GEOTECHNICAL PROPERTIES OF LATERITIC SOIL STABILIZED WITH BONE ASH AND HYDRATED LIME FOR ROAD CONSTRUCTION APPLICATIONS

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MASTER OF SCIENCE AND ENGINEERING

By

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Supervised by

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CERTIFICATION

This is to certify that the thesis titled "Geotechnical Properties of Lateritic Soil Stabilized with Bone Ash and hydrated lime for Road Construction Applications" submitted to the school of postgraduate studies, African University of Science and Technology (AUST), Abuja, Nigeria for the award of Master's degree is a record of original research carried out by **Etekume Chukwutem** in the Department of Materials Science and Engineering.

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ABSTRACT

This research is focused on evaluating the geotechnical properties of lateritic soil stabilized with bone ash and hydrated lime to improve the strength and quality of Nigerian lateritic soil (acquired from Galadimawa in Abuja, Nigeria) for road construction applications.

California Bearing Ratio (CBR), Particle size distribution (Sieve analysis), Atterberg limits test, Compaction test, Moisture content and Specific gravity tests were utilized to investigate the influence of bone ash and lime on lateritic soil samples. 2%, 4%, 6% of lime and 5%, 10%, 15% of bone ash was used in stabilization of the laterite soil sample.

There is positive outcome from this study because the strength of the lateritic soil were improved by bone ash stabilization and this implies that bone ash can be used in place of lime for the stabilization of lateritic soil for road construction.

Keywords: Geotechnical properties, lateritic soil, stabilization, bone ash, road construction, California Bearing Ratio, soil compaction, specific gravity, Atterberg limits.

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DEDICATION `

This thesis is dedicated to the Almighty God Jehovah and to my dearest mother Mrs Lady Etekume.

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LIST OF SYMBOLS

AASHTO – American Association of State Highway and Transportation Officials

FTIR – Fourier Transform InfraRed

CBR – California Bearing Ratio

ASTM **–** American Society for Testing and Materials

CBA **–** Cattle bone ash

OMC **–** Optimum moisture content

MDD **–** Maximum dry density

CHAPTER 1

INTRODUCTION

1.1 Background

Lateritic soil is any of a group of zonal soils developed under humid tropical forest vegetation. Lateritic soils have granular dark reddish brown surface soils underlain by reddish friable clay B-horizons and red reticulately mottled lateritic parent material [1].

Lateritic soil can be defined as weathered tropical or sub-tropical leftover soil, generally covered with sesquioxide rich solidifications [2]. Soil is described with high temperature and moisture content prompting exceptional chemical weathering that structures well graded residual soils [3]. Lateritic soils are environmentally friendly materials which are plentiful in its natural occurrence.

Lateritic soils have been the most broadly known and utilized construction material in building and road construction. In tropical parts of the world, lateritic soils are utilized as a road making material and they form the structure of subgrade of most tropical roads. Moreso, in rural regions of Nigeria, they are utilized as building material for plastering and moulding of bricks [4]

Lateritic soils are characterized as sustainable building and construction materials that fix current problems without jeopardizing people's ability to address their own issues satisfactorily in the future [4]. Structures built of earth materials are the most widely recognized moderate accommodation since earth materials are readily accessible anyplace on the planet[5].

The American Society for Testing and Materials (ASTM) states the following as the reasons for soil stabilization: increasing the strength of existing soil to enhance its load-bearing capacity, improving soil permeability and enhancing the resistance of soil to weathering process and traffic utilization etc. [6].

Soil stabilization is the process of changing some of the soil properties by chemical or mechanical process. This is done to produce soil with improved and desired engineering properties [7].

Soil stabilization can likewise be viewed as the alteration of soils to improve their physical properties. Stabilization can build the shear strength of a soil or potentially control the shrink-swell properties of a soil, thereby improving the load bearing capacity of a sub-grade to support pavements and foundations [8].

Soil stabilization accomplishes various goals that are significant in acquiring a dependable structure from locally accessible earth materials and these include; better mechanical qualities, better attachment between particles which decrease the porosity and changes in volume because of moisture changes, improved protection from wind, erosion and rain. Soil stabilization techniques include mechanical, physical and chemical stabilization[9].

Availability and cost have affected the options of construction and building material generally. In most non-industrial nations, owning a house is generally troublesome because of significant expense of construction materials and to solve this threat, better approaches of producing building materials from locally accessible materials effortlessly should be investigated [9].

Lateritic soil comprises of high plastic clay; soil plasticity may cause cracks and damage on structural foundations, pavement, roadway or any other construction projects. It is in this way significant to comprehend the actions of lateritic soil and subsequently sort out the strategy for soil stabilization [10].

Cow bone is a type of waste, which its production runs to millions of tonnes in Nigeria, from which bone ash is obtained [11]. The current removal system of burning in open sites and haphazard discard on any site turns out poorly for the wellbeing of individuals and it likewise establishes ecological danger. Utilization of Bone Ash (BA) disposal for road construction, for example, rigid pavement construction, is huge and thus serves different advantages to the surroundings. This application will advance waste administration at little expense, landfill reduction, decrease contamination by these wastes and increment financial base of butchers when such wastes are sold, consequently stimulating more production. Additionally, bone ash production requires less energy request as compared with Portland cement production and recovers the required unfamiliar trade spent on importation of cement and its parts [11]. Previous work done of bone ash and lime focused on the morphology and compressive strength of stabilized lateritic soil. In this research, bone ash and hydrated lime were utilized as the stabilizing agents for the lateritic soil. The major chemical constituent of the bone ash is calcium oxide/ calcium phosphate. Therefore, this research is aimed at studying the behaviour of bone ash and hydrated lime on the geotechnical properties of lateritic soil as an alternative stabilizer in road construction applications.

1.2 Statement of Problem

Significant increase in the price of cement and conventional structural materials has brought about the requirement for utilization of domestic materials for construction application purposes in view of its accessibility, cost viability and capacity to secure the environment.

Lateritic soils are one of such locally accessible material which is a good option in contrast to regular conventional structural materials aside from a couple of issues. Lateritic soils possess high clay content and lower cation exchange capacity [12]. The plasticity of which may bring about cracks and thereafter damage on roadways, pavements, building foundations, and some other construction works. This gives rise to the necessity for stabilization of lateritic soils.

