

**USE OF GEOFIBRES IN THE RECONSTRUCTION OF IFITE ROAD AWKA ANAMBRA STATE,
NIGERIA**

BY

AKUJOR PAUL CHIJOKE

(NAU/2017224047)

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CERTIFICATION

I, certify that this work was carried out by me and have not been submitted either in part or whole to this university or other institutions for the award of a degree.

BY

AKUJOR PAUL CHIJOKE
Reg No: 2017224047
(Project Student)

Date

APPROVAL PAGE

This research work "Use of Geofibres in the Reconstruction of Ifite Road Awka Anambra State, Nigeria" has been assessed and approved by department of civil engineering Nnamdi Azikiwe University.

Engr. B.A. Njotae
(Project Supervisor)

Date

Engr. Prof. C. A. Ezeagu
(Head of Department)

Date

----- **Engr. Prof. D.O.Onwuka**

Date **(External Examiner)**

DEDICATION

This work is dedicated to Almighty God for the gift of life and also for guiding me through school.

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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.

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ABSTRACT

The study was undertaken to evaluate the effect of geofibres in the reconstruction of Ifite Road Awka Anambra State, Nigeria. Samples of sub-grade soil were collected within the failed section of Ifite Road. Geofibres was added to the soil in an increasing order of 5%, 10%, 15% and 20% by weight of the soil in a single and double layered system. The sub-grade soil samples and sample stabilized with geofibres was subjected to laboratory testing. The test conducted were sieve analysis test, specific gravity test, atterberg limit test, compaction test and CBR test. Results obtained from sieve analysis test classified the samples as A-7-6 according to AASHTO Soil Classification System and CH (clay of high plasticity) according to Unified Soil Classification System, the specific gravity of the sub-grade soil was 2.66, the liquid limit, plastic limit and plasticity index of the sub-grade soil was 34.8%, 21.5% and 13.3%, the maximum dry unit weight of the sub-grade soil increased from 20.7kN/m^3 to 22.67kN/m^3 , for the single layered disposition of geofibres while for the double layered disposition of geofibres, the maximum dry unit weight of the sub-grade soil increased from 20.7kN/m^3 to 23.2kN/m^3 . The CBR of the sub-grade soil increased from 25.8% to 32.6% for the single layered system, 27.4% to 34.8% for the double layered. The study therefore recommends the use of geofibres in road construction as improvement in the strength properties of the sub-grade soil was observed.

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LIST OF SYMBOL & ABBREVIATION

CBR – California Bearing Ratio

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

D₃₀- Particle Size such that 30% is finer than the Size

D₆₀- 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

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CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Roads infrastructure are the most essential component for socioeconomic development of any country (Mittal and Shukla, 2019). (Burnett, 2011) opined that there are countless advantages associated with the construction of good road networks particularly within the confines of socioeconomic and environmental benefits. Highway pavement is an integrated system comprising of layers of superimposed processed materials above the natural compacted sub-grade soil which function primarily to distribute the wheel load of vehicle to the supporting soil in such a way that the bearing capacity of the supporting soil is not exceeded (Kadeyali, 1997). Pavement types ranges from flexible to rigid to semi-rigid and composite pavement (Kadeyali, 1997).

One of the widely used pavement types in Nigeria is flexible pavement. Flexible pavements are multi-layered system consisting sub-grade (pavement foundation), sub-base, base course and wearing course (asphalt concrete). Performance of a flexible pavement during service is significantly influenced by the strength and stiffness of the sub-grade layer as it serves as foundation for the pavement (Kadeyali, 1997). Sub-grade is natural compacted earth composed soils ranging from laterite, clays and there are cases where the sub-grade may contain expansive soils that its strength as strength cannot be guaranteed under applied loads (Osinubi, 2013). In such scenario stabilization of the sub-grade soil become necessary. Soil stabilization involves the placement of a material in a given soil layer where the presence of the material causes a redistribution of stresses and strains in the soil favorable to the purpose at hand (Palmeira, 2014). Currently, soil stabilization is most commonly performed with geosynthetics, leading to an increase in the strength and a decrease in the compressibility of the composite material. In other words, the addition of geosynthetic reinforcement in regions of tensile strain helps to inhibit the stresses in the soil, thereby increasing the shearing characteristics of the composite material (Jewell, 2012).

Moreover, the escalating cost of materials and lack of resources available have

motivated highway engineers to explore new alternatives in building new roads and rehabilitation of existing ones (Chandra, et al., 2008). Recently, synthetic materials like geofibers have evoked considerable interest among both highway engineers and manufacturers for using these materials as reinforcing materials in flexible pavements. Geofibers have been used countries like India in the construction of flexible pavement. (Pandey, et al., 2012) carried out a comparative study on performance of geofiber and non geofiber reinforced flexible pavements in India. Results suggested that geofiber reinforced flexible pavement performs satisfactorily in service than pavement constructed with conventional materials.

Geofibers are usually polypropylene fibers blended into soils to create an ideal reinforcement system for the repair of slope failures, reinforcement of pavement sub-grades, foundation stabilization, and improvement of retaining wall backfill (Chatrabhuj and Maheshwari, 2020). They are manufactured in large scale and have fourth largest volume in production after polyesters, polyamides and acrylics. By synergistically meshing with the soil already on site, geofibers help create a soil reinforcement system with dramatically improved engineering properties. They are made in the form of manufactured sheet, including a regular network of integrally associated parts, which may be linked by extrusion, bonding or interlacing, whose openings are larger than the constituents, made into an extremely exposed, network like arrangement, i.e. they have large apertures. They work as reinforcement materials. According to (Chatrabhuj and Maheshwari, 2020), geofibres have the potential of been used as a conventional materials for road construction.

Ifite road is a one-lane single carriage way located at the outskirts of Nnamdi Azikiwe University Awka Anambra State Nigeria. The road passes through places such as Yahoo Junction, Miracle Junction, Commissioner Quarters, First and Second Markets and terminates at a stepped terrain in Aroma. These road majorly used by student and lecturers of Nnamdi Azikiwe University is characterized by severe pavement distresses ranging from large potholes, alligator cracking, collapse and clogging of drainage channels evident in regions especially at Miracle and Yahoo junction respectively. Occurrence of this distresses have been largely attributed to poor geotechnical properties of the sub-grade soil, therefore it is highly pertinent from civil engineering

standpoint to enhance the strength properties of the sub-grade soil as a means of minimizing the distresses recorded along Ifite road.

In other to reduce pavement distresses by enhancing the strength of sub-grade soil along Ifite road Awka Anambra State, Nigeria and also promote the use of geofiber as a conventional material for road construction in Nigeria, this study will therefore investigate the structural benefits of using geofibers as material for strength enhancement of sub-grade soils along Ifite road Awka Anambra State, Nigeria.

1.2 Statement of Problem

The increasing loss in serviceability of Ifite road Awka Anambra State, Nigeria is a major source of concern to road users. Ifite road is characterized by severe pavement distresses ranging from large potholes, alligator cracking, rutting and raveling. These distresses could be due to the poor geotechnical properties of the sub-grade soil. Moreover, performance of a flexible pavement during service is significantly influenced by the strength and stiffness of the sub-grade layer as it serves as foundation for the pavement (Kadeyali, 1997). Sub-grade is natural compacted earth composed soils ranging from laterite, clays and there are cases where the sub-grade may contain expansive soils that its strength as strength cannot be guaranteed under applied loads (Osinubi, 2013). In such scenario stabilization of the sub-grade soil become necessary.

Strength enhancement of sub-grade soils using conventional stabilizing agents (cement, lime) is a relatively expensive process and as a result, highway engineers have explored new alternatives in constructing new roads and rehabilitation of existing ones (Chandra, et al., 2008). The utilization of synthetic materials like geofibers in road construction have generated considerable interest as the material have the potential to create an ideal reinforcement system for the repair of slope failures, reinforcement of pavement sub-grades, foundation stabilization, and improvement of retaining wall backfill (Chatrabhuj and Maheshwari, 2020).

In other to explore the use of geofibers as a cost effective material for strength

improvement of sub-grade soil in road construction, this study will therefore evaluate the use of geofiber as a material for strength enhancement of sub-grade soils along Ifite road Awka Anambra State, Nigeria.

1.3 Aim and Objectives of Study

The aim of the study is to evaluate the use of geofiber as a material for strength improvement of sub-grade soil in road construction while the objectives are:

- 1 Ascertain the feasibility and efficacy of using geofibers as an additive for strength enhancement of sub-grade soils along Ifite road Awka Anambra State, Nigeria.
- 2 Evaluate the index properties of geofibers and sub-grade soils collected along Ifite road.
- 3 Study the effect of geofibres on strength properties of sub-grade soils collected along Ifite road.
- 4 Determine the maximum amount of geofibers needed for optimum improvement in strength of sub-grade soils.
- 5 Draw conclusion and make relevant recommendation in the light of the findings obtained from the study.

1.4 Scope of Study

The study is focused basically on promoting the use of geofibres as an additive for strength enhancement of sub-grade soils along Ifite road Awka Anambra State, Nigeria. The geofibre will be added to the sub-grade soils in increasing percentages of 5% in a

two layered system by weight of the sub-grade soils. Samples of sub-grade soils and geofibres will be collected and subjected to laboratory testing. The laboratory testing includes: Sieve analysis test, Specific gravity test, Atterberg limit (Liquid and Plastic limit) test, Compaction test and California Bearing Ratio test. The California Bearing Ratio test will be used as index to evaluate the strength of the sub-grade soil. During the experimental investigation for determination of California Bearing Ratio (CBR) value of the sub-grade soils modified geofibre, single layer and double layer of geofibre will be placed horizontally at varying depth so as to ascertain the strength of the modified sub-grade soils. Recommendations will be made based on key findings obtained from California Bearing Ratio test.

1.5 Significance of Study

The use of geofibres in the reconstruction of Ifite Road Awka Anambra State, Nigeria will be of immense economic benefits. Some of the conventional practice adopted in strength enhancement of weak sub-grade soils includes: complete excavation and importation of soils with higher strength and density, treatment through stabilization using chemical stabilizers like lime and Portland cement, these are relatively expensive process. Geofibres which are residue obtained during production of plastics will offset the high cost associated with treatment of weak sub-grade soils if incorporated as a component in road construction and reconstruction process. The economic benefits associated with the use of geofibres in road construction comes from the fact that geofibres are cheap to procure and will also replace relatively expensive additives like Portland cement, lime and stone dust used as a conventional materials in strength enhancement of weak sub-grade soils. Therefore, a considerable cost savings will be fostered should geofibres be used as a material for improvement of bearing strength of weak sub-grade soils.

1.6 Justification of Study

Performance of a flexible pavement during service is significantly influenced by the

strength and stiffness of the sub-grade layer as it serves as foundation for the pavement (Kadeyali, 1997). Sub-grade is natural compacted earth composed soils ranging from laterite, clays and there are cases where the sub-grade may contain expansive soils that its strength as strength cannot be guaranteed under applied loads (Osinubi, 2013). In such scenario stabilization of the sub-grade soil become necessary.

Moreover, escalating cost of materials and lack of resources available have motivated highway engineers to explore new alternatives in building new roads and rehabilitation of existing ones (Chandra, et al., 2008). It is based on this backdrop that this study will explore the use of geofibers for road construction. Geofibers are usually polypropylene fibers blended into soils to create an ideal reinforcement system for the repair of slope failures, reinforcement of pavement sub-grades, foundation stabilization, and improvement of retaining wall backfill (Chatrabhuj and Maheshwari, 2020). Research on use of geofibers for road construction is done solely on a limited bases and this research will explore deeply on the use of geofiber as a material for strength modification of sub-grade soils along Ifite road Awka, Anambra State Nigeria.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

An arrangement comprising of layers of overlay materials above the usual sub-grade which acts as foundational layer is referred to as pavement. The mechanism of load transfer in a pavement structure regardless of the pavement types is surface or wearing course to base course to sub-base and ultimately to the natural compacted sub-grade which acts primarily as the pavement foundation, this sub-grade thereafter, transfer the load to the underlying soil or soil of sufficient bearing capacity (Kadeyali, 1997). The bearing capacity of the underlying soil must not be exceeded otherwise, failure of the pavement might occur thereby compromising the design life of such pavement design. The pavement structure is expected to possess desirable characteristics for it to perform satisfactorily during its service life and this feature includes: adequate skid resistance, durability, favorable light reflecting characteristics, minimum noise pollution, and good

riding surface, long design life with low repair cost, impermeable surface and structural efficiency.

The primary aim of providing superimposed layers in a pavement structure is to ensure that the stress generated due to traffic load are considerably reduced, such that it is transferred to a soil of sufficient bearing capacity. Flexible and rigid pavements are the commonly used type of pavement structure (Kadeyali, 1997). Flexible pavement are usually composed of bitumen (binder), aggregate (crushed gravel and sand) and filler materials (quarry dust or stone dust) with the bitumen acting as the most chemically active and energetically expensive constituents while rigid pavement are composed of aggregate (sand and crushed rock), binder (cement), water and reinforcement with the cement acting as the most chemically active and energetically expensive constituents.

Rigid pavement possess flexural rigidity such that the stress generated due to traffic load are not transferred from grain to grain to the lower layers but rather depends solely on the concrete slab which transfers the load to a wider area in accordance with the design. However, in flexible pavement wheel load transfer does not depend on the flexural strength but rather depends on the grain to grain contact of the aggregate. Therefore the flexural strength of flexible pavement is relatively low compared to that of the rigid pavement. This chapter will therefore focus essentially on flexible pavement structure as well as promote the use of geofibers as an additive for enhancement of sub-grade strength in flexible pavements.

2.2 Road Transportation and Societal Need

Road transport is regarded as the engine of growth and development in any economy (Badejo, 2014). As a public utility, road transport supplies essential goods and services, the absence of which can result in a total or partial collapse of an economy (Bos, 2014). The importance of road transportation to any nation can be appreciated if it is considered that it provides for economic, social, political, cultural and technological needs of individual and society (Badejo, 2014). The varied roles stem from the fact that human activities are not concentrated in just a location, and therefore, the need for man to access the diverse needs, ranging from shelter, recreation, work, social interaction, religious, and to commercial activities (Morenikeji, 2017). It is on this premise that road

transportation is being described as lifelines for people and society (Johansson, 2014). But when road infrastructure is undeveloped in any human settlement, for certain reasons, economic costs are imposed (Bogale, 2016). Similarly, (Oyesiku, 2016) posited that the road transport development process is not without externalities such as pollution, noise, dirt and congestion, which affect people's health and climate change.

Studies have been conducted focusing on the impact of road transportation development globally. (Johansson, 2014) studied the socio-economic impacts of road condition on low volume roads in rural areas of the northern periphery of Europe. Johansson was interested in the socio-economic considerations taken by the road management of partner countries (Scotland, Norway, Sweden and Finland) and concluded that the target standards for the general road conditions and lowest acceptable standards are more or less expressed and socioeconomic models are used for budget discussions and budget distribution. (Lalnundanga, et al. 2015) studied the impact of road construction on the socio-economic condition of the communities in the hilly terrain of Lunglei district, Mizoram, India and results revealed that road construction brought about an improvement in the community livelihood and increase in the number of educational and health centres. Also, there was an increased number of people in certain jobs such as carpentry and handloom, and further, stimulate the efficiency of import and export of goods and services.

