)	29.13	24.53	30.69

Table B10: Plastic Limit Results for LAT + 2.5%SD + 0%CD

LAT 2.5%SD + 0%CD	Test 1	Test 2	Test 3
Wt of empty tin (g)	15.18	16.48	15.54
Wt of tin + wet soil (g)	15.83	17.28	16.54
Wt of tin + dry soil (g)	15.71	17.09	16.35
Wt of wet soil (g)	0.65	0.8	1

Wt of dry soil (g)	**0.53**	**0.61**	**0.81**
Wt of water (%)	**0.12**	**0.19**	**0.19**
Plastic Limit (%)	**22.64**	**31.15**	**23.46**

Table B11: Plastic Limit Results for LAT + 5%SD + 0%CD

LAT + 5%SD + 0%CD	Test 1	Test 2	Test 3
Wt of empty tin (g)	14.32	15.84	14.82
Wt of tin + wet soil (g)	34.77	29.24	36.74
Wt of wet soil (g)	20.45	13.4	21.92
Wt of tin + dry soil (g)	31.31	26.91	33.09
Wt of dry soil (g)	16.99	11.07	18.27
Wt of water (g)	3.46	2.33	3.65
Plastic Limit (%)	20.36	21.05	19.98

Table B12: Plastic Limit Results for LAT + 7.5%SD + 0%CD

LAT + 7.5%SD + 0%CD	Test 1	Test 2	Test 3
Wt of empty tin (g)	15.62	14.7	13.64
Wt of tin + wet soil (g)	26.84	30.52	34.88
Wt of wet soil (g)	11.22	15.82	21.24
Wt of tin + dry soil (g)	25.02	28.44	31.61
Wt of dry soil (g)	9.4	13.74	17.97
Wt of water (g)	1.82	2.08	3.27
Plastic Limit (%)	19.36	15.14	18.20

Table B13: Plastic Limit Results for LAT + 10%SD + 0%CD

LAT + 10%SD + 0%CD	Test 1	Test 2	Test 3
Wt of empty tin (g)	14.63	15.42	16.88
Wt of tin + wet soil (g)	24.86	28.69	32.88
Wt of wet soil (g)	10.23	13.27	16
Wt of tin + dry soil	23.49	27.03	30.47

(g)			
Wt of dry soil (g)	8.86	11.61	13.59
Wt of water (g)	1.37	1.66	2.41
Plastic Limit (%)	15.46	14.30	17.73

Table B14: Plastic Limit Results for LAT + 0%SD + 2.5%CD

Wt of Empty Tin (g)	15.21	14.88	16.32
Wt of Tin + Wet Soil (g)	30.2	24.81	23.49
Wt of Wet Soil (g)	14.99	9.93	7.17
Wt of Tin + Oven-dried Soil (g)	28.22	23.66	22.79
Wt of Oven-dried Soil (g)	13.01	8.78	6.47
Wt of Water (g)	1.98	1.15	0.7
Moisture Content (%)	15.22	13.10	10.82

Table B15: Plastic Limit Results for LAT + 2.5%SD + 2.5%CD

LAT + 2.5%SD + 2.5%CD	Test 1	Test 2	Test 3
Wt of empty tin (g)	17.62	16.86	14.49
Wt of tin + wet soil (g)	21.86	19.42	19.67
Wt of wet soil (g)	4.24	2.56	5.18
Wt of tin + dry soil (g)	21.42	19.14	19.01
Wt of dry soil (g)	3.8	2.28	4.52
Wt of water (g)	0.44	0.28	0.66
Plastic Limit (%)	11.58	12.28	14.60

Table B16: Plastic Limit Results for LAT + 5%SD + 2.5%CD

Wt of Empty Tin (g)	15.21	14.88	16.32
Wt of Tin + Wet Soil (g)	28.7	25.92	30.9
Wt of Wet Soil (g)	13.49	11.04	14.58
Wt of Tin + Oven-dried Soil (g)	28.02	24.66	28.99
Wt of Oven-dried Soil (g)	12.81	9.78	12.67
Wt of Water (g)	0.68	1.26	1.91
Moisture Content (%)	5.31	12.88	15.07

APPENDIX C

Compaction Test

Table C1: Dry Unit Weight Determination for LAT + 0%SD + 0%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.4	1.4	13.73	3.74	13.77
8	0.001	4	5.55	1.55	15.21	6.08	15.27
12	0.001	4	5.7	1.7	16.68	11.17	16.79
16	0.001	4	5.85	1.85	18.15	14.61	18.29
20	0.001	4	5.8	1.8	17.66	22.73	17.89

Table C1.1: Moisture Content Determination for LAT + 0%SD + 0%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	14.71	28.34	13.63	27.85	13.14	0.49	3.73
8	15.03	40.04	25.01	39.04	24.01	1	4.16
12	14.31	46.22	31.91	43.06	28.75	3.16	10.99
16	17.82	65.65	47.83	59.54	41.72	6.11	14.65
20	13.56	63.34	49.78	52.78	39.22	10.56	26.93

Table C1.2: Moisture Content Determination for LAT + 0%SD + 0%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	15.83	32.73	16.9	32.12	16.29	0.61	3.74
8	14.44	46.43	31.99	44.06	29.62	2.37	8.00
12	14.06	45.44	31.38	42.24	28.18	3.2	11.36
16	17.45	55.99	38.54	51.09	33.64	4.9	14.57
20	13.79	55.75	41.96	49.19	35.4	6.56	18.53

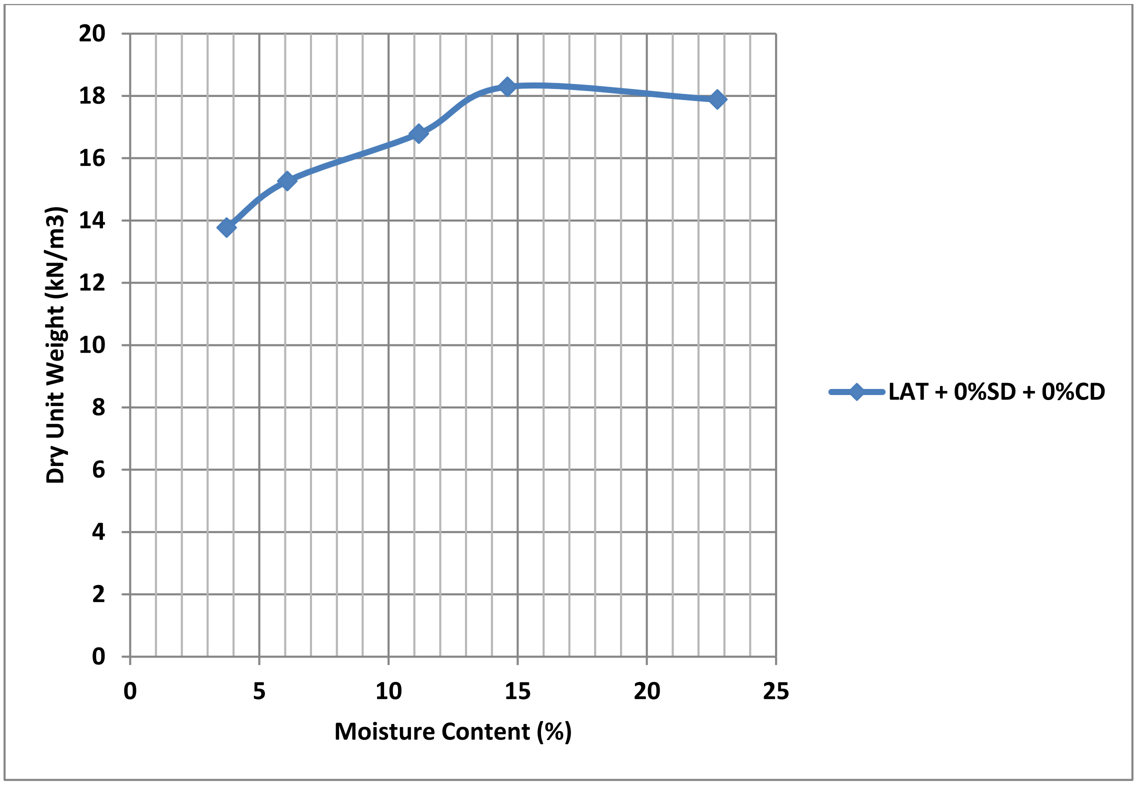

Figure C1: Compaction Curve for LAT + 0%SD + 0%CD

Table C2: Dry Unit Weight Determination for LAT + 2.5%SD + 0%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.5	1.5	14.72	4.55	`14.08
8	0.001	4	5.75	1.75	17.17	8.24	17.25
12	0.001	4	5.85	1.85	18.15	11.80	18.27
16	0.001	4	5.95	1.95	19.13	14.53	19.27
20	0.001	4	5.9	1.9	18.64	19.06	18.83

Table C2.1: Moisture Content Determination for LAT +2.5%SD + 0%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	14.53	30.36	15.83	29.67	15.14	0.69	4.56

8	14.04	39.51	25.47	37.68	23.64	1.83	7.74
12	14.54	43.27	28.73	40.24	25.7	3.03	11.79
16	14.28	48	33.72	43.79	29.51	4.21	14.27
20	14.82	52.36	37.54	46.37	31.55	5.99	18.99

Table C2.2: Moisture Content Determination for LAT + 2.5%SD + 0%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	14.56	36.92	22.36	35.95	21.39	0.97	4.53
8	14.56	40.2	25.64	38.14	23.58	2.06	8.74
12	17.13	55.11	37.98	51.1	33.97	4.01	11.80
16	15.68	59.39	43.71	53.76	38.08	5.63	14.78
20	15.11	59.32	44.21	52.22	37.11	7.1	19.13

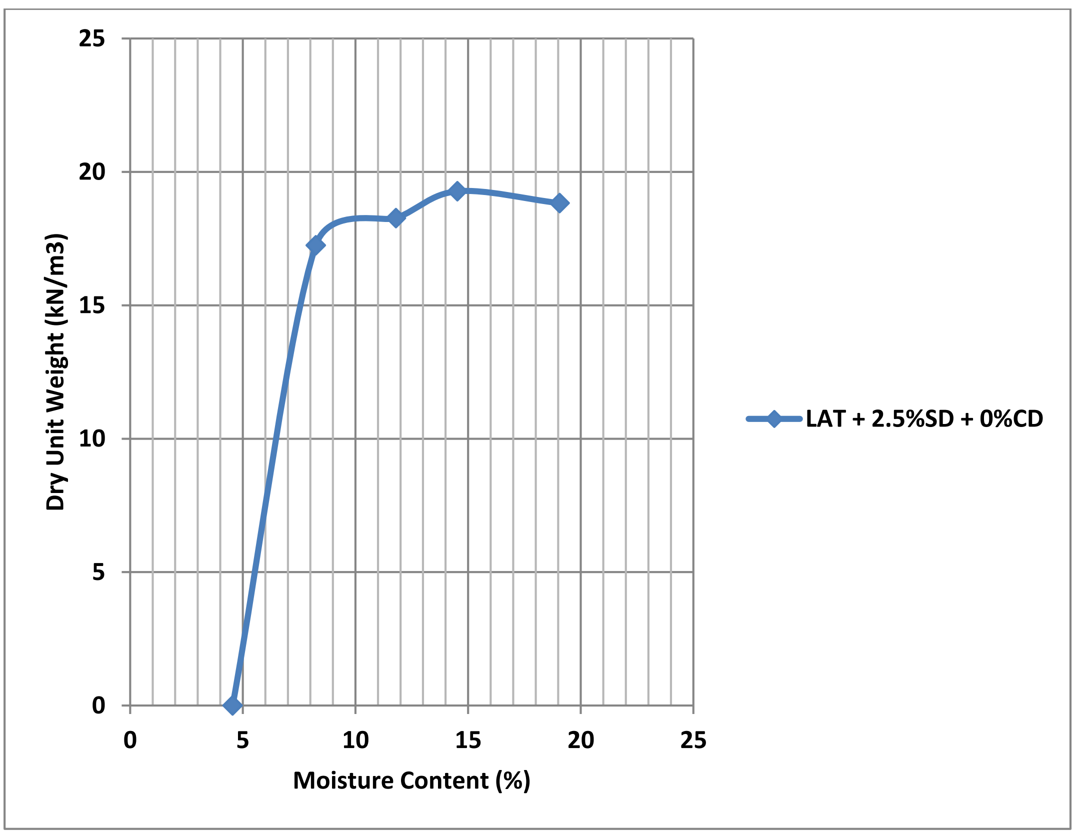

Figure C2: Compaction Curve for LAT + 2.5%SD + 0%CD

Table C3: Dry Unit Weight Determination for LAT + 5%SD + 0%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.6	1.6	15.70	5.96	15.76
8	0.001	4	5.75	1.75	17.17	10.07	17.27
12	0.001	4	5.95	1.95	19.13	14.21	19.27
16	0.001	4	6	2	19.62	17.78	19.80
20	0.001	4	5.9	1.9	18.64	21.58	18.85

Table C3.1: Moisture Content Determination for LAT + 5%SD + 0%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	16.65	34.58	17.93	33.38	16.73	1.2	7.17
8	15.88	47.69	31.81	45.16	29.28	2.53	8.64
12	15.3	51	35.7	46.74	31.44	4.26	13.55
16	14.18	70.95	56.77	62.5	48.32	8.45	17.49
20	15.08	65.43	50.35	56.86	41.78	8.57	20.51

Table C3.2: Moisture Content Determination for LAT + 5%SD + 0%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	14.85	29.22	14.37	28.57	13.72	0.65	4.74
8	17.82	58.27	40.45	54.1	36.28	4.17	11.49
12	17.82	46.41	28.59	42.71	24.89	3.7	14.87
16	15.52	64.84	49.32	57.29	41.77	7.55	18.08
20	16.64	67.76	51.12	58.32	41.68	9.44	22.65

