EMPIRICAL INVESTIGATION OF THE FLEXURAL STRENGTH OF COMPRESSED STABILIZED EARTH SLAB

BY

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CERTIFICATION

I certify that this work, **"Comparative Study of Strength of Truss Reinforced Concrete Beam and Conventional Reinforced Concrete Beam"** was carried out by **Godfrey Chimezie Nwokorobia (Reg. No 20124766378)** in partial fulfillment for the award of Master of Engineering (M. Eng) in Structuresin the Department of Civil Engineering, Federal University of Technology, Owerri.

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DEDICATION

This work is dedicated to my son Anyadiegwu Ebubechukwu Pius.

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DEFINITION OF NOTATIONS

NOTATIONS	MEANING
EA	Effective area of cylinder
ArS	Area of slab
b	Breath of slab
t	Thickness of the slab
C_U	Coefficient of uniformity
C_C	Coefficient of curvature
D	Flexural rigidity
E	Young's modulus of elasticity of concrete
F	Applied force
M	Moment
M_C	Moisture
FL	Fines in laterite
X	Total sand
X_{LR}	Total of laterite and river sand
SL	Sand in laterite
%F	%Fines in view
%S	%Sand in view
RS	River sand
90%EqL	90% equivalent laterite
90%EqRS	90% equivalent river sand
q	Uniformly distributed load
W	Weight of container
W_1	Weight of container and wet sample
W_2	Weight of container and dry sample
Z	Modulus of section
W_k	Central deflection
%F	% Fines in view
ϱ	Density
dϱ	Dry density
φ	Flexural strength
µ	Poisson's ratio of plate
ᵞ	Poisson's ratio of Concrete

ABSTRACT

This research aimed at empirical investigation of flexural strength of compressed stabilized earth slab. Two sets of 500 x 500 x 150mm compressed stabilized earth slabs were cast. One set was cast with BRC mesh of 5 x 150 x 150mm with strength of 250N/mm^2 as reinforcement and the other set was cast without reinforcement. Eight mixture proportions of laterite, river sand and cement were used in this research work and optimum moisture content obtained from compaction test of the mixture proportions were used for the casting of the compressed stabilized earth slabs and compressed stabilized earth cubes. Each mixture proportion was used to cast twelve compressed stabilized slabs and six compressed stabilized earth cubes. A total of ninety six compressed stabilized earth slabs and forty eight compressed stabilized earth cubes of 150 x150 x150mm were cast. Comprising 48 reinforced compressed stabilized earth slabs and 48 unreinforced compressed stabilized earth slabs, out of which, 24 of reinforced compressed earth slab and 24 unreinforced compressed earth slab were compressed using 6N/mm^2 compaction load while the remaining equal number of 24 reinforced and unreinforced were respectively compressed with 8N/mm^2 compaction load, using Magnus frame. The maximum flexural strength, central deflection and moment obtained using 6N/mm^2 compaction load on reinforced compressed stabilized earth slab were 4.74x10^{-4}N/mm^2, 3.17x10^{-3}mm and 887.97Nmm while the corresponding value for unreinforced compressed stabilized earth slab were 4.06x10^{-4}N/mm^2, 2.71x10^{-3}mm and 760.56Nmm. Also, the maximum flexural strength, central deflection and moment obtained using 8N/mm^2 compaction load on reinforced compressed stabilized earth slab were 5.50^{-4}N/mm^2, 3.68x10^{-3}mm and 1030.8Nmm while the corresponding value for unreinforced compressed stabilized earth slab were 4.53x10^{-4}N/mm^2,3.03x10^{-3}mm and 849.36Nmm. From this research, it can be concluded that reinforced compressed stabilized earth slabs with high compaction load have high flexural strength, central deflection and moment when compare with unreinforced compressed stabilized earth slabs.

Keywords: *compressed stabilized earth slab, flexural strength, compressive strength, laterite, river sand.*

CHAPTER ONE

INTRODUCTION

1.1BACKGROUND OF STUDY

The choice of appropriate building material is one of the important criteria, which determines the strength, aesthetic quality, durability and economy of any construction projects. In the older days, stone, sand, earth, grass, logs, animal hides, etc. were mainly used as building materials in their crude form. As technique advanced, the crude as well as the partly refined materials were replaced by others, especially made for different purposes such as dressed stones, bricks, cement, different metals, reinforced and prestressed concrete etc., which then triggered the rapid development of construction techniques (Abebe,2007) .

The building culture of pre-independence Nigeria was an absolute dependence on earth building techniques such as use of adobe bricks (sun-dried bricks) and wattle and daub (mud wall construction). These techniques were predominant in major rural and semi-urbanized towns and cities in Nigeria. These techniques were durable, adequate and accessible enough for them to meet their housing needs. The techniques were also sustainable since they do not deplete the natural resources of the environment neither do their production processes lead to the emission of gases that causes global climate change. (Alagbe, 2011).

Concrete is a composite material which is commonly used for activities of construction purpose. Concrete is also a relatively brittle material that performs Significantly well in compression, but is considerably less effective in tension and its tensile strength is only approximately one tenth of the compressive strength. Tensile stresses are induced in concrete due to its shrinkage in both plastic and hardened stage resulting in the cracking of concrete. Historically, steel reinforcement is used to absorb these tensile stresses and to prevent the cracking to some extent. The addition of steel reinforcement significantly increases the strength of concrete. But to produce concrete with homogeneous tensile properties the micro cracks develops in concrete should be suppressed (Likhil, 2014).

The introduction of fibers was brought in as solution to develop concrete in the view of enhancing its flexural and torsional strengths. Fibers are most generally discontinuous and have random distribution over the cement matrices. The term “Fiber Reinforced Concrete” (FRC) is composed of cement, various sizes of aggregates along with discrete and discontinuous fibers. The concept of using fibers to improve the properties of construction materials is very old. Historically, horsehair was used in mortar and straw in mud bricks. In the early 1900’s asbestos fibers were used in concrete. By the 1960’s steel, glass, synthetic and natural fibers were also used in concrete and nowadays many types of fibers are available for use in concrete (Sukontasukkul, 2004).

Hollow sandcrete blocks containing a mixture of sand, cement and water are used extensively in many countries of the world especially in Africa. In many parts of Nigeria, sandcrete block is the major cost component of the most common buildings. The high and increasing cost of constituent materials of sandcrete blocks has contributed to the non-realization of adequate housing for both urban and rural dwellers. Hence, availability of alternatives to these materials for construction is very desirable in both short and long terms as a stimulant for socio-economic development. In particular, materials that can complement cement in the short run, and especially if cheaper, will be of great interest. (Oyekan, 2011).

Over the past decade, the presence of mineral admixtures in construction materials has been observed to impart significant improvement on the strength, durability and workability of cementitious products (Mental, 1994; Falade, 1997; Oyekan, 2001).

The compressed earth block is the developed form of moulded earth block, more commonly known as the adobe block. This technology offers an economic, environment-friendly-masonry system. The stabilized compressed earth block has a wide spectrum of application in construction starting from walling, roofing, arched openings, corbels etc. Stabilized earth blocks are manufactured by compacting raw material (earth mixed with a stabilized such as cement or lime) under a pressure of 20 – 40 kg/cm using manual soil press (Dinachandra and Shrich, 2007).

Due to large-scale construction programs in Nigeria in the recent years, the demand for conventional building materials like cement, steel, bricks and timber has outstripped their supply. As a result of this imbalanced demand and supply, the cost of cement and other associated materials increased substantially resulting in inflated prices mainly for cement-based materials. This has put the middle and low-income groups into a serious financial crisis in their effort to build their own shelters. For instance the cost of concrete blocks, reinforcement bars, cement, have increased more than double-fold than they were few years back. This calls for identification of alternative solutions, which reduce construction costs and minimize the burden of the community.
In the bid to address these problems discussed so far, this research work decided to embark on project entitled “Empirical investigation of the flexural strength of reinforced compressed stabilized earth slab”

1.2 STATEMENT OF PROBLEM

A conventional reinforced concrete slab is made of concrete and reinforcement bars. The cost of the slab is high owing to high cost of cement which is the major component of concrete. Consequently, there is need to use locally available materials like earth to reduce the cost of construction of slab, thus reducing the cost of construction of building. In order to achieve this, this research shall employ the use of earth as a major construction material for construction of both reinforced and unreinforced compressed stabilized earth slabs. The slabs shall be compressed using compaction load of $6N/mm^2$ and $8N/mm^2$ respectively on Magnus frame so as to determine the maximum moment, central deflection and maximum flexural strength of both reinforced and unreinforced compressed stabilized earth slab. The results of reinforced compressed stabilized earth slab shall be compared with that of unreinforced compressed stabilized earth slab.

1.3 OBJECTIVES OF STUDY

The main objective of this study is Empirical Investigation of the Flexural Strength of Compressed Stabilized Earth Slab. The specific objectives are:

i. To obtain the optimum moisture content of various mixture proportions of fines and sand in compressed stabilized earth slab.

ii. To determine the central deflection and moment of reinforced and unreinforced compressed stabilized earth slab.

iii. To determine the mixture proportion that will give the maximum flexural strength of reinforced and unreinforced compressed stabilized earth slab using compaction load of $6N/mm^2$ and $8N/mm^2$ distributed uniformly over the slab area respectively.

1.4 JUSTIFICATION OF THE STUDY

The justification of this research work includes the following:

i. The most important benefit of this research work is the application of laterite material in construction of compressed stabilized earth slab.
ii. It helps the engineers to calculate maximum central deflection and moment of compressed stabilized earth slab using finite difference method.
iii. It provides an alternative and cheap material to enable the construction of affordable houses for low income individual.
iv. It will allow unskilled and unemployed people to learn a skill, get a job and rise in the social scale.

1.5 SCOPE OF STUDY

This research is limited to Investigation of Flexural Strength of Reinforced and Unreinforced Compressed Stabilized Earth Slab. Here, central deflection, moment and flexural strength of both reinforced and unreinforced compressed stabilized earth slab were determined experimentally, when compaction load of $6N/mm^2$ and $8N/mm^2$ were respectively applied to the compressed stabilized earth slabs during their casting. The slab dimension was 500 x 500 x 150 mm in size. Crushing loads used were uniform distributed loads. Curing was done by sprinkling of water twice a day. Other tests carried out in the course of this research include moisture content, compaction, moisture content and sieve analysis. The flexural strength, deflection and moment values of the reinforced compressed stabilized earth slabs were compared with that unreinforced compressed stabilized earth slabs.

CHAPTER TWO

LITERATURE REVIEW

2.1 HISTORY OF EARTHEN CONSTRUCTION

A brief state-of art review is given by Walker et al. (2000). Mud wall construction is one of the oldest and remains one of the most widespread forms of wall construction. In the Middle East, for example, remains of adobe (sundried mud blocks) wall construction have been dated back to 8000 BC. Many of these ancient techniques, such as adobe and cob constructions, are still widely practiced in many countries today.

Unsterilized mud construction is associated with two major problems:

i. Loss of strength on saturation.
ii. Erosion of soil due to the impact of rain.

These problems can be handled by the techniques of soil stabilization. Compressed earth block or stabilized mud block, as they are commonly called in India, represent, an example of alternative component for masonry construction produced by utilizing natural soils, sand and other industrial waste products such as fly ash.

Although adobe blocks have long been tamped into slip form moulds, the dawn of compressed earth block technology is attributed to Francois Cointeraux, who developed a timber block press, based upon a wine press, in eighteenth century in France. However, it is only in the last so many years that compressed earth blocks have been widely adopted, largely due to the development of soil-cement block technology and invention of CINVA-RAM press in 1952 by Ramirez, a Chilean Engineer (Walker et al. 2000).

Mud wall construction in India has centuries of history and even now practiced in rural parts of India. The earliest Indian example of soil-cement buildings probably is to be seen in the refugee-housing programme in and around Karnal in

Haryana state. 4000 buildings were constructed in 1948 using the concept of rammed earth soil-cement walls. A couple of problems like cracks and peeling off of cement plaster from the walls were noticed later. These problems may be attributed to inadequate stabilization of fine grained soils used for walls. Some of these houses are still in use with minor repairs and modifications. Development of Cinvaram block press in 1952 led to the concept of machine pressed stabilized mud blocks. Number of groups started working on stabilized mud block technology all over the world. The Ellson block master, a machine of South Africa origin was manufactured in Rajkot of Gujarat state during early seventies. This is heavier than Cinvaram, having the flexibility of interchangeable moulds. Some buildings were built using this machine in Gujarat, Kerala etc. Major impetus for stabilized mud blocks technology came after the formation of canter for ASTRA (Application of Science and Technology to Rural Areas) in 1974 at IIISc, Bangalore (Walker et al. 2000).

Compressed soil masonry blocks, formed using moist soil compacted mechanically to improve physical characteristics, have gained popularity over the past so many years. Benefits of earth in this manner include improved strength and durability as compared to adobe while maintaining significantly low embodied energy levels than alternative materials. However problems arise from the material’s low tensile strength, brittle behaviour and deterioration in the presence of water. Stabilization by a hydraulic binder such as cement or lime or a combination of the two can significantly improve water resistance and strength to some extent. Also natural fibres have been used in adobe and other traditional forms of earthen construction for many thousands of years, to reduce shrinkage cracking, to improve tensile strength, durability and improved ductility in tension. Apart from that, baking of composite bricks with natural fibres and grain leaves a porous structure which consequently enhances thermal and acoustical insulation of the finished products. Theoretical models were also developed on composite soil blocks reinforced with fibres subjected to shear. In almost all the above studies, the fibres used are sisal fibres, coconut fibres, vegetable fibres, straw, palm fibre etc.

2.2 COMPRESSED STABILIZED EARTH BLOCK TECHNOLOGY (CSEB)

One of the drawbacks using earth alone as a material for construction is its durability which is strongly related to its compressive strength (Morel et al. 2001; Guettala et al., 2006; Reddy and Kumar, 2010). But most soil in their natural condition lack the strength, dimensional stability and durability required for building construction. At the same time any material used for wall construction should possess adequate wet compressive strength and erosion resistance. The technique to enhance natural durability and strength of soil is defined as soil stabilization. There are several types of stabilization: first, mechanical stabilization, second, physical stabilization and third chemical stabilization (Walker, 1995; Billong et al., 2008; Riza et al., 2011). For stabilizing, cementituous admixtures such as cement and lime and bitumen are added. Cement is the most widely used stabilizing agent (Walker, 1995; Morel et al, 2000; Forth and Zoorob, 2002; Perera and Jayasinghe, 2003; Bahar et al., 2004; Mesbah et al., 2004; Reddy and Gupta, 2006; Krishnaiah and Reddy, 2008; Galan-Marin et al., 2010). Compacted soil blocks, naturally dried are ecological and economical materials with no air pollution arising from their fabrication process. However uses of these additives also significantly increase both material cost and their environmental impact. (Morel et al., 2000; Mesbah et al., 2004). The properties of stabilized soil can be further improved by the process of compaction. The process of compaction leads to higher densities, thus higher compressive strength and better erosion resistance can be achieved. Exploring the stabilization and compaction techniques, a cheap, yet strong and durable material for wall construction is the stabilized pressed block. The merits of this block are: low cost and no burning or firing is required, use of locally available soil, bricks can be made at site with no transportation of blocks, moreover simplicity in manufacture and no special skills required (Krishnaiah and Reddy, 2008).

Over the past 40 to 50 years, there has been an increasing interest in the use of stabilized compressed earth blocks for residential construction (Oliver and Gharbi, 1995; Walker and Stace, 1997). A mixture of soil, sand, stabilizer, and water is compacted using a machine to produce SMBs, also called compressed earth blocks CEB or soil cement blocks when only cement is used as a binder. Cement and lime are the most commonly used stabilizers in SMBs. Stabilized mud blocks have been used for masonry construction in Australia, France, India, Columbia, Chile, Venezuela, Bolivia, Zambia, Brazil, Thailand, Algeria, Mauritania, Morocco, Upper Volta, the Ivory Coast, and many other countries (Jagadish, 1988; Walker et al., 2000; Reddy and Gupta, 2006).

Compaction of moist soil, often combined with 4 to10% cement stabilization, significantly improves compressive strength and water resistance in comparison with traditional adobe blocks (Morel et al., 2007).
The stabilized compressed earth block has a wide application in construction for walling, roofing, arched openings, corbels etc (Singh and Singh, 2003).

The two thrust areas in the housing sector are the promotion of building material units using local materials consistent with ecological balance, and the production of building materials with low energy inputs which substitute for energy intensive building materials. Common burnt clay bricks are increasingly becoming costly due to excessive cost of fuel to burn them and not many suitable brick earths are found everywhere. Stabilized mud block could be an economic alternative to the traditional brick (Choudhary, 2004). These blocks maximize utilization of local materials, require simple construction methods and offer high thermal and acoustic insulation. Typically cement stabilized soil blocks require less than 10% of the input energy used to manufacture similar fired clay and concrete masonry units (Walker, 1995).

The performance specification of CSEB (Compressed stabilized Earth Blocks) were based on BIS code IS 1725, 1982 and tested in accordance with IS 3495 – 1992.

Table 2.1: The properties of the block (CSEB)

D	WCS	WA	ER	EXPS	SC	MP
+/-2mm	20-30Kg/cm^3	<15% by weight	<5% by weight	<0.15% in block thickness	No pitting on the surface	1 skilled, 6-8 unskilled

Source: (IS 3495 – 1992)

Where D = dimensional variations, WCS = wet compressive strength, WA = water absorption, ER = Erosion, EXPS = Expansion on saturation, SC = Surface characteristics and MP = Manpower.

For soil to provide the required level of performance as a walling material the process of stabilization must improve or impart new properties to the soil. The aims of stabilization are to

i. Increase the wet strength of the soil.
ii. Provide adequate cohesion.
iii. Increase volume stability.
iv. Increase durability, resistance to erosion and frost attack.
v. Lower permeability. (Bryan, 1988)

Stabilizer for CSEB is playing an important role in creating bonding between soil-stabilizer mixes. One of the main functions of the stabilizing medium is to reduce the swelling properties of the soil through forming a rigid framework with the soil mass, enhancing its strength and durability. Portland cement is the most widely used stabilizer for earth stabilization. Many research works (Walker, 1995) found that soil with plasticity index below 15 is suitable for cement stabilization. Typically, cement binder is added between 4 and 10% of the soil dry weight (Mesbah et al., 2004). However, if the content of cement is greater than 10% then it becomes uneconomical to produce CSEB brick. For brick using less than 5% of cement, it often too fragile for easy handling (Walker, 1995). For soil that has plasticity index below 15 more suitable to use cement as a stabilizer whether for the soil that has plasticity index above 15 or have clay content, it is suggested to use lime as a stabilizer. Lime can be added to the cement and clay mix to enhance stabilization process because with the additional lime, the lime-clay ratio will be increased due to the existing of lime in cement and the present of lime attributed to the immediate reduction of plasticity. Although the same trend happen to the soil-cement mixes, the immediate effect of modification more obvious in the soil-lime mixes. When lime is added to the clay soil, first it is adsorbed by the clay mineral until the affinity of the soil for lime achieved, its call lime fixation and normally the amount between 1 to 3% limes added by weight. The addition of lime after lime fixation contributes to the pozzolanic reaction that creates hydrated gel and this process is time dependent where strength developes gradually over long period. When clay soil is blended with Portland cement in the presence of water, hydration reaction will take place. The compound of C_3S and C_2S present in the Portland cement react with water forming complex Calcium Silicate Hydrates (C-S-H) gel. C-S-H gel has beneficial effect in clay material by reduction of deleterious heaving effects such as the growth of ettringite due to the rapid removal of alumina. The formation of ettringite contributes to the increase of porosity and simultaneously decreases the free moisture content. The C-S-H gel formed fill the void spaces and bind the soil particles together thus imparting strength to the soil mixture.

For laterite soil, it has been noted that lime stabilization of soil is a function of quantity of lime, curing time, environmental condition and testing method.
Billong et al. (2008) also observed the potential of using lime and other pozzolanic material to form a binder that can act as a stabilizer. It is suggested the combination of lime with ground granulated blast furnace (product in the manufacturing of pig iron), will give better performance compared to the use of cement as the stabilizer. Natural stabilizer as proposed by Mesbah et al. (2004) is more environmental friendly and cheaper. Even though stabilization with hydraulic binder (cement) significantly improved strength and water resistance but it contributes to negative environmental impact. Guettala et al. (2006) suggested the use of an aqueous dispersion of resin as an additive in earth stabilizer. The additive increased the strength significantly to 2-3 folds to those indicated by standards for both wet and dry conditions. In general, soil stabilizations enhance quite significant bricks properties. Types of soil played an important role to determine the proper stabilizer for specific properties of brick to be enhanced. Even though the best soil for stabilization is the soil that has low plasticity, the advantages of using cement for soil with low plasticity can be substituted with lime and other pozzolanic based stabilizer for soil with high plasticity and high clay content. The inventions of new stabilizers whether it is from natural or artificial substances have had broaden the range of options to be chosen from. (Riza et al., 2011).

Stabilized soil has been used for the construction of sub bases of roads, pavements and rammed earth walls. Cement stabilized soil can be compacted into a high density block, which can be termed as soil-cement block. Such blocks are used for load bearing masonry structures. Cement stabilized hand compacted blocks (size: 350 x 250 x 150 mm) were used to build 260 houses in Bangalore (India) in 1948 (Jagadish, 2007). CINVA RAM press was the first machine developed to compact soil into a high density block in Columbia during 1952.