In Nigeria, road transportation is the predominant mode with over 90% of domestic freights and passengers being moved by this mode (Badejo, 2017). This overdependence has been linked to its advantages of accessibility, flexibility and availability (Badejo, 2014). It is also noteworthy that the demand for road transport has been on the rise due to growing urban population throughout Nigeria (Ogwude, 2017). However, the road network is being described as poor except for Abuja, which is a new city having modern roads and an extensive network of the pedestrian walkway (Ogwude, 2017). While roads in Nigeria are in deplorable condition, the efforts by the government to address the issue are also noteworthy as over 60% of the national investment on transportation has been allocated to road transport infrastructure (Badejo, 2014). Given the above background, it is evident that there is a correlation between the construction of road facilities and the economic development of a city. It is also worth noting that

road development impacts could either be direct or indirect. There are also impacts during construction, those along a newly completed road, and those with long-term impacts (Wanjiku, 2018). However, most studies focus on the impacts of the road construction after completion, but there is a dearth of study particularly in developing countries including Nigeria that examined road infrastructure development impacts during construction and post-construction phases.

2.3 Flexible Pavement

A flexible pavement is one of the commonly constructed pavement structures due to its relative economy in construction and service life. In a flexible pavement, stresses generated by wheel load are transmitted to a lower layer (usually sub-grade) by grain to grain transfer mechanism as it does not rely on its flexural strength for load transfer (Kadeyali, 1997). Flexible pavement consist of a bituminous surface placed over a layer of granular material and a layer of suitable mixture of fine and coarse aggregate resting on the natural compacted sub-grade acting as the pavement foundation. Flexible pavements are mostly of bituminous material acting as the binding agent such that it remains in contact with the underlying materials even when minor deficiencies occurs.

Flexible pavements are further divided into three sub-group namely: high type, intermediate and low type. High type pavements have surface course that sufficiently support the anticipated traffic load without visible distress due to fatigue and they are not vulnerable to unfavorable weather condition. Intermediate type pavements have surface course that moderately support anticipated traffic load with likelihood of the pavement developing distress and this mainly due to the quality of the treated surface as their treated surface are low compared to the high type pavements. Low type pavements are highly vulnerable to environmental conditions, marginally support expected traffic load with high possibility of distress been developed. This type of flexible pavement are used mainly for low cost roads and have wearing course ranging from untreated to loosed natural materials to surface treated earth.

2.3.1 Structural Component of a Flexible Pavement

The structural component of a flexible pavement includes: sub-grade or prepared road bed, sub-base, base course and wearing course, all these components are superimposed on each other and perform distinct functions (Kadeyali, 1997). The performance of each component largely dictates the performance of the flexible pavements and as a result proper evaluation of these components is required for effective pavement performance and service life.

2.3.1.1 Sub-grade

The sub-grade is one of the most important structural components of a flexible pavement. It is a natural compacted earth lying beneath other layers and act as interface between the pavement and the underlying soil. It is referred to as the pavement foundation as it transmits the expected traffic load to the underlying soil of sufficient bearing capacity. The sub-grade consists mainly of earth material and must be compacted to the desirable density, near the optimum moisture content. The strength and stiffness of the sub-grade considerably influences the performance of a pavement structure (Chandravali, 2019). The stiffness is referred to as the degree of resistance upon loading and it depends primarily upon the soil properties, existing stress conditions and soil stress history (Susanka, 2016).

2.3.1.2 Sub-base

The sub-base is a layer of material above the sub-grade and beneath the base course and they function primarily to provide structural support, improve drainage and reduce intrusion of fines from the sub-grade to the pavement structure. The structural capacity of the wearing course can be used to determine whether a sub-base can be dispensed with. If the pavement is constructed over a high quality wearing surface, stiff sub-grade may not require additional features offered by a sub-base layer and in such condition, sub-base may be dispensed with.

2.3.1.3 Base-course

The base-course is a layer of materials directly above the sub-base and beneath the wearing or surface course, it reduces the magnitude or intensity of the load transmitted to the underlying pavements layers. It provides additional load distribution mechanism and contributes to sub-surface drainage. It may be composed of crushed stone, crushed slug and other untreated or stabilized materials.

2.3.1.4 Wearing Course

Wearing course is a layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete. The functions and requirements of this layer are: It provides characteristics such as friction, smoothness, drainage. Also, it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade, it must be tough to resist the distortion under traffic and provide a smooth and skid resistant riding surface, it must be water proof to protect the entire base and sub-grade from the weakening effect of water.

2.3.2 Typical Coat used in Flexible Pavement

Typical coats of a conventional flexible pavement includes seal coat, prime coat and tack coat. Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance while tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water, it provides proper bonding between two layers of binder course and must be thin, uniformly cover the entire surface and set very fast and prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed. It provides bonding between two layers. Unlike tack cost, prime coat penetrates into layer below, plugs the voids, and forms a water tight surface.

2.3.3 Factors Influencing Performance of Flexible Pavement

2.3.3.1 Traffic

Traffic is the most important factor influencing pavement performance. The performance of pavements is mostly influenced by the loading magnitude, configuration and the number of load repetitions by heavy vehicles (Sharad and Gupta, 2004). The damage caused per pass to a pavement by an axle is defined relative to the damage per pass of a standard axle load, which is defined as 80kN single axle load (E80). Thus a pavement is designed to withstand a certain number of standard axle load repetitions (E80's) that will result in a certain terminal condition of deterioration.

2.3.3.2 Moisture

Moisture can significantly weaken the support strength of natural gravel materials, especially the sub-grade. Moisture can enter the pavement structure through cracks and holes in the surface, laterally through the sub-grade, and from the underlying water table through capillary action (Sharad and Gupta, 2004). The result of moisture ingress is the lubrication of particles, loss of particle interlock and subsequent particle displacement resulting in pavement failure.

2.3.3.3 Sub-grade

The sub-grade is the underlying soil that supports the applied wheel loads. If the sub-grade is too weak to support the wheel loads, the pavement will flex excessively which ultimately causes the pavement to fail (Sharad and Gupta, 2004). If natural variations in the composition of the sub-grade are not adequately addressed by the pavement design, significant differences in pavement performance will be experienced.

2.3.3.4 Construction Quality

Failure to obtain proper compaction, improper moisture conditions during construction, quality of materials, and accurate layer thickness (after compaction) all directly affect the performance of a pavement (Sharad and Gupta, 2004). These conditions stress the need for skilled staff and the importance of good inspection and quality control procedures during construction.

2.3.3.5 Maintenance

Pavement performance depends on what, when, and how maintenance is performed. No matter how well the pavement is built, it will deteriorate over time based upon the mentioned factors (Sharad and Gupta, 2004). The timing of maintenance is very important; if a pavement is permitted to deteriorate to a very poor condition then the added life is typically about 2 to 3 years. This added life would present about 10 percent of the total life. Delay in maintenance hold further implications, in that, there will be an increment in repair and rehabilitation cost. Thus, postponing maintenance because of financial constraints will result in a significant financial penalty within a few years.

2.4 Durability of Flexible Pavement

Flexible pavement consists mainly of layered materials which include the sub-grade, base course, sub-base and the surface course and the strength and durability of the pavement is largely dependent on the nature of the various components (Obeta and Njoku, 2016). The sub-grade (regardless of the nature of frost susceptibility or fluctuation in water table) functions primarily as the pavement foundation providing a favorable platform for the construction of the pavement. The sub-base whether natural or stabilized with Portland cement, asphalt, lime, fly ash, act as a support the base course, prevent the intrusion of fine grained sub-grade soil into the base course and ensuring the drainage of free water (Obeta and Njoku, 2016). The base course which comprises chiefly of good quality aggregates (bound or unbound) provides an important portion of the structural capacity of the pavement bearing significant amount of the wheel load transmitted to it through the pavement surface and transferring this load to the underlying layers (sub-base) while the surface course typically made of asphaltic concrete (wearing course) withstand skidding, traffic abrasion and disintegration effect of climate (Christopher et al, 2006). It is therefore evident that the durability of pavement is affected by the nature of these materials expressed in terms of strength, moisture content, drainage and spatial variability.

The opposition of a pavement to weathering and abrasive action of traffic within its design life is used to gauge the durability of a pavement. Depending on the factor of concern, it can be gauged using the thin-film oven test, rolling thin-film oven test, pressure ageing vessel method and concept of durability index from the Marshal test. With regards to asphalt paving materials, durability can also be defined as the resistance posed by these materials in the asphalt pavement structure to adverse effects of environmental conditions such as water, ageing and temperature variations for a lengthy period without any substantial deterioration while taking into account a given volume of traffic loading (Scholz and Brown, 1996). Thus, pavement durability is also the measure of how asphalt binder physical properties change with age (age hardening).

2.5 Geofibers

Geofibers are usually polypropylene fibers blended into soils to create an ideal reinforcement system for the repair of slope failures, reinforcement of pavement sub-grades, foundation stabilization, and improvement of retaining wall backfill (Chatrabhuj and Maheshwari, 2020). They are manufactured in large scale and have fourth largest volume in production after polyesters, polyamides and acrylics. By synergistically meshing with the soil already on site, geofibers help create a soil reinforcement system with dramatically improved engineering properties. They are made in the form of manufactured sheet, including a regular network of integrally associated parts, which may be linked by extrusion, bonding or interlacing, whose openings are larger than the constituents, made into an extremely exposed, network like arrangement, i.e. they have large apertures. They work as reinforcement materials. According to (Chatrabhuj and Maheshwari, 2020), geofibers have the potential of being used as a conventional material for road construction.

2.5.1 Benefit of Using Geofibers in Flexible Pavement

There are two main benefits of using geofiber in the sub-grade layer of flexible pavements. For a given cross-section of the pavement, addition of geofiber leads to an increase in serviceability life and reduction in the maintenance cost of the pavement.

This alternative is feasible when the maintenance and replacement costs during the service life of the pavement are offset by the high initial cost of using the geofiber for a given project (Perkins and Ismeik, 1997). Also, if the pavement is designed for same serviceability life as an unreinforced pavement, addition of geofiber may results in reduction in the thickness of the layers above the sub-grade level of flexible pavement. This alternative is feasible if the cost of the geofiber is less than the combined cost of the replaced sub-base material and any construction related costs associated with a reduced sub-grade thickness (Perkins and Ismeik, 1997). Both of the above alternatives are desirable, as part of the design process involves minimizing the total cost of the pavement structure, including initial costs plus maintenance costs. The savings of 10-20% of total project cost have been estimated by combining these benefits (Berg et al., 2000).

The aforementioned benefits are primarily related with the ability of geofiber reinforcement to resist traffic loads. However, the pavement structures deteriorate as a result of the combined effects of traffic and environment-related damage. An additional use of geofiber in flexible pavement to resist environmental loads has been proposed recently (Zornberg and Gupta, 2009). The benefits involve the mitigation of longitudinal cracks when pavements are constructed over expansive sub-grades. The construction of roadways over these sub-grades (which are common in New Delhi, India) have led to significant volume changes during subsequent cycles of seasonal wetting and drying due to moisture fluctuations. These volume changes induce vertical movements, accelerate the degradation of pavement materials, and ultimately shorten the service life of the roadway. The specific problem addressed in this research included the occurrence of longitudinal cracks that develop due to above environmental loading on pavements constructed over such expansive sub-grades.

2.5.2 Review of Works on Use of Geofiber for Pavement Construction

A study conducted by (Pitti and Raman, 2018) on improvement of cbr strength of clay soils using geofiber. The effect of geofiber on the strength of the clay soil was assessed

through California bearing ratio (CBR) test. The geofiber was mixed with clay soil in different ratios of 0%, 0.25%, 0.50%, 0.75%, and 1% respectively. The Liquid limit, Plastic Limit, Dry Density, Optimum Moisture Content and Compressive Strength of the soil sample with varying percentage of fiber is also studied. Then CBR test is conducted with the corresponding OMC for the different ratio of 0.25%, 0.50%, 0.75%, and 1% of polypropylene. From the findings it was observed that as the ratio of geofiber increased, the optimum moisture of the soil decreased while the California bearing ratio of the soil increased consistently with increase in percentages of geofibers.

In another study, (Viswanadhum, et al., 2011) investigated the Influence of randomly distributed geofibers on the integrity of clay-based landfill covers. A series of centrifuge tests was performed on model clay-based landfill covers with and without geofiber reinforcement at 40 gravities. A hydraulic-based differential settlement simulator was used to induce continuous differential settlements with a distortion level up to 0.125. Analysis and interpretation of the test results indicate a significant potential for geofiber reinforcement to decrease and to retard soil crack potential in a discrete and randomly distributed soil barrier reinforced with geofibers, while retaining its hydraulic performance.

(Mittal and Shukla, 2019) investigated Strength Improvement of Poor Sub-grade Soil Reinforced with geofibers. Geofiber sheets are placed in single and double layers at various depths of soil sub-grade and heavy compaction. California bearing ratio (CBR) and unconfined compressive strength (UCS) tests were conducted. The test results indicate significant improvements in CBR, UCS and axial strain at failure as well as a reduction in post peak strength loss. Maximum improvements in unconfined compressive strength and California bearing ratio were recorded at 36% and 41%, 62% and 70%, respectively. The unconfined compressive strength values were recorded when the geofiber was placed in single layer (0.2H) and in double layers (0.2H and 0.4H) from the top of the specimen. Scanning electron microscopy (SEM) was used to study the micromechanical interaction between soil and geofiber surface. It was observed that interlocking and surface friction between soil particles and fibers of the geofiber are responsible for strength enhancement of weak sub-grade soil.

In order to bridge gaps on previous works and increase awareness on the efficacy of

geofiber as a material for strength enhancement of sub-grade soils in road construction, this study will be assess the effect of geofibers on strength of sub-grade soils collected along Ifite road Awka Anambra State Nigeria.

CHAPTER THREE

MATERIALS AND METHODS

This section presents the materials and methods used to actualize the research goal. Relevant standards and journals were employed to ascertain how the materials collected be analyzed and also the various laboratory tests to be conducted. All Tests such as sieve analysis test, specific gravity test, atterberg limit (liquid and plastic limit) test, compaction test and California bearing ratio test were carried out at Civil Engineering Laboratory located in Nnamdi Azikiwe University Awka Anambra State, Nigeria.

3.1 Collection, Preservation and Preparation of Materials

3.1.1 Sub-grade Soils

Disturbed sub-grade samples were collected at the failed section of the pavement located along ifite road Awka Anambra State Nigeria. The choice of collecting samples along paved was justified by the fact that the sample was a representation of the sub-grade soil. Sample collected was lateritic in appearance. The sample was collected in

empty cement bags with the aid of shovel and was conveyed to the laboratory for various laboratory testing. Upon arrival, the in-situ moisture content of the sample was determined before subsequent experimental investigations.