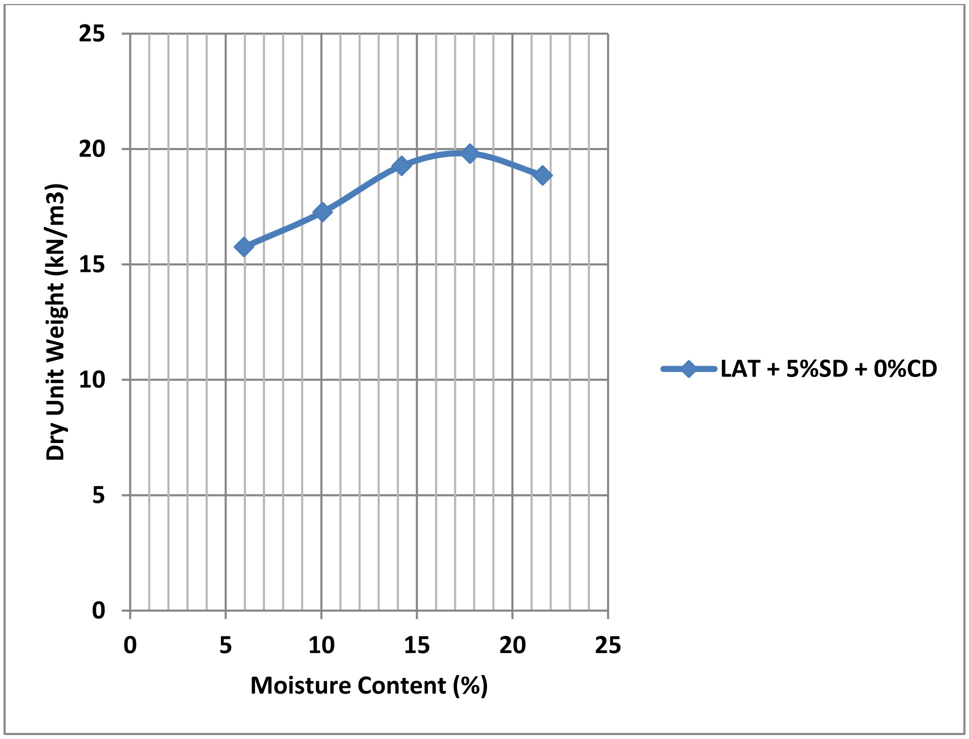

Figure C3: Compaction Curve for LAT + 5%SD + 0%CD

Table C4: Dry Unit Weight Determination for LAT + 7.5%SD + 0%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.7	1.7	16.68	5.18	16.73
8	0.001	4	5.85	1.85	18.15	9.52	18.24
12	0.001	4	5.95	1.95	19.13	12.89	19.26
16	0.001	4	6.05	2.05	20.11	17.08	20.28
20	0.001	4	6	2	19.62	20.66	19.83

Table C4.1: Moisture Content Determination for LAT + 7.5%SD + 0%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	15.57	37.16	21.59	36.1	20.53	1.06	5.16
8	15.36	35.15	19.79	33.41	18.05	1.74	9.64

12	14.48	41.96	27.48	38.89	24.41	3.07	12.58
16	13.6	53.16	39.56	47.5	33.9	5.66	16.70
20	16.7	58.92	42.22	51.67	34.97	7.25	20.73

Table C4.2: Moisture Content Determination for LAT + 7.5%SD + 0%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	14.98	43.71	28.73	42.29	27.31	1.42	5.20
8	15.22	38.73	23.51	36.71	21.49	2.02	9.40
12	13.84	57.38	43.54	52.3	38.46	5.08	13.21
16	15.86	63.41	47.55	56.34	40.48	7.07	17.47
20	14.49	60.63	46.14	52.75	38.26	7.88	20.60

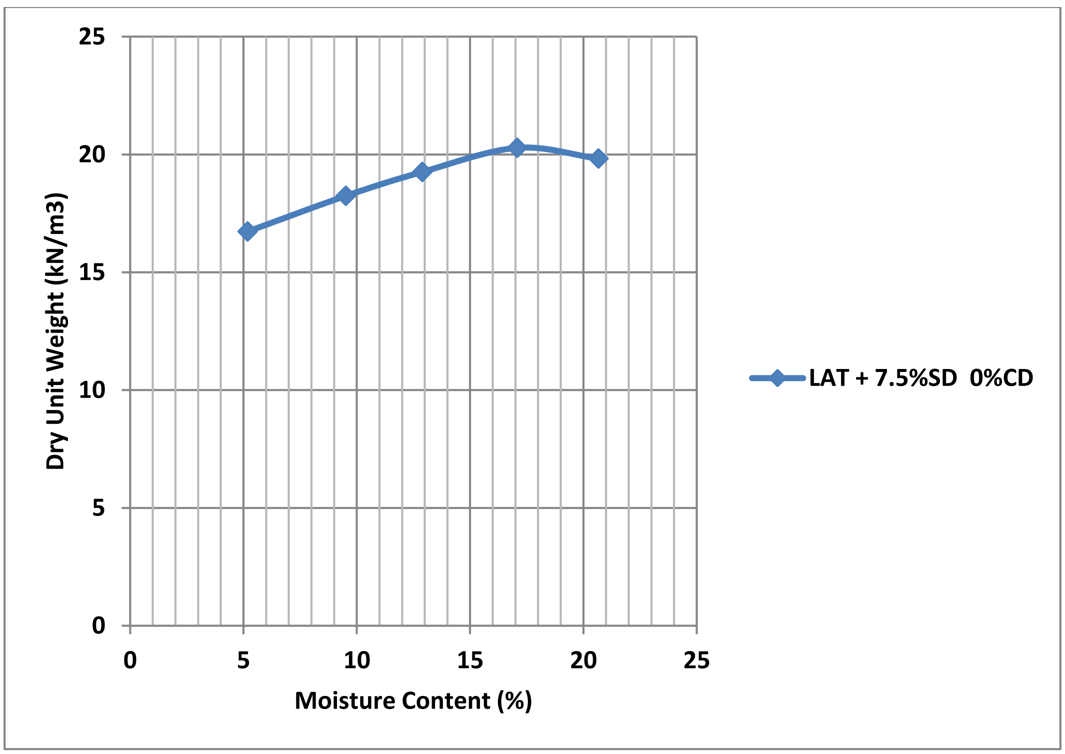

Figure C4: Compaction Curve for LAT + 7.5%SD + 0%CD

Table C5: Dry Unit Weight Determination for LAT + 10%SD + 0%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould	Wt of Wet	Bulk Density	Moisture Content	Dry Unit

			+ Wet Soil	Soil			Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.65	1.65	16.19	4.13	16.23
8	0.001	4	5.85	1.85	18.15	6.43	18.21
12	0.001	4	6	2	19.62	7.86	19.70
16	0.001	4	6.1	2.1	20.60	12.94	20.73
20	0.001	4	6.05	2.05	20.11	15.53	20.27

Table C5.1: Moisture Content Determination for LAT + 10%SD + 0%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	15.7	31.13	15.43	30.53	14.83	0.6	4.05
8	14.07	38.5	24.43	37.04	22.97	1.46	6.36
12	17.79	47.27	29.48	45.85	28.06	1.42	5.06
16	14.36	56.93	42.57	52.08	37.72	4.85	12.86
20	15.07	62.54	47.47	55.95	40.88	6.59	16.12

Table C5.2: Moisture Content Determination for LAT + 10%SD + 0%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	17.45	33.78	16.33	33.12	15.67	0.66	4.21
8	14.71	38.94	24.23	37.46	22.75	1.48	6.51
12	14.98	55.77	40.79	51.84	36.86	3.93	10.66
16	16.07	54.59	38.52	50.15	34.08	4.44	13.03
20	15.75	53.62	37.87	48.7	32.95	4.92	14.93

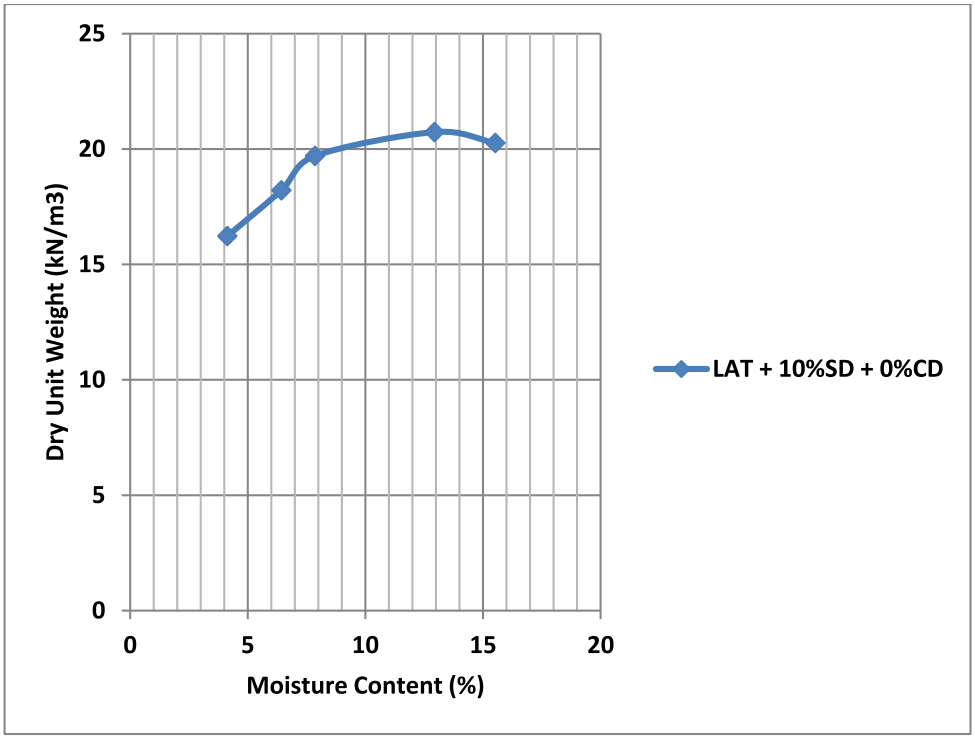

Figure C5: Compaction Curve for LAT + 10%SD + 0%CD

Table C6: Dry Unit Weight Determination for LAT + 0%SD + 2.5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.6	1.6	15.70	7.18	15.77
8	0.001	4	5.8	1.8	17.66	10.68	17.76
12	0.001	4	5.9	1.9	18.64	13.74	18.78
16	0.001	4	6	2	19.62	16.88	19.79
20	0.001	4	5.9	1.9	18.64	18.90	18.83

Table C6.1: Moisture Content Determination for LAT + 0%SD + 2.5%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)

4	15.57	37.31	21.74	35.93	20.36	1.38	6.78
8	15.36	38.45	23.09	36.27	20.91	2.18	10.43
12	14.53	45.31	30.78	41.65	27.12	3.66	13.50
16	13.59	50.38	36.79	44.93	31.34	5.45	17.39
20	16.62	60.99	44.37	53.49	36.87	7.5	20.34

Table C6.2: Moisture Content Determination for LAT + 0%SD + 2.5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	15.04	35.34	20.3	33.91	18.87	1.43	7.58
8	15.22	46.59	31.37	43.5	28.28	3.09	10.93
12	13.85	44.41	30.56	40.66	26.81	3.75	13.99
16	15.86	58.79	42.93	52.75	36.89	6.04	16.37
20	14.37	67.17	52.8	59.32	44.95	7.85	17.46

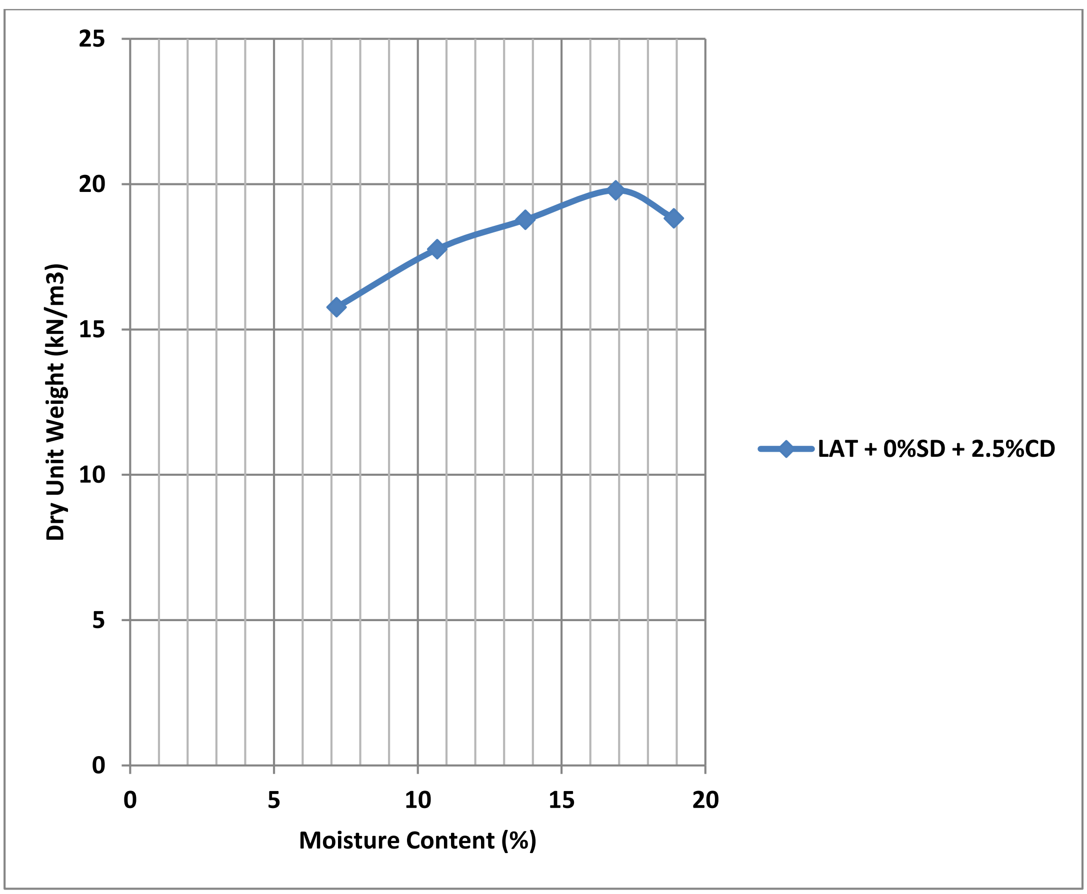

Figure C6: Compaction Curve for LAT + 0%SD + 2.5%CD

Table C7: Dry Unit Weight Determination for LAT + 2.5%SD + 2.5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.7	1.7	16.68	3.57	16.71
8	0.001	4	5.85	1.85	18.15	6.23	18.21
12	0.001	4	6	2	19.62	9.13	19.71
16	0.001	4	6.05	2.05	20.11	15.06	20.26
20	0.001	4	6	2	19.62	18.31	19.80