A serious danger to the sustainability of the human race is environmental pollution. Bones are scattered about everywhere in Nigerian meat markets and abattoirs, causing problem to human affairs. Thus, the purpose behind utilizing bones ash for the stabilization of lateritic soil materials in this study.

1.3 Significance of he Study

Lateritic soil stabilization enhances increase in its strength and durability by decreasing its porosity. This leads to durable roads and structures built with stabilized lateritic soil consequently sparing the expense of maintenance. It also prevents future problems like swelling, cracks and damping that might lead to failure of the structure built with untreated lateritic soil. It likewise forestalls future issues like expanding, damping and cracks that may prompt structural failure of untreated lateritic soil. Bone ash was chosen to tackle the issue of environmental pollution. This research has the potential for making sustainable roads from locally available earth materials (lateritic soil) stabilized with cattle bone ash.

1.4 Aim and Objectives

The aim of this research is to examine the effect of bone ash and hydrated lime on the geotechnical properties of lateritic soil as an alternative stabilizer for road construction applications

The objectives are as follows:

- To effectively classify and understand the behavior of the untreated lateritic soil sample.
- To study the effect of hydrated lime and bone ash on the California Bearing Ratio (CBR) of lateritic soil.
- To determine the effect of bone ash on the Atterberg limit property of lateritic soil.

1.5 Scope of Work

Geotechnical tests that were performed in the laboratory include CBR, compaction test, sieve analysis, Atterberg limits, specific gravity, moisture content etc.

The scope of this research covers the following:

1) Characterization of the lateritic soil;
2) Experimental setup to use different levels of the selected stabilization materials (bone ash and hydrated lime) to develop stabilized lateritic soil.
3) Comparison of the strength of the stabilized soils to the raw sample collected;
4) Use of CBR to evaluate the effectiveness of the stabilization agents in improving the quality of lateritic soil for road construction.

1.6 Limitation of Work

Due to the differences in lateritic soil formations, the results obtained from this research will only be applicable to lateritic soil specimen produced from lateritic soils in Galadimawa or any other samples with similar characteristics. Moreso due to time constraints all the required tests weren't completed as was supposed.

CHAPTER 2

LITERATURE REVIEW

2.1 Definition and Formation of Lateritic soil

Lateritic soil develops by intensive and delayed weathering of the fundamental parent rock. Tropical weathering (laterization) is a delayed process of chemical weathering that creates a great variety in the thickness, grade, chemistry and ore mineralogy of the subsequent soils [1]. It has been discovered that lateritic soils are commonly acceptable construction materials and are in this manner widely utilized in construction [13]. Lateritic soil is a residual of rock decay that is red, reddish in colour and has a high substance of oxides of iron and hydroxides of aluminium and low percentage of silica. Lateritic soil are materials with no consistent properties, it can connote alternate material to individuals living in various parts of the world. [13] .

Lateritic soils forms underneath the surface in soil zones, unconsolidated silts, or decayed rocks where interrelations of ground water, soil/water table, and geography are beneficial. A basic factor in its development is a substituting or fluctuating moisture cycle, and it is created in relationship with forests and grasslands on lowland surfaces in tropical and mild areas [13]. Precipitation from the water table is presently commonly viewed as of a lot more noteworthy significance as a powerful means in lateritic soil development than capillary action. Despite the fact that lateritic soil doesn't form in arid regions, it is found in them as a relict from prior, wetter atmospheres[13].

2.2 Soil Stabilization

Soil stabilization from an expansive perspective fuses the different techniques used for changing soil properties to improve its engineering qualities and execution [14]. Stabilization is utilized for different engineering works, the most application being in road construction and airfield pavements, with the primary goal of building the strength and solidness of soil and decrease cost of construction by utilizing locally accessible materials [8]. The treatment of normal soil to improve its engineering properties or any means by which soil materials are improved and made more stable is soil stabilization. Further reasons for soil stabilization are conservation of energy, dust control, soil waterproofing and improved durability [13].

2.3 Methods of Soil Stabilization

Different types of soil stabilization have been used for thousands of years. They include chemical, mechanical/physical and polymer soil stabilization [15]. A stabilized soil will have vast improved weight bearing capacity, and be significantly more resistant to being damaged by frost, water, or inclement conditions [15] .

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2.3.1 Chemical Stabilization

Chemical stabilization is a mechanism to improve expansive soils which includes the utilization of chemical compounds and emulsions as compaction help to soils, as binders and water anti-agents, and as a method for adjusting soil behavior [16]. It additionally includes profound blending and grouting [16]. Regular chemical stabilization agents are Portland cement, lime, asphalt, biomass ashes, calcium chloride, sodium chloride, and paper mill wastes. Soil conditions, stabilizer properties, and construction types (roads, houses, and so on) decide the adequacy of these added substances. Moreso, choosing a specific added substance relies upon accessibility, cost, advantages, and reasonableness of its application. The conduct of every one of these admixtures boundlessly from the others; each has its specific use and alternately, each has its own constraints [17]. Chemical stabilization can be accomplished through different combinations which are:

a) **Lime as a soil stabilizer**

Lime is used as a compelling method to alter soils - improving both usefulness and load bearing qualities while expanding impermeability and stability [18]. The sort of lime utilized as a stabilizing agent fluctuates from nation to nation. The most usually utilized items are hydrated lime [Ca (OH)2], MgO, calcitic quicklime [CaO], and dolomitic quicklime CaO.MgO [6]. Upgrades in soil properties are because of response between the soil and lime. Hydrated lime is a fine powder, though quicklime is a more granular substance. Quicklime is more scathing than hydrated lime, so extra security techniques are needed with this material. Expansion of lime builds the cation exchange capacity and soil pH. Stabilization takes place when the correct measure of lime is added to receptive soil. When bringing lime into soil for stabilization, Ca2+ is halfway adsorbed on the surfaces of earth particles in substitution of monovalent cations, for example, Na+ and K+. The measure of Ca2+ adsorbed relies upon the cation exchange capacity of the treated soil [19].