Plate 3.0: Sample of Disturbed Sub-grade Soils collected along Ifite Road.

3.1.2 Geofiber

Geofibers of 12mm in length and 34 microns in diameter were used for the experimental study. The geofiber used for the experimental investigation is designated as GF. This fiber was procured from plastic industries at Onitsha, Anambra State and will be partially added to the sub-grade soils in a stepped increase of 5% to 20% in a single and doubled layered system by weight of sub-grade soil.



Plate 3.1: Sample of Geofibre used for the Experimental Study



Figure 3.1.1: Sample of Geofibre used for the experimental study

3.2 Sampling Locality

Disturbed sub-grade samples were collected within the failed section of the pavement located along Ifite Road Awka Anambra State, Nigeria. Ifite road located within Anambra North local government area is a one-lane single carriage way used by commercial motorist. The road is classified as trunk B road since it is owned by the state government. Ifite road passes through places like Yahoo junction, Miracle Junction, Commissioner quarters, first and Second market terminating at a stepped terrain in Aroma. The road is used majorly by student and lecturers of Nnamdi Azikiwe University due to its proximity and ease of accessibility to the study center. Ifite road are lies within longitude $6^{\circ}45'E$ to $7^{\circ}30'E$ and latitude $6^{\circ}00'N$ to $6^{\circ}30'N$.

3.3 Experimental Investigation

This section presents the experimental procedure and laboratory tests that were adopted for the project work. The tests was conducted for the sub-grade samples, geofibers and sub-grade modified and this tests include: sieve analysis test, specific gravity test, water absorption test, atterberg limit (liquid and plastic limit) test, compaction test and California bearing ratio test. The aforementioned tests were carried out at Civil Engineering Laboratory located in Nnamdi Azikiwe University Awka, Anambra, State Nigeria. Below is a description of test procedures and apparatus:

3.3.1 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^oC.
- 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 result.

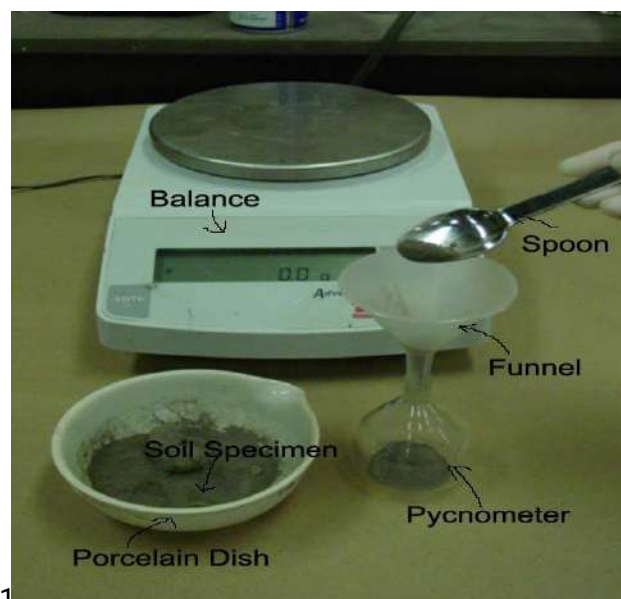
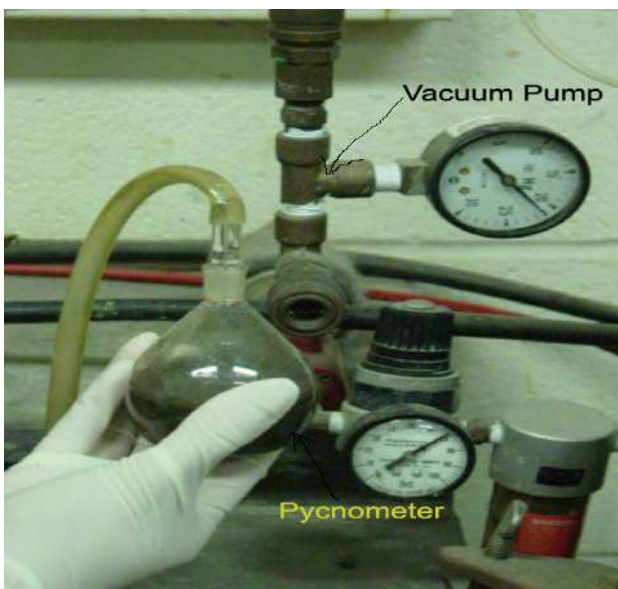


Plate 3.2: Apparatus used for Specific Gravity Test (Source: Braja, 2006)

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 are as follows:

$$\text{Specific gravity } (G_s) = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)}$$

Where M_1 = weight of density bottle + stopper

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

3.3.2 Particle Size Distribution (Sieve Analysis) Test

Sieve analysis is a procedure used to assess the particle size distribution of a granular material (Atkinson 2000). The size distribution is often of critical importance to the behaviour of the material during use. Sieve analysis can be 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.

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

1. Sand and other coarser particles are visible to the naked eye.
2. Silt particles become dusty and are easily brushed off.
3. Clay particles 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 (C_u) 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.

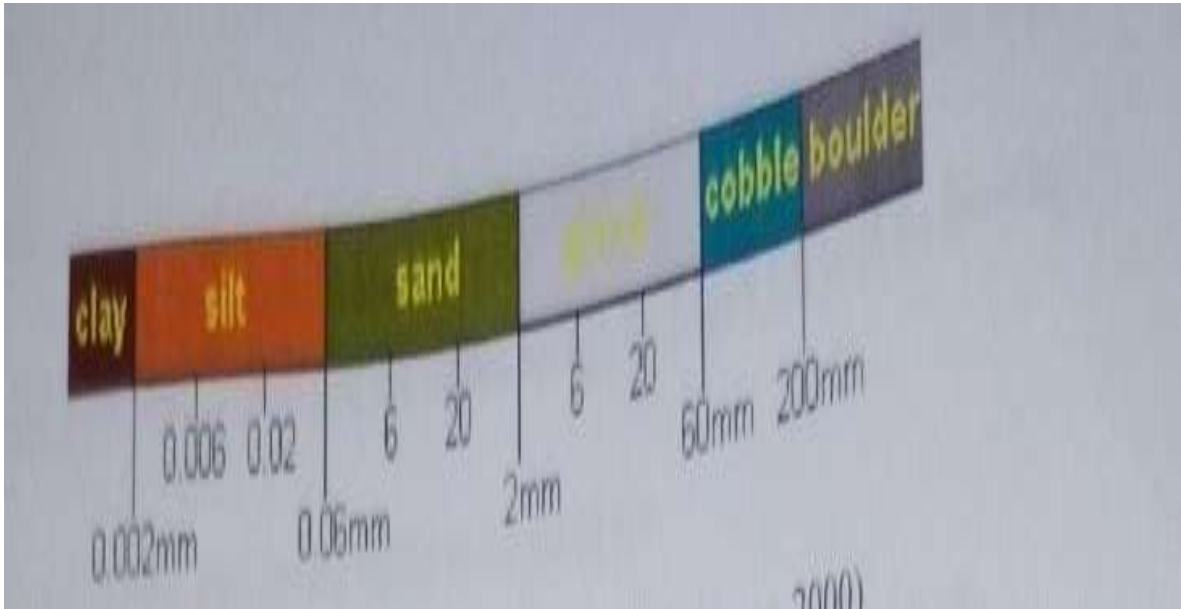


Fig 3.1 Ranges for grain Sizes of different Soil type (Atkinson, 2000).

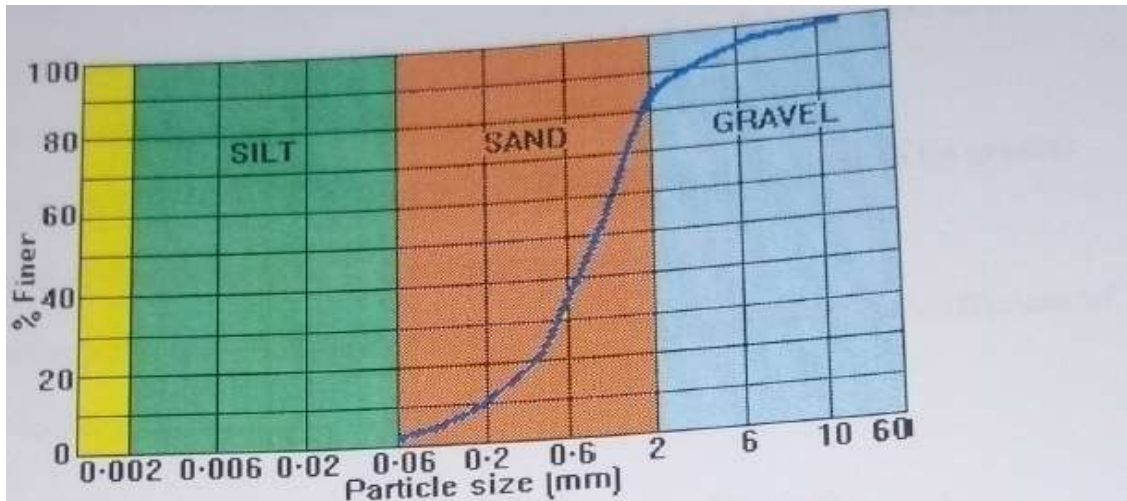


Fig 3.2 Grading Curve Ranges for Different Soil Types (Atkinson, 2000).

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°C-110°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.

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

$$\text{Cumulative percentage retained} = \sum \text{Percentage retained (\%)}$$

$$\text{Cumulative Percentage Finer (\%)} = 100 - \text{Cumulative percentage retained.}$$

$$\text{Coefficient of Curvature} = \frac{D_{60}}{D_{10}}$$

$$\text{Coefficient of Uniformity} = \frac{(D_{30})^2}{D_{10} \times D_{60}}$$

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.

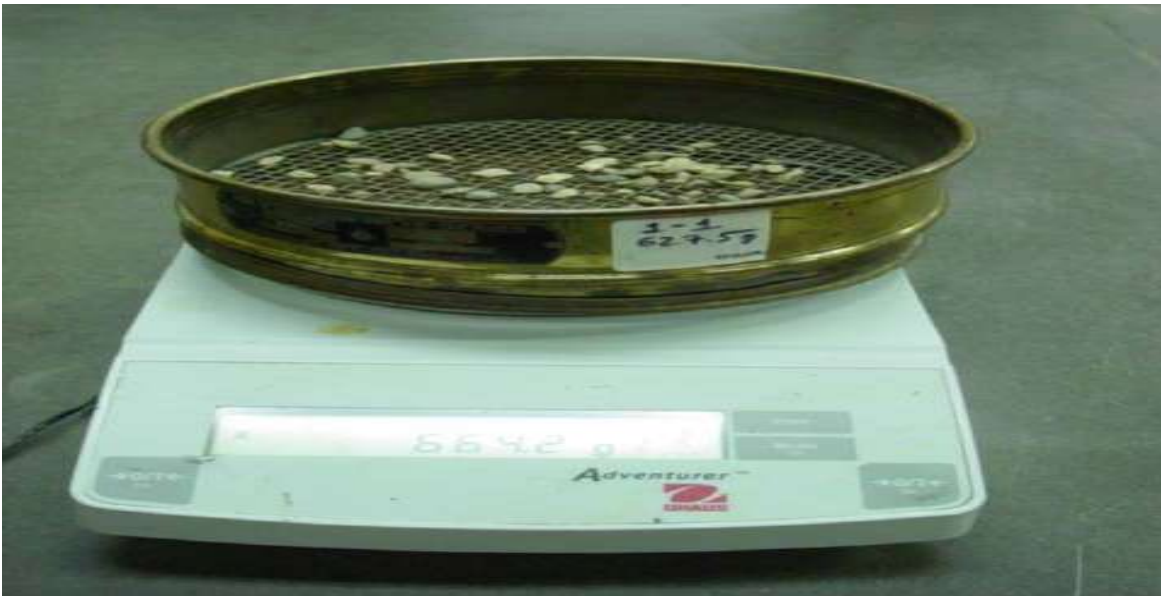


Plate 3.3 Apparatus for Particle Size Distribution Test (Source: Braja, 2006).



Plate 3.3.1 Apparatus for Particle Size Distribution Test (Source: Braja, 2006)

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°C for 16-24hrs.

- 5 The sample was removed from the oven and the weight was determined (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 3.4: Weighing of Sub-grade Soil for Particle Size Determination

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 inferences 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 (SL)

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

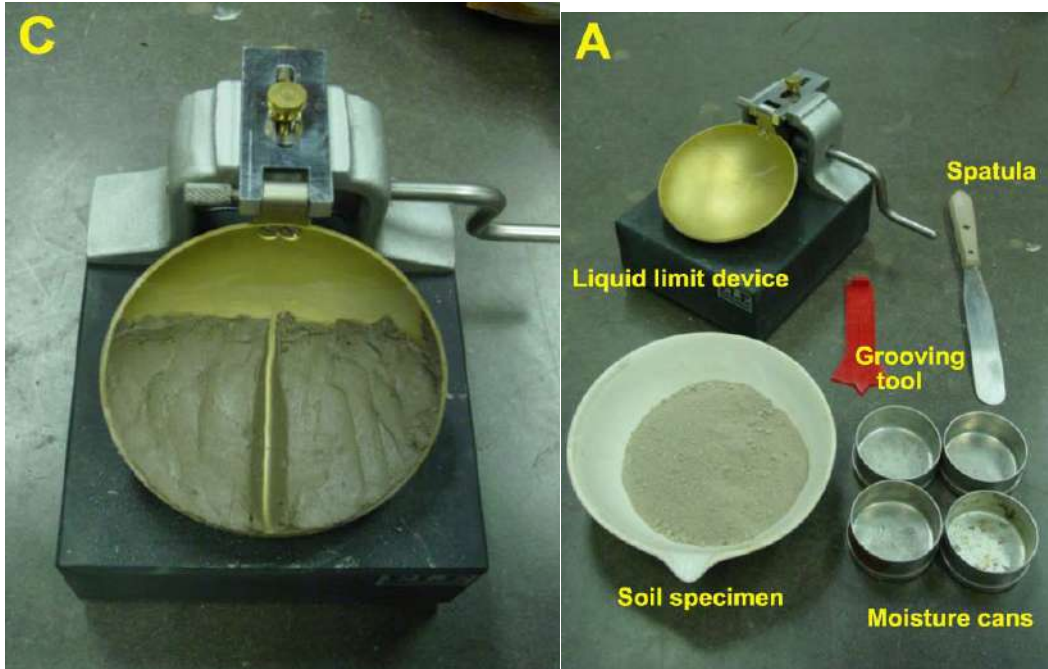


Plate 3.5 Apparatus for Atterberg Limit Test

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 two 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:

$$\text{Moisture content} = \frac{\text{Weight of water}}{\text{weight of dry soil}} \times 100 = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

Where W_1 = Weight of empty tin.