The construction of a large number of houses using compacted stabilized blocks have come up in many parts of the world. At present there are more than 12,000 buildings spread all over India (Walker et al., 2000). Currently more than 100 types of soil block making machines are available in the world market (Walker, 2004). More details on stabilized mud block technology can be found in the earlier studies (Walker et al., 2000; Walker, 2004) and many other publications. Some of the major findings/recommendations from the earlier studies, regarding production and properties of soil cement blocks have been summarized below:

a) Sandy soils containing predominantly non-expansive clay minerals (like kaolinite) are ideally suited for the production of soil-cement blocks. It is desirable that such soils have sand content >65% and a clay fraction of about 10%. Soils with higher clay fractions can be reconstituted by adding inert materials like sand/stone quarry dust/mine wastes etc. to bring down the clay fraction of the mix.

b) Soil-cement blocks produced using high clay soils are prone for damage due to rain impact and possess poor durability characteristics.

c) Strength of the block is sensitive to its density and preferable to obtain greater than 1.8 g/cc dry density for blocks. Wet to dry strength ratio for the blocks will always be less than unity.

d) Compressive strength of soil-cement blocks increases with the increase in cement content. Soil-cement mixes with 7% cement give sufficient wet compressive strength for the blocks to build two-storeyed load bearing residential buildings. Block strength can be easily manipulated by adjusting the cement content (Reddy and Guptha, 2006).

According to Ngowi (1997), the strength of the cement-stabilized bricks is 70% higher than the bricks stabilized with lime, as the strength of lime mortar is only a third of the cement mortar. Atzeni et al. (2008) added stabilizers such as hydraulic cements, hydrated lime and polymers (acrylic latex and an aqueous solution of naphthalene–sulphonate), thus increasing compression resistance from 0.9 (unsterilized) to 5.1 (polymer impregnated). Bahar et al. (2004) improved to 4.5MPa with an addition of 10% of cement and up to 6.5MPa with an addition of 20% of cement as stabilizer. Spanish standards indicate maximum values of 3.6MPa with lime stabilization and 6.6MPa with Portland stabilization (Galan-Marin et al., 2010).

More details on SMB technology can be found in the studies of Reddy and Jagadish (1995); Walker and Stace (1997); Walker (2004) and in many other publications.

2.3 PRINCIPLE OF STABILIZATION

The strength of the soil used in producing blocks can be improved in many ways, simplest being compaction with a mechanical press. This increases the compressive strength and makes the block denser (Roy et al., 2013). To increase earth blocks strength and durability even further, stabilizing materials can be added to the soil. Currently, there are over 100 potential stabilizers capable of blending effectively with earth, but there is a very thin margin of distinction amongst them. The most commonly used stabilizers are cement and lime. Bitumen, chemicals, and other enzyme-based stabilizers have been used with the same objective as all other stabilizers (Heath and Walker, 2013). According to (Mohammad and Lee, 2003) there are three (3) basic stabilization processes:

i. Mechanical Stabilization: This is the compaction of the soil with the aid of a mechanical press to improve its strength, durability, and water resistance.

ii. Physical stabilization: It involves the modification of the soil texture through heat and electrical treatment.

iii. Chemical Stabilization: The process of adding chemicals to modify the properties of the soil or by creating a matrix for binding the grains together.

There are certain guidelines listed in the literature (Obonyo et al., 2010), that can be used as a benchmark for the selection of stabilizer. Appropriate stabilizer types for various soil types are listed in Table 2.1.

Table 2.1: Types of Stabilizers for different soil types

Type of Soil/Condition	**Stabilizer**
For nearly all types of soils	Portland
Medium, moderate, fine and fine-grained soils	Hydrated Lime
Coarse grained soils with little if any fine grains	Fly Ash
Cold climate applications	Calcium Chloride
For increasing resistance to water and frost	Bitumen

Source: (Obonyo et al., 2010)

Silt and clay are unstable, especially when water is added. The clay particles tend to swell when wet and shrink when dry. This phenomenon can easily lead to cracking in earth blocks, which in return increases the possibility of surface erosion and compromises the structural integrity of the block (Adam and Agib, 2001). The adoption of right stabilizing method can improve the compressive strength by almost 400% and also increases the block's resistance to surface erosion (Adam and Agib, 2001).

2.3.1 Cement Stabilization

Portland cement is by far the most common stabilizing agent used in the production of earth blocks. When water is added to cement, it hydrates and as a result the reaction produces a cementitious gel, which is made up of calcium silicate hydrates, calcium aluminate hydrates, and hydrated lime. This process is known as hydration (Adam and Agib, 2001). This chemical reaction produces a matrix of interlocking filler which covers the aggregates, to form a strong binding force (Molla, 2012). The addition of cement in the soil mixture, improves the performance and resistance to water. Cement can be used with any soil type, but it is considered uneconomical when added to soils with a Plastic Index greater than 15% (Riza et al., 2006). Generally, cement content varies between 3% to 18% by weight depending on the soil type (Adam and Agib, 2001).

2.3.2 Lime Stabilization

In the process of lime stabilization, 4 chemical reactions take place, namely; cation exchange, flocculation and agglomeration, carbonation and pozzolanic reactions. The last stage is the most crucial and occurs between the lime and clay particles, which form a cementitious compound binding the particles together (Adam and Agib, 2001). Generally, soils with a Plastic Index greater than 15 are best stabilized with lime (Riza et al., 2006). The calcium ions in lime are exchanged with the metallic ions of the clay thus stronger fine particles are formed. It reduces the absorption rate of the clayey soil making it more resistant to moisture penetration (Adam and Agib, 2001). In a rural setting, lime is more commonly used as a stabilizer as compared to cement because it is cheaper, and can be produced locally in a traditional kiln. Some other advantages of lime over cement is that, it requires less fuel during production thus releases less carbon in the atmosphere (Adam and Agib, 2001)

2.3.3 Pozzolanas

Pozzolanas are siliceous and aluminous materials, which in itself possess little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties (ASTM 595). Clay minerals such as kaolinite, montmorillonite, mica and illite are pozzolanic in nature. Artificial pozzolanas such as ashes are products obtained by heat treatment of natural materials containing pozzolanas such as clays, shales and certain silicious rocks. Plants when burnt, silica taken from soils as nutrients remains behind in the ashes contributing to pozzolanic element. Rice husk ash and rice straw and bagasse are rich in silica and make an excellent pozzolana (Sherwood, 1993).

2.3.4 Blast Furnace Slags

These are the by-product in pig iron production. The chemical compositions are similar to that of cement. It is however, not cementitious compound by itself, but it possesses latent hydraulic properties which upon addition of lime or alkaline material the hydraulic properties can develop (Sherwood, 1993; Åhnberg et al., 1999). Depending on cooling system, Sherwood (1993) itemized slag in three forms, air-cooled slag, hot slag after leaving the blast furnace may be slowly cooled in open air, resulting into crystallized slag which can be crushed and used as aggregate. Such as clays, shales and certain silicious rocks. Plants when burnt, silica taken from soils as nutrients remains behind in the ashes contributing to pozzolanic element. Rice husk ash and rice straw and bagasse are rich in silica and make an excellent pozzolana (Sherwood, 1993).

2.3.5 Fly–Ash

Fly ash is a byproduct of coal fired electric power generation facilities; it has little cementitious properties compared to lime and cement. Most of the fly ashes belong to secondary binders; these binders cannot produce the desired effect on their own. However, in the presence of a small amount of activator, it can react chemically to form cementitious compound that contributes to improved strength of soft soil. Fly ashes are readily available, cheaper and environmental friendly. There are two main classes of fly ashes; class C and class F (FM 5-410). Class C fly ashes are produced from burning subbituminous coal; it has high cementing properties because of high content of free CaO. Class C from lignite has the highest CaO (above 30%) resulting in self-cementing characteristics (FM 5-410). Class F fly ashes are produced by burning anthracite and bituminous coal; it has low self-cementing properties due to limited amount of free CaO available for flocculation of clay minerals and thus require addition of activators such as lime or cement. The reduction of swell potential achieved in fly ashes treated soil relates to mechanical bonding rather than ionic exchange with clay mineral. However, soil fly ash stabilization has the following limitations (White, 2005):

- Soil to be stabilized shall have less moisture content; therefore, dewatering may be required.
- Soil-fly ash mixture cured below zero and then soaked in water is highly susceptible to slaking and strength loss
- Sulfur contents can form expansive minerals in soil-fly ash mixture, which reduces the long term strength and durability.

2.4 FIBER REINFORCEMENT IN COMPRESSED STABILIZED EARTH BLOCKS

Earthen materials in general are quite weak and brittle, and thus in order to improve its compressive strength stabilizers are added, and for tensile strength fibers either organic or synthetic are required to help reduce cracking (Rigassi, 1995). At peak loading conditions fiber reinforcement reduces the effects of cracking, by keeping the particles closer together thereby acting as tensile reinforcements. Fibers also increase local toughness of the blocks. For low cost housing, organic (plant) fibers are preferred as they are readily available, renewable and cheaper than synthetic fibers, but they offer variable properties to compressed stabilized earth blocks (Donkor, 2013). The fibers either increase or reduce compressive strength; this inconsistency can be attributed to the adhesion between the fibers and the soil, the hydrophilic characters of the fibers, and the distribution of the fibers within the design mix (Donkor, 2013).

The use of organic fibers in the production of compressed stabilized earth blocks was studied (Okoye, 2013), Palm kernel fibers were used and the cement content was kept constant whilst varying the fiber content. The water absorption rates of the blocks ranging from 5-12% were recorded. The lower values were recorded at 1% fiber content and the highest at 5%. This research also showed that water absorption increases with increase in fiber content; therefore natural fibers are not a good option for water resistant earth blocks (Okoye, 2013). This is as a result of the water absorbed by the cellulose fibers, which is influenced by the volume of the voids and how much fiber is present in the mix (Okoye, 2013). These results further solidify the notion that fibers absorb moisture and expand during mixing and drying of the blocks. Consequently they swell and push away the soil, at the end of the drying stage, water is lost from the fibers and they shrink back to its original size. This process introduces fine voids to the overall block.

2.5 PRACTICAL APPLICATIONS OF CSEB AS A BUILDING MATERIAL

Building with earth blocks is an ancient practice dating far back as 8000 to 6000 BC in different parts of the world most notably in Turkestan, Assyria, which was built in 4000 BC (Minke, 2006). Compressed stabilized earth blocks are made from naturally occurring soil with the addition of synthetic or organic fibers to improve its strength and durability. Earthen blocks are considered as a sustainable material because its energy requirement during production is 70% lower as compared to fired clay brick. They are also roughly 20-40% cheaper than fired brick (Jennifer et al., 2005). Building material is a factor in the construction industry that requires serious attention since the material cost constitutes about 50% of the construction cost. In developing countries, the overdependence of foreign imported products is the main cause of high construction costs (Minke, 2006).

Today 30% of the world's population lives in earthen houses. This figure represents a great benefit to the global struggle in reducing greenhouse gases to our environment. With the use of modern materials such as steel, concrete, and plastic as our only means of building material, we tend to drive towards ecological breakdown (Minke, 2006). Earth provides an alternative building material and a cheaper means of providing shelter.

Earth construction can be a viable option for tornado-proof structures, which are capable of surviving decades. They are relatively comfortable, renewable and noise proof, these characteristics amongst others make them durable. Earth blocks capability to resist tornados are based on the lump mass in the block, which will be so hard to crush or carried away (Jennifer et al., 2005).

2.6 COMPRESSIVE STRENGTH OF CSEB

The compressive strength of compressed stabilized earth blocks is the ability of the blocks to withstand applied loads. The amount of stabilization such as cement and lime in CSEBs affects the compressive strength. An increase in stabilization generally increases the strength (Heath and Walker, 2013). The water content in a mix design also affects the strength of the blocks. The strength of the blocks increases when small quantity of water is added to the mix during production (Jennifer et al., 2005). Water content of less than 1% recorded the highest average compressive strength of about $6N/mm^2$. Increase in water lowers the strength, at 3% water content, the capacity was reduced by 1/3 (Heath and Walker, 2013).

2.7 CONSTITUENTS OF REINFORCED COMPRESSED STABILIZED EARTH SLABS

2.7.1 Cement

The cement commonly used is the general normal setting Portland cement (the colour resembles Portland stone, hence, the name). Others include rapid-hardening Portland cement, blast furnance Portland cement, low heat Portland cement, super-sulphate Portland cement and high alumnia cement. Super-sulphate cement is used for very corrosive soils while low heat cement is better for massive concreting e.g. dam construction. These other types of Portland cement with additives. It should be noted that high Alumina cement which is useful for emergency works where very high early strength is desired (e.g. during war time) is not a Portland cement. The principal chemical compounds of Portland cement are, tricalcium silicate ($3CaOSiO_2$), dicalcium silicate ($2CaOSiO_2$), tricalcium aluminate ($3CaOAl2O_3$) and tetracalcium alumino ferrite ($4CaOAl_2O3Fe_2O_3$). The most important of these are the dicalcium and tricalcium silicates (Oyenuga, 2005).

BS 12 specifies some tests governs the quality of cement. They include fineness test, chemical composition test, setting time test, soundness test, strength test and heat of hydration test. Cement for concrete work should meet, at least, the minimum requirements.

2.7.2 River sand

River sand is used in the construction industry mainly for concrete production and cement-sand mortar production. River sand is obtained by dredging from river beds. It has the major characteristics that since it has been subjected to years of abrasion, its particle shape is more or less rounded and smooth, and since it has been subjected to years of washing, it has very low silt and clay contents.

In terms of particle size as used by geologists, sand particles range in diameter from 0.0625 mm (or 1⁄16 mm) to 2 mm. An individual particle in this range size is termed a sand grain. Sand grains are between gravel (with particles ranging from 2 mm up to 64 mm) and silt (particles smaller than 0.0625 mm down to 0.004 mm). The size specification between sand and gravel has remained constant for more than a century, but particle diameters as small as 0.02 mm were considered sand under the Albert Atterberg standard in use during the early 20th century. A 1953 engineering standard published by the American Association of State Highway and Transportation Officials set the minimum sand size at 0.074 mm. A 1938 specification of the United States Department of Agriculture was 0.05 mm. Sand feels gritty when rubbed between the fingers (silt, by comparison, feels like flour). (Schildkamp, 2009).

2.7.3 Laterite

The word Laterite describes no material with reasonable constant properties. To those in the temperate countries, it could be described as a red friable clay surface. To those in the hilly tropical countries, it could be described as a very hard homogenous vescular massive clinker – like materials with a framework of red hydrated ferric oxides of vescular infill of soft aluminium oxides of yellowish colour and in less hilly country, it could exist as a very hard, or soft coarse angular red. Lateritic soils as a group rather than well-defined materials are most commonly found in a leached soils of humid tropics. Laterite is a surface formation in hot and wet tropical areas which is enriched in iron and aluminium and develops by intensive and long lasting weathering of the underlying parent rock (Schildkamp, 2009).

According to Osunade (2002) the term “laterite” was used to describe a ferruginous, vesicular, unstratified and porous material with yellow ochre caused by its high iron content, occurring abundantly in Malabar in India. It was locally used in making bricks for buildings, and hence the name “laterite” from the Latin word “later” meaning “brick”. Although laterite is a material that has been used in the building construction industry of Nigeria for a very long time, especially in the rural areas, there is lack of adequate data to fully understand the behavior of this abundant material. There is need to improve indigenous technology on the practical usefulness of lateritic soils in building and allied industries. A lot of research activities are now being carried out on lateritic soils. Earlier published works on laterized concrete appear to have been a study in which the strength properties of normal concrete were compared with those of laterized concrete (Adepegba, 1975).

2.7.4 Clay

These are the finest particles in soils with size of less than 0.002mm. Clay also has unique characteristics, such as inclusion of microscopic mineral particles such as kaolinites, illites, and montmorillonites. They are very different from other particles, both physically and chemically, their plate-like shape molecules are electrically charged, which attracts water easily (Schildkamp, 2009).

2.7.5 Silts

With respect to the physical and chemical properties, silt and sand particles are quite similar. Silt has a particle size between 0.002 and 0.006mm, and lacks cohesion when dry. It has the ability to swell and shrink when exposed to different levels of humidity. They provide the soil with some stability by increasing its internal friction and filling the voids in the grains. (Schildkamp, 2009).

2.7.6 Water

The quality of water used in mixing the concrete must be such that the chemical reactions, which take place during the setting of the cement, are not impaired. In general, Portable water is suitable for concreting. Thus, the water should be free from impurities such as suspended solids, organic matters and salts etc. which may affect the setting of the cement (Oyenuga, 2005).

2.7.7 Reinforcement

Reinforcement should be kept clean by stacking them off the ground. Prior to usage reinforcements should be free from mud, oil, paint, loose rust, all which weakens the bond with the concrete. Unless the bars are rigidly fixed in the correct position the reinforcement may be displaced during concreting, particularly where the concrete is to be vibrated (Oyenuga 2005).

2.8 Magnus Frame

A twinned steel channel frame with high tensile bolted corners and spacers is 4.61m long, 2.53m high and 1.2m wide. The cross bearers at each end under the base distribute the self-weight of about 1 Tonne to four anti-vibration leveling feet. The working spacer within the frame is 4m x 1.6m high and the clearance between the twin verticals of the frames is 600mm. The top channel members are used to carry a travelling carriage on which the 200KN ram is fixed. A comprehensive range of cross bearers, thick steel plates, half round and full round bearings, and height spacing units enables specimens to be set up quickly and easily. Magnus frame frontal view picture is shown as plate G1 in Appendix G.

2.9 REVIEW OF PREVIOUS WORKS RELATED TO COMPRESSED STABILIZED EARTH SLAB.

Asmamaw and Abebe (2008) worked on Study of Compressed Cement Stabilised Earth Blocks as an Alternative Wall Making Material. The materials used were Kara soil, cement, and water. A pre-installed M7 E380 machine designed on the quasi-static compression principal was used for the entire samples to produce the blocks. The compressive strength results values are encouraging and increase with the cement content and test ages. For 6% and above cement additions, the 28 days compressive strength values are better than the minimum compressive strength requirement of Class C hollow concrete blocks. It is to be noted that Class C hollow concrete blocks are required to have a mean of 2Mpa according to ESC.D3.3010. Samples produced using 6% cement as a stabilizer and tested at the age of 56 days also satisfied the Class C hollow concrete requirement. Research made earlier on the quality of HCB in and around Addis Ababa reported that over 95% of the samples collected for compressive strength tests could not even satisfy Class C requirements (Abebe and Asnake, 2003). This indicates that if properly produced, compressed cement stabilized earth blocks can provide competitive advantage and in higher doses of cement even better performance can be achieved over that of hollow concrete blocks which are usually available in local market without fulfilling standard requirements.

Oyelade and Akintoye (2011) worked on the Coconut Husk Ash as a Partial Replacement of Cement in Sandcrete Block Production. In this study, the hollow ‘blocks were manufactured with the use of the fabricating machine. One mix proportion of 1:8 was used in the production of 450 x 225 x 225mm sandcrete block. One hundred and forty of 450 x 225 x 225mm hollow sandcrete blocks were produced. The quantities of materials obtained from the mix design were measured in each case by volume. The percentage of CHA content was varied in steps of 5% to a maximum of 30%. For the experiment, hand mixing was employed, and the materials were turned over a number of times until an even colour and consistency was attained. Water was then added as required through a fire hose, and the materials were further turned over to secure adhesion. It was then rammed into the machine mould, compacted and smoothened off with a steel face tool.

After removal from the machine moulds, the blocks were left on pallets under cover and kept wet by watering through a fine watering hose. Testing for crushing strength was then carried out at 7, 14, 21 and 28 days.

The main conclusions derived from this investigation are as follows:

i. Agriculture wastes such as coconut husk ash does not show good pozzolanic property in the production of sandcrete blocks.
ii. The maximum compressive strength of 2.16 N/mm^2 was obtained for the sandcrete block specimens at a percentage CHA content of 5%.
iii. Coconut husk ash addition should not exceed 5% of the weight of cement for best results.
iv. The maximum compressive strength achieved at 5% is more than recommendation of 2.00N/mm^2 recommended by Nigeria National Building Code (2006), for non-load bearing wall.
v. As the percentage of CHA content in the mix increase the compressive strength decreased appreciably to a value of 0.06N/mm^2 at 30% CHA content.
vi. There is no noticeable relationship between CHA content and dry density in the mix.

Alagbe (2011) worked on Prospects and Challenges of Compressed Stabilized Laterite Bricks in Enhancing Sustainable Housing Development in Nigeria.

He evaluated CSLBs as a building materialh for sustainable housing construction. The study focused primarily on evaluating its physical properties as a building material as well as a measure of its level of acceptability for housing construction among the populace. The study was carried out in four local governments namely; Ogbomoso North, Ibadan Southwest in Oyo State. Ado-Odo Ota in Ogun State and Agege Local Govenment in Lagos State, Nigeria.

The methodology adopted was survey method which involved the administration of 600 questionnaires on randomly selected household heads out of which 551 responded. The data obtained was analyzed using various statistical tools.

The result showed that there is apathy towards acceptability and use of CSLBs for housing construction due to lack of knowledge about its physical properties. It was also found out that non-availability of CSLBs in the open market was a major determinant of the apathy.