Table C7.1: Moisture Content Determination for LAT + 2.5%SD + 2.5%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	15.23	31.78	16.55	31.21	15.98	0.57	3.57
8	14.85	47.69	32.84	45.76	30.91	1.93	6.24
12	14.54	56.54	42	53.04	38.5	3.5	9.09
16	14.12	59.37	45.25	53.01	38.89	6.36	16.35
20	14.07	59.08	45.01	51.04	36.97	8.04	21.75

Table C7.2: Moisture Content Determination for LAT + 2.5%SD + 2.5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	17.61	35.53	17.92	34.94	17.33	0.59	3.40
8	14.58	48.44	33.86	46.46	31.88	1.98	6.21
12	14.8	46.62	31.82	43.95	29.15	2.67	9.16
16	14.64	60.66	46.02	55.09	40.45	5.57	13.77
20	14.43	58.76	44.33	53.02	38.59	5.74	14.87

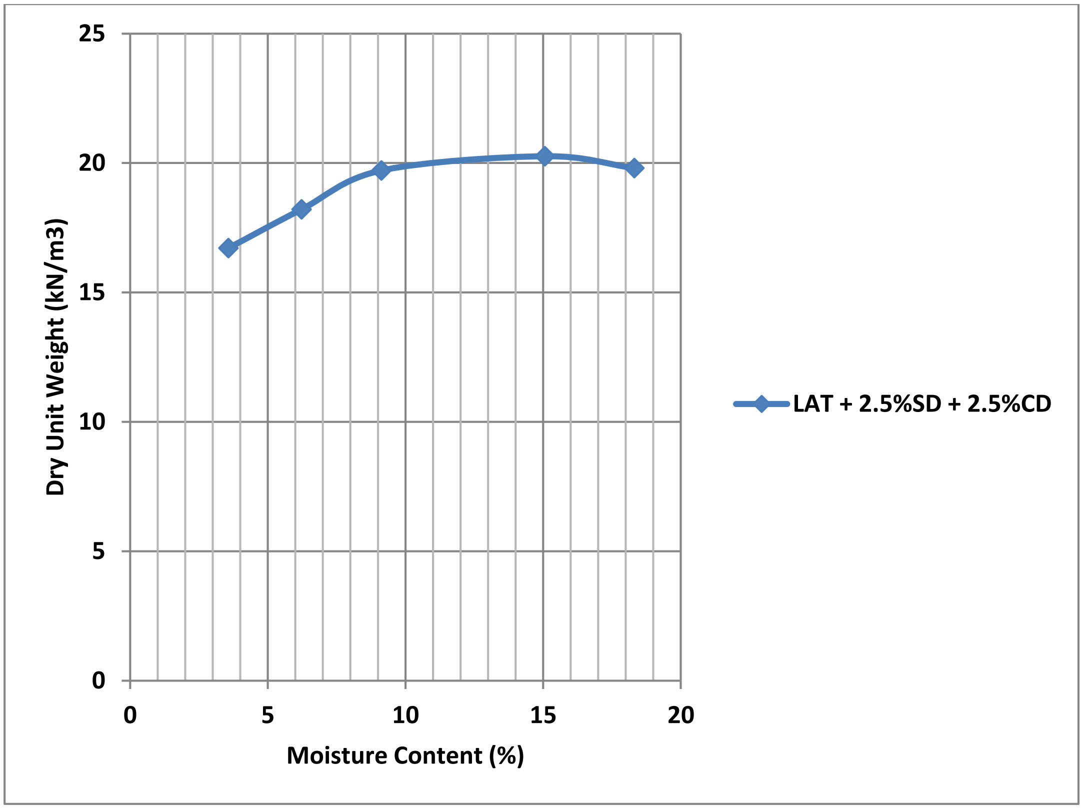

Figure C7: Compaction Curve for LAT + 2.5%SD + 2.5%CD

Table C8: Dry Unit Weight Determination for LAT + 5%SD + 2.5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.7	1.7	16.68	6.26	16.74
8	0.001	4	5.85	1.85	18.15	9.70	18.25
12	0.001	4	5.95	1.95	19.13	11.99	19.25
16	0.001	4	6.1	2.1	20.60	14.72	20.75
20	0.001	4	6	2	19.62	17.20	19.79

Table C8.1: Moisture Content Determination for LAT + 5%SD + 2.5%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)

4	15.55	30.48	14.93	29.64	14.09	0.84	5.96
8	15.35	32.87	17.52	31.39	16.04	1.48	9.23
12	14.45	56.08	41.63	51.59	37.14	4.49	12.09
16	13.6	48.82	35.22	44.42	30.82	4.4	14.28
20	16.4	77.33	60.93	68.54	52.14	8.79	16.86

Table C8.2: Moisture Content Determination for LAT + 5%SD + 2.5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	14.96	31.69	16.73	30.66	15.7	1.03	6.56
8	15.21	37.1	21.89	35.08	19.87	2.02	10.17
12	13.82	40.93	27.11	38.05	24.23	2.88	11.89
16	15.83	56.01	40.18	50.72	34.89	5.29	15.16
20	14.41	70.05	55.64	61.75	47.34	8.3	17.53

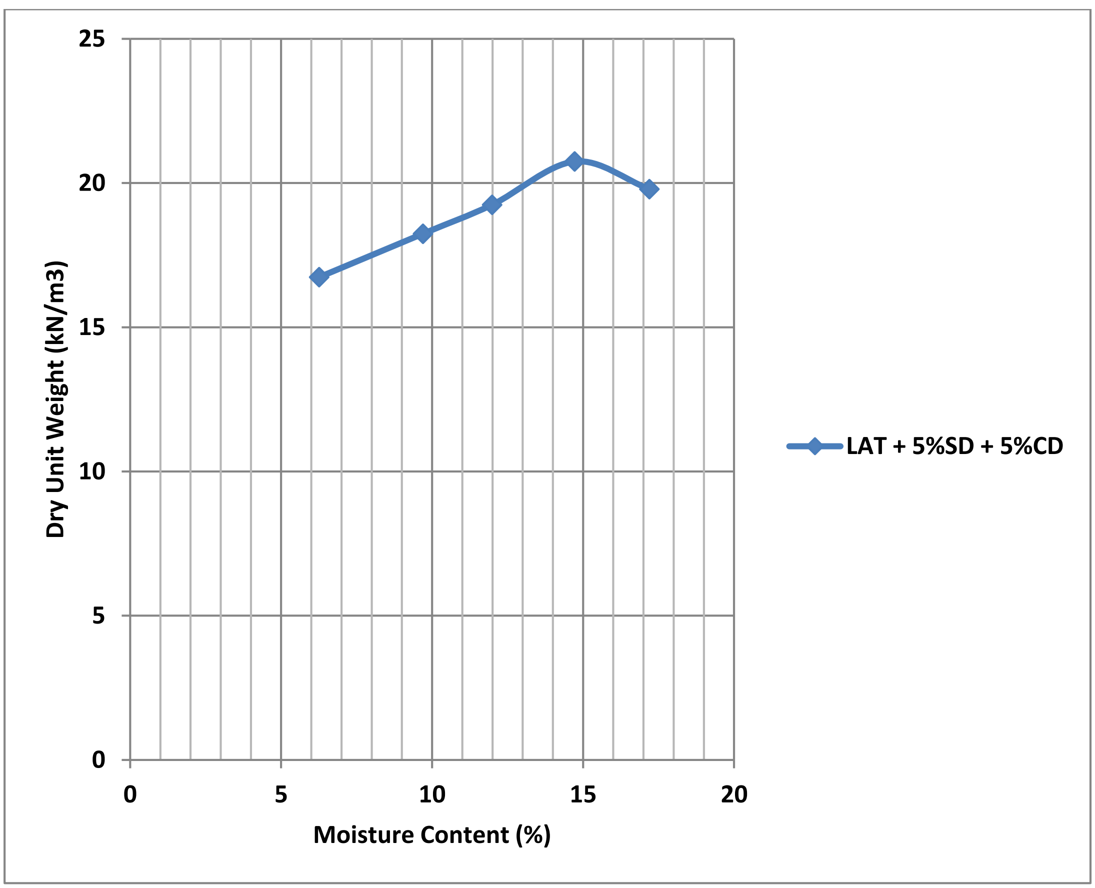

Figure C8: Compaction Curve for LAT + 5%SD + 2.5%CD

Table C9: Dry Unit Weight Determination for LAT + 7.5%SD + 2.5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.7	1.7	16.68	3.60	16.71
8	0.001	4	5.9	1.9	18.64	7.94	18.72
12	0.001	4	6.05	2.05	20.11	9.31	20.20
16	0.001	4	6.15	2.15	21.09	12.47	21.22
20	0.001	4	6.1	2.1	20.60	18.98	20.79

Table C9.1: Moisture Content Determination for LAT + 7.5%SD + 2.5%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	15.24	27.46	12.22	26.73	11.49	0.73	6.35
8	14.83	34.28	19.45	32.72	17.89	1.56	8.72
12	17.98	55.72	37.74	52.64	34.66	3.08	8.89
16	14.09	70.04	55.95	64.06	49.97	5.98	11.97
20	16.07	68.12	52.05	57.99	41.92	10.13	24.17

Table C9.2: Moisture Content Determination for LAT + 7.5%SD + 2.5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	17.57	33.04	15.47	32.91	15.34	0.13	0.85
8	17.24	44.76	27.52	42.92	25.68	1.84	7.17
12	14.78	57.05	42.27	53.3	38.52	3.75	9.74
16	14.63	60.32	45.69	55.07	40.44	5.25	12.98
20	14.44	71.57	57.13	64.64	50.2	6.93	13.80

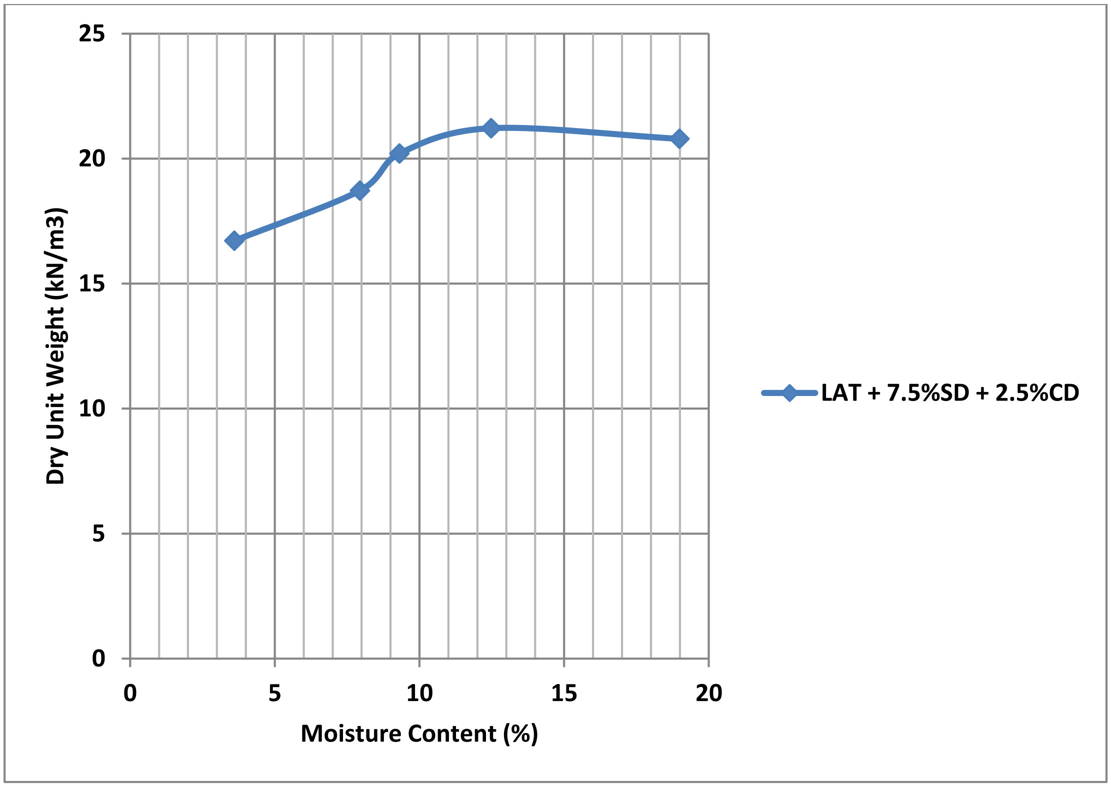

Figure C9: Compaction Curve for LAT + 7.5%SD + 2.5%CD

Table C10: Dry Unit Weight Determination for LAT + 10%SD + 2.5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.8	1.8	17.66	3.93	17.70
8	0.001	4	5.95	1.95	19.13	6.49	19.19
12	0.001	4	6.05	2.05	20.11	9.36	20.20
16	0.001	4	6.15	2.15	21.09	12.21	21.21
20	0.001	4	6.1	2.1	20.60	14.22	20.74

Table C10.1: Moisture Content Determination for LAT + 10%SD + 2.5%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	16.55	36.37	19.82	35.66	19.11	0.71	3.72

8	13.79	42.91	29.12	41.17	27.38	1.74	6.36
12	14.98	42.17	27.19	39.95	24.97	2.22	8.89
16	13.94	54.73	40.79	50.25	36.31	4.48	12.34
20	14.36	56.1	41.74	50.92	36.56	5.18	14.17

Table C10.2: Moisture Content Determination for LAT + 10%SD + 2.5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	14.57	30.4	15.83	29.77	15.2	0.63	4.14
8	17.25	42.2	24.95	40.65	23.4	1.55	6.62
12	15.15	46.88	31.73	44.04	28.89	2.84	9.83
16	14.41	52.65	38.24	48.53	34.12	4.12	12.08
20	14.52	60.15	45.63	54.45	39.93	5.7	14.27