W_2 = Weight of tin + wet soil.

W_3 = Weight of tin + oven-dried soil.



Plate 3.6: Weighing of Sample to be matured for Liquid Limit Determination

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 3.1 gives the plasticity ratings of fine grained soils.

Table: 3.1 Plasticity Ratings for Fine grained Soil (Braja, 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 80-110⁰C 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 (W₃).
9. The test procedure was repeated for at least two trials and takes the average

plastic limit value for all the trials.

The Computation for Plastic Limit is as follows:

$$\text{Plastic limit} = \frac{\text{Weight of water}}{\text{Weight of oven-dried soil}} \times 100 = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

Where W_1 = Weight of empty tins.

W_2 = Weight of tin plus wet soil

W_3 = Weight of tin plus oven-dried soil

3.3.5 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 its dry density. It could also be stated as the process of packing the soil particles 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 results 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 the sub-grade soils and sub-grade soil modified geofiber.

Details of British Standard Compaction Process

Table 3.2 Details of Compaction Mould.

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

Table 3.3 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

$$\text{Mechanical energy} = \frac{\text{Weight of rammer} \times \text{no of layers} \times \text{no of blows} \times \text{height of drop}}{\text{Volume of mould}}$$
$$= \frac{2.5\text{g} \times 3\text{layers} \times 27\text{blows} \times 300\text{mm}}{1000} = 60.75\text{kgm} = 60.75 \times 9.81\text{Nm} = 596\text{j}$$

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

British Standard Heavy

$$\text{Mechanical energy} = \frac{4.5 \times 5 \times 27 \times 450}{1000} = 2652\text{j}$$

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

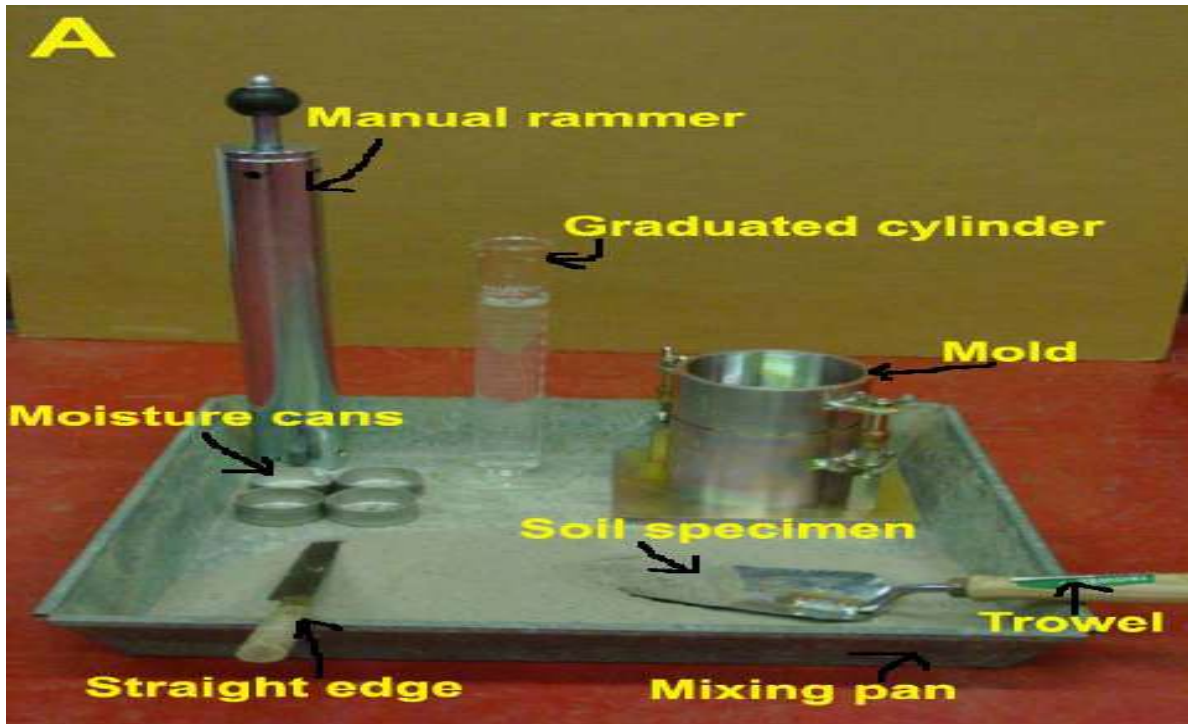


Plate 3.7: Apparatus employed for Compaction Test.

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 levelled 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

$$\text{Bulk Density (kg/m}^3\text{)} = \frac{\text{Wt of wet soil (kg)}}{\text{Vol of mould (m}^3\text{)}} = \frac{W_2 - W_1}{W_4}$$

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

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

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

$$\text{Wt of tin (kg)} = W_1$$

$$\text{Wt of tin + wet soil} = W_2$$

$$\text{Wt of wet soil (kg)} = W_3 = W_2 - W_1$$

$$\text{Wt of tin + dry soil (kg)} = W_4$$

$$\text{Wt of dry soil (kg)} = W_5 = W_4 - W_1$$

$$\text{Wt of water (kg)} = W_6 = W_3 - W_5$$

$$\text{Moisture Content (\%)} = \frac{\text{Wt of water}}{\text{Wt of dry soil}} \times 100 = \frac{W_6}{W_5} \times 100$$



Plate 3.8: Laboratory Determination of Compaction Properties of Sub-grade Soils

3.3.5 California Bearing Ratio (CBR) 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 its behavior under worst condition (flooding as a result of intense rainfall).

Table 3.1 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 ± 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.



Plate 3.9: California Bearing Ratio Test Machine.

Test Procedure

The methods used for California Bearing Ratio Test are:

1. Compression with tamping.
2. Compaction with known maximum dry unit weight (MDUW) and optimum moisture content (OMC).
3. For this course of study the method for compacted 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 $\frac{\text{test load}}{\text{standard load}} \times 100$

Where

Test load = dial gauge reading × proof ring constant

CHAPTER FOUR

RESULTS AND DISCUSSION

This section presents experimental results valuable in assessing the use of geofibres in road construction. These results are presented in Table 4.0 – 4.1 below:

4.1 Results

Table 4.0: Index Properties of the Sub-grade Soil Samples

Properties	Soil Sample
Specific Gravity	2.66
Liquid Limit (%)	34.8
Plastic Limit (%)	21.5
Plasticity Index (%)	13.3
Plasticity Rating	Medium Plasticity
Percentage Passing Sieve No 200 (0.075mm)	43.7
AASHTO Soil Classification System	A-7-6
Unified Soil Classification System	CH

Table 4.1: Compaction and CBR Characteristics of Soil Stabilized with Geofibres

Percentage Replacement/ Properties	0% G F	5% GF	10% GF	15% GF	20% GF
Maximum Dry Unit Weight (kN/m ³) (single layered system)	20.7	21.7	22.2	22.2	22.67
Optimum Moisture Content (%) (single layered system)	11.8	13.8	10.8	12.21	10.68
Maximum Dry Unit Weight (kN/m ³) (single layered system)	20.7	21.73	22.64	23.1	23.2
Optimum Moisture Content (%) (single layered system)	11.8	14.97	7.85	7.3	15.1
CBR Values (single layered system)	25.8	27.3	29.5	30.3	32.6
CBR Values (double layered system)	25.8	28.8	31.6	32.5	34.8

4.2 Evaluation of the Index Properties of the Soil Sample

Figure 4.0 is a semi-logarithmic plot of the particle size distribution of the natural clayey soils. The percentage passing sieve No 200 (0.075mm) was 43.7 and as a result, the soil

sample was classified as CH (clay of high plasticity) according to Unified Soil Classification System and A-7-6 according to AASHTO Soil Classification System. The shape parameter (D10) cannot be determined from the particle size distribution chart and as a result, the gradation of the clayey samples could not be ascertained.

Atterberg limit test of the soil sample revealed that the liquid limit, plastic limit and plasticity index of the samples were 34.8%, 21.5% and 13.3% respectively. The results meets the requirement given by Federal Ministry of Works and Housing, (1999) which state that the liquid limit and plasticity index of sub-grade soil samples must not exceed 80% and 55% respectively.

The specific gravity of the sample was 2.66; this value obtained satisfied the specification given by Federal Ministry of Works and Housing, (1999) which state that the specific gravity of sub-grade soils must lie within the range of 2.5 to 2.75. The specific gravity value obtained (2.66) also suggest the presence of clay or silt which is advantageous at the sub-grade level of road construction.

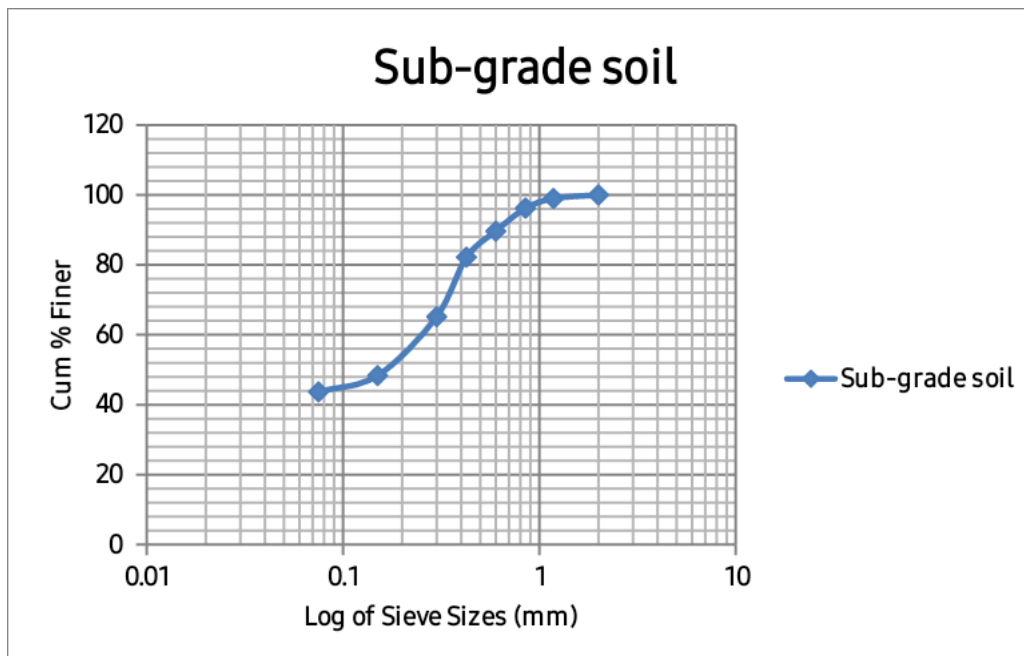


Table 4.3 Economic Analysis Pavement Reconstructed with Geofiber and Non Geofibre Reinforced Sub-grade Soil along Ifite Road Awka Anambra State, Nigeria.

		Geofibre Reinforced Sub-grade Soils	Non-Geofibre Reinforced Sub-grade Soils
Bill No	Description	Amount (#)	Amount (#)
1	Earth work	5,125,000.00	9,989,200.00
2	Road work	50,840,000.00	54,899,000.00
	Sub Total	55,840,000.00	64,888,200.00
	Add 5% Contingency	2,798,250.00	3,244,410.00
	Sub Total	58,763,250.00	68,136,610.00
	Add 5% VAT	2,938,162.50	3,406,663.50
	Grand Total	61,701,412.50	71,539,240.00

4.2.5 Economic Assessment of Geofibre and Non Geofibre Constructed Pavement Structure

Table 4.3 depicts the economic assessment of the pavement constructed with sub-grade reinforced with geofibre and non geofibre reinforced sub-grade soils. From the findings obtained, it is very obvious that the cost of pavement constructed with sub-grade reinforced with geofibre was relatively lesser compared to that constructed without the use of geofibre. The discrepancy in cost is due to the relative cheapness of geofibre and ease of replacement of expensive materials used for strength enhancement of the sub-grade soils. It is therefore pertinent to incorporate the use of geofibre as a material for road construction as this will not only enhance the bearing strength of the sub-grade soil but also foster cost effectiveness in both pavement construction and reconstruction process.

Figure 4.0: Particle Size Distribution Curve for the Soil Sample

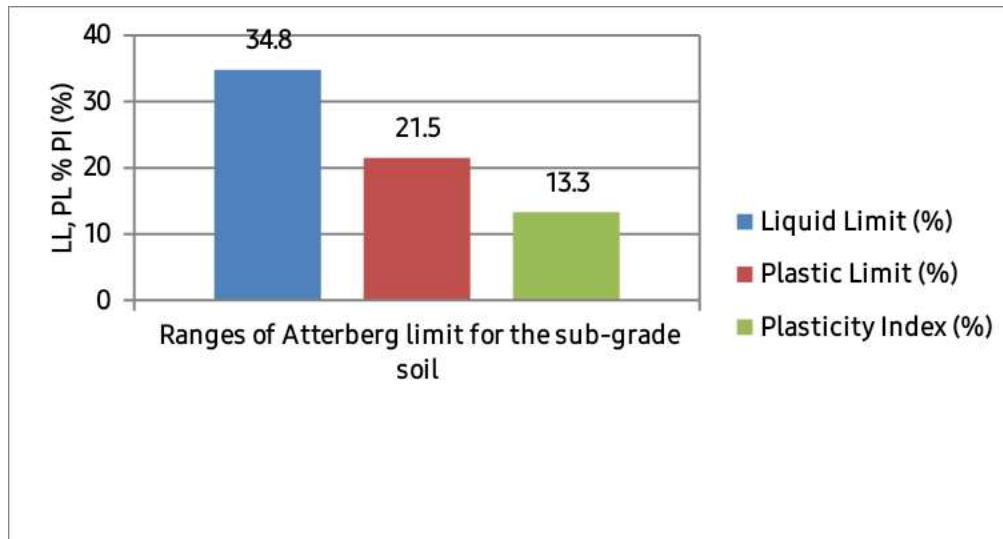


Figure 4.1: Liquid, Plastic and Plasticity Index of the soil Sample

4.3 Evaluation of the Compaction and CBR Characteristics of the Sub-grade Soil Stabilized with Geofibres

Figure 4.1-4.3 shows the results of maximum dry unit weight and optimum moisture content obtained at varying percentages of geofibres for both single and double layered system. Results obtained revealed that the maximum dry unit weight of the soil increased on consistent addition of geofibers to the soil from 5% to 20% for the single layered disposition of geofibres. Although, a slight deviation was observed at 15% geofibre content, this could be attributed to lapses in the experimentation process. While for the doubled layered disposition of geofibres, a trend of decrease and increase in maximum dry unit weight of the sub-grade soil was observed. The peak maximum dry unit weight was recorded at 15% geofibre content. The optimum moisture content on

the other hand, was found to decrease with increasing percentages of geofibers. Comparative assessment of the effect of single and double layered disposition of geofibers on the compaction characteristics of the soil shows that the increase in the maximum dry unit weight of the sub-grade soil was consistent for the single layered disposition of geofibres than that of the double layer. However, the peak maximum dry unit weight for the double layered disposition of geofibres was higher than that of the single layer. Works indicative of these findings are the works of (Nangia et al. 2015), (Krishna and Rao, 2017) and (Dayakar, et al. 2018).