He concluded that to ensure sustainable housing development via CSLBs, there must be continuous sensitization of the populace by stakeholders through construction of model houses with CSLBs. More researches on fabrication and production of the CSLBs making machines so as to make it more readily accessible should also be funded.

Riza et al. (2011) worked on Preliminary Study of Compressed Stabilized Earth Brick (CSEB).

Mixes: Stabilizer for CSEB playing an important role in creating bonding between soil-stabilizers mixes. One of the main functions of the stabilizing medium is to reduce the swelling properties of the soil through forming a rigid framework with the soil mass, enhancing its strength and durability (Anifowose, 2000). Portland cement is the most widely used stabilizer for earth stabilization. Many research works (Guettala, 2002; Walker, 1997) found that soil with plasticity index below 15 is suitable for cement stabilization. Typically, cement binder is added between 4 and 10 % of the soil dry weight (Mesbah, 2004). However, if the content of cement is greater than 10% then it becomes uneconomical to produce CSEB brick. For brick using less than 5% of cement, it often too friable for easy handling (Walker, 1995).

For soil that has plasticity index below 15 more suitable to use cement as a stabilizer whether for the soil that has plasticity index above 15 or have clay content, it is suggested to use lime as a stabilizer (Guettala, 2002; Osula, 1996). Lime can be added to the cement and clay mix to enhance stabilization process because with the additional lime, the lime-clay ratio will be increased due to the existing of lime in cement and the present of lime attributed to the immediate reduction of plasticity (Attoh-Okine, 1995). Although the same trend happen to the soil-cement mixes, the immediate effect of modification was more obvious in the soil-lime mixes (Osula, 1996). When lime added to the clay soil, first it adsorbed by the clay mineral until the affinity of the soil for lime achieved, its call lime fixation and normally the amount between 1 to 3% lime added by weight. The addition of lime after lime fixation contributed to the pozzolanic reaction that created hydrated gel and this process is time dependent where strength developed gradually over long period (Bell, 1996).

When clay soil is blended with Portland cement in the presence of water, hydration reaction will take place. The compound of C3S and C2S present in the Portland cement react with water forming complex Calcium Silicate Hydrates (C-S-H) gel (Attoh-Okine, 1995). C-S-H gel has beneficial effect in clay material by reduction of deleterious heaving effects such as the growth of ettringite due to the rapid removal of alumina. The formation of ettringite contributes to the increase of porosity and simultaneously decreases the free moisture content. The C-S-H gel formed fill the void spaces and bind the soil particles together thus imparting strength to the soil mixture (Oti, 2009).

For laterite soil, Attoh-Okine (1995) noted that lime stabilization of soil is a function of quantity of lime, curing time, environmental condition and testing method. Billong (2008) also observed the potential of using lime and other pozzolanic material to form a binder that can acts as a stabilizer. Oti (2009) suggested the combination of lime with ground granulated blast furnace (product in the manufacturing of pig iron) that will gives better performance compared to the use of cement as the stabilizer. Natural stabilizer as proposed by Mesbah et al. (2004) is more environmental friendly and cheaper. Even though stabilization with hydraulic binder (cement) significantly improved strength and water resistance but it contributes to negative environmental impact. Guettala et al. (2006) suggested the use of an aqueous dispersion of resin as an additive in earth stabilizer. The additive has increased the strength significantly until 2-3 fold to those indicated by standards for both wet and dry conditions.

In general, soil stabilizations enhance quite significant bricks properties. Types of soil played an important role to determine the proper stabilizer for specific properties of brick to been hanced. Even though the best soil for stabilization is the soil that has low plasticity, the advantages of using cement for soil with low plasticity can be substituted with lime and other pozzolanic based stabilizer for soil with high plasticity and high clay content. The inventions of new stabilizers whether it is from natural or artificial substances have broadened the range of options to be chosen from (Walker, 2004).

Performance of CSEB: Strength: Apparently, compressive strength is the most universally accepted value for determining the quality of bricks. Nevertheless, it intensely related with the soil types and stabilizer content. Typically, determination of compressive strength in wet condition will gives the weakest strength value. Reduction in compressive strength under saturation condition can be attributed to the development of pore water pressures and the liquefaction of unstabilized clay minerals in the brick matrix. Factors affecting the CSEB brick strength are cement-content, types of soil (plasticity index), compaction pressure and types of compaction.

Optimum cement content for the stabilization is in the range of 5% to 10% where addition above 10% will affect the strength of the bricks in negative way. Plasticity index of the clay soil is usually in the range of 15 to 25. The best earth soils for stabilization are those with low plasticity index. But for plasticity index >20, it is not suitable with manual compaction (Walker, 1995). Anifowose (2000) found that iron presents in the soil are responsible for low compressive strength in the soil stabilization process. The strength of the CSEB can be increased by adding natural fibers where it can improve the ductility in tension. The improvement is by retarding the tensile crack propagation after initial formation and also the shrinkage cracking (Mesbah, 2004).

Since there is no standard testing for CSEB, most researchers determined the compressive strength using the testing method used for fired clay brick and concrete masonry block such as ASTM 1984, BS 6073-1:1981, BSI 1985, BS EN 772-1, BS 1924-2:1990, Standard Australia 1997, Australian Standard 2733 (Walker, 1995; Walker, 2004; Oti, 2009). The unconfined compressive test needs expensive equipment and must be carried out in the laboratory, hence some researchers suggest using indirect compressive test (i.e. flexural test/modulus of rupture/three-point bending test). These indirect test provide simple, inexpensive and fast assessment of insitu bending strength of the brick (Morel, 2005; Morel, 2002). Walker (1995; 2004) suggested to use factors that modulus of rupture is equivalent with one-sixth of its compressive strength and in his latest experiment suggested that unconfined compressive strength is about five times of the bending strength.

Compacting procedure also affect considerably on the compressive strength of the CSEB brick. Guettala et al. (2002) concluded that by increasing the compacting stress from 5 to 20 MPa, it will improve the compressive strength up to 70%. His conclusion was strengthened by Bahar et al. (2004) observed that by using dynamic compaction energy dry compressive strength increases by more than 50% but for vibro-static compaction increases slightly for about 5%.

Brick strength and brick characteristic flexural bond strength are the factors that limit the bond strength between bricks and mortars in wall panels made from CSEB (Walker, 1999). Hence, types of bricks such as solid, interlocking or hollow and type of bond like English, Flemmish or Rat trap bond also play an important role in flexural strength of the panels (Jayasinghe and mallawaarachchi, 2009).

Njike et al. (2014) worked on Structural performance of evolved eco-block wall.

Materials and various procedures used in this study are explained below.

Stabilized composite earth block: Materials used to produce stabilized composite earth blocks were laterite, 20% of river sand and 6% cement. The previous work done by Njike et al. (2014) delved into basic material properties, as well as strength tests on specimens made of blended or composite soil. Material properties were the same as those presented in (Njike et al., 2014) as the same materials were used. The percentage of stabilizer used was 6% of cement and soil was blended with 20% sand. Results obtained from this study showed that composite blocks stabilized with 6% of cement had a satisfactory higher strength of 4.4MPa which is above the minimum strength required by Kenya standard of 2.5MPa. The stabilized composite earth blocks were then used to produce panel walls which were tested in this study.

Conventional stone block: Conventional stone blocks from Ndarugu quarry, Kenya were used. The bedrock in this area (i.e. Ndarugu, Kenya) is soft granitestones, which may have been formed as a result of volcanic eruption (Ndegwa et al., 2007). According to (Gichuhi, 2011) quarry stone block produce compressive strength between 2-5 MPa depending on the type of stone, which varies from region to region. It was noted that the strength of conventional stone block used in this work was 2.1MPa performed using a 1500kN capacity universal testing machine in accordance to BS 1881-116. Mortar: Mortar is a homogeneous mixture of cementitious materials, inert materials and water produced for joining masonry units. Mortar has a function to bond the bricks or blocks together so that they will resist the loads applied to the wall (give strength and durability to a wall). In this work, the mortar mix proportion was 1:3 (cement: sand) and the water/cement ratio was determined by keeping the workability of the mortar to be equal to 1.

This research has shade light on comparative structural behaviour of walls made with stabilized blocks and conventional stone blocks. It is therefore concluded that, walls constructed with stabilized blocks perform better structurally than those made with conventional stone blocks. This could be attributed to the intrinsically bound and structure stabilized blocks has in comparison to homogeneous stone blocks. The specific indicators of this superiority differences was that the compressive strength per unit area of stabilized block wall was 1.0643N/mm^2 while that of conventional stone wall was 0.9517 N/mm^2 respectively.

Pkla et al. (2007) worked on Compressive strength testing of compressed earth blocks.

There are many different techniques to use earth as a raw material. Adobe is a natural building material made from sand, clay, and water, with some kind of fibrous or organic material (sticks, straw, dung), which is shaped into bricks using frames and dried in the sun. It is similar to cob and mudbrick. Adobe bricks are unfired sun-dried clay units, whose dimensional stability and control of shrinkage cracks can be achieved by adding organic fibres. Similar to bricks in shape, but bigger in size, they can be stabilized with lime or cement. Clay is the major binder in traditional adobe. Earth used in traditional adobe production must contain approximately 30% clay. To obtain the final dried material, the blocks must be cured for 15–21 days prior to utilization in a site sheltered from sun and rain (Mesbah, 2004).

The rammed earth is a clay soil (earth) compacted into a formwork. The earth composition varies greatly but contains no organic component and sufficient clay, which acts as a binder between the grains, a mixture of silt, sand, gravel and stones with a diameter of a few centimetres. Compaction is performed using a water content considered optimum i.e. that provides the highest dry density for fixed compaction energy. For traditional rammed earth, the only binder is clay, it is referred to as ‘‘unstabilized rammed earth’’. Modern rammed earth appeared in western countries after industrialization when other binders were added, such as cement, hydraulic or calcium lime (Bui et al., 2008) they are called ‘‘stabilized rammed earth’’. The main advantage of stabilizing the rammed earth is to increase its durability (with respect to water attack) and mechanical performance (compressive strength).

Compressive crushing strengths between 0.6 and 2.25 MPa for unstabilized soils are shown by (Jiménez and Cañas, 2006). According to Spanish standards (MOPT, 1992). Compressive strength testing of compressed earth blocks. Construction Build Mater by Morel et al. (2007) summarizes previous studies focused on the mechanical behaviour of unstabilized rammed earth characteristics, showing compressed earth blocks that have been made using a manual press present compressive strength in a range of 1.5–3 MPa and densities from 1763 to 2160 kg/m3. Higher strengths are achievable using hydraulic presses and/or higher cement contents, but compressive strengths in the range 2–3 MPa are most typical. In situ measurements to validate laboratory results were done by (Bui et al., 2008) in a rammed earth house erected near Thiers (France) and chosen as the subject of the study. The densities obtained were 1980 kg/m^3 and compression tests 1.65 MPa. Stabilizers such as lime, cement or bitumen, are added to improve particular properties (Hossain et al., 2007). In countries such as Papua New Guinea clay soils are stabilized with native materials: various percentages of volcanic ash (VA), finely ground natural lime (L), cement and their combinations. The influence of stabilizers and their combinations are evaluated by Hossain et al., 2007. Compressive strength in this case varies between 0.39 and 3.1 MPa. According to Ngowi (1997) the strength of the cement-stabilized bricks is 70% higher than the bricks stabilized with lime, as the strength of lime mortar is only a third of the cement mortar.

Atzeni et al., 2008 added stabilizers such as hydraulic cements, hydrated lime and polymers (acrylic latex and an aqueous solution of naphthalene–sulphonate), thus increasing compression resistance from 0.9 (unstabilized) to 5.1 (polymer impregnated). Bahar et al., 2004 improved to 4.5 MPa with an addition of 10% of cement and up to 6.5 MPa with an addition of 20% of cement as stabilizer.
Spanish standards (MOPT, 1992). Indicate maximum values of 3.6 MPa with lime stabilization and 6.6 MPa with Portland stabilization. Specimens sizes vary widely from cubes 5 x 5 x 5cm, cubes 10cm, cubes 15cm to prismatic 100 x 100 x 30cm or 30 x 30 x 60cm.

Issac and Manasseh (2008) worked on the Use of Cement-Sand Admixture in Laterite Brick Production for Low Cost Housing.
The soil used in this study is a reddish brown laterite soil classified as A-2-7(0) using AASHTO soil classification system (AASHTO, 1986) and GP by the United Soil Classification system (ASTM, 1992). Disturbed sample of laterite was obtained from Ikpayongo (between latitude 7°30′P and 7°35′P N and longitude 8°30′P and 8°35′P E) a distance of 22 km from Makurdi, the capital of Benue State of Nigeria, along Makurdi-Otukpo road. Sand used for the test was obtained from River Benue in Makurdi. Dangote brand of ordinary Portland

cement purchased from the open market and used in this study as the stabilizing agent while portable tap water was employed in the laboratory tests conducted. Laterite bricks were produced using soil-sand-cement mixtures with 0 and 45% sand content and 0, 3, 6, and 9 cement content. Laterite and sand were air dried for 24 hours before passing them through 10 mm sieve. Particles passing through the sieve were used for brick production. The required proportions of sand, laterite and cement were mixed manually on a clean and firm platform using a shovel.

The damp mix was poured into the twin steel moulds of a locally fabricated manual press machine, after lubrication with water/oil. A wooden pallet was placed at the bottom of the mould to allow easy removal of the bricks after being pressed. The damp mix was poured into the mould with the aid of a shovel, while tamping was carried out with a 20 mm diameter rod. A hinged mould lid weighing 15 kg was dropped six times from a height of 30 cm onto the exposed top of the mixture in the mould. This is equivalent to a pressure of 3 N/mm^2.

Using the optimum cement content of 5% and a 28 day compressive strength of 1.65 N/mm^2 for bricks as the criteria, compressive strength test results show that soil-cement mixtures did not satisfy both requirements. The requirement was met at 9% cement, which is far above the economic cement content. For a laterite-cement mixture of 45% sand and 5% cement, a compressive strength of 1.80 N/mm^2 (obtained by interpolation) was obtained. This value met the requirements.

When the cement content was slightly increased to 6%, laterite-sand-cement mixture of 6% cement and 45% sand met the strength of 2.0 N/mm^2 proposed by (Adam, 2001) where bricks are to be used for one-storey building.

It can be observed that the pressure of 3 N/mm^2 applied in the moulding of bricks in this study fell into the range of low pressure used by (Adam, 2001). If the higher-pressure ranges were used in moulding the bricks, the expected compressive strength results would have been higher than the values obtained in this study. (Olabiran et al.,1989). Reported such increase in compressive strength with compactive effort.

Namango and Madara (2014) worked on Compressed Earth Blocks Reinforced with Sisal Fibres.
Materials used, Sisal vegetable fibres brought in from Kenya were cut to an average length of 3 – 10 mm and had a thickness of 0.2 – 1.0 mm. Portland cement type CEM I, 32.5R, was used for stabilization.

Material Preparation, addition of sisal, cement or sisal-cement to soil was done in ratios by weight of dry soil. In the first batch, compressed bricks were made by reinforcing the soil with 0.25, 0.5, 0.75, 1.0 and 1.25% sisal fibres. Portland cement in the following proportions: 5, 9 and 12 % was used for stabilisation in the second batch. The third batch involved the use of both sisal and cement. In the final case, pressed soil blocks were made without cement stabilisation or sisal reinforcement. In total 24 mixtures were used. For every mixture, 8 full blocks were fabricated. Mixing of cement, sisal or sisal-cement in soil was done by hand on a wheel borough in a dry state. The mixing was thoroughly done before water was added to sufficient workability. Addition of about 2% water above the optimum moisture content provided a composition that would gain adequate block density on drying. A manually operated constant volume press borrowed from "artifact gGmbH" of Glücksburg, Germany, was used for fabrication of compressed earth blocks. Although it was not possible to measure exactly the compaction pressure, numerous past researchers have indicated that such a single acting ram press is capable of developing pressures of between 2 – 4 MN/m^2. The press used in this investigation produces full blocks with nominal dimensions, length; 230mm, width; 110 mm and height; 60 mm .

The sisal reinforced compressed blocks were extracted from the press and air dried in the open for a period of 28 days before being tested. The cement and sisal-cement blocks were cured under polythene sheeting for 14 days and moistened daily to allow for complete hydration of cement then left in the open to dry for another 14 days before testing for mechanical strength. The equipment available for testing of both compressive and tensile strength, required prisms of the size, length; 160 mm , width; 40 mm and height; 40 mm. These smaller scale blocks were obtained by cutting the full blocks in a diamond coated rotary power cutter. Because of the diamond coat, it was possible to cut through the full bricks with high precision and without the risk of breakages. The rotary power saw model “WOCO-TOP 300-A2 is manufactured by Conrad Apparatus. five trials were done for each respective parameter.

Results and Discussion, Compressive and flexural strength were measured on prisms of dimension, length; 160mm, width; 40 mm and height; 40 mm .

For determination of compressive strength, each specimen was loaded in a Toniversal-Tonitechnik hydraulic press at a rate of 1.5 $N/mm^2/s$. The flexural strength was conducted by uniaxial point loading on Toniversal-Tonitechnik hydraulic press at a rate of 0.05 kN/s. Results show a clear increase in both compressive and flexural strength with increasing sisal levels from 0.25% to 1.0%. Optimal strength of 9.14 N/mm^2 is attained at 0.75% sisal content. Strength increase would have been due to creation of isotropic matrix between the clay structure and the fibre network; such a matrix would oppose movement of particles and create stability mainly because fibres appear to distribute tension throughout the bulk of material. In other words, the presence of omni-directional fibres would improve tensile and compressive strength. Considered at the level of a potential crack, Houben, (1994) explains that the fibre opposes formation of a crack in step with the increase in the stress. The addition of fibres beyond 1.0% content leads to decrease in strength. Greater amounts of sisal (more than 1.0%)

may have lead to appearance of micro-fractures at sisal-soil interfaces, such that compressive strength fell to 4.16N/mm^2 at 1.25% sisal content. It is also possible, that addition of fibres to earth may lead to decrease in relative clay content (Minke, 2000). Houben, (1994), states that over-large quantity reduces density too much while the number of contact points between fibre and soil, which are responsible for transmitting stress, becomes too low so the strength of the block is reduced.

Compressive Strength, Change in the 28 day dry compressive strength as a function of both cement and sisal stabilization. In general, for each level of sisal, i.e. 0.25%, 0.5%, 0.75%, 1.0% and 1.25%, the 28 day dry compressive strength increased with an increasing level of cement in a linear relationship would be due to the increasing amount of C_2S and C_3S brought about by increasing level of cement. The increasing amount of $C_3S_2H_3$ which is derived from the hydration of C_2S and C_3S better tied fibres and soil particles together in the mixture, leading to an increase of strength. It may have been expected that a combination of both cement and fibres would provide greater strength than cement or fibres on their own. Results of the present investigations show however, that this is not the case. Compared with blocks reinforced with only sisal or stabilised with only cement, it is noted that the compressive strength rises within a rather limited range of 2.37 N/mm^2 to 6.75 N/mm^2. As expected, the rate of increase is lower for 1.0% and 1.25% sisal levels, meaning therefore that higher amounts of sisal in combination with cement are relatively detrimental to compressive strength.

It is catalogued (Houben, 1994) that the fibre armature has its effect at the macroscopic level; fibres thus reinforce at the level of grain aggregations rather than at the level of individual grains. Cement stabilisation on the other hand, results in filling of voids with an insoluble binder which coats the grains and holds them in an inert matrix.

In general strength values fall with increase in sisal levels. It would appear therefore that, improvement of compressive strength in cement-sisal stabilised blocks is due to cement and not sisal presence. Likely, in situations of high sisal content, the amount of soil-cement which surrounded each fibre may no longer have been enough to provide sufficient friction (Minke, 2000).

Flexural Strength, the trends are similar to compressive strength tendencies. Indeed, the flexural strength lies in the range of 17.5% to 22% of the compressive strength. The flexural strength of fibre reinforced specimens was lower than that of unreinforced specimens at 5% and 9% cement level, the vegetable fibres were therefore detrimental to matrix quality for this test. At 12% cement level, the flexural strength is for all the 6 fibre levels greater than the unreinforced case.

At each level of sisal, there was an increase in flexural strength with an increasing level of cement; this would be due to $C_3S_2H_3$ compounds brought about by the hydration of cement. In general, 0.5% sisal content provides the best flexural strength; likely because this fibre content and the amount of soil-cement which surrounded each fibre might be the optimum combination of the two for the composite to provide both friction and shear strength (Minke, 2000). Observation confirms what was earlier stated, that improvement of strength in cement-sisal stabilised blocks is due to cement and not sisal presence. It is clear that the flexural strength for both 5% and 9% cement contents is lower than in the unreinforced soil block. Stabilisation with 12% cement brings about strength (up to 1.36 N/mm^2) that is only slightly higher than in the unreinforced case (0.992 N/mm^2).

Priyanka et al. (2013) study shows the effect of partial replacement of natural sand by manufactured sand on the compressive strength of cement mortar of proportion 1:2, 1:3 and 1:6 with water cement ratio as 0.5 and 0.55. The results are compared with reference mix of 0% replacement of natural sand by manufactured sand. The compressive strength of cement mortar with 50%

replacement of natural sand by manufactured sand reveals higher strength as compared to reference mix. The overall strength of mortar linearly increases for 0%, 50% replacement of natural sand by manufactured sand as compared with reference mix. Manufactured sand has a potential to provide alternative to natural sand and helps in maintaining the environment as well as economical balance.