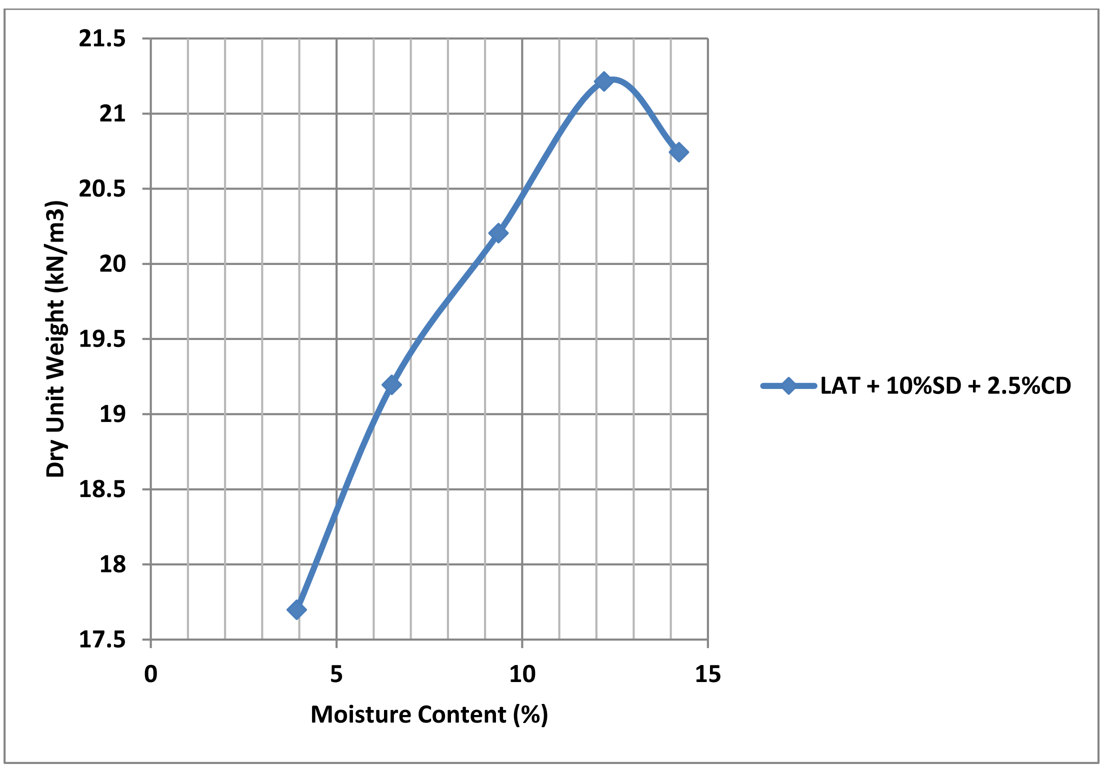

Figure C10: Compaction Curve for LAT + 10%SD + 2.5%CD

Table C11: Dry Unit Weight Determination for LAT + 0%SD + 5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.8	1.8	17.66	2.79	17.69
8	0.001	4	5.95	1.95	19.13	5.21	19.18
12	0.001	4	6.1	2.1	20.60	7.96	20.68
16	0.001	4	6.15	2.15	21.09	13.75	21.23
20	0.001	4	6	2	19.62	17.38	19.79

Table C11.1: Moisture Content Determination for LAT + 0%SD + 5%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	12.82	19.01	6.19	18.84	6.02	0.17	2.82
8	12.66	30.05	17.39	29.17	16.51	0.88	5.33
12	12.84	40.53	27.69	38.51	25.67	2.02	7.87
16	12.81	47.72	34.91	43.05	30.24	4.67	15.44
20	12.95	49.83	36.88	44.02	31.07	5.81	18.70

Table C11.2: Moisture Content Determination for LAT + 0%SD + 5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	12.73	22.43	9.7	22.17	9.44	0.26	2.75
8	12.66	43.05	30.39	41.58	28.92	1.47	5.08
12	12.71	53.6	40.89	50.55	37.84	3.05	8.06
16	12.59	50.24	37.65	46.19	33.6	4.05	12.05
20	15.3	77.83	62.53	69.18	53.88	8.65	16.05

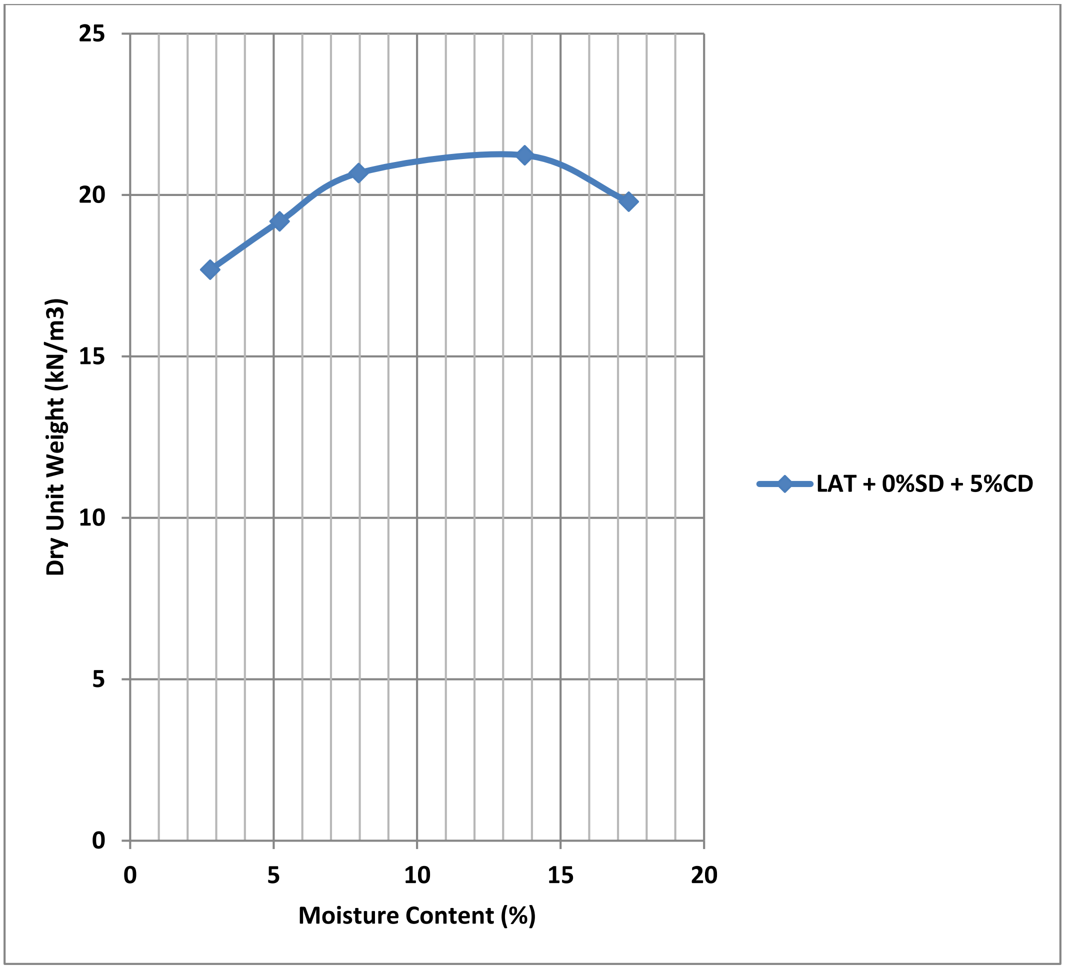

Figure C11: Compaction Curve for LAT + 0%SD + 5%CD

Table C12: Dry Unit Weight Determination for LAT + 2.5%SD + 5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.75	1.75	17.17	4.31	17.21
8	0.001	4	5.9	1.9	18.64	6.37	18.70
12	0.001	4	6	2	19.62	9.04	19.71
16	0.001	4	6.15	2.15	21.09	12.39	21.22
20	0.001	4	6.1	2.1	20.60	17.49	20.78

Table C12.1: Moisture Content Determination for LAT + 2.5%SD + 5%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	16.62	39.19	22.57	38.33	21.71	0.86	3.96
8	15.85	32.25	16.4	31.28	15.43	0.97	6.29
12	15.29	52.04	36.75	48.97	33.68	3.07	9.12
16	14.18	49.28	35.1	45.35	31.17	3.93	12.61
20	15.1	55.5	40.4	50.6	35.5	4.9	13.80

Table C12.2: Moisture Content Determination for LAT + 2.5%SD + 5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	14.8	35.71	20.91	34.78	19.98	0.93	4.65
8	17.18	46.51	29.33	44.73	27.55	1.78	6.46
12	15.4	50.66	35.26	47.76	32.36	2.9	8.96
16	15.53	52.6	37.07	48.58	33.05	4.02	12.16
20	16.67	53.45	36.78	47.02	30.35	6.43	21.19

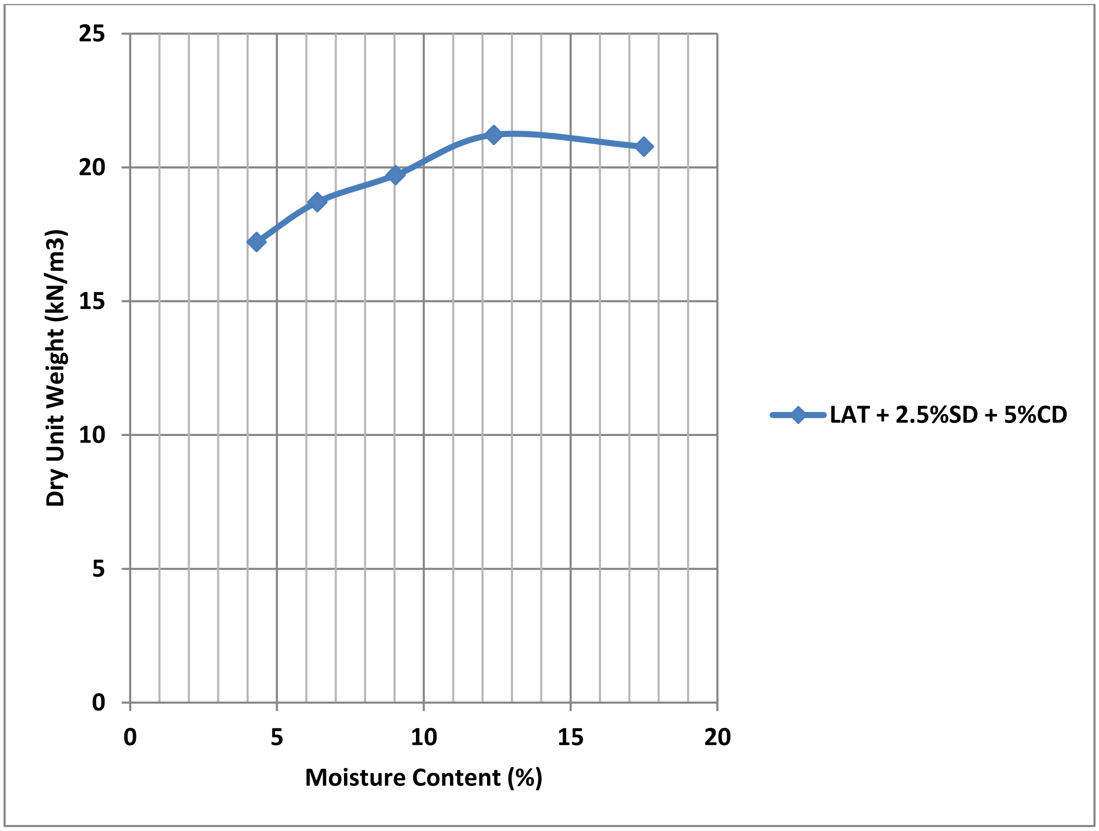

Figure C12: Compaction Curve for LAT + 2.5%SD + 5%CD

Table C13: Dry Unit Weight Determination for LAT + 5%SD + 5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.9	1.9	18.64	4.15	18.68
8	0.001	4	6.05	2.05	20.11	4.29	20.15
12	0.001	4	6.15	2.15	21.09	6.31	21.15
16	0.001	4	6.2	2.2	21.58	11.54	21.70
20	0.001	4	6.1	2.1	20.60	15.68	20.76

Table C13.1: Moisture Content Determination for LAT + 5%SD + 5%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture

(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	16.24	32.26	16.02	31.68	15.44	0.58	3.76
8	14.82	33.96	19.14	33.18	18.36	0.78	4.25
12	17.99	61.75	43.76	59.12	41.13	2.63	6.39
16	14.09	63.46	49.37	58.01	43.92	5.45	12.41
20	16.32	51.78	35.46	46.25	29.93	5.53	18.48

Table C13.2: Moisture Content Determination for LAT + 5%SD + 5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	17.58	35.78	18.2	34.99	17.41	0.79	4.54
8	17.21	40.12	22.91	39.17	21.96	0.95	4.33
12	15.42	50.38	34.96	48.33	32.91	2.05	6.23
16	14.21	70.52	56.31	65.09	50.88	5.43	10.67
20	15.78	51.19	35.41	47.15	31.37	4.04	12.88