Table 4.2 depicts the CBR characteristics of the soil samples stabilized with geofibres for both single and double layered arrangements. Results obtained for the single layered system shows that addition of geofibres to the soil improved the CBR characteristics of the soil from its natural value of 25.8% to 32.6% while for the double layered disposition, the CBR characteristics of the soil increased from 27.4% to 34.8%. The addition of geofibres enhanced the CBR of the soil making them suitable for use as both sub-base type 2 and sub-base type 1 material as recommended by Federal Ministry of Works and Housing, (1999).

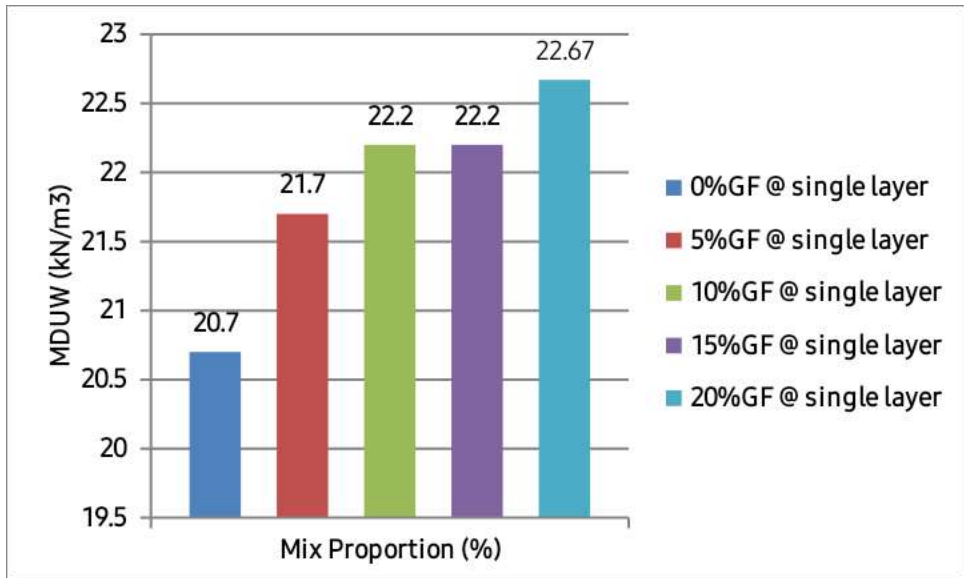


Figure 4.2:

Maximum Dry Unit Weight for Single layer Disposition of Geofibres

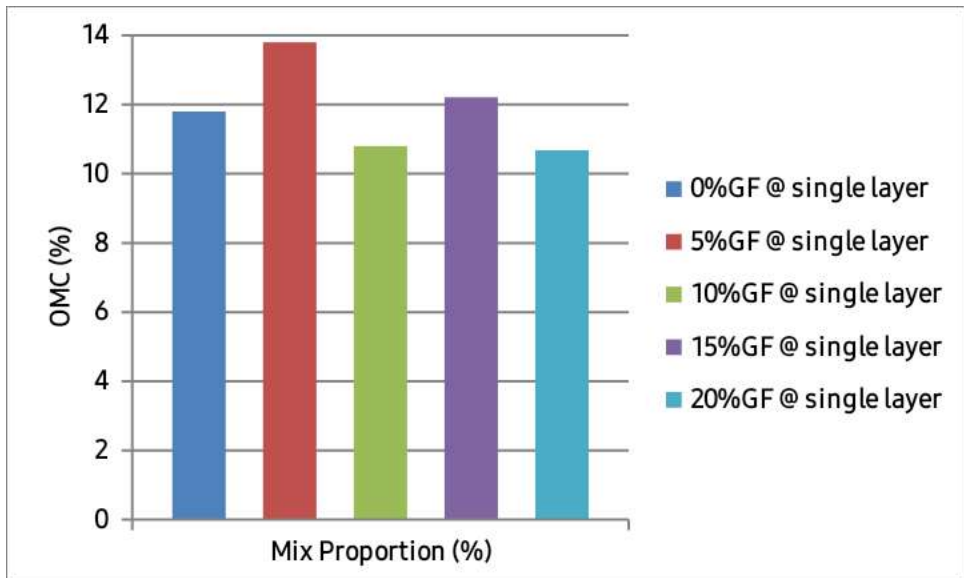


Figure 4.3:

Optimum Moisture Content for Single layer Disposition of Geofibres

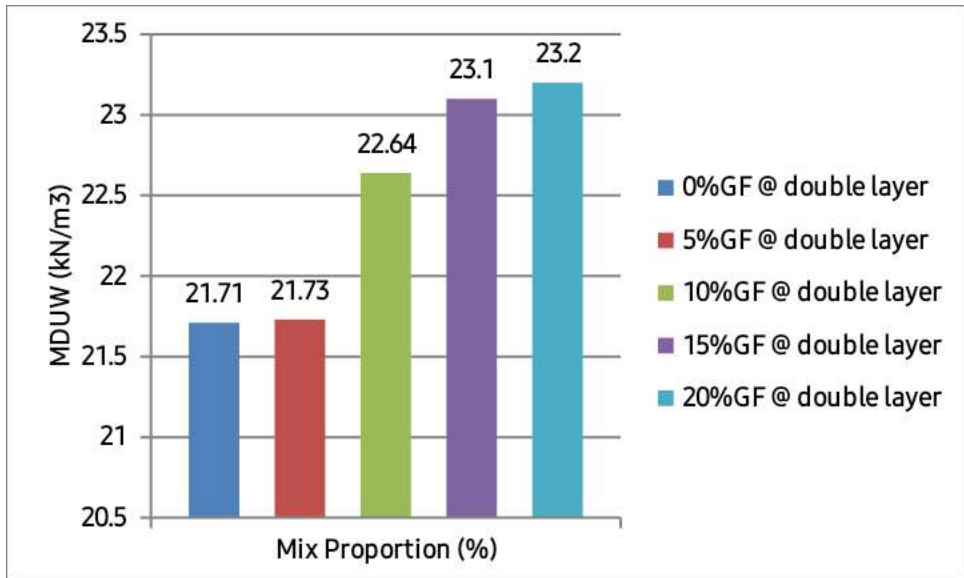


Figure 4.4:

Maximum Dry Unit Weight for Double layer Disposition of Geofibres

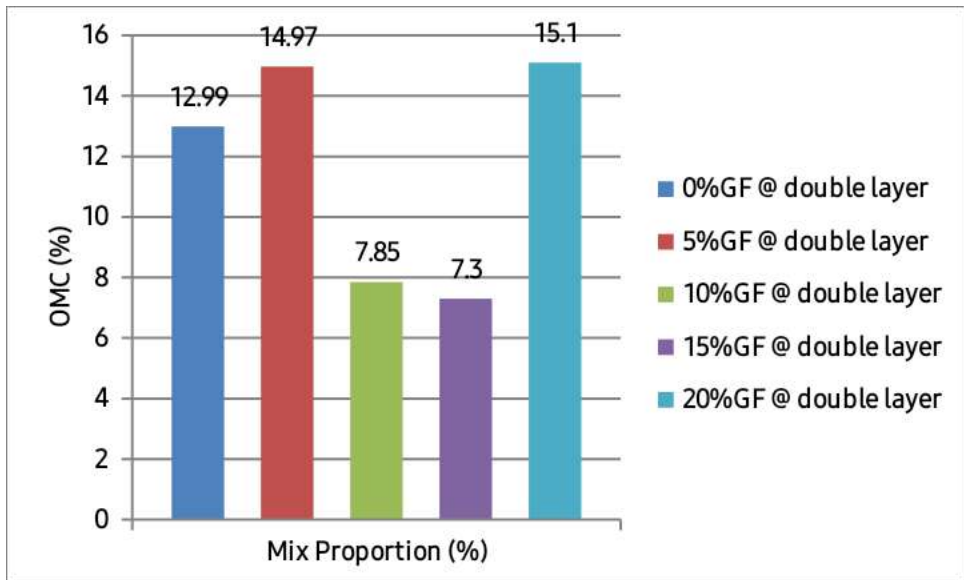
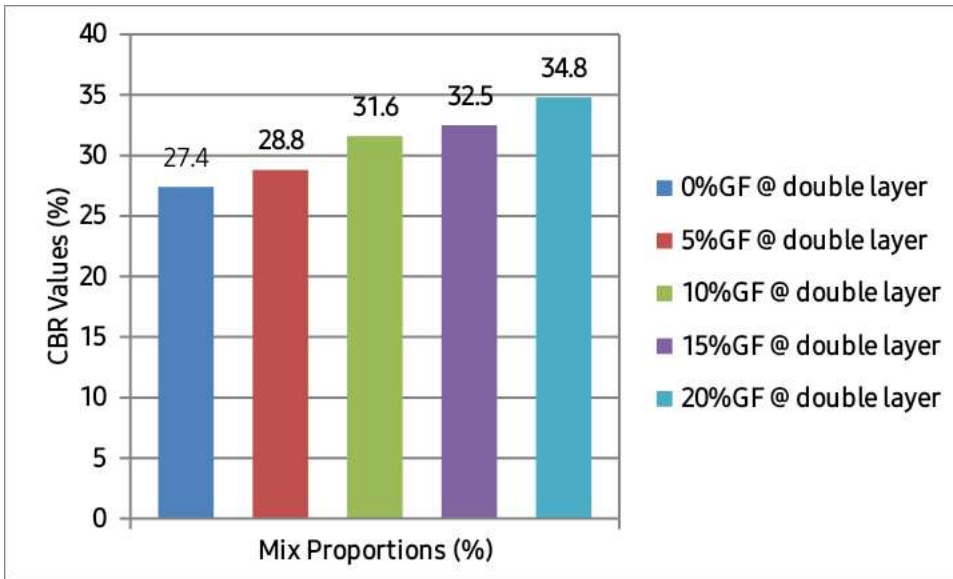
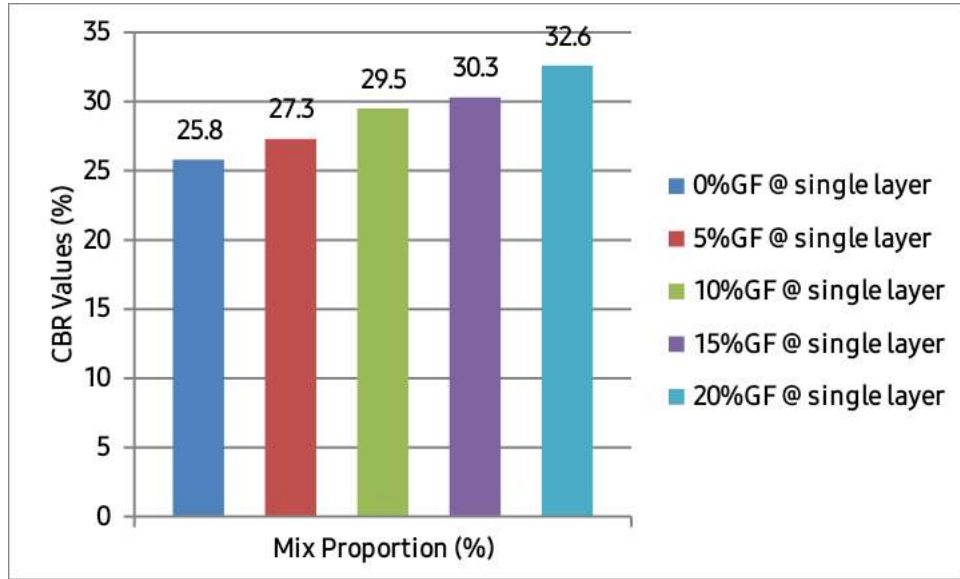


Figure 4.5:

Optimum Moisture Content for Double layer Disposition of Geofibres



0% GF @ double layer

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

From the findings obtained on the assessment of the effect of geofibres as a material for road construction, the following conclusion can be drawn:

- 1 Evaluation of the particle size distribution of clay shows that the percentage passing sieve No 200 (0.075mm) was 43.7 and as a results, the clay sample was classified as CH (clay of high plasticity) according to Unified Soil Classification System and A-7-6 according to AASHTO Soil Classification System.
- 2 The specific gravity, liquid limit, plastic limit and plasticity index of the soil sample were 2.66, 34.8%, 21.5% and 13.3% .
- 3 The maximum dry unit weight of the soil sample was found to increase on consistent addition of geofibres from 5% to 20% for the single layered disposition of geofibre while for the double layered disposition of geofibre, a

range of fluctuating values was obtained.

- 4 The optimum moisture content of the soil sample was found to decrease on consistent addition of geofibres to the soil from 5% to 20% for both the single and double layer disposition of geofibres.
- 5 The California Bearing Ratio of the soil sample was found increase on consistent addition of geofibres to the soil from 5% to 20% for both the single and double layer disposition of geofibres.
- 6 The geofiber enhanced the CBR characteristics of the soil making them suitable for use as both sub-base type 1 and 2 material
- 7 The compaction and CBR characteristics of the double layered disposition of geofibers were higher than that of the single layer.
- 8 The geofibers were adjudged as a cost effective material for enhancing the density and strength properties of soils used for road construction.

5.2 Recommendation

The following recommendation in the light of the findings obtained on use of geofibres in road construction can be made:

- 1 The study recommend the use of geofibres particularly double layered disposition of geofibers in road construction as geofibres has positive effect on strength properties of soils used for road construction.
- 2 The study also admonishes highway construction industries, professional bodies and highway practicing engineers to emulate countries like India which incorporate the use of geofibres in road construction and also promote locally the

potentials of geofibres as a material for road construction as this will foster economy in road construction and ensure rational use of material in road construction.