Vinayak et al. (2012) study shows the replacement of natural sand by 60% artificial sand results in producing the concrete of satisfactory workability and strength properties. It is also possible to minimize the area of surface cracks of concrete, thus achieving the durable concrete. However, for more than 60% replacement of natural sand by artificial sand causes reduction in compressive strength of concrete mixes with increase in the area of cracks. The replacement of natural sand with artificial sand will help in conserving the natural resources of sand and maintain the ecological balance of the nature.

Singh et al. (2010) has evaluated the strength and flexure toughness of Hybrid Fibre Reinforced Concrete (HyFRC) containing different combinations of steel and polypropylene fibres.The specimens incorporated steel and polypropylene fibres in the mix proportions of 100-0%, 75-25%, 50-50%, 25-75% and 0-100% by volume at a total volume fraction of 1.0%. The results indicate that concrete containing a fibre combination of 75% steel fibres + 25% polypropylene fibres can be adjudged as the most appropriate combination to be employed in Hybrid Fibre Reinforced Concrete for compressive strength, flexural strength and flexural toughness. A maximum increase in compressive strength of the order of 18% over plain concrete was observed in case of concrete containing 75% steel fibres +25% polypropylene fibres. In case of static flexural strength tests, a maximum increase in flexural strength of the order of 80%, centre point deflection corresponding to peak load of the order of 84% was observed for HyFRC with 75% steel fibres + 25% polypropylene fibres. The results obtained in this investigation indicate that, in terms of flexural toughness, concrete with fibre combination of 75% steel fibres + 25% polypropylene fibres gives the best performance.

Ezeokonkwo et al. (2011) have examined the use of polypropylene fibres to improve the compressive strength of sandcrete blocks. This involved the reinforcement of sandcrete blocks with twisted polypropylene fibres of length 50mm, 75mm and 100mm respectively at 5 different volume fractions of 1 per cent, 2 per cent, 3 per cent, 4 per cent and 5 per cent, and 5 different water/cement ratios of 0.4, 0.5, 0.6, 0.7 and 0.8. Analyses of the results showed that, addition of fibre increased the compressive strength from 2.236 per cent to 35.783 per cent and it is dependent on the length, volume fraction of fibre and water/cement ratio.

Patel et al. (2012) has explored properties such as compressive strength, flexural strength, split tensile strength and shear strength of polypropylene fibre reinforced concrete. Triangular shaped polypropylene fibre of 12 mm length and having density 1400 kg/m3, with fibre volume fractions 0%, 0.5%, 1%, 1.5% and 2 % were used in the experiments. The compressive strength of material increases from 8% to 16% for PFRC with increasing fibre content. The splitting tensile strength due to polypropylene fibre addition enhanced from 5% to 23%. The flexural strength increased with increasing fibre content. The maximum increase in flexural strength of PFRC was 36%.

Vairagade et al. (2012) have studied the compressive strength, flexural strength and tensile strength of fibrillated polypropylene fiber reinforced concrete (PFRC) containing fibers of 0%, 0.25% and 0.4% volume fraction of fibrillated polypropylene fibers of 15mm, 20mm and 24mm length. It was observed that the compressive strength for M20 grade of concrete from three different cut length fibers at same volume fraction shows nearly same results with minor increase. By addition of 0.4%, 24 mm cut length fibrillated Polypropylene fibers showed maximum compressive strength. With same volume fraction, change in length of fiber result nearly minor effect on compressive strength of fiber reinforced concrete. For longer length fibers, the split tensile strength was higher. Used of 24 mm long fiber with same volume of fraction had given maximum split tensile strength over fiber 15 mm and 20 mm cut length.

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

The materials used in this work include cement, river sand, and water Laterite BRC mesh and Clay.

3.1.1 Cement

The cement used was Dangote brand of Portland cement. It was purchased at retails outlet, along Nekede road and transported to Federal Polytechnic Nekede, Owerri concrete laboratory where the tests were conducted. The quality of cement used was in conformity with specifications in NIS 444-1:2003.

3.1.2 River Sand

River sand was used as fine aggregate. The river sand was obtained from Otamiri River, Nekede, Owerri, Imo State. The sand was free of debris, silt and other organic materials.

3.1.3 Laterite

Laterite was purchased at Otamirri borrow pit, Nekede and was transported to the Laboratory for test. This soil composed of 21.7% of fines (clay and silt) and 78.3% sand.

3.1.4 Water

Water obtained from Federal Polytechnic, Nekede, Owerri water distribution system, was used for the mixing of compressed stabilized earth slabs and cubes. The water was colourless and free from suspended solids and organic matters.

3.1.5 BRC Mesh

5 x 150 x 150mm BRC mesh with strength of 250N/mm^2 was used as reinforcements. The BRC mesh was purchased from Naze timber (Ogbo Osisi) market, Owerri, Imo State. It was kept clean by packing it off the ground. Prior to usage, it was free from oil, paint, mud and loose rust which all weakens the bond with the earth slab. The mesh was cut in to 450 x 450mm for use.

3.1.6 Clay

Clay was purchased at Iyiezi borrow pit, along Isi-iyi road in Umuasua Autonomous community, in Isuikwuato LGA of Abia State and was transported to the Laboratory for test.

3.2 METHOD: The following experiments were conducted

(a) Sieve analysis

(b) Moisture content test

(c) Compaction test

3.2.1Sieve Analysis

500g sample was weighed from air-dry river sand. The sieves were dried, cleaned, weighed and then recorded. The selected sieves were nest in proper order as shown in table D1.the sample were poured on to the top sieve in the stack of sieves.

The stack of sieves was placed onto the sieve shaker and placed the three armed bracket on the lid of the stack. The straight-arm bracket was lowered and we made sure that the end pins penetrated appropriate holes on the frame so that the stack will be secured. The sieve shaker was timed for 15 minutes after which it was switched off.

The mass of the sample retained in each sieve were determined and recorded.

Mass of soil retained = mass of sample retained in sieve - mass of empty sieve

Let the mass of retained on these sieves be respectively, M_1, M_2……, M_9 and the mass of soil retained on the pan be M_{10}. The sum of all these masses is, obviously, equal to the total mass of sample M. Percentage sample retained on the sieves and pan are expressed as P_1, P_2,…….,P_9 and P_{10}.

$$P_1 = \frac{M_1}{M} * 100 \tag{3.1}$$

$$P_{10} = \frac{M_{10}}{M} * 100 \tag{3.2}$$

The cumulative percentage (C) of sample retained on any sieve is equal to the sum of the percentage of soil retained on the sieve and the retained on all sieves coarser than that sieve. Therefore,

$$C_1 = P_1 \tag{3.3}$$

$$C_2 = P_1 + P_2 \tag{3.4}$$

$$C_9 = P_1 + P_2 + ----------- + P_9 \tag{3.5}$$

The percentage passing (N) of any sieve is obtained by subtracting the cumulative percentage retained on the sieve from100% thus,

$$N_1 = 100 - C_1 \tag{3.6}$$

$$N_2 = 100 - C_2 \tag{3.7}$$

$$N_9 = 100 - C_9 \tag{3.8}$$

3.2.2 Moisture Content Test

The container was cleaned, dried, weighed and recorded as W. The sample was crumbled and placed loosely in the container and covered. The container and contents were then weighed and recorded as W_1.

The container and contents were placed in the oven and dried at 110 - 1 1 5 ˚C for 24hours. After drying, the container and the contents were removed from the oven and placed in a desiccator to cool. The container and the content were then weighed and recorded as W_2.

The moisture content of the soil (MC) is calculated as a percentage of the dry soil weight from the formula.

$$MC = \frac{W_1 - W_2}{W_2 - W} * 100\% \qquad (3.9)$$

3.2. 3 Compaction Test

Compaction test was conducted for the eight mixture proportion to obtain the dry density and optimum moisture content which will be used in the casting of the reinforced compressed stabilized earth slab.

An air-dried representative sample was passed through a 20mm sieve and 7kg of the sample was used for this test, it was weighed according to the mix ratio. The sample comprises of cement, fines and river sand. Clay was used in replacement of cement due to dehydration.

The sample was poured on the tray then, thoroughly mixed with water to a fairly low moisture content of 6%, 9%, 12%, 15%, and 18% for the sample.

The sample was then compacted in a metal mould of internal diameter 150mm using a 4.5kg rammer, of 50mm diameter, free falling from 450mm above the top of the sample.

Compaction was effected in five layers, of approximately equal depth, each depth given 27 blows spread evenly over the sample surface.

The top of the compacted sample was trimmed level with the top of the mould. The base of mould was removed and the mould and the test sample it encloses were weighed. Samples for water content determination were then taken from the top and base of the soil sample, and were oven dried for 24 hours.

The rest of the soil sample was removed from the mould, broken down. The test continued until the weight of the wet soil in the mould attains a maximum value and begins to decrease. At the completion of the test a graph of moisture content against dry density was plotted.

The test required a series of weighing to be carried out. The procedure includes.

Weight of container	=	W (g)
Weight of container + wet sample	=	W_1 (g)
Weight of container + dry sample	=	W_2 (g)
Weight of wet sample	=	$W_1 – W$ (g)
Weight of dry sample	=	$W_2 – W$ (g)
Weight of moisture	=	$W_1 – W_2$ (g)
Moisture content	=	MC (%)
Weight of cylinder + compacted sample	=	M_1 (g)
Mass of cylinder	=	M (g)
Volume of cylinder	=	V (cm^3)
Density	=	ϱ (g/cm^3)
Dry density	=	dϱ (g/cm^3)
Average moisture content	=	G

$$Mc = \frac{W_1 - W_2}{W_2 - W} * 100\% \tag{3.9}$$

$$\varrho = \frac{M_1 - M(g)}{V(cm^3)} \tag{3.10}$$

$$d\varrho = \frac{\varrho\left(\frac{g}{cm^3}\right)}{1 + G} \tag{3.11}$$

The calculations of the compaction test, results and the graphs of moisture content versus dry density are shown in Appendix C.

3.2.4 BRC Mesh Preparation

The BRC mesh was unrolled, straighten and cut into 450 x 450mm sizes, it was kept clean by packing it off the ground. Prior to usage.

3.2.5 Method of Batching and Mixing

Batching was done by weight .Eight different mixture proportions were used for the casting of compressed stabilized earth slabs and cubes. Optimum moisture content used was obtained from compaction test. Twelve slabs were cast for each mixture proportion. Total compressed stabilized earth slabs cast were ninety six, forty eight were reinforced while the other forty eight were unreinforced. The compressed stabilized earth cubes cast were forty eight, three cubes per batch. First forty eight compressed stabilized earth slabs and twenty four compressed stabilized earth cubes were cast using compaction load of $6N/mm^2$ and the other forty eight compressed stabilized earth slabs and twenty four compressed stabilized earth cubes were cast using compaction load of $8N/mm^{2.}$

Table 3.1 shows the mixture proportion and the optimum moisture content used. The calculation for the mixture proportions are shown in AppendixB.

Table 3.1 Percentage mixture proportion and the optimum moisture content.

Mix No	Laterite (%)	River sand (%)	Cement (%)	OMC (%)
1	52.25807	37.74193	10	0.075
2	57.64977	32.35023	10	0.08
3	63.04147	26.95853	10	0.094
4	68.43318	21.56682	10	0.102
5	73.82489	16.17511	10	0.097
6	79.21659	10.78341	10	0.119
7	84.60829	5.391705	10	0.097
8	90	0	10	0.128

3.2.6 Mixing of Materials

Mixing was done manually by use of shovel after the combination of the constituent in their right proportions. The mixing was done on concrete floor, before the mixing the floor was wetted with water. River sand was first weighed out on a scale in batches, when the quantity of river sand required was obtained, the quantity of laterite and cement were weighed out in the same manner and mixed thoroughly with the use of shovel. The quantity of water required was measured and poured into the materials and was mixed together.

3.2.7 Casting of Compressed Stabilized Earth Slabs and cubes

The slab and cube steel moulds were cleaned of old pebbles that may have coated on them with a metallic brush and then with a dry rag. The internal surfaces of the moulds were lubricated so as to avoid adherence between the content and the steel moulds. It also aids the easy removal of the cast samples from the moulds.

Trial test were conducted with compressed stabilized earth slabs and cubes to know the exact quantity of mixed sample that when compressed with compaction load of $6N/mm^2$ and $8N/mm^2$ in magnus frame gives desired height of earth slabs and cubes.

The steel mould was fill with mixed sample, and was reinforced with 5x150x 150mm BRC mesh and cover of 25mm. The mould and sample was taken to the magnus frame. It was centralized between the ram and support frame, thick plate was placed on the sample to ensure uniform distribution of load. The compaction load was applied gradually and allowed for 10minutes before unloadding, marks were made for easy identification. Unreinforced compressed stabilized earth slabs were also cast in the same manner but in this case, BRC mesh was not used.

The sample was poured in the cube mould and was taken to the magnus frame, same procedure was taken as that of compressed stabilized earth slab. The slabs were kept undisturbed for 24 hours before removal from the mould. The cubes were removed from the mould immediately and kept for 24 hour before both compressed stabilized earth slabs and cubes were cured. Compressing of earth slab in Magnus frame and after compression is shown as Plate G2 and G3 in Appendix G.

3.2.8 Curing Condition

The demoulded compressed stabilized earth slabs and cubes were cured for 28days by sprinkling of water twice a day and cover with leather proof. Curing is important because it enable the chemical action to continue. It is also necessary because a significant loss of water due to evaporation might cause hydration process to stop with a consequent reduction in strength. Compressed stabilized earth slabs after 28days of curing is shown as Plate G4 in Appendix G.

3.2.9 Crushing Of Compressed Stabilized Earth Cubes and Slabs

The crushing of the cubes was done to BS EN 12390 – 3:2009 (Compression Strength of Test Specimens) with the use electric powered concrete compressive testing machine with a capacity of up to 2500KN. The compressed stabilized earth cubes were placed in the machine and the machine was switched on to apply a compressive force which was deflected on its gauge. On failure of the cubes, the machine was switched off and the compressive force that crushed the cube was read off the gauge. This force was then used to calculate the compressive strength of the cubes. Forty eight cubes were crushed in all and their compressive force recorded.

The compressed stabilized earth slabs were crushed using a Magnus frame. The compressed stabilized earth slabs were placed on supports placed within the frame in such a way that the ram from the Magnus frame would apply its force on the centre of the compressed stabilized earth slabs and thick plate was placed on the sample to ensure uniform distribution of loads. The machine was operated by manually pumping hydraulic till the ram of the Magnus frame made contact with the thick plate and exerted pressure on the earth slab till it failed. The load that caused the failure of the earth slab was then read off the Bourdons gauge of the machine and recorded. These procedures were repeated for other earth slabs and at the end ninth six compressed earth slabs were crushed. Twenty four of the compressed stabilized earth slabs were reinforced and twenty four unreinforced with compaction load of $6N/mm^2$. Twenty four of the compressed stabilized earth slabs were reinforced and twenty four (24) unreinforced with compaction load of $8N/mm^2$. The machine is calibrated to measure up to 160 Bars. Crushing of compressed stabilized earth cube is shown as PlateG5 in Appendix G.

3.3 Determination of Maximum Central Deflection and Moment of Slab using Finite Difference Method.

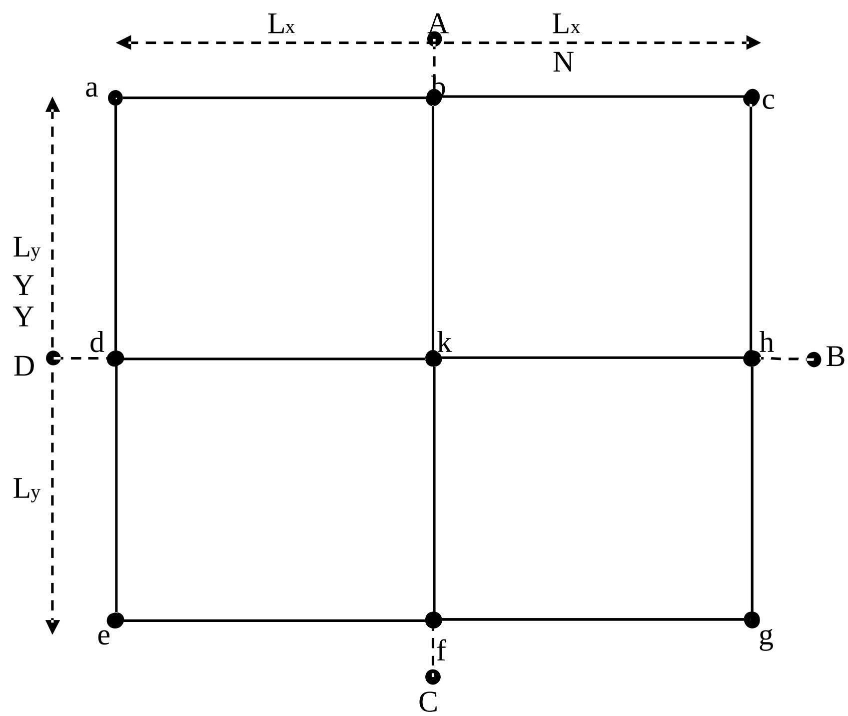


Fig. 3.1: Square plate divided into four panels

The slab was divided into four panels as shown in Fig.3.1. Advantage of symmetry was utilized here. None of the nodes located at the four edges was given a nodal number because the numbers were reserved for nodes that will deflect.

Since the edges are simply support. They do not deflect. Some nodes were created outside the boundaries of the slab. They are called fictitious nodes.

They help in completing our patterns for real nodes inside the slab. Since the slab is square, the aspect ratio P is equal to one, i.e. P=1.

L_x, L_y = dimension of the slab from side of central node on x, y - directions

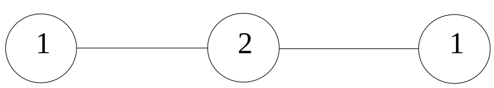
Pattern for ∇^4 (Laplace operation) will be used in this solution.

$$\nabla^4_w = \frac{q}{D} \tag{3.12}$$

Where D = flexural rigidity and q = uniformly distributed load

$$L_y{}^4 \nabla^4_w = \frac{qL_y{}^4}{D} \tag{3.13}$$

Using central finite difference method.

or node 

The displacement, W_k, W_h, W, W_f d, W_b, W_a, W_c, W_g, W_e, W_A, W_B, W_C and W_D are expressed as

$$20W_k - 8W_h - 8W_f - 8W_d - 8W_b + 2W_a + 2W_c + 2W_g + 2W_e + W_A + W_B$$

$$+W_C + W_D = \frac{qL_y{}^4}{D} \tag{3.14}$$

Where W = deflection, and F”(x) is the moment pattern in X direction

$$\text{Therefore } W_A - 2W_b + W_k = 0 \tag{3.15}$$

Hence $W_A = - W_k$

Similarly

$W_k - 2W_h + W_B = 0$

$W_B = -W_k$

Substituting $W_A = -W_k, W_B = -W_k, W_D = -W_k$ and $W_C = -W_k$ into eqn.1

$$20W_k - W_k - W_k - W_k - W_k = \frac{qL_y^4}{D} \quad (3.16)$$

$$16\,W_k = \frac{qL_y^4}{D} \quad (3.17)$$

But $L_y = b/2$

Substituting $L_y = \frac{b}{2}$ into Eqn.3.17

$$W_k = \frac{q\left(\frac{b}{2}\right)^4}{16D}$$

$$W_k = \frac{qb^4}{256D} \quad (3.18)$$

Eqn.3.9 is the equation for central deflection.

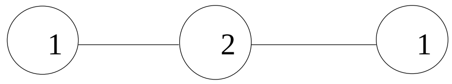
MOMENT AT POINT k

From the theory of plate,

$$M_x = -D\left(\frac{\partial^2 w}{\partial x^2} + \frac{\mu\partial^2}{\partial y^2}\right) \text{ or } -D\,(d^2_x w + \mu d^2_y w) \quad (3.19)$$

$$M = -D\left(\frac{\partial^2 w}{\partial y^2} + \mu\frac{\partial^2}{\partial x^2}\right) \text{ or } -D(d^2_y w + \mu d^2_x w) \quad (3.20)$$

Where D= flexural rigidity of the plate, W= deflection and μ= Poisson ratio

Moment M, x and y- direction were determined thus for x-axis, pattern for moment M_x 

$L_x^2 d_x^2 w = w_d - 2w_k + w_h$

Where $w_d = w_h = 0$

$L_x^2 d_x^2 w = -2w_k$

$$d_x^2 w = -\frac{2w_k}{L_x^2} \tag{3.21}$$

For y axis

$L_y^2 d_y^2 w = w_b - 2w_k$

Where $w_b = w_f = 0$

$L_y^2 d_y^2 w = -2w_k$

$$d_y^2 w = -\frac{2w_k}{L_y^2} \tag{3.22}$$

therefore M = M i.e.Isotropic plate

Hence,

$$M = -D\left(-\frac{2w_k}{L_x^2} + \mu * -\frac{2w_k}{L_y^2}\right)$$

Where $L_x^2 = L_y^2$

$$M = \left(-D * -\frac{2w_k}{L_y^2}\right)(1 + \mu) \tag{3.23}$$

$$M = \frac{2w_k D(1 + \mu)}{L_y^2} \tag{3.24}$$

Substituting eqn.3.17 into eqn.3.24

$$M = \frac{\left[\frac{qb^4(1+\mu)}{128}\right]}{L_y^2} \qquad (3.25)$$

But $n = \frac{b}{2}, L_y^2 = \frac{b^2}{4}$

Substituting $L_y^2 = \frac{b^2}{4}$ into eqn.3.24

$$M = \frac{[4qb^2(1+\mu)]}{128} \qquad (3.26)$$

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. RESULTS

4.1.1 Compaction Test.

Table 4.1 shows the various masses, crushing loads, compressive strength and average compressive strength of compressed stabilized earth cubes after 28days strength, using compaction load of 6N/mm^2 and 8N/mm ^{2} distributed uniformly over the cubes area during casting.