The greater the exchange capacity, the higher the measure of Ca^{2+} consumed by the soil. Indeed, all the adsorbed cations are not, at this point accessible for pozzolanic responses. The measure of lime needed to fulfil the affinity of soil for lime is called the Lime Fixation Point (LFP). The lime in overabundance of the LFP is involved in the process of cementing. The reactions between the lime, silica and alumina-free, adding to new mineral formation like CSH (calcium silicate hydrates), CAH (calcium aluminate hydrates) and CASH (aluminocalcium silicate hydrates), are primarily responsible for the consolidation. [19].

b) **Cement as a Soil Stabilizers**

The primary response in a soil/cement mixture results from the hydration of the two anhydrous calcium silicates [3CaO. SiO_2 (C_3S)] and 2CaO. SiO_2 (C_2S)], the significant constituents of cement, which form two new compounds: calcium hydroxide (hydrated lime called portlandite) and CSH, the principle binder of concrete. Cement will make actual connections between particles, expanding the soil quality; then lime needs silica and alumina from clay particles to create pozzolanic responses [20]. Cement stabilization methods is predominantly controlled by hydrolysis and hydration. Cement stabilization brings about reduced density, expanded compressive strength, reduced plasticity, reduced volume, and change in attributes of expansive clays when contrasted with the characteristic soil [20].

c) **Bone Ash as a Soil Stabilizer**

Bone ash is grey-white powdery ash acquired from the burning (calcination) of bones. Normal bone ash consists of about 55.82% calcium oxide, 42.39% phosphorus pentoxide, and 1.79% water [21]. It is essentially made out of calcium phosphate. Bone ash is made from cow bones. Calcination is a high-temperature heating process within the sight of environmental oxygen. The final result being unadulterated bone mineral, a compound identified with hydroxyapatite.

Any utilization of bone ash in sand and clay stabilization will be represented by the physical and chemical composition of the ash. Calcined bone ash at a temperature of 1100°C contains the accompanying oxides: CaO (55.25%), P_2O_5 (41.65%), MgO (1.40%), CO_2 (0.43%), SiO_2 (0.09%), FeO (0.08%) and AlO (0.06%) [22].

2.3.2 Mechanical Stabilization

This is the most seasoned technique for soil stabilization wherein the actual property of the soil is adjusted for better gradation, strength and different attributes. Mechanical stabilization is broadly utilized in road construction and demands an earlier examination of the soil to decide the ideal water content for better soil compressibility. Mechanical stabilization involves compaction of the soil to influence its resistance, compressibility, penetrability and porosity [19].

The soil is mechanically treated so that almost all air can be removed and this adds to an expansion in its density. With mechanical stabilization, the particle size distribution that makes up the material isn't affected; however its structure is changed in light of the fact that the particles are reallocated [19].

2.3.3 Physical Stabilization

Physical stabilization is the alteration of soil particle size distribution and plasticity through expansion or deduction of various soil divisions to change its actual properties and for better structural property of the soil [23]. Physical stabilization may likewise include introduction of synthetic or plant fibers, animals and minerals into the soil. This strategy is utilized when there are reasons not to influence the particle size distribution of the soil or if the material is sensitive to movements prompted by factors like water action, thermal expansion, etc. [19].

2.4 Engineering Classification of Soil

Classification of various soils with comparable properties into groups and sub groups should be possible as indicated by their engineering behavior. The classification frameworks give a premise to quickly communicate the overall attributes of soils, which are changed, without detailed descriptions. The American Association of State Highway and transportation Officials (AASHTO) classification system and the Unified Soil Classification System (USCS) are two classification systems normally utilized by soils engineers. The two systems consider the particle-size distribution and Atterberg limits. AASHTO classification system is utilized generally by state and county highway divisions. Geotechnical engineers for the most part incline toward the Unified system [24].

2.4.1 AAS HTO Classification System

The AASHTO Soil Classification System created by the American Association of State Highway and Transportation Officials (AAS HTO), is utilized as a guide for soil classification and soil-aggregate blends for highway construction reasons. As indicated by this system, soil is categorized into seven significant groups: A-1 through A-7. Soils categorized under groups A-1, A-2, and A-3 are granular materials of which 35% or less of the particles go through the No. 200 sieve. Soils of which over 35% pass through the No. 200 sieve are categorized into groups A-4, A-5, A-6, and A-7. These soils are generally silt and clay-type materials. The classification system depends on the following standards:

l. Grain size

a. Gravel: fragments passing the 7-5-mm (3-in.) sieve and held on the No. l0 sieve

b. Sand: fragments passing the No. 10 sieve and held on the No.200 sieve

c. Silt and clay: fragments passing the No. 200 U.S. sieve

2. Plasticity: The term silty is utilized when the fine fragments of the soil have a plasticity index of 10 or less. The term clayey is utilized when the fine fragments have a plasticity index of at least 11.

3. In the event that cobbles and rocks (a size larger than 75 mm) are come across, they are avoided from the bit of the soil sample from which grouping is made. Nevertheless, the percentage of such material is recorded [24].

2.4.2 Unified Soil Classification System

This is a classification system proposed by Casagrande in 1942 during World War II for use in airfield construction attempted by the Army Corps of Engineers. In collaboration with the U.S. Bureau of Reclamation, the Corps updated this system in 1952. It is generally utilized by engineers (ASTM designation D -2481) as of now. To utilize this classification system, these points must be remembered:

1. The grouping depends on material passing a 75 mm (3 in.) sieve.

2. Coarse fragments: percent held over No. 200 sieve = $100–F_{200} = R_{200}$

3. Fine fragments: percent passing No. 200 sieve = F_{200}

4. Gravel fragments: percent held above No.4 sieve = R_4

As indicated by the Unified Soil Classification System (USCS), soils are separated into two significant classes:

l. Coarse-grained soils sandy and gravelly in form with under half going through the No. 200 sieve. Group symbols start with prefixes of one or the other G or S. G represents rock or gravelly soil, and S for sand or sandy soil.

2. Fine-grained soils with half or more going through the No. 200 sieve. The group symbols start with prefixes of M, which represents inorganic silt, C for inorganic clay, and O for organic silts and clays. The symbol Pt is utilized for peat, muck, and other exceptionally natural soils. Different symbols utilized for the classifications are:

W- Well graded

P- Poorly graded

L - Low plasticity (liquid limit less than 50)

H- High plasticity (liquid limit more than 50) [24].