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APPENDICES

APPENDIX A

Sieve Analysis Test

Table A1: Sieve Analysis Test Results for the Sub-grade Soil

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cum % Retained	Cum % Finer
2	0.03	0.006	0.006	99.994
1.18	5.04	1.008	1.014	98.986
0.85	13.78	2.756	3.77	96.23
0.6	32.95	6.59	10.36	89.64
0.425	37.26	7.452	17.812	82.188
0.03	85.14	17.028	34.84	65.16
0.15	84.09	16.818	51.658	48.342
0.075	23.21	4.642	56.3	43.7
Tray	0.68	0.136	56.436	43.564
Total	500			

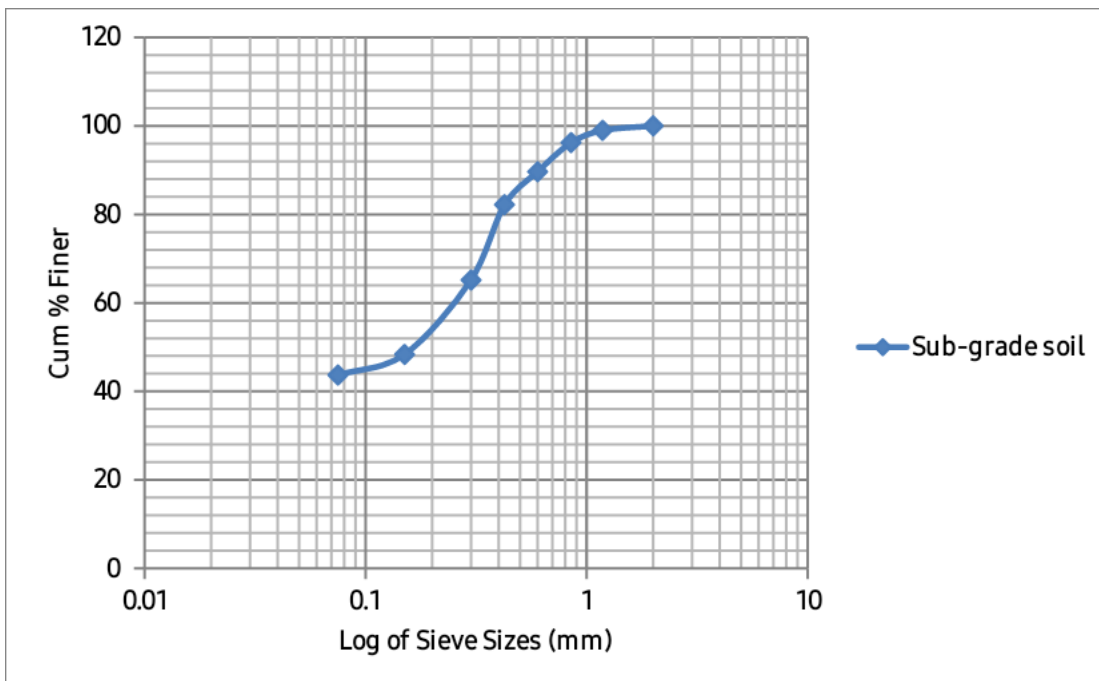


Figure A1: Particle Size Distribution Curve for the Sub-grade Soil

APPENDIX B

Specific Gravity Test

Table B1. Specific Gravity Result for sub-grade soil

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

The Specific gravity of the sample is calculated as follows:

Specific Gravity for sub-grade soil

$$\text{Trial 1 (G}_{s1}) = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)} = \frac{(34.74 - 24.76)}{(34.74 - 24.76) - (84.33 - 78.07)} = 2.68$$

$$\text{Trial 2 (G}_{s2}) = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)} = \frac{(35.63 - 25.64)}{(35.63 - 25.64) - (85.15 - 78.94)} = 2.64$$

$$\text{Trial 3 (G}_{s3}) = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)} = \frac{(35.90 - 25.90)}{(35.90 - 25.90) - (85.79 - 79.56)} = 2.65$$

$$\text{Specific Gravity} = \frac{(G_{s1} + G_{s2} + G_{s3})}{3} = \frac{(2.68 + 2.64 + 2.65)}{3} = 2.66$$

APPENDIX C

Liquid and Plastic Limit Test

Table C1: Liquid Limit Result for the Sub-grade Soil

BLOWS	38	33	28	23	18
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)	17.84	17.01	21.79	19.17	17.88
Wt of wet soil (g)	3.92	4.41	5.28	4.52	5.24
Wt of dry soil (g)	3.14	3.48	4.03	3.31	3.67
Wt of water (g)	0.78	0.93	1.25	1.21	1.57
Moisture Content (%)	24.84	26.72	31.02	36.56	42.78

Table C2: Plastic Limit Result for the Sub-grade Soil

Sub-grade Soil	Test 1	Test 2	Test 3
Wt of empty tin (g)	16.28	15.68	15.27
Wt of tin + wet soil (g)	17.2	16.34	16.59
Wt of tin + dry soil (g)	17.04	16.21	16.38
Wt of wet soil (g)	0.92	0.66	1.32
Wt of dry soil (g)	0.76	0.53	1.11
Wt of water (%)	0.16	0.13	0.21
Plastic Limit (%)	21.05	24.53	18.92

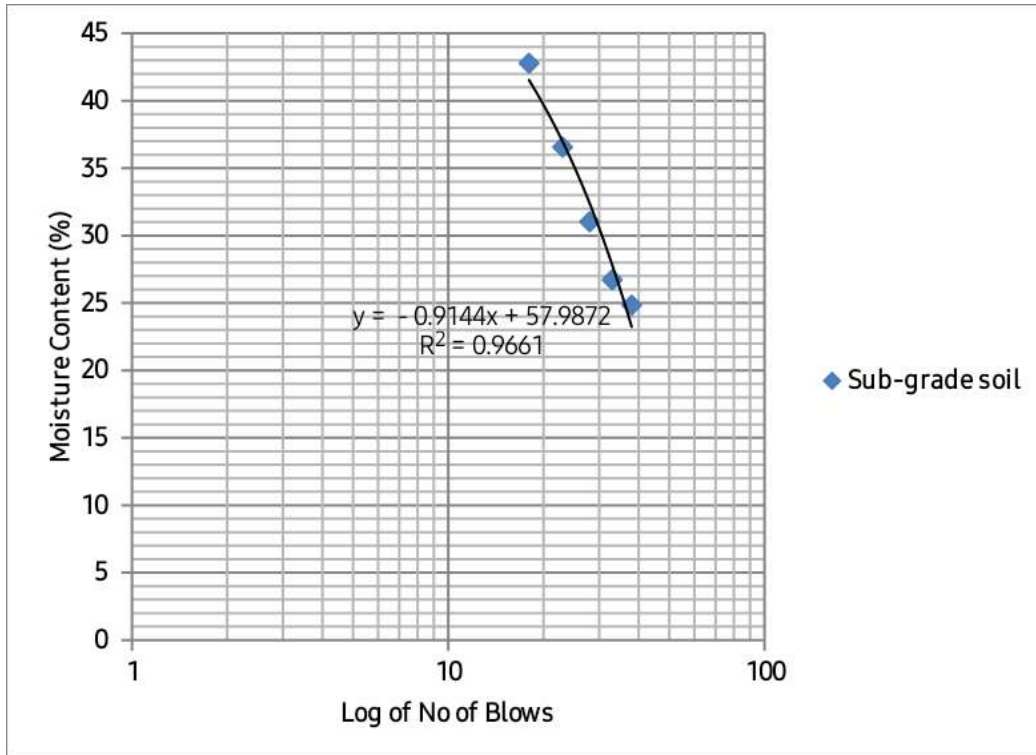


Figure C1: Liquid Limit Graph for the Sub-grade Soil

APPENDIX D

Compaction Test

Table D1: Dry Unit Weight Result for Sub-grade Soil + 0% GF at Single Layer

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	3.49	15.17
8	0.001	4	5.75	1.75	17.17	6.23	16.16
12	0.001	4	5.9	1.9	18.64	9.13	17.08
16	0.001	4	6.1	2.1	20.60	11.80	18.43
20	0.001	4	6	2	19.62	14.01	17.21

Table D1.1: Moisture Content Determination (Top)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry Soil (g)	Wt of Water (g)	Moisture Content (g)
(%)	(g)	Soil (g)		(g)	Soil (g)		(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	54.61	40.49	4.76	11.76
20	14.07	59.08	45.01	53.64	39.57	5.44	13.75

Table D1.2: Moisture Content Determination (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	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	55.79	41.15	4.87	11.83
20	14.43	58.76	44.33	53.22	38.79	5.54	14.28

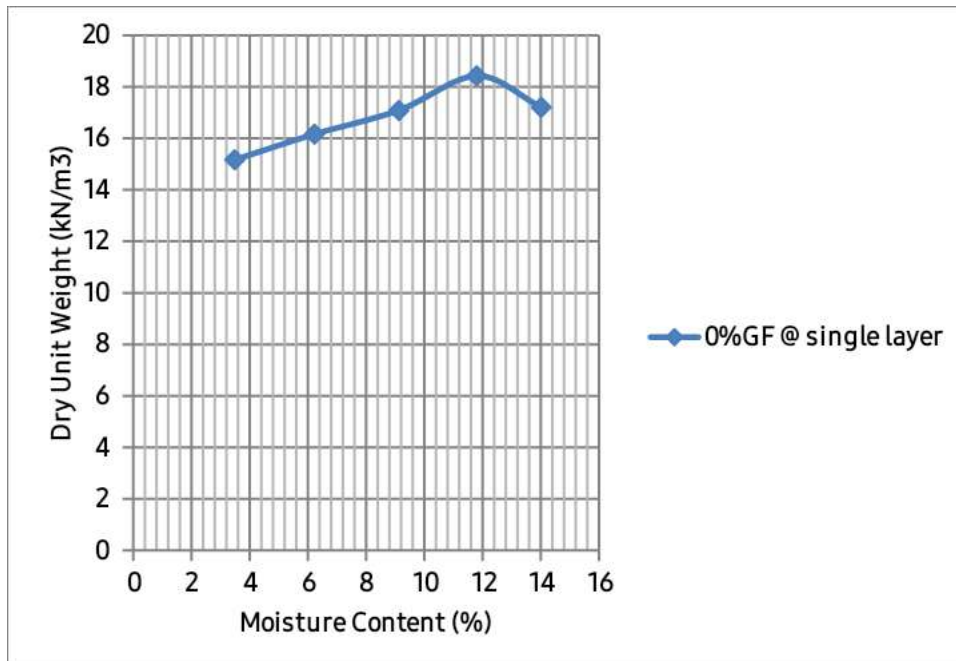


Figure D1: Compaction Curve for Sub-grade soil + 0% GF at Single Layer

Table D2: Dry Unit Weight Result for Sub-grade soil + 5% GF at Single Layer

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	5.55	1.55	15.21	4.52	14.55
8	0.001	4	5.65	1.65	16.19	9.02	14.85
12	0.001	4	6.05	2.05	20.11	11.99	17.96
16	0.001	4	6.2	2.2	21.58	13.81	18.96
20	0.001	4	6	2	19.62	16.61	16.82

Table D2.1: Determination of Moisture Content (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 (%)
4	15.55	30.48	14.93	29.84	14.29	0.64	4.48
8	15.35	32.87	17.52	31.59	16.24	1.28	7.88
12	14.45	56.08	41.63	51.59	37.14	4.49	12.09
16	13.6	48.82	35.22	44.92	31.32	3.9	12.45
20	16.4	77.33	60.93	68.84	52.44	8.49	16.19

Table D2.2: Determination of Moisture Content (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 (%)
4	14.96	31.69	16.73	30.96	16	0.73	4.56
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	61.95	47.54	8.1	17.04

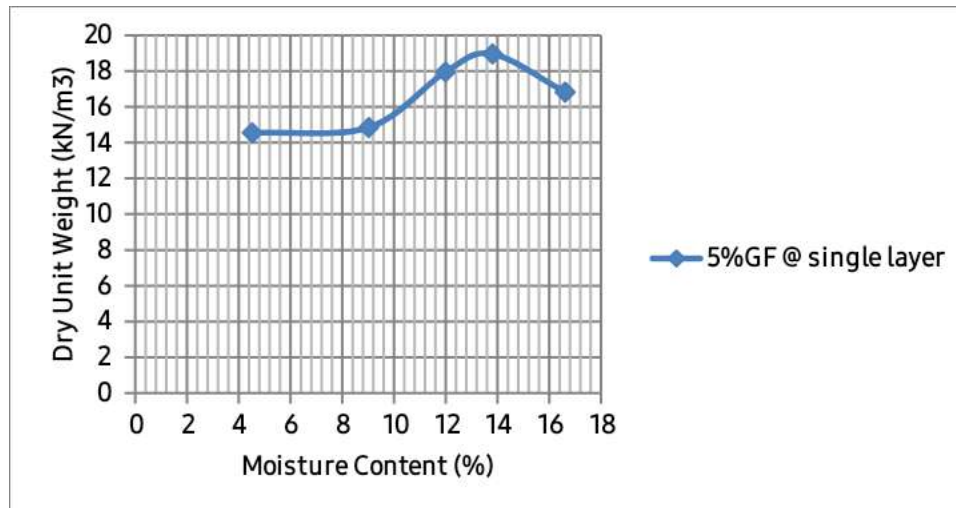


Figure D2: Compaction Curve for Sub-grade soil + 5% GF at Single Layer

Table D3: Dry Unit Weight Result for Sub-grade soil + 10% GF at Single Layer

Percentages of Water (%)	Vol of Mould (m ³)	Wt of Mould (kg)	Wt of Mould + Wet Soil (kg)	Wt of Wet Soil (kg)	Bulk Density (kN/m ³)	Moisture Content (%)	Dry Unit Weight (kN/m ³)
4	0.001	4	5.7	1.7	16.68	3.36	16.14
8	0.001	4	5.95	1.95	19.13	7.94	17.72
12	0.001	4	6.15	2.15	21.09	9.31	19.29
16	0.001	4	6.25	2.25	22.07	10.82	19.92
20	0.001	4	6	2	19.62	18.98	16.49

Table D3.1: Determination of Moisture Content (Top)

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

				Soil			
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	15.24	27.46	12.22	26.93	11.69	0.53	4.53
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	64.56	50.47	5.48	10.86
20	16.07	68.12	52.05	57.99	41.92	10.13	24.17

Table D3.2: Determination of Moisture Content (Bottom)

Percentages of Water	Wt of tin	Wt of tin + wet	Wt of wet Soil (g)	Wt of tin + dry Soil	Wt of dry Soil (g)	Wt of Water (g)	Moisture
(%)	(g)	Soil (g)		(g)	Soil (g)		Content (g)
4	17.57	33.04	15.47	32.71	15.14	0.33	2.18
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	55.87	41.24	4.45	10.79
20	14.44	71.57	57.13	64.64	50.2	6.93	13.80

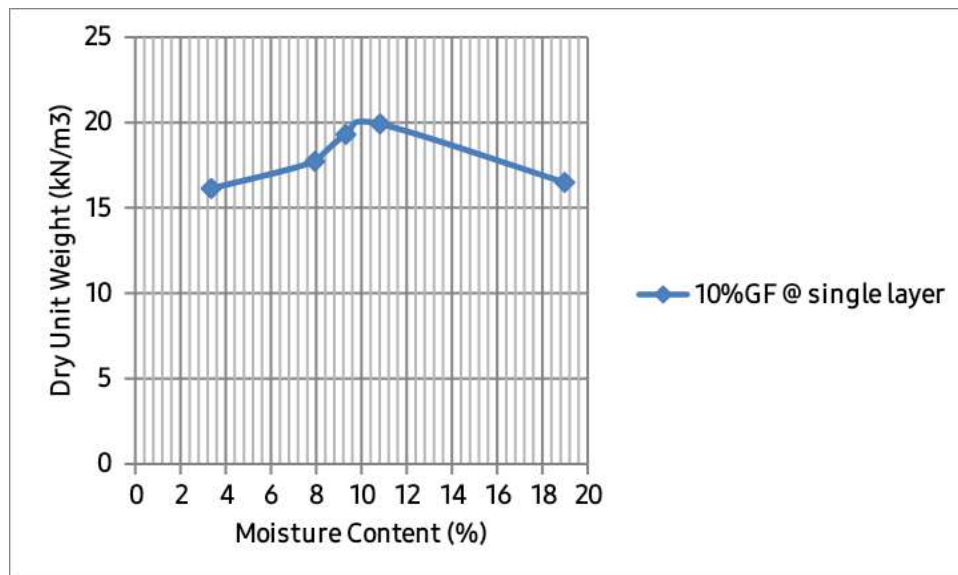


Figure D3: Compaction Curve for Sub-grade soil + 10% GF at Single Layer

Table D4: Dry Unit Result for Sub-grade soil + 15% GF at Single Layer

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	3.72	16.08
8	0.001	4	5.85	1.85	18.15	6.49	17.04
12	0.001	4	5.95	1.95	19.13	9.36	17.49
16	0.001	4	6.25	2.25	22.07	12.21	19.67
20	0.001	4	6.2	2.2	21.58	14.22	18.89