Table 4.1 compressed stabilized earth cubes strength for compaction load of 6N/mm^2 and 8N/mm^2.

Earth cube strength for compaction load of 6 N/mm2and 8N/mm2 respectively.									
Sample tag	Cube label	Mass (Kg)	Crushing load(KN)	Cube strength (N/mm2)	Ave. Cube strength (N/mm2)	Mass (Kg)	Crushing load(KN)	Cube strength (N/mm2)	Ave. Cube strength (N/mm2)
	SCS01A	7.5	70	3.11		7.8	80	3.56	
	SCS01B	7.7	90	4.00		7.6	85	3.78	
1	SCS01C	7.7	80	3.56	3.56	7.9	95	4.22	3.85
	SCS02A	7.7	100	4.44		7.6	96	4.27	
	SCS02B	7.6	90	4.00		7.8	95	4.22	
2	SCS02C	7.4	90	4.00	4.15	7.7	105	4.67	4.39
	SCS03A	7.4	60	2.67		7.9	80	3.56	
	SCS03B	7.8	120	5.33		8.1	110	4.89	
3	SCS03C	7.6	70	3.11	3.70	7.8	88	3.91	4.12
	SCS04A	7.8	150	6.67		8.2	160	7.11	
	SCS04B	7.7	70	3.11		7.9	90	4.00	
4	SCS04C	7.7	80	3.56	4.44	7.9	89	3.96	5.02
	SCS05A	7.5	170	7.56		9	180	8.00	
	SCS05B	7.6	130	5.78		8.4	145	6.44	
5	SCS05C	7.8	140	6.22	6.52	8.2	150	6.67	7.04

	SCS06A	7.5	130	5.78		7.6	140	6.22	
	SCS06B	7.9	140	6.22		8.9	150	6.67	
6	SCS06C	7.6	130	5.78	5.93	8.2	145	6.44	6.44
	SCS07A	8.1	140	6.22		8.5	150	6.67	
	SCS07B	8.3	160	7.11		8.3	160	7.11	
7	SCS07C	7.9	110	4.89	6.07	7.9	130	5.78	6.52
	SCS08A	7.8	140	6.22		8.7	180	8.00	
	SCS08B	7.2	180	8.00		8	150	6.67	
8	SCS08C	7.5	120	5.33	6.52	7.9	140	6.22	6.962

4.1.2 Loading Compressed Stabilized Earth Slab to Failure at 28 Days Strength.

Table 4.2 and 4.3 shows the various crushing loads of reinforced and unreinforced compressed stabilized earth slab after 28days strength and its average loads, using compaction loads of 6N/mm^2 and 8N/mm^2 distributed uniformly over the slab area during casting.

Table 4.2 Crushing loads of compressed stabilized earth slab for compaction load of 6N/mm^2.

Mix No	Reinforced		Unreinforced	
	pressure from scale N/mm$_2$	average Pressure N/mm$_2$	pressure from scale N/mm$_2$	average pressure N/mm$_2$
SCS 01A	1.4		1.5	
SCS 01B	1.6	I.5	1.1	1.27
SCS 01C	1.5		1.2	
SCS 02A	1.6		1.4	
SCS 02B	1.75	1.7	1.5	1.47
SCS 02C	1.75		1.5	
SCS 03A	1.9		1.4	
SCS 03B	1.7	1.82	1.6	1.57
SCS 03C	1.85		1.7	

SCS 04A	1.8	2.03	1.8	1.8
SCS 04B	2.2		1.9	
SCS 04C	2.1		1.7	
SCS 05A	2	2.3	2.1	1.97
SCS 05B	2.54		1.9	
SCS 05C	2.5		1.9	
SCS 06A	1.4	1.57	1.5	1.3
SCS 06B	1.8		1.3	
SCS 06C	1.5		1.1	
SCS 07A	1.7	1.67	1.4	1.4
SCS 07B	1.8		1.3	
SCS 07C	1.5		1.5	
SCS 08A	1.8	1.9	1.5	1.67
SCS 08B	2		1.7	
SCS 08C	1.9		1.8	

Table 4.3 Crushing loads of compressed stabilized earth slab for compaction load of 8N/mm^2.

Mix No	Reinforced		Unreinforced	
	pressure from scale N/mm2	average Pressure N/mm2	pressure from scale N/mm2	Average Pressure N/mm2
SCS 01A	1.6	1.9	1.5	1.4
SCS 01B	2		1.6	
SCS 01C	2.1		1.1	
SCS 02A	1.8	2.1	2	1.8
SCS 02B	2.1		1.6	
SCS 02C	2.4		1.8	
SCS 03A	2	2.27	2	1.93
SCS 03B	2.3		2.1	
SCS 03C	2.5		1.7	
SCS 04A	2.5	2.4	2.1	2.07
SCS 04B	2.4		2.1	
SCS 04C	2.3		2	

SCS 05A	2.8		2.3	
SCS 05B	2.6	2.67	2.1	2.2
SCS 05C	2.6		2.2	
SCS 06A	2.4		1.8	
SCS 06B	1.8	2.07	2.1	1.83
SCS 06C	2		1.6	
SCS 07A	1.9		1.8	
SCS 07B	1.8	1.93	1.6	1.63
SCS 07C	2.1		1.5	
SCS 08A	2.2		1.7	
SCS 08B	2.4	2.23	2.1	1.93
SCS 08C	2.1		2	

Table 4.4, 4.5, 4.6 and 4.7 shows the results of calculated force, uniformly distributed load, central deflection, moment, flexural strength of reinforced and unreinforced compressed stabilized earth slab and cube strength using compaction load of $6N/mm^2$ and $8N/mm^2$ distributed uniformly over the slab area respectively and the corresponding percentage mixture proportions of fines and sand. The calculations and analysis are shown in Appendix F.

Table 4.4 Central deflection, moment, and flexural strength of reinforced compressed stabilized earth slab and cube strength for compaction load of $6N/mm^2$.

%fine soil	% sand	Reinforced					Ave. cube strength (N/mm^2)
		Force (N)	Uniformly Distributed load (N/mm^2)	Central Deflection (mm)	Moment Nmm	Flexural strength (N/mm^2)	
12.6	77.4	14254.98	0.05702	0.00207	579.11	$3.09x10^{4}$	3.556
13.9	76.1	16155.64	0.06462	0.00234	656.32	$3.50x10^{-4}$	4.148
15.2	74.8	17296.04	0.06918	0.00251	702.65	$3.75x10^{-4}$	3.704

16.5	73.5	19296.04	0.07717	0.00280	783.73	$4.18x10^{-4}$	4.444
17.8	72.2	21857.64	0.08743	0.00317	887.97	$4.74x10^{-4}$	6.519
19.1	70.9	14920.21	0.05968	0.00216	606.13	$3.23x10^{-4}$	5.926
20.4	69.6	15870.54	0.06348	0.00230	644.74	$3.44x10^{-4}$	6.074
21.7	68.3	18056.31	0.07223	0.00262	733.54	$3.91x10^{-4}$	6.519

Table 4.5 Central deflection, moment, and flexural strength of unreinforced compressed stabilized earth slab and cube strength for compaction load of $6N/mm^2$.

%fine soil	% sand	Unreinforced					Ave. cube strength (N/mm^2)
		Force (N)	Uniformly Distributed load (N/mm^2)	Central Deflection (mm)	Moment Nmm	Flexural Strength (N/mm^2)	
12.6	77.4	12069.22	0.04828	0.00175	490.31	$2.61x10^{4}$	3.556
13.9	76.1	13969.88	0.05588	0.00202	567.53	$3.03x10^{-4}$	4.148
15.2	74.8	14920.21	0.05968	0.00216	606.13	$3.23x10^{-4}$	3.704
16.5	73.5	17105.98	0.06842	0.00248	694.93	$3.71x10^{-4}$	4.444
17.8	72.2	18721.54	0.07489	0.00271	760.56	$4.06x10^{-4}$	6.519
19.1	70.9	12354.32	0.04942	0.00179	501.89	$2.68x10^{-4}$	5.926
20.4	69.6	13304.65	0.05322	0.00193	540.50	$2.88x10^{-4}$	6.074
21.7	68.3	15870.54	0.06348	0.00230	644.74	$3.44x10^{-4}$	6.519

Table 4.6 Central deflection, moment, and flexural strength of reinforced compressed stabilized earth slab and cube strength for compaction load of $8N/mm^2$.

%fine soil	% sand	Reinforced					Ave. cube strength (N/mm^2)
		Force (N)	Uniformly Distributed load (N/mm^2)	Central Deflection (mm)	Moment Nmm	Flexural Strength N/mm^2	
12.6	77.4	18056.31	0.07223	0.00262	733.54	$3.91x10^{4}$	3.85
13.9	76.1	19956.97	0.07983	0.00289	810.75	$4.32x10^{-4}$	4.39
15.2	74.8	21572.54	0.08629	0.00313	876.38	$4.67x10^{-4}$	4.12
16.5	73.5	22807.97	0.09123	0.00331	926.57	$4.94x10^{-4}$	5.02
17.8	72.2	25373.86	0.10150	0.00368	1030.80	$5.50x10^{-4}$	7.04
19.1	70.9	19671.87	0.07869	0.00285	799.17	$4.26x10^{-4}$	6.44
20.4	69.6	18341.41	0.07337	0.00266	745.12	$3.97x10^{-4}$	6.52
21.7	68.3	21192.40	0.08477	0.00307	860.94	$4.59x10^{-4}$	6.96

Table 4.7 Central deflection, moment, and flexural strength of unreinforced compressed stabilized earth slab and cube strength for compaction load of $8N/mm^2$.

%fine soil	% sand	Unreinforced					Ave. cube Strength (N/mm^2)
		Force (N)	Uniformly Distributed load (N/mm^2)	Central Deflection (mm)	Moment N/mm	Flexural Strength (N/mm^2)	
12.6	77.4	13304.65	0.05322	0.00198	540.50	$2.88x10^{-4}$	3.85
13.9	76.1	17105.98	0.06842	0.00248	694.93	$3.7110x^{-4}$	4.39
15.2	74.8	18341.41	0.07337	0.00266	745.12	$3.97x10^{-4}$	4.12
16.5	73.5	19671.87	0.07869	0.00285	799.17	$4.26x10^{-4}$	5.02
17.8	72.2	20907.30	0.08363	0.00303	849.36	$4.53x10^{-4}$	7.04

19.1	70.9	17391.08	0.06956	0.00252	706.51	$3.77x10^{-4}$	6.44
20.4	69.6	15490.41	0.06196	0.00224	629.30	$3.36x10^{-4}$	6.52
21.7	68.3	18341.41	0.07337	0.00266	745.12	$3.97x10^{-4}$	6.96

4.1.3 Representation of Graphs

Figures 4.1- 4.5 shows the graphical representation and behavior of fines and sand versus flexural strength, cube strength versus flexural strength, fines and sand versus cube strength when compaction load of $6N/mm^2$ were applied on reinforced and unreinforced compressed stabilized earth slab and compressed stabilized earth cube .

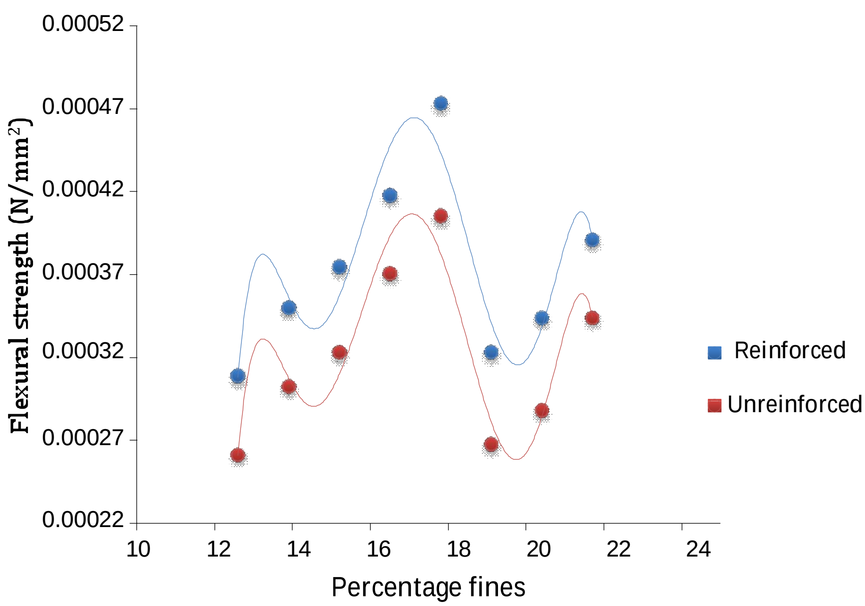


Fig. 4.1: Percentage fines versus flexural strength using compaction load of $6N/mm^2$ (Polynomial).

Equation of graph of percentage fines versus Flexural strength for unreinforced compressed stabilized earth slab

$$Y = -1E-07X^6 + 1E-05X^5 - 0.0006X^4 + 0.013X^3 - 0.1643X^2 + 1.0942X - 3.0123$$

The regression of the equation $R^2 = 0.9207$

Equation of graph of percentage fines versus Flexural strength for reinforced compressed stabilized earth slab

$$Y = -1E - 07X^6 + 1E - 05X^5 - 0.0006X^4 + 0.0136X^3 - 0.1709X^2 + 1.1398X - 3.1409$$

The regression of the equation $R^2 = 0.88$

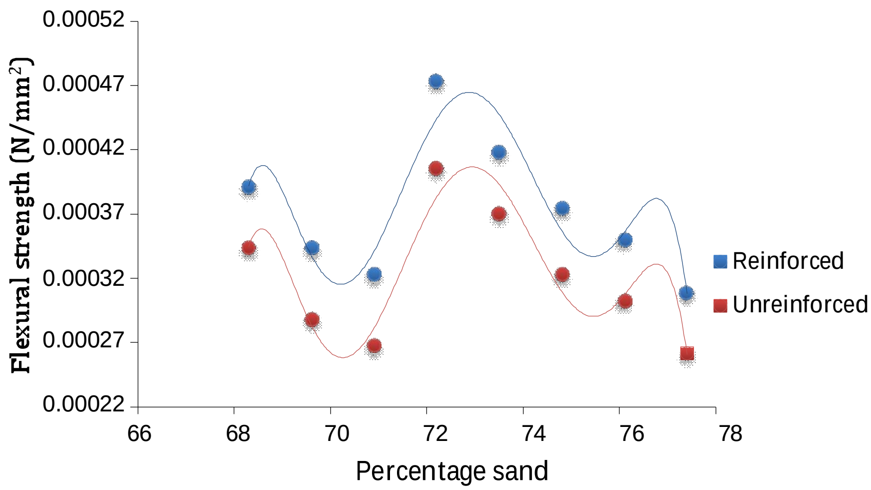


Fig. 4.2: Percentage sand versus flexural strength using compaction load of 6N/mm^2 (Polynomial).

Equation of graph of percentage sand versus Flexural strength for unreinforced compressed stabilized earth slab

$$Y = -1E - 07X^6 + 6E - 05X^5 - 0.0104X^4 + 1.0112X^3 - 55.134X^2 + 1602.5X - 19400$$

The regression of the equation $R^2 = 0.9207$

Equation of graph of percentage sand versus Flexural strength for reinforced compressed stabilized earth slab

$$Y = -1E - 07X^6 + 6E - 05X^5 - 0.0108X^4 + 1.0469X^3 - 57.068X^2 + 1658.4X - 20070$$

The regression of the equation $R^2 = 0.88$

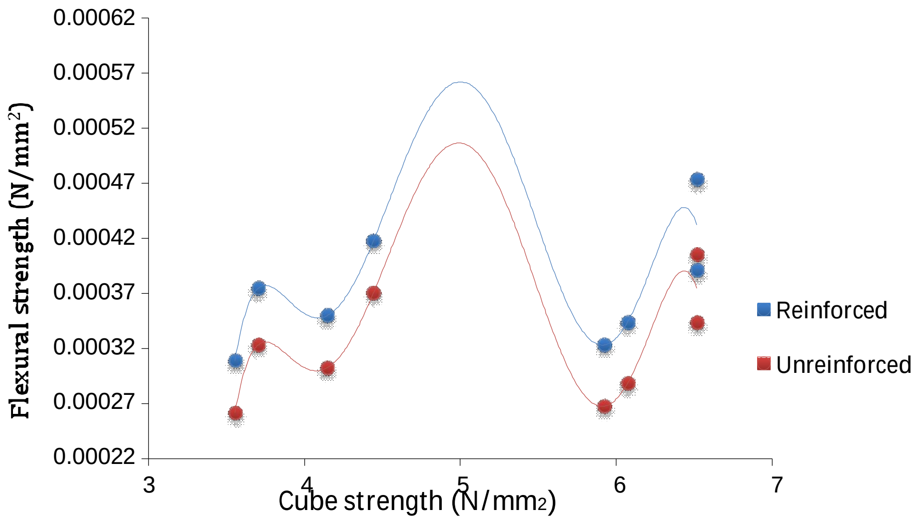


Fig. 4.3: Cube strength versus flexural strength using compaction load of $6N/mm^2$ (polynomial).

Equation of graph of cube strength versus Flexural strength for unreinforced compressed stabilized earth slab

$$Y = -0.0001X^6 + 0.0042X^5 - 0.0521X^4 + 0.3424X^3 - 1.252X^2 + 2.4151X - 1.9207$$

The regression of the equation $R^2 = 0.8937$

Equation of graph of percentage sand versus Flexural strength for reinforced compressed stabilized earth slab

$$Y = -0.0001X^6 + 0.0043X^5 - 0.054X^4 + 0.355X^3 - 1.2994X^2 + 2.5094X - 1.9978$$

The regression of the equation $R^2 = 0.8341$

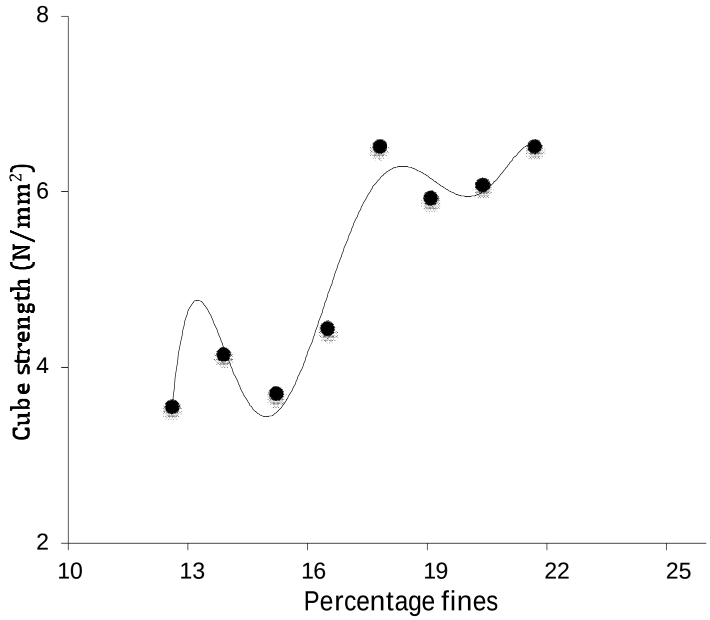


Fig.4.4: Percentage fines versus cube strength using compaction load of $6N/mm^2$ (Polynomial).

Equation on graph of percentage fines versus cube strength of compressed stabilized earth

$$Y = -0.0013X^6 + 0.1398X^5 - 6.1193X^4 + 141.67X^3 - 1829.2X^2 + 12486X - 35195$$

The regression of the equation $R^2 = 0.9658$

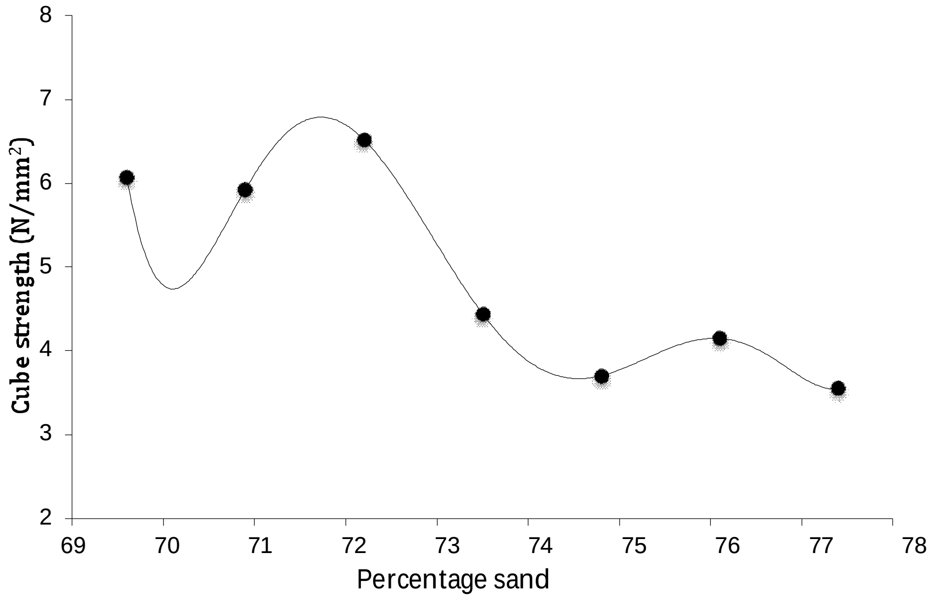


Fig. 4.5: Percentage sand versus cube strength using compaction load of $6N/mm^2$ (Polynomial).