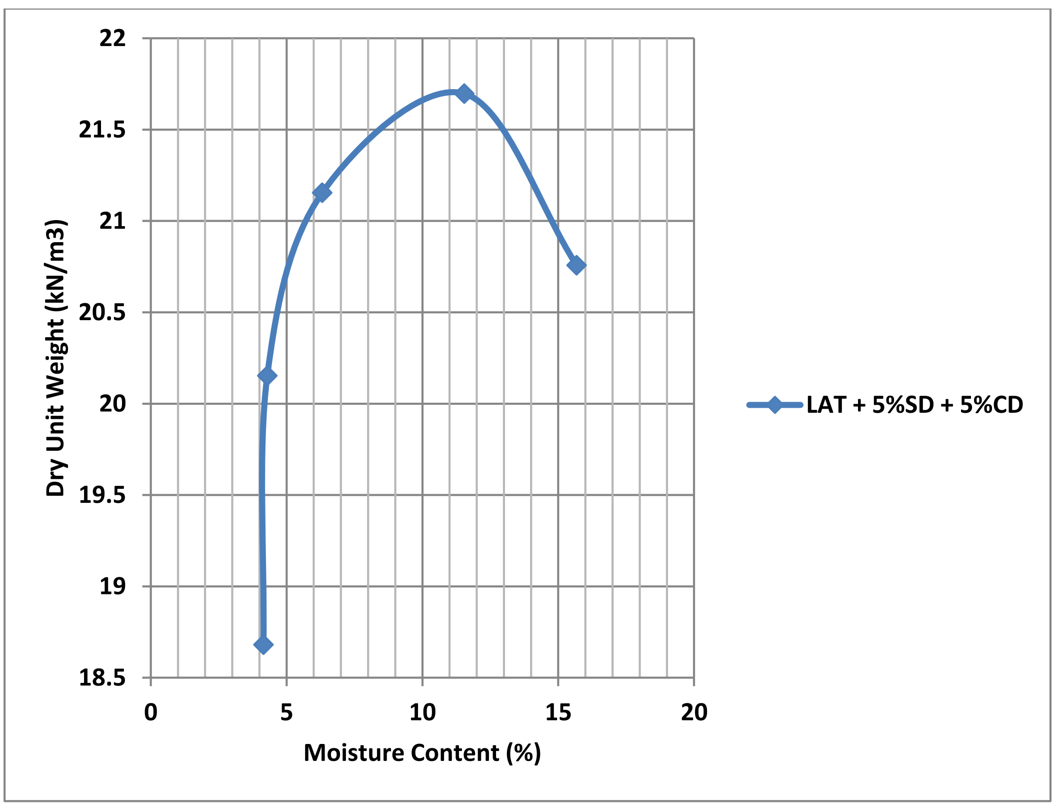

Figure C13: Compaction Curve for LAT + 5%SD + 5%CD

Table C14: Dry Unit Weight Determination for LAT + 7.5%SD + 5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.8	1.8	17.66	4.72	17.71
8	0.001	4	5.95	1.95	19.13	8.22	19.21
12	0.001	4	6.1	2.1	20.60	10.34	20.70
16	0.001	4	6.2	2.2	21.58	11.19	21.69
20	0.001	4	6.15	2.15	21.09	16.69	21.26

Table C14.1: Moisture Content Determination for LAT + 7.5%SD + 5%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	15.94	47.19	31.25	46.16	30.22	1.03	3.41
8	13.8	38.67	24.87	36.89	23.09	1.78	7.71
12	14.94	47.21	32.27	44.41	29.47	2.8	9.50
16	13.92	57.64	43.72	54.76	40.84	2.88	7.05
20	14.34	59.84	45.5	52.16	37.82	7.68	20.31

Table C14.2: Moisture Content Determination for LAT + 7.5%SD + 5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	16.57	46.96	30.39	45.23	28.66	1.73	6.04
8	17.26	43.41	26.15	41.31	24.05	2.1	8.73
12	14.12	52.31	38.19	48.47	34.35	3.84	11.18
16	16.66	48.94	32.28	44.65	27.99	4.29	15.33
20	16.09	67.11	51.02	61.21	45.12	5.9	13.08

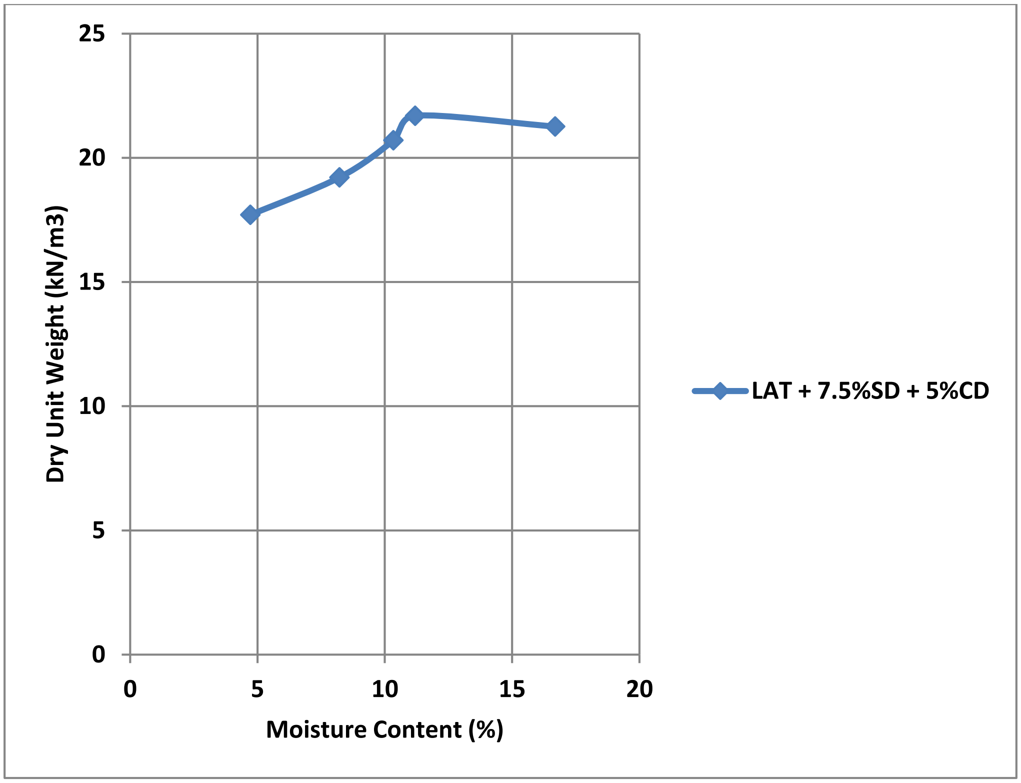

Figure C14: Compaction Curve for LAT + 7.5%SD + 5%CD

Table C15: Dry Unit Weight Determination for LAT + 10%SD + 5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.9	1.9	18.64	4.09	18.19
8	0.001	4	6.1	2.1	20.60	8.04	20.68
12	0.001	4	6.2	2.2	21.58	9.75	21.68
16	0.001	4	6.25	2.25	22.07	10.88	22.18
20	0.001	4	6.15	2.15	21.09	17.39	21.27

Table C15.1: Moisture Content Determination for LAT + 10%SD + 5%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content

							(g)
4	13.36	32.56	19.2	31.85	18.49	0.71	3.84
8	14.21	43.22	29.01	41.27	27.06	1.95	7.21
12	15.65	46.71	31.06	44.44	28.79	2.27	7.88
16	16.23	38.9	22.67	37.12	20.89	1.78	8.52
20	14.42	56.68	42.26	50.84	36.42	5.84	16.04

Table C15.2: Moisture Content Determination for LAT + 10%SD + 5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	15.31	38.64	23.33	37.67	22.36	0.97	4.34
8	14.95	40.09	25.14	38.04	23.09	2.05	8.88
12	16.47	46.76	30.29	43.61	27.14	3.15	11.61
16	15.28	52.24	36.96	47.92	32.64	4.32	13.24
20	15.72	60.84	45.12	53.72	38	7.12	18.74

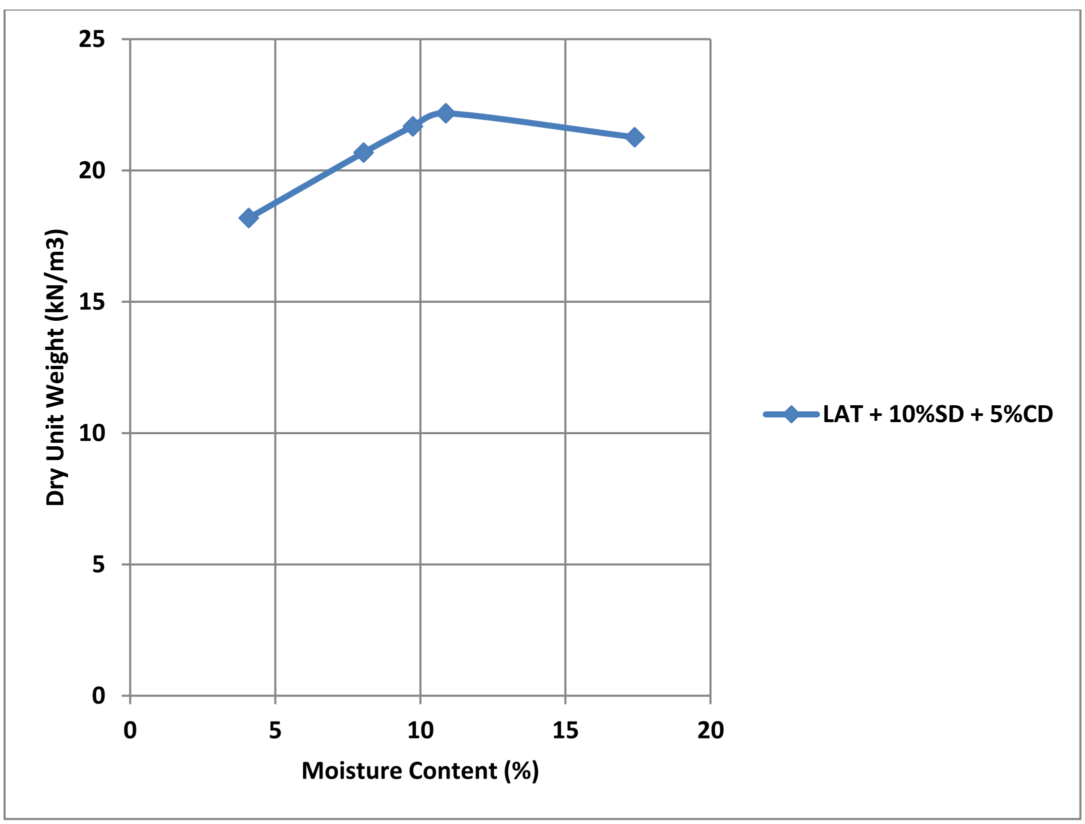

Figure C15: Compaction Curve for LAT + 10%SD + 5%CD

Table C16: Dry Unit Weight Determination for LAT + 0%SD + 7.5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.8	1.8	17.66	5.04	17.71
8	0.001	4	6	2	19.62	9.54	19.72
12	0.001	4	6.1	2.1	20.60	12.87	20.73
16	0.001	4	6.15	2.15	21.09	16.72	21.26
20	0.001	4	6.1	2.1	20.60	20.59	20.81

Table C16.1: Moisture Content Determination for LAT + 0%SD + 7.5%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	14.56	38.94	24.38	37.68	23.12	1.26	5.45
8	15.24	42.16	26.92	39.76	24.52	2.4	9.79
12	16.84	44.86	28.02	41.51	24.67	3.35	13.58
16	16.67	50.94	34.27	45.98	29.31	4.96	16.92
20	17.05	61.28	44.23	53.57	36.52	7.71	21.11

Table C16.2: Moisture Content Determination for LAT + 0%SD + 7.5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	14.21	45.68	31.47	44.29	30.08	1.39	4.62
8	15.16	48.34	33.18	45.52	30.36	2.82	9.29
12	16.34	51.28	34.94	47.49	31.15	3.79	12.17
16	15.55	54.72	39.17	49.17	33.62	5.55	16.51
20	14.82	58.86	44.04	51.5	36.68	7.36	20.07

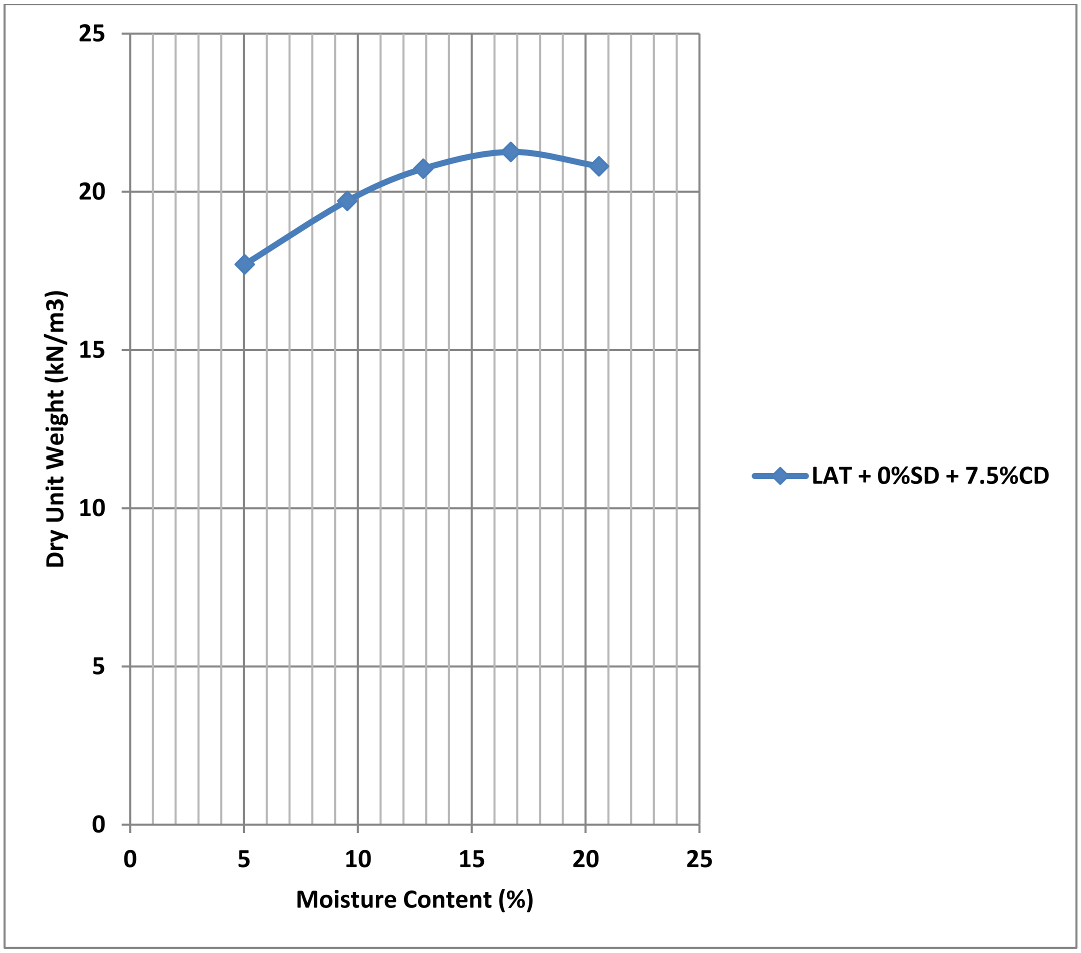

Figure C16: Compaction Curve for LAT + 0%SD + 7.5%CD

Table C17: Dry Unit Weight Determination for LAT + 2.5%SD + 7.5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	6	2	19.62	4.67	18.19
8	0.001	4	6.15	2.15	21.09	7.85	21.17
12	0.001	4	6.2	2.2	21.58	10.62	21.69
16	0.001	4	6.25	2.25	22.07	14.63	22.22
20	0.001	4	6.15	2.15	21.09	18.73	21.28