2.5 Previous Works on Stabilization of Lateritic soil

The impact of bone ash on soil shear strength was explored by Ayininuola and Shogunro (2013) and results acquired demonstrated that bone ash contained high portion of calcium oxide and phosphate that assumed a captivating function in expanding the shear strength of the soil.

Stabilization of lateritic soil with egg shell powder and sodium silicate used as filler material in road construction was analysed by J. Oke and M Olowoyo (2019) and the outcomes obtained from the research showed that an ideal mix of 12% Egg Shell Powder and 8% sodium silicate can be utilized to balance out lateritic soil material for use as fill material for the construction of light traffic roads. The precedence of applying the Egg Shell Powder is the reduction in the adverse natural effect of egg shell waste. Peak Unconfined Compressive Strength (UCS) were recorded at7-and 28-days curing periods separately at an ideal mix of 12% Egg Shell Powder and 8% sodium silicate content individually.

Ramonu et al (2018) did a research to determine the effect of yam peel ash on geotechnical properties of lateritic soil as an alternative stabilizing agent for subgrade in road construction. Yam Peel Ash was used as replacement by weight of dry soil at different percentages. The CBR values obtained from the results of untreated lateritic soil was 29% while the optimum CBR values obtained for the stabilized lateritic soil was 40% at 6% Yam Peel Ash content. The effect of Yam Peel Ash stabilization on the geotechnical properties of lateritic soil improved the physical Engineering characteristics of the lateritic soils as evidence by the results of the test.

Achampong et al. (2013) researched on the chemical stabilization of lateritic soils for road construction by considering the case study of the lateritic soils at Legon in Ghana. They found that only 6% lime inclusion was the most appropriate for stabilizing the soil. However, the outcomes were contrasted with the details of the Ghana Highway Authority (GHA).

A review of the stabilization of lateritic soils with some agricultural waste products by Adedokun and Oluremi (2019) showed their effectiveness in improving geotechnical properties of lateritic soils. The wastes considered include saw dust ash (SDA), coconut husk ash (CHA), millet husk ash (MHA), corn cob ash (CCA), rice husk ash (RHA), bagasse ash (BA) and locust bean pod ash (LPBA). It was established that these ashes are good pozzolanic materials. Also, increase in ash contents led to a significant decrease in the liquid limit, plasticity index, swelling index and shrinkage limit of soils. The maximum dry density of soil increased from 0 to 4% substitutions of SDA, CHA and CCA while it decreased with the addition of ashes from other wastes. Additionally, CBR and UCS generally increased with increasing amount of the stabilizers whereas soil permeability and swell potential decreased as the ash content increased. Ash produced from these wastes can be used to improve the geotechnical properties of soil and to synthesize a stable soil mix, that are suitable for highway construction purposes.

Abiola et al (2018) studied the geotechnical Properties of Lateritic Soil Stabilized with Periwinkle Shells Powder and concluded that Periwinkle Shell Powder (PSP) could be considered as good stabilizer for clayey or lateritic soil, and its uses as a stabilizer could also provide a big relief to the environmental pollution caused by its indiscriminate dumping.

CHAPTER 3

MATERIALS AND RESEARCH METHODOLOGY

3.1 Materials and Sample Preparation

Lateritic soil is readily available and at abundance in Nigeria also used in many geotechnical engineering constructions. The lateritic soil was obtained from a depth of 1-1.5m below the ground surface. The samples considered for this research work were obtained from Galadimawa Abuja, Nigeria. The materials collected were dried at room temperature and ground to fine particles (<80 μm). Bone ash got from calcined cattle bones were used to stabilize the laterite materials differently. The hydrated lime and the bone ash were passed through No. 40 sieve before usage. The samples are shown in Fig. 1.

Figure 1 (a): Raw laterite

Figure 1 (b): Hydrated lime (soil stabilizer)

Figure 1 (c): Grinded and calcined cattle bone ash

3.2 Preliminary Laboratory Tests

To effectively classify and understand the behavior of the lateritic soil samples used in this research, geotechnical tests were carried out on the natural unstabilized lateritic soil sample to obtain its basic properties. The necessary preliminary tests included Sieve analysis, Moisture Content Test, specific gravity and Atterberg Limits Test, Compaction test. Thereafter California Bearing Ratio (CBR), Atterberg limit tests were carried out on the stabilized samples.

3.2.1 Sieve Analysis

This test determines the particle size distribution of soil from the coarse sand size down to fine clay size. The data from particle size distribution test is used to determine suitability of soil for road construction, air field etc. In this research, a known mass of material, the amount being dictated by the biggest size of aggregate, was placed on the top of a stack of sieves (the top sieve had the biggest screen aperture and the screen aperture sizes reduced with each sieve down to the base sieve which had the smallest aperture size screen for the kind of material determined) and shaken by mechanical means for a while. Materials held on every one of the sieve was weighed. The combined technique necessitated that each sieve starting at the top be set in a formerly weighed pan (known as the tare weight), weighed, the next sieve's contents added to the pan, and the total weighed. This was repeated until all sieves and the base pan equally added and weighed.

3.2.2 Water /Moisture Content Test

The moisture content test was utilized to determine the amount of water in the lateritic soil sample to its oven dry mass. The moisture content in a soil represents the different properties of soil for example permeability, compaction, particle size and so on. Percentage moisture content was ascertained as explained in ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil Aggregate Mixtures. Moisture content of some soils is used to establish the tie between soil properties and behavior. Fine-grained soils consistency relies more on its moisture content and is also a means of expressing phase relationships of air, water, and solids in a specified mass of soil.

To carry out this test, the moisture can and cover number were recorded. The mass of unfilled, clean, and dry moisture can with its cover (MC) was weighed and recorded. Wet soil was put in the moisture can and the cover fastened. The mass of the moisture can (presently containing the wet soil) with the cover (MCMS) was determined and recorded. The cover was taken out and the moisture can (containing the wet soil) was placed in the drying oven set at a temperature of 105 °C. The oven was left overnight and then the moisture can was removed from the oven. The cover on the moisture can cautiously remove and safely replaced with glove and was permitted to cool to room temperature. The mass of the moisture can and cover (containing the dry soil) (MCDS) was determined and recorded then water/moisture content of the laterite was then determined.