Equation of graph of percentage sand versus cube strength of compressed stabilized earth cube

$$Y = 0.0039X^6 - 1.7429X^5 + 322.12X^4 - 31740X^3 + 2E + 06X^2 - 5E + 07X + 6E + 08$$

The regression of the equation $R^2 = 1$

Figures 4.6- 4.10 shows the graphical representation and behavior of fines and sand versus flexural strength, cube strength versus flexural strength, fines and sand versus cube strength when compaction load of $8N/mm^2$ were applied on reinforced and unreinforced compressed stabilized earth slab and compressed stabilized earth cube .

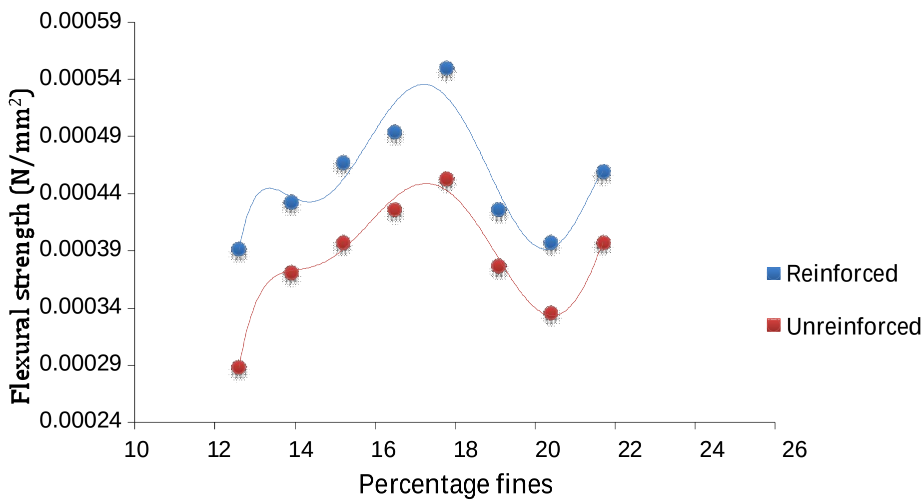


Fig.4.6: Percentage fines versus flexural strength using compaction load of $8N/mm^2$. (Polynomial function)

Equation of graph of percentage fines versus Flexural strength for unreinforced compressed stabilized earth slab

$$Y = -4E-08X^6 + 4E-06X^5 - 0.0002X^4 + 0.0043X^3 - 0.05521X^2$$
$$+0.377X - 1.0629$$

The regression of the equation $R^2 = 0.9838$

Equation of graph of percentage fines versus Flexural strength for reinforced compressed stabilized earth slab

$$Y = -7E-08X^6 + 7E-06X^5 - 0.0003X^4 + 0.0071X^3 - 0.09X^2$$
$$+0.6057X - 1.6825$$

The regression of the equation $R^2 = 0.9061$

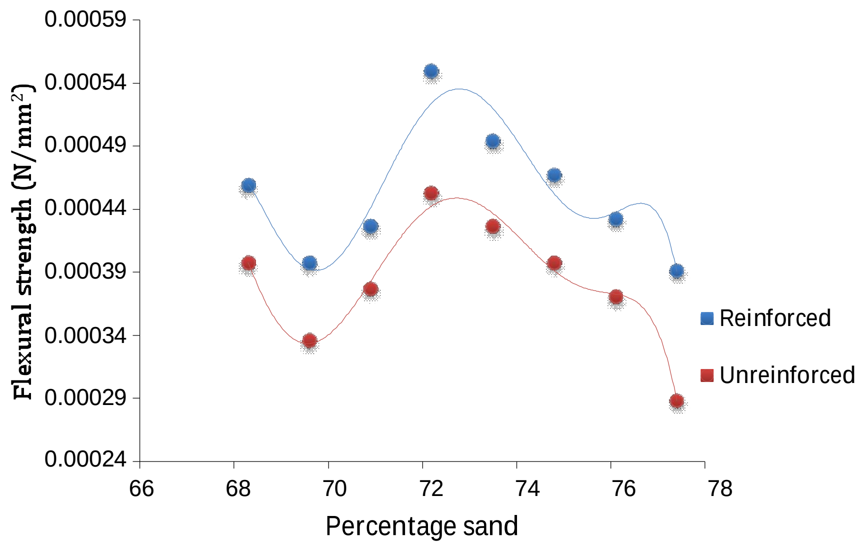


Fig. 4.7: Percentage sand versus flexural strength using compaction load of $8N/mm^2$ (Polynomial).

Equation of graph of percentage sand versus Flexural strength for unreinforced compressed stabilized earth slab

$$Y = -4E-08X^6 + 2E-05X^5 - 0.0031X^4 + 0.2968X^3 - 16.054X^2 + 462.9X - 5557.9$$

The regression of the equation $R^2 = 0.9838$

Equation of graph of percentage sand versus Flexural strength for reinforced compressed stabilized earth slab

$$Y = -7E-08X^6 + 3E-05X^5 - 0.0054X^4 + 0.5219X^3 - 28.352X^2 + 821.08X - 9902.4$$

The regression of the equation $R^2 = 0.9061$

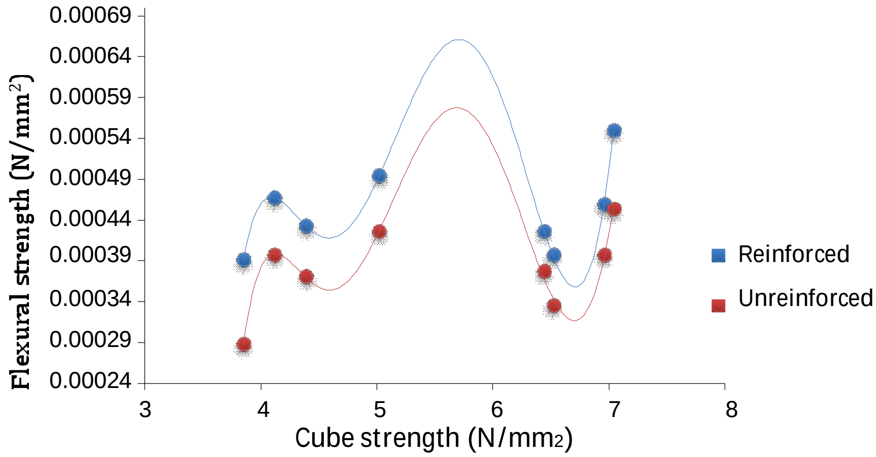


Fig. 4.8: Cube strength versus flexural strength using compaction load of $8N/mm^2$ (Polynomial).

Equation of graph of cube strength versus Flexural strength for unreinforced compressed stabilized earth slab

$$Y = -3E-05X^6 + 0.0012X^5 - 0.0176X^4 + 0.1338X^3 - 0.5637X^2 + 1.2472X - 1.1326$$

The regression of the equation $R^2 = 0.9914$

Equation on graph of cube strength versus Flexural strength,for reinforced compressed stabilized earth slab

$$Y = -2E-05X^6 + 0.0008X^5 - 0.0119X^4 + 0.0941X^3 - 0.4089X^2 + 0.9269X - 0.8577$$

The regression of the equation $R^2 = 0.9998$

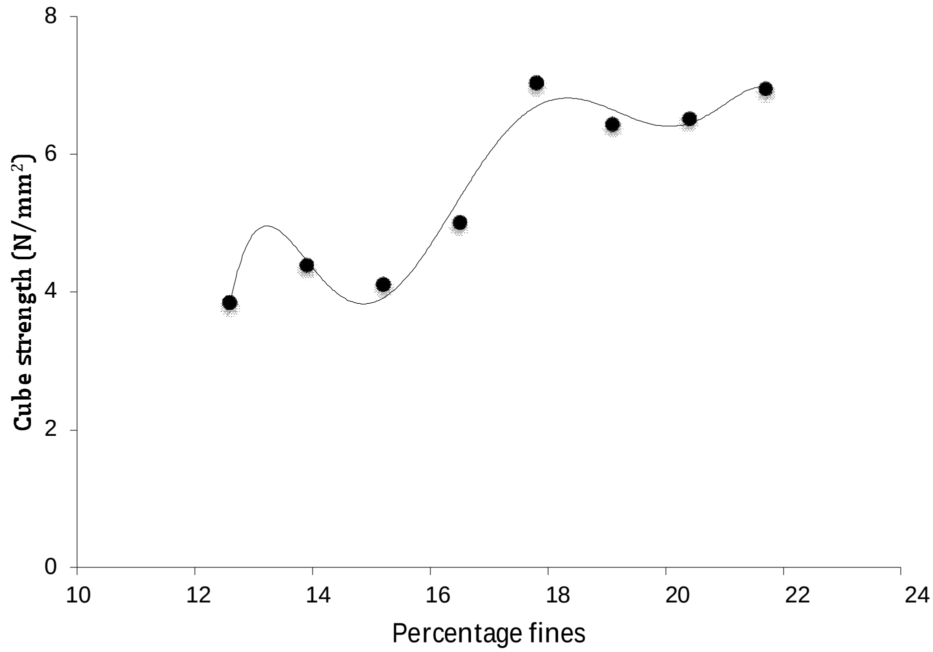


Fig. 4.9: Percentage fines versus cube strength using compaction load of 8N/mm ^{2} (Polynomial).

Equation of graph of percentage fines versus cube strength of compressed stabilized earth.

$$Y = -0.0013X^6 + 0.1369X^5 - 5.9838X^4 + 138.32X^3 - 1783.1X^2 + 12151X - 34187$$

The regression of the equation $R^2 = 0.9734$

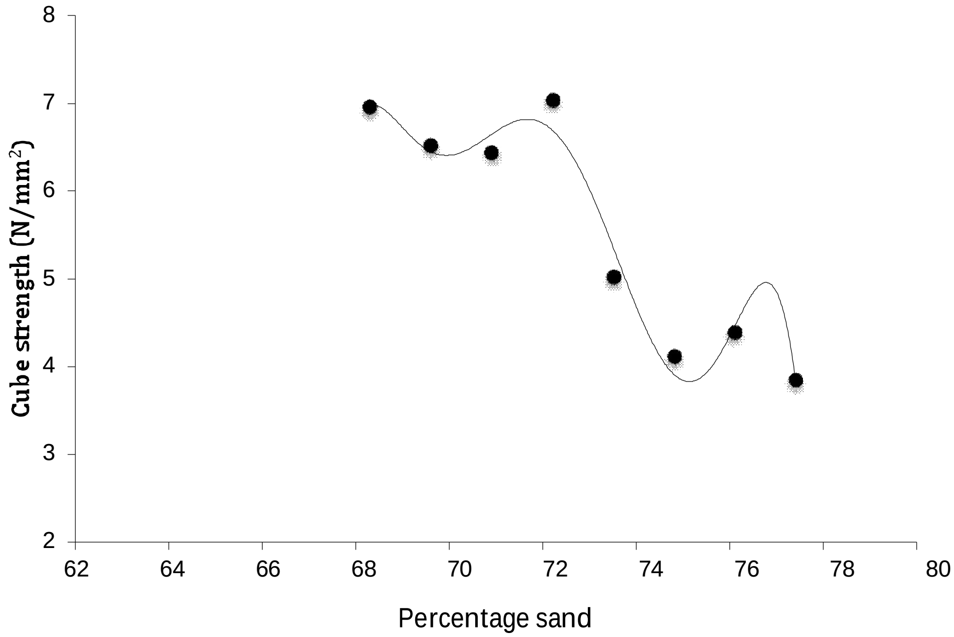


Fig. 4.10: Percentage sand versus cube strength using compaction load of 8N/mm^2 (Polynomial).

Equation of graph of percentage sand versus cube strength of compressed stabilized earth.

$$Y = -0.0013X^6 + 0.5623X^5 - 101.7X^4 + 9805X^3 - 531499X^2 + 2E + 07X - 2E + 08$$

The regression of the equation $R^2 = 0.9734$

4.2 DISCUSSIONS

4.2.1 Discussions of Materials Results

The result of moisture content of river sand and laterite soil in table A1as shown in Appendix A shows that the average moisture content of river sand used was 5.89%, and that of the laterite soil 9.61%. This means that the laterite contains more water than river sand.

The optimum moisture contents of the eight mixture proportions were read off from the graphs of average moisture content versus dry density in figures C1 to C8 as shown in Appendix C. The optimum moisture contents were 0.08, 0.094, 0.102, 0.097, 0.119, 0.097 and 0.128. The results show that moisture content increases as laterite content increases and river sand decreases.

Gradation curves of sieve analysis of river sand and laterite in figures D1- D2 are shown in Appendix D. The coefficient of uniformity and coefficient of curvature of river sand were 3.7 and 0.78, while that of laterite were 2.2 and 0.8. Its grading fell in the range of 0.075mm to 4.75mm and zone 1, 2 and 3. The river sand and laterite were well graded.

4.2.2 Discussions of Graph Results

The results of the fines versus flexural strength, sand versus flexural strength, Fines versus Compressive strength, Sand versus Compressive strength and Compressive strength versus Flexural strength are represented graphically as shown in figures 4.1– 4.10 above and are discussed below.

4.2.2.1 Fines and Sand versus Flexural strength

Graphs in figures 4.1 and 4.2 show that at 17.8% fines and 72.2% sand for compaction load of 6N/mm^2, the flexural strength of reinforced compressed stabilized earth slab was at its maximum, which is 4.74x10^{-4} N/mm^2. At 12.6% fines and 77.4% sand, it had minimum flexural strength of 3.09x10^{-4} N/mm^2. At the same percentage fines and sand, the maximum and minimum flexural strength of unreinforced compressed stabilized earth slab are 4.06x10^{-4} N/mm^2 and 2.61x10^{-4} N/mm^2 respectively.

Figures 4.6 and 4.7 show that at 17.8% fines and 72.2% sand for compaction load of 8 N/mm^2, the flexural strength of reinforced compressed stabilized earth slab was at its maximum, which was 5.50x10^{-4} N/mm^2. At 12.6% fines and 77.4% sand, it had minimum flexural strength of 3.91x10^{-4} N/mm^2. At the same percentage fines and sand, the maximum and minimum flexural strength of unreinforced compressed stabilized earth slab were 4.53x10^{-4} N/mm^2 and

$2.88x10^{-4}$ N/mm^2 respectively. The flexural strength of reinforced compressed stabilized earth slab was higher when compare with unreinforced compressed stabilized earth slab. The higher the compaction load when casting, the higher the flexural strength of compressed stabilized earth slab.

4.2.2.2 Compressive strength versus Flexural strength

Graph in figure 4.3 shows relationship between the compressive strength of compressed stabilized earth cubes and the flexural strength of compressed stabilized earth slab. At maximum compressive strength of $6.519N/mm^2$ the corresponding maximum flexural strength for the reinforced compressed stabilized earth slab was $4.74x10^{-4}N/mm^2$ and $4.06x10^{-4}N/mm^2$ for unreinforced compressed stabilized earth slab. At minimum compressive strength of $3.556N/mm^{2,}$ the corresponding flexural strength for the reinforced compressed stabilized earth slab was $3.09x10^{-4}N/mm^2$ and $2.61x10^{-4}N/mm^2$ for the unreinforced compressed stabilized earth slab using compaction load of $6N/mm^2$. Graph in figure 4.8 followed the same trend. At maximum compressive strength of $7.04N/mm^2$ the corresponding maximum flexural strength for the reinforced compressed stabilized earth slab was $5.50x10^{-4}N/mm^2$ and $4.53x10^{-4}N/mm^2$ for unreinforced compressed stabilized earth slab. At minimum compressive strength of $3.85N/mm^2$, the corresponding flexural strength for the reinforced compressed stabilized earth slab was $3.91x10^{-4}N/mm^2$ and $2.88x10^{-4}N/mm^2$ for the unreinforced compressed stabilized earth slab using compaction load of $8 N/mm^2$.

4.2.2.3 Fines and Sand versus Compressive strength

Graphs in figures 4.4 and 4.9 show relationship between the percentage fines and compressive strength of compressed stabilized earth cubes. At 17.8% fines, compressive strength of compressed stabilized earth cubes were at maximum of $6.519N/mm^2$ and $7.04N/mm^2$. Minimum compressive strength of $3.556N/mm^2$

and 3.85N/mm^2 occurred at 12.6% fines using compaction load of 6N/mm^2 and 8N/mm^2 respectively.

Graphs in figures 4.5 and 4.10 show relationship between the percentage sand and compressive strength of compressed stabilized earth cubes. At 72.2% sand, compressive strength of compressed stabilized earth cubes were at maximum of 6.519N/mm^2 and 7.04N/mm^2. Minimum compressive strength of 3.556N/mm^2 and 3.85N/mm^2 occurred at 77.4% sand using compaction load of 6N/mm^2 and 8N/mm^2 respectively.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The following conclusions were drawn based on the results of the research study:

The optimum moisture content of various mixture proportions of fines and sand in compressed stabilized earth slab were obtained with maximum value of 0.128%.

The central deflection and moment of reinforced compressed stabilized earth slabs were obtained. The maximum central deflection and moment of reinforced compressed stabilized earth slabs were obtained as 3.17×10^{-3}mm and 887.97Nmm respectively for 6N/mm^2 compaction load while that of 8N/mm^2 compaction load were 3.68×10^{-3}mm and 1030.8Nmm respectively.

The central deflection and moment of unreinforced compressed stabilized earth slabs were also obtained, with the maximum value of 2.02×10^{-3}mm and 760.56Nmm for 6N/mm^2, while that of 8N/mm^2 were obtained as 3.03×10^{-3}mm, 849.36Nmm respectively.

The optimum flexural strength of reinforced and unreinforced compressed stabilized earth slabs were obtained as 4.74×10^{-4}N/mm^2 and 4.06×10^{-4}N/mm^2 for compaction loads of 6N/mm^2 and 5.50×10^{-4}N/mm^2 and 4.53×10^{-4}N/mm^2 for compaction loads of 8N/mm^2 respectively.

The optimum mixture proportion is 1:1.6:7.4.

The flexural strength of reinforced and unreinforced compressed stabilized earth slab was very low that it cannot withstand its own weight.

5.2 RECOMMENDATIONS

The following recommendations were made:

i. Further research should be carried out on this using 10mm reinforcement bar in replacement of BRC mesh.

ii. That moulding compaction load of the compressed stabilized earth slab should be increased in other to achieve high flexural and compressive strength.

iii. That the percentage of the stabilizing agent (cement) and fines should be increased and percentage river sand reduced.

5.3 CONTRIBUTIONS TO KNOWLEDGE

i. This provides polynomial functions for determining flexural strength of reinforced compressed stabilized earth slab for different mixture proportion.

ii. It also provides polynomial functions for determining flexural strength of unreinforced compressed stabilized earth slab for different mixture proportion.

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APPENDIX A

Calculations of Moulding Compaction Load and Natural Moisture Content

Moulding Compaction Load calculations

Given compaction load of $6N/mm^2$

Force, F = Applied Load x Effective area of cylinder, EA

Thickness of the cylinder, t = 5mm , Diameter of cylinder, d_1=120mm

Effective diameter of cylinder, $d = d_1 - 2t = 110mm$

$$\text{Moulding compaction load} = \frac{\text{Applied force}}{\text{Area of plate}}$$

Slab plate = 500mm x 500mm, cube plate = 150mm x 150mm

Area of slab plate = $250000mm^2$

Effective area of cylinder, $EA = \frac{\Pi d^2}{4} (mm^2)$

$$EA = \Pi * \frac{110^2}{4} = \frac{3.141 * 110^2}{4} = 9503.32mm^2$$

Force $= 6 * 9503.32 = 57019.92N$

$$\text{Moulding compaction load} = \frac{57019.92}{250000} = 0.22808N/mm^2$$

Same applied compaction load of $8N/mm^2$

Natural moisture content calculations

Moisture content, $Mc = \frac{(W_1 - W_2) * 100}{W_2 - W}$

Where W = Weight of container

W_1 = Weight of container and wet sample.

W_2 = Weight of container and dry sample.

Calculations of moisture content and average moisture content of river sand. For can no. 1, W = 11, W_1 = 67 and W_2 = 64

$$Mc = \frac{(67 - 64) * 100}{64 - 11} = 5.660377$$

For can no. 2, $W = 11$, $W_1 = 63$ and $W_2 = 60$

$$Mc = \frac{(63 - 60) * 100}{60 - 11} = 6.122449$$

Average moisture content of the river sand $= (5.660377 + 6.122449)/2 =$ 5.8914132.

The results of natural moisture content of river sand and laterite soil is shown in table A1.

Table A1. Moisture content of river sand and laterite soil.