Table D4.1: Determination of Moisture Content (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 D4.2: Determination of Moisture Content (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

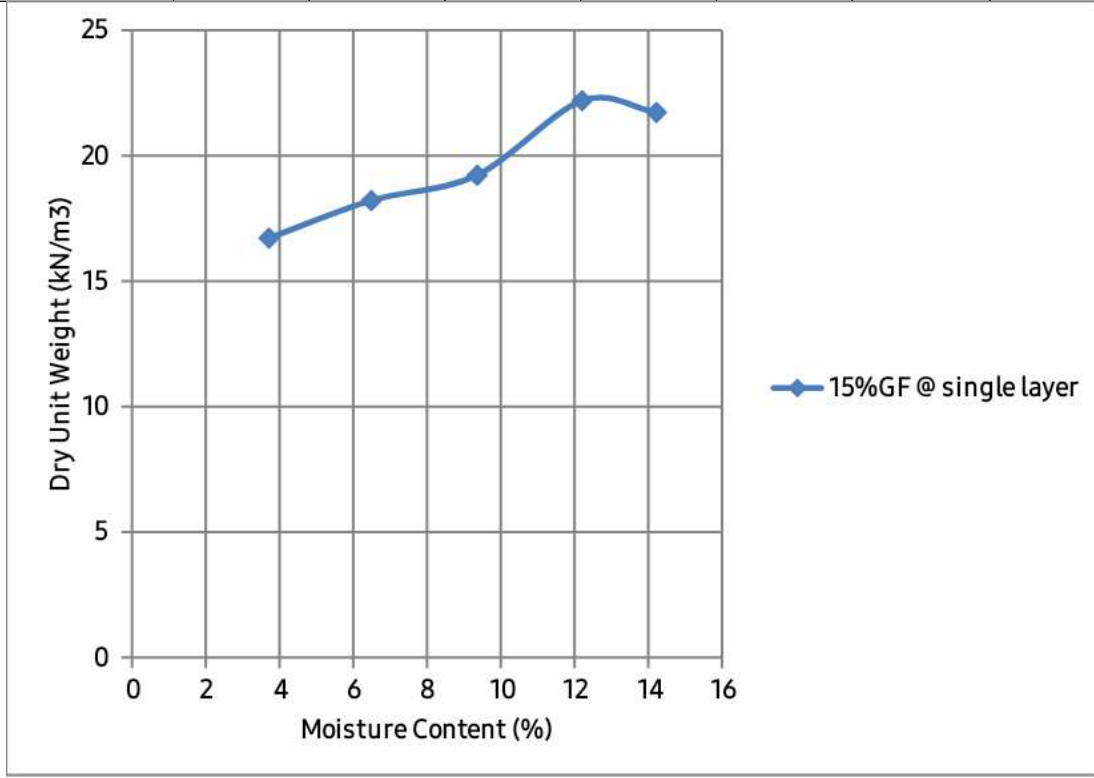


Figure D4: Compaction Curve for Sub-grade soil + 15% GF at Single Layer

Table D5: Dry Unit Weight Results for Sub-grade soil + 20% GF at Single Layer

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
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			Soil				
(%)	(m ³)	(kg)	(kg)	(kg)	(kN/m ³)	(%)	(kN/m ³)
4	0.001	4	5.8	1.8	17.66	2.79	17.18
8	0.001	4	6.05	2.05	20.11	5.21	19.12
12	0.001	4	6.15	2.15	21.09	7.96	19.54
16	0.001	4	6.3	2.3	22.56	10.68	20.39
20	0.001	4	6.2	2.2	21.58	12.32	19.21

Table D5.1: Determination of Moisture Content (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 (%)
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	44.75	31.94	2.97	9.30
20	12.95	49.83	36.88	45.88	32.93	3.95	12.00

Table D5.2: Determination of Moisture Content (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 (%)
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	70.81	55.51	7.02	12.65

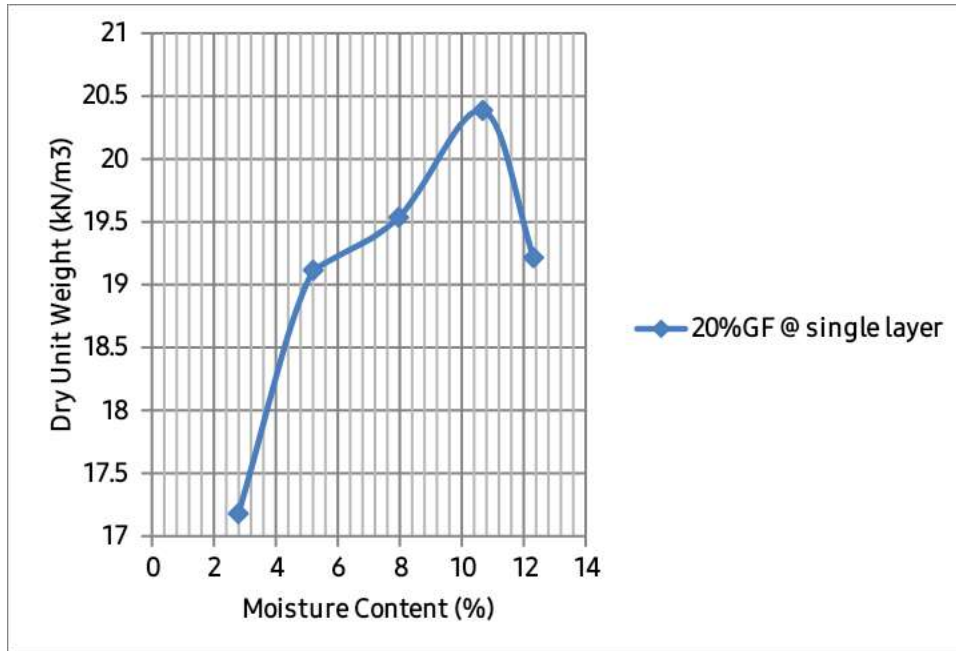


Figure D5: Compaction Curve for Sub-grade soil + 20% GF at Single Layer

Table D6: Dry Unit Weight for Sub-grade Soil + 0% GF at Double Layer

Percentages of Water (%)	Vol of Mould (m ³)	Wt of Mould (kg)	Wt of Mould + Wet Soil (kg)	Wt of Wet Soil (kg)	Bulk Density (kN/m ³)	Moisture Content (%)	Dry Unit Weight (kN/m ³)
4	0.001	4	5.9	1.9	18.64	4.09	17.91
8	0.001	4	6.15	2.15	21.09	8.04	19.52
12	0.001	4	6.2	2.2	21.58	10.12	19.60
16	0.001	4	6.2	2.2	21.58	12.99	19.10
20	0.001	4	6.15	2.15	21.09	17.39	17.97

Table D6.1: Determination of Moisture Content (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 (%)
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	44.24	28.59	2.47	8.64
16	16.23	38.9	22.67	36.59	20.36	2.31	11.35
20	14.42	56.68	42.26	50.84	36.42	5.84	16.04

Table D6.2: Determination of Moisture Content (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 (%)
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	47.52	32.24	4.72	14.64
20	15.72	60.84	45.12	53.72	38	7.12	18.74

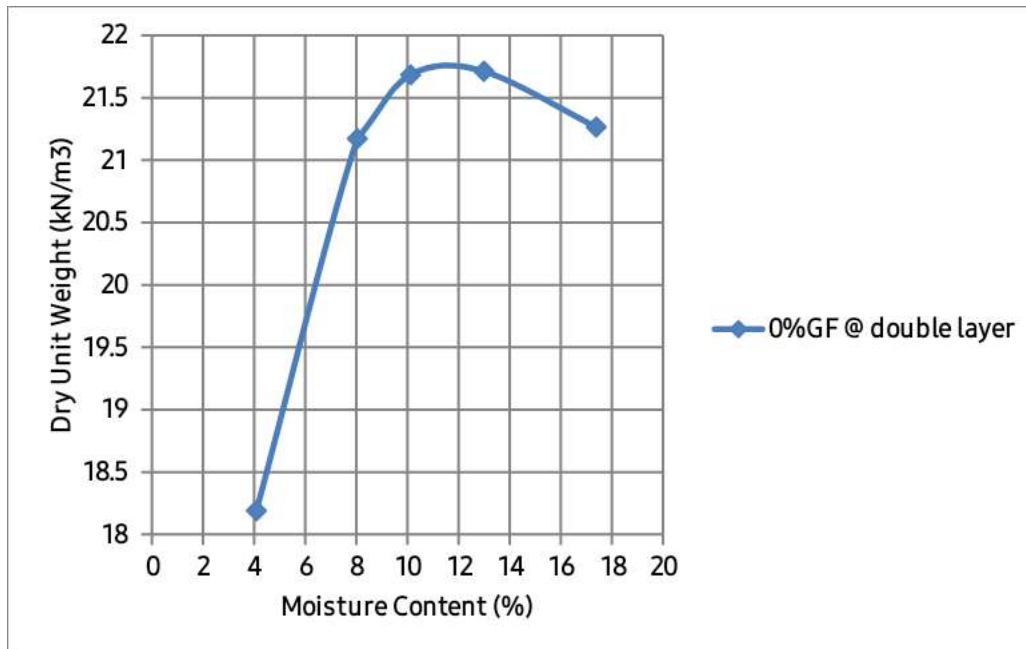


Figure D6: Compaction Curve for Sub-grade soil + 0% GF at Double Layer

Table D7: Dry Unit Weight Results for Sub-grade soil + 5% GF at Double Layer

Percentages of Water (%)	Vol of Mould (m ³)	Wt of Mould (kg)	Wt of Mould + Wet Soil (kg)	Wt of Wet Soil (kg)	Bulk Density (kN/m ³)	Moisture Content (%)	Dry Unit Weight (kN/m ³)
4	0.001	4	5.8	1.8	17.66	5.04	16.81
8	0.001	4	6	2	19.62	9.54	17.91
12	0.001	4	6.15	2.15	21.09	12.87	18.69
16	0.001	4	6.2	2.2	21.58	14.97	18.77
20	0.001	4	6.1	2.1	20.60	20.59	17.08

Table D7.1: Determination of Moisture Content (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	46.88	30.21	4.06	13.44
20	17.05	61.28	44.23	53.57	36.52	7.71	21.11

Table D7.2: Determination of Moisture Content (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

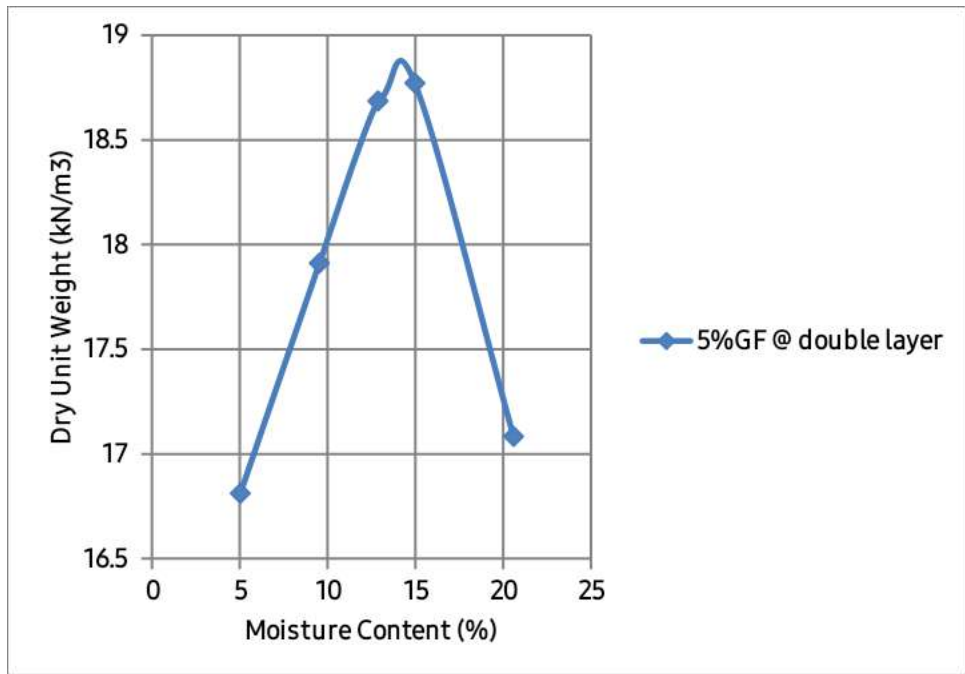


Figure D7: Compaction Curve for Sub-grade soil + 5% GF at Double Layer

Table D8: Dry Unit Weight Result for Sub-grade soil + 10% GF at Double Layer

Percentages of Water (%)	Vol of Mould (m³)	Wt of Mould (kg)	Wt of Mould + Wet Soil (kg)	Wt of Wet Soil (kg)	Bulk Density (kN/m³)	Moisture Content (%)	Dry Unit Weight (kN/m³)
4	0.001	4	6	2	19.62	4.67	18.74
8	0.001	4	6.3	2.3	22.56	7.85	20.92
12	0.001	4	6.25	2.25	22.07	10.62	19.95
16	0.001	4	6.25	2.25	22.07	14.63	19.26
20	0.001	4	6.15	2.15	21.09	18.73	17.76

Table D8.1: Determination of Moisture Content (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 8.2: Determination of Moisture Content (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