Table C17.1: Moisture Content Determination for LAT + 2.5%SD + 7.5%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	15.24	40.68	25.44	39.58	24.34	1.1	4.52
8	14.38	48.64	34.26	45.86	31.48	2.78	8.83
12	15.16	50.48	35.32	46.95	31.79	3.53	11.10
16	16.2	52.11	35.91	47.44	31.24	4.67	14.95
20	17.12	56.85	39.73	50.81	33.69	6.04	17.93

Table C17.2: Moisture Content Determination for LAT + 2.5%SD + 7.5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	14.88	41.36	26.48	40.14	25.26	1.22	4.83
8	15.64	47.88	32.24	45.81	30.17	2.07	6.86
12	16.39	45.28	28.89	42.62	26.23	2.66	10.14
16	12.86	50.42	37.56	45.72	32.86	4.7	14.30
20	15.12	61.28	46.16	53.74	38.62	7.54	19.52

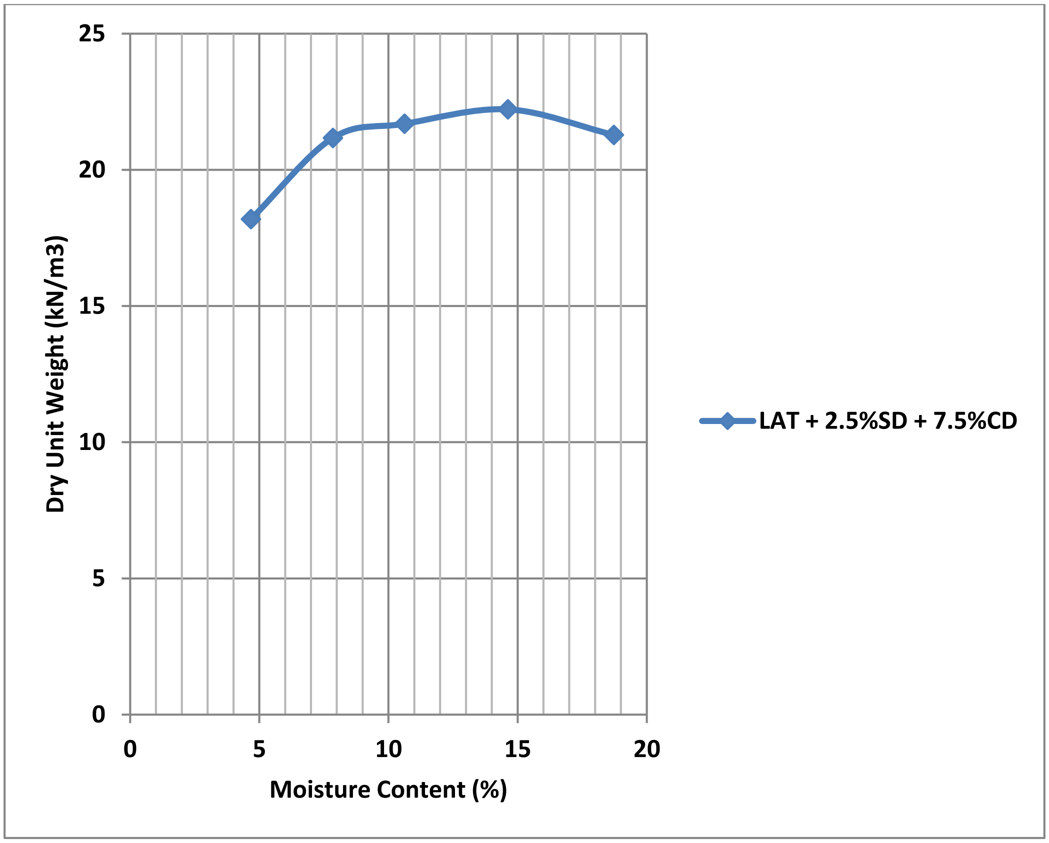

Figure C17: Compaction Curve for LAT + 2.5%SD + 7.5%CD

Table C18: Dry Unit Weight Determination for LAT + 5%SD + 7.5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.95	1.95	19.13	5.60	19.19
8	0.001	4	6.1	2.1	20.60	8.11	20.68
12	0.001	4	6.2	2.2	21.58	12.74	21.71
16	0.001	4	6.25	2.25	22.07	14.03	22.21
20	0.001	4	6.2	2.2	21.58	18.42	21.77

Table C18.1: Moisture Content Determination for LAT + 5%SD + 7.5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture

(%)	**(g)**	**Soil (g)**		**(g)**	**Soil (g)**		**Content (g)**
4	**15.06**	**41.26**	**26.2**	**40.12**	**25.06**	**1.14**	**4.55**
8	**14.68**	**40.55**	**25.87**	**38.85**	**24.17**	**1.7**	**7.03**
12	**14.12**	**48.59**	**34.47**	**44.66**	**30.54**	**3.93**	**12.87**
16	**17.16**	**52.11**	**34.95**	**47.74**	**30.58**	**4.37**	**14.29**
20	**15.07**	**59.72**	**44.65**	**53.11**	**38.04**	**6.61**	**17.38**

Table C18.2: Moisture Content Determination for LAT + 5%SD + 7.5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	**(g)**	**Soil (g)**		**(g)**	**Soil (g)**		**Content (g)**
4	**14.88**	**41.36**	**26.48**	**40.14**	**25.26**	**1.22**	**4.83**
8	**15.64**	**47.88**	**32.24**	**45.81**	**30.17**	**2.07**	**6.86**
12	**16.39**	**45.28**	**28.89**	**42.62**	**26.23**	**2.66**	**10.14**
16	**12.86**	**50.42**	**37.56**	**45.72**	**32.86**	**4.7**	**14.30**
20	**15.12**	**61.28**	**46.16**	**53.74**	**38.62**	**7.54**	**19.52**

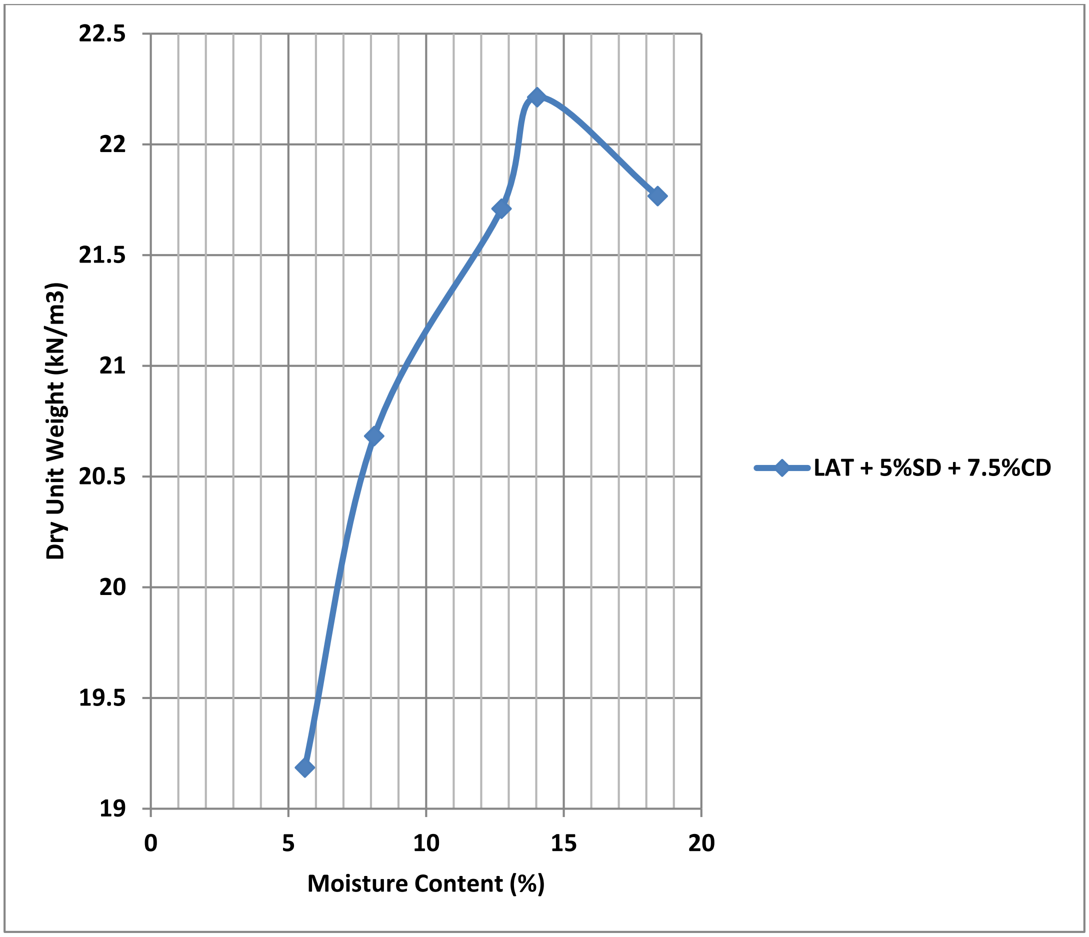

Figure C18: Compaction Curve for LAT + 5%SD + 7.5%CD

Table C19: Dry Unit Weight Determination for LAT + 7.5%SD + 7.5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	6	2	19.62	5.89	18.19
8	0.001	4	6.15	2.15	21.09	7.31	21.16
12	0.001	4	6.2	2.2	21.58	11.89	21.70
16	0.001	4	6.3	2.3	22.56	13.72	22.70
20	0.001	4	6.2	2.2	21.58	19.22	21.77

Table C19.1: Moisture Content Determination for LAT + 7.5%SD + 7.5%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	14.88	41.36	26.48	40.14	25.26	1.22	4.83
8	15.64	47.88	32.24	45.81	30.17	2.07	6.86
12	16.39	45.28	28.89	42.62	26.23	2.66	10.14
16	12.86	50.42	37.56	45.72	32.86	4.7	14.30
20	15.12	61.28	46.16	53.74	38.62	7.54	19.52

Table C19.2: Moisture Content Determination for LAT + 7.5%SD + 7.5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	15.06	41.26	26.2	40.12	25.06	1.14	4.55
8	14.68	40.55	25.87	38.85	24.17	1.7	7.03
12	14.12	48.59	34.47	44.66	30.54	3.93	12.87
16	17.16	52.11	34.95	47.74	30.58	4.37	14.29
20	15.07	59.72	44.65	53.11	38.04	6.61	17.38

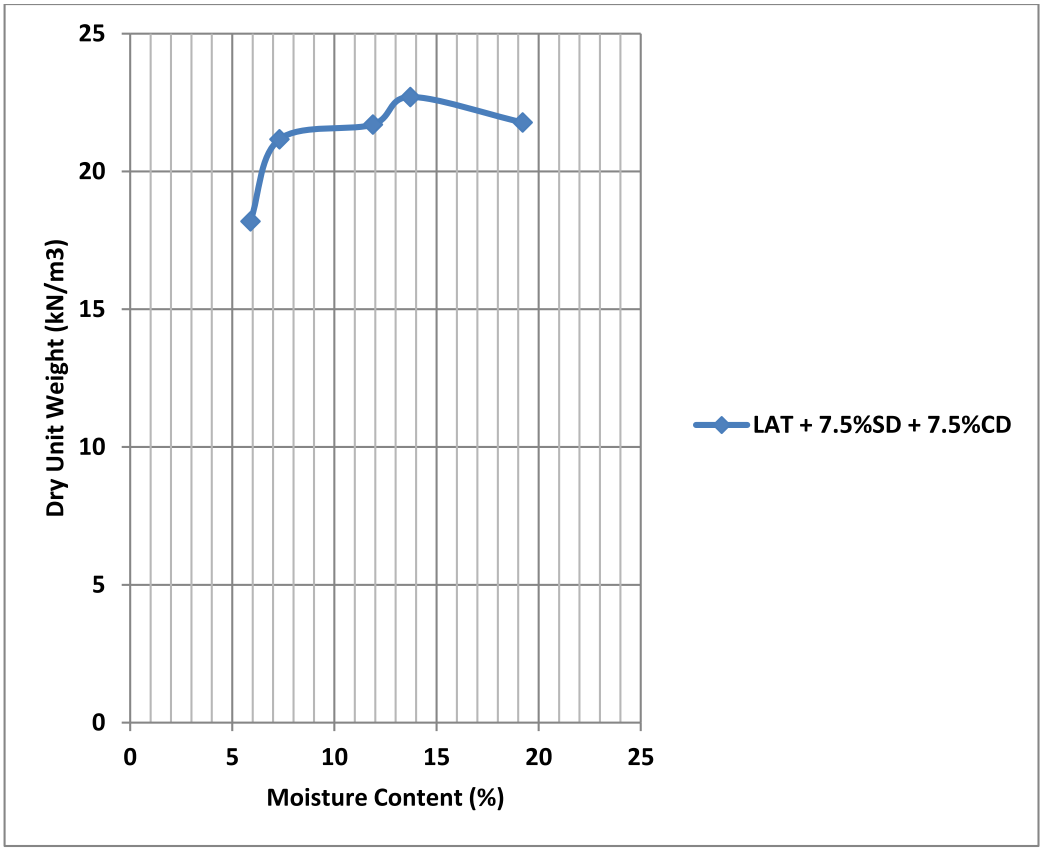

Figure C19: Compaction Curve for LAT + 7.5%SD + 7.5%CD

Table C20: Dry Unit Weight Determination for LAT + 10%SD + 7.5%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.9	1.9	18.64	5.00	18.69
8	0.001	4	6.15	2.15	21.09	8.33	21.17
12	0.001	4	6.3	2.3	22.56	11.54	22.68
16	0.001	4	6.25	2.25	22.07	16.31	22.24
20	0.001	4	6.2	2.2	21.58	20.61	21.79

Table C20.1: Moisture Content Determination for LAT + 10%SD + 7.5%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture

(%)	**(g)**	**Soil (g)**		**(g)**	**Soil (g)**		**Content (g)**
4	**15.24**	**43.76**	**28.52**	**42.15**	**26.91**	**1.61**	**5.98**
8	**14.92**	**46.84**	**31.92**	**44.76**	**29.84**	**2.08**	**6.97**
12	**13.36**	**49.28**	**35.92**	**45.75**	**32.39**	**3.53**	**10.90**
16	**15.21**	**53.74**	**38.53**	**49.18**	**33.97**	**4.56**	**13.42**
20	**17.44**	**55.94**	**38.5**	**49.44**	**32**	**6.5**	**20.31**

Table C20.2: Moisture Content Determination for LAT + 10%SD + 7.5%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	**(g)**	**Soil (g)**		**(g)**	**Soil (g)**		**Content (g)**
4	**16.42**	**42.15**	**25.73**	**40.74**	**24.32**	**1.41**	**5.80**
8	**14.54**	**48.74**	**34.2**	**46.31**	**31.77**	**2.43**	**7.65**
12	**16.28**	**50.12**	**33.84**	**46.26**	**29.98**	**3.86**	**12.88**
16	**13.58**	**58.42**	**44.84**	**52.91**	**39.33**	**5.51**	**14.01**
20	**15.69**	**63.26**	**47.57**	**55.96**	**40.27**	**7.3**	**18.13**

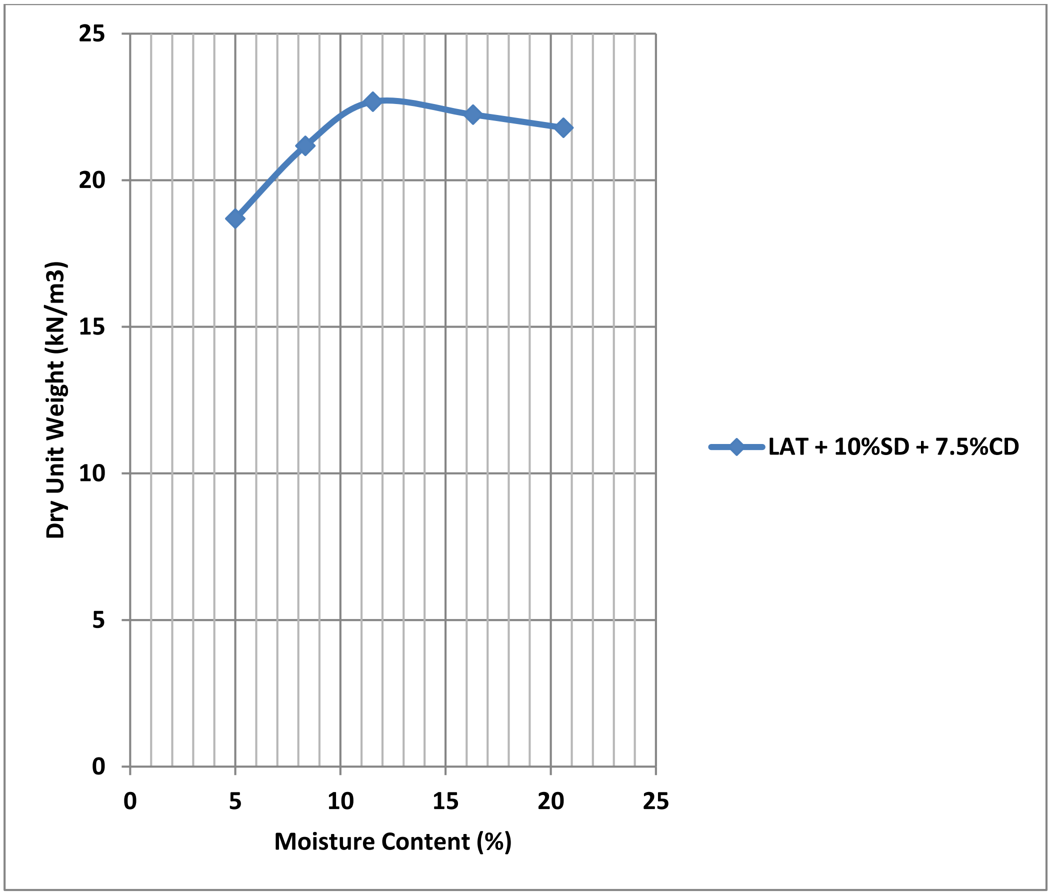

Figure C20: Compaction Curve for LAT + 10%SD + 7.5%CD

Table C21: Dry Unit Weight Determination for LAT + 0%SD + 10%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.95	1.95	19.13	6.10	18.19
8	0.001	4	6.05	2.05	20.11	8.70	20.20
12	0.001	4	6.15	2.15	21.09	13.48	21.23
16	0.001	4	6.2	2.2	21.58	16.61	21.75
20	0.001	4	6.1	2.1	20.60	19.29	20.79

Table C21.1: Moisture Content Determination for LAT + 0%SD + 10%CD (Top)

Percentages of Water (%)	Wt of tin (g)	Wt of tin + wet Soil (g)	Wt of wet Soil (g)	Wt of tin + dry Soil (g)	Wt of dry Soil (g)	Wt of Water (g)	Moisture Content (g)
4	15.21	46.38	31.17	44.83	29.62	1.55	5.23
8	16.84	52.28	35.44	49.15	32.31	3.13	9.69
12	14.58	48.64	34.06	45.26	30.68	3.38	11.02
16	14.38	50.52	36.14	45.59	31.21	4.93	15.80
20	15.12	52.18	37.06	46.05	30.93	6.13	19.82

Table C21.2: Moisture Content Determination for LAT + 0%SD + 10%CD (Bottom)

Percentages of Water (%)	Wt of tin (g)	Wt of tin + wet Soil (g)	Wt of wet Soil (g)	Wt of tin + dry Soil (g)	Wt of dry Soil (g)	Wt of Water (g)	Moisture Content (g)
4	14.68	50.56	35.88	48.64	33.96	1.92	5.65
8	14.52	56.42	41.9	52.54	38.02	3.88	10.21
12	15.43	55.38	39.95	51.71	36.28	3.67	10.12
16	16.62	44.92	28.3	41.88	25.26	3.04	12.03
20	14.88	67.12	52.24	59.09	44.21	8.03	18.16

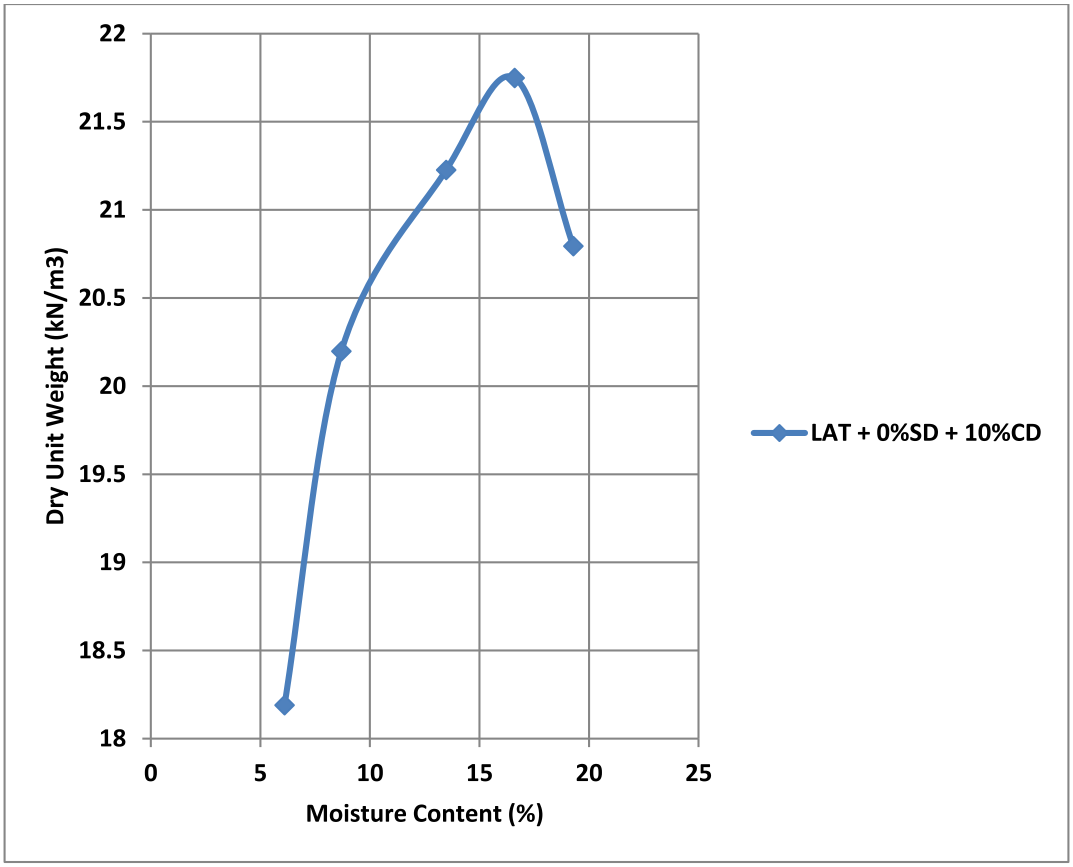

Figure C21: Compaction Curve for LAT + 0%SD + 10%CD

Table C22: Dry Unit Weight Determination for LAT + 2.5%SD + 10%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	6	2	19.62	5.44	19.67
8	0.001	4	6.1	2.1	20.60	9.95	20.70
12	0.001	4	6.2	2.2	21.58	10.57	21.69
16	0.001	4	6.25	2.25	22.07	13.92	22.21
20	0.001	4	6.2	2.2	21.58	18.99	21.77

Table C22.1: Moisture Content Determination for LAT + 2.5%SD + 10%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content

							(g)
4	14.48	44.58	30.1	43.17	28.69	1.41	4.91
8	17.12	51.93	34.81	49.25	32.13	2.68	8.34
12	15.38	46.88	31.5	43.66	28.28	3.22	11.39
16	14.45	48.36	33.91	43.91	29.46	4.45	15.11
20	15.12	54.28	39.16	47.45	32.33	6.83	21.13

Table C22.2: Moisture Content Determination for LAT + 2.5%SD + 10%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	13.48	45.09	31.61	43.56	30.08	1.53	5.09
8	14.52	52.63	38.11	49.7	35.18	2.93	8.33
12	15.16	55.76	40.6	51.51	36.35	4.25	11.69
16	16.68	48.29	31.61	43.58	26.9	4.71	17.51
20	15.12	64.92	49.8	56.59	41.47	8.33	20.09

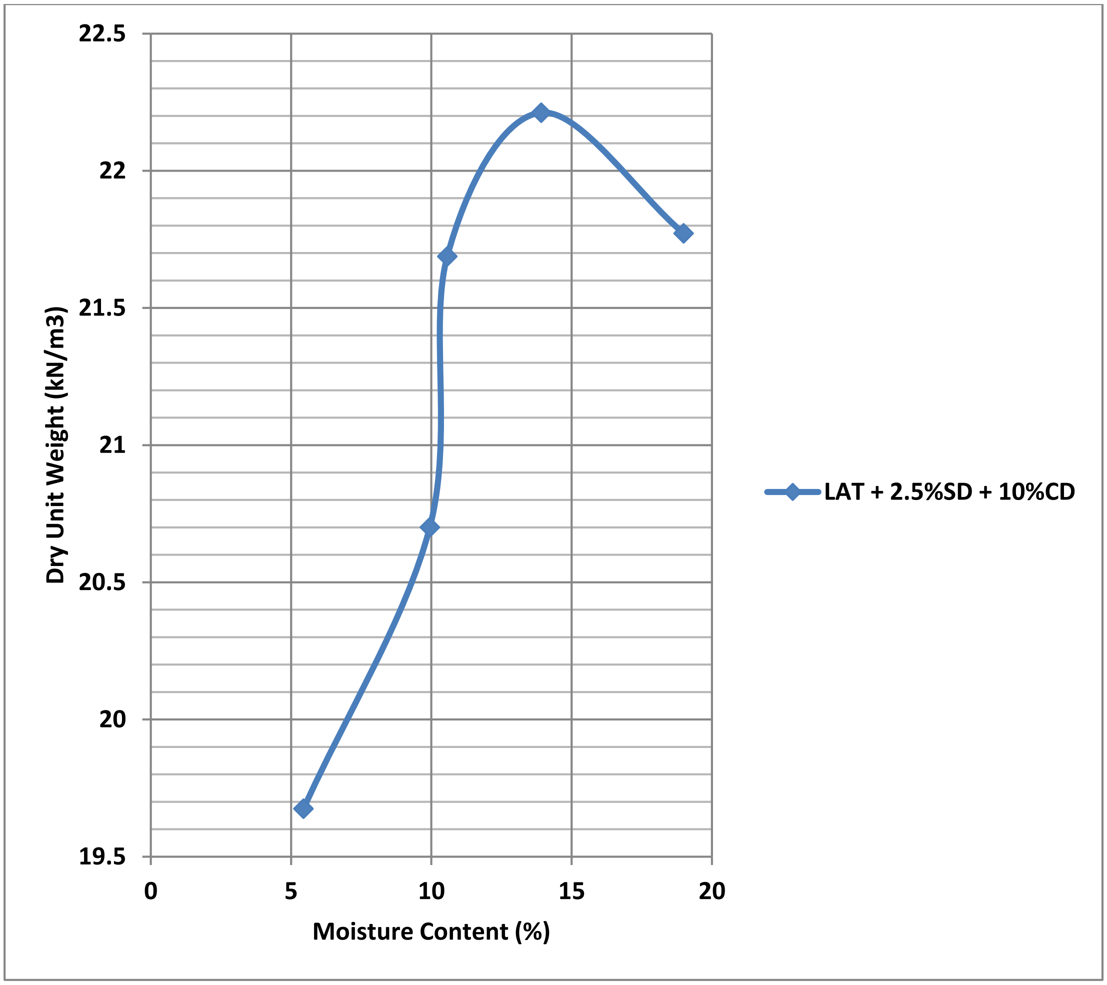

Figure C22: Compaction Curve for LAT + 2.5%SD + 10%CD

Table C23: Dry Unit Weight Determination for LAT + 5%SD + 10%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	6.05	2.05	20.11	2.69	18.19
8	0.001	4	6.2	2.2	21.58	7.76	21.66
12	0.001	4	6.3	2.3	22.56	11.58	22.68
16	0.001	4	6.2	2.2	21.58	15.06	21.73
20	0.001	4	6.1	2.1	20.60	19.39	20.79