NATURAL MOISTURE DETERMINATION								
Soil sample	Can no.	Wt. of empty can (g). W	Wt. of wet sample + can(g) W_1	Wt. of dry sample + can(g) W_2	wet of dry sample(g)	Wt. of water (g)	Moisture Content (%)	Average moisture Content (%)
River sand	1	11	67	64	53	3	5.660377	5.8914132
	2	11	63	60	49	3	6.122449	
Laterite	3	14	58	55	41	3	7.317073	9.6109175
	4	14	61	56	42	5	11.90476	

APPENDIX B

Calculation for the mixture proportions for the determination of compressed stabilized earth slab is shown below.

X = Total sand

X_{LR} = Total of laterite and river sand

SL = Sand in laterite

FL = Fines in laterite

%F = %Fines in view

%S = %Sand in view

RS = River sand

90%EqL = 90% equivalent laterite

90%EqRS = 90% equivalent river sand

$$X = \frac{FL(1 - \%F)}{\%F} \quad \text{Bi}$$

$$\%F = \frac{FL}{FL + X} * 100 \quad \text{Bii}$$

$$RS = X - SL \quad \text{Biii}$$

$$\%S = 100 - \%F \quad \text{Biv}$$

$$X_{LR} = L + R \quad \text{Bv}$$

$$\%L = \frac{L}{X_{LR}} * 100 \quad \text{Bvi}$$

$$\%RS = L - \%L \quad \text{Bvii}$$

$$90\%\ E_qL = \frac{90 * \%L}{100} \quad \text{Bviii}$$

$$90\%\ E_qRS = \frac{90 * \%RS}{100} \quad \text{Bvix}$$

Table B1. shows the various percentages of fines in view and the corresponding sand in laterite for the eight mixture proportions used in the determination of flexural strength of reinforced stabilized compressed earth slab.

Table B1. Percentage of fines and sand in view in laterite soil.

Clay	**Sand**
12.6	87.4
13.9	86.1
15.2	84.8
16.5	83.5
17.8	82.2
19.1	80.9
20.4	79.6
21.7	78.3

The laterite soil is composed of 21.7% of fines (clay and silt) and 78.3% of sand. Calculation for the derivation of the main mixture proportions used is shown as follows

Total sand is calculated using equation Bi, where fines in laterite = 21.7% and % fines in view = 0.126,

$$X = \frac{21.7(1 - 0.126)}{0.126} = 150.5222\%$$

Fines in view is calculated using equation Bii, where fines in laterite = 21.7% and total sand = 150.5222%

$$\%F = \frac{21.7}{21.7 + 150.5222} * 100 = 12.6\%$$

River sand is calculated using equation Biii, where total sand =150.222% and sand in laterite = 78.3%

$$RS = 150.5222 - 78.3 = 72.2222\%$$

Sand in laterite is calculated using equation Biv, where % Fines in view =12.6%

$$\%S = 100 - 12.6 = 87.4\%$$

Total laterite and river sand is calculated using equation Bv, where laterite = 100% and river sand = 72.22222%

$$X_{LR} = 100 + 72.22222 = 172.22222\%$$

%Laterite is calculated using equation Bvi, where laterite = 100% and total laterite and river sand =172.22222%

$$\%L = \frac{100}{172.22222} * 100 = 58.06452\%$$

%River sand is calculated using equation Bvii, where %laterite is 58.06452 and Laterite is 100%

$$\%RS = 100 - 58.06452 = 41.93548\%$$

90% equivalent of laterite is calculated using equation Bviii, where %L =58.06452%.

$$90\%EqL = \frac{90 * 58.06452}{100} = 52.2580652\%$$

90% equivalent of river sand is calculated using equation Bix, where %RS = 41.93548%.

$$90\%EqRS = \frac{90 * 41.93548}{100} = 37.7419348\%$$

Table B2. Shows the percentage composition of fines and sand in the laterite used, fines in view, percentage total sand, river sand, percentage fines and sand for the eight mixture proportions.

Where $12.6\% \leq \text{Fines} \leq 21.7\%$ and $78.3\% \leq \text{Sand} \leq 87.4\%$.

Table B2. Composition of fines and sand in laterite, fines in view, total sand and river sand.

Fines in laterite (%)	Sand in laterite (%)	Fines in view	Total sand (%)	River sand (%)	Fines in view (%)	Sand in view (%)
21.7	78.3	0.126	150.5222	72.22222	12.6	87.4
21.7	78.3	0.139	134.4151	56.11511	13.9	86.1
21.7	78.3	0.152	121.0632	42.76316	15.2	84.8
21.7	78.3	0.165	109.8152	31.51515	16.5	83.5
21.7	78.3	0.178	100.2101	21.91011	17.8	82.2
21.7	78.3	0.191	91.91257	13.61257	19.1	80.9
21.7	78.3	0.204	84.67255	6.372549	20.4	79.6
21.7	78.3	0.217	78.3	0	21.7	78.3

TableB3. Shows 100 % of laterite, % of river sand, % summation of laterite and river sand, % of laterite and river sand, 90% equivalent Laterite, 90% equivalent river sand and 10 percent of cement for the eight various mixture proportions.

Table B3. Mixture proportions of laterite, river sand and cement.

Laterite	River sand	Total of laterite & river sand	%Laterite	%River sand	90% equivalent Laterite	90% equivalent river sand	Cement
100	72.22222	172.2222	58.06452	41.93548	52.2580652	37.7419348	10
100	56.11511	156.1151	64.0553	35.9447	57.6497688	32.3502312	10
100	42.76316	142.7632	70.04608	29.95392	63.0414737	26.9585263	10
100	31.51515	131.5152	76.03687	23.96313	68.4331805	21.5668195	10
100	21.91011	121.9101	82.02765	17.97235	73.8248862	16.1751138	10
100	13.61257	113.6126	88.01843	11.98157	79.2165867	10.7834133	10
100	6.372549	106.3725	94.00922	5.990783	84.6082949	5.39170505	10
100	0	100	100	0	90	0	10

APPENDIX C

Calculation of moisture content, average moisture content, density and dry density for compaction test.

For 12.6% of fines and 6% water of the mass of the sample used, the calculation is shown below.

Wt. of cylinder + compacted sample, M_1 (g) = 10750g

Mass of cylinder, M = 4110g

Volume of cylinder, V = 3316.85cm^3

Moisture content = Mc

Average moisture content = G

Density = ϱ

Dry density = dϱ

$$Mc = \frac{W_1 - W_2}{W_2 - W} * 100\% \qquad \text{Ci}$$

$$\varrho = \frac{M_1 - M(g)}{V(cm^3)} \qquad \text{Cii}$$

$$d\varrho = \frac{\varrho\left(\frac{g}{cm^3}\right)}{1 + G} \qquad \text{Ciii}$$

Moisture content is calculated using equation Ci.

Can no 1A, W = 13g, W_1 = 61g, W_2 = 59g

Can no 1B, W = 14g, W_1 = 57g, W^2 = 55g

Can no 1C, W = 11g, W_1 = 55g, W_2 = 53g

For can no1A, W_1 – W = 61 – 13 = 48g

W_2 – W = 59 – 13 = 46g

W_1 – W_2 = 61 – 59 = 2g

$$Mc = \frac{2}{46} = 0.04$$

For can no1B, W_1 – W = 57 – 14 = 43g

W_2 – W = 55 – 14 = 41g

$W_1 – W_2 = 57 – 55 = 2g$

$$Mc = \frac{2}{41} = 0.05$$

For can no1C, $W_1 – W = 55 – 11 = 44g$

$W_2 – W = 53 – 11 = 42g$

$W_1 – W_2 = 55 – 53 = 2g$

$$Mc = \frac{2}{42} = 0.05$$

Average moisture content G is calculated as shown

$$G = \frac{0.04 + 0.05 + 0.05}{3} = 0.05$$

Density is calculated using equation Cii

$$\varrho = \frac{10750 - 4110}{3316.85} = 2.00 g/cm^3$$

$$d\varrho = \frac{2.00}{1 + 0.05} = 1.19 g/cm^3$$

Table C1. Shows the result of compaction test data for the eight mixture proportions used in the casting of compressed stabilized earth slabs and cubes.

Table C1. Moisture content, average moisture content, density and dry density of compaction test.

Sample group	**%Fine soil in mix**	**Added water (% of total sample mass)**	**Can no**	**Mass of empty can, W (g)**	**Mass of can + wet sample, W1 (g)**	**Mass of can + dry sample, W2 (g)**	**Mass of wet sample, W1-W (g)**	**Mass of dry sample, W2-W (g)**	**Mass of Moisture, W1-W2 (g)**	**Moisture Content (g)**	**Average Moisture content (g)**	**Wt of cylinder + compacted sample, M1 (g)**	**Density (M1-M)/V g/cm3**	**Dry density, ϱd g/cm3**
1	12.60%	6% (420g)	1A	13	61	59	48	46	2	0.04	0.05	10750	2.00	1.91
			1B	14	57	55	43	41	2	0.05				
			1C	11	55	53	44	42	2	0.05				
		9% (630g)	1D	11	54	50	43	39	4	0.10	0.08	11070	2.10	1.94
			1E	11	46	44	35	33	2	0.06				
			1F	13	56	53	43	40	3	0.08				
		12% (840g)	1G	12	60	55	48	43	5	0.12	0.13	10990	2.07	1.84
			1H	11	57	52	46	41	5	0.12				
			1J	12	52	47	40	35	5	0.14				
		15% (1060g)	1K	14	63	57	49	43	6	0.14	0.14	10850	2.03	1.79
			1L	11	68	61	57	50	7	0.14				

			1M	11	63	57	52	46	6	0.13				
		18% (1260g)	1N	11	62	54	51	43	8	0.19	0.17	10650	1.97	1.68
			1P	11	72	63	61	52	9	0.17				
			1Q	11	55	49	44	38	6	0.16				
2	13.90%	6% (420g)	2A	16	48	46	32	30	2	0.07	0.07	10880	2.04	1.91
			2B	14	44	42	30	28	2	0.07				
			2C	21	65	62	44	41	3	0.07				
		9% (630g)	2D	13	52	49	39	36	3	0.08	0.08	11120	2.11	1.95
			2E	12	49	46	37	34	3	0.09				
			2F	11	52	49	41	38	3	0.08				
		12% (840)	2G	14	57	52	43	38	5	0.13	0.12	10990	2.07	1.84
			2H	12	49	45	37	33	4	0.12				
			2J	10	47	43	37	33	4	0.12				
		15% (1060g)	2K	13	49	45	36	32	4	0.13	0.15	10800	2.02	1.76
			2L	12	54	48	42	36	6	0.17				
			2M	12	51	46	39	34	5	0.15				
		18% (1260g)	2N	10	63	55	53	45	8	0.18	0.18	10440	1.91	1.62
			2P	13	68	60	55	47	8	0.17				
			2Q	22	104	91	82	69	13	0.19				
3	15.20%	6% (420g)	3A	10	40	38	30	28	2	0.07	0.07	10850	2.03	1.90
			3B	13	43	41	30	28	2	0.07				

			3C	13	45	43	32	30	2	0.07				
		9% (630g)	3D	13	45	42	32	29	3	0.10	0.09	11900	2.35	2.15
			3E	12	43	41	31	29	2	0.07				
			3F	12	42	39	30	27	3	0.11				
		12% (840)	3G	13	47	44	34	31	3	0.10	0.11	11050	2.09	1.88
			3H	13	46	42	33	29	4	0.14				
			3J	14	45	42	31	28	3	0.11				
		15% (1060g)	3K	17	49	45	32	28	4	0.14	0.14	10750	2.00	1.75
			3L	13	54	49	41	36	5	0.14				
			3M	13	44	40	31	27	4	0.15				
		18% (1260g)	3N	11	53	47	42	36	6	0.17	0.16	10650	1.97	1.70
			3P	14	57	51	43	37	6	0.16				
			3Q	10	58	52	48	42	6	0.14				
4	16.50%	6% (420g)	4A	14	42	40	28	26	2	0.08	0.11	10700	1.99	1.80
			4B	13	36	33	23	20	3	0.15				
			4C	13	49	46	36	33	3	0.09				
		9% (630g)	4D	14	46	43	32	29	3	0.10	0.10	11200	2.14	1.94
			4E	11	41	39	30	28	2	0.07				
			4F	14	48	44	34	30	4	0.13				
		12% (840)	4G	11	59	54	48	43	5	0.12	0.13	11000	2.08	1.85
			4H	11	50	46	39	35	4	0.11				

			4J	12	59	53	47	41	6	0.15				
		15% (1060g)	4K	11	61	54	50	43	7	0.16	0.16	10600	1.96	1.69
			4L	11	54	48	43	37	6	0.16				
			4M	11	66	59	55	48	7	0.15				
		18% (1260g)	4N	11	85	73	74	62	12	0.19	0.18	10400	1.90	1.60
			4P	13	91	79	78	66	12	0.18				
			4Q	13	107	93	94	80	14	0.18				
5	17.80%	6% (420g)	5A	13	45	43	32	30	2	0.07	0.09	10810	2.02	1.85
			5B	12	43	40	31	28	3	0.11				
			5C	14	49	46	35	32	3	0.09				
		9% (630g)	5D	11	37	35	26	24	2	0.08	0.10	11060	2.10	1.91
			5E	13	45	42	32	29	3	0.10				
			5F	12	44	41	32	29	3	0.10				
		12% (840)	5G	12	45	41	33	29	4	0.14	0.14	11090	2.10	1.85
			5H	15	47	43	32	28	4	0.14				
			5J	14	55	50	41	36	5	0.14				
		15% (1060g)	5K	11	46	42	35	31	4	0.13	0.15	10750	2.00	1.74
			5L	13	52	46	39	33	6	0.18				
			5M	11	52	47	41	36	5	0.14				
		18% (1260g)	5N	13	51	44	38	31	7	0.23	0.21	10430	1.91	1.57
			5P	16	52	46	36	30	6	0.20				

			5Q	16	57	50	41	34	7	0.21				
6	19.10%	6% (420g)	6A	11	36	34	25	23	2	0.09	0.20	10500	1.93	1.61
			6B	12	48	37	36	25	11	0.44				
			6C	13	46	44	33	31	2	0.06				
		9% (630g)	6D	11	44	41	33	30	3	0.10	0.09	10720	1.99	1.83
			6E	14	44	42	30	28	2	0.07				
			6F	14	47	44	33	30	3	0.10				
		12% (840)	6G	12	40	37	28	25	3	0.12	0.12	11130	2.12	1.89
			6H	24	65	61	41	37	4	0.11				
			6J	14	49	45	35	31	4	0.13				
		15% (1060g)	6K	11	54	49	43	38	5	0.13	0.14	10770	2.01	1.76
			6L	11	52	47	41	36	5	0.14				
			6M	10	48	43	38	33	5	0.15				
		18% (1260g)	6N	12	58	51	46	39	7	0.18	0.18	10700	1.99	1.69
			6P	13	69	61	56	48	8	0.17				
			6Q	15	74	65	59	50	9	0.18				
7	20.40%	6% (420g)	7A	11	39	37	28	26	2	0.08	0.07	10750	2.00	1.86
			7B	13	47	45	34	32	2	0.06				
			7C	13	52	49	39	36	3	0.08				
		9% (630g)	7D	14	51	48	37	34	3	0.09	0.10	11360	2.19	1.99
			7E	13	52	49	39	36	3	0.08				

			7F	13	51	47	38	34	4	0.12				
		12% (840)	7G	10	50	45	40	35	5	0.14				
			7H	12	55	50	43	38	5	0.13	0.13	11130	2.12	1.88
			7J	14	55	51	41	37	4	0.11				
		15% (1060g)	7K	11	61	54	50	43	7	0.16				
			7L	12	53	48	41	36	5	0.14	0.15	10850	2.03	1.76
			7M	13	64	57	51	44	7	0.16				
		18% (1260g)	7N	13	66	58	53	45	8	0.18				
			7P	15	74	65	59	50	9	0.18	0.18	10690	1.98	1.68
			7Q	11	58	51	47	40	7	0.18				
8	21.70%	6% (420g)	8A	8	40	38	32	30	2	0.07				
			8B	9	40	38	31	29	2	0.07	0.08	10710	1.99	1.85
			8C	11	46	43	35	32	3	0.09				
		9% (630g)	8D	14	48	44	34	30	4	0.13				
			8E	12	51	47	39	35	4	0.11	0.13	11340	2.18	1.93
			8F	14	56	51	42	37	5	0.14				
		12% (840)	8G	15	58	53	43	38	5	0.13				
			8H	13	53	48	40	35	5	0.14	0.14	11030	2.09	1.82
			8J	10	47	42	37	32	5	0.16				
		15% (1060g)	8K	9	54	48	45	39	6	0.15	0.17	10790	2.01	1.73
			8L	11	58	51	47	40	7	0.18				

			8M	11	53	47	42	36	6	0.17				
		18% (1260g)	8N	11	69	59	58	48	10	0.21	0.21	10650	1.97	1.63
			8P	24	91	79	67	55	12	0.22				
			8Q	23	101	88	78	65	13	0.20				

Figures C1 to C8 show the graph of average moisture content versus dry density for the eight mixture proportions.

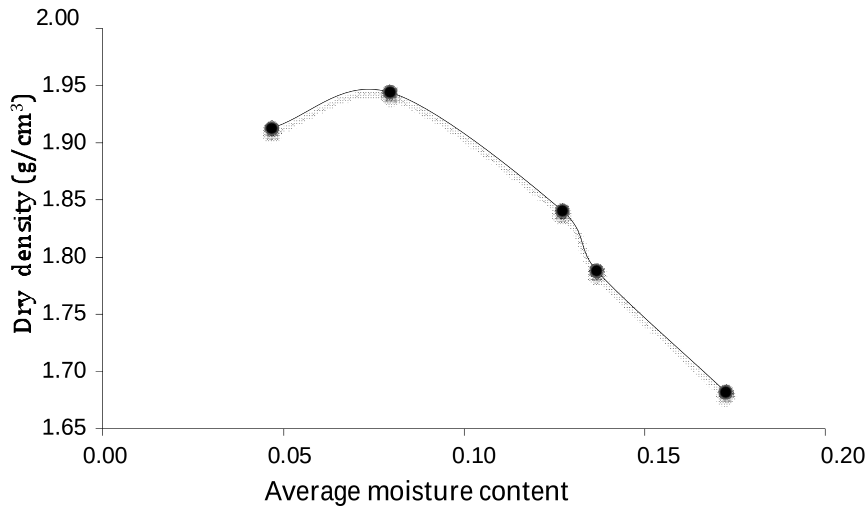


Fig.C1: Average moisture content versus dry density for 12.6% fines.

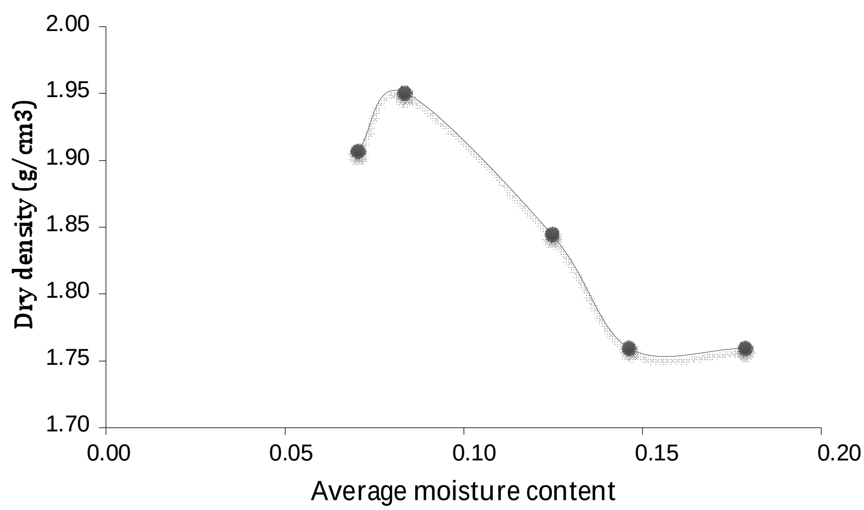


Fig.C2: Average moisture content versus dry density for 13.9% fines.

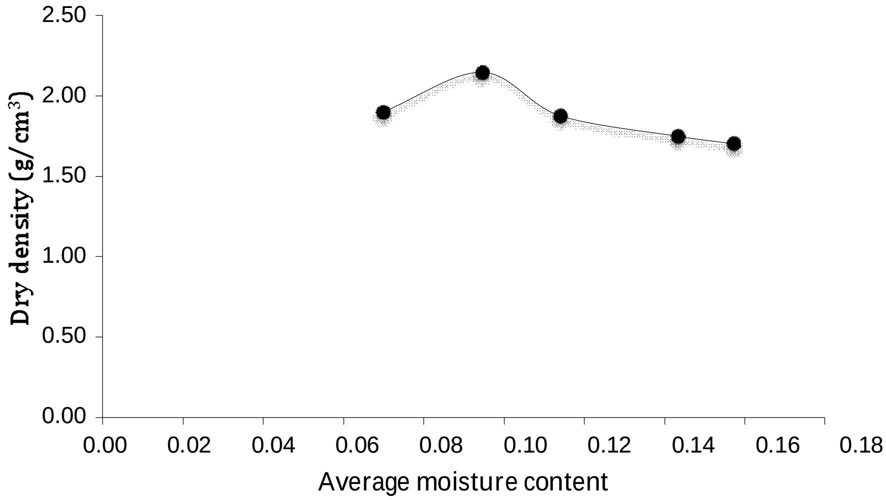


Fig.C3: Average moisture content versus dry density for 15.2% fines.