3.2.3 Specific gravity test

Specific gravity of soil is the ratio of the weight of soil in air of a given volume at a standard temperature to the weight in air of an equal volume of distilled water at the same stated temperature. To carry out this test, the density bottle along with the stopper, are both dried and cooled in the desiccator and then weighed to the nearest 0.001g (W_1). The soil sample, which had been dried, is transferred to the density bottle directly from the desiccator in which it was cooled. The bottles and contents together with the stopper is weighed to the nearest 0.001g (W_2). The soil is covered with air-free distilled water from the glass wash bottle and left for a period of 2 to 3hrs for soaking. Water is added to fill the bottle to about half. Entrapped air is removed by heating the density bottle on a water bath or a sand bath. The bottle is kept without the stopper in a vacuum desiccator for about 1 to 2hrs until there is no further loss of air. The soil in the density bottle is gently stirred with a clean glass rod, and adhering particles carefully washed off from the rod with some drops of distilled water until no more soil particles are lost. The process is repeated till no more air bubbles are observed in the soil-water mixture. The constant temperature in the bottle is observed and recorded. The stopper in the density bottle is inserted, wiped and weighed (W_3). The bottle is emptied, cleaned thoroughly and the density bottle is filled with distilled water at the same temperature. The stopper is again inserted in the bottle, wiped dry from the outside and weighed (W_4). At least two such observations are taken for the same soil sample.

3.2.4 Atterberg Limits Test

The Atterberg Limits test was conducted to ascertain the plastic and liquid limits of fine grained soil. The test was conducted as stated in ASTM D 4318 - Standard Test Method for Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) of Soils. The Atterberg limits are dependent on the soil moisture. The PL is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without disintegrating.

The liquid limit (LL) on the other hand is the moisture content that characterizes the point at which a soil changes from a plastic to a viscous fluid state. The shrinkage limit is the moisture content which characterizes where the soil volume won't diminish further if the moisture content is decreased. The Plasticity index (PI) is the measure of the plasticity of a soil. It is the size of the scope of water contents at which the soil displays plastic properties. Soil descriptions dependent on PI include: Non plastic (PI=0), slightly plastic (PI <7), medium plastic (7-17) and highly plastic (>17). Soils with a high PI will in general be clay, those with a lower PI are oftentimes silt while those with a PI of zero (nonplastic) will in general have almost no silt/clay. Different soil engineering properties have been related to the liquid and plastic limits, and these Atterberg limits are additionally used to group a fine-grained soil according to the Unified Soil Classification System or AASHTO system.

3.3 Experimental Design

Various tests including compaction and CBR were used to determine the engineering properties and to ascertain the effectiveness of the hydrated lime and bone ash stabilizers on the lateritic soil samples.

3.3.1 Compaction Test

Compaction test is used in determining the optimal moisture content at which a soil will achieve its maximum dry density. That is to study the moisture-density relationship of compacted lateritic soil. To carry out this test, air-dried lateritic soil sample of known weight passing through No. 4 sieve was compacted at known moisture content in a cylindrical mould of standard dimensions using a compactive effort of specific weight and frequency. Specimens are prepared so that the estimated moisture content is recorded. The moisture content is varied for at least two percent each and the moisture content increment not exceeding four percent. The process is repeated for various moisture contents and the dry densities are determined for each. The graphical relationship of the dry density to moisture content is then plotted to create a compaction curve. The maximum dry density (MDD) is the peak point of the curve and its corresponding moisture content which is also known as the optimal moisture content (OMC).

3.3.2 CBR Test

California Bearing Ratio (CBR) value is the resistance to a penetration of 2.5 mm of a standard cylindrical plunger of 50 mm diameter expressed as a percentage of the known resistance of the plunger to 2.5 mm in penetration in crushed aggregate (taken as 13.2 kN). The strength of a subgrade, sub base and base course materials for road construction is expressed in terms of their CBR value. To carry out this test, a known mass of material passed through 20mm sieve and retained on 4.75mm sieve is mixed thoroughly with water (OMC recorded). The equipment is shown in Fig. 2. The extension collar and the base plate is fixed to the mould, the spacer disc inserted over the base, and filter paper placed over the spacer disc. The mix is compacted in at least three layers, each layer given 55 blows with a 2.6kg rammer and the collar is removed then excess soil trimmed out afterwards. After compacting, the mould is turned upside down then the base plate and spacer disc is removed. The mould plus compacted soil is weighed to determine the bulk density and dry density. Next, the stress and strain dial gauge is set to zero, and the mould assembly with surcharge weight placed on the penetration test machine, but in no case in excess of 4kg so that full contact of the piston on the sample is established. Load on the piston is applied so that the penetration rate is about 1.25mm/min. Load readings at penetration of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10, 12.5mm observed and recoded. Mould is detached from the loading equipment and about 20 to 50grams of soil from the top layer used to determine the moisture content. CBR values are usually calculated for penetration of 2.5mm and 5mm respectively.

Figure 2: CBR machine

3.3.3 FTIR Test

Characterization of the bone ash used in the research was done using the Nicolet is5 Thermo Scientific FTIR spectrometer as shown in Figure 3.

Figure 3 : FTIR spectrometer

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Structure and Composition of Samples

The lateritic soil sample used in this study is reddish brown in colour and was gotten from Galadimawa, Airport road, Abuja Nigeria. Table 1 shows the chemical compositions of the lime used for the study, table 2 shows the chemical composition of bone ash used for the study while table 3 shows the chemical composition of natural lateritic soil samples used for the study.

Table 1: Composition of hydrated lime used for the study [6]

Constituents	Percentages (%)
Ca (OH)2	95.0%
Substances not precipitated by Ammonium oxalate (as Sulfate)	2.5%
Sulfate (SO4)	0.4%
Heavy metals (as Pb)	0.005%
Chloride (Cl)	0.04%

Iron (Fe)	0.1%
Loss on ignition	1.955%

Table 2: **Chemical composition of bone ash used for the study** [6]

Constituents (oxides)	**Percentages (%)**
Calcium Oxide (CaO)	52.2020
Phosphorus Oxide (P2O5)	48.0770
Magnesium Oxide (MgO)	2.0770
Sodium Oxide (Na2O)	1.3290
Aluminium Oxide (Al2O3)	0.6130
Chloride (Cl)	0.3400
Sulphur(S)	0.2124
Potassium Oxide (K2O)	0.0907
Iron Oxide (Fe2O3)	0.0303
Zinc Oxide (ZnO)	0.0069
Nickel Oxide (Ni2O)	0.0003
Manganese Oxide (MnO)	0.0002

Table 3: **Chemical composition of natural lateritic soil samples used for the study** [6].