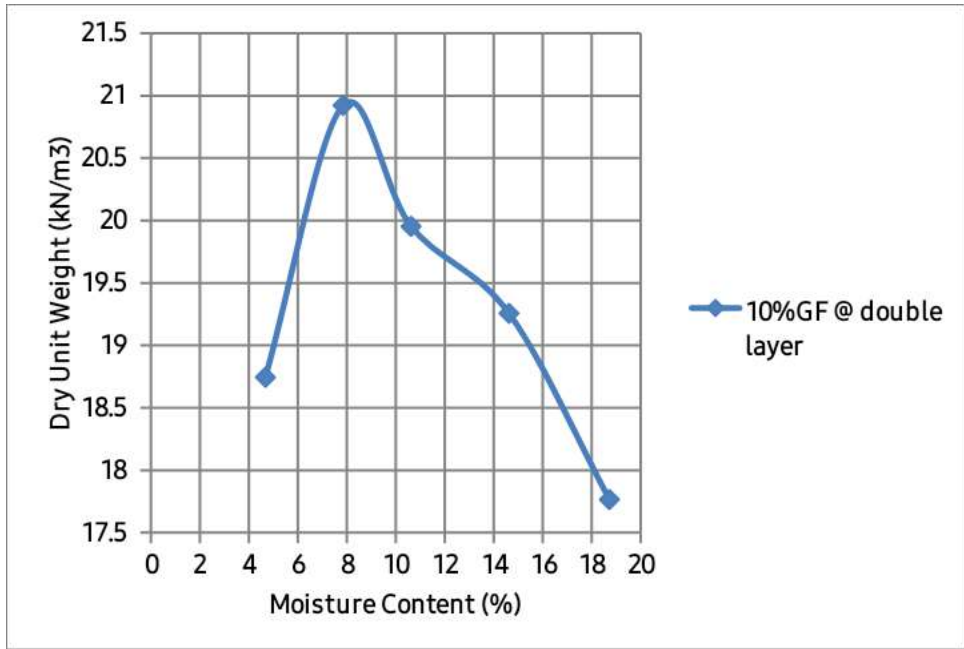


Figure D8: Compaction Curve for Sub-grade soil + 10% GF at Double Layer

Table 9: Dry Unit Weight Results for Sub-grade soil + 15% GF at Double Layer

Percentages of Water (%)	Vol of Mould (m ³)	Wt of Mould (kg)	Wt of Mould + Wet Soil (kg)	Wt of Wet Soil (kg)	Bulk Density (kN/m ³)	Moisture Content (%)	Dry Unit Weight (kN/m ³)
4	0.001	4	6.1	2.1	20.60	5.89	19.46
8	0.001	4	6.35	2.35	23.05	7.31	21.48
12	0.001	4	6.3	2.3	22.56	11.89	20.17
16	0.001	4	6.25	2.25	22.07	15.27	19.15
20	0.001	4	6.2	2.2	21.58	19.96	17.99

Table 9.1: Determination of Moisture Content (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	48.96	33.75	4.78	14.16
20	17.44	55.94	38.5	49.44	32	6.5	20.31

Table 9.2: Determination of Moisture Content (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	52.11	38.53	6.31	16.38
20	15.69	63.26	47.57	55.46	39.77	7.8	19.61

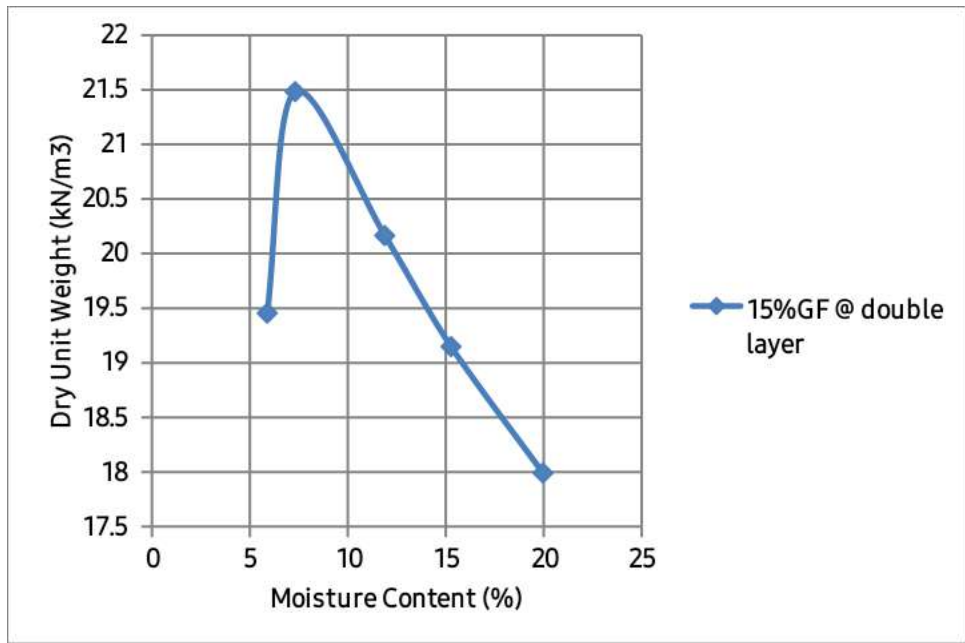


Figure D9: Compaction Curve for Sub-grade soil + 15% GF at Double Layer

Table D10: Dry Unit Weight Result for Sub-grade soil + 20% GF at Double Layer

Percentages of Water (%)	Vol of Mould (m ³)	Wt of Mould (kg)	Wt of Mould + Wet Soil (kg)	Wt of Wet Soil (kg)	Bulk Density (kN/m ³)	Moisture Content (%)	Dry Unit Weight (kN/m ³)
4	0.001	4	6.05	2.05	20.11	6.27	18.92
8	0.001	4	6.2	2.2	21.58	7.76	20.03
12	0.001	4	6.3	2.3	22.56	9.85	20.54
16	0.001	4	6.35	2.35	23.05	15.06	20.04
20	0.001	4	6.2	2.2	21.58	19.39	18.08

Table D10.1: Determination of Moisture Content (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	14.46	48.62	34.16	46.83	32.37	1.79	5.53
8	15.38	49.52	34.14	47.11	31.73	2.41	7.60
12	13.78	51.64	37.86	48.44	34.66	3.2	9.23
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 D10.2: Determination of Moisture Content (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	14.24	52.87	38.63	50.34	36.1	2.53	7.01
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

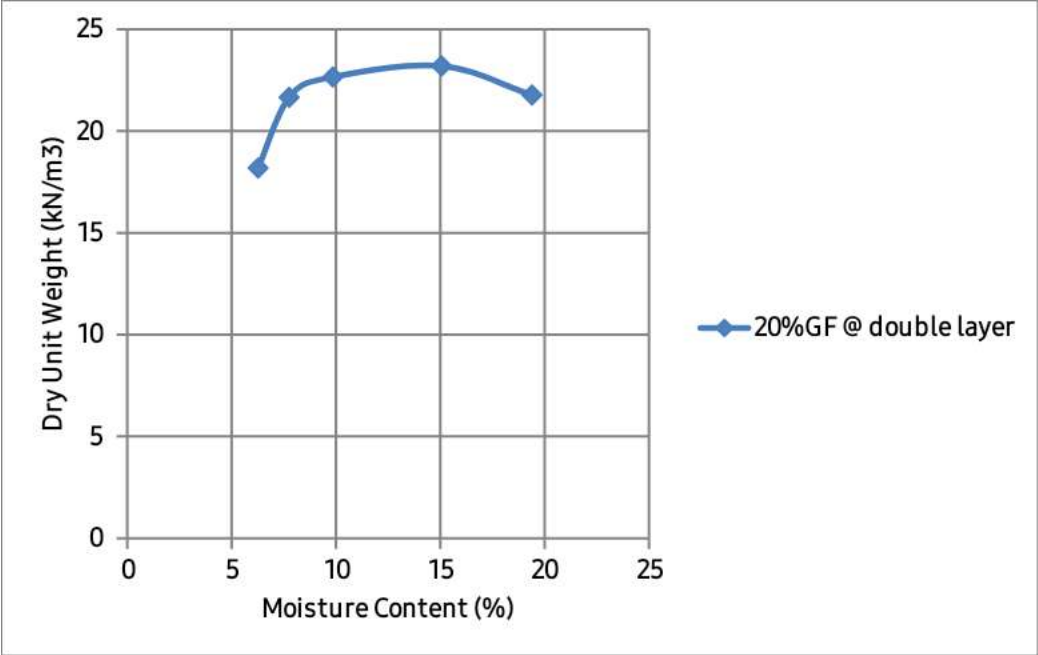


Figure D10: Compaction Curve for Sub-grade soil + 20% GF at Double Layer

APPENDIX E

CBR Test

Table E1: CBR Test Results for Sub-grade soil + 0% GF at Single Layer

Penetration (mm)	Dial Reading (Top)	Force (KN)	Dial Reading (Bottom)	Force (KN) ²
0.5	36	1.5	10	0.7
1	54	1.8	25	1.1
1.5	71	2.4	38	1.4
2	84	2.8	52	1.7
2.5	96	3.4	67	2.1
3	108	3.6	82	2.4
3.5	115	3.9	99	2.9
4	122	4.2	110	3.2
4.5	126	4.4	126	3.6
5	130	4.7	137	3.9
5.5	136	5	148	4.2
6	140	5.2	157	4.6
6.5	154	5.4	166	4.8
7	158	5.7	174	5.1

Table E2: CBR Test Results for Sub-grade soil + 5% GF at Single Layer

Penetration (mm)	Dial Reading (Top)	Force (KN)	Dial Reading (Bottom)	Force (KN) ²
0.5	36	1.8	10	1
1	54	2.2	25	1.3
1.5	71	2.7	38	1.7
2	84	3.2	52	2.2
2.5	96	3.6	67	2.6
3	108	3.9	82	2.9
3.5	115	4.1	99	3.3
4	122	4.3	110	3.8
4.5	126	4.7	126	4.2
5	130	5.1	137	4.5
5.5	136	5.4	148	4.7
6	140	5.6	157	5.1
6.5	154	5.9	166	5.4
7	158	6.1	174	5.6

Table E3: CBR Test Results for Sub-grade soil + 10% GF at Single Layer

Penetration (mm)	Dial Reading (Top)	Force (KN)	Dial Reading (Bottom)	Force (KN) ²
0.5	36	2.1	10	1.3
1	54	2.5	25	1.7
1.5	71	2.9	38	2.1
2	84	3.4	52	2.5
2.5	96	3.9	67	2.8
3	108	4.2	82	3.2
3.5	115	4.5	99	3.6

4	122	4.8	110	4
4.5	126	5.2	126	4.3
5	130	5.5	137	4.7
5.5	136	5.8	148	5
6	140	6.1	157	5.3
6.5	154	6.4	166	5.7
7	158	6.7	174	6

Table E4: CBR Test Results for Sub-grade soil + 15% GF at Single Layer

Penetration (mm)	Dial Reading (Top)	Force (KN)	Dial Reading (Bottom)	Force (KN) ²
0.5	36	2.6	10	1.2
1	54	2.9	25	1.5
1.5	71	3.2	38	1.9
2	84	3.6	52	2.3
2.5	96	4	67	2.6
3	108	4.3	82	3
3.5	115	4.6	99	3.4
4	122	4.9	110	3.7
4.5	126	5.2	126	4.1
5	130	5.4	137	4.4
5.5	136	5.6	148	4.8
6	140	5.8	157	5.1
6.5	154	6.1	166	5.4
7	158	6.3	174	5.7

Table E5: CBR Test Results for Sub-grade soil + 20% GF at Single Layer

Penetration (mm)	Dial Reading (Top)	Force (KN)	Dial Reading (Bottom)	Force (KN) ²
0.5	36	2.5	10	1.5
1	54	2.9	25	1.9
1.5	71	3.3	38	2.3
2	84	3.8	52	2.6
2.5	96	4.3	67	2.9
3	108	4.7	82	3.3

3.5	115	5.1	99	3.8
4	122	5.5	110	4.2
4.5	126	5.8	126	4.6
5	130	6.1	137	5
5.5	136	6.3	148	5.3
6	140	6.7	157	5.6
6.5	154	7	166	5.9
7	158	7.3	174	6.2

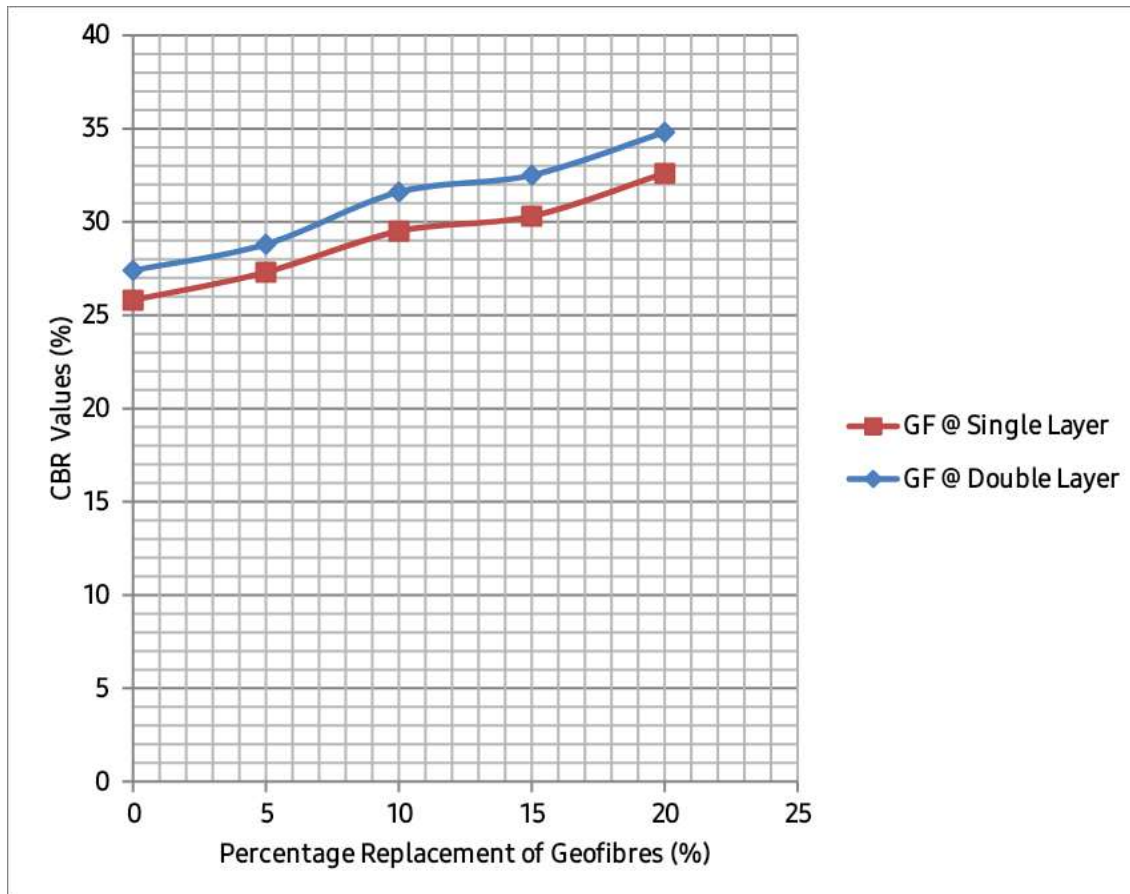


Figure 4.7: Graph Showing the CBR Values of the Sub-grade Soils Stabilized at Different Disposition of Geofibres