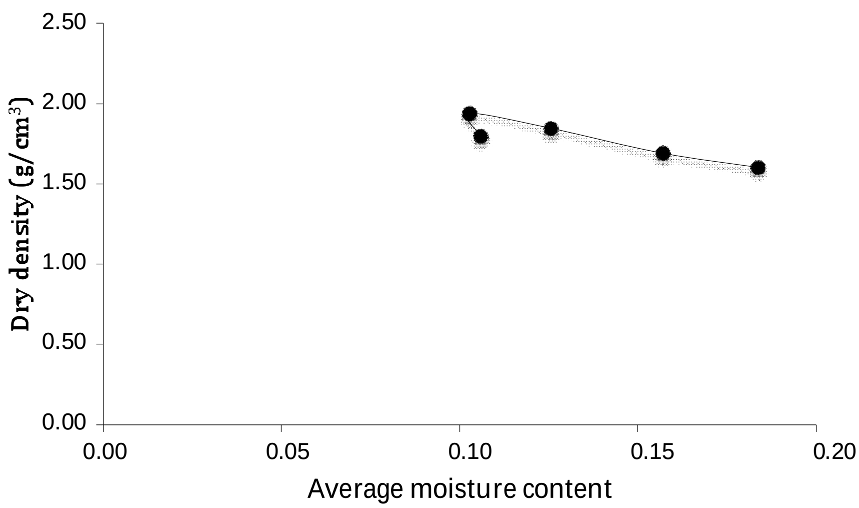


Fig.C4: Average moisture content versus dry density for 16.5% fines.

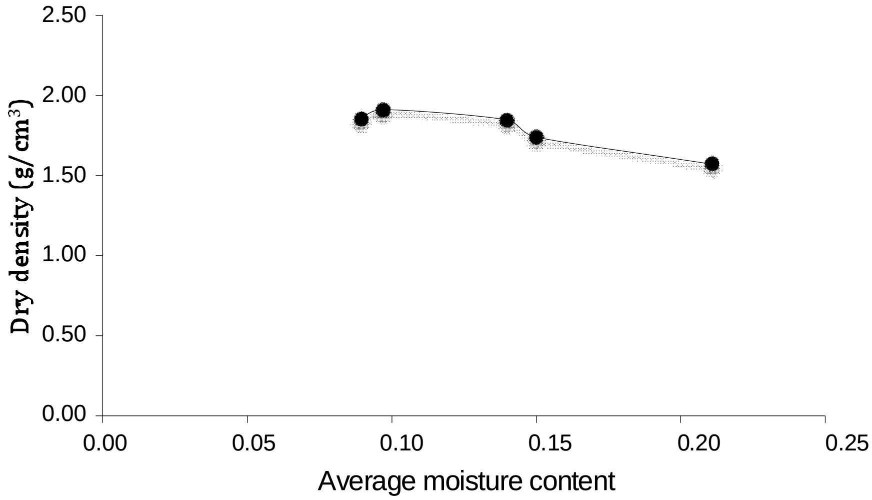


Fig.C5: Average moisture content versus dry density for 17.8% fines.

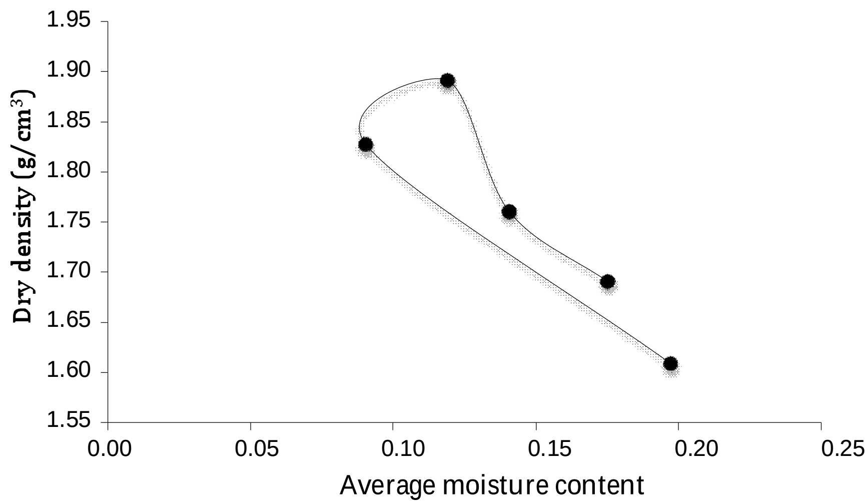


Fig.C6: Average moisture content versus dry density for 19.1% fines.

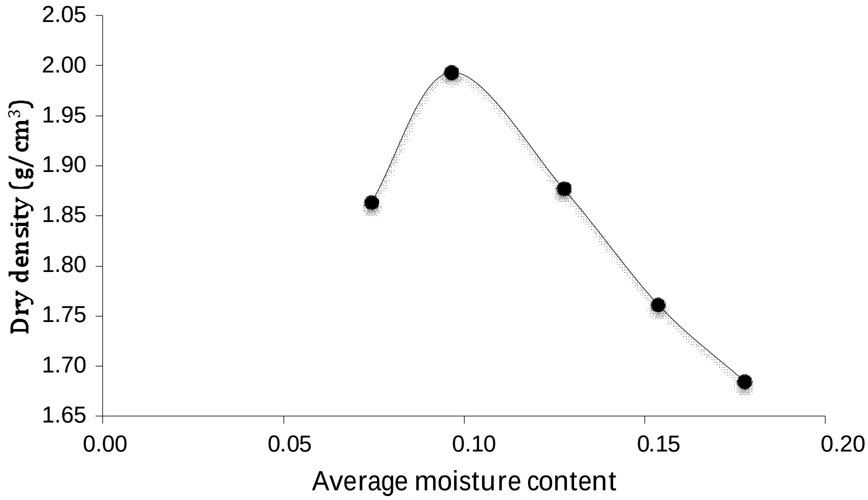


Fig.C7: Average moisture content versus dry density for 20.4% fines.

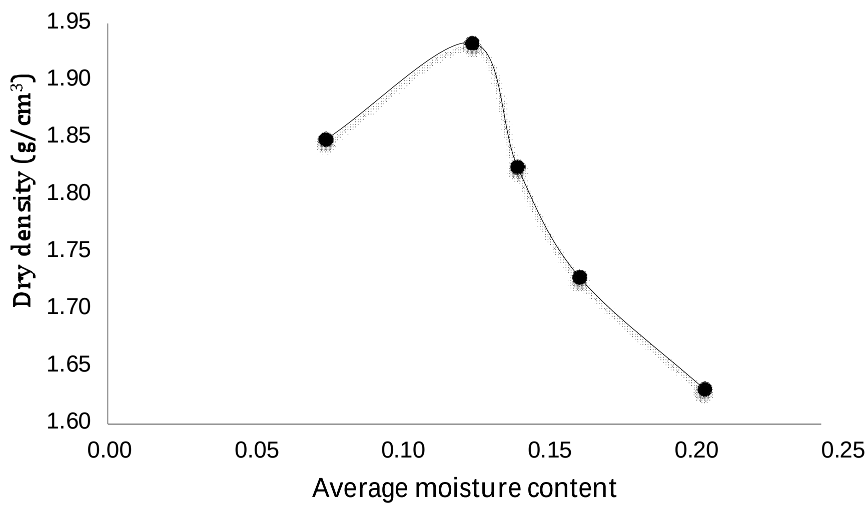


Fig.C8: Average moisture content versus dry density for 21.7% fines.

APPENDIX D

Coefficient of curvature Cc

Coefficient of uniformity Cu

$$Cc = \frac{(D_{30})^2}{D_{60} * D_{10}} \qquad Di$$

$$Cu = \frac{D_{60}}{D_{10}} \qquad Dii$$

Tables D1 andD2 shows the sieve analysis of the river sand and laterite used for this research.

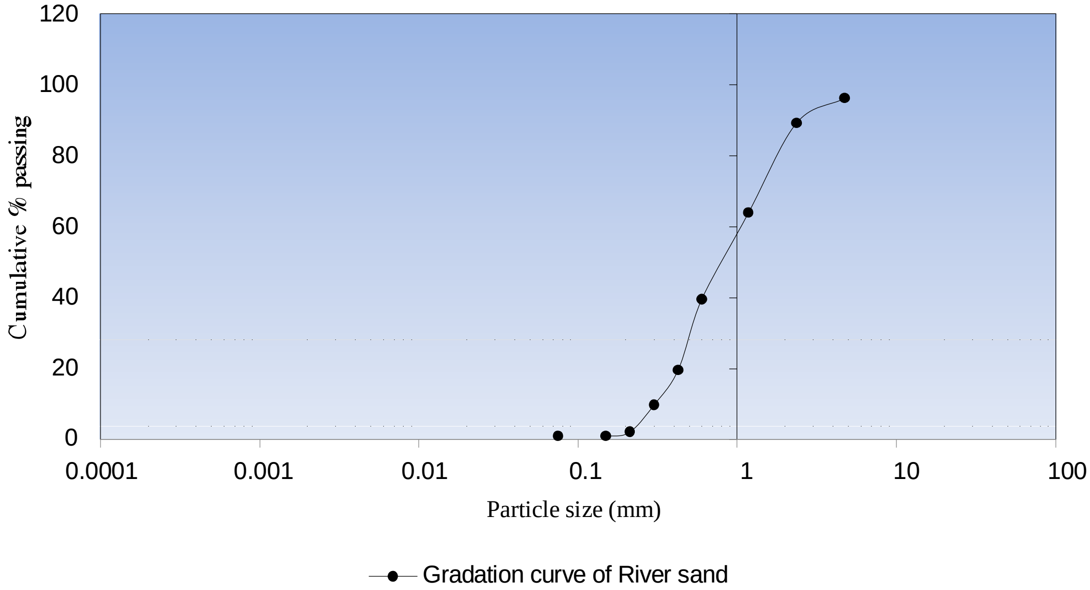
TableD1 shows the result of the sieve analysis of river sand.

SAND (500g)							
Sieve No	**Sieve opening diameter (mm)**	**Mass of empty sieve (g)**	**Mass of sieve + retained soil (g)**	**Mass of retained soil (g)**	**% Retained**	**Cumm. % of soil retained (g)**	**% Passing**
4.75mm	4.75	362	381	19	3.8	3.8	96.2
2.36mm	2.36	340	375	35	7	10.8	89.2
1.18mm	1.18	334	460	126	25.2	36	64
600µm	0.6	318	440	122	24.4	60.4	39.6
425µm	0.425	326	426	100	20	80.4	19.6
300µm	0.3	303	352	49	9.8	90.2	9.8
212µm	0.212	302	340	38	7.6	97.8	2.2
150µm	0.15	332	338	6	1.2	99	1
75µm	0.075	284	284	0	0	99	1
Pan	0	265	270	5	1	100	0
			TOTAL	500			

Table D2 shows the result of the sieve analysis of laterite soil.

LATERITE (500g)							
Sieve No	**Sieve opening diameter (mm)**	**Mass of empty sieve (g)**	**Mass of sieve + retained soil (g)**	**Mass of retained soil (g)**	**% Retained**	**Cumm. % of soil retained (g)**	**% Passing**
4.75mm	4.75	362	362	0	0	0	100
2.36mm	2.36	340	343	3	0.6	0.6	99.4
1.18mm	1.18	334	351	17	3.4	4	96
600µm	0.6	318	410	92	18.4	22.4	77.6
425µm	0.425	326	447	121	24.2	46.6	53.4
300µm	0.3	303	404	101	20.2	66.8	33.2
212µm	0.212	302	442	140	28	94.8	5.2
150µm	0.15	332	342	10	2	96.8	3.2
75µm	0.075	284	285	1	0.2	97	3
Pan	0	265	280	15	3	100	0
			TOTAL	500			

Figures D1- D2 shows the gradation curve of river sand and laterite soil.



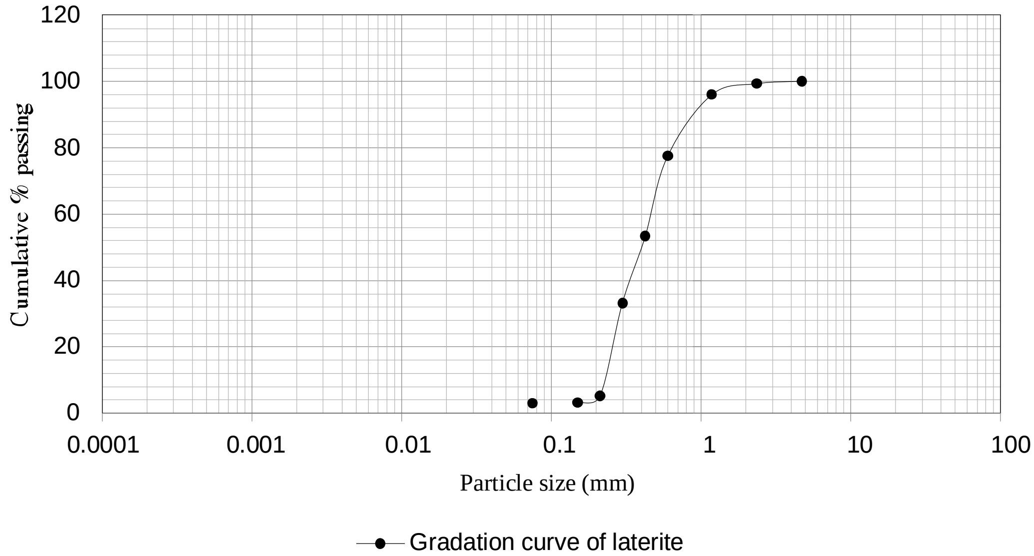
Clay	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	C
	SILT			SAND			GRAVEL			

Fig. D1: Gradation curve of river sand.

From the gradation curve, D_{60} = 1.1, D_{30} = 0.5 and D_{10} = 0.3 and coefficient of curvature and uniformity is calculated using Di and Dii.

$$Cu = \frac{1.1}{0.3} = 3.71$$

$$Cc = \frac{0.5^2}{1.1 * 0.3} = 0.76$$



Clay	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	C
	SILT			SAND			GRAVEL			

Fig. D2: Gradation curve of laterite.

From the gradation curve, $D_{60} = 0.48$, $D_{30} = 0.29$ and $D_{10} = 0.22$

$$Cu = \frac{0.48}{0.22} = 2.21$$

$$Cc = \frac{0.29^2}{0.48 * 0.22} = 0.8$$

APPENDIX E

Material Batching Calculations

First mix

For (laterite: foreign sand: cement) %

For Mix Ratio 52.25807: 37.74193:10

$$\text{Mass of laterite} = \frac{52.25807 * 150\text{kg}}{100} = 78.39\text{Kg}$$

$$\text{Mass of river sand} = \frac{37.74193 * 150\text{kg}}{100} = 56.61\text{kg}$$

$$\text{Mass of cement} = \frac{10 * 150\text{kg}}{100} = 15\text{kg}$$

Optimum moisture content = 0.08

$$\text{Mass of water} = 0.075 * 150\text{kg} = 11.25\text{kg}$$

For second mix

For Mix Ratio 57.64977: 32.35023:10

$$\text{Mass of laterite} = \frac{57.64977 * 150\text{kg}}{100} = 86.47\text{kg}$$

$$\text{Mass of river sand} = \frac{32.35023 * 150\text{kg}}{100} = 48.53\text{kg}$$

$$\text{Mass of cement} = \frac{10 * 150\text{kg}}{100} = 15\text{kg}$$

Optimum moisture content = 0.08

$$\text{Mass of water} = 0.08 * 150\text{kg} = 12\text{kg}$$

For third mix

For Mix Ratio 63.04147: 26.95853:10

$$\text{Mass of laterite} = \frac{63.04147 * 150\text{kg}}{100} = 94.56\text{kg}$$

$$\text{Mass of river sand} = \frac{26.95853 * 150\text{kg}}{100} = 40.44\text{kg}$$

$$\text{Mass of cement} = \frac{10 * 150\text{kg}}{100} = 15\text{kg}$$

Optimum moisture content = 0.094

Mass of water = $0.094 * 150kg = 14.1kg$

For fourth mix

For Mix Ratio 68.43318: 21.56682:10

Mass of laterite = $\frac{68.43318 * 150kg}{100} = 102.65kg$

Mass of river sand = $\frac{21.56682 * 150kg}{100} = 32.35kg$

Mass of cement = $\frac{10 * 150kg}{100} = 15kg$

Optimum moisture content = 0.102

Mass of water = $0.102 * 150kg = 15.3kg$

For fifth mix

For Mix Ratio 73.82489: 16.17511:10

Mass of laterite = $\frac{73.82489 * 150kg}{100} = 110.74kg$

Mass of river sand = $\frac{16.17511 * 150kg}{100} = 24.26kg$

Mass of cement = $(10 * 150kg)/100 = 15kg$

Optimum moisture content = 0.097

Mass of water = $0.097 * 150kg = 14.55kg$

For sixth mix

For Mix Ratio 79.21659: 10.78341:10

Mass of laterite = $\frac{79.21659 * 150kg}{100} = 118.82kg$

Mass of river sand = $\frac{10.78341 * 150kg}{100} = 16.18kg$

Mass of cement = $(10 * 150kg)/100 = 15kg$

Optimum moisture content = 0.119

Mass of water = $0.119 * 150kg = 17.85kg$

For seventh mix

For Mix Ratio 84.60829: 5.391705:10

Mass of laterite $= \frac{84.60829 * 150kg}{100} = 126.91kg$

Mass of foreign sand $= \frac{5.391705 * 150kg}{100} = 8.09kg$

Mass of cement $= \frac{10 * 150kg}{100} = 15kg$

Optimum moisture content =0.097

Mass of water $= 0.097 * 150kg = 14.55kg$

For eighth mix

For Mix Ratio 90:0:10

Mass of laterite $= \frac{90 * 150kg}{100} = 135kg$

Mass of foreign sand $= \frac{0 * 150kg}{100} = 0kg$

Mass of cement $= \frac{10 * 150kg}{100} = 15kg$

Optimum moisture content = 0.128

Mass of water $= 0.128 * 150kg = 19.2kg$

APPENDIX F

Calculations and Analysis of Earth Slab and Cube using the average result obtained in tables 4.1, 4.2 and 4.3.

Geometrical properties:

Dimension of plate = 500mm x 500mm

Effective diameter of cylinder, d = 110mm

10bar = 1N/mm^2

µ = Poisson's ratio of plate = 0.3

E = Young's Modulus of Elasticity of Concrete = 23000N/mm^2

v = Poisson's ratio of Concrete = 0.2

t = Thickness of the slab = 150mm

b = Breath of slab = 500mm

EA = Effective area of cylinder

Applied force = F

Modulus of section = Z

Flexural strength = φ

Area of slab =ArS

Uniformly distributed load = q

Central deflection = W_k

Moment = M

Flexural rigidity =D

$$EA = \frac{\Pi d^2}{4} \ (mm^2) \qquad \text{Fi}$$

$$F = \text{Applied load} * EA \ (N) \qquad \text{Fii}$$

$$Z = \frac{bh^2}{6} (mm^3) \qquad \text{Fiii}$$

$$\varphi = \frac{M}{Z} (N/mm^2) \qquad \text{Fiv}$$

$$q = \frac{F}{ArS} \ (N/mm^2) \qquad Fv$$

$$Wk = \frac{qb^4}{256D} \ (mm) \qquad Fvi$$

$$M = \frac{[4qb^2(1 + \mu)]}{128} \ (Nmm) \qquad Fvii$$

$$D = \frac{Et^3}{12(1 - v^2)} \qquad Fviii$$

Area of circular face of Ram is calculated using equation Fi.

$$EA = \Pi * \frac{110^2}{4} = \frac{3.141 * 110^2}{4} = 9503.32mm^2$$

Applied force is calculated using equation Fii.

Where applied Load =1.5N/mm^2

$$F = 1.5 * 9503.32 = 14254.98N$$

Uniformly distributed load is calculated using equation Fv.

$$ArS = 500 * 500 = 250{,}000mm^2$$

Where applied force = 14254.98N

$$q = \frac{14254.98}{250{,}000} = 0.05702N/mm^2$$

Central deflection is calculated using equation Fvi, flexural rigidity is also calculated with equation Fviii.

$$D = \frac{23000 * 150^{\ 3}}{12(1 - 0.2^2)} = 6738281250Nmm$$

$$W_k = \frac{(0.05702 * 500^4)}{256 * 6738281250} = 0.00207mm$$

Moment is calculated using equation Fvii.

$$M = \frac{4 * 0.05702 * 500^2(1 + 0.3)}{128} = 579.11Nmm$$

Modulus of section and flexural strength are calculated using equation Fiii and Fiv.

$$Z = \frac{500 * 150^2}{6} = 1875000\text{mm}^3$$

$$\text{Flexural Strength} = \frac{579.11}{1875000} = 3.09X10^{-4}\text{N/mm}^2$$

APPENDIX G

PLATES SHOWING VARIOUS WORK ACTIVITIES

Plate G1: Frontal view of Magnus frame

Plate G2: Compressing of earth slab in Magnus frame

Plate G3: Compressed stabilized earth slab

Plate G4: Compressed stabilized earth slabs ready for crushing after curing

Plate G5: Crushing of compressed stabilized earth slab in Magnus frame

PlateG6: Crushing of compressed stabilized earth cubes