Constituents (oxides)	**Percentages (%)**
Silicon Oxide (SiO2)	68.1210
Aluminium Oxide (Al2O3)	19.5280
Iron Oxide (Fe2O3)	5.8743
Sodium Oxide (Na2O)	0.3680
Magnesium Oxide (MgO)	1.2590
Potassium Oxide (K2O)	1.8219
Calcium Oxide (CaO)	0.1109
Zinc Oxide (ZnO)	0.0045
Sulphur (S)	0. 1134
Manganese Oxide (MnO)	0. 0906
Phosphorus Oxide (P2O5)	0.3837

Nickel Oxide (Ni2O)	0.0014

4.2 Characterization of Bone Ash

FTIR was used in characterizing the bone ash used for this study as shown in the figure 4 below. The FTIR identified the mineral as a poorly crystalline, CO32--containing apatite, presenting bands typically described in hydroxyapatite. The v3PO43– (1200-900 cm–1) appeared as a broad band with a discrete shoulder. The v1PO43– (980-940 cm–1) band was generally overlapped with the v3PO43– whereas, the v4PO43– (650-500 cm– 1) was partially resolved into two broad peaks. These shapes of the PO43– bands depict the low crystallinity of the minerals. The presence of CO32– was as a result of the clear bands of the v3CO32– (1600-1350 cm–1). Peaks of the v1OH– (3572 cm–1) and v2OH– (3572 cm–1) were observed to overlap each other as shown in Figure 4. A peak of vLOH– (630 cm–1) was not seen in the FTIR spectra. The presence of Isothiocyanate (2000 cm-1) was also observed [6].

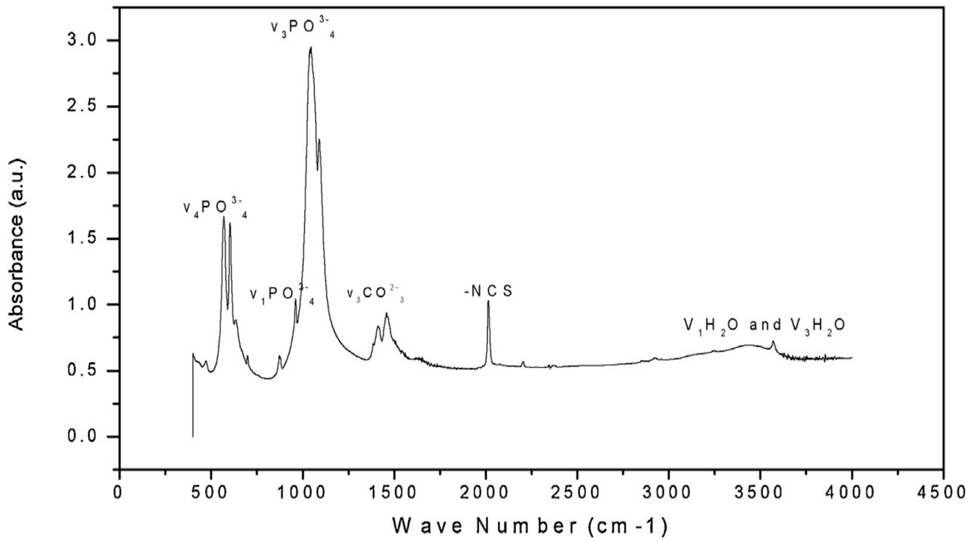

Figure 4 : FTIR Spectra of CBA used for the Study [6]

4.3 Sieve Analysis Results

The result from the sieve analysis is as shown in Figure (5) below. The sieve analysis (particle size distribution) and classification for the lateritic soil sample used in this research were determined using British standards. Based on the size of particles that are more ascendant in the soil, soils are generally classified as gravel, sand, silt or clay. Classification based on BS 1377: Part 2: 1990: 4.3 indicated that the particle size distribution curve observed in Figure (5) was that of silt.

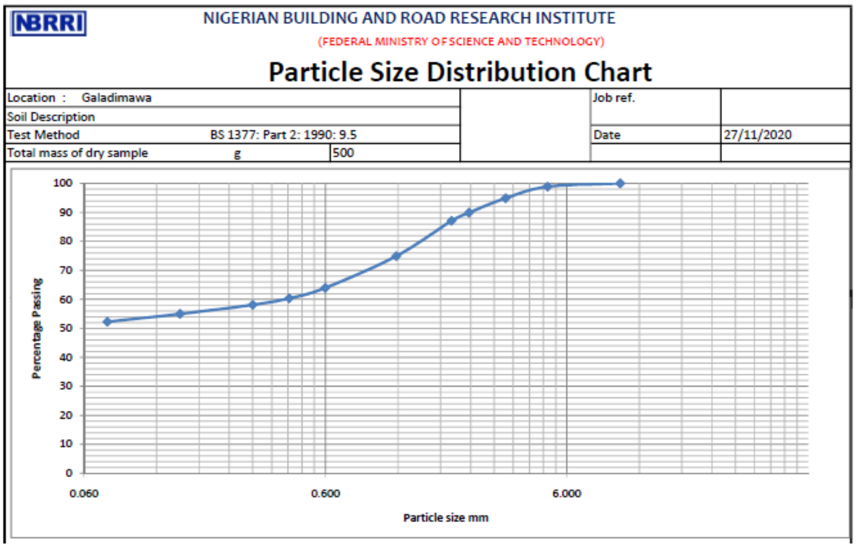

Figure 5: Particle size distribution of Lateritic soil sample

4.4 Water /Moisture Content Test results

The natural moisture content test value was 13.23% which shows that the laterite soil samples had high natural moisture content and would definitely retain water.

4.5 Specific gravity test results

The specific gravity value was 2.8208kg which shows that the lateritic soil sample has a good amount of clay mineral because clay has higher specific gravity as compared to sand.

4.6 Atterberg Limit Test Results

The British standard was used in determining the Atterberg limits and classification for the laterite samples used in this research. According to BS 1377: Part 2: 1990: 4.3 classifications. Using the plasticity chart classification, the results obtained from the Atterberg Limits Test (Figure 6) revealed that Laterite sample was silt with high plasticity and hence had more clay content as evidenced by their PI values.

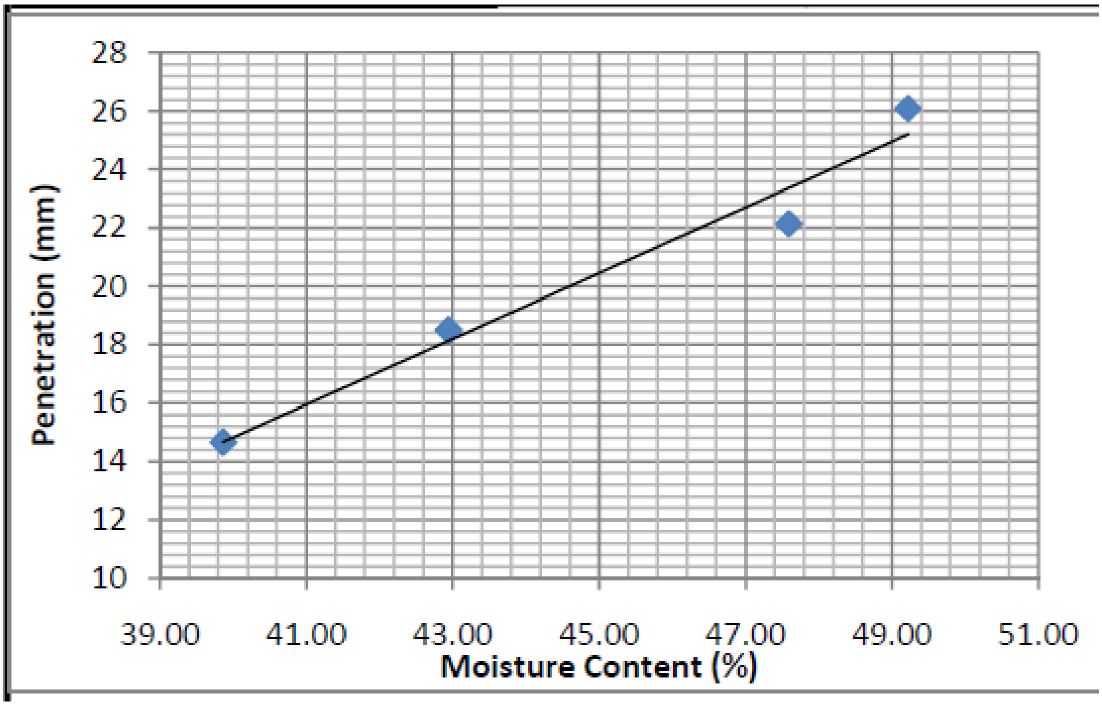

Figure 6: Atterberg Limits (Cone penetration) test results for Lateritic soil sample**.**

4.7 Compaction test result

The figure 7 below shows a plot of dry density against moisture content. The optimum moisture content (OMC) from the compaction test result is 11.40% while the maximum dry density (MDD) is 1.83 kg/m^3.

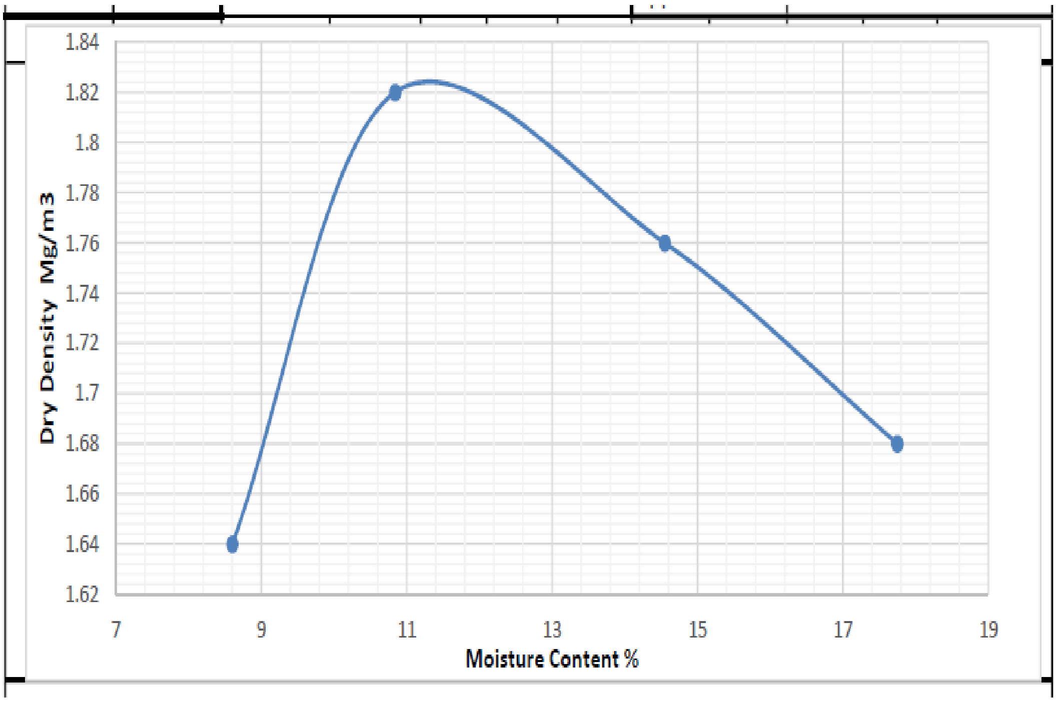

Figure 7: Compaction test result for the lateritic soil sample

Table 4: Engineering Properties of natural lateritic soil sample

Engineering properties	Values
Liquid limit, LL (%)	44.8
Plastic limit, PL (%)	24.92
Plasticity index, PI (%)	19.88
Linear Shrinkage (%)	14.44
Natural moisture content (%)	13.23
Plasticity Chart Classification	Silt with high plasticity
OMC (%)	11.40
MDD(kg/m^3)	1.83
CBR(unsoaked) %	38.03
Specific gravity(kg)	2.8208

4.8 Effect of bone ash and lime Stabilization on CBR of lateritic soil sample

From the laboratory test results with 2%, 4%, 6 % lime and 5%, 10%, 15% bone ash, the CBR values are as shown in table 5 below. Increase in the percentage of CBA resulted in decrease in CBR for the soaked sample whereas, increase in the percentage of CBA resulted in an increase in the value of CBR for unsoaked sample. The water absorbed during soaking could have resulted in decrease in CBR of soaked samples. However, increase in the percentage of hydrated lime resulted in an increase in the CBR value for both soaked and unsoaked samples.

Table 5: CBR Values for lime and bone ash stabilized lateritic soil

	Percentages	Soaked	Unsoaked
Control	0%	5.53	38.03
Hydrated lime	2%	31.40	8.70
	4%	37.00	9.15
	6%	38.15	14.50
CBA	5%	12.20	30.45
	10%	9.62	51.82
	15%	9.47	73.41

4.9 Effect of lime and bone ash on Atterberg limits of the stabilized soil

The results of the Atterberg limits of the lateritic soil sample stabilized with hydrated lime and bone ash are shown in table 6. The addition of hydrated lime reduced the linear shrinkage, liquid limit, plastic limit and plasticity index of the sample. This indicates that the hydrated lime improved the properties of the soil sample making it more suitable for construction applications. However, addition of bone ash increases the linear shrinkage, liquid limit and plastic limit**.**

Table 6: Atterberg limit Values for Lime and Bone Ash stabilized lateritic soil

	Percentages	Linear shrinkage	Liquid limit	Plastic limit	Plasticity index
Control	0%	14.44	44.8	24.92	19.88
Hydrated lime	2%	11.86	48	28.47	19.53
	4%	8.85	45.9	26.88	19.02
	6%	8.48	42.1	24.89	17.21
CBA	5%	8.30	36.20	20.60	15.60
	10%	8.27	38.90	19.29	19.61
	15%	8.49	39.20	21.66	17.54

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the laboratory test results conducted on the natural untreated lateritic soil sample, the soil is classified as silt with high plasticity.

There was a significant increase in the CBR value for unsoaked lateritic soil sample with increase in percentage of CBA whereas a decree for the soaked which could be as a result of the absorbed water during soaking process. However, increase in the percentage of hydrated lime resulted in an increase in the CBR value for both soaked and unsoaked samples.

5.2 RECOMMENDATION

Due to low cost, availability and energy efficiency of local materials like laterite materials in developing countries, it is recommended from this research that lateritic soil samples be used more as compared to conventional modern.

Proper classification and scientific understanding of lateritic soil is relevant and should be done for effective application and utilization of this naturally abundant material.

Research should be encouraged on locally available materials through awareness and trainings programs.

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APPENDICES

APPENDIX 1:
ATTERBERG LIMITS TEST FOR UNSTABILIZED LATERITIC SOIL

NBRRI NIGERIAN BUILDING AND ROAD RESEARCH INSTITUTE

(FEDERAL MINISTRY OF SCIENCE AND TECHNOLOGY)

Atterberg Limits - Cone Test

Location : Galadimawa		Job ref.	
Soil Description:	Redish Brown	Sample No	1
		Depth (m)	1
Test Method	BS 1377: Part 2: 1990: 4.3	Date	

PLASTIC LIMIT

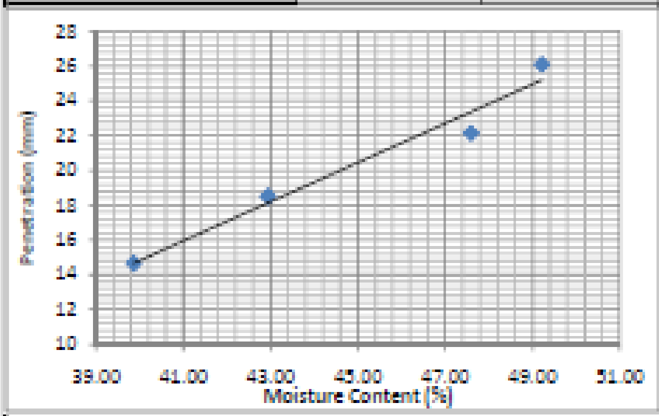
Test Number		1	2
Container No		B2	MO
Mass of wet soil + container	g	35.56	33.96
Mass of dry soil + container	g	33.54	31.6
Mass of container	g	23.1	20.04
Mass of moisture	g	2.02	2.36
Mass of dry soil	g	10.44	11.56
Moisture content	%	19.35	20.42
Average Moisture Content	%	19.88	

LINEAR SHRINKAGE

Test Number	1	2
Initial length mm	140	140
Oven dried length mm	119.81	119.77
Linear Shrinkage %	14.42	14.45
Av. Linear Shrinkage %	14.44	

LIQUID LIMIT

Test No	1		2		3		4	
Initial dial gauge reading mm	0	0	0	0	0		0	0
Final dial gauge reading mm	14.5	14.8	18.4	18.6	22.1	22.2	26	26.2
AVR Penetration mm	14.65		18.5		22.15		26.1	
Container No	Z2	51	V1	P02	P1	5	U1	A3
Mass of wet soil + container g	34.55	35.98	35.13	38.71	40.72	36.87	33.47	37.54
Mass of dry soil + container g	30.36	31.42	30.64	34.01	35.04	32.42	29.02	32.8
Mass of container g	19.86	19.97	20.19	23.06	23.13	23.05	19.94	23.21
Mass of moisture g	4.19	4.56	4.49	4.7	5.68	4.45	4.45	4.74
Mass of dry soil g	10.5	11.45	10.45	10.95	11.91	9.37	9.08	9.59
Moisture content %	39.90	39.83	42.97	42.92	47.69	47.49	49.01	49.43
Average Moisture Content %	39.87		42.94		47.59		49.22	



Sample preparation		
As collected from site		
Passed through	425 µm sieve	
Liquid Limit	%	44.8
Plastic Limit	%	19.88
Plasticity index	%	24.92
Operator		
Checked		
Approved		