Table C23.1: Moisture Content Determination for LAT + 5%SD + 10%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	15.21	44.86	29.65	43.26	28.05	1.6	5.70
8	14.12	48.76	34.64	45.98	31.86	2.78	8.73
12	13.58	52.36	38.78	47.62	34.04	4.74	13.92
16	14.55	54.78	40.23	48.99	34.44	5.79	16.81
20	16.12	60.42	44.3	52.87	36.75	7.55	20.54

Table C23.2: Moisture Content Determination for LAT + 5%SD + 10%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	15.48	45.62	30.14	43.78	28.3	1.84	6.50
8	14.59	49.82	35.23	47.01	32.42	2.81	8.67
12	15.82	52.22	36.4	48.02	32.2	4.2	13.04
16	14.48	59.68	45.2	53.31	38.83	6.37	16.40
20	17.11	64.38	47.27	57.16	40.05	7.22	18.03

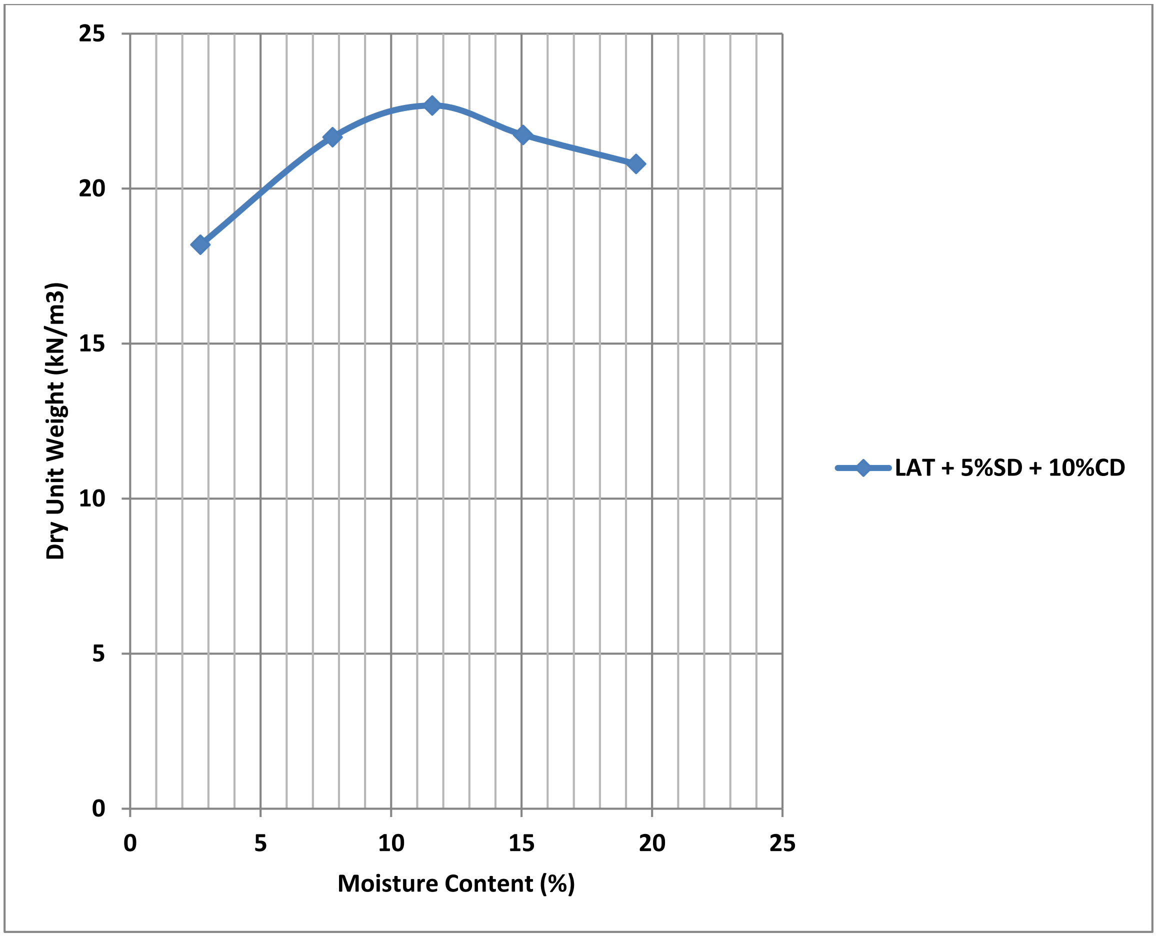

Figure C23: Compaction Curve for LAT + 5%SD + 10%CD

Table C24: Dry Unit Weight Determination for LAT + 7.5%SD + 10%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	6	2	19.62	5.81	19.68
8	0.001	4	6.1	2.1	20.60	9.17	20.69
12	0.001	4	6.2	2.2	21.58	12.77	21.71
16	0.001	4	6.35	2.35	23.05	15.69	23.21
20	0.001	4	6.3	2.3	22.56	19.99	22.76

Table C24.1: Moisture Content Determination for LAT + 7.5%SD + 10%CD (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	15.21	46.38	31.17	44.83	29.62	1.55	5.23
8	16.84	52.28	35.44	49.15	32.31	3.13	9.69
12	14.58	48.64	34.06	45.26	30.68	3.38	11.02
16	14.38	50.52	36.14	45.59	31.21	4.93	15.80
20	15.12	52.18	37.06	46.05	30.93	6.13	19.82

Table C24.2: Moisture Content Determination for LAT + 7.5%SD + 10%CD (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	14.68	50.56	35.88	48.64	33.96	1.92	5.65
8	14.52	56.42	41.9	52.54	38.02	3.88	10.21
12	15.43	55.38	39.95	51.71	36.28	3.67	10.12
16	16.62	44.92	28.3	41.88	25.26	3.04	12.03
20	14.88	67.12	52.24	59.09	44.21	8.03	18.16

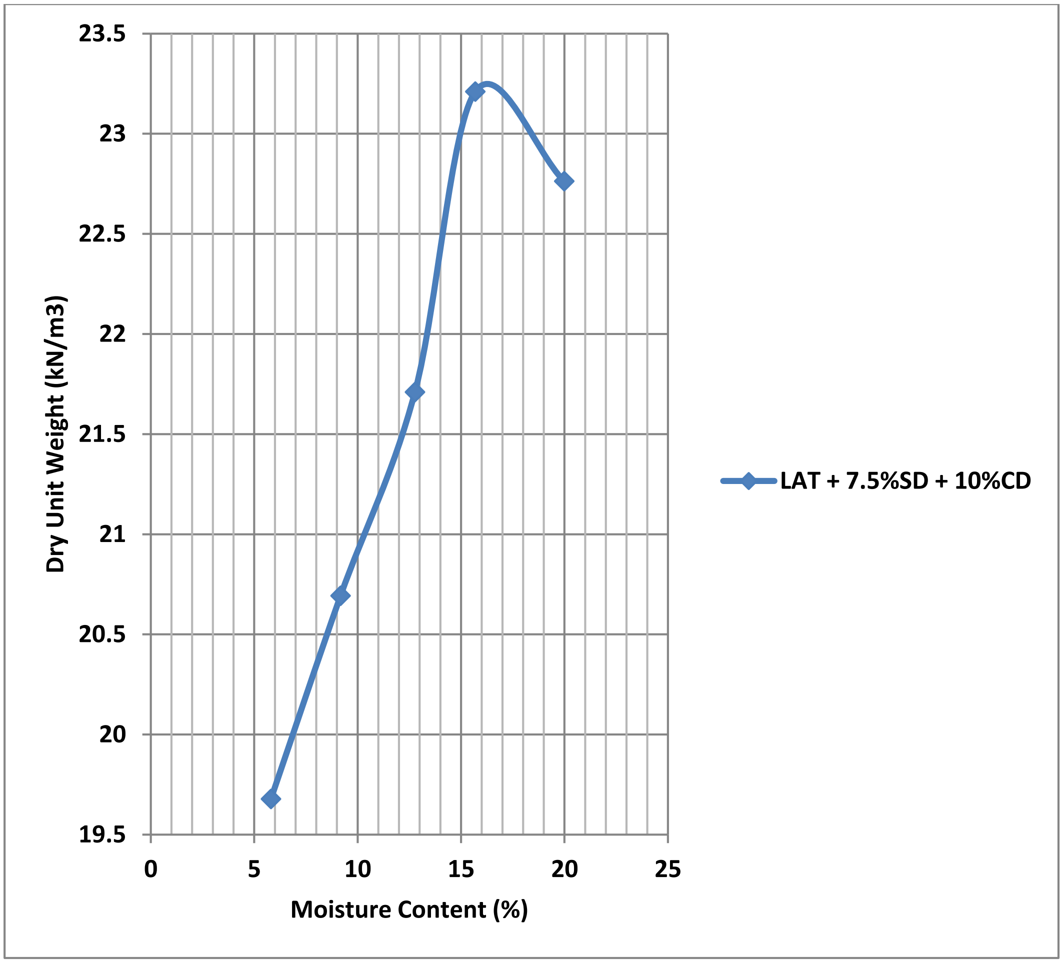

Figure C24: Compaction Curve for LAT + 7.5%SD + 10%CD

Table C25: Dry Unit Weight Determination for LAT + 10%SD + 10%CD

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	6.05	2.05	20.11	4.09	18.19
8	0.001	4	6.2	2.2	21.58	8.04	21.66
12	0.001	4	6.3	2.3	22.56	10.12	22.66
16	0.001	4	6.4	2.4	23.54	12.99	23.67
20	0.001	4	6.3	2.3	22.56	17.39	22.74

Table C25.1: Moisture Content Determination for LAT + 10%SD + 10%CD (Top)

Percentages of Water (%)	Wt of tin (g)	Wt of tin + wet Soil (g)	Wt of wet Soil (g)	Wt of tin + dry Soil (g)	Wt of dry Soil (g)	Wt of Water (g)	Moisture Content (g)
4	14.46	48.62	34.16	47.83	33.37	0.79	2.37
8	15.38	49.52	34.14	47.11	31.73	2.41	7.60
12	13.78	51.64	37.86	47.38	33.6	4.26	12.68
16	16.33	52.95	36.62	48.69	32.36	4.26	13.16
20	17.48	66.72	49.24	58.87	41.39	7.85	18.97

Table C25.2: Moisture Content Determination for LAT + 10%SD + 10%CD (Bottom)

Percentages of Water (%)	Wt of tin (g)	Wt of tin + wet Soil (g)	Wt of wet Soil (g)	Wt of tin + dry Soil (g)	Wt of dry Soil (g)	Wt of Water (g)	Moisture Content (g)
4	14.24	52.87	38.63	51.74	37.5	1.13	3.01
8	14.86	55.74	40.88	52.74	37.88	3	7.92
12	15.13	58.26	43.13	54.17	39.04	4.09	10.48
16	14.54	60.82	46.28	54.11	39.57	6.71	16.96
20	16.38	65.72	49.34	57.56	41.18	8.16	19.82

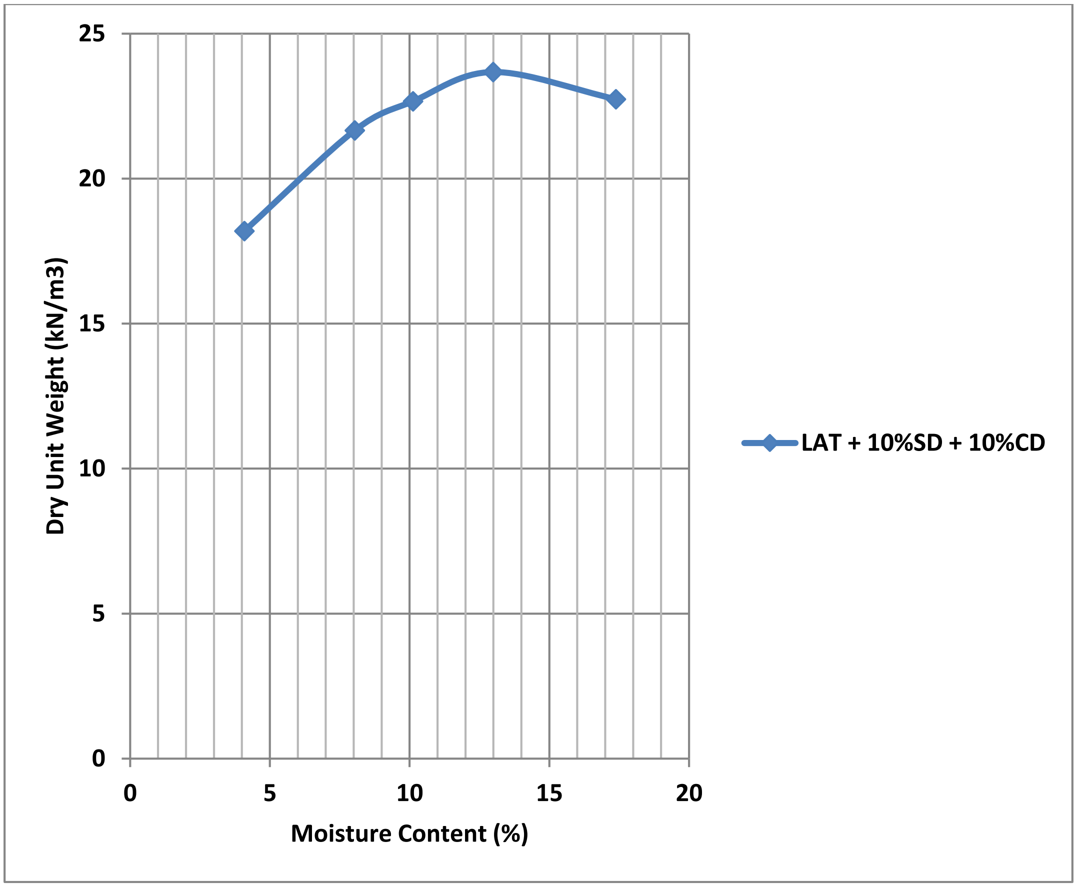

Figure C25: Compaction Curve for LAT + 10%SD + 10